DEVELOPMENT AND VALIDATION OF

QUANTATATIVE PHOSPHORUS

LOSS ASSESSMENT TOOL

By

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Chapter 1

Introduction

Phosphorus (P) is a pollutant of concern in Oklahoma's waters. The water quality of Oklahoma's lakes and streams is being degraded by excess algal growth. This excess growth is the result of an overabundance of nutrients, primarily nitrogen and P. P is often the limiting nutrient for algal growth and reducing P concentration is often the most effective method of control (Schindler 1978). P in Oklahoma's waters originate from point sources, such as municipal waste water treatment plants, or from diffuse nonpoint sources found throughout the landscape. P is ubiquitous in our environment; it is found in every living thing and every drop of rain that runs off the surface of the land.

The diffuse nature of nonpoint sources makes control far more difficult than for point sources. Point sources are regulated by National Pollutant Discharge Elimination System (NPDES) authorized by the Section 402 of the Clean Water Act (1972). Entities are permitted and required to follow strict limits on the amount of pollutant they discharge. These sources can be quantified and controlled; whereas, nonpoint sources are far more difficult to manage. Although P is found throughout our environment, its concentration varies. Urban and agricultural land generates runoff with far higher P concentrations than the same area would under more natural conditions. These anthropogenic effects are primarily the result of P enrichment through fertilization and soil disturbance. Section 319(h) of the Clean Water Act is directed at controlling nonpoint sources primarily through education, with technical and financial assistance for landowners who implement Best Management Practices (BMPs) which reduce P loss. Unlike Section 402, which regulates point source discharges, Section 319(h) programs are completely voluntary.

Nonpoint sources contribute a large amount of P to Oklahoma's waters. Of particular interest is eastern Oklahoma, the home of Oklahoma's Scenic Rivers and a thriving poultry production industry. Eastern Oklahoma is dominated by poultry and pasture cow/calf production agriculture on thin rocky soils; the majority of the region is unsuitable for cultivation. The poultry production in the region is responsible for a large influx of P in the form of poultry feed. Poultry production results in far greater P accumulation at the farm level as compared to crop or dairy production (Sharpley 1999). Poultry litter is an excellent yet unbalanced fertilizer; compared to nitrogen it contains far more phosphorus than is needed for plant growth. Litter is often applied at rates to meet crop nitrogen requirements, resulting in an over application of P. When P in excess of what the crop can use is applied, P builds up in the soil. Runoff extracts soluble P from the soil and carries litter and sediments containing P to streams. Due to concerns about water quality, eastern Oklahoma continues to be a hotbed of legal activity between the states, municipalities, state agencies, and corporately managed poultry farms.

While Section 319(h) of the Clean Water Act is completely voluntary, the application of animal manures in Oklahoma must comply with the Natural Resource Conservation Services (NRCS) 590 standard for nutrient management. To meet this standard, each state must develop a P management strategy. In Oklahoma, Comprehensive Nutrient Management Plans (CNMPs) compliant with the 590 standard are primarily developed using a Soil Test Phosphorus (STP) limit; above the limit and no animal manure is allowed. This approach is simple and easy to implement, but STP is only one of many factors influencing P loss. Most states have adopted the P Index approach (Sharpley et al. 2003). A P Index is an assessment tool for use by planners and land users to assess the risk for P leaving a site and traveling toward a water body (NRCS 1994). A P Index is typically a qualitative tool yielding a categorical rating of P loss risk from a single site based on a number of field metrics and management parameters thought to influence P loss and transport to nearby streams. Each factor is assigned a weight based on professional judgment and may contain empirical relationships derived from local studies. The individual weighting factors are combined into a single numerical P Index, which is interpreted into categories of P loss risk potential. This rating is used to determine allowable application of fertilizers and animal manures. P Indices were not initially developed to be quantitative predictors of P loss (Lemunyon and Gilbert 1993) nor were they intended to be used as a regulatory tool (NRCS 1994). The original role of P Indices as a planning tool has been expanded to develop CNMPs to meet the NRCS 590 standard for nutrient management. With the use of P Indices as regulatory tools, the need for accuracy has increased beyond the intent of the original P Index framework. A more comprehensive quantitative tool to evaluate P loss under differing management scenarios is needed to address this application.

Hydrologic models, such as the Erosion Productivity Impact Calculator (EPIC) (Williams 1990), have been successfully used to predict P loads under differing management scenarios before P Indices existed. Many of EPIC's routines are included in the Soil and Water Assessment Tool (Arnold et al. 1998), a distributed parameter basin scale model developed by the USDA Agricultural Research Service. Unfortunately, these models are very complex, necessitated by the complexity of the system these models are intended to represent. A model representing a large basin in detail requires vast amounts of data in the form of Geographic Information Systems (GIS) data. These models require a great deal of specialized knowledge and data not readily available to P Index users; farmers and conservation agents require a simpler tool (Veith et al. 2005).

Models like SWAT are internally complex, as are the interfaces which drive them. Many of the options available in SWAT interfaces are not necessary for many applications. Often individual input parameter values are dependent upon higher level model scenarios. For example, the simulation of a hay pasture requires a certain set of parameter values for Curve Number, Manning's n, crop heat units, planting dates, and other parameters. A single set of appropriate parameter values can be used each time the user simulates a hay field. These parameters can be modified based on user specified haying dates or fertilization. An interface can translate a relatively simple set of instructions from the user to a complex set input parameters needed by the SWAT model. There is a need for a P management tool which is similar in complexity to that of a traditional qualitative P Index, which can make predictions using the power of a quantitative model, without loss of prediction accuracy.

The implementation of Best Management Practices (BMPs) is often used to reduce P loss from agricultural and urban lands. State and federal programs, such as the Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), Environmental Quality Incentives Program (EQIP), and various state cost-share programs funded by Section 319(h) and state funds, seek to reduce non-point source pollution by implementing conservation practices. The Oklahoma Conservation Commission (OCC) and the Oklahoma Natural Resources and Conservation Service (NRCS) administer these programs in priority watersheds across the state of Oklahoma. Unfortunately, only a fraction of fields within a priority watershed can be enrolled in these programs due to limited funding. The identification of critical source areas within a watershed is one method to place BMPs where they are needed most. This approach has been adopted by the OCC in recent years in a number of priority watersheds (Storm et al. 2005a; Storm et al. 2005b; Storm et al. 2003b). The SWAT model is commonly used to identify these critical source areas.

Targeting critical source areas may identify areas with excessive P loss, but does not recommend any specify BMP or practice to reduce P loss. The effectiveness of a BMPs are extremely variable and highly dependent upon local conditions. BMP efficiencies are often derived from field studies conducted under different conditions and may not be applicable to the site in question. Tools such as EPA's Spreadsheet Tool for the Estimation of Pollutant Load (STEPL) (Tetratech 2005) are available to estimate BMP efficiencies, but these tools still rely exclusively on measured BMP efficiencies from other sites and cannot adjust for local conditions. The use of a process based model should better account for local conditions, allowing better BMP selection for a particular site.

Agencies, such as the OCC and NRCS, are under pressure to quantify the impact of the programs they administer. Millions of dollars are spent on these programs in Oklahoma alone. Water quality data may be collected before and after implementation to demonstrate improvements associated with these programs. To account for changes in weather, data are generally collected in a separate control watershed which receives no BMPs. This paired watershed design (EPA 1993) is a useful tool, but may be complicated by other factors which influence pollutant load in either the control or experimental watersheds. Changes in land use and inherent pollutant storage within the system are just a few of the factors which may complicate these studies. Models have been accepted as surrogate measure of success and may be used to quantify the impacts of BMP programs. Unfortunately, the complexity of models, like SWAT, prevents widespread usage for BMP selection and evaluation, even though they are well suited for the task. The development of more simplistic model interfaces is needed.

Overview of the SWAT Model

SWAT is a basin-scale distributed hydrologic model. Distributed hydrologic models allow a basin to be broken into many smaller subbasins to incorporate spatial detail. Water yield and pollutant loads 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 Hydraulic Response Units (HRUs). A single subbasin can be further divided into areas with the same soil and land use. Unique combinations of soil and landcover within a subbasin become individual HRUs. Processes within each HRU are calculated independently; the total nutrient or water yield for a subbasin is the sum of all the HRUs it contains. HRUs allow more spatial detail to be included by allowing more land use and soil classifications to be represented in a computationally efficient manner.

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. Relative impacts 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).

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 1990) all contributed to the development of SWRRB. SWAT was created to overcome maximum area limitations of SWRRB. SWRRB can only be used on watersheds a few hundred square kilometers in area and has a limitation of ten subbasins. SWAT can be used for much larger areas. The HUMAS (Hydrologic Unit Model for the United States) project (Srinivasan et al. 1998) used SWAT to model 350 USGS six-digit watersheds in the 18 major river basins in the United States.

The SWAT model continues to be updated every few years to include new features and functionality. The current version, SWAT 2005, is widely used both in the United States and internationally. SWAT 2005 is distributed with the full Formula Translator (FORTRAN) source code, allowing anyone to make modifications to the model.

Research Objectives

The primary purpose of this research was to develop a P management tool combining the ease of use of traditional P Indices with accuracy and flexibility of an existing process based hydrologic and water quality model. This model based P management tool is simple to use by field personnel, with readily available inputs, and insulates the user from the complexity of the model by generating model inputs and interpreting model output. By using the process-based SWAT model, this tool more accurately simulates a wider variety of management options and field characteristics compared to traditional quantitative P Indices. The tool can be used as a quantitative P Index alternative for the existing STP based Oklahoma NRCS 590 standard. Statewide databases were developed with this research to make this P Index applicable to the entire state of Oklahoma. The development of allowable P loss rates for agricultural fields will be needed before this tool can be implemented in a regulatory mode. This task was not undertaken by this research.

This new P management tool is applicable for BMP selection and the quantification of BMP implementation effects. The evaluation of the effectiveness of state and federal contributions to BMP programs is highly desirable. Unfortunately, most methods of BMP selection and evaluation are based on fixed BMP performance efficiencies and crude estimates of P loss prior to BMP implementation. These efficiencies are generally based on data collected at locations dissimilar to the site in question and contain a great deal of uncertainty. BMPS are highly site specific (Djodjic et al. 2002; Gitau et al. 2004). BMPs may even increase P loss under some circumstances (Storm et al. 2006b). The following were more specific research objectives:

Develop a SWAT Interface (PPM Calculator) for Pasture Systems in the Lake Eucha/Spavinaw Basin

The Pasture Phosphorus Management (PPM) Calculator is a quantitative P Index based on SWAT. The PPM Calculator arose from litigation between the City of Tulsa and several poultry companies operating in eastern Oklahoma and western Arkansas. The PPM calculator is a simplified interface for the SWAT 2000 model designed to make predictions for a single pasture. The SWAT model on which PPM Calculator is based was used to link the application of litter with P loads to lakes Eucha and Spavinaw in the original litigation (Storm et al. 2002). This tool is applicable to pastures in the Lake Eucha/Spavinaw basin only. The tool has been successfully applied in the basin, but not in a regulatory mode due to a lack of a specified maximum allowable P load limit. This work is proof of concept that a complex model can be used as a P Index. The remainder of this research is an expansion of this tool.

Expand the PPM Calculator into PPM Plus and Include Commonly Cultivated Crops in Oklahoma

Cultivated agriculture generally yields an order of magnitude more P loss than pastures under similar conditions. The inclusion of cultivated agriculture into the PPM Calculator necessitated a complete rewrite. The new tool, PPM Plus, simulates cultivated fields, which are typically managed more diversely than pastures. A farmer has a myriad of tillage implements and cropping systems to employ. This expansion was required to make PPM Plus applicable to the entire state of Oklahoma.

Expand PPM Plus to Include Statewide Weather and Soils Data

In order for PPM Plus to be used statewide, additional weather and soils databases were included. Oklahoma has tremendous differences in annual rainfall, ranging from 15 in/yr in the panhandle to 55 in/yr in the mountains of the southeastern Oklahoma. This tremendous difference must be accounted for in a statewide P management tool. Climate for nine regions encompassing the State were included in PPM Plus. Climatic and geologic diversity has given Oklahoma a wide variety of soil types. Over 3,000 soils were included in the model.

Statewide Hydrologic Calibration

The original PPM Calculator uses a SWAT model calibrated for conditions in the Lake Eucha/Spavinaw Basin. To improve the accuracy of PPM Plus, SWAT was calibrated for conditions across Oklahoma. Eleven basins across the state were simulated using SWAT and calibrated for total streamflow. A single set of calibration parameters was identified which produce the best hydrologic calibration at all sites. These calibration parameters were incorporated into PPM Plus.

Improve SWAT P Algorithms

The P routines in SWAT originate from Erosion and Productivity Impact Calculator (EPIC), a field-scale model. Both models have demonstrated the ability to predict P loads originating from agricultural areas with reasonable accuracy throughout the literature. There is, however, room for improvement. The P routines in SWAT and EPIC were developed in early 1980's and have changed very little since, even though the body of research concerning P has expanded tremendously. Other researchers have proposed significant updates to better represent manure application in models like SWAT, but there is at this time no plan to include these routines in SWAT. This research focused on changing static coefficients in the SWAT model to dynamic coefficients, modifying manure applications to account for alum amendments and other relatively easy modifications.

Include Support for Additional Best Management Practices

P Indices generally give some fixed credit for the application of BMPs. Evaluations of BMP effectiveness often rely on field studies conducted at locations dissimilar to the site in question. BMPs are highly site specific and have significant variability. In an effort to better evaluate the effect of BMPs, all BMPs which could be simulated using SWAT were included in PPM Plus. Other BMP which could not be simulated by SWAT were recorded in the interface for record keeping purposes. BMPs which were included in PPM Plus are listed below:

- Ponds
- Manure application setbacks
- Contour planting and terracing
- Riparian and grass buffers
- Cattle exclusion from riparian zones
- Alum amended animal manures

Validate PPM Plus using field scale measured flow, sediment and nutrient data to evaluate its accuracy.

The validation of PPM Plus on multiple data sets was necessary to assess its accuracy. Model performance varies under differing conditions. EPIC, the source of SWAT's field scale components, has been expensively tested nationally, but to my knowledge SWAT has not been tested at the field scale. PPM Plus was validated using 283 field years of field scale data gathered from sites across the southern United States. PPM Plus predictions were well correlated with measured edge of field runoff, sediment, and P.

Chapter 2

Literature Review

There are countless articles about P Indices and SWAT individually, but little or no work has been published on using a basin-scale model as a P Index. The majority of this literature, while useful and supports this work, is not directly related to my research. The focus of this research is how to apply an existing, very complex model (SWAT) as the engine for an easy to use P management tool.

P Loss Mechanisms

There are several mechanisms of P loss from an agricultural field. These mechanisms must be considered when predicting P loss. The most important loss pathways involve runoff. When rainfall exceeds infiltration, runoff begins. This moving water can readily extract soluble mineral and organic P from soil surface. The concentration in runoff is related to the concentration and solubility of P at the soil surface. If manure is on the soil surface, the concentration of soluble P in the runoff is much higher (Sharpley et al. 2001, Pierson et al. 2001a). Soluble mineral P is of particular interest because it is the most biologically available form. This is the primary mechanism for P loss from good condition pastures and other crops with very low erosion.

Runoff may transport particulate matter containing P. The energy dissipated by raindrop impacts and moving runoff water detach and transport P containing organic matter and soil particles to nearby streams. If the velocity of sediment laden runoff water drops, so does its ability to carry particulate matter. The particulate matter may be deposited; this is one mechanism by which filter strips and riparian buffers remove nutrients (Cerucci and Conrad 2003). This is the primary P loss mechanism from cultivated fields and overgrazed pastures. Cultivation reduces soil cover which increases erosion.

While runoff P transport occurs almost everywhere, other loss mechanisms require more specific circumstances. P is often thought of as an immobile nutrient; however, P will readily move within soils in soluble or colloidal forms under certain circumstances. Subsurface P losses have been demonstrated in multiple studies (Heathwaite and Dilsb 2000, Ilg et al. 2005, Carlyle and Hill 2001). If the soil is saturated with P, P becomes more mobile. The degree of P saturation has been experimentally linked to both soluble P and colloidal P in leachate (Ilg et al. 2005). P leaching is generally limited to highly permeable sandy and cherty soils which have little available aluminum, iron, calcium, or manganese to precipitate it. These soils are often alluvial, and confining layers within the soil profile are common. Leachate which meets a confining layer may move laterally down slope, delivering that P to nearby waterways through a media which has little or no P retention capability. Leachate may also return to the soil surface down slope. This phenomena, dubbed saturation excess runoff, is thought to be significant in eastern Oklahoma and western Arkansas (Chaubey et al. 2006). Alternatively, leachate carries P downward to an aquifer. Aquifers are often composed of large particles with little surface area to facilitate P precipitation reactions. Iron commonly found in ground water is often Fe^{2+} due to the low oxygen conditions. Without Fe^{3+} or other minerals to precipitate P, P may enter a nearby stream in baseflow. Carlyle and Hill (2001) found significant ground water P concentration in ground water discharges to streams from a shallow unconfined aquifer.

Animals may facilitate the transfer of P from the landscape to streams. Cattle consume forages which contain P extracted from the soil by the plant. Cattle with stream access may deposit manure directly in the stream. Byers et al. (2005) found a 65% reduction in P export from a small watershed following cattle exclusion from streams. Another minor pathway for P to enter surface waters is by wind erosion. Dry and wet deposition of P in lakes is a significant source. Ahn and Thomas (2001) found 0.36 lb/acre/yr P deposited from atmospheric sources in the Florida Everglades. Although the amount is relatively small, the bioavailability of this atmospheric P is high.

Models and Field Scale P Predications

Literature concerning the use of SWAT to make edge of field P predictions is almost nonexistent. SWAT is a basin scale model and is not generally used to make predictions at the field scale. However, SWAT is a direct decedent of EPIC, a widely used field scale model. SWAT's field level processes are based on EPIC. There is extensive literature detailing the use of EPIC to predict edge of field P load.

Wang et al. (2006) used EPIC on six small (4.0 to 8.4 ha) cultivated fields in Texas, with a portion of these fertilized with poultry litter. EPIC was calibrated and validated with excellent results; observed and predicted sediment, organic nitrogen and P, soluble P, and NO_3-nitrogen losses had coefficient of determination (r^2) values exceeding 0.70 on an annual basis. Organic and soluble P had a relative error of 5.5% and -10.3% during the validation period. There were no statistically significant differences between observed and predicted nutrient losses and crop yields. This research demonstrates the accuracy possible with hydrologic models under some conditions.

Pierson et al. (2001b) used EPIC on 6 mixed forage pastures (0.72 ha to 0.79 ha) fertilized with poultry litter. The uncalibrated EPIC model predicted soluble P with an r^2 of 0.65 and 0.75 on an event and annual basis, respectively. The model significantly under predicted soluble P on an annual basis (3.3 kg/ha/yr predicted, 6.3 kg/ha/yr observed). The authors attributed this under prediction to the way manure is simulated in the model. Both SWAT and EPIC simulate manures as a simple addition of nutrients; in reality, manure sits on the soil surface, and for a time, interacts directly with runoff. The relatively high r^2 values indicate that the model could perform significantly better had it been calibrated. These types of bias errors are generally minimized through calibration.

Veith et al. (2005) compared SWAT and the Pennsylvania P Index on 22 cultivated fields in south-central Pennsylvania. SWAT output was transformed into qualitative categories similar to P risk categories specified in the Pennsylvania P Index. SWAT and the P Index categorized 77% fields identically; only a single field differed by more than one categorical rating. The purpose of this research was to demonstrate the similar predictions from both a simplistic P Index and a complex hydrologic model. No measured P data by field were collected, limiting the utility of this work for the purposes of this research.

This body of literature suggests that SWAT should be capable of making accurate predictions at the field scale if properly parameterized and calibrated. EPIC was designed for this purpose and examples of successful application of EPIC in literature are plentiful. It stands to reason that since SWAT contains EPIC's routines, SWAT should have similar success.

Model Limitations and Recent Advancements

A significant perceived limitation in both SWAT and EPIC is the treatment of manure as a simple addition of nutrients into the mineral and organic pools of the surface soil layer. In reality, these materials sit on the soil surface and interact more directly with runoff. This direct interaction leads to elevated P in runoff shortly after application, which may not be completely reflected in SWAT predictions. The effect of these manures is large after application and diminishes with time. Sharpley et al. (2001) found that Mehlich-3 Soil Test P (STP) was highly correlated with P in runoff with no poultry litter application for at least six months. The same study found little correlation between P in runoff and STP within three weeks of application. DeLaune et al. (2004a) similarly found a strong relationship between STP and P in runoff with no recent litter application and no significant relationship after application. While it seems clear that shortly after litter application STP effects are not significant, the influence of STP on the annual P load is not clear. Pierson et al. (2001a) found a decrease in measured P in runoff with time, with P concentration in runoff decreasing logarithmically with days since application. Gaston et al. (2003) found decreases in P in runoff with successive events, with larger decreases in plots with lower STP. The rate at which P in runoff decreases after manure application is a key issue. The faster this decrease occurs, the more profound the effect of STP on P loss. If the effect of manure lasts only a few months and a field receives litter once every couple of years, STP should be the dominant factor in the prediction of P in runoff on an annual basis. Work is underway by Vadas et al. (2007) to create a separate manure layer on the soil surface which may reduce this limitation and increase the accuracy of SWAT predictions on an event basis.

Another limitation of the SWAT model in manured pasture systems are the transformations between the organic and mineral P pools. SWAT uses fixed ratios to define the magnitude of these pools at equilibrium. The rate should vary with soil characteristics and time. There are efforts currently underway to improve SWAT and other models to reduce this limitation. Vadas et al. (2006) recently modified Erosion Productivity Impact Calculator's (EPIC) sorption and desorption constants to dynamic factors based on a series of P sorption and desorption experiments. The net result of these improvements is theoretically better model performance in runoff soluble P, shortly after fertilization.

The currently released version of SWAT 2005 does not track subsurface P movement. This loss pathway may be important in sandy and cherty soils. Chaubey et al. (2006) demonstrated this loss mechanism in eastern Oklahoma. A version of SWAT 2005 which does consider subsurface P losses is currently in beta testing but was not released in time for inclusion in PPM Plus.

SWAT Soil P Model Updates

Several important model limitations will be addressed by direct modification of the SWAT model. SWAT uses fixed ratios to define soil mineral P partitioning; there is strong evidence that the relationships between these fractions are nonlinear. Sharpley et al. (2004) presented data which illustrate how these fractions change as STP increases. The fraction of the total mineral P within the soil extracted by Mehlich III increases nonlinearly. This also implies that the amount of fertilizer required to raise STP by one unit is higher at low STP than at a higher STP. Other studies support a nonlinear relationship between STP and the total soil P. Pautler and Sims (2000) found a relationship between total P and STP, which appears to be nonlinear. Allen (2004) found higher STP to total P ratios at higher STP levels. Whalen and Chang (2001) observed a STP to total P ratio of 0.13 in plots with no manure application and a ratio of 0.27 in a soil with long term additions of manure.

SWAT does not account for the addition of alum to poultry manures. Alum reduces soluble P content by precipitating P with aluminum. The addition of alum reduced water soluble P in manures by 66% in farm scale data collected by Sims and Luka-McCafferty (2002). Other researchers have published similar results, although plot scale experiments tend to have greater reductions (Moore and Miller 1994). The addition of alum to soils resulted in reduced P loss, higher STP, and reduced leaching on long term plots (Moore and Edwards 2007).

SWAT uses fixed rate constants to move P between soil P pools. Vadas et al. (2006) developed dynamic and improved static coefficients for labile/active P pool interactions. Active/Stable pool interactions are very slow, taking several years to return to equilibrium. In the SWAT model, after fertilization, STP drops rapidly for a few days, then slowly over a couple of years. These rate constants were derived from Jones et al. (1984), which is based on long term STP reductions following fertilization observed by Cox et al. (1981). More recent soil incubation studies indicate that these active/stable rate constants may be significantly underestimated. Laboski and Lamb (2003) measured STP in soils incubated for nine months after receiving manure and inorganic P. STP changed significantly only during the first month after manure application in the majority of soils. Ebeling et al. (2003) incubated a silt-loam receiving various P application rates for 64 weeks. STP stabilized after 16 weeks of incubation except at very high rates. Koopmans et al. (2004) found strong indications that the total pool of sorbed P (sum of reversibly adsorbed P and quasi-irreversibly bound P) to be close to equilibrium with the faster reacting P in a long term P uptake study. These studies suggest that the transfer between the active and stable pools to regain equilibrium is faster than the current SWAT routines allow at least for non-calcareous soils.

Models and P Indices

Currently, the primary tools for P management at the field and farm scale are P Indices. In recent years, these P Indices have become increasingly complex in an effort to improve accuracy to meet the demands of a regulatory use for which they were not originally designed. In effect, P Indices have become more model like. North Carolina abandoned the P Index approach all together in favor of a more physical model like the P assessment tool (N.C. Plat Committee 2005). The North Carolina index was developed using data, but is not based on existing models. Other P Indices have demonstrated a high correlation with measured P losses (Eghball and Gilley 2001 and Sharpley et al. 2001), indicating that these indices could be used to predict quantities of P loss. Harmel et al. (2005) evaluated the Texas, Iowa, and Arkansas P Indices using data collected from both pasture and cultivated fields receiving poultry litter for a period of three years in Texas. The P Indices had r^2 of 0.31, 0.31, and 0.09 for Texas, Iowa and Arkansas, respectively. This study illustrates the wide range in P Index performance. The inclusion of actual sediment yields improved r^2 to 0.51, 0.90, and 0.32 for Texas, Iowa and Arkansas P Indices, respectively. This study illustrates the importance of accurate sediment estimates in P loss predictions. The majority of P Indices now incorporate predictions from models such as the Revised Universal Soil Loss Equation (RUSLE) to better predict particulate P loss (Sharpley et al. 2003).

P is a basin scale problem which must be addressed at the field level. P Indices have been applied at the basin scale by Birr and Mulla (2001), but models like SWAT were developed specifically for this purpose (Arnold et al. 1998). Birr and Mulla (2001) applied a modified P Index to 60 USGS 8-digit watersheds in Minnesota. This work compared the proportion of water P samples exceeding 0.25 mg/l with the P Index scaling. Although these were well correlated, relationships were logarithmic, i.e. not linear, an indication of P Index scaling issues. This study demonstrates the utility of P Indices for regional planning in a qualitative way, and the limitations when using a P Index when used to predict absolute loading. More basin scale evaluation of P Indices are urgently needed (Sharpley et al. 2003). The SWAT model is routinely validated in this manner (Saleh et al. 2000, Santhi 2001, Storm et al. 2001) to predict actual nutrient loading.

SWAT Modeling Studies in Oklahoma

A portion of the work cited here may not directly address the use of SWAT for a field scale P management tool. These studies do, however, illustrate the applicability of SWAT in Oklahoma and its prior usage for planning, TMDLs, BMP evaluation, targeting critical source areas, and litigation.

The effect of subbasin descritization and soil database selection within SWAT was examined by White (2001) in the Great Salt Plains Reservoir and the Lake Eucha basins. White found that SWAT sediment and nutrient yields were sensitive to subbasin size, but runoff volume was relatively insensitive to model descritization. The Great Salt Plans Reservoir basin (Northwestern Oklahoma) was also simulated by White et al. (2001) to predict the effect of various BMPs. This model was also used to locate portions of the basin with the highest potential sediment loads. The Lake Eucha basin (northeastern Oklahoma) was modeled by Storm et al. (2001) and Storm et al. (2002). This work was commissioned by the City of Tulsa to determine the effect of poultry manure applications in the Lake Eucha basin, one of the city's water supply reservoirs. Model predictions were used to define the contribution of various P sources in the basin for the purposes of litigation. SWAT model results were deemed admissible in Federal Court (U.S. District Court Case No. 01-CV-0900-EA(C)). This work demonstrates the utility and a history of SWAT for the purposes of regulation.

The SWAT model has been used extensively in Oklahoma for the purpose of identifying priority areas to receive cost share funding for the establishment of BMPs. The Fort Cobb Reservoir Basin in Central Oklahoma was simulated by Storm et al. (2003b) using SWAT in conjunction with the WEPP Roads model to target critical sediment source areas in the basin. Conservation funding was distributed to landowners based on the targeting results. The same area was simulated again by Storm et al. (2006a) in support of a Total Maximum Daily Load (TMDL) for the Fort Cobb Reservoir. Stillwater Creek in Central Oklahoma was also modeled using SWAT by Storm et al. (2003a) to identify sediment priority areas and estimate the effect of county roads on the total basin sediment loading. These studies were performed using relatively standard datasets and model descritization.

Other studies in Oklahoma have used more detail. SWAT was adapted for making grid cell (30 m x 30 m pixel) based sediment and nutrient predictions in Turkey Creek (western Oklahoma) by Storm et al. (2005a). This information was used to locate the most effective locations for BMP establishment. SWAT was used to locate P loss priority areas in Spavinaw Creek (northeastern Oklahoma) by Storm et al. (2005b) using a high resolution dataset (4 m) with a HRU size of 8.7 acres. These applications, though unvalidated with field scale measured data, demonstrate the use of SWAT to make field scale predictions.

The Illinois River was simulated by Storm et al. (2006c) to predict reductions in point sources and poultry litter application required to meet a 0.037mg/l P criteria for Oklahoma's Scenic rivers. This work included the development of a new in-stream model for P which is currently being incorporated into SWAT 2005. This work demonstrates how the SWAT model is already being used in Oklahoma to estimate the impacts of policy change and the actions required to meet water quality standards.

SWAT was used in the Lake Wister basin to target critical P source areas by Storm et al. (2006b). They also used SWAT in combination with Landsat satellite imagery to predict the impact of a Section 319(h) BMP implementation program in the Oklahoma portion of the basin. The authors found improvement with some BMPS such as fencing, but other BMPs such as P fertilization, significantly increased P loss. This project demonstrates the need for a simple tool which can be used to predict the impact of a BMP at the field scale before BMP implementation. Such tools could be used to identify not only the best BMP for a particular site, but also estimate the load reduction which should arise from the implementation of the BMP. Models like SWAT can be used to make quantifiable measures of success for cost share or other BMP establishment programs.

Chapter 3

Development of a Quantitative Pasture Phosphorus Index using the SWAT Model

Abstract

The Pasture Phosphorus Management (PPM) Calculator predicts average monthly and annual P losses from pasture systems. PPM Calculator is a vastly simplified interface for the Soil and Water Assessment Tool (SWAT) model and requires no knowledge of SWAT. PPM Calculator is intended as an alternative to qualitative P indices used to develop CNMPs for pasture systems. By insulating the user from the complexities of SWAT, the PPM Calculator allows CNMP developers to take advantage of the predictive capacity of a comprehensive hydrologic water quality model typically reserved for use by hydrologists and engineers. The quantitative nature of PPM Calculator allows it to be linked directly with numeric water quality standards. PPM Calculator was successfully validated using 33 months of data on four fields in northwestern Arkansas. This tool has been extensively applied in the Lake Eucha/Spavinaw Basin in northeastern Oklahoma and northwestern Arkansas by court order. PPM Calculator is applied in a non-regulatory capacity. This research demonstrates the applicability of existing water quality models in the development of user friendly P management tools.

Justification

The over application of fertilizers containing P to agricultural fields may have a direct negative impact on the water quality of lakes and streams. Excess nutrients may trigger algal blooms which kill fish and produce undesirable water conditions for recreation or consumption. P concentration in surface waters is highly correlated with primarily productivity (Schindler 1978). Primarily productivity is often limited based on P availability. P concentration in lakes is tightly coupled to loads from rivers and streams which feed them (Lathrop et al. 1997). Although lakes, rivers and streams differ in their response to anthropogenic P, reducing P concentration is often an effective strategy to control aquatic plant and algal growth because it is in short supply. Nutrient availability in lakes and reservoirs increases naturally over time with the slow process of eutrophication. The anthropogenic nutrient enrichment of these systems accelerates this natural aging process, significantly reducing the useful lifespan of lakes and reservoirs. It is important that we protect these valuable water resources for future use.

P is found throughout the environment, but its concentration varies significantly. Industrial animal production by Concentrated Animal Feeding Operations (CAFOs) import large quantities of P in animal feed, yet export little P in the products produced. The majority of P consumed by animal is excreted in animal manures which are often applied as fertilizer on or near the farm. Poultry production results far greater P accumulation at the farm level, as compared to crop or dairy production (Sharpley 1999). The economics of scale and transportation force CAFOs to locate near industrial animal processing and ration production facilities, resulting in regions with high CAFO densities and net P accumulation. One such region of concentrated poultry production is located in eastern Oklahoma and western Arkansas. The management of P at both the farm and regional scale is needed to protect water quality.

One approach to P management at the farm scale is the P Index. A P Index is an assessment tool used by planners and land users to assess the potential of P leaving a site and traveling toward a water body (NRCS 1994). To date, a P Index is typically a qualitative tool which yields a categorical rating of P loss from a single site based on field metrics and management options thought to influence P loss to nearby streams. Each factor is assigned a weight based on professional judgment and/or empirical relationships derived from local P loss studies. These individual weighted factors are combined into a single numerical P Index, which is interpreted into categories of P loss potential. These categories are then used to specify allowable application rates of animal manures and/or commercial fertilizers.

The P Index concept was developed by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) in the early 1990's (Lemunyon and Gilbert 1993). At that time, ARS had at least 15 years vested in hydrologic model development. Comprehensive hydrologic and water quality models, such as Agricultural Non-Point Source model (AGNPS) (Young et al. 1989) and Erosion Productivity Impact Calculator (EPIC) (Williams 1990), were already fully capable of making predictions of P loss from agricultural fields. However, P Indices and comprehensive hydrologic models had two distinctly separate purposes and users: P Indices provided simple qualitative assessment of P loss for field planners, and models provided quantitative assessment of multiple constituents to be used by more specialized model operators.

P Indices were not initially developed to be quantitative predictors of P loss (Lemunyon and Gilbert 1993), nor were they intended to be used as a regulatory tool (NRCS 1994). The role of P Indices has been expanded to aid in the development of Comprehensive Nutrient Management Plans (CNMPs) to meet the USDA Natural Resource Conservation Services (NRCS) Conservation Practice Standard for Nutrient Management Code 590 and to specify manure application rates in watersheds with impaired or threatened surface waters. To meet the 590 Standard, each state must develop a P management strategy; most states have adopted the P Index approach (Sharpley et al. 2003). The processes of P loss and transport are complex (Sharpley et al. 2002). With the increased need for accuracy to meet a regulatory or a specific water quality goal, P Indices have become more refined and complex. The flexible framework of the P Index approach readily allows the incorporation of new science to improve prediction accuracy. The majority of P Indices now incorporate predictions from other models, such as the Revised Universal Soil Loss Equation (RUSLE), to better predict particulate P loss (Sharpley et al. 2003).

P Indices are not always a qualitative tool. Some P Indices have demonstrated a high correlation with measured P yields (Harmel et al. 2005; Eghball and Gilley, 2001; Sharpley et al. 2001), indicating that these indices may have the potential to predict quantities of P loss. The ability of some P Indices to function as quantitative P models has further blurred the line between a P Index and a P model. Current comprehensive hydrologic and water quality models, like Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998), have a full P sub-model, which is process based and attempts to mimic the complete P cycle. These models also evolve as new science is developed and incorporated.

Existing hydrologic water quality models, like SWAT, have several advantages over P Indices. First, SWAT can make quantitative predictions of actual P loss at both the field and basin scales. P is a watershed-scale problem which requires changes in management at the field level. Current P Indices are only a piece of the solution and should be applied in the framework of watershed scale water quality objectives. Qualitative P Indices are categorical, which makes it difficult or impossible to interpret them in the context of numeric water quality standards or goals. Quantitative P Indices have been applied at the basin scale (Birr and Mulla 2001). However, they do not consider larger scale water quality processes and nonagricultural contributions, which is necessary to evaluate downstream water quality impacts. The SWAT model is applicable to field scale P loss and basin scale water quality assessment. The accuracy of SWAT at the field scale may be further enhanced by calibrating SWAT at the basin scale using widely available water quality data and applying that calibration at the field scale where little or no measured P loss data are available.

The second advantage of hydrologic models, like SWAT, is they are process based and can accurately predict P load reductions from diverse conditions under various management scenarios, including Best Management Practices (BMPs). Traditional P Index coefficients are, at best, developed empirically using only locally measured P loss data, resulting in a high degree of regional or local specificity. Under those conditions they may perform well, but under different conditions performance may decline significantly (Harmel et al. 2005). SWAT is the product of over 30 years of research and model development and has been validated and tested extensively both domestically and internationally (Gassman et al. 2007). Finally, hydrologic models like SWAT can make predictions of not only P, but other important parameters like nitrogen, sediment, pesticides, and bacteria. Phosphorous is only one of many emerging water quality concerns; the US Environmental Protection Agency lists more waters impaired due to bacteria (13.3%) and sediment (10.7%) than for nutrients (8.8%) (USEPA 2005). In the future CNMP developers may have to consider multiple pollutants to develop a single farm plan.

Basin scale models like SWAT have one primary weakness: they are complex. These models require a great deal of specialized knowledge and extensive data, which are not readily available to P Index users. Conservation agents and farmers/ranchers require a simpler tool (Veith et al. 2005). Interfaces available for SWAT are very complex, as they are designed to represent a large basin in detail and offer the user extensive options. If the scale is reduced to a single field and the options restricted, data requirements are comparable to existing P Indices. An interface can translate a relatively simple set of instructions from the user to a complex set of input parameters required by the SWAT model. The purpose of this research is to develop a P management tool which is similar in complexity to that of a traditional P Index, yet able to make P load predictions using the power of a quantitative process based hydrologic model for pasture systems.

Materials and Methods

Program Structure

The Pasture Phosphorus Management (PPM) Calculator is a quantitative P assessment tool based on the SWAT model and designed to make P loss predictions for a single pasture. PPM Calculator is a simplified interface for the SWAT model and was designed to be easy to use; the user does not see or directly interact with the SWAT model. Data entered by the user are transformed into SWAT model input files and the model is executed in the background. SWAT results are translated and summarized, then presented to the user. A conceptual diagram of PPM Calculator is given in Figure 3.1. PPM was developed specifically for the Lake Eucha/Spavinaw Basin in northeast Oklahoma and northwest Arkansas, U.S.A, a region of extensive poultry production. PPM Calculator utilizes hydrologic parameters ported from a calibrated Lake Eucha/Spavinaw Basin SWAT 2000 model (Storm et al. 2002) for maximum accuracy.

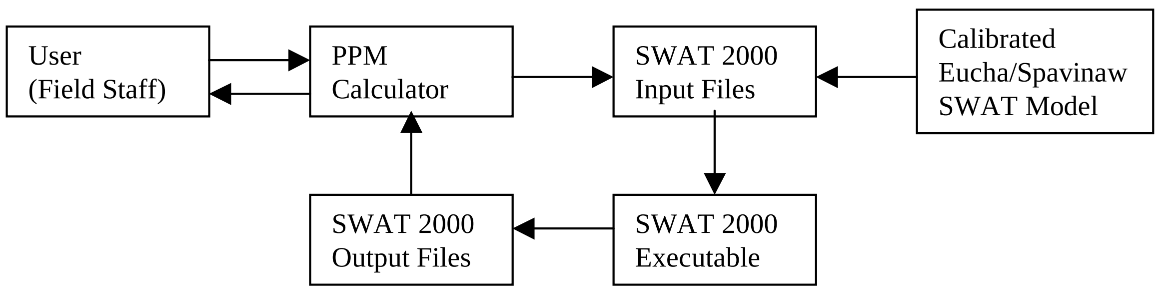


Figure 3.1 PPM Calculator conceptual diagram.

PPM Calculator Inputs

To limit complexity, PPM calculator uses only the field scale routines of the SWAT model. SWAT subdivides a basin into subbasins which are further partitioned into Hydrologic Response Units (HRUs). A basin scale SWAT model may contain thousands of HRUs; PPM Calculator uses a single HRU to represent a single pasture. SWAT model inputs for this HRU are generated with relative simple data from the user. Technical SWAT inputs like biomass consumption, trampling, manure production, and nutrient content (all required to simulate grazing), are generated from more familiar inputs like stocking rate. As a basin scale model, SWAT has many input parameters. If used to simulate a single pasture, only a small number of relatively simple inputs are required.

PPM Calculator requires a variety of user data, most of which are also used by other P Indices. Several field management inputs can be specified monthly to better account for seasonal changes in climate and forage production which may influence P loss. A list of PPM Calculator inputs which are used to predict P loss are given in Table 3.1; all other inputs are used for record keeping or are not active in version 1.01. In addition, PPM Calculator includes critical reference tables and calculators to aid in appropriate input parameter estimation.

Table 3.1 PPM Calculator inputs used in the SWAT 2000 model.

User input	Description
Soil Type	Select one of 35 soils common in the Lake Eucha/Spavinaw Basin
Forage Type	Specify warm, cool, or mixed forages
STP	Mehlich III Soil Test Phosphorus
Minimum Dry Forage	Minimum dry forage present on the field during the growing season. Grazing is suspended by SWAT when this level is reached
Field Slope	The average field slope.
Slope Length	Revised Universal Soil Loss Equation Slope Length
Hay	Select months when hay is cut
Stocking Rate	Number of animal units per acre grazed each month
Litter N	Total amount of nitrogen (as N) applied in litter each month
Litter P	Total amount of phosphorus applied in litter each month
Commercial N	Amount of nitrogen (as N) applied in commercial fertilizer each month
Commercial P	Amount of phosphorus applied in commercial fertilizer each month

All PPM Calculator user inputs are located in a single dialog; the user interface is shown in Figure 3.2. Once all user data are entered and “Run” is pressed, the inputs are checked to ensure that they are numeric, positive, and in the acceptable range for each input parameter. All program files are inspected to detect modifications or corruption, which may invalidate predictions. The SWAT model is then automatically executed in the background and performs a 15 year simulation using measured weather data collected in the Lake Eucha/Spavinaw Basin. All the information entered by the user is listed in the output, along with monthly and annual precipitation, runoff, sediment, total P, and estimated available forage.

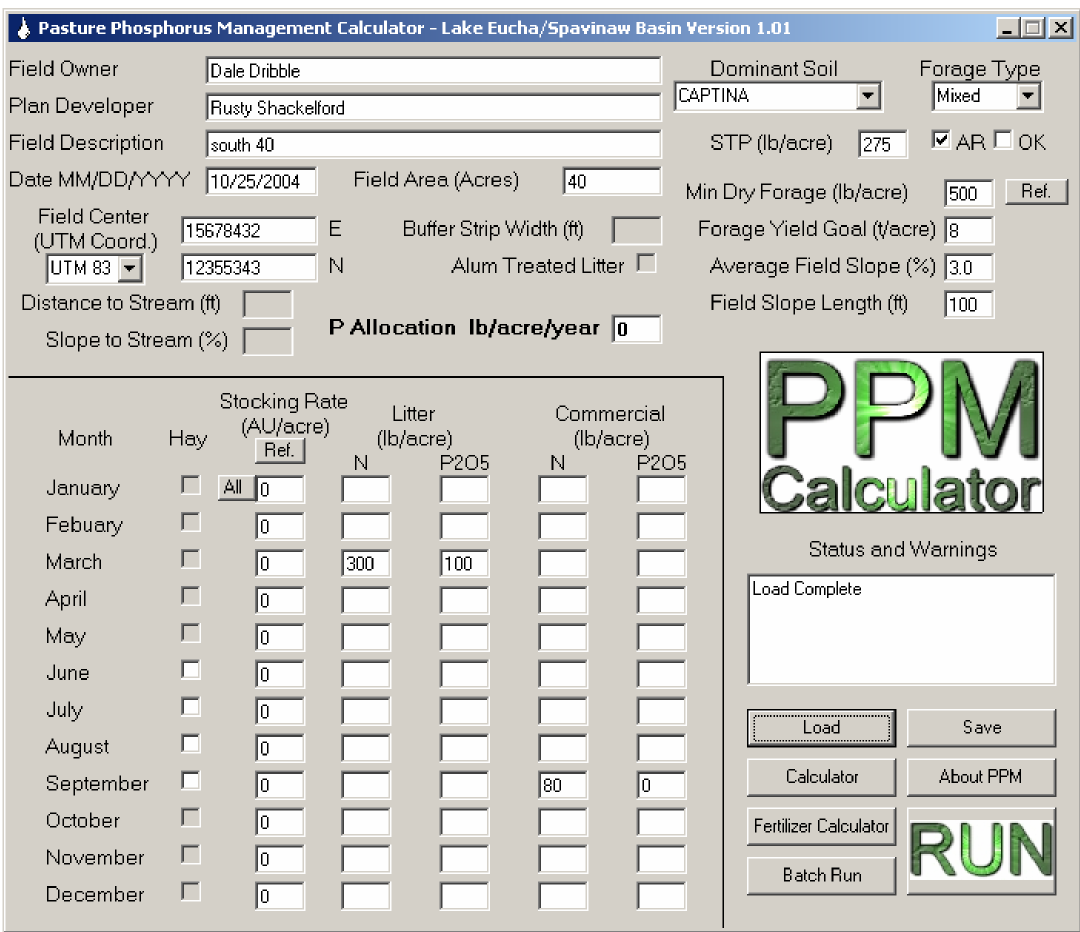


Figure 3.2 PPM Calculator interface (Version 1.01)

Results and Discussion

Validation

PPM Calculator was validated for runoff and total P. Validation is an effort to gage the uncertainty in the model predictions. Validation tests the model with observed data that was not used in the development of the model. The PPM Calculator was validated using 33 months of data on four fields 12 miles west of Fayetteville, Arkansas. These data were presented by Edwards et al. (1994) and Edwards et al. (1996b). This study monitored four fields under natural rainfall, with elevated STP due to historical application of poultry litter. Two fields received additional litter during the study (A, C) period and two received only commercial nitrogen (B, D).

The overall performance of the PPM Calculator using these data was good. PPM Calculator performed better on fields receiving litter (A, C) than those which received only commercial nitrogen (B, D) (Table 3.2). PPM Calculator generally under predicted total phosphorous on fields B and D, which was likely due to the application of poultry litter on these fields just prior to the study, which was not included in parameterization of PPM Calculator. Fields B and D experienced significant decreases in runoff soluble phosphorous concentration and Soil Test P (STP) during the monitoring period. The under prediction by the PPM Calculator for total and soluble P on these two fields was expected because the PPM Calculator does not consider litter application prior to the study period, even though that litter application may continue to influence P loss. Pierson et al. (2001) found elevated soluble P losses for 19 months after litter application. Relative error in predicted sediment yields ranged from 28% to -99%. Although this error was large on a relative basis, sediment yields from these fields were very small and the maximum over prediction by the model was only 72 kg/ha. Runoff volume error ranged from 53% to -76%. Although these relative errors were quite variable, there was little overall bias in the model predictions.

Table 3.2 Pasture Phosphorus Management (PPM) Calculator validation results using data from Edwards et al. (1994).

Parameter	Field			
	A	B	C	D
Litter (Mg/ha/yr)	13	-	12	-
Commercial N (kg/ha/yr)	-	95	-	84
Ave Stocking Rate (AU/ha)	1.1	1.2	0.80	0.36
Observed Runoff (mm/yr)	210	45	71	190
Predicted Runoff (mm/yr)	170	80	85	89
Runoff Relative Error (%)	19%	-76%	-20%	53%
Observed Total P (kg/ha/yr)	4.6	0.77	2.0	2.7
Predicted Total P (kg/ha/yr)	5.7	0.55	2.2	0.91
Total P Relative Error (%)	-25%	29%	-12%	66%
Observed Soluble P (kg/ha/yr)	4.3	0.66	1.6	2.7
Predicted Soluble P (kg/ha/yr)	4.3	0.39	1.8	0.50
Soluble P Relative Error (%)	2%	41%	-15%	81%
Observed TSS (kg/ha/yr)	78	29	68	120
Predicted Sediment (kg/ha/yr)	150	56	49	100
Sediment Relative Error (%)	-99%	-90%	28%	14%

Conclusions

Comprehensive hydrologic water quality models have been available long before the introduction of P Indices. P Indices were developed as alternatives to these models with an emphasis on simplicity and ease of use. However, the cost of this simplicity is qualitative scaling. P loss is a function of many factors; while it is certainly possible to over complicate a model with irreverent processes and parameters, a certain level of complexity is required to accurately predict P loss under a wide range of conditions. This research focuses on the simplification of an existing well tested and validated process-based model that can easily be used by CNMP developers and linked to basin scale water quality objectives or numeric water quality standards.

PPM Calculator demonstrates that a complex model like SWAT can be the engine for an easy to use P Index. PPM Calculator has been applied in the Lake Eucha/Spavinaw Basin. P Indices need not avoid complex routines, only complex interfaces. Models continue to evolve as our understanding of P dynamics grows. Much of the information accumulated by P researchers is yet to be included in models like SWAT and EPIC. Advancements in P and manure routines have been developed (Vadas et al. 2007; Vadas et al. 2006), but are not yet included in mainstream models. Significant improvements in model accuracy are likely in the near future. A new version of PPM is currently under development and will include a number of improvements:

- Expanded validation dataset
- Applicable to the entire state of Oklahoma
- Support for cultivated crops
- Support for additional BMPs
- Improved SWAT P submodel

The ability of these process based models to predict P loss under diverse conditions may pave the way to regional or national P management tools. Current P Indices are applicable to only a narrow range of conditions which limits any single P Index to a state or portion of a state. Models have wider applicability because they can account for very diverse climate, management, topography, and soils. The development of separate P Indices for each state results in an unnecessary duplication of effort. The collection of field data in each state or region necessary to validate individual P Indices is extremely expensive. Sufficient data are already available to validate models for this purpose. Models can utilize data collected from any site so long as the conditions under which the data were collected are included in the model. It is likely that any national P Index would have a process based hydrologic model at its core.

Chapter 4

PPM Plus Model Description and Development

PPM Plus is the next generation of the PPM Calculator. The PPM Calculator (White et al. 2003) is only applicable to pasture systems in the Lake Eucha/Spavinaw basin. PPM Plus has a structure similar to the PPM Calculator (Figure 4.1), but is applicable to the entire state of Oklahoma, and includes statewide weather, soils, and common Oklahoma agricultural crops. PPM Plus has a significant number of improvements over the PPM Calculator.

- Updated SWAT 2005 engine
- Updated soil P model routines
- Applicable to the entire state of Oklahoma
- Flexible operation scheduling
- Allows cultivated crops and irrigation
- Rotational grazing and supplemental feed
- Hydrology calibrated from observed data across Oklahoma
- Supports additional BMPs
    - Cattle exclusion from riparian zones
    - Riparian and grass buffers
    - Ponds
    - Contour planting and terraces

    - Alum amended animal manure

- Predicts average annual STP change
- Multiple soils allowed within a single field
- Predict average and range of probable P losses based on 25 years of climate data
- Non-simulated BMPs tracked for record keeping
- Extensively validated using 283 field years of data

This chapter details the development and initial testing of PPM Plus. This includes the structure and functions used in PPM Plus and the databases which allow statewide implementation. Changes to the SWAT subroutines and a detailed sensitivity analysis are also included.

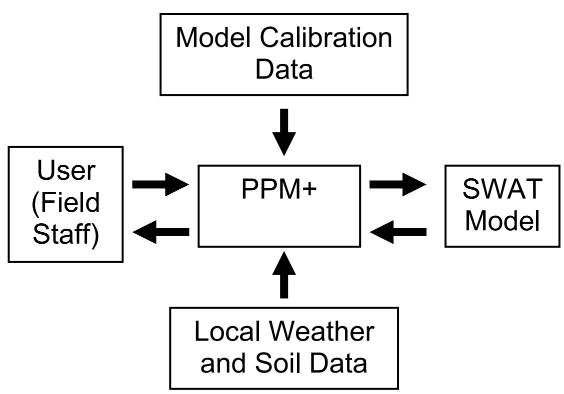


Figure 4.1 PPM Plus structure.

PPM Plus User Interface

The PPM Plus user interface is the only portion of the tool that the user sees; the SWAT model is hidden. The majority of inputs are displayed on the main form. There are four sections: Field Information, Best Management Practices, Management, and Simulation. The main form is shown in Figure 4.2.

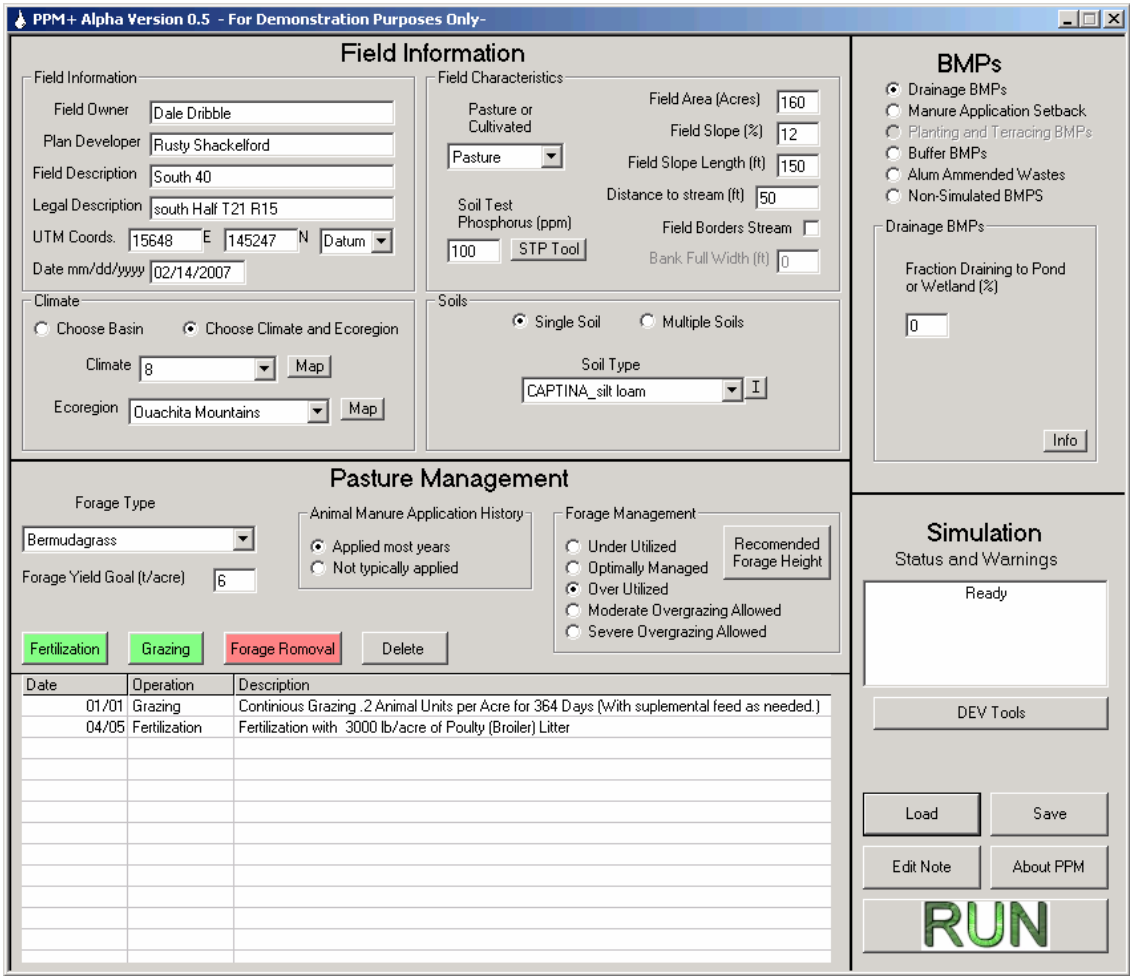


Figure 4.2 PPM Plus main form.

Field Information

This portion of the form contains entries for field record keeping, topographical characteristics, soil types, and climate selection. All of these data entered into PPM Plus are saved if the user saves the project. These saved PPM Plus files can be compiled for the purposes of record keeping or project management. Below are descriptions of each dialog box in the Field Information section of PPM Plus.

Field Owner **-** Owner or manager responsible for the property.

Plan Developer - Person who uses PPM Plus to develop a nutrient management plan for a particular field.

Field Description (optional) - Owners of multiple fields may include a description or name.

Legal Description (optional) – Legal description of the property

UTM Coords. (optional) - Universal Transverse Mercator (UTM) field coordinates. Note most USGS topographical maps use UTM projections.

Date - Date plan is developed.

Pasture or Cultivated – Allows the user to select between pasture and cultivated crop.

Soil Test Phosphorus (ppm) - Input for Mehlich III Soil Test Phosphorus in mg/kg or part per million. The STP tool (Figure 4.3) can be used to convert various STP Indices into a Melich III, 1:10 extractant ratio, colorimetric technique equivalent STP; the standard used by the Oklahoma State University Soil, Water and Forage Analytical Laboratory. The University of Arkansas Soil Testing and Research Laboratory uses an Inductively Coupled Argon Plasma (ICAP) method as opposed to the colorimetric procedure used in Oklahoma. Before 2006, Arkansas also used a 1:7 Melich III extractant ratio, but has since converted to a 1:10 ratio. The conversions used in PPM Plus are listed below:

- 1 mg/kg = 2 lb/acre – Assumes 6 inch soil sample.
- Melich III 1:10 extractant (lb/acre) = 1.27 * Melich 1:7 extractant (lb/acre) + 14.9 (Storm et al. 2001)
- Melich III Colorimetric (mg/kg) = 0.89 * Melich III ICAP (mg/kg) - 4.4 (Pittman et al. 2005)

Field Area (acres) - Area of field including buffers.

Field Slope (%) - The average field slope in percent.

Slope Length (ft) - Revised Universal Soil Loss Equation slope length.

Distance to Stream (ft) **-** Distance from field to nearest stream (intermittent or perennial) on a 1:24,000 scale USGS topographic map.

Field Borders Stream – Field contains or is adjacent to a perennial or intermittent stream.

Bank Full Width (ft) **-** Stream width from bank to bank; Includes the portion of the stream bank which is subject to annual submergence or scouring.

Climate Region - Select from one of nine climate zones for the state of Oklahoma.

Ecoregion - Select an Omernick Level III Ecoregion. This information will be used to determine if the allowable P loss (lb P/acre/yr) limits for a particular field are exceeded. Limits will be developed by ecoregion. The limits will not be developed as part of this research. A map of Oklahoma Level III ecoregions is given in Figure 4.4.

Soils - PPM Plus allow the use of up to three soils for a field. If multiple soils are selected, the user must indicate the percentage of the field occupied by each soil type. There are over 3,000 soil types included in PPM Plus. A soil browser is included in PPM Plus, which displays the Official Soil Series Description provided by the NRCS (NRCS, 2007) to aid in soil selection.

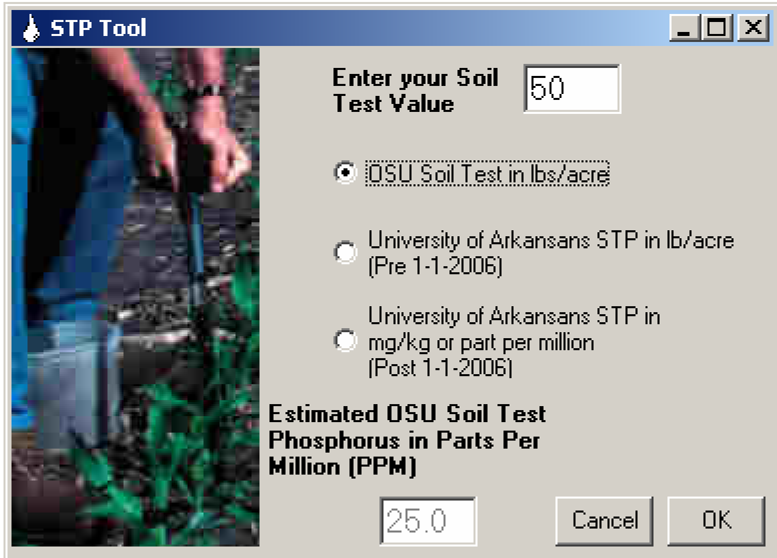


Figure 4.3 PPM Plus Soil Test P tool.

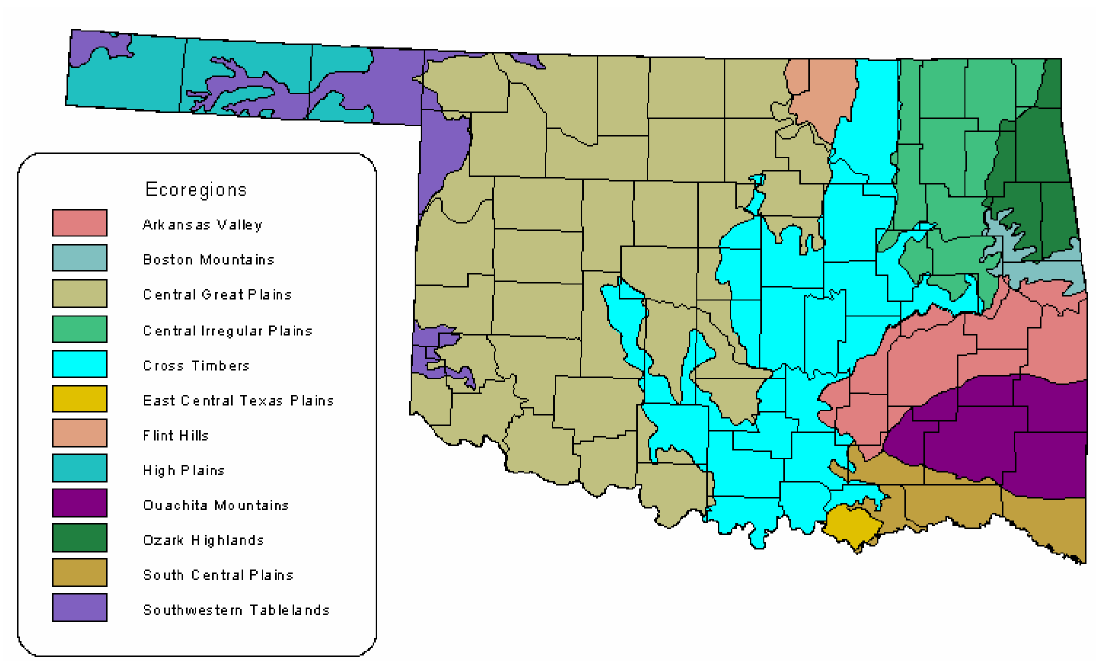


Figure 4.4 Oklahoma Omernick Level III Ecoregions.

Crop and Pasture Management

The management routines of the SWAT model are flexible, but require a large number of parameters. The crop and pasture management dialogs in PPM Plus are the most complex portion of the interface. Pasture and cultivated agricultural are treated separately; the management dialogs change depending upon whether pasture or cropland is selected in the field information section (Figure 4.5). With each change, only relevant management operation buttons are shown. These management buttons spawn other dialogs upon which the user details each management operation. Once the user completes each management operation, the button color changes from red to green and the operation is shown in the management table with a plain language description. Below is a description of each available management dialog:

Crop and Harvest – Allows the user to select a crop, planting and harvest dates, irrigation, and harvest type. Options are available for crops which are not harvested. If irrigation is selected, scheduling is based on crop need and will differ with rainfall and temperature. Dialog is given in Figure 4.6. This dialog is only available for cultivated crops.

Fertilization – Allows user to select fertilization materials, dates, and nutrient content. There are three available options:

1. Select a common fertilizer and amount of bulk material applied
2. Input actual nutrient application rates
3. Specify fertilizer analysis and bulk application rates

The interface calculates the actual nutrient application rates and provides this information in the bottom of the fertilizer dialog (Figure 4.7).

Tillage – Allows user to select tillage types and dates (Figure 4.8). Tillage operations are divided into primary and secondary tillage. One primary tillage type must be selected; the choices are conventional tillage, conservation tillage, and no-till. Conventional tillage includes a plowing operation resulting in a clean residue free surface. Conservation tillage is less aggressive and results in significant surface residue.

No-till eliminates tillage from pre-plant operations. Secondary tillage operations include weed removal, seedbed preparation, and incorporate material; these simulate a row cultivator, field cultivator, and disking respectively. SWAT uses a mixing depth and soil mixing efficiency to simulate tillage; implement type is less critical. This dialog is only available for cultivated crops.

Grazing – Allows the user to specify the start date, the end date, and the number of animal units per acre grazing (Figure 4.9). Two types of grazing are supported:

1. Cattle are moved on and off the field throughout the specified period as available forage changes. Includes rotational and flash grazing systems. This grazing system is used in highly managed farms to increase forage production.
2. Cattle remain on this field throughout the specified period; supplemental feed (hay or feed) are given as available forage declines. Common with less intensively managed farms.

Additional tables are given to aid in the estimation of animal units from stocking rate and animal weight. Grazing is halted or supplemental feed is provided if the available forage declines below a level specified in the forage management section of the pasture management dialog. SWAT uses a grazing cutoff (BIOMIN) value measured in kg dry forage per hectare. Five options are available and are described below:

1. Under Utilized - Under-stocked, excellent forage stand during the growing season. Minimum dry forage is 2000 kg/ha during the growing season.

Corresponds to approximately 10 cm of excellent condition fescue or 12 cm of good condition fescue (Barnhart 1998).

2. Optimally Managed - Optimally managed for forage production; no significant overgrazing during the growing season. Minimum dry forage is 1500 kg/ha during the growing season. Corresponds to approximately 7 to 10 cm of fescue depending on condition (Barnhart 1998), which is within the optimal provided by Bidwell and Woods (1996).
3. Over Utilized - Over-utilized due to excessive stocking. Short periods of overgrazing allowed during the growing season. No visible signs of erosion. Minimum dry forage is 1200 kg/ha during the growing season. Corresponds to approximately 5 to 7 cm of fescue depending on condition (Barnhart 1998).
4. Moderate Overgrazing Allowed - Moderate overgrazing allowed during the growing season. Visible signs of erosion. Minimum dry forage is 800 kg/ha during the growing season. Corresponds to approximately 4 to 6 cm of fescue depending on condition (Barnhart 1998).
5. Severe Overgrazing Allowed - Severe overgrazing allowed for a significant portion of the year. Severe erosion occurring, with active gullies and rills visible. Minimum dry forage is 500 kg/ha during the growing season. Corresponds to 3 to 5 cm of fescue depending on condition (Barnhart 1998).

Grazing on cultivated fields is suspended when available dry forage falls below 800 kg/ha. These grazing cutoffs only occur during the growing season; SWAT does not simulate grazing when forage is dormant.

Forage Removal – Allows the user to specify haying (Figure 4.10). The SWAT model was modified to leave a residue of 1000 kg/ha regardless of harvest efficiency. Hay cutting equipment does not remove all the forage present and generally leaves a fairly constant residual. SWAT utilizes a harvest efficiency which takes a fixed portion of the aboveground biomass. This approach may cause unrealistically low forage residuals after multiple hay cutting or hay cutting following grazing. Intensive managed Bermuda grass fields may be cut monthly throughout the growing season.

Forage Type – Four forage types are allowed in PPM Plus. These are listed below:

1. Cool Season (Fescue, Rye) – Simulated as tall fescue.
2. Bermuda grass – Simulated as Bermuda grass.
3. Native Grass – Simulated as Indian grass.
4. Mixed Warm and Cool Grasses – Simulated with custom crop parameters given in Table 4.1.

Mixed warm and cool season forages are popular in eastern Oklahoma. Unfortunately, SWAT 2005 does not allow multiple crops to grow simultaneously. A new crop was created by mixing fescue and Bermuda grass crop growth parameters. The biomass produced by the new crop was evaluated on a seasonal basis using PPM Plus. Initially the combination of parameters produced excessive biomass. These parameters were adjusted such that the growth was reasonable for mixed forage pastures. These parameters are given in Table 4.1. Work continues to develop better crop growth parameters (including radiation use efficiencies) for forages (Kiniry et al. 2007). All pasture crop radiation use efficiencies were adjusted to produce reasonable forage yields for each of the four forage types simulated. Additional comparison and or calibration of biomass production could significantly improve the crop growth predictions so that available forage or estimated yield could be reported in PPM Plus output. This was beyond the scope of this research.

Forage Yield Goal – Computes the maximum recommended rate of nitrogen application based on user yield goal. Determination of maximum nitrogen application rates is based on OSU soil test recommendations (Zhang et al. 2003). The user is warned if the total nitrogen application rate exceeds the maximum recommendation. If the application rate exceeds the maximum allowable rate by 150% or more, the model will not run. This input is available only with pastures.

Animal Manure Application History – The application of P rich animal manures alters the P distribution within the soil profile. Pastures which have a recent history of manure application have a P enriched zone at the soil surface. P has limited mobility in the soil profile. Franzluebbers et al. (2002) examined Mehlich III extractable P with depth on Bermuda grass pastures. They found the application of broiler litter significantly increased extractable P in the surface soil layer. The effect of litter on extractable P decreased with increasing depth. The SWAT model was modified to allow the initial soil P in the surface 10 mm to be set. The model was also modified to output total soil P in the upper two soil layers. A series of SWAT simulations were performed under differing managements and fertilization schemes. The ratio of soil surface P (10mm) to the layer below was recorded for a 25 year period. These data are given in Figure 4.11. Only scenarios including excessive P application due to manure had high surface enrichment. Grazing seemed to increase surface enrichment, likely due to the manure deposited by the cattle. Management options without poultry litter had similar enrichment ratios. Surface/subsurface P ratios were estimated for littered pastures and all other types of management combined. If there is a history of animal manure application, the surface

10 mm is set to 4.7 times the STP of the remaining profile; the average enrichment of SWAT scenarios including litter application. If there is no history of animal manure application the surface is 1.2 times the STP at a depth greater than 10 mm, the average of all other SWAT scenarios. This option is available for pastures only; tillage mixes the soil and prevents dramatic buildup of P at the surface. The 1.2 enrichment ratio is applied to cultivated fields regardless of fertilization history.

Other SWAT Management Related Inputs

The majority of user-to-SWAT parameter transformations are discussed in the section describing each particular dialog box. However, a few SWAT parameters are based on multiple user inputs across several dialogs; these are described here. The most important of these inputs is Curve Number (CN). CN has a direct impact upon the fraction of rainfall which becomes runoff. CN for pastures is based on Hydrologic Soil Group, grazing, and field condition. CN for pastures is given in Table 4.2. These were based on values given in the SWAT 2005 manual (Neitsch et al. 2005), which in turn were based on (SCS 1986). CN for small grains and row crop were derived from the SWAT manual and differ based on crop, tillage type, and BMPs used. CN for cultivated fields is given in Table 4.3.

Manning's n for overland flow is used in the calculation of peak flow by SWAT and is based on the same management variables which influence CN. Manning's n values are given in Tables 4.2 and 4.3. These are taken directly from the SWAT 2005 manual, which derived values from Engman (1983). Manning's n for tributary channels was set to 0.035, which was cited by LMNO (2007) as a value for pasture and farmland floodplains or cobble streams.

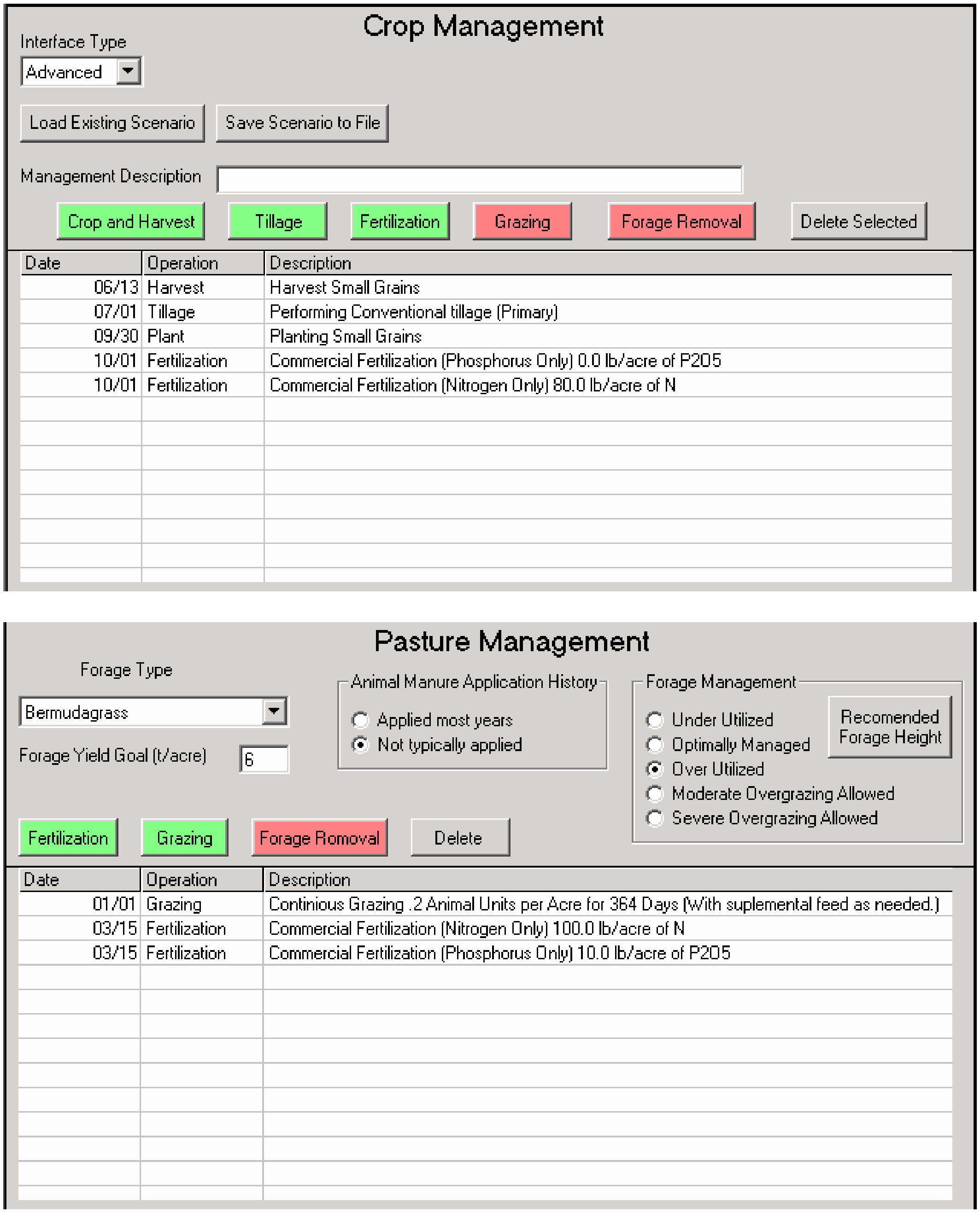


Figure 4.5 PPM Plus crop and pasture management dialogs.

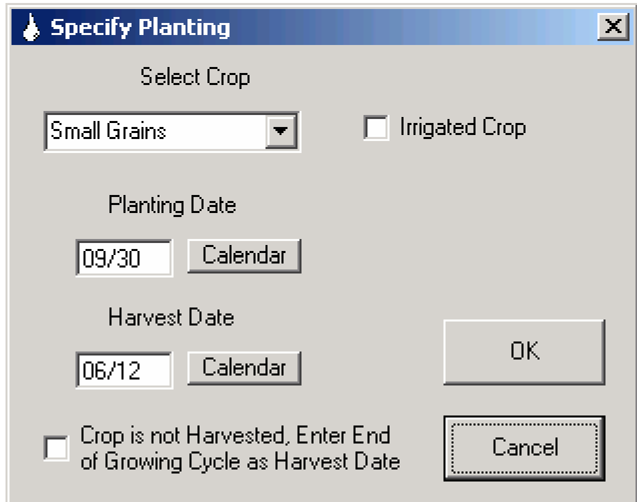


Figure 4.6 Crop selection dialog for cultivated crops.

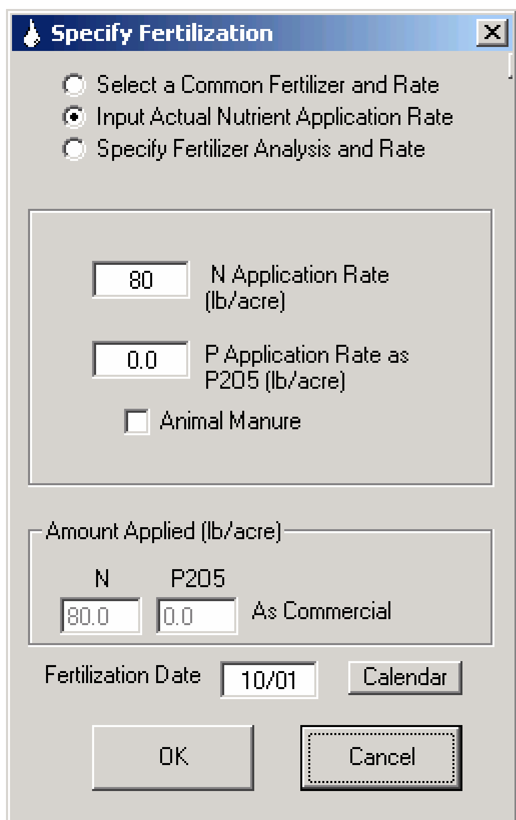


Figure 4.7 Fertilization dialog available with both pasture and cultivated crops.

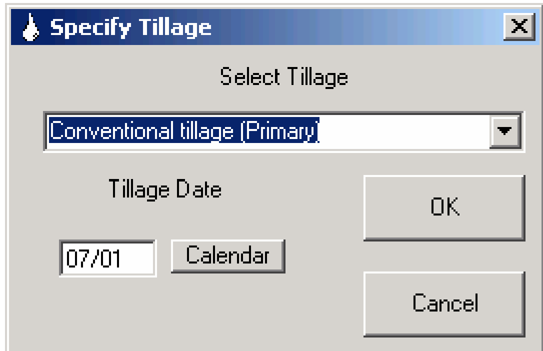


Figure 4.8 Tillage dialog for cultivated fields.

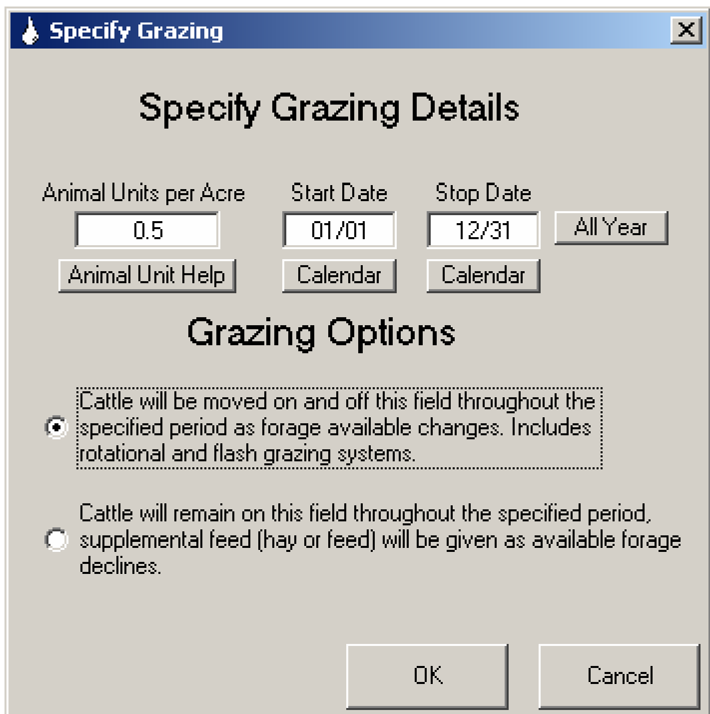


Figure 4.9 Grazing dialog for pasture and cultivated fields.

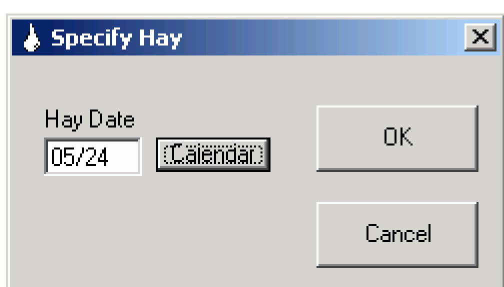


Figure 4.10 Forage removal dialog for pasture and cultivated fields.

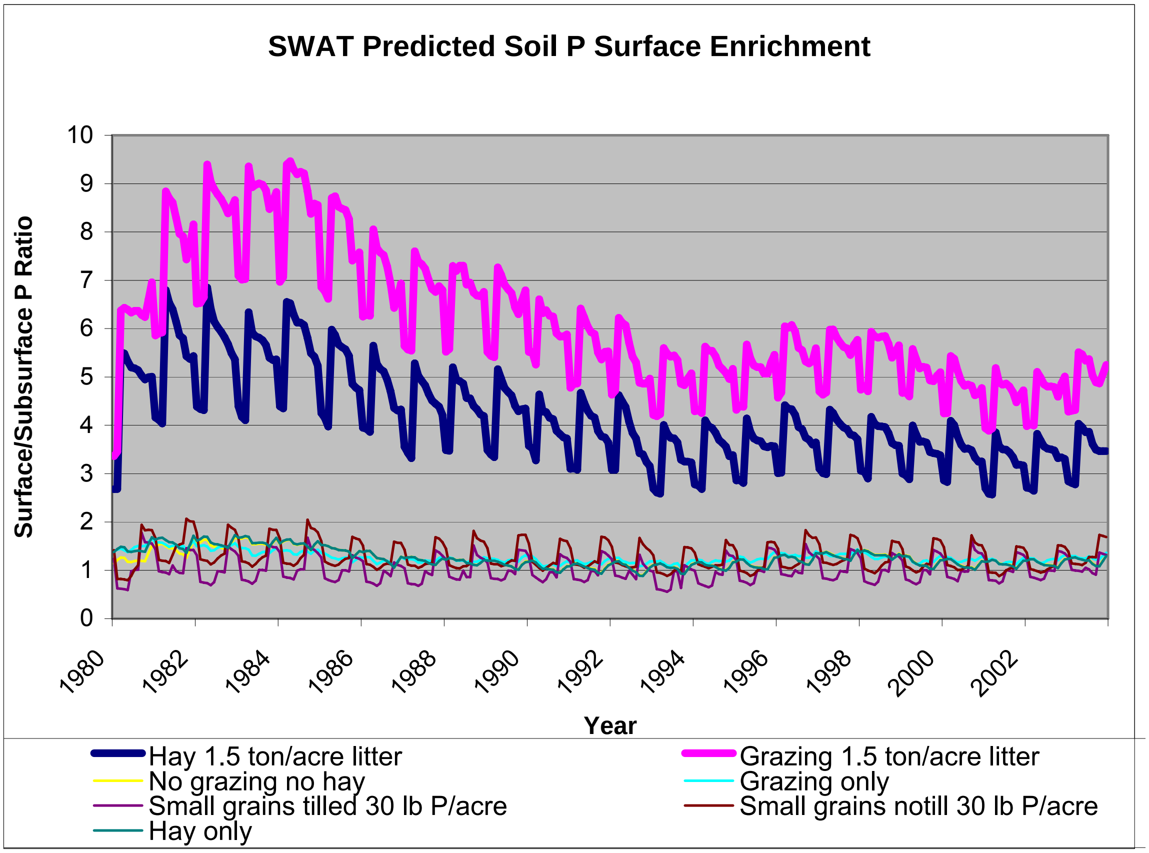


Figure 4.11 SWAT predicted soil P surface enrichment under differing managements for 25 years.

Table 4.1 SWAT crop growth parameters used in PPM Plus.

Parameter	Fescue	Bermuda	Indiangrass	Mixed
BIO_E	10	10	9	10
HVSTI	0.9	0.9	0.9	0.9
BLAI	4	4	3	4
FRGRW1	0.15	0.05	0.05	0.15
LAIMX1	0.01	0.05	0.1	0.03
FRGRW2	0.5	0.49	0.25	0.5
LAIMX2	0.95	0.95	0.7	0.95
DLAI	0.8	0.99	0.35	0.99
CHTMX	1.5	0.5	1	1
RDMX	2	2	2	2
T_OPT	15	25	25	25
T_BASE	0	12	12	0
CNYLD	0.0234	0.0234	0.016	0.0234
CPYLD	0.0033	0.0033	0.0022	0.0033
BN1	0.056	0.06	0.02	0.06
BN2	0.021	0.0231	0.012	0.022
BN3	0.012	0.0134	0.005	0.013
BP1	0.0099	0.0084	0.0014	0.0093
BP2	0.0022	0.0032	0.001	0.0027
BP3	0.0019	0.0019	0.0007	0.0019
WSYF	0.9	0.9	0.9	0.9
USLE_C	0.003	0.003	0.003	0.003
GSI	0.005	0.005	0.005	0.005
VPDFR	4	4	4	4
FRGMAX	0.75	0.75	0.75	0.75
WAVP	8	10	10	9
CO2HI	660	660	660	660
BIOEHI	39	36	39	37.5
RSDCO_PL	0.025	0.025	0.025	0.025

Table 4.2 Curve Number and Manning’s n for pastures in PPM Plus. Derived from Neitsch et al. (2005), SCS (1986), and Engman (1983).

Pasture Management Condition	Hydrologic Soil Group				Manning's n for Overland Flow
	A	B	C	D	
Severe Overgrazing Allowed	68	79	86	89	0.15
Moderate Overgrazing Allowed	59	74	83	87	0.20
Over Utilized	49	69	79	84	0.25
Optimally Managed	44	65	77	82	0.30
Under Utilized	39	61	74	80	0.35
Not Grazed	30	58	71	78	0.40

Table 4.3 Curve Number and Manning's n for cultivated fields in PPM Plus. Derived from Neitsch et al. (2005), SCS (1986), and Engman (1983).

Crop	Planting BMP	Tillage	Hydrologic Soil Group				Manning's n for Overland Flow
			A	B	C	D	
Row Crop	Strait Rows	Conventional	67	78	85	89	0.09
Row Crop	Contour	Conventional	65	65	82	86	0.09
Row Crop	Contour and Terraced	Conventional	62	71	78	81	0.09
Row Crop	Strait Rows	Conservation	64	75	82	85	0.12
Row Crop	Contour	Conservation	64	74	81	85	0.12
Row Crop	Contour and Terraced	Conservation	61	70	77	80	0.12
Row Crop	Strait Rows	No-till	60.8	71.3	77.9	80.8	0.15
Row Crop	Contour	No-till	60.8	70.3	77	80.8	0.15
Row Crop	Contour and Terraced	No-till	58	66.5	73.2	76	0.15
Small Grains	Strait Rows	Conventional	63	75	83	87	0.09
Small Grains	Contour	Conventional	61	73	81	84	0.09
Small Grains	Contour and Terraced	Conventional	59	70	78	81	0.09
Small Grains	Strait Rows	Conservation	60	72	80	84	0.12
Small Grains	Contour	Conservation	60	72	80	83	0.12
Small Grains	Contour and Terraced	Conservation	58	69	77	80	0.12
Small Grains	Strait Rows	No-till	57	68.4	76	79.8	0.15
Small Grains	Contour	No-till	57	68.4	76	78.9	0.15
Small Grains	Contour and Terraced	No-till	55.1	65.6	73.2	76	0.15

Best Management Practices

Any BMP that could be reliably simulated using SWAT was included in PPM Plus. A number of additional BMP were included for record keeping purposes, but do not influence model predictions. BMPs were categorized and described in the following groups:

Drainage BMPs

Drainage BMP options allow the user to specify a portion of the field which drains to a pond or wetland (Figure 4.12). If included, SWAT will simulate a pond receiving runoff from that portion of the field. Pond size is based on the field location within the state of Oklahoma. Whitis (2002) recommended drainage area to surface area ratios between 30:1 to 5:1 depending on the land use and soils within the drainage area. This ratio was assumed to be 30:1 in western Oklahoma and 15:1 in eastern Oklahoma to reflect different rainfall conditions. This ratio is linearly interpolated based on selected climate zone. These data are used to estimate the size of the pond only; the drainage area is calculated from user inputs. Ponds are assumed to be 1.5 meters (4.9 ft) in depth and initially 75% full. All other pond parameters are default. P removal efficiencies for these ponds are high and thus the vast majority of P entering ponds is removed. Knight and Cooper (1990) measured 70% removal efficiency for nitrogen and P compounds in a 1.09 ha flood and sediment control structure. The removal efficiency is in part a function of detention time. Many small ponds in Oklahoma discharge only a small fraction of the water they receive in a typical year, and have very long detention times, and high P trapping efficiency. The ponds represented in PPM are intended to represent farm pond conditions, not sediment retention basins or flood control structures.

Manure Application Setback

Manure application guidelines use setbacks to prevent manure application in sensitive areas near streams, wellheads, and property boundaries. The area in setbacks may be a significant fraction of the total acreage in smaller fields. Setbacks are not treated as buffers. Setbacks receive no special management other that they do not receive manures, and are not segregated from the main field. Setbacks may be cultivated or grazed. A field may have both setbacks and buffers.

Planting and Terracing

Planting and terracing BMPs are among the most popular ways to reduce sediment and nutrient losses from cultivated fields.

1. Straight Rows – Default condition, crop is planted in strait rows regardless of slope.
2. Contour Planted - Crop is planted along the contour.

3. Terrace and Contour - Field is terraced and crop is planted along the contour.

These BMPs are simulated by adjusting the Modified Universal Soil Loss Equation (MUSLE) Practices (P) factor according to the practice used and the slope of the field according to Haan et al. (1994). P factors are given in Table 4.4. These BMPS are not credited in pastures even though they may exist.

Riparian and Grass Buffers

Grass and riparian buffers trap sediment and nutrients passing through them before they reach waterways. Buffers are among the most effective BMPS when properly established and maintained. For buffers to work properly, they must receive relatively uniform overland flow along their length. Channels or concentrated flow through buffers bypass the buffer itself and dramatically reduce the effectiveness of this important BMP. Both grass and forested riparian buffers are permitted in PPM Plus individually or together.

Buffer width and total field area in buffers must be specified. The area in buffers is removed from the area of the main field and simulated as grass and/or forested. The filtering effect of buffers is simulated by SWAT. SWAT 2005 added support for field buffers using a trapping effect based on buffer width. The same trapping efficiency was used for particulate nutrients, and sediment.

Klapproth and Johnson (2000) presented a summary of existing literature on the removal mechanisms of P in buffers. They concluded that the primary mechanism of P removal is deposition with sediments. Some soluble P may attach to clays, taken by plants or infiltrate within the buffer. Unfortunately, uptake by plants may not permanently remove P from the systems, as much of this material is eventually recycled. Clays in riparian areas can become saturated with large influxes of P from surrounding areas. Peterjohn and Correll (1984) found 85% removal of total P and no net loss of soluble P within a riparian buffer. The SWAT model was modified to treat soluble nutrients as conservative through buffers since soluble nutrients are less affected by buffers.

Cattle exclusion from riparian area is offered as a BMP even though the effect of cattle in the riparian zone is not simulated by SWAT. Cattle are assumed to have unrestricted access to the stream if the field is adjacent to the stream. The fraction of time that cattle spend in riparian zones was measured by James et al. (2007) using dairy cattle. They found that 12% of cattle manure was deposited within 32 feet of a stream and 6% was deposited directly into water. These estimates and the width of the stream are used in PPM Plus to estimate the fraction of all cattle manure which is deposited in the stream. Cattle manure production rates simulated by SWAT are combined with the fraction of time cattle spend in the stream to estimate the total P contribution of cattle in the riparian zone. A study by Kleinman et al. (2002) was used to estimate the solubility of these manures. These simulated P loads are estimated monthly and added into PPM Plus output unless the riparian buffer cattle exclusion is checked or the field is not adjacent to a stream.

Alum Amended Animal Manures

The application of alum to animal manures prior to application can significantly reduce soluble P losses in runoff. The SWAT model was modified to accept alum amended manures. The application of these manures still increases soil P, but P is applied in more stable forms not readily available for dissolved P loss in runoff. The addition of alum reduced water soluble P in manures by 66% in farm scale data collected by Sims and Luka-McCafferty (2002). At the full recommended rate of 0.2 lb (0.09kg) per bird capacity (Moore et al. 1999), 66% of the mineral P in manure was applied in stable forms. The following options are available:

1. No Alum (default)
2. Less than 0.075 lb (0.034 kg) alum per bird
3. 0.075 to 0.15 lb (0.034 to 0.068 kg) alum per bird (1/2 recommended rate)
4. 0.15 to 0.2 lb (0.068 to 0.09 kg) alum per bird (recommended rate)

The *½ recommended rate* reduces a stable fraction of 33% as opposed to the 66% at the full *recommended rate*. A *less than 0.075 lb per bird* rate is available as many producers use alum for ammonia control, but apply it at rates which do little to stabilize P. This option offers no benefit in PPM Plus.

Non-Simulated BMPS

A number of BMPs are available which are not simulated in PPM Plus. These are included for record keeping purposes and may be activated in future versions. A list of non-simulated BMPs is given below:

1. Composting Facility
2. Heavy Use Area Protection
3. Conservation Crop Rotation
4. Alternative Water Sources
5. Wind Barriers
6. Streambank Protection
7. Drop Structure
8. Grassed Waterways

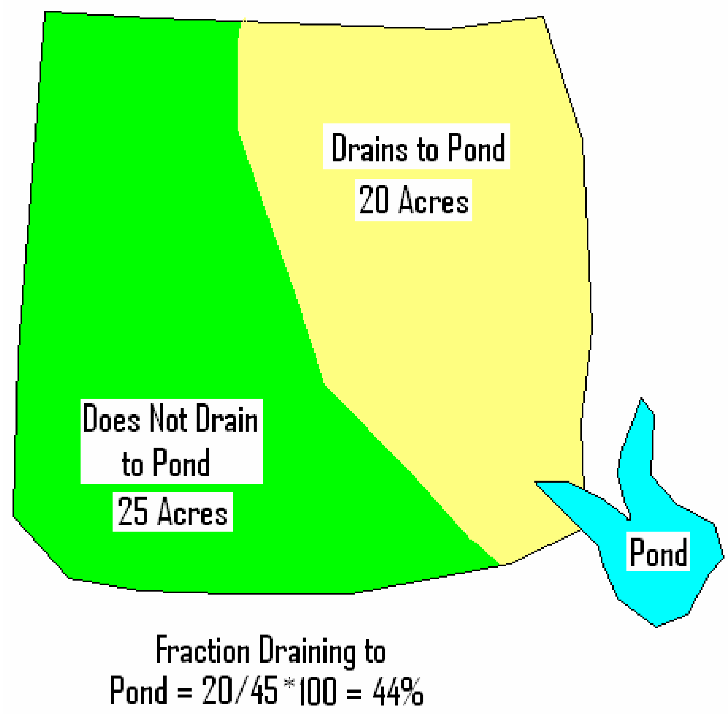


Figure 4.12 Calculation of the fraction of field draining to pond or wetland in PPM Plus.

Table 4.4 Modified Universal Soil Loss Equation crop Practice (P) factors.

Condition	Slope range (%)	MUSLE P factor
Strait Row	0-25	1.00
Contour	0-2	0.90
Contour	2-5	0.80
Contour	5-8	0.70
Contour	8-12	0.60
Contour	12-16	0.50
Contour	16-20	0.50
Contour	20-25	0.60
Terraced	0-2	0.12
Terraced	2-8	0.10
Terraced	8-12	0.12
Terraced	12-16	0.14
Terraced	16-20	0.16
Terraced	20-25	0.18

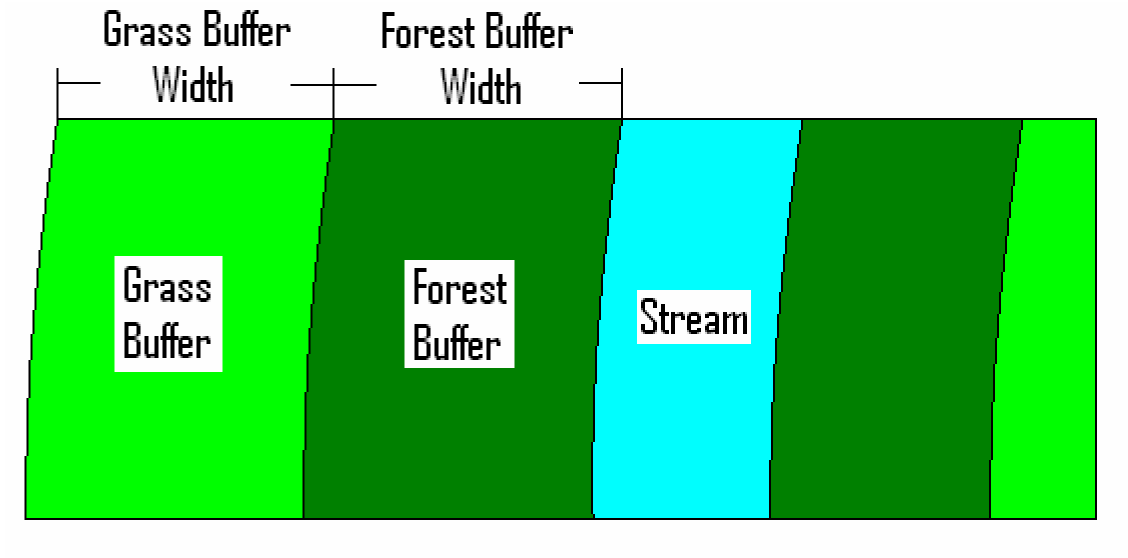


Figure 4.13 Buffers as defined in PPM Plus.

PPM Plus Model Structure

Model Descritization

The PPM Plus SWAT model is simple as compared to typical SWAT model applications. The model consists of one subbasin and six HRUs. PPM Calculator uses a single HRU. Each of the six HRUs is listed below and depicted in Figure 4.14:

- HRU 1 - Primary soil type main field
- HRU 2 - Secondary soil type main field (optional)
- HRU 3 - Ternary soil type main field (optional)
- HRU 4 – Manure application setback (optional)
- HRU 5 – Grass buffer (optional)
- HRU 6 – Riparian forest buffer (optional)

The majority of these HRUs are optional depending upon which BMP and soil configuration is selected. When not used, these optional HRUs are assigned areas of zero and do not contribute to overall P loss.

SWAT was developed to make predictions at the basin or watershed scale. SWAT contains the field scale components to make these predictions, but it was not the initial intent of the model. PPM Plus makes predictions of sediment, runoff, and nutrients delivered to the stream, not at the edge of the field like PPM Calculator. PPM Plus capitalizes on subbasin scale components in SWAT to make these predictions. A portion of the sediment and nutrients liberated from the soil surface via runoff are not transported to the stream. These materials are often redeposited elsewhere in the field or in route to the stream. The amount of sediment delivered typically decreases with increasing area, but may be irregular in cases of geomorphic transitions (Jiongxin and Yunxia 2005). The ratio of delivered material vs. the detached material is defined as the delivery ratio. Delivery ratio is a function of many factors including drainage area. SWAT uses the MUSLE (Williams 1975) equation to predict sediment delivery. MUSLE was developed using small mixed land use watershed data and implicitly includes a delivery ratio. Area is included directly into MUSLE and indirectly in the form of peak flow which is also used in MUSLE. The peak flow calculation used in MUSLE is sensitive to tributary channel length. The SWAT model is sensitive to both subbasin area and the distance to the stream. Other research has found SWAT sediment predictions to be sensitive to subbasin area (White 2001, Bingner et al. 1997).

PPM Plus predicts the load delivered to the stream, not the edge of field load. The entire drainage area contributing where the delivered material meets the stream is used in MUSLE, not the area of the field. This point where flow from the field meets the stream is referred to as the outlet. The entire drainage area contributing at the outlet is taken as the subbasin area in SWAT. These are depicted in Figure 4.15. The *distance to stream* is defined as the distance from the edge of the field to the outlet; in SWAT this is taken as the longest flow path within a subbasin as determined using a GIS. In PPM Plus the user must measure the distance from the field to the nearest stream from a 1:24,000 USGS topographic map. The distance from the field to the outlet is easily measured, but the drainage area at that point (subbasin area) is not. The appropriate subbasin area is estimated automatically within PPM Plus based on the climate zone selected by the user.

A series of topographic analyses were conducted in basins across Oklahoma to estimate the subbasin size necessary to approximate the drainage density provided by a standard USGS 1:24,000 topographic map. National Hydrographic Dataset (NHD) was used to determine the average subbasin size corresponding to this 1:24,000 drainage network. NHD GIS data have separate entities for each stream reach which are broken at each confluence, the same stream descritization scheme used by SWAT to define subbasins.

NHD data for 19 USGS 8-digit Hydrologic Units were analyzed to determine their average subbasin areas. These data are given in Figure 4.16 and Table 4.5. Tucker and Bras (1998) found a positive correlation between drainage density and rainfall, although many other factors influence drainage density. Average subbasin area was larger in the more arid panhandle region. Drainage density is a function of Analysis of Variance (ANOVA) procedure was used to determine which zones had significantly different mean areas. Tukey 95% simultaneous confidence intervals (Tukey 1953) were developed for all pairwise comparisons by climate zone. There were no significant differences (α=0.05) among zones 3-9; only zones 1 and 2 were significantly different. The mean area derived from each significantly different climate zone group was used to set the subbasin area used by the SWAT model in PPM Plus (Figure 4.17). There is significant scatter in these data. However, other factors such as drainage network age, relief, and geology, which may explain additional variability (Tucker and Bras 1998) were not included due to simplicity requirements. An informal series of PPM Plus test simulations indicated SWAT was relatively insensitive to subbasin size over the 100 to 300 acre range.

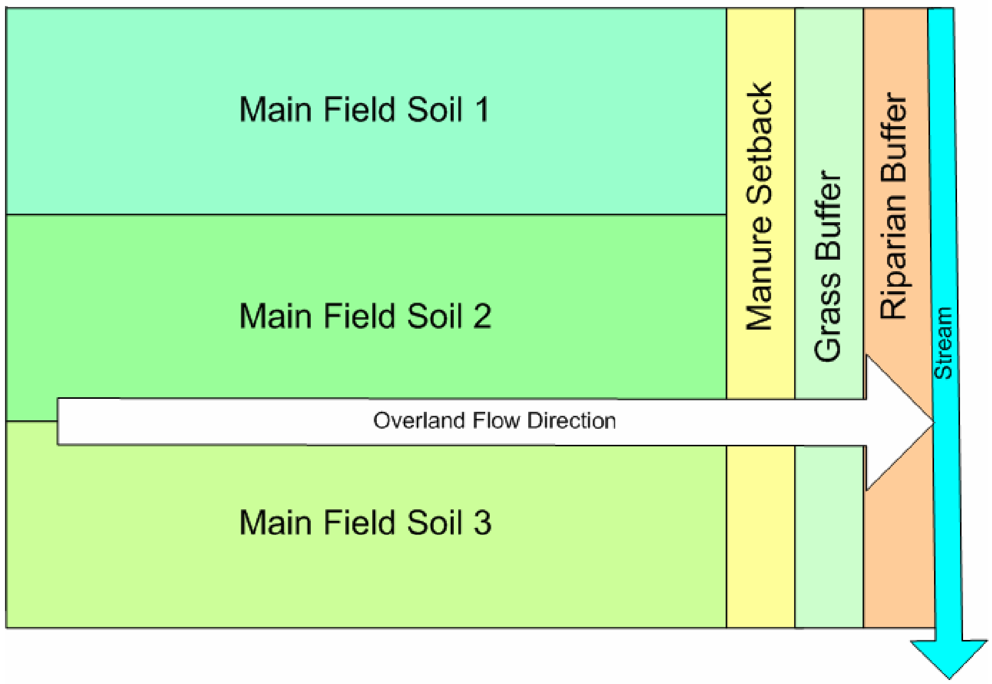


Figure 4.14 SWAT model Hydrologic Response Units (HRUs) used in PPM Plus. Includes optional HRUs based on Best Management Practice (BMP) and three soil selections.

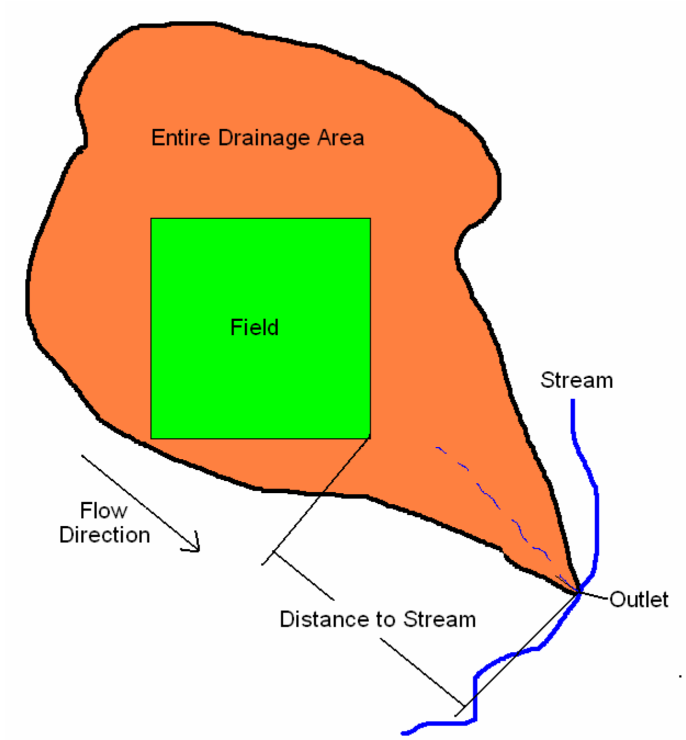


Figure 4.15 Illustration representing the field within a larger subbasin area. The subbasin area is defined as the drainage area at the outlet.

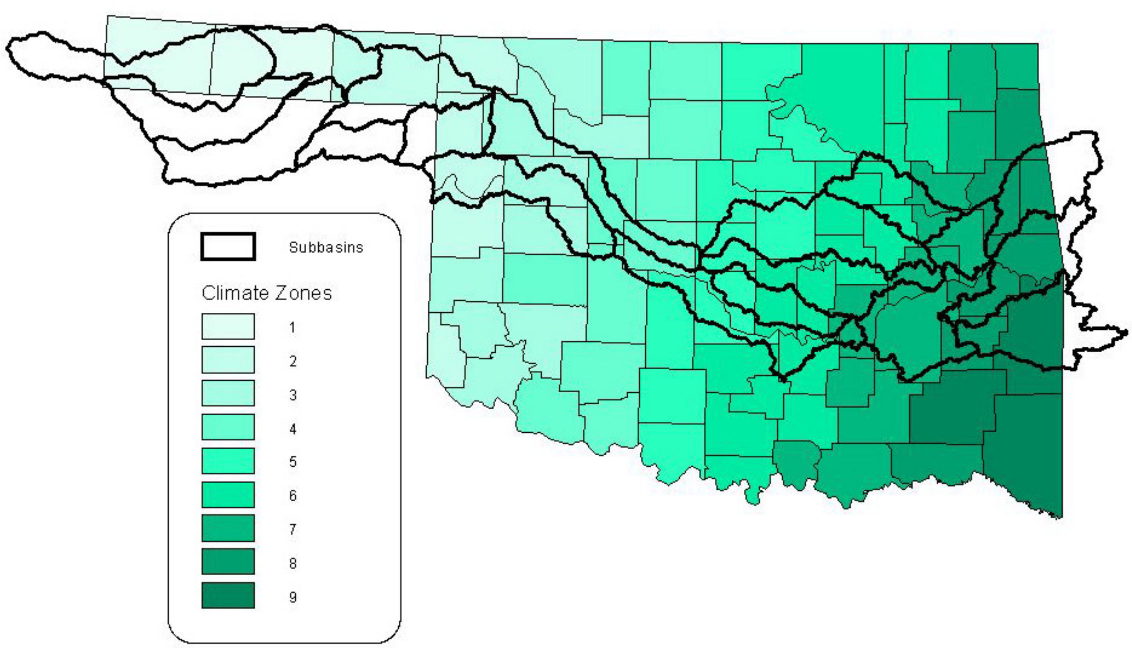


Figure 4.16 US Geologic Survey 8-digit Hydrologic Units used to estimate 1:24,000 subbasin sizes.

Table 4.5 1:24000 subbasin area for select US Geologic Survey 8-digit Hydrologic Units across the state of Oklahoma.

USGS Hydrologic Unit	Subbasin Area (ha)
Upper Beaver. New Mexico, Oklahoma, Texas.	129
Middle Beaver. Kansas, Oklahoma.	126
Coldwater. Oklahoma, Texas.	158
Palo Duro. Oklahoma, Texas.	134
Lower Beaver. Oklahoma, Texas.	40
Upper Wolf. Texas.	52
Lower Wolf. Oklahoma, Texas.	42
Middle North Canadian. Oklahoma.	79
Lower North Canadian. Oklahoma.	48
Deep Fork. Oklahoma.	34
Polecat-Snake. Oklahoma.	38
Dirty-Greenleaf. Oklahoma.	32
Illinois. Arkansas, Oklahoma.	43
Robert S. Kerr Reservoir. Arkansas, Oklahoma.	55
Poteau. Arkansas, Oklahoma.	45
Lower Canadian-Deer. Oklahoma,Texas.	46
Lower Canadian-Walnut. Oklahoma.	31
Little. Oklahoma.	47
Lower Canadian. Oklahoma.	49

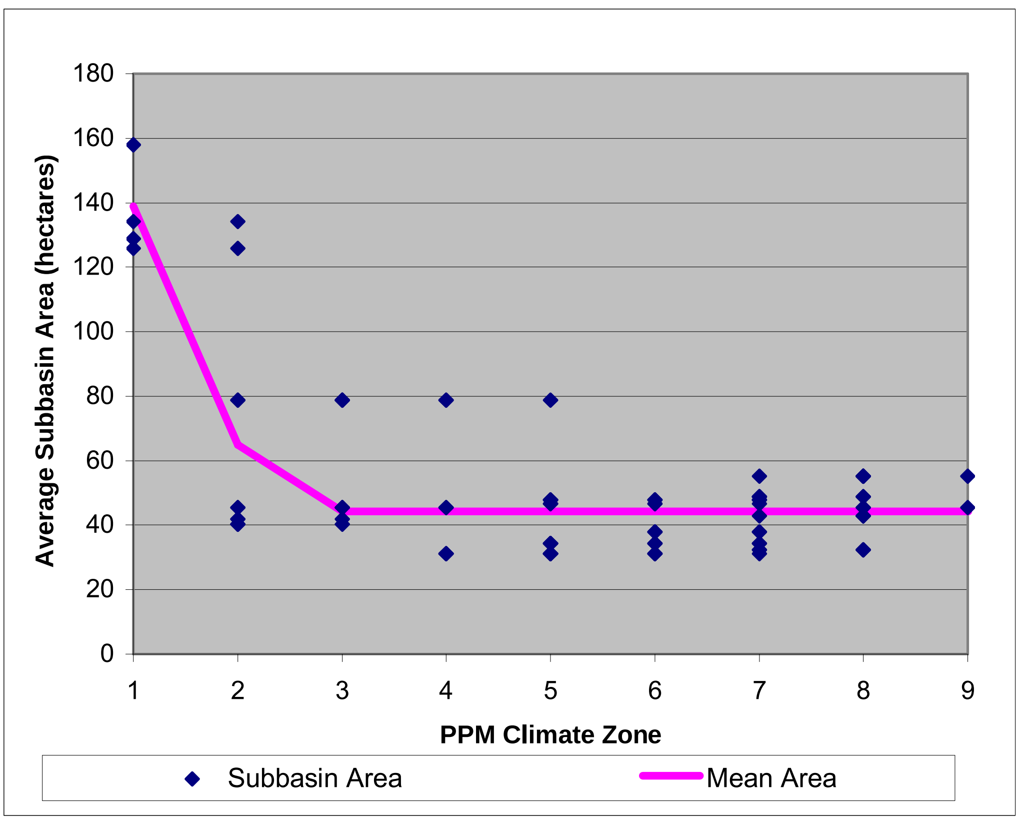


Figure 4.17 Average subbasin size as a function of PPM Plus climate zone.

PPM Plus SWAT File Exchange

PPM Plus acts as an input and output interpreter for a modified version of SWAT 2005. Many files are passed back and forth during a model simulation. A diagram of the file structure is given in Figure 4.18. Files used by SWAT are grouped into static and dynamic input files. Static files are not modified by PPM Plus at runtime. Dynamic input files are modified at runtime based on user inputs and passed to the SWAT model prior to simulation execution.

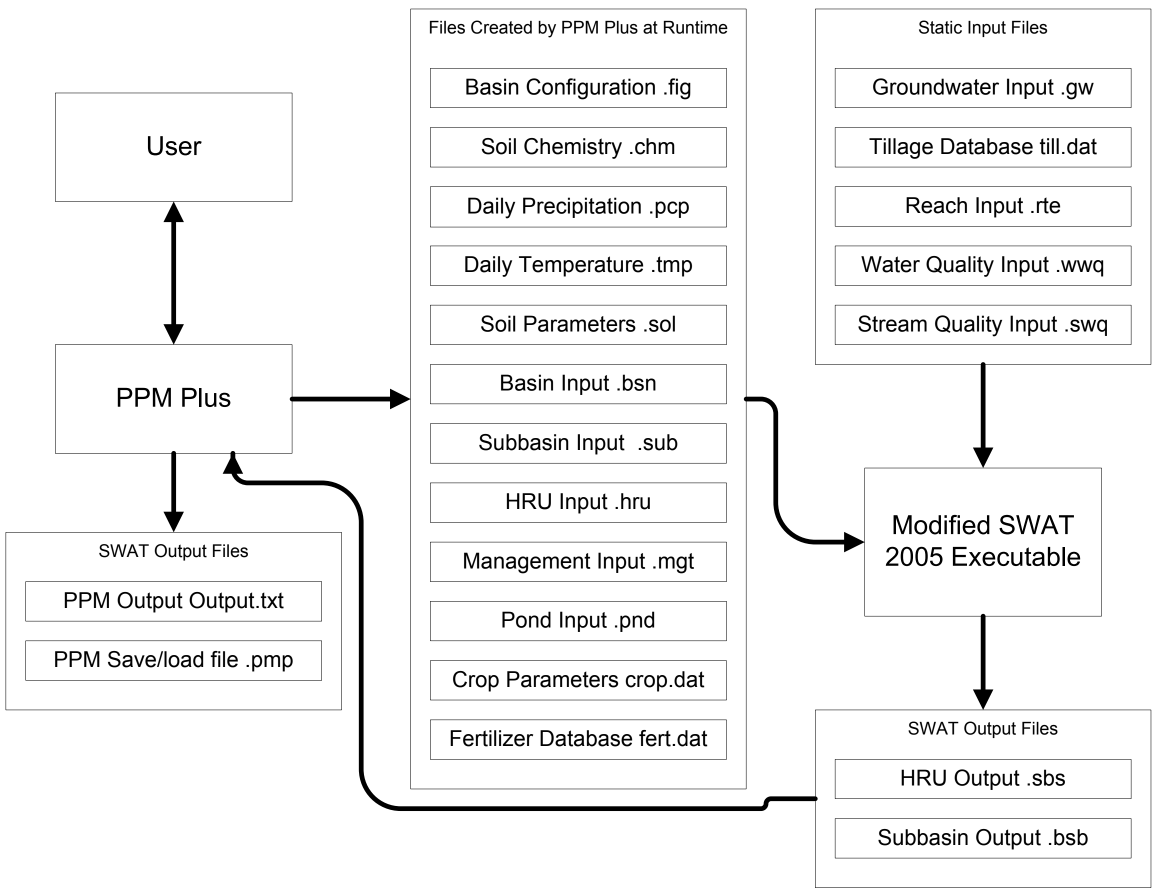


Figure 4.18 PPM Plus SWAT file exchange structure.

Statewide Database Development

PPM Plus has wider applicability than PPM Calculator. PPM Calculator is only applicable to the Lake Eucha/Spavinaw basin. PPM Plus is applicable to the entire state of Oklahoma. Supporting databases for climate and soils were necessary to properly represent the variety of conditions across Oklahoma.

Climate

Oklahoma has tremendous differences in annual rainfall, ranging from 15 in/yr (381 mm/yr) in the panhandle to 55 in/yr (1,397 mm/yr) in southeastern Oklahoma. Rainfall is the driving force for P loss and must be properly represented in the model to make accurate predictions. Oklahoma was broken into nine climate zones based on annual rainfall as estimated by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al. 2001). Each county was assigned to a single climate zone; a National Weather Service (NWS) Cooperative observer network station was selected within each zone to represent the climate for the entire zone. These climate zones are given in Figure 4.19; corresponding precipitation averages are given in Table 4.6.

Cooperative observer weather data are collected by professional NWS personnel, cooperators of the NWS such as other federal and state agencies, and private unpaid volunteers. The majority of these data are collected by unpaid volunteers. For this reason, these data are plagued with missing days, months, or even years. These data were processed to replace questionable and missing records with interpolated data from surrounding stations to provide a continuous daily record from 1950 to 2005 for rainfall, maximum temperature, and minimum temperature. PPM Plus uses weather data from 1970 to 2005 to conduct a 25 year simulation. Data from 1950 to 1970 were included to allow longer simulation periods for research purposes.

A two year warm-up period was included in all simulations to allow the model equilibrate to current conditions. The SWAT model includes parameterization for initial conditions such as soil moisture content, surface residue, and aquifer height all of which default to zero. Zero is an inappropriate value for many of these parameters and the model produces erroneous output for the first year or two of the simulation. SWAT allows the user to specify a warm-up period; model predictions during the warm-up period are discarded and do not appear in SWAT output or summaries. A two year warm-up period was selected for use in PPM Plus because it is the shortest reasonable period. For PPM Plus to run quickly, it was important to use a short simulation period. Informal evaluation of differing warm-up periods using PPM Plus found poor model performance with a single year warm-up and little difference between 2 and 3 years of warm-up.

Soils Database

Geologic and rainfall diversity have produced many differing soils across Oklahoma. Soil characteristics are among the most important data required by SWAT. Soils were derived from the State Soil Geographic (STATSGO) and Soil Survey Geographic (SSURGO) databases. SSURGO was the primary source for soil characteristics. Available data were processed for each Oklahoma county and Arkansas counties which border Oklahoma using the Arcview SWAT 2005 (AVSWATX) interface. These county data were combined and sorted into a single database containing all SSURGO data for Oklahoma. The database was analyzed to remove questionable records. Many of these soils list differing textural properties. Sand, silt, clay, and rock fractions were used to determine textural class using software developed by Gerakis and Baer (1999). Soil series name was appended with the textural class of the surface layer to take advantage of this information. For example, within the Clark soil series three separate textural listings are available: loam, fine sandy loam, and clay loam. Users may select any of these variants within the Clark series.

SSURGO data are the most detailed digital soil data available for Oklahoma, but the database is incomplete. There are missing counties and inconsistencies in the data which cause the Arcview SWAT SSURGO converter to fail. To cover soil series which were unavailable in SSURGO, older STATSGO data were used. STATSGO soil data have been preprocessed for use in other SWAT model interfaces. STATSGO soils for Oklahoma and all neighboring states were included in PPM Plus. Many minor soil series found in Oklahoma are not listed in the STATSGO data for Oklahoma. These soils may be found in STATSGO data from surrounding states where they are more common. Only soil series which were not available from SSURGO were included. This STATSGO database was combined the SSURGO database resulting in over 3,200 soils. A custom Visual Basic application was developed to transform these preprocessed databases into files directly compatible with the SWAT model. The source code for this application is given in Appendix B. PPM Plus includes the Official Soil Series Description (OSSD) provided by the NRCS (NRCS 2007) for each soil series in the database.

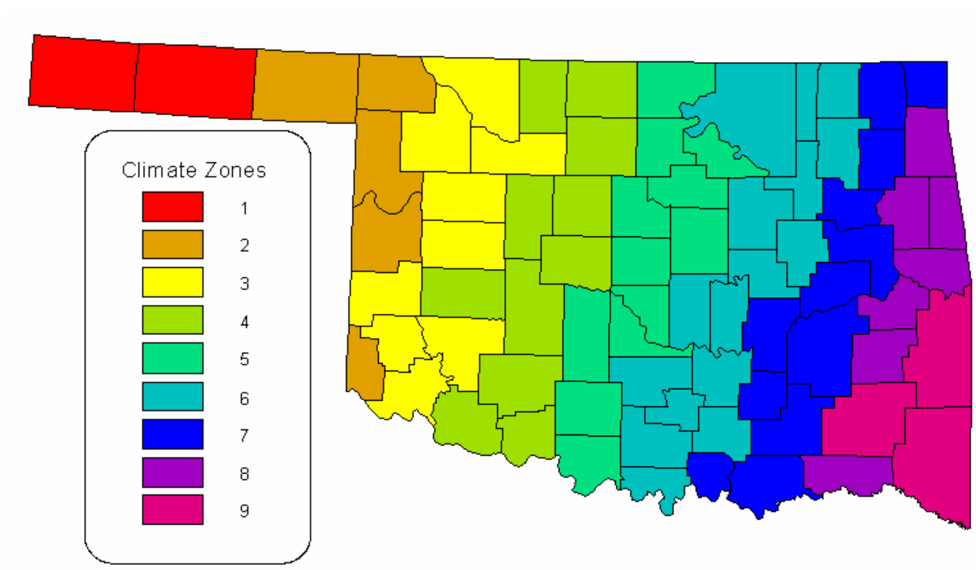


Figure 4.19 Oklahoma climate zones available in PPM Plus.

Table 4.6 Average annual precipitation for the representative weather station for each climate zone.

Climate Zone	Precipitation (mm)	Precipitation (in)
1	429	16.9
2	543	21.4
3	701	27.6
4	737	29.0
5	865	34.1
6	1021	40.2
7	1123	44.2
8	1166	45.9
9	1385	54.5

Hydrologic Calibration

PPM Plus uses hydrologic calibration parameters derived from 11 SWAT models developed for USGS 8-digit Hydrologic Unit Code (HUC) basins across Oklahoma. The specially modified version of SWAT 2005 used in PPM Plus was used to simulate stream flow in each basin. SWAT predictions were compared to observed USGS stream flow records to develop a single set of calibration parameters applicable to the entire state of Oklahoma. This single set of parameters was used in PPM Plus.

Model Development

Fifteen basins were initially selected based on the availability of USGS daily stream flow records. Daily stream flow records from 1955 to 2005 were compiled for each basin. A simplistic SWAT model was developed for each of the 15 basins. Impoundments were not simulated, to reduce the time required to prepare each model. The inclusion of large reservoirs requires significant effort to parameterize each structure and how it is managed. Due to computer processing limitations, model descritization was coarse as compared to other SWAT models developed for Oklahoma (Storm et al. 2001, Storm et al. 2003a, Storm et al. 2003b). Model descritization has a significant effect on sediment and nutrients, but little impact on runoff volume (White 2001, Jha et al. 2004, Bingner et al. 1997). The models were constructed using the following datasets:

- USGS 30 meter resolution Digital Elevation Model (DEM)
- National Hydrography Data (NHD) stream locations
- State Soil Geographic (STATSGO) soils GIS and attribute data
- National Land Cover Data (NLCD) derived from imagery captured in 1992.
- Observed daily precipitation and minimum and maximum temperature derived from National Weather Service Cooperative observing network station data.

Management for each basin was derived from past Oklahoma State University SWAT modeling projects and professional judgment (Storm et al. 2001, White 2001, Storm et al. 2003b). Management was held constant across ecoregions, but varied generally from west to east with changing precipitation.

Multi-model Calibration

Only 11 of the initial 15 basins were used in the final calibration (Table 4.7 and Figure 4.20). Two of the original 15 basins were excluded from the calibration due to the presence of large reservoirs which had a significant impact on hydrology. Two basins in the panhandle were excluded due to the scarcity of flow events in the observed record.

A single set of calibration parameters was developed using the remaining 11 basins. Two of the most sensitive SWAT parameters, (Soil Evaporation Compensation factor (ESCO) and Curve Number (CN)), were adjusted to obtain the best fit for all 11 basins simultaneously. Values of ESCO from 0.8 to 1 and CN adjustments from +8 to -8 were explored using customized computer software. Eight levels of ESCO (0.8, 0.9, 0.92, 0.94, 0.95, 0.97, 0.98, and 1.0) and eight levels of CN adjustment (-8, -6, -4, -2, 0, 2, 4, and 8) were explored in a full factorial. Source code for the multi-model calibration software is given in Appendix B. A total of 64 combinations were evaluated on each of the 11 models. Each combination was evaluated using relative error (Figure 4.21) and Nash Sutcliffe Efficiency (NSE) (Nash and Sutcliffe 1970) (Figure 4.22) for observed and predicted average annual stream flow. Relative error and NSE for streamflow were normalized and combined into a single indicator of model performance. The indicator was calculated using the equation shown below:

$$P_i = (NSE_{best} - NSE_i) + (|RE_i| - |RE_{best}|)$$

where P_i is the performance indicator (lower is better) for parameter set i ; NSE_{best} and RE_{best} are the best NSE and relative error of any parameter combination.; NSE_i and RE_i are the best NSE and relative error of parameter combination i.

Figure 4.23 illustrates how model performance changed over the range of ESCO and CN adjustments explored. There are several combinations of ESCO and CN adjustment which resulted in similar model performance (Table 4.8). Of these, values of ESCO = 0.98 and CN adjustment = 0 were selected for the calibrated model due to their proximity to the default SWAT values (ESCO = 0.95 and CN adjustment = 0). Monthly observed and predicted surface runoff and total flow were examined and found to be acceptable.

Table 4.7 Selected characteristics of basins used in the development of PPM Plus calibration parameters.

USGS Gage Name	Primary Ecoregion	Drainage Area (km^2)	Simulation Length (yr)
Skeleton Creek near Lovell, OK	Central Great Plains	1058	38
Sand Creek at Okesa, OK	Cross Timbers	359	33
Big Cabin Creek near Big Cabin, OK	Central Irregular Plains	1161	51
Spavinaw Creek near Sycamore, OK	Ozark Highlands	343	44
Illinois River near Tahlequah, OK	Ozark Highlands	2474	51
Gaines Creek near Krebs, OK	Arkansas Valley	1517	8
Fourche Maline near Red Oak, OK	Arkansas Valley	315	51
Lee Creek near Short, OK	Boston Mountains	1084	51
Blue Beaver Creek near Cache, OK	Central Great Plains	63	38
Cobb Creek near Eakly, OK	Central Great Plains	341	37
Mountain Fork at Smithville, OK	Ouachita Mountains	826	14
Average	---	867	38

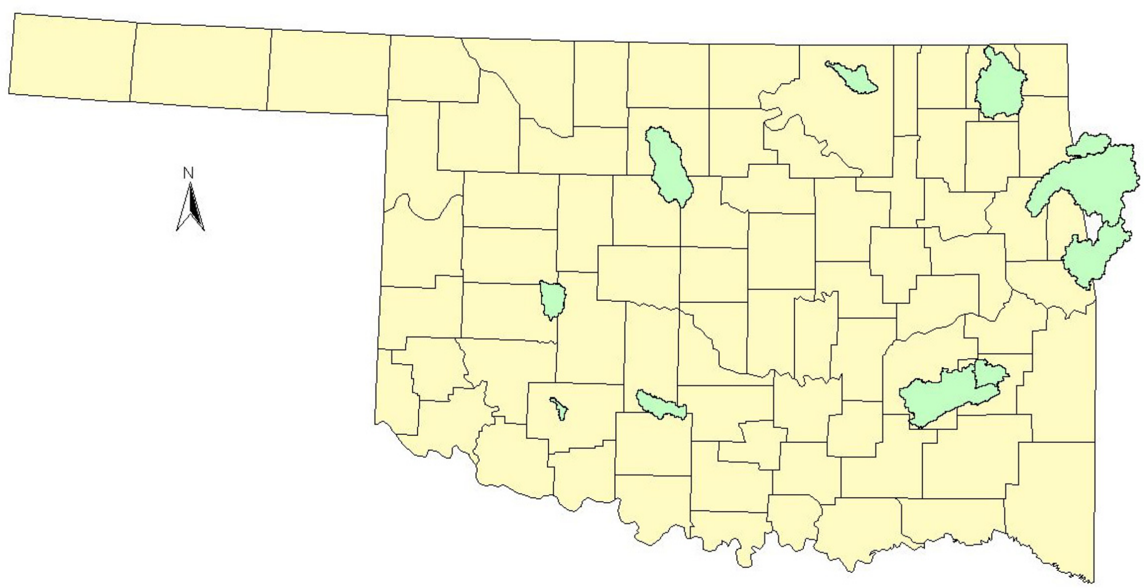


Figure 4.20 Eleven basins used in the development of state-wide hydrologic SWAT calibration parameters for use in PPM Plus.

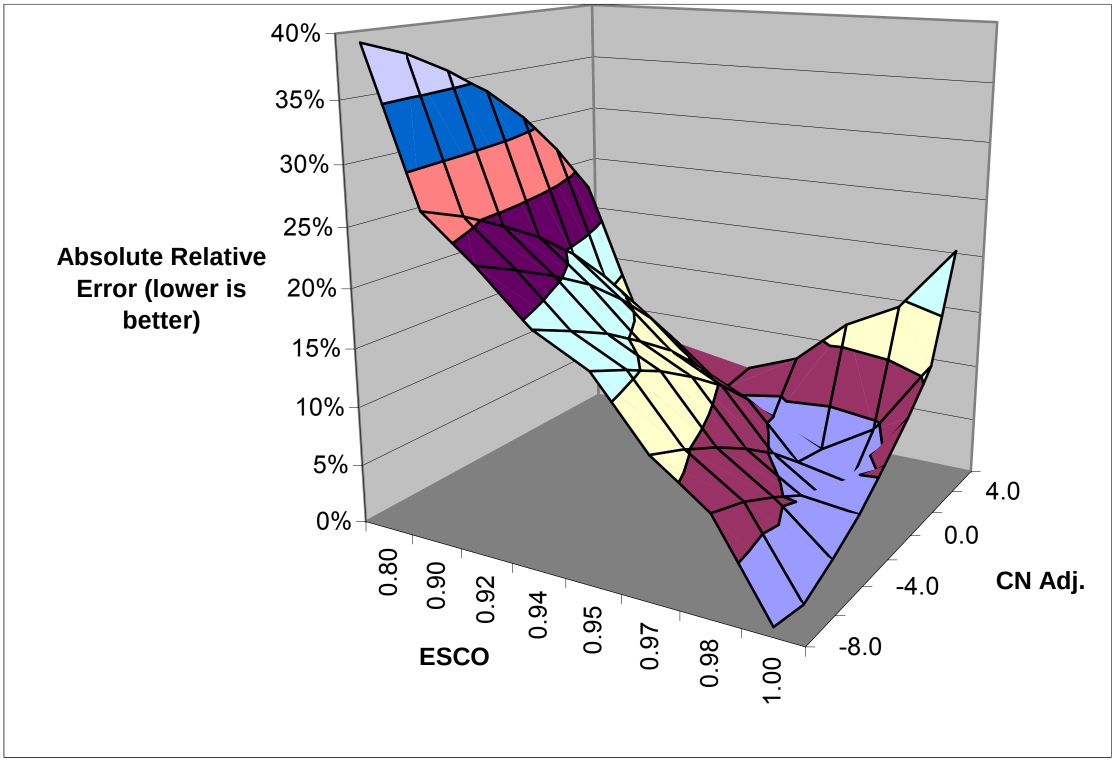


Figure 4.21 Total flow SWAT model absolute relative error as a function of Soil Evaporation Compensation factor (ESCO) and Curve Number (CN) Adj. (adjustment).

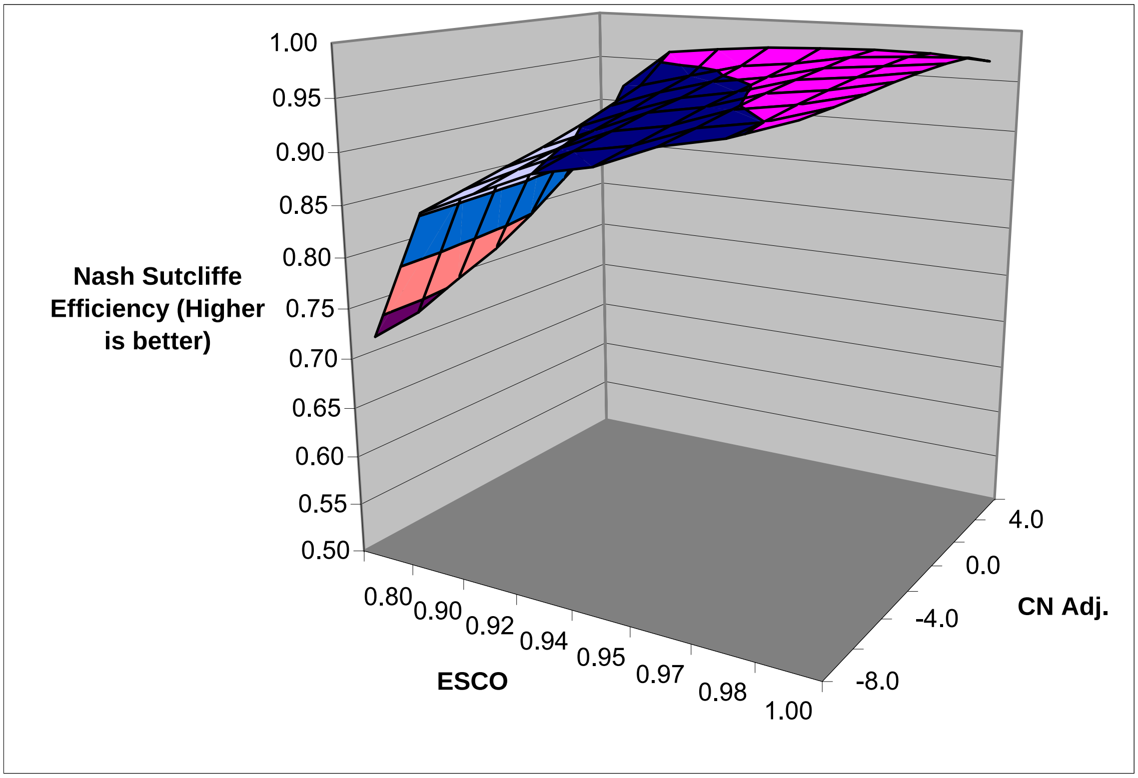


Figure 4.22 SWAT Nash Sutcliffe Efficiency for average annual total flow as a function of Soil Evaporation Compensation factor (ESCO) and Curve Number (CN) adjustment.

Table 4.8 SWAT highest performing combinations of Soil Evaporation Compensation Factor (ESCO) and Curve Number (CN) during model calibration. Values selected for final calibration shown in grey.

Soil Evaporation Compensation Factor	Curve Number Adjustment	Relative Error	Nash Sutcliffe Efficiency
0.9	8.0	0%	0.96
0.92	8.0	-3%	0.97
0.97	2.0	2%	0.97
0.97	4.0	-1%	0.97
0.98	0.0	1%	0.97
0.98	2.0	-1%	0.97
1	-8	1%	0.96
1	-6	0%	0.97
1	-4	-2%	0.97
1	-2	-3%	0.97

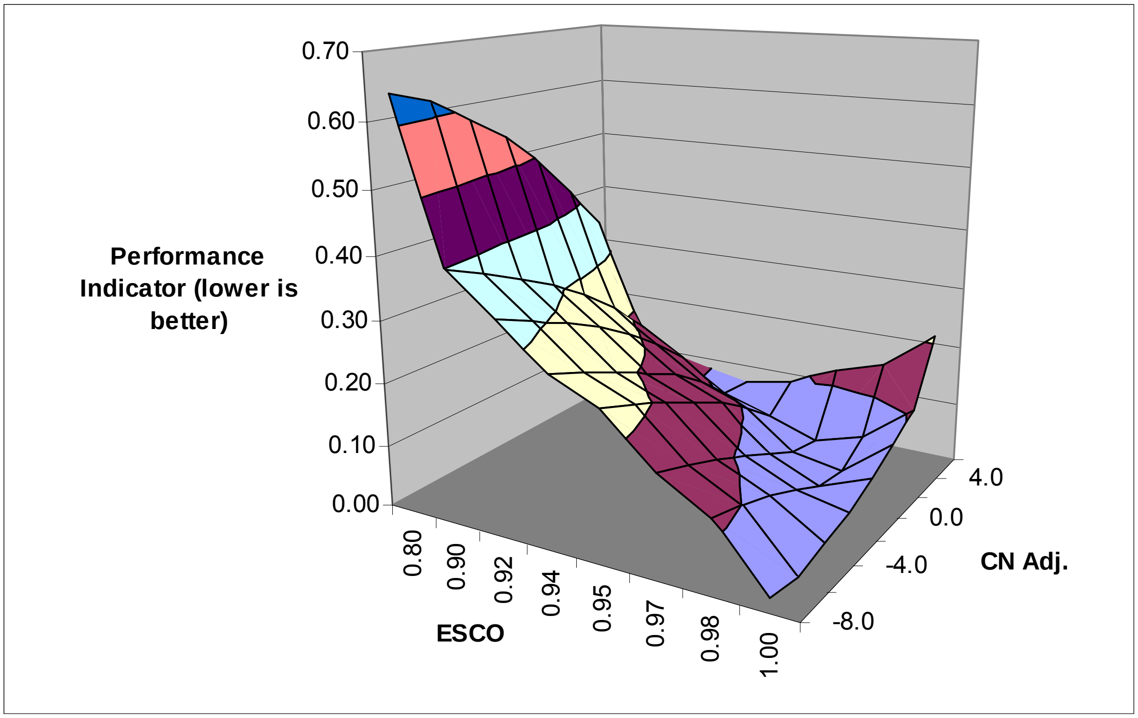


Figure 4.23 Combined SWAT model performance indicator as a function of Soil Evaporation Compensation factor (ESCO) and Curve Number (CN) Adj. (adjustment). Indicator based on a combination of absolute relative error and Nash Sutcliffe Efficiency for total flow.

Modifications to SWAT 2005 Routines

The FORTRAN source code for the SWAT 2005 model was modified to include a number of improvements and modifications to improve its field scale P predictions. These improvements were primarily to the soil P routines, which were updated to include recent literature findings and an improved understanding of P cycling in soils since the original development of the SWAT model. These modifications were fairly simple; other more complex modifications, such as the addition of a manure submodel, are still needed. More complex modifications were beyond the scope of this research.

SWAT Phosphorus Model

The SWAT P model is virtually identical to that in EPIC; both are based on the concept of separate P pools within each soil layer (Figure 4.24). SWAT partitions soil P in six pools: three intended to represent mineral P forms and three for organic forms. The three mineral pools are *Stable*, *Active* and *Solution*. These pools are in a dynamic equilibrium based on constant ratios. The organic pools are *Stable*, *Active* and *Fresh*. Transformations between these pools are based on mineralization, decomposition, and immobilization equations and will not be modified in this research. It should be noted that there tends to be significant confusion by scientists and engineers as to what exact forms of P are in each pool.

The *Stable* mineral pool represents stable insoluble P forms not readily available for plant uptake. The stable mineral pool reaches equilibrium very slowly with the *Active* pool, and by default is four times larger than the *Active* pool. This is the largest of the mineral P pools.

The Active mineral pool interacts slowly with the *Stable* pool and quickly with the *Solution* pool. This pool represents P which is reversibly precipitated or adsorbed, but is less active than *Solution* P. By default this pool is 1.5 times larger than the *Solution* pool.

The *Solution* pool includes soluble mineral P in soil solution and P which can easily become soluble. Plant P uptake, soluble P in surface runoff and P leaching are taken from this pool. Mineralized organic matter P and inorganic fertilizer P enter this pool. The initial value for this pool is a user defined concentration. The initial *Solution* pool value, which is a SWAT input, sets both the active and stable P pools via fixed ratios. Note that sometimes this *Solution* pool is known as the labile pool.

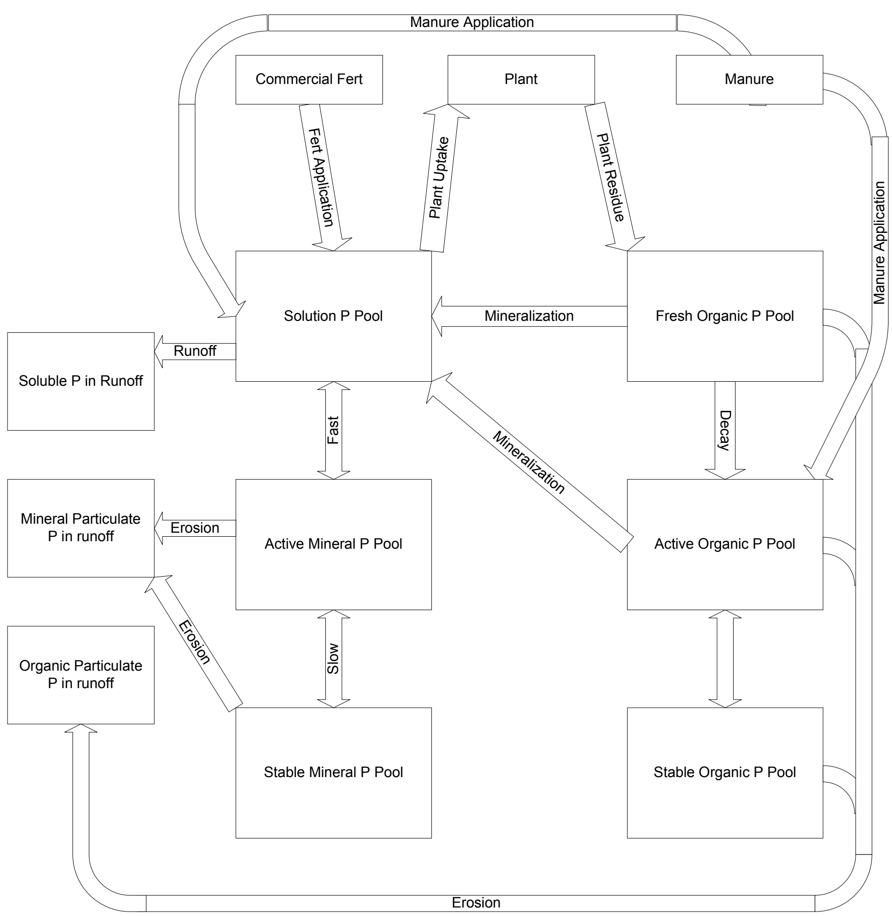


Figure 4.24 SWAT phosphorus routine

Redefining Phosphorus Pool Equilibriums

SWAT uses fixed ratios to define the equilibrium between the *Solution*, *Active*, and *Stable* mineral pools. The fixed ratio between the *Active* and *Stable* mineral P pools (currently 1:4) was changed to a dynamic coefficient based on Soil Test P (STP). A relationship between Mehlich III STP and total mineral soil P was developed using data presented by Sharpley et al. (2004) (Figure 4.25). These data indicated that as STP increased, the fraction of the total mineral P within the soil extracted by Mehlich III increased nonlinearly. This also implies that the amount of P fertilizer required to raise STP by one unit is higher at low initial STP than at a higher STP. These data contain a variety of soils at varying STPs; some have a long term history of manure application. Other studies support a nonlinear relationship between STP and the total soil P. Pautler and Sims (2000) found a relationship between total P and STP, which appears to be nonlinear. Allen (2004) found higher STP to total P ratios at higher STP levels. Whalen and Chang (2001) observed a STP to total P ratio of 0.13 in plots with no manure application and a ratio of 0.27 in a soil with long term additions of manure. Long term manure application generally results in elevated STP and total soil P. The change in STP to total P ratio is consistent with the other work cited. A preponderance of the available literature indicates that the extractability of P changes with increased soil P content, and that a dynamic coefficient between the stable and active pools was warranted.

The STP extractability relationship, based on Sharpley et al. (2004) data, was used to allow Melich III STP a direct SWAT input. The STP fraction was assumed to be the sum of the Soluble and *Active* mineral P pools, and neglects any Melich III extractable organic P which may be significant in some high organic soils. The existing equilibrium relationship between the *Stable* and *Active* pools was modified to an equilibrium relationship between the *Stable* pool and the sum of *Active* and *Solution* pools. The new equilibrium ratio varies between 7.0 at low STP to 0.9 at high STP. This dynamic ratio was developed empirically on measured soil data provided by Sharpley et al. (2004). The modified and original mineral P models are given in Figure 4.26.

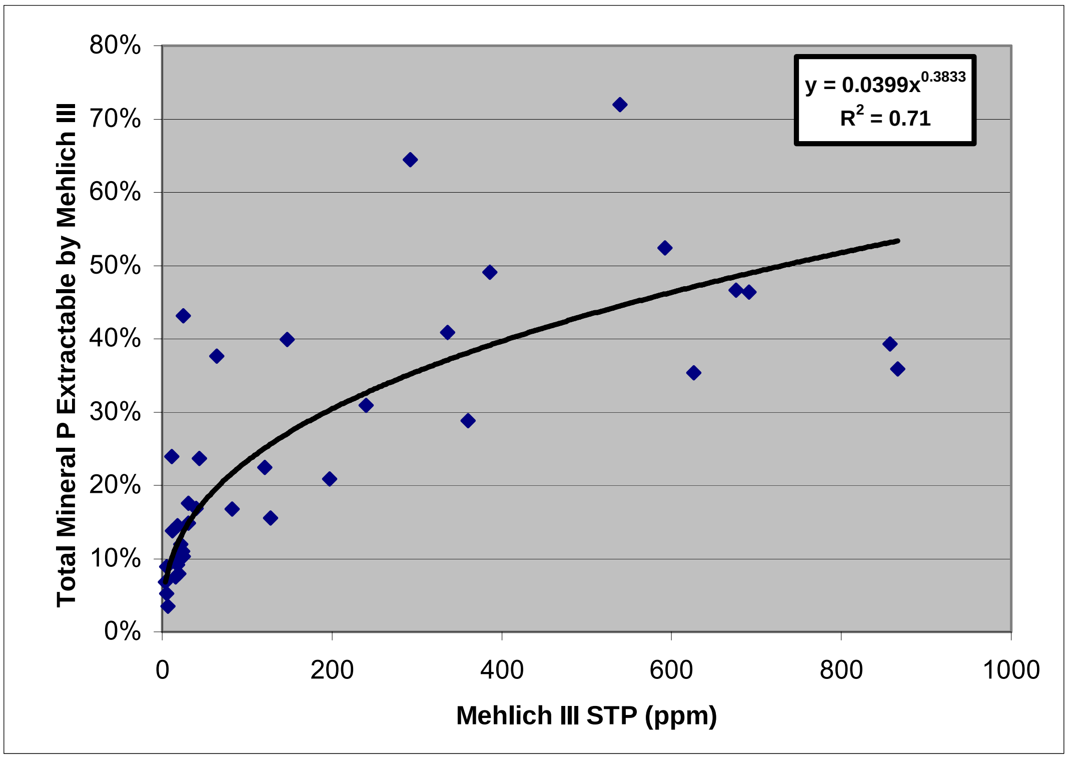


Figure 4.25 Total mineral P extracted by Mehlich III as a function of soil test phosphorus (STP). Relationship developed from data presented by Sharpley et al. (2004).

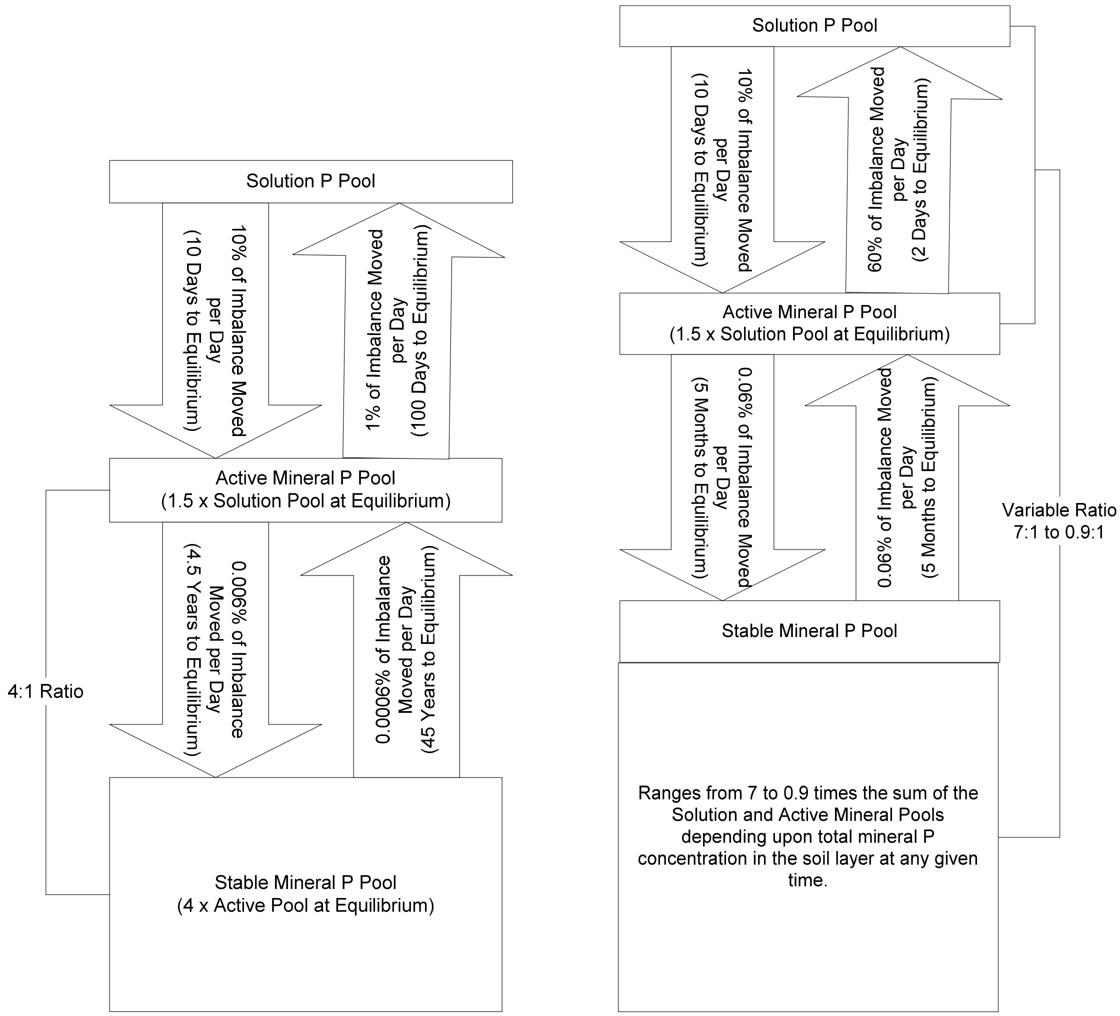


Figure 4.26 Original SWAT P Model (left) and modified SWAT P Model used in PPM Plus (right).

Nutrient Stabilized Manures

The addition of aluminum (i.e. aluminum sulfate or alum), iron or calcium containing amendments to animal manures has been shown to reduce the solubility of P (Moore et al. 2000). When amended manures are applied to agricultural fields, soluble runoff P concentrations are reduced compared to unamended manures (Sims and Luka-McCafferty 2002, Moore et al. 1999, and Moore et al. 2000). In an effort to account for reduced solubility of P in treated manures, the SWAT model was modified to allow the addition of stable P forms in animal manure, which do not directly influence soluble P in surface runoff.

The SWAT model assumes animal manures are composed of relatively soluble mineral and readily degradable organic forms. These are directed to the *Solution* and *Fresh Organic* pools upon application. The addition of alum reduced water soluble P in manures by 66% in farm scale data collected by Sims and Luka-*McCafferty* (2002). In an effort to better represent the reduced P solubility in alum treated manures, the SWAT model was modified to allow manure P to be further subdivided into soluble mineral, organic, and stable mineral forms.

The new amended manure stable mineral fraction is directed to the *Stable* soil pool upon application and does not immediately increase STP within the model; however, the total soil P increases. The fractionation of different animal manures into mineral, stable mineral and organic forms is specified in the SWAT Fertilizer database file (fert.dat). Alum amended manures have 66% of the mineral fraction directed to the stable mineral pool, where it is not directly available for loss as soluble P. This fraction was taken from Sims and Luka-*McCafferty* (2002), and reduced soluble P losses attributable to manure application by approximately two thirds during testing. These modifications allow SWAT to better account for this important BMP.

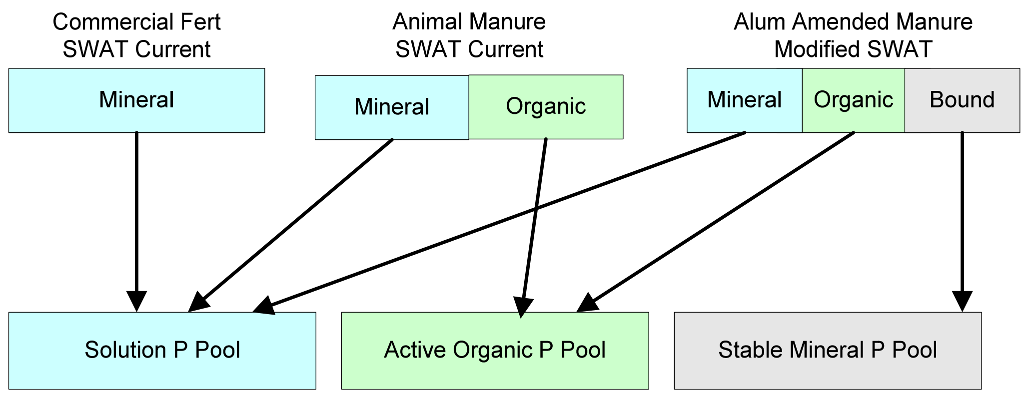


Figure 4.27 SWAT fertilizer routine modifications for PPM Plus to all for the application of stable P.

Rate of Phosphorus Transformation

SWAT uses fixed rate constants to move a fraction of the P imbalance between the *Solution*, *Active*, and *Stable* P pools. Ten percent (0.10) of the imbalance between the Ten percent (0.10) of the *Solution* and the *Active* pools are moved daily when the imbalance favors movement from *Solution* to *Active* (sorption). One percent (0.01) is moved if the imbalance favors movement from *Active* to *Solution* (desorption). Vadas et al. (2006) developed dynamic coefficients for *Solution* and *Active* pool interactions. Due to the complexity of the method, these dynamic coefficients could not be easily incorporated into the SWAT model. Vadas et al. (2006) also presented static coefficients (0.10 for sorption, 0.60 for desorption) which improved EPIC model predictions. These static coefficients were incorporated into the modified SWAT model for PPM Plus.

P transfer coefficient between the *Active* and *Stable* P pools was increased. SWAT transfers a relatively small amount of the imbalance between the *Active* and *Stable* pools each day (0.006% or 0.0006%, depending upon the direction). Only about 90% of excess P in the *Active* pool will be moved to the *Stable* pool in four years. These rate constants were based on Jones et al. (1984) and Cox et al. (1981), who used the decline in STP following fertilization over several years at plot scale. It is difficult to separate the effects of P stabilization (indicated by reduced STP) to less available forms from other complicating factors. A net loss of P from crop uptake and runoff losses will also result in reduced STP over time. All of these mechanisms contribute to reducing STP over time. It is very difficult to isolate any singe process with plot scale experiments.

Soil incubation studies allow better isolation of individual effects than field studies. These studies are not complicated by P losses in runoff or plant uptake. Laboski and Lamb (2003) measured STP in soils incubated for nine months after receiving manure and inorganic P for eight soils. STP changed significantly only during the first month after manure application for a majority of the soils. They observed a relative small (<3%) decrease in adjusted STP after inorganic P fertilization between months one and nine. Ebeling et al. (2003) incubated a silt-loam receiving various P application rates for 64 weeks. STP stabilized after 16 weeks of incubation except at very high rates. Koopmans et al. (2004) found strong indications that the total pool of stable sorbed P (sum of reversibly adsorbed P and quasi-irreversibly bound P) to be close to equilibrium with the faster reacting P (*Active* and Soluble P) in a long term P uptake study on noncalcareous soils, indicating rapid P stabilization reactions in noncalcareous soil. These studies suggest that the transfer between the active and stable pools to regain equilibrium is faster than the current SWAT routines allow. Little data are available to gage the appropriate value for the *Active*/*Stable* transfer coefficient. A value of 0.006 (one order of magnitude greater than the current default coefficient) was selected as a replacement coefficient. Changes to the SWAT source code are given in Appendix C.

SWAT Buffer Modification

The SWAT 2005 model was modified to make soluble P conservative through buffers. The primary mechanism of P removal in buffers is settling of particulate P. Buffers are far less effective in removing soluble P (Klapproth and Johnson, 2000). This issue is discussed in greater detail in the Best Management Practice section of this chapter. The filter subroutine was modified and is given in Appendix C.

SWAT STP Rollback Modifications

The goal of PPM is to predict average P loss under current conditions, as defined by user inputs. Because P loss varies from year to year with weather, PPM Plus uses a 25-year span of measured weather data containing differing weather conditions to make predictions for the average year. This is performed with a single continuous 25-year simulation with the same fertilization and management each year of the simulation. Each year model predictions are influenced by the previous year's management. Large applications of P increase STP; with 25 years of P application the STP is far greater in year 25 than it was at year one. It is not the purpose of PPM to predict P loss with 25 years of identical fertilization. To prevent this problem, the SWAT model was modified to store the soil P status after a warm-up period (2 years) and reinitialize the soil P status to those values every year for the remainder of the simulation. All five P pools are reset for each soil layer and every HRU in the model. A short warm-up period is necessary for all SWAT simulations, because initial values for surface residue, plant biomass, groundwater height, soil moisture, and many other parameters are generally set to zero or default values. These modifications were made to the *Simulate* subroutine which is given in Appendix C.

Grazing Manure Deposition Modification

This modification was intended to preserve the field level P balance during cattle grazing. Cattle consume forage containing a P content dictated by the crop growth nutrient uptake routines and excrete manure containing a different amount of P specified by the user in the *fert.dat* and management files of SWAT. Cattle excrete the vast majority of P consumed in their diet. SWAT 2005 was modified such that P deposited in manure during grazing is equal to the P consumed in forage during grazing. These modifications were made to the graze subroutine and are given in Appendix C.

Predicted STP Change

Oklahoma's current 590 standard is currently based on STP. STP is a useful management endpoint to control P loss and a major factor in most P Indices. The SWAT model was modified to output an average annual HRU level P balance. The balance includes fertilizer and manure additions, all P losses in runoff and crop harvest, and P stored in the crop and each soil layer. This information, along with the relationship between soil P and Melich III Extractable P from Sharpley et al. (2004), allows PPM Plus to estimate the change in STP associated with a given management scenario from January 1 to December 31. The rate of STP increase is valuable information for farmers planning future manure applications and to identify long term sustainable solutions. These modifications were to the *HRUmon* and *Simulate* subroutines given in Appendix C.

Hay Cutting Residual

PPM Plus uses a *harvest only* operation to represent hay cutting in the SWAT model. Biomass is harvested using a harvest efficiency, which under multiple harvest operations may reduce standing biomass to unrealistically low levels. This issue was observed in initial PPM Plus testing with bermuda intensive managed for haying. The *Harvestop.f* subroutine was modified to ensure a residual of 1000 kg/ha after any hay cutting. These modifications are given in Appendix C.

Phosphorus Model Conclusions

SWAT and EPIC are the result of many years of development by talented researchers. The SWAT model in its original form does a good job of predicting P loss from manured field areas after calibration. Models like SWAT and EPIC have been used successfully in these situations for years. However, there is room for improvement, especially when models are uncalibrated. We currently have data available to develop better process based P models. Our models are on the right track, but the older P routines do not represent our current state of knowledge. Model developers and P researchers should work together to develop more physically based routines. Given the widespread use of these models, it is important that they contain the best possible algorithms. The changes suggested in this research were relatively minor and easy to implement. These changes can be incorporated with changes suggested by other researchers to build more realistic P models.

PPM Plus Sensitivity Analysis

Models like PPM Plus and SWAT have many different input parameters and options. Each has a different impact on predicted P loss. The purpose of a sensitivity analysis is to identify the most important parameters in the model, and to make sure that each parameter change causes an appropriate model response. 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 S_r = Relative sensitivity (dimensionless), P_b = Parameter investigated baseline value, O_b = Selected model output for baseline 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, and O_2 = Selected model output @ P_2.

Relative sensitivity is a measure of model's sensitivity to a particular model input in a particular configuration. The sensitivity of each parameter is also a function of all other model parameters. The estimation of relative sensitivity requires changing each model input individually while holding all other inputs constant. It is possible to estimate parameter sensitivity by changing multiple parameters simultaneously, but the analysis is much more complex. Relative sensitivity differs based on the system being simulated. To evaluate the range in relative sensitivity the model should be applied in multiple configurations. For this analysis, three scenarios were constructed, each representing a common agricultural situation in Oklahoma. The first scenario represents a pasture in eastern Oklahoma receiving poultry litter. The second is a similar pasture which does not receive litter. The third is a wheat field in central Oklahoma. Each scenario uses fertilization, STP, and soils consistent with those applications. These scenarios are detailed below:

1. Pasture grazed at 0.25 animal units continuously receiving 120 lb/acre of both nitrogen and P_2O_5 in a single April poultry litter application. Slope is 5% on a Captina silt loam with a STP of 150 ppm. Climate region 8 representing littered pastures in eastern Oklahoma.
2. Pasture grazed at 0.25 animal units continuously receiving 120 lb/acre commercial nitrogen. Slope is 5% on a Captina silt loam with a STP of 50 ppm. Climate region 8 representing pastures in eastern Oklahoma.
3. Conventional tilled wheat, moderately grazed from November to February. Nitrogen was applied at a rate of 80 lb N /acre with 10 lb P_2O_5/acre. Slope is 3% on a Kirkland silt loam with a STP of 25 ppm. Climate region 5 for central Oklahoma.

A total of five simulations were performed for each parameter examined with each scenario above. Input parameter values were adjusted by a percentage of the original parameter value. The simulation with the smallest input parameter value and the largest value were used to identify sensitivity in the region surrounding the default value. Relative sensitivity was assumed constant between those points such that a single value could be estimated. Relative sensitivity for various PPM input parameters is given in Table 4.8. Sensitivity graphs depicting normalized P load are given in Figures 4.28 to 4.41. P load was normalized such that at 100% of each input parameter value the normalized P load is 100%. The equation is given below:

$$N_i = \frac{P_i}{P_{100}}$$

where N_i is the normalized P loss for simulation i; P_i is the P loss at i; and P_{100} is the P loss at the original parameter value. Note P_{100} may be taken from another location if the original parameter value does not exist or is categorical.

Graphs of delivered sediment and runoff are given in Appendix D. Changes to model input parameters produced expected responses in all parameters analyzed based on past experience with the SWAT model. Changes in STP produced an almost linear response in total P load in Figure 4.28. The application of nitrogen fertilizer produced little total P response in pastures (Figure 4.29). However, wheat had much higher P loads at lower nitrogen rates. This is likely due to decreased biomass production and increased erosion at lower nitrogen application rates. Figure 4.30 illustrates the effect of increasing P fertilization. Littered pasture was the most sensitive since it has the highest initial P application rate. Wheat had only a small increase; it only received $1/12^{th}$ the P applied to litter pasture. Figure 4.31 demonstrates the effect of field area; all scenarios had decreasing P loss with larger field areas. This is expected since delivery ratio and drainage areas should be inversely related. The wheat scenario had the greater change, likely due to higher sediment yields. Distance to stream sensitivity (Figure 4.32) yielded less P delivery at larger distances to stream. Like field area, the difference was greater for wheat due to a higher sediment bound P fraction. Buffer width (Figure 4.33) showed a significant decrease in P load with larger buffers. The effect of buffers was greatest with wheat. Increasing the fraction of the field draining to ponds produced a linear decrease in P loss (Figure 4.34). Riparian buffers (Figure 4.35) produced results similar to grass buffers (Figure 4.33). All buffers use the same removal equation in the SWAT model. Stocking rate (Figure 4.36) was influential on P loss. All scenarios had higher P loss with increasing stocking, but the relationships were not linear. At some critical stocking rate, P loss increased more quickly. Field slope (Figure 4.37) and slope length (Figure 4.38) were positively correlated with P loss, though the relationships differ. Figure 4.39 illustrates the effect of climate zone. P loss was highly dependant upon climate zone; in climate zone 1 there was very little P loss. The relationship was not monotonic, even though rainfall changed monotonically with climate zone (Figure 4.6). This may have been due to differences in seasonal rainfall or intensity between zones. Forage management (Figure 4.40) showed increased P loss with poorer forage management. It is likely that this effect would be magnified at higher stocking rates. Overall, all model parameters affected outputs as expected based on past experience with SWAT. This sensitivity analysis confirmed that the model functioned as planned.

Table 4.8 Relative sensitivity for various PPM Plus input parameters.

		Relative Sensitivity		
		Scenario		
Input Parameter	Model Output	Pasture With Litter	Pasture Com. N Only	Wheat
Soil Test P	Total P	0.356	0.366	0.315
	Sediment	0.000	0.000	0.000
	Runoff	0.000	0.000	0.000
N Application	Total P	-0.004	0.000	-0.168
	Sediment	-0.022	-0.022	-0.144
	Runoff	0.000	0.000	-0.206
P Application	Total P	0.431	0.000	0.042
	Sediment	0.000	0.000	0.000
	Runoff	0.000	0.000	0.000
Field Area	Total P	-0.011	-0.019	-0.023
	Sediment	-0.042	-0.042	-0.030
	Runoff	-0.040	-0.040	-0.025
Distance to Stream	Total P	-0.024	-0.043	-0.052
	Sediment	-0.085	-0.085	-0.066
	Runoff	-0.074	-0.074	-0.050
Grass Buffer Width	Total P	-0.005	-0.009	-0.026
	Sediment	-0.025	-0.025	-0.027
	Runoff	0.000	0.000	0.000
Fraction Draining to Pond	Total P	-0.008	-0.008	-0.009
	Sediment	-0.010	-0.010	-0.011
	Runoff	-0.010	-0.010	-0.009
Forested Riparian Buffer width	Total P	-0.005	-0.010	-0.026
	Sediment	-0.027	-0.027	-0.027
	Runoff	0.000	0.000	0.000
Stocking Rate	Total P	0.182	0.443	0.049
	Sediment	0.369	0.369	0.036
	Runoff	-0.032	-0.032	0.076
Field Slope	Total P	0.423	0.715	0.776
	Sediment	1.571	1.571	1.304
	Runoff	0.020	0.020	0.009
Field Slope Length	Total P	0.120	0.200	0.233
	Sediment	0.375	0.375	0.331
	Runoff	-0.022	-0.022	-0.007

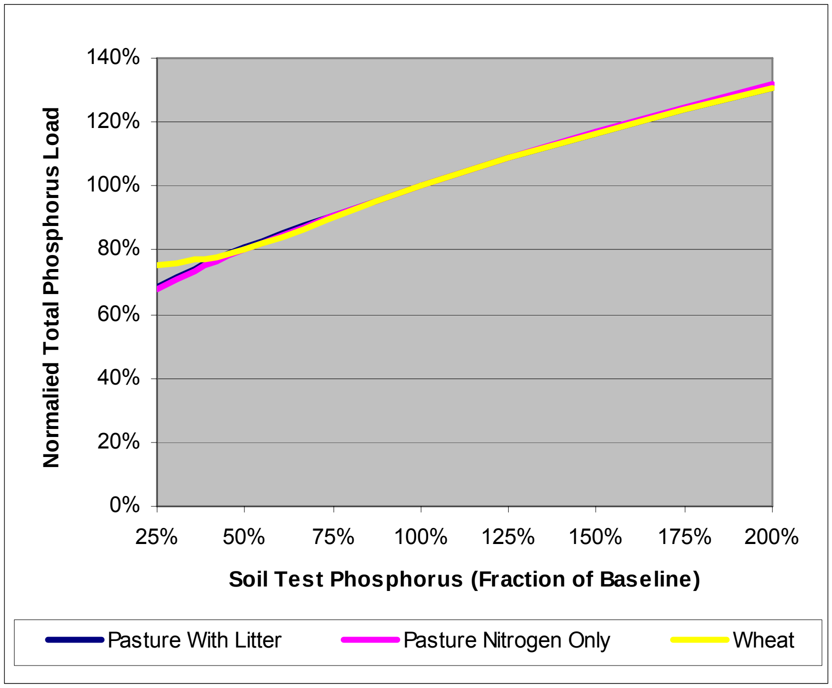


Figure 4.28 Normalized phosphorus loss with Soil Test Phosphorus (STP) change for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

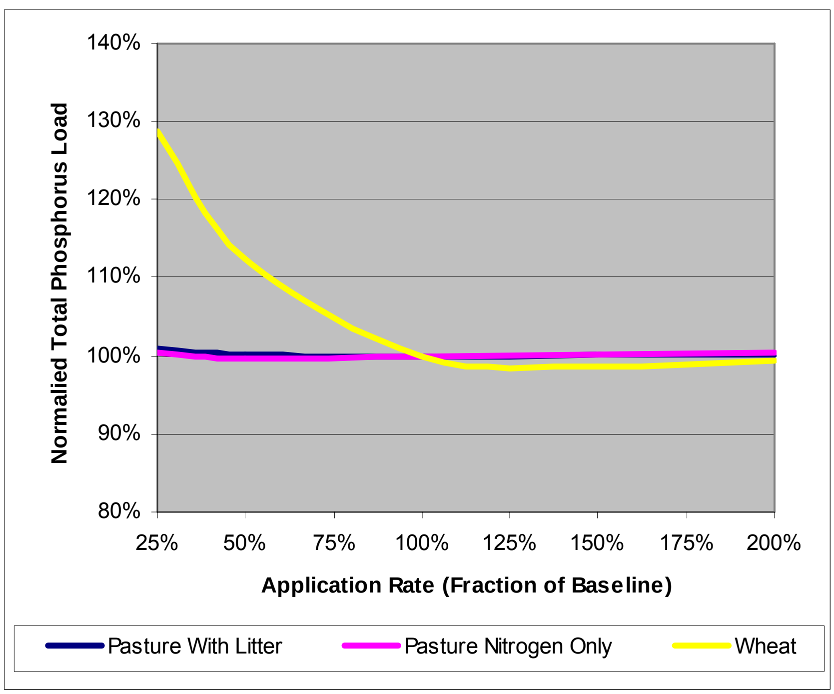


Figure 4.29 Normalized phosphorus loss with nitrogen fertilizer application rate for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

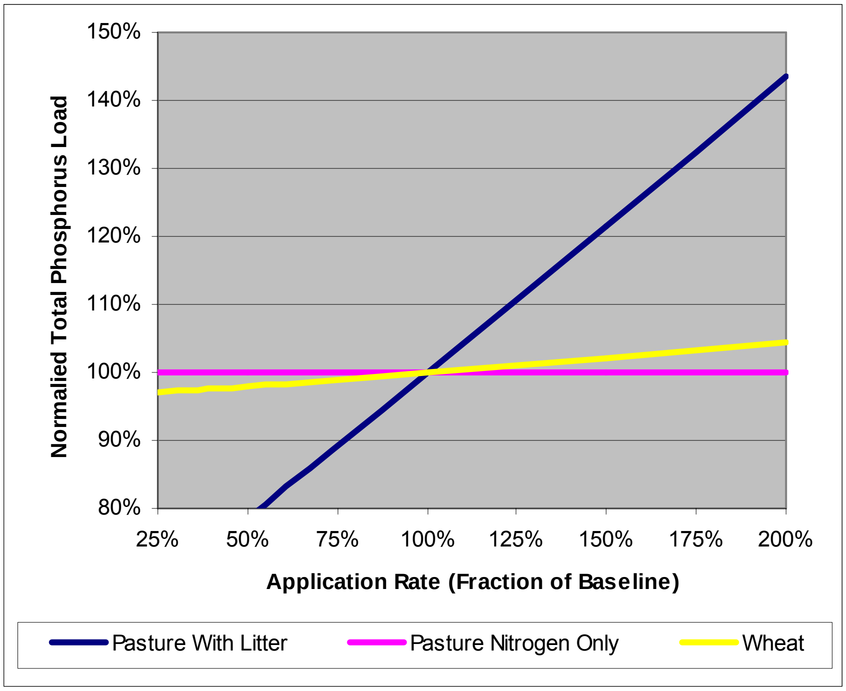


Figure 4.30 Normalized phosphorus loss with phosphorus fertilizer application rate for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

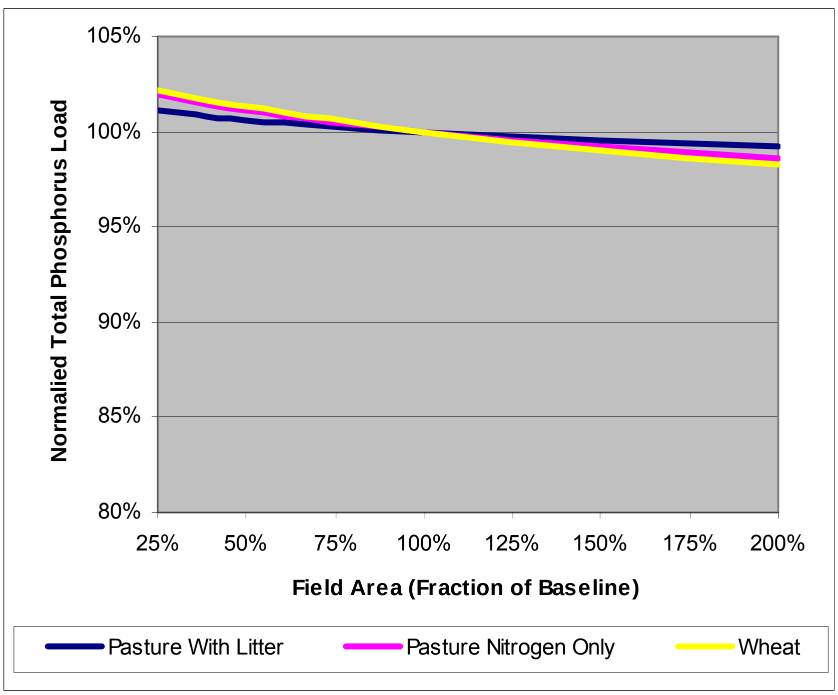


Figure 4.31 Normalized phosphorus loss with field area for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

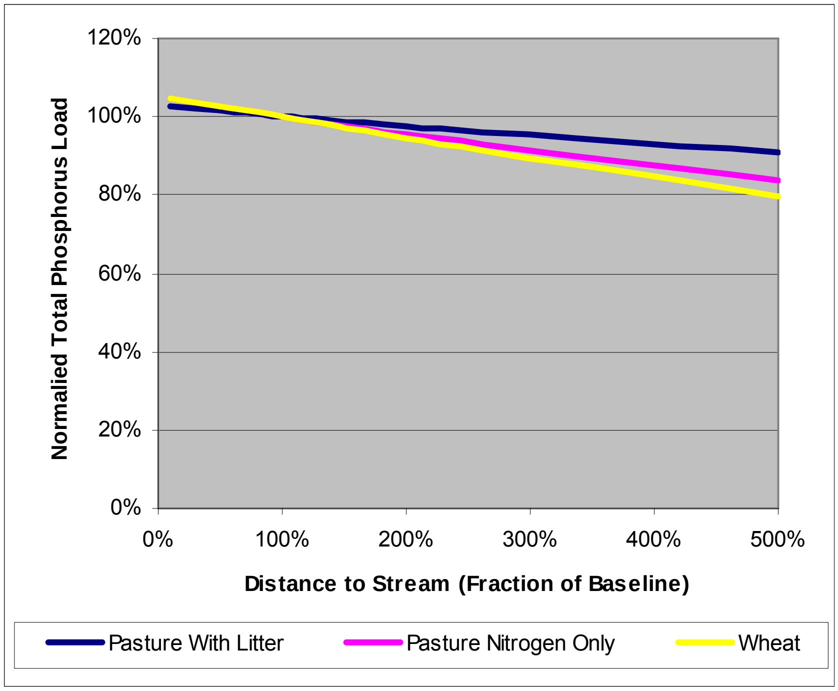


Figure 4.32 Normalized phosphorus loss with distance to stream for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

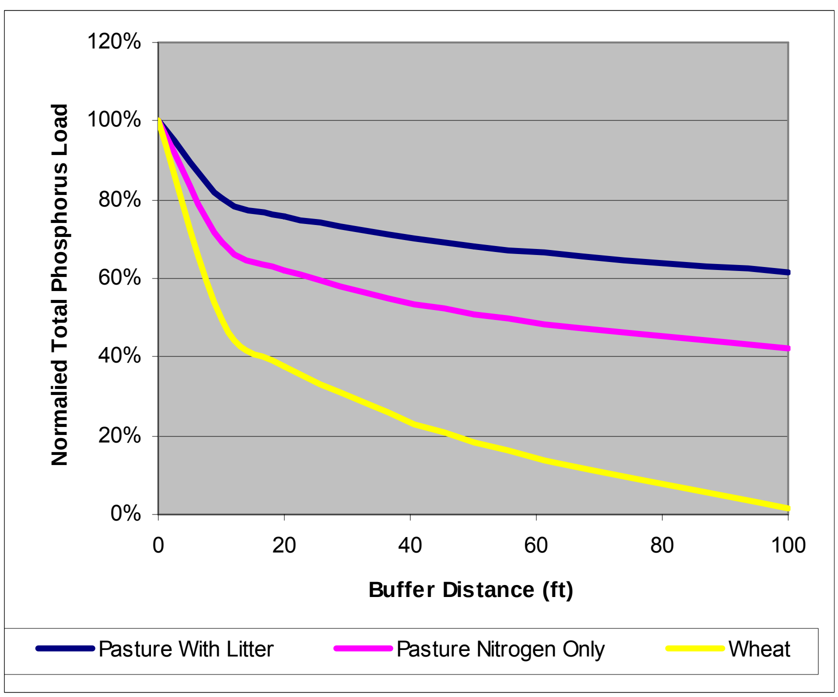


Figure 4.33 Normalized phosphorus with grass buffer width for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

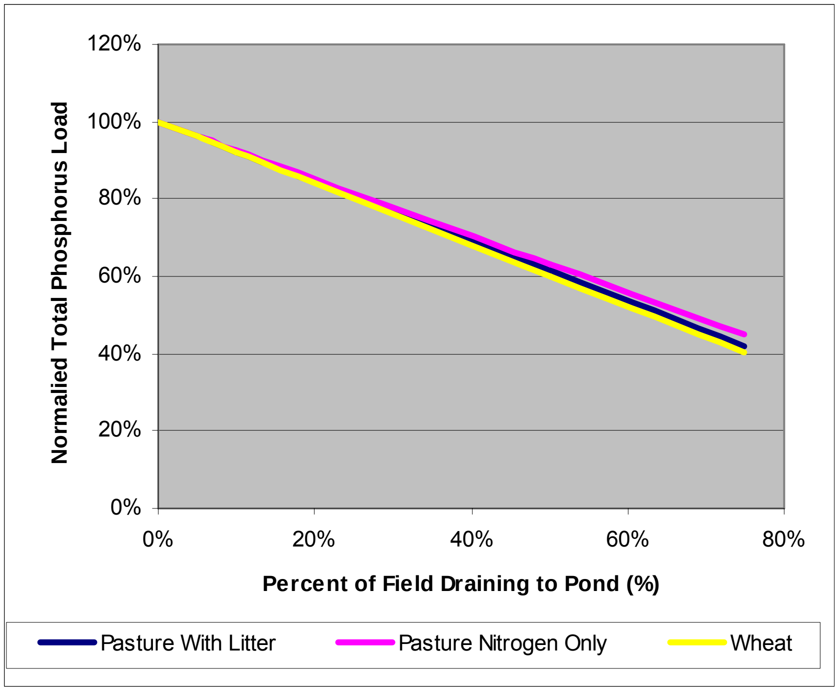


Figure 4.34 Normalized phosphorus loss with percent of field draining to ponds for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

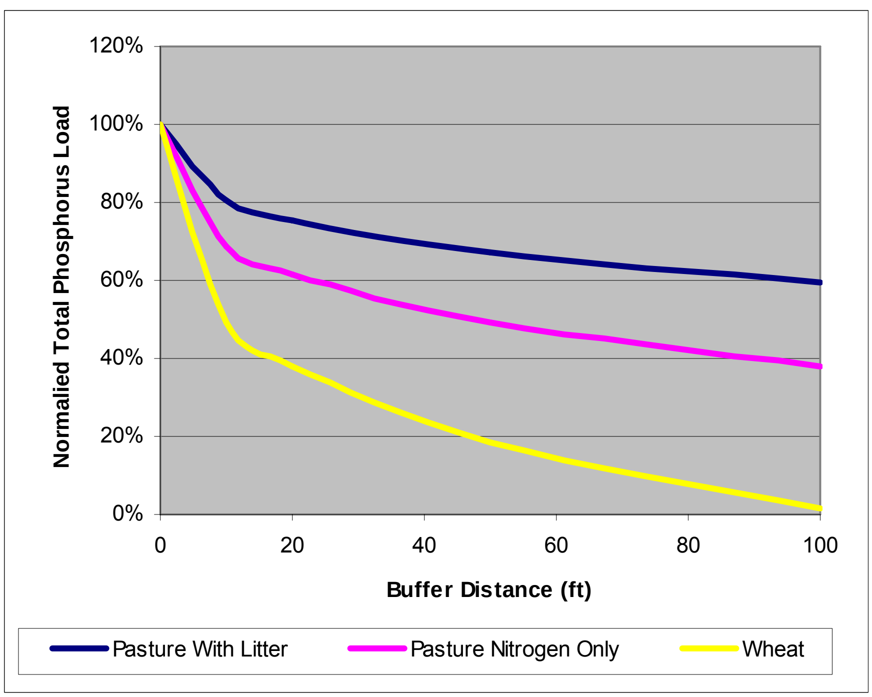


Figure 4.35 Normalized phosphorus loss with riparian buffer width for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

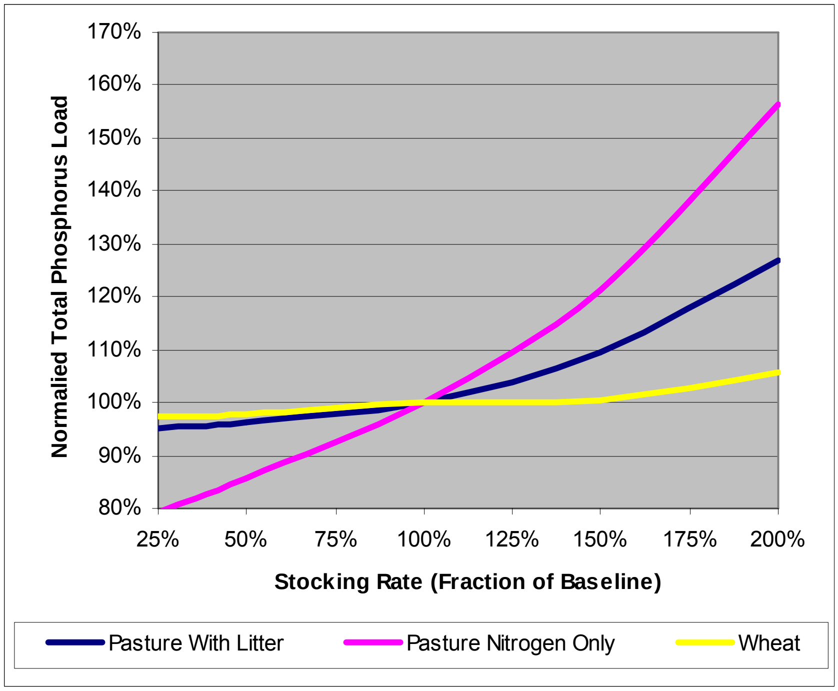


Figure 4.36 Normalized phosphorus loss with stocking rate for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

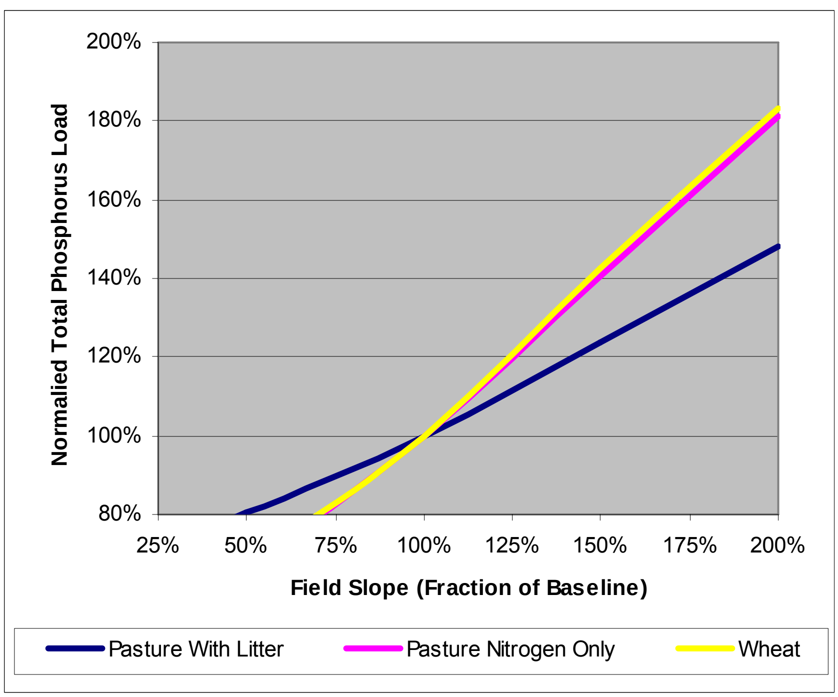


Figure 4.37 Normalized phosphorus loss with field slope for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

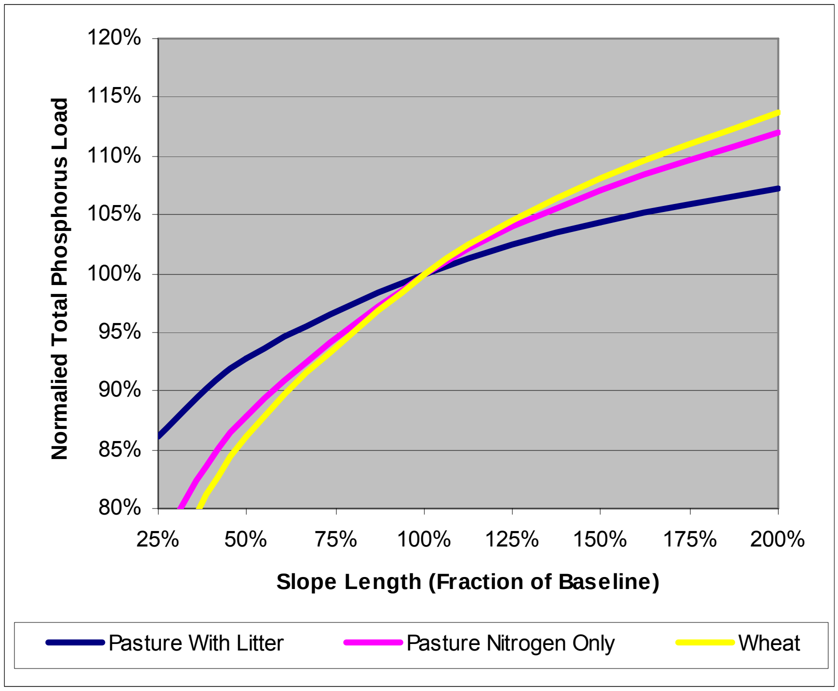


Figure 4.38 Normalized phosphorus loss with field slope length for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

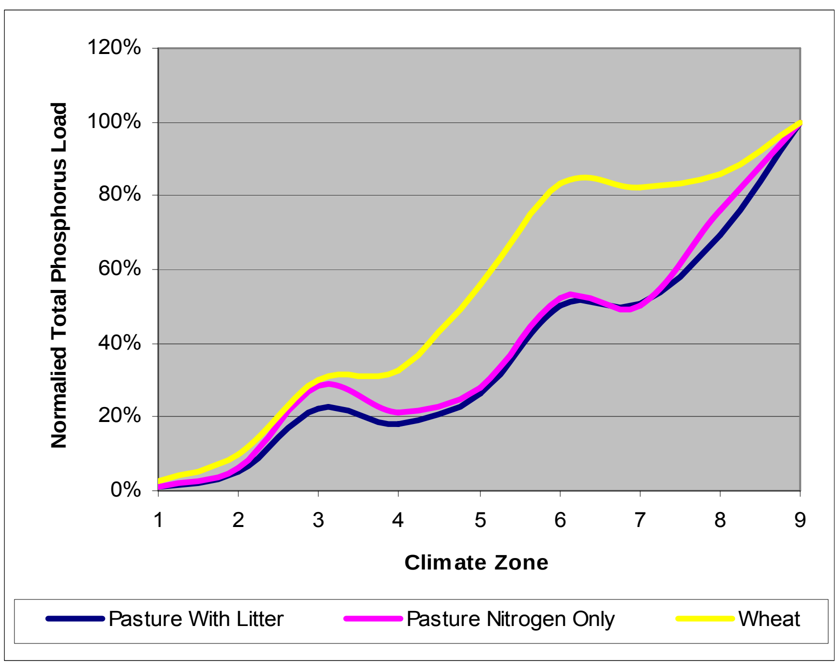


Figure 4.39 Normalized phosphorus loss with climate zone for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat).

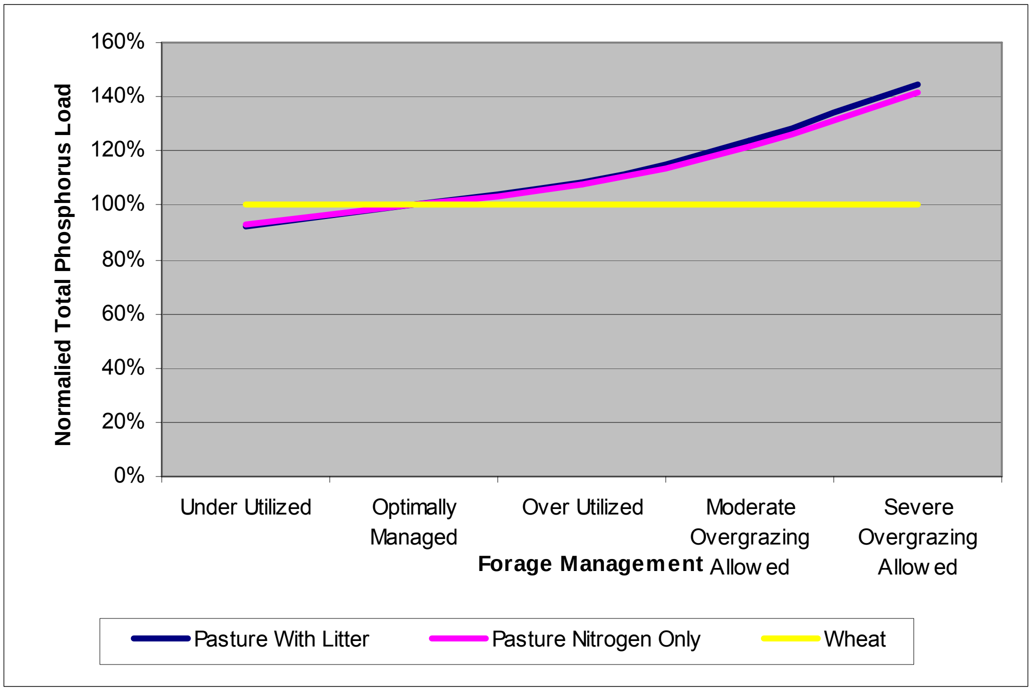


Figure 4.40 Normalized phosphorus loss with forage management for poultry littered grazed pasture (Pasture With Litter), commercial nitrogen applied to grazed pasture (Pasture Nitrogen Only), and commercial nitrogen and phosphorus applied to grazed wheat (Wheat). Note forage management is not an option on cultivated crops.

Chapter 5

PPM Plus Accuracy Assessment

The primary reason for using a model as the engine for PPM Plus is that a process based model can better account for the diversity of conditions present across Oklahoma as compared to a traditional qualitative P Index. The SWAT model is a mixture of imperial and physically based routines which seek to replicate the major processes important to the constituents it predicts. These routines are by definition a simplification of natural processes and should be validated when possible. In this chapter, PPM Plus was extensively tested using field scale P loss data from several studies. No published literature could be located which present a P Index validated with the amount and diversity of field scale data presented here.

Evaluating Uncertainty

The Roman naturalist and scholar Pliny the Elder once said “The only certainty is uncertainty”. This statement has held true for 2000 years in both everyday life and scientific endeavors. Uncertainty permeates the physical world and our assessments of it. Every measurement we take, every prediction we make contains uncertainty. Even a theoretically ideal measurement contains uncertainty at the quantum level; the very act of measuring something disturbs it such that the measurement is no longer exact.

Though our measurements and models of the physical world contain uncertainty, they still offer the guidance to make important decisions.

All model predictions contain error; the direction and magnitude of this error determines the utility of the model. Uncertainty is a measure of the possible error in model predictions. Reckhow (1994) stated "*The magnitude of the uncertainty provides a measure of value of information: the smaller the uncertainty, the more confident (and valuable) is the assessment".* A model with high uncertainty may make a prediction that is very close to the actual value, thus containing little error. The same model may also make a prediction containing tremendous error. Hence the old adage "A broken clock is right twice a day". A clock is a mechanical model for the passage of time, and even a broken one may have little error depending upon when you choose to evaluate it. Error in a single measurement or group of related measurements may not show the true range in error or uncertainty in a model's prediction. The majority of P Indices are developed and tested on a small amount of data from a particular region or group of similar fields. Under those conditions they may perform well, but under more diverse conditions, performance may decline significantly (Harmel et al. 2005). To reasonably evaluate the accuracy of a P Index, it should be tested with data as diverse as the conditions under which it will be applied.

Models by definition are simplification of real world processes. These mathematical constructs typically have to ignore potentially significant processes. The perfect model would be the system itself (Kleijnen 1995). Our understanding is always lacking; our models become more sophisticated and comprehensive as our understanding of the processes involved in the phenomena of interest grows. Figure 5.1 illustrates how models evolve from simple qualitative judgments to physically based models as our knowledge increases. PPM Plus is a step up this ladder from qualitative indices. Model uncertainty should theoretically decrease with improved models.

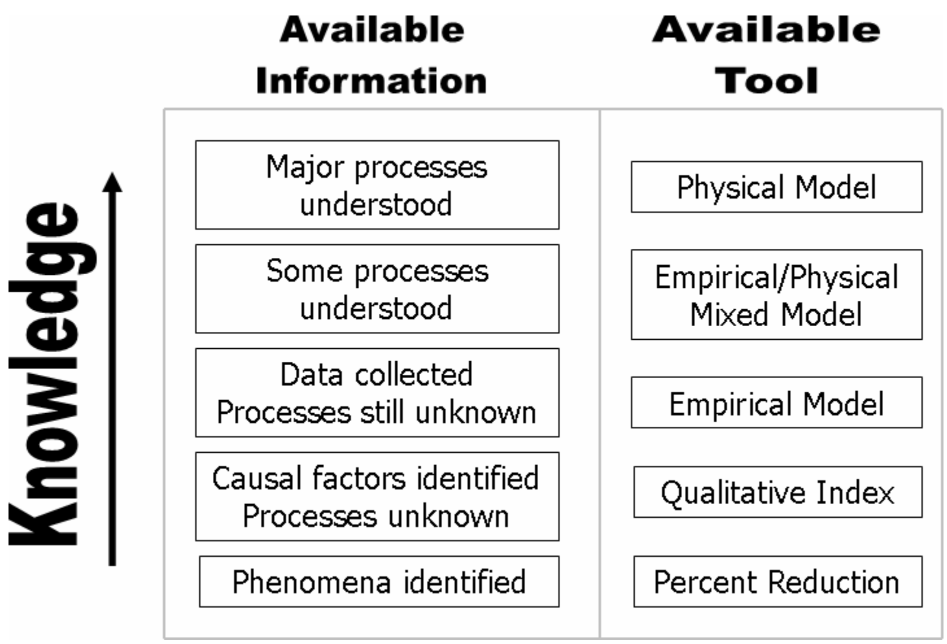


Figure 5.1 Model evolution over time

There are three sources of uncertainty in model predictions: the model structure, the parameterization of the model, and the unpredictable nature of the environment. Uncertainty due to environmental factors is easy to understand; rain will wash P into streams. If it rains less, or not at all, less P is moved. The second type of uncertainty is built into the model during its creation by the model developers. It is closely related to and often inseparable from the third type of uncertainty which is due to the parameterization of the model by the users. Model structural assumptions effect uncertainty and are less commonly acknowledged than parameter uncertainty (Draper 1995). The separation of the second and third sources is convenient because the model developers and model users are generally two different groups. Watershed models are typically developed by federal and state entities. Users are generally engineers, planners, and consultants. Incomplete understanding of the primary processes during the development of a model builds in model uncertainty. The assumptions by model developers during the structuring of the models are an important source of uncertainty. Model parameterization is perhaps the most controllable source of uncertainty. The parameters a modeler chooses based on available information are critical to developing a good model. Parameter values are often adjusted through calibration to reduce model uncertainty.

Reducing Uncertainty

Appropriate Model Selection

Models are crafted from the assumptions of model developers. Often several different models may be applicable to any given analysis. Models invariably range from simplistic to complex. The use of a more complex model does not necessarily mean there is less uncertainty. More complex models have more parameters which need to be estimated or measured. Cox (1999) offered the viewpoint: "*The need to estimate more uncertain quantities undermines the advantages of greater descriptive realism so much that the final risk estimates are less certain than the ones traditionally obtained from simpler, less realistic, statistical curve-fitting models".* A contrasting view is that to incorporate more of the biologically important processes and more measured data should always reduce uncertainty. In the end, Cox (1999) found that in general more complex risk models had less uncertainty, and that uncertainty in the some inputs does not necessarily translate to uncertainty in the predicted risk. Cox (1999) added the condition that unjustified or "spurious" complexities in models were removed. Identifying the "spurious" complexities is not an easy task, and the parts of the model that are "spurious" may differ from one application to another.

Model Calibration

Model calibration is the adjustment of uncertain parameter estimates to make the model more closely match observed data. Model calibration generally reduces the uncertainty. Complex models often have many parameters, each with a range of values which may be equally valid. Careful selection of a single value within the appropriate range may improve model predictions. Calibration requires observed data, which may not be available. In the absence of observed data, calibration is not an option. However, portions of a model may be calibrated, and other portions may not be calibrated.

Model Validation

The goal of validation is to determine whether the conceptual simulation model is an accurate representation of the system under study (Kleijnen 1995). There is some confusion in the literature about what validation is and what it means to validate a model (Rykiel 1996). For our purpose, model validation is the process during which model predictions are evaluated against measured data not used in calibration or model development. The purpose of validation is to provide an independent assessment of model performance. Models can be calibrated such that they seem to perform well during the calibration period by mimicking measured data, but the model may not properly represent the fundamental processes which are important to the system. Validation challenges the model to replicate similar performance in a separate system or time. Reckhow (1994) added the condition that the validation dataset be different in the sense that the important processes and forcing functions or responses differ from the calibrated condition. This condition implies that a model cannot be calibrated and truly validated using data collected under similar conditions. The key to a reliable validation is diversity. Diversity is often lacking from P Index validations.

Model validation requires that a portion of the available data be purposefully excluded from model calibration. However, data are often too limited to be subdivided between calibration and validation. Calibration is always given precedence because it performs multiple purposes. One alternative is split the measured data set, perform model calibration and validation, and then recalibrate the model with the entire data set. During calibration, the model is adjusted to provide the best prediction possible. Validation affects model uncertainty, not model error. Models typically yield somewhat lower performance during validation than calibration.

Calibration and Validation Sites

Data for the calibration and validation of PPM Plus were collected in the Lake Eucha/Spavinaw basin. These data were supplemented with data from other field scale P studies data in Oklahoma, Arkansas, Texas, and Georgia (Figure 5.2). The Manage database (Harmel et al. 2006) was used to identify many data sources from published literature. In many cases data were obtained directly from the articles authors. Much of these data were provided upon the condition that these data would not be disclosed or published. For this reason certain tabular data have been omitted from this document. These data, however, do appear in graphical forms when grouped with other data.

A total of 437 field years of data were included in the calibration and validation of PPM Plus. Approximately 35% of these data were collected at the same sites with overlapping time periods and are not truly independent. For example, in Table 5.1 a publication described a site from 1985 to 1995 with a single average annual P loss, and another publication described the same field from 1990 to 2000 with a similar single average loss. Both studies contain independent data (1985-1990 and 1995-2000), but they also share data during the overlapping period (1990-1995). The studies combined represent 15 years of measured data, yet 20 years are reported. An adjusted weight for each source was developed to account of these overlaps. Each 10 year study in the example receives an adjusted weight of 7.5 years, totaling 15 years between the two studies. Because these data are derived from published sources, it is not possible to exclude all overlap without discarding many studies. A total 283 fields years of data were used if adjusted for overlapping periods.

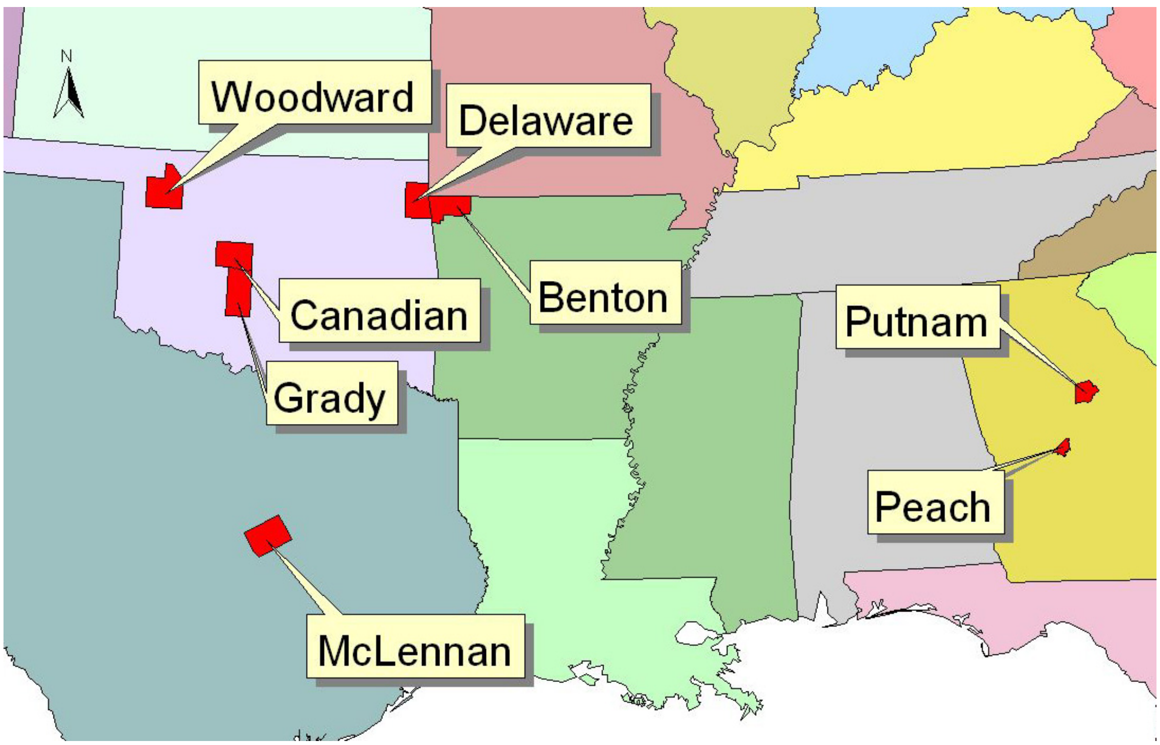


Figure 5.2 Field study site locations used to evaluate PPM Plus.

Table 5.1 Example illustrating adjusted weighting factor development.

Study	Reported Time frame	Study Length (yr)	Overlaping data (yr)	Non Overlapping data (yr)	Adjusted Weight (yr)
Study 1	1985-1995	10	5	5	7.5
Study 2	1990-2000	10	5	5	7.5
Sum	1985-2000	20			15

Lake Eucha basin, Oklahoma

Eight pasture fields in Delaware County, Oklahoma were monitored from May 2006 to July 2007. These data were specifically collected from the Lake Eucha basin for the purpose of validating PPM Plus (Figure 5.3). All sites were pastures ranging from 1 to 5 acres (Table 5.2). Slopes ranged from less than 1% to 16%. All had relatively low STP (<50 ppm) and half had very low STP (<12.5 ppm). Three fields received poultry litter at relatively low application rates. Rainfall data were collected at each site and were included in PPM Plus.

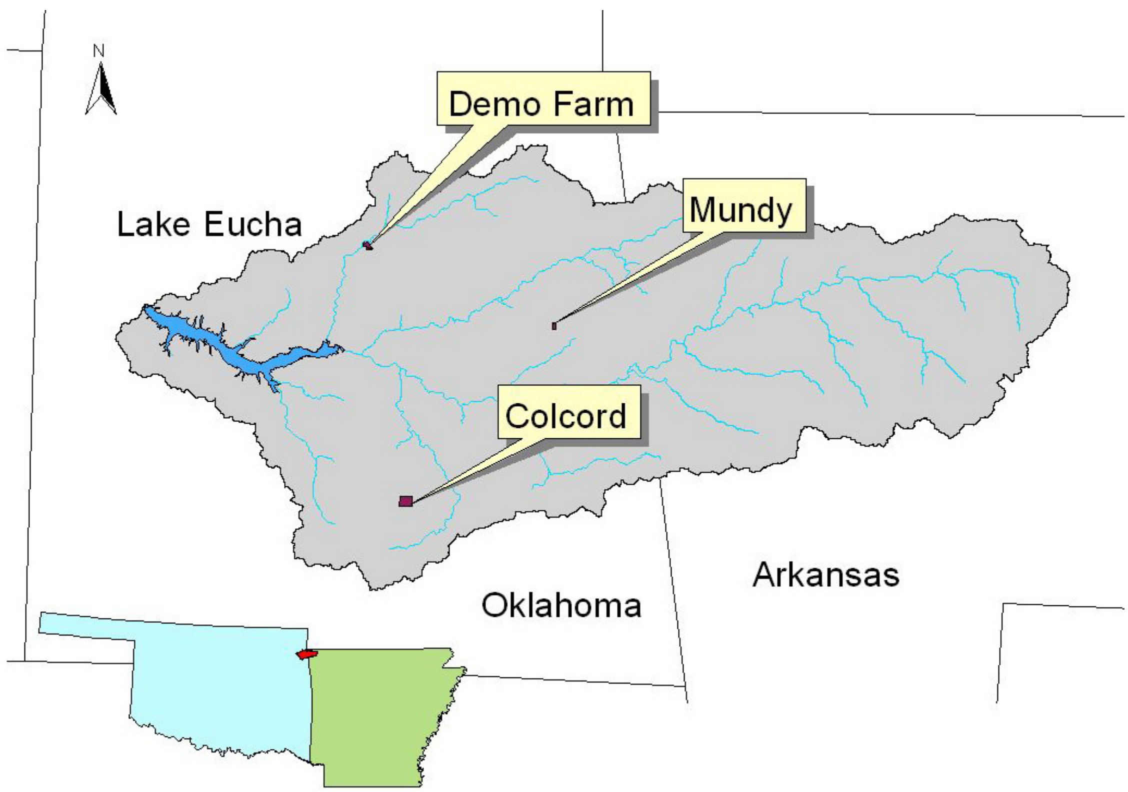


Figure 5.3 Lake Eucha basin field monitoring site locations.

Table 5.2 Selected field characteristics and management options from sites in the Lake Eucha basin, Oklahoma. (1 kg/hectare = 0.89 lb/acre, 1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Nitrogen Applied (lb N/acre)	Phosphorus Applied (lb P/acre)	Manure Fertilizer	Grazing	Area (acres)	Primary Soil
1 Mundy West	22.5	1.8	95	18	Yes	Yes	2.2	Choteau
2 Mundy East	22.5	2.4	95	18	Yes	Yes	2.2	Newtonia
3 Demo South East	12.5	16.3	27	31	No	Yes	1.1	Clarksville
4 Demo south West	12.5	14.1	27	31	No	Yes	1.1	Clarksville
5 Demo North	50	12.5	80	40	Yes	Yes	4.8	Clarksville
6 Colcord Hay	31.5	1.7	50	0	No	Yes	5.4	Captina
7 Colcord West	7.5	0.9	0	0	No	Yes	1.7	Captina
8 Colcord East	7.5	1.0	0	0	No	Yes	1.7	Captina

*Mehlich Soil Test Phosphorus

Moore's Creek, Arkansas

These data were collected over 33 months on four pastures 12 miles west of Fayetteville Arkansas in Benton County. These data were available from various publications (Edwards et al. 1996a; Edwards et al. 1996b; Edwards et al. 1994). This study monitored four fields under natural rainfall, with elevated STP due to the application of poultry litter (Table 5.3). Two fields received additional litter during the study period and two received only commercial nitrogen. The authors provided measured daily rainfall and all measured concentration and flow data collected over the entire period at each study site. These data were summarized for 1992, 1993, and the entire study period 9/1/1992 to 3/30/1994 separately. Because these periods overlapped, they were given appropriately reduced weighting in the analysis.

Table 5.3 Moore’s Creek, Arkansas field site characteristics. (1 kg/hectare = 0.89 lb/acre, 1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Nitrogen Applied (lb N/acre)	Phosphorus Applied (lb P/acre)	Manure Fertilizer	Grazing	Area (acres)	Primary Soil
Moore's Creek (R Litter)	177	3.0	350	146	Yes	Yes	3.04	Captina
Moore's Creek (R Com N)	246	2.0	158	0	No	Yes	1.41	Tadlock
Moore's Creek (W Litter)	187	4.0	293	99	Yes	Yes	2.62	Allegheny
Moore's Creek (W Com N)	364	4.0	135	0	No	Yes	3.61	Linker

*Mehlich Soil Test Phosphorus

Putnam County, Georgia

These data were collected at the Central Georgia Branch Station in Putnam County, Georgia by Pierson et al. (2001a) and Pierson et al. (2001b). Data were collected from three small (< 2 acre) fertilized and grazed pasture fields. One goal of this study was to explore the effect of grazing method (rotational vs. continuous). Grazing method was not a significant factor, for this reason, the authors provided data from only half of the study fields (2, 4, and 6). Average annual loads and measured precipitation data were provided to augment these published data. These fields had low STP and were heavily littered (3-6 ton/acre, 7-13 Mg/ha). Data were available to represent 1995 and 1996 separately without overlap. Selected field characteristics are given in Table 5.4.

Table 5.4 Putnam County, Georgia site characteristics. (1 kg/hectare = 0.89 lb/acre, 1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Nitrogen Applied (lb N/acre)	Phosphorus Applied (lb P/acre)	Manure Fertilizer	Grazing	Area (acres)	Primary Soil
Georga Putnam Field 2 1995	42.6	8.0	476	192	Yes	Yes	1.95	Altavista
Georga Putnam Field 2 1996	70.5	8.0	659	205	Yes	Yes	1.95	Altavista
Georga Putnam Field 4 1995	29.3	6.0	476	198	Yes	Yes	1.87	Altavista
Georga Putnam Field 4 1996	57.1	6.0	659	270	Yes	Yes	1.87	Altavista
Georga Putnam Field 6 1995	32.9	6.0	476	216	Yes	Yes	1.78	Helena
Georga Putnam Field 6 1996	60.1	6.0	659	291	Yes	Yes	1.78	Helena

*Mehlich Soil Test Phosphorus

Peach County, Georgia

This study from Peach County, Georgia was conducted by Vervoort et al. (1998a) and Vervoort et al. (1998b) to evaluate the effect of composting poultry litter on nutrient losses. Three hay fields were instrumented for two years. These fields were not grazed and had low to moderate STP values. Two fields received poultry litter (4.5 and 9 ton/acre, (10 and 20 Mg/ha)) and one field received composted poultry litter at a very high application rate (22 ton/acre, (50Mg/ha)) combined with normal litter at a nominal rate (4.5 ton/acre). The mineral P content of this composted litter mixture was very low as compared to typical litter. The measured organic and mineral content of this mixture was incorporated into the PPM Plus simulation. On site measured rainfall data were not available; simulations are based on a nearby Cooperative Observer gage (COOP ID 091448). Site characteristics are given in Table 5.5.

Table 5.5 Peach County, Georgia site characteristics. (1 kg/hectare = 0.89 lb/acre, 1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Nitrogen Applied (lb N/acre)	Phosphorus Applied (lb P/acre)	Manure Fertilizer	Grazing	Area (acres)	Primary Soil
Georga Peach W1 (Excessive)	61	2.8	1034	773	Yes	No	1.1	Esto
Georga Peach W2 (2x Litter)	11	2.8	616	233	Yes	No	1.1	Esto
Georga Peach W3 (1x Litter)	15	2.8	322	102	Yes	No	1.1	Faceville

*Mehlich Soil Test Phosphorus

El Reno, Oklahoma

These data were collected at the Grazinglands Research Laboratory near El Reno in Canadian County, Oklahoma. These data span from 1977 to 1992 and were derived from several publications (Sharpley et al. 1985, Smith et al. 1991, Sharpley et al. 1992, Smith et al. 1992, and Sharpley, 1995). Runoff and nutrient yields from several overlapping periods were detailed in the literature; all were included with adjusted weighting factors. These fields were primarily grazed pasture, although some fields were converted to wheat. STP values were generally low and fertilization was primarily limited to wheat fields. None of these fields received animal manure. Slopes were less than 4% and Kirkland silt loam was the dominant soil type in all fields. A summary of site characteristics is given in Table 5.6. Only static field characteristics are listed; all fields were used in multiple simulations with differing management. There is a high degree of overlap in these data; analysis of PPM Plus employed corrective weighting factors.

Table 5.6 Static characteristic of the El Reno, Oklahoma field sites. (1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Land Use	Grazing	Area (acres)	Primary Soil
E1	13	2.6	Native Grass	Yes	4.0	Kirkland
E2	15	2.9	Native Grass	Yes	4.0	Kirkland
E3	14	3.2	Native Grass	Yes	4.0	Kirkland
E4	15	3.6	Native Grass	Yes	4.0	Kirkland
E6	32	2.9	Grass/Wheat	Yes	4.0	Kirkland
E7	38	2.9	Grass/Wheat	Yes	4.0	Kirkland
E8	21	2.7	Grass/Wheat	Yes	4.0	Kirkland

*Mehlich Soil Test Phosphorus

Woodward, Oklahoma

These data were collected at the Southern Plains Research Station at Woodward, Oklahoma by Sharpley et al. (1985), Smith et al. (1991), Sharpley et al. (1992), and Sharpley (1995). These data span from 1977 to 1992 and include four fields which have been managed on and off as native range or wheat. STP values were generally low (<25 ppm) and wheat received between 50 and 100 lb/acre (56 and 112 kg/ha) N and 20 lb P_2O_5/acre (22 kg P_2O_5/ha) during cultivation. Native range received little or no fertilization and was grazed. A summary of site characterizes is given in Table 5.7. These data also contained a high degree of overlap which was accounted for in the analysis.

Table 5.7 Selected Woodward, Oklahoma field site characteristics. (1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Land Use	Grazing	Area (acres)	Primary Soil
W1	14	7.0	Native Grass	Yes	4.0	Kirkland
W2	15	8.2	Native Grass	Yes	4.0	Kirkland
W3	29	8.6	Grass/Wheat	Yes	4.0	Kirkland
W4	40	7.4	Grass/Wheat	Yes	4.0	Kirkland

*Mehlich Soil Test Phosphorus

Chickasha, Oklahoma

These data were collected at the Chickasha South Central Research Station in Grady County, Oklahoma by Olness et al. (1975), Menzel et al. (1978), Olness et al. (1980), and Sharpley et al. (2004). These data were collected on a mixture of cultivated fields (irrigated cotton and small grains) and rangeland. STP values were lower in rangeland than cultivated fields; fertilization varied by year and crop. Slopes were less than 1% in cultivated fields and less than 3.5% on rangeland. Soils were primarily of the Grant and McLain series. Five cultivated and two rangeland sites were used. An additional two rangeland sites were rejected due to large bare areas and lack of surface cover as reported by Olness et al. (1975). These sites were rejected because a pasture or rangeland with less than 500 kg/ha minimum standing biomass cannot be properly represented in PPM Plus. The most overgrazed condition available in the forage management section of PPM Plus prevents grazing with less than 500 kg/ha. The descriptions provided by Olness et al. (1975) were consistent with less than 500 kg/ha of standing biomass. Selected site characteristics are given in Table 5.8.

Table 5.8. Selected Chickasha, Oklahoma site characteristics. (1 hectare = 2.47 acres)

Field Name	STP* (ppm)	Slope (%)	Land Use	Area (acres)	Primary Soil
C1	20	0.5	Cropland	17.8	McLain
C3	20	0.1	Cropland	44.2	McLain
C4	30	0.1	Cropland	29.9	McLain
C5	28	0.1	Cropland	12.8	McLain
C6	20	0.1	Cropland	13.1	McLain
R5	5	2.7	Pasture	23.7	Grant
R6	10	2.7	Pasture	27.2	Grant

*Mehlich Soil Test Phosphorus

Riesel, Texas

These pasture and crop data were collected at Riesel in McLennan County, Texas at the USDA-ARS Grassland Soil and Water Research Laboratory. Data from these sites were published in Harmel et al. (2004), Harmel et al. (2005), and Harmel et al. (2006), but the majority of these data were obtained directly from the publications first author. These data were very well documented. These data (Table 5.9) span from 2000 to 2006. Crops on cultivated fields shifted between corn and wheat in a single calendar year, and thus these data were not included in the analysis because PPM Plus does not simulate double crops. Most fields received animal manure annually beginning in 2001. Slopes were less than 4% and Houston Black and Heiden Clay were the dominate soils. Daily rainfall was available for each field for the entire study period from a network of rainfall gages. Rainfall for each site was estimated using Thiessen polygonal weighting (Boots 1980). Climate was taken from the Cooperate observer site (ID # 415611) approximately 10 miles from the fields. Data for these fields were available annually and each year was represented individually in the calibration and validation of PPM Plus. There was no data overlap.

Table 5.9 Selected characteristics of field monitored in Riesel, Texas.

Watershed	Area (ac)	Slope (%)	Terraced	Dominat Landuse
Y6	16.3	3.2	Yes	Corn/Wheat
Y8	20.8	2.2	Yes	Corn/Wheat
Y10	18.5	1.9	Yes	Corn/Wheat
Y13	11.4	2.3	Yes	Corn/Wheat
W12	9.9	2.0	Yes	Corn/Wheat
W13	11.4	1.1	Yes	Corn/Wheat
SW12	3.0	3.8	No	Pasture/Hay
SW17	3.0	1.8	No	Pasture/Hay
W10	19.8	2.5	Yes	Pasture/Hay
Y14	5.7	1.6	No	Pasture/Hay

Calibration/Validation Overview

The SWAT model used in PPM Plus was calibrated for flow using data from 11 basins across the state of Oklahoma. The original intent was to recalibrate PPM Plus for runoff volume, sediment, and P at the field scale using half of the available field scale data. PPM Plus was not calibrated at the field scale as originally intended. PPM Plus was evaluated against the calibration dataset, but none of the adjustments explored during the calibration process resulted in improved model performance. Because these data were not used to calibrate PPM Plus, all available field scale data were used in the validation. PPM Plus was validated for runoff volume, sediment, and P.

A total of 283 field years of data were available to calibrate and validate PPM Plus. Available data for the calibration and validation of PPM Plus were split into approximately two equal portions. Data were loosely grouped by source; even records were assigned to validation (145 years after adjustment for overlap), and odd records to calibration (138 years after adjustment for overlap).

Field Scale Calibration

Although PPM Plus was not actually calibrated at the field scale, the comparisons made during the calibration process are presented to justify that decision. Records selected for the calibration process are given in Table 5.10.

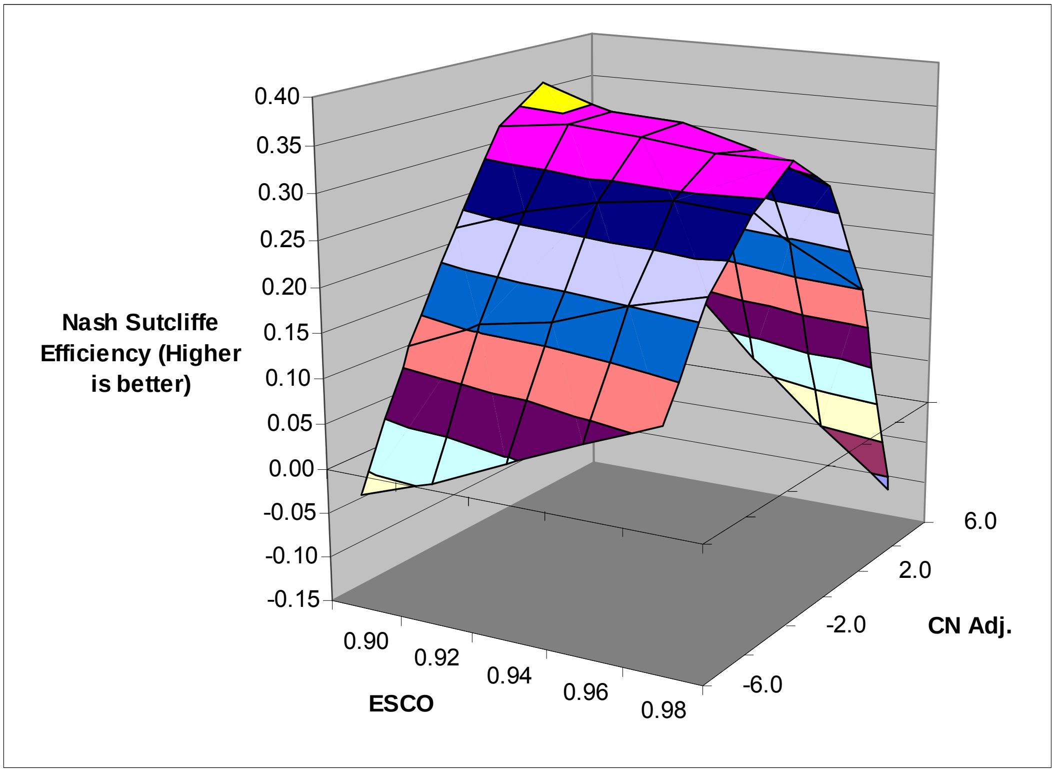
Table 5.10 PPM Plus calibration field monitoring sites with overlap adjusted weighting factor.

Field ID	Location	Start Date	End Date	Weight (yr)
Eucha Mundy	Delaware County, OK	5/1/2006	6/30/2007	1.2
Eucha Demo	Delaware County, OK	5/1/2006	6/30/2007	1.2
Eucha Demo	Delaware County, OK	5/1/2006	6/30/2007	1.2
Eucha Colcord	Delaware County, OK	5/1/2006	6/30/2007	1.2
Riesel W10	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel W10	McLennan County, TX	1/1/2002	12/31/2002	1.0
Riesel W10	McLennan County, TX	1/1/2004	12/31/2004	1.0
Riesel SW12	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel SW12	McLennan County, TX	1/1/2002	12/31/2002	1.0
Riesel SW12	McLennan County, TX	1/1/2004	12/31/2004	1.0
Riesel SW17	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel SW17	McLennan County, TX	1/1/2002	12/31/2002	1.0
Riesel SW17	McLennan County, TX	1/1/2004	12/31/2004	1.0
Riesel Y14	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel Y14	McLennan County, TX	1/1/2002	12/31/2002	1.0
Riesel Y14	McLennan County, TX	1/1/2004	12/31/2004	1.0
Riesel Y6	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel Y6	McLennan County, TX	1/1/2005	12/31/2005	1.0
Riesel Y8	McLennan County, TX	1/1/2005	12/31/2005	1.0
Riesel Y10	McLennan County, TX	1/1/2005	12/31/2005	1.0
Riesel Y13	McLennan County, TX	1/1/2005	12/31/2005	1.0
Riesel W12	McLennan County, TX	1/1/2002	12/31/2002	1.0
Riesel W13	McLennan County, TX	1/1/2000	12/31/2000	1.0
Riesel W13	McLennan County, TX	1/1/2005	12/31/2005	1.0
Moore's Creek 1 (R Litter)	Benton County, AR	1/1/1992	12/31/1992	0.5
Moore's Creek 2 (R Com N)	Benton County, AR	9/1/1991	3/30/1994	1.7
Moore's Creek 2 (R Com N)	Benton County, AR	1/1/1993	12/31/1993	0.5
Moore's Creek 3 (W litter)	Benton County, AR	1/1/1992	12/31/1992	0.5
Moore's Creek 4 (W Com N)	Benton County, AR	9/1/1991	3/30/1994	1.7
Moore's Creek 4 (W Com N)	Benton County, AR	1/1/1993	12/31/1993	0.5
Georgia Peach W2 (2x Litter)	Peach County, GA	3/1/1995	2/28/1997	2.0
Georgia Putnam Plot 2	Putnam County, GA	1/1/1995	12/31/1995	1.0
Georgia Putnam Plot 4	Putnam County, GA	1/1/1995	12/31/1995	1.0
Georgia Putnam Plot 6	Putnam County, GA	1/1/1995	12/31/1995	1.0
elrenoFR1	Canadian County, OK	1/1/1977	12/31/1989	5.8
elrenoFR2	Canadian County, OK	1/1/1977	12/31/1989	5.8
elrenoFR3	Canadian County, OK	1/1/1977	12/31/1989	5.8
elrenoFR4	Canadian County, OK	1/1/1977	12/31/1980	1.3
elrenoFR5	Canadian County, OK	1/1/1977	12/31/1978	2.0
elrenoFR6	Canadian County, OK	1/1/1984	12/31/1988	2.5
elrenoFR7	Canadian County, OK	1/1/1984	12/31/1988	2.5
elrenoFR8	Canadian County, OK	1/1/1977	12/31/1978	2.0
elrenoE2	Canadian County, OK	1/1/1977	12/31/1992	8.8
elrenoE4	Canadian County, OK	1/1/1977	12/31/1992	8.8
elrenoE7	Canadian County, OK	1/1/1984	12/31/1992	6.5
Woodwardw1	Woodward County, OK	1/1/1977	12/31/1992	8.8
Woodwardw3	Woodward County, OK	1/1/1979	12/31/1986	5.5
Woodwardww1	Woodward County, OK	1/1/1977	12/31/1980	1.3
Woodwardww2	Woodward County, OK	1/1/1977	12/31/1980	1.3
Woodwardww2	Woodward County, OK	1/1/1982	12/31/1986	1.7
Woodwardww3	Woodward County, OK	1/1/1987	12/31/1989	3.0
Woodwardww4	Woodward County, OK	1/1/1977	12/31/1979	3.0
Woodwardww4	Woodward County, OK	1/1/1982	12/31/1986	2.5
Woodwardgraze	Woodward County, OK	1/1/1980	12/31/1986	7.0
chickashaC3	Grady County, OK	7/1/1972	6/30/1976	4.5
chickashaC5	Grady County, OK	7/1/1972	6/30/1976	4.5
chickashAR6	Grady County, OK	7/1/1972	6/30/1976	4.0
chickashaC1	Grady County, OK	7/1/1972	6/30/1973	1.0
chickashaC4	Grady County, OK	7/1/1972	6/30/1973	0.5
chickashaC6	Grady County, OK	7/1/1972	6/30/1973	0.5
chickashAR5	Grady County, OK	7/1/1972	6/30/1973	1.0
chickashAR6	Grady County, OK	7/1/1972	6/30/1973	0.5

Field Scale Hydrologic Calibration

As previously presented, the hydrologic parameters used in PPM Plus were derived by calibrating 11 basins across the state of Oklahoma using total streamflow from USGS gages. The statewide calibration yielded an ESCO of 0.98 and a CN adjustment of zero. The calibration field scale runoff data were used to evaluate this statewide calibration to determine if further adjustment was necessary. CN adjustments from 6 to -6 were explored in combination with ESCO values from 0.90 to 0.98. PPM Plus was executed on each field in the calibration dataset for each combination of ESCO and CN, which was a full factorial with five levels of ESCO and seven levels of CN adjustment. These simulations were compared to measured field data to identify the combination of parameters which produced the best fit across all calibration sites. NSE and absolute relative error were used as performance metrics, which are given in Figures 5.3 and 5.4. Both the NSE and relative error indicated a band of maximum model performance with zero to slightly positive CN adjustments. This band crossed most of the ESCO range, which appeared to be less sensitive than during the basin scale hydrologic calibration. Multiple combinations of ESCO and CN adjustments produced reasonable results and are given in Table 5.11. The highest performing combination was 0.9 for ESCO and 2.0 for CN adjustment. However, the performance was only slightly better than 0.98 and 0.0, which was the closest set to SWAT default parameter values (0.95, 0.0). This set (0.98, 0.0) was already the default for PPM Plus as determined by the state wide basin scale calibration during the development phase. For these reasons, ESCO and CN adjustment were left unchanged from the state wide calibration since no significant improvement in model performance could be gained by recalibration with these data. In summary, PPM Plus was not recalibrated at the field scale for hydrology.

Overall fit for runoff volume was acceptable. These results are given in Figure 5.5. Individual studies were weighted by study duration and adjusted for overlap. The linear regression line in Figure 5.5 was developed using a weighted least squares regression in Minitab (Minitab 2007). The slope of this line is less than one, indicating that PPM Plus had a tendency to under predict runoff at larger values. PPM Plus uses surface runoff volume as predicted by SWAT; SWAT also predicts lateral flow which may have been measured at some field studies. Water which infiltrates the soil surface and encounters a soil layer of reduced permeability or a layer of high permeability may travel laterally and reemerge down slope. The field study monitoring sites may or may not have been placed to capture this lateral flow. There was no way of knowing which studies captured this subsurface component. Field sites with higher reported total water yield may have captured a portion of this flow, leading to an under prediction by PPM Plus.



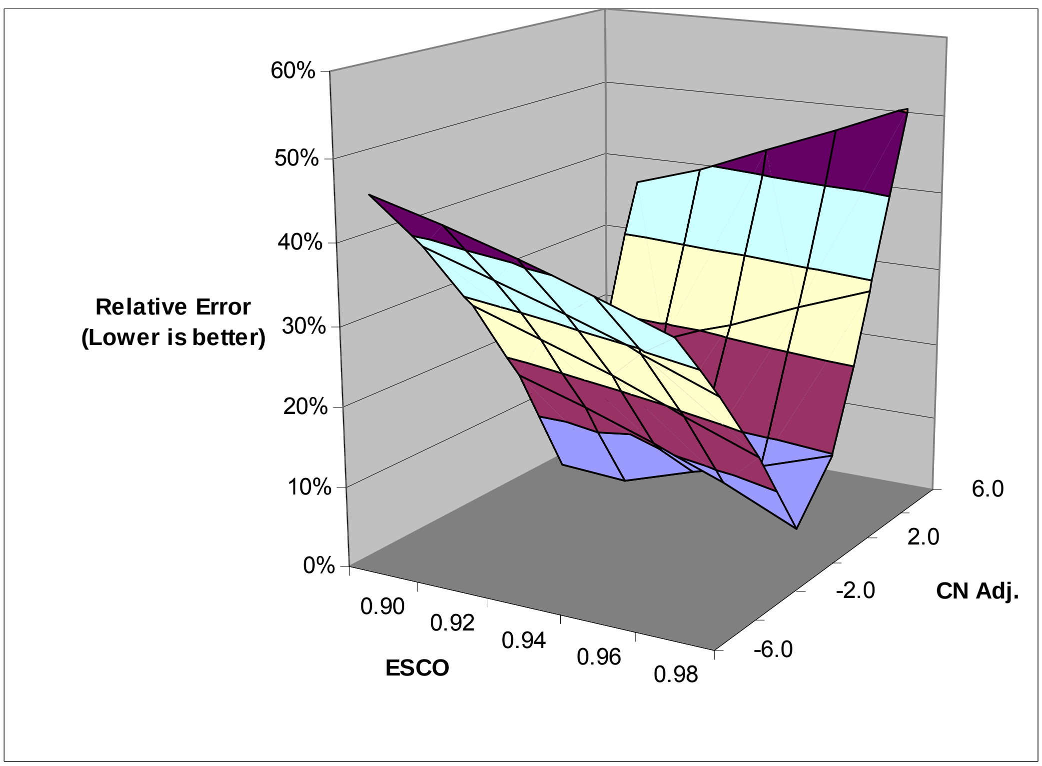


Figure 5.4 Nash Sutcliff Efficiency (top) and Relative Error (bottom) of simulated PPM Plus and observed runoff volume as a function of Soil Evaporation Compensation factor (ESCO) and Curve Number (CN) Adj. (adjustment) across all calibration field sites.

Table 5.11 Combination of ESCO and CN adjustments which yielded acceptable performance in the field calibration of runoff volume in PPM Plus. Selected combination shown in grey.

Soil Evaporation Compensation Factor	Curve Number Adjustment	Relative Error	Nash Sutcliffe Efficiency
0.90	2	2%	0.37
0.92	2	-1%	0.34
0.94	2	-4%	0.34
0.98	0	3%	0.33
0.96	2	-7%	0.32

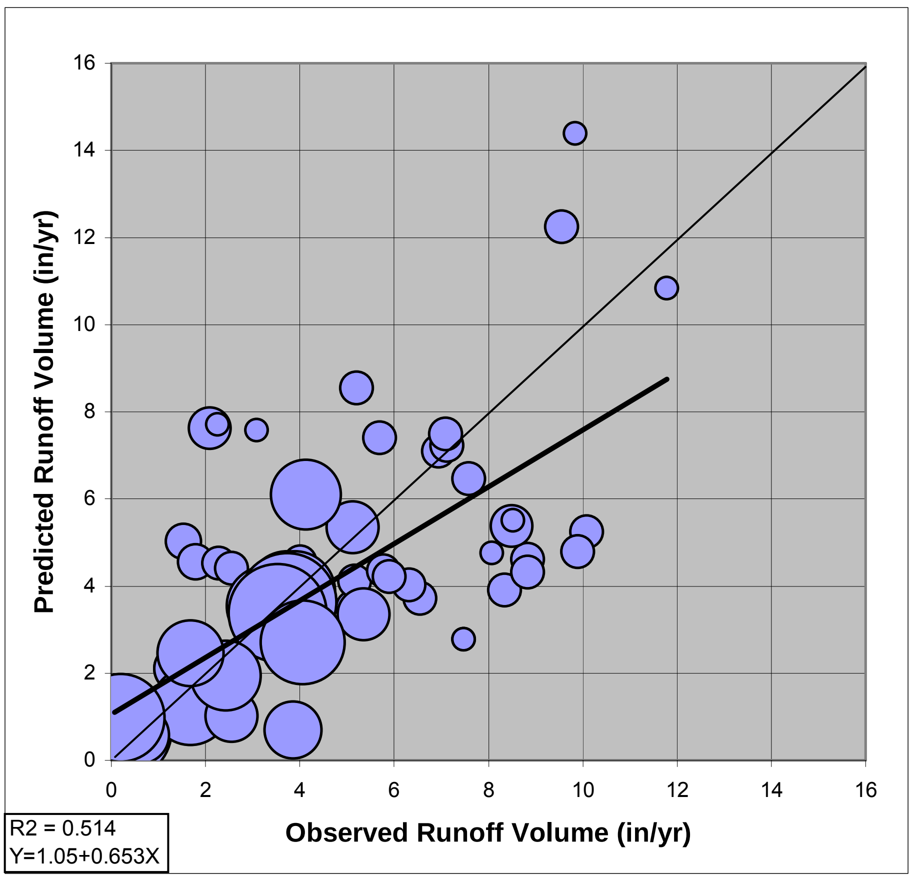


Figure 5.5 Runoff volume evaluation for PPM Plus across all calibration field sites using weighted least square regression. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Field Scale Phosphorus Calibration

Total and soluble P were evaluated against measured data from the field calibration dataset. P percolation coefficient (PPERCO) (units of $10m^3/Mg$) and P soil partitioning coefficient (PHOSKD) (units of m^3/Mg) were selected as calibration parameters since they are among the most sensitive parameters with respect to P loss, and commonly used for calibration (Storm et al. 2001, White 2001) . Five values between 5.0 and 17.5 were explored for PPERCO (SWAT default 10) and nine values of PHOSKD (SWAT default 175) between 100 and 300. PPM Plus was executed for a full factorial of 54 combinations of PPERCO and PHOSKD using each of the 62 calibration fields (3,328 simulations) in the calibration dataset. NSE was used as a performance metric to judge the fit of total and soluble P. This NSE was not weighted by adjusted study length, as this weighted least squares regression procedure required manual calculation using Minitab. Because there were 54 comparisons, the process required automation. Figure 5.6 illustrates how unweighted NSE (average of total P and soluble P) change over the range of PHOSKD and PPERCO explored. As with the hydrologic calibration there were multiple combinations of PPERCO and PHOSKD which yielded similar model performance, among these were the default SWAT values. The parameter set which yielded the best unweighted NSE (PPERCO = 5 PHOSKD = 175) and the default parameter set (PPERCO = 10 PHOSKD = 175) were evaluated more closely.

These simulations were evaluated in Minitab using weighted least squares regression (adjusted for overlap); these results are given in Figures 5.7 to 5.10. The parameter set with the best average unweighted NSE (PPERCO = 5 PHOSKD = 175) performed similarly to the default SWAT values using the weighted least square regression procedure. Both total and soluble P show small improvements in r^2 (less than 0.008), but the slopes were closer to 1.0 with the default values (total P 0.857 vs. 0.915, soluble P 0.459 vs. 0.550). Therefore, default P parameters were not modified since the other tested parameter values did not significantly improve model performance.

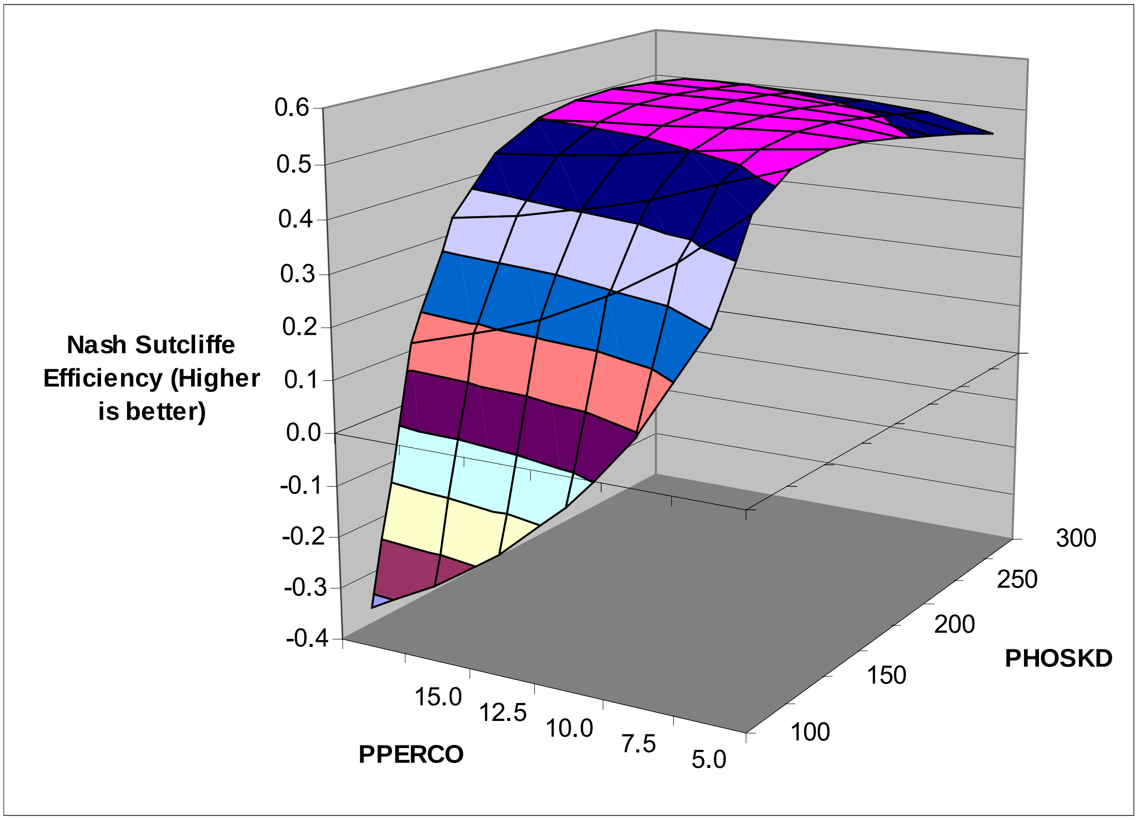


Figure 5.6 PPM Plus predicted average Nash Sutcliffe Efficiency (NSE) of soluble and total phosphorus as a function of P percolation coefficient (PPERCO) and phosphorus soil partitioning coefficient (PHOSKD) for the calibration dataset. Data were not weighted by study length.

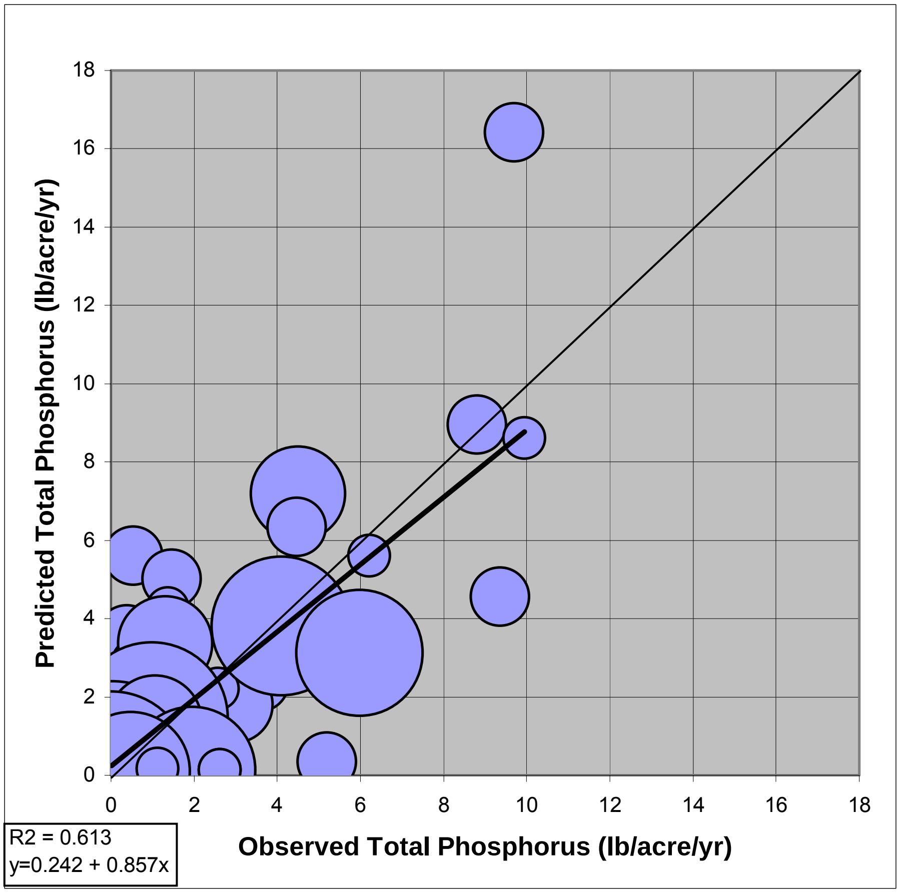


Figure 5.7 Total phosphorus comparison at calibration field sites with a P percolation coefficient (PPERCO) value of 5 ($10m^3/Mg$) and a phosphorus soil partitioning coefficient (PHOSKD) value of 175 (m^3/Mg) using weighted least square regression. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

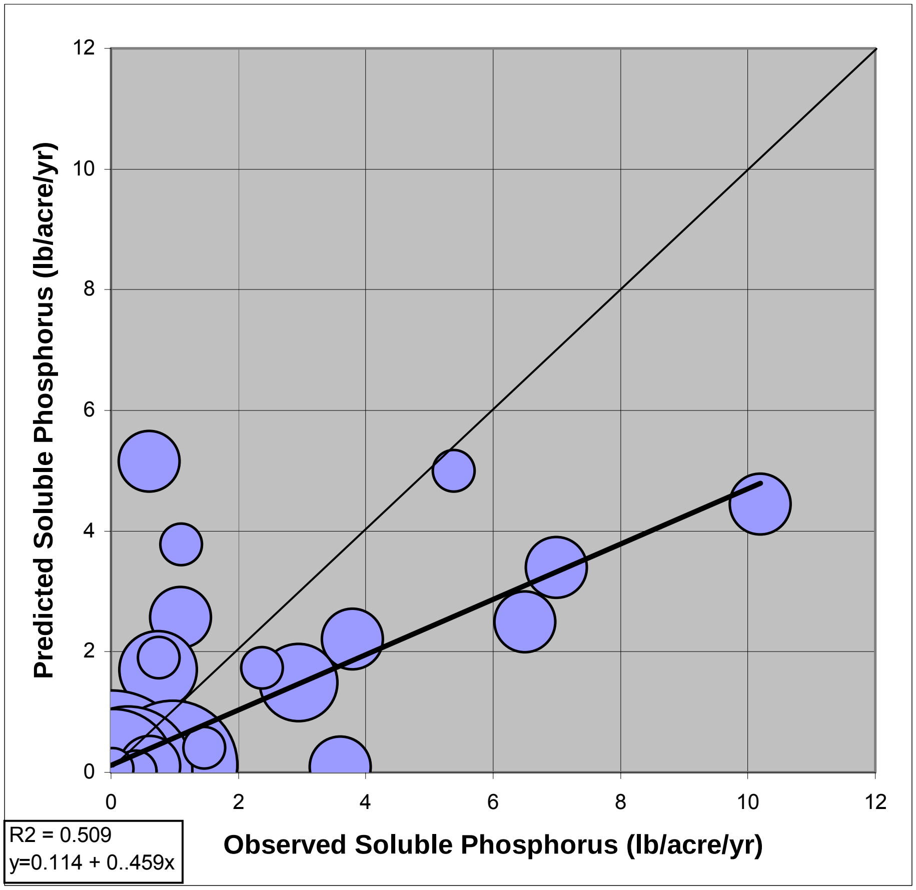


Figure 5.8 Soluble phosphorus comparisons at calibration sites with a phosphorus percolation coefficient (PPERCO) value of 5 ($10m^3$/Mg) and a phosphorus soil partitioning coefficient (PHOSKD) value of 175 (m^3/Mg). Dot size indicates adjusted study length; regression line is weighted by adjusted study length.

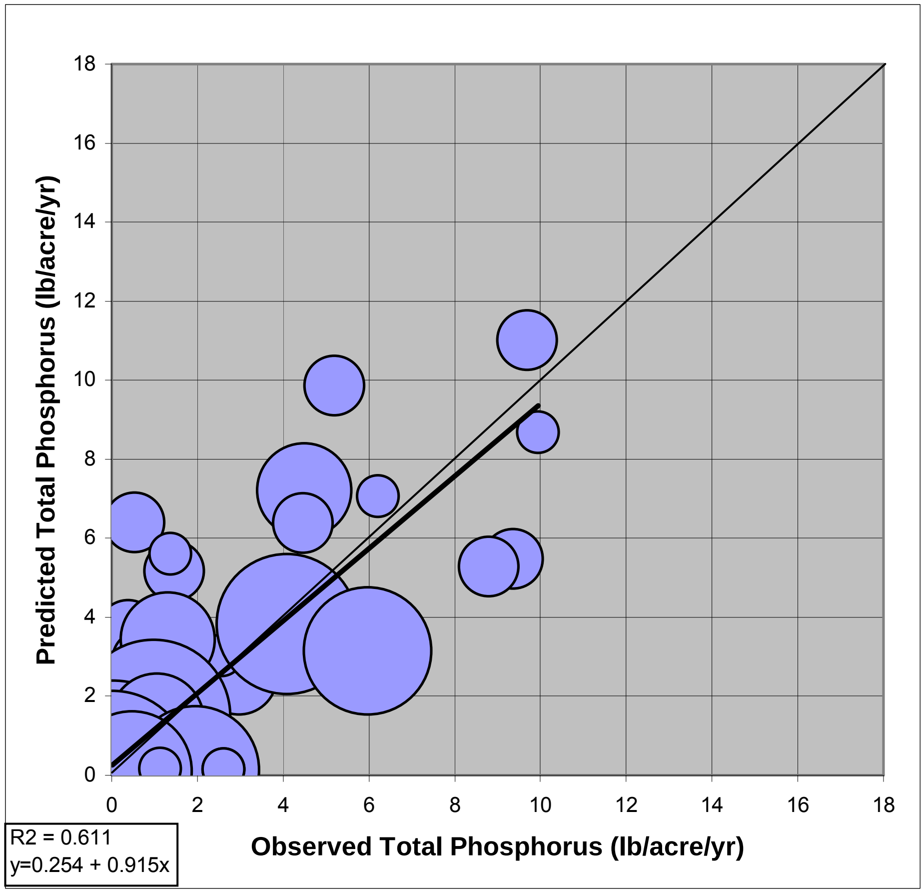


Figure 5.9 Total P comparisons at calibration sites with default values of percolation coefficient (PPERCO) and phosphorus soil partitioning coefficient (PHOSKD) using the calibration dataset. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

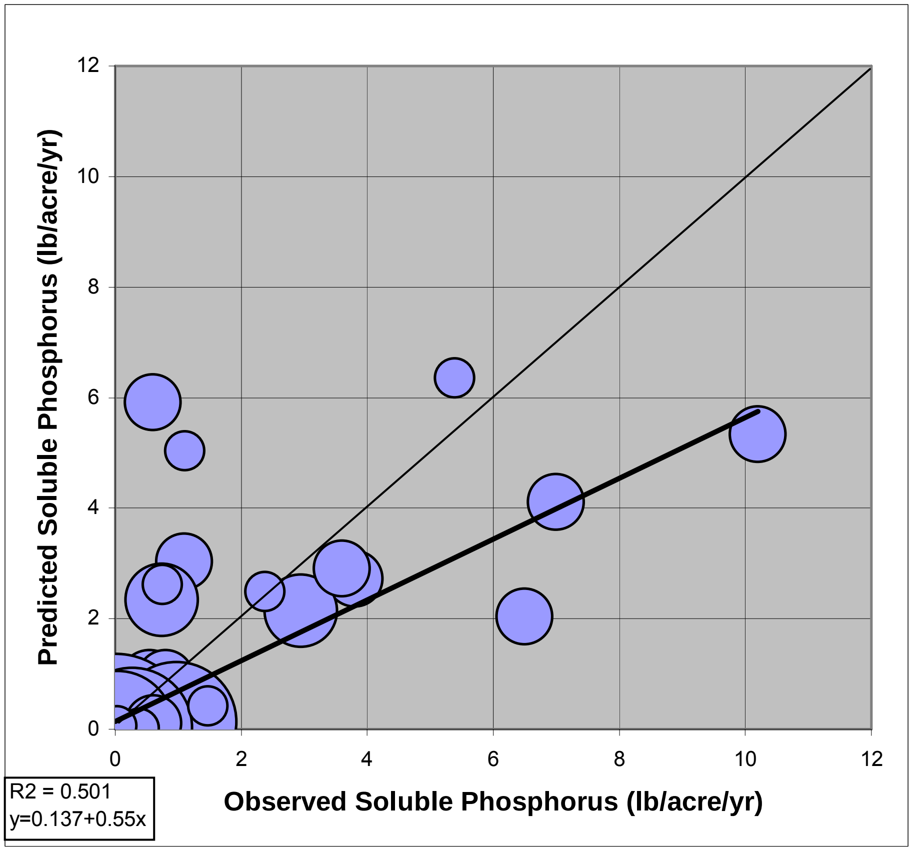


Figure 5.10 Soluble P comparisons at calibration sites with default values of percolation coefficient (PPERCO) and phosphorus soil partitioning coefficient (PHOSKD) using the calibration dataset. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Field Scale Validation

Validation is the process of testing a model with data not used in the calibration or development of the model. The original intent was to calibrate PPM Plus using half of the available field scale data and validate the model with the remaining half. Note that PPM Plus was evaluated against the calibration portion of the field dataset, but no parameter adjustments were made. Therefore, the model was not calibrated at the field scale. However, PPM Plus was calibrated at the basin scale prior to the field scale evaluation, and those hydrologic parameter values remain unchanged. To optimize the use of available data, field scale data originally designated for calibration were included in the validation of PPM Plus. In addition to the sites listed in Table 5.12, sites from Table 5.10 were used in the validation dataset. A total of 283 field years of data were used in the validation of PPM Plus.

Table 5.12 PPM Plus validation field scale monitoring sites, these data along with data from Table 5.10 were used in the validation.

Field ID	Location	Start Date	End Date	Weight (yr)
Eucha Mundy	Delaware County, OK	5/1/2006	6/30/2007	1.17
Eucha Demo	Delaware County, OK	5/1/2006	6/30/2007	1.17
Eucha Colcord	Delaware County, OK	5/1/2006	6/30/2007	1.17
Eucha Colcord	Delaware County, OK	5/1/2006	6/30/2007	1.17
Riesel W10	McLennan County, TX	1/1/2001	12/31/2001	1
Riesel W10	McLennan County, TX	1/1/2003	12/31/2004	1
Riesel W10	McLennan County, TX	1/1/2005	12/31/2005	1
Riesel SW12	McLennan County, TX	1/1/2001	12/31/2001	1
Riesel SW12	McLennan County, TX	1/1/2003	12/31/2004	1
Riesel SW12	McLennan County, TX	1/1/2005	12/31/2005	1
Riesel SW17	McLennan County, TX	1/1/2001	12/31/2001	1
Riesel SW17	McLennan County, TX	1/1/2003	12/31/2004	1
Riesel SW17	McLennan County, TX	1/1/2005	12/31/2005	1
Riesel Y14	McLennan County, TX	1/1/2001	12/31/2001	1
Riesel Y14	McLennan County, TX	1/1/2003	12/31/2004	1
Riesel Y14	McLennan County, TX	1/1/2005	12/31/2005	1
Riesel Y6	McLennan County, TX	1/1/2002	12/31/2002	1
Riesel Y8	McLennan County, TX	1/1/2002	12/31/2002	1
Riesel Y10	McLennan County, TX	1/1/2002	12/31/2002	1
Riesel Y13	McLennan County, TX	1/1/2002	12/31/2002	1
Riesel W12	McLennan County, TX	1/1/2000	12/31/2000	1
Riesel W12	McLennan County, TX	1/1/2005	12/31/2005	1
Riesel W13	McLennan County, TX	1/1/2002	12/31/2002	1
Moore's Creek 1 (R Litter)	Benton County, AR	9/1/1991	3/30/1994	1.66
Moore's Creek 1 (R Litter)	Benton County, AR	1/1/1993	12/31/1993	0.5
Moore's Creek 2 (R Com N)	Benton County, AR	1/1/1992	12/31/1992	0.5
Moore's Creek 3 (W litter)	Benton County, AR	9/1/1991	3/30/1994	1.66
Moore's Creek 3 (W litter)	Benton County, AR	1/1/1993	12/31/1993	0.5
Moore's Creek 4 (W Com N)	Benton County, AR	1/1/1992	12/31/1992	0.5
Georgia Peach W1 (Excessive)	Peach County, GA	3/1/1995	2/28/1997	2
Georgia Peach W3 (1x Litter)	Peach County, GA	3/1/1995	2/28/1997	2
Georgia Putnam Plot 2	Putnam County, GA	1/1/1996	12/31/1996	1
Georgia Putnam Plot 4	Putnam County, GA	1/1/1996	12/31/1996	1
Georgia Putnam Plot 6	Putnam County, GA	1/1/1996	12/31/1996	1
elrenoFR1	Canadian County, OK	1/1/1977	12/31/1980	1.33
elrenoFR2	Canadian County, OK	1/1/1977	12/31/1980	1.33
elrenoFR3	Canadian County, OK	1/1/1977	12/31/1980	1.33
elrenoFR4	Canadian County, OK	1/1/1977	12/31/1989	5.83
elrenoFR6	Canadian County, OK	1/1/1977	12/31/1978	2
elrenoFR7	Canadian County, OK	1/1/1977	12/31/1978	2
elrenoFR8	Canadian County, OK	1/1/1984	12/31/1988	2.5
elrenoE1	Canadian County, OK	1/1/1977	12/31/1992	8.84
elrenoE3	Canadian County, OK	1/1/1977	12/31/1992	8.84
elrenoE6	Canadian County, OK	1/1/1979	12/31/1992	11.5
elrenoE8	Canadian County, OK	1/1/1979	12/31/1992	11.5
Woodwardw2	Woodward County, OK	1/1/1977	12/31/1992	8
Woodwardw4	Woodward County, OK	1/1/1982	12/31/1986	0
Woodwardww1	Woodward County, OK	1/1/1977	12/31/1989	5.83
Woodwardww2	Woodward County, OK	1/1/1977	12/31/1989	5
Woodwardww3	Woodward County, OK	1/1/1977	12/31/1979	3
Woodwardww3	Woodward County, OK	1/1/1982	12/31/1986	2.5
Woodwardww4	Woodward County, OK	1/1/1987	12/31/1989	3
Woodwardnograze	Woodward County, OK	1/1/1977	12/31/1979	3
Woodwardduration	Woodward County, OK	1/1/1980	12/31/1986	7
chickashaC4	Grady County, OK	7/1/1972	6/30/1976	4.5
chickashaC6	Grady County, OK	7/1/1972	6/30/1976	4.5
chickashAR8	Grady County, OK	7/1/1972	6/30/1976	4
chickashaC3	Grady County, OK	7/1/1972	6/30/1973	0.5
chickashaC5	Grady County, OK	7/1/1972	6/30/1973	0.5
chickashaR5	Grady County, OK	5/1/1975	4/30/1976	1
chickashaR6	Grady County, OK	5/1/1975	4/30/1976	0.5

Runoff Volume Validation

PPM was calibrated for hydrology at the basin scale, yet the parameters were only slightly adjusted (ESCO = 0.98, default 0.95). The model simulated surface runoff volume at the field scale data well (R^2 = 0.56), especially given that many sites utilized rainfall data which were collected off site or used offsite data to patch missing data. Observed and predicted surface runoff volumes are given in Figure 5.11. PPM Plus uses surface runoff as predicted by the SWAT model, yet SWAT also predicts lateral flow which may contribute to total water yield especially at the base of slopes. Overall there was an under prediction at higher runoff volumes (slope = 0.67). This may be attributed to the fact that some of the field site data may have measured some of this lateral flow, which would result in PPM Plus under predicting runoff. Other performance metrics include the normalized Objective Function (NOF) and NSE are given in Table 5.13. NOF is the ratio of standard deviation of differences to the overall mean (Fox et al. 2006).

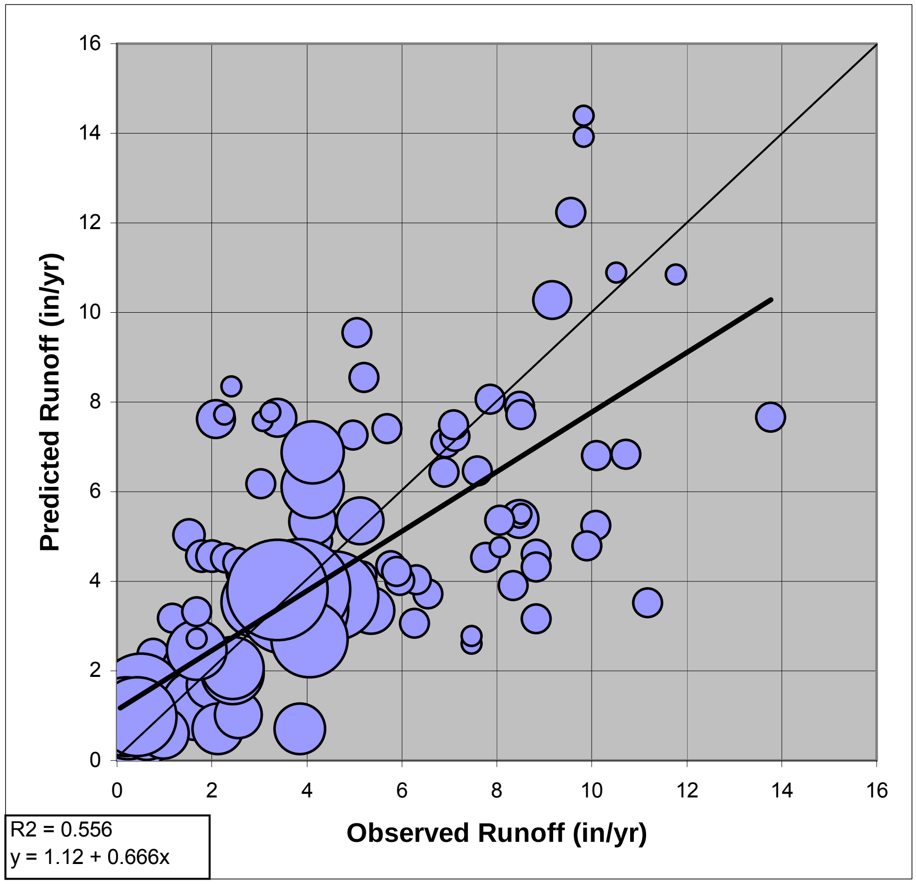


Figure 5.11 Observed and predicted runoff volume for all field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Table 4.13 Performance metrics for comparisons of measured field data and PPM Plus predictions.

Performance Metric	Normalized Objective Function	Nash Sutcliffe Efficiency	Coefficient of Determination	Weighted Adjusted Coefficient of Determination
Total P Load	0.90	0.63	0.67	0.68
Dissolved P Load	1.71	0.42	0.43	0.45
Runoff Volume	0.59	0.45	0.45	0.56
Sediment Load	1.13	0.61	0.71	0.74
Total P Load (Pasture Only)	1.28	0.70	0.72	0.74
Dissolved P Load (Pasture Only)	1.58	0.41	0.42	0.45
Total P Load (Cultivated Only)	0.88	-0.01	0.32	0.26
Dissolved P Load (Cultivated Only)	0.79	0.27	0.48	0.43
Total P Concentration	1.11	0.20	0.43	0.60
Soluble P Concentration	1.31	0.15	0.43	0.45
Soluble P Concentration (Pasture Only)	1.33	0.14	0.41	0.49
Soluble P Concentration (Cultivated Only)*	0.82	-0.20	0.12	--

* No Significant Relationship

Sediment Yield Validation

PPM was not calibrated for sediment at the field or basin scale. The sediment routines of the SWAT model were not modified. The USLE minimum Cropping (C) factor was set to 0.001 from a default value of 0.003 for all grasses during the initial construction of PPM Plus. A USLE minimum C factor value of 0.001 had been used in extensively in previous SWAT modeling studies (Storm et al. 2005b, Storm et al. 2002, Storm et al.

2006c, Storm et al. 2003b). This is a better default value for grasses that has been used prior to the development of PPM Plus.

PPM Plus performed better on sediment than any other constituent (R^2 = 0.742). These data are given in Figure 5.12. The slope of the weighted best fit line was 0.97). It is unlikely that calibration could have improved the default model parameters.

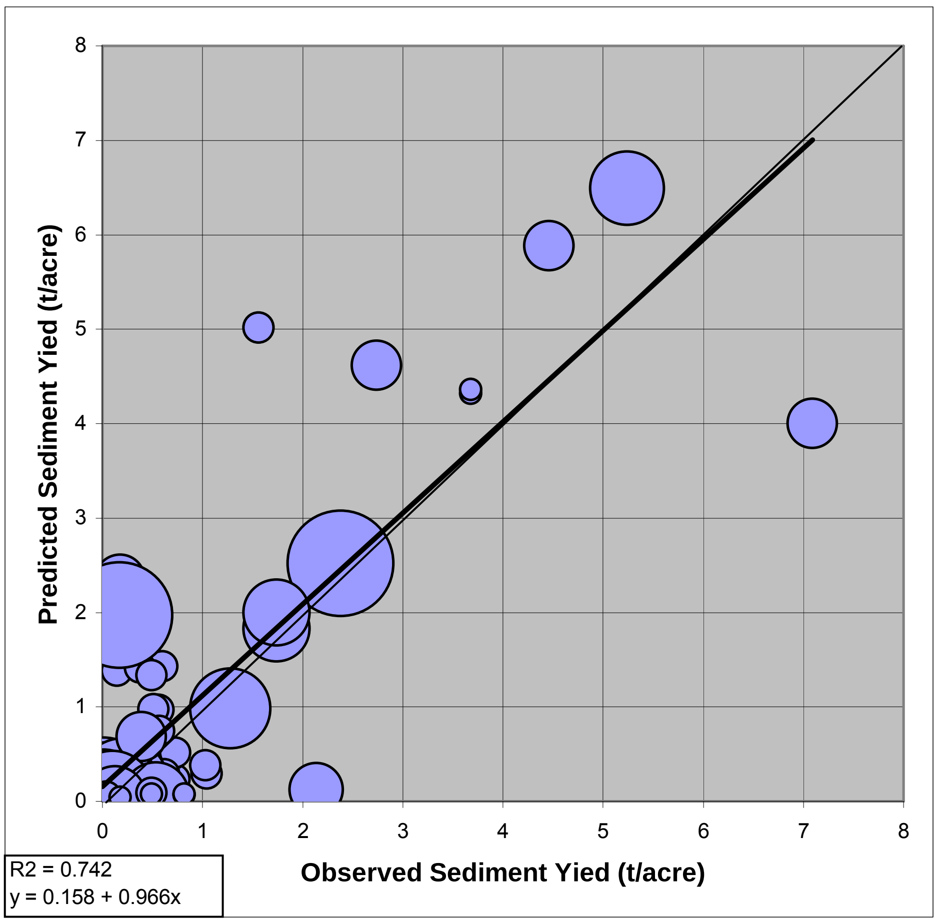


Figure 5.12 Observed and predicted sediment yield at all sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Total P Validation

PPM Plus performed well during the total P validation, especially considering there was no P model calibration. Observed and predicted total P are given in Figure 5.13. The fit of these data was good given the diversity of field data included in this validation. These data are shown on a log-log scale in Figure 5.14 to better visualize scatter at lower values of total P loss. These data are grouped by cultivated and grassland landuses in Figure 5.15. The model performed better in grassland (R^2 0.73) than cultivated (R^2 0.26) sites. One possible explanation is the wide range of management possible with cultivated fields. Accurate tillage, harvesting and planting dates are critical for the prediction of total P. Management for cultivated fields at Riesel, TX was well documented. However, management at the other cultivated sites (Chickasha, Woodward, and El Reno) was far less detailed. Model simulations were grouped by study site in Figure 5.16. Putnam County, Georgia yielded the highest values of total P loss and was most influential in the estimation of statistics like R^2. Visual comparisons confirm that the fit across all values of total P was acceptable.

Total P comparisons were scrutinized to identify possible outliers in the field dataset. Fields with high absolute relative error were examined visually using observed and predicted total P plots. The 5% of the dataset (adjusted for study length) estimated to have the poorest fit is shown in Figure 5.17 and Table 5.14. A total of 11 observations were tagged as possible outliers. These observations tended to be short periods; nine were one year in length. Short study lengths are more variable and more sensitive to changes in management than long term averages. For example, two of the Riesel fields Y14 and W10 received poultry litter for the first time in July of 2001. During the spring of 2001 litter had no influence during spring rainfall when most P is lost. Observed P loss was very small (<0.5 lb/acre, (<0.6 kg/ha)) even though large quantities of poultry litter were applied. In PPM Plus, management is constant from year to year. PPM treated the field as though it received litter the previous July due to the built in two year warm up period, which resulted in a significant over prediction in total P loss. These issues are unavoidable without significantly reducing the data available for validation. Even though they may not be ideal candidates for validation of PPM Plus, they were left in the validation dataset.

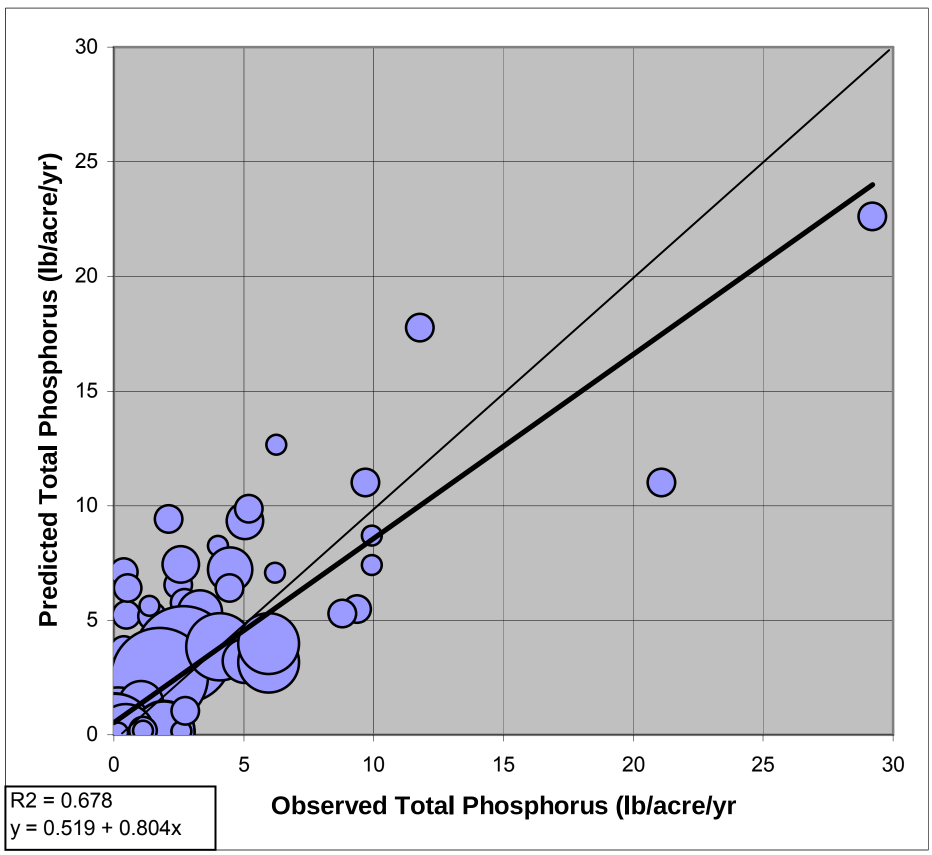


Figure 5.13 Observed and PPM Plus predicted total phosphorus at all field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

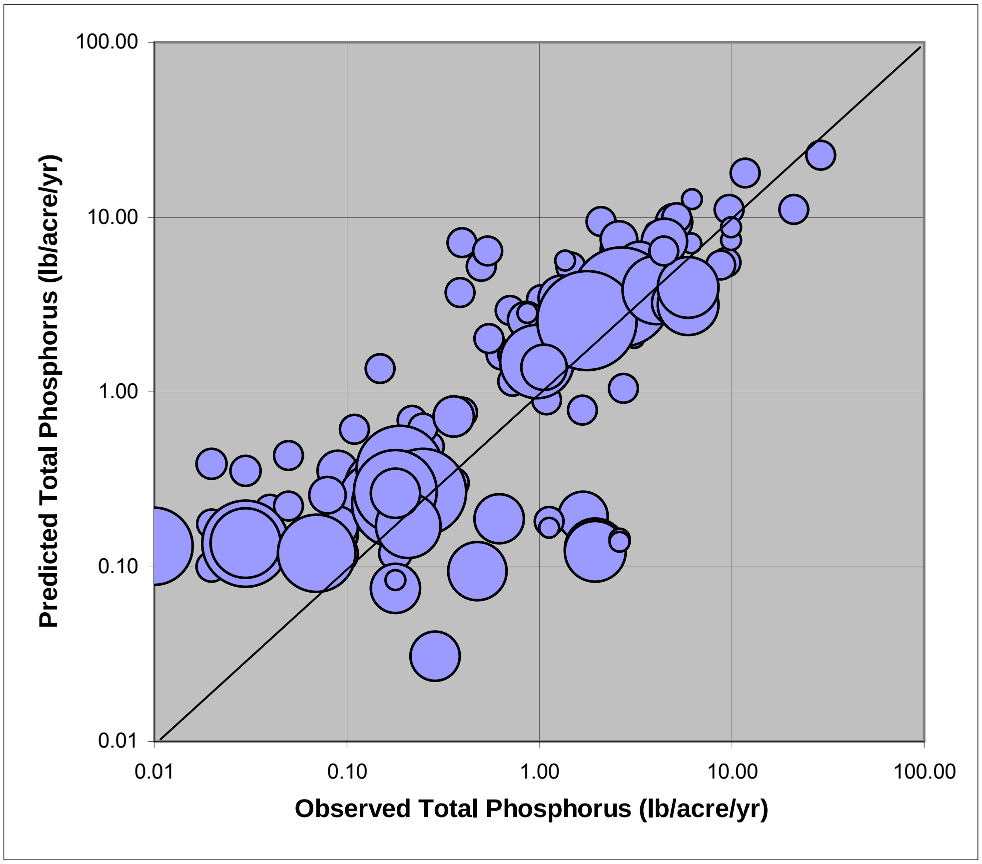
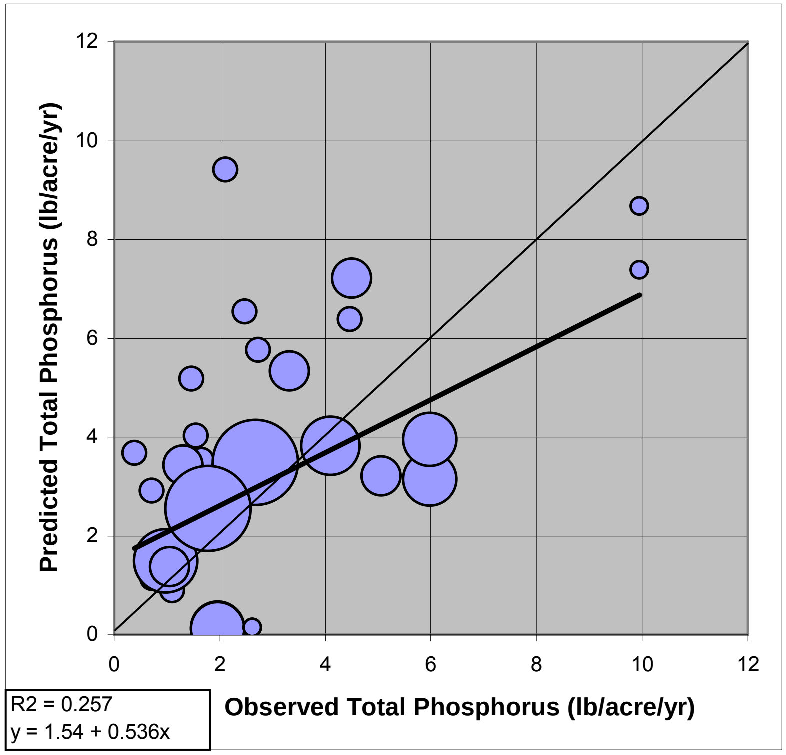


Figure 5.14 Observed and PPM Plus predicted total phosphorus at all field sites. Shown with log-log scaling. Dot size indicates study length adjusted for overlap.



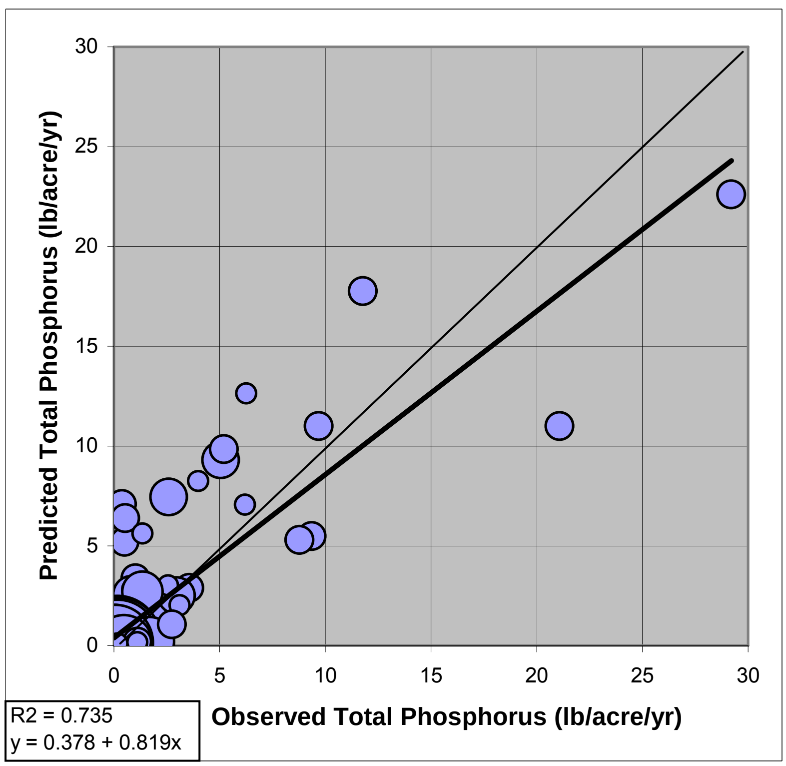


Figure 5.15 Observed and PPM Plus predicted total phosphorus for cultivated (top) and grassland (bottom) field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

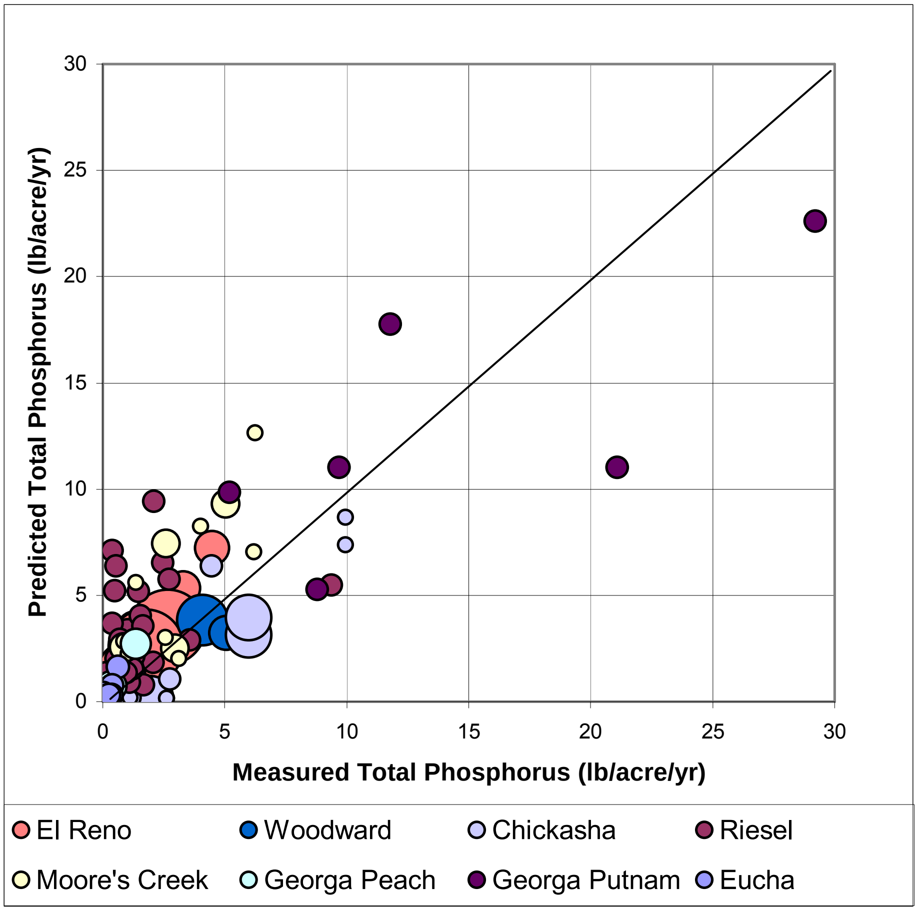


Figure 5.16 PPM Plus predicted and measured total phosphorus loss by study. Includes all field sites. Dot size indicates study length adjusted for overlap.

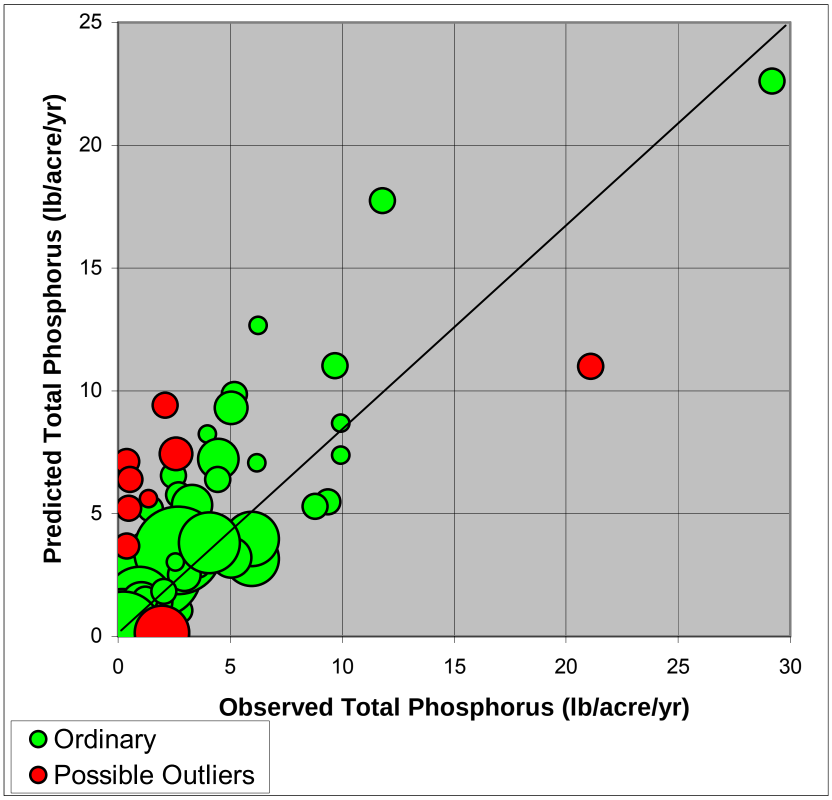


Figure 5.17 Possible outliers in the total phosphorus validation of PPM Plus. Dot size indicates study length adjusted for overlap. Five percent of dataset marked as possible outliers.

Table 5.14 Unusual observations in the total phosphorus validation of PPM Plus.

Filename	Length (yr)	Land Cover	Error (%)
Riesel Y14 2001	1.00	Pasture	-179%
Riesel Y14 2002	1.00	Pasture	-169%
Riesel W10 2001	1.00	Pasture	-165%
Riesel Y8 2002	1.00	Cropland	-127%
Riesel Y6 2000	1.00	Cropland	-162%
Chickasha wheatC61972to73	1.00	Cropland	180%
Chickasha wheatC51972to73	1.00	Cropland	179%
Georga Putnam Plot 4 1996	1.00	Pasture	63%
Moors Creek 3 (W Litter) 1992	1.00	Pasture	-121%
Chickasha wheatC61972to76	4.00	Cropland	177%
Moors Creek 3 (W Litter) Entire	2.66	Pasture	-96%

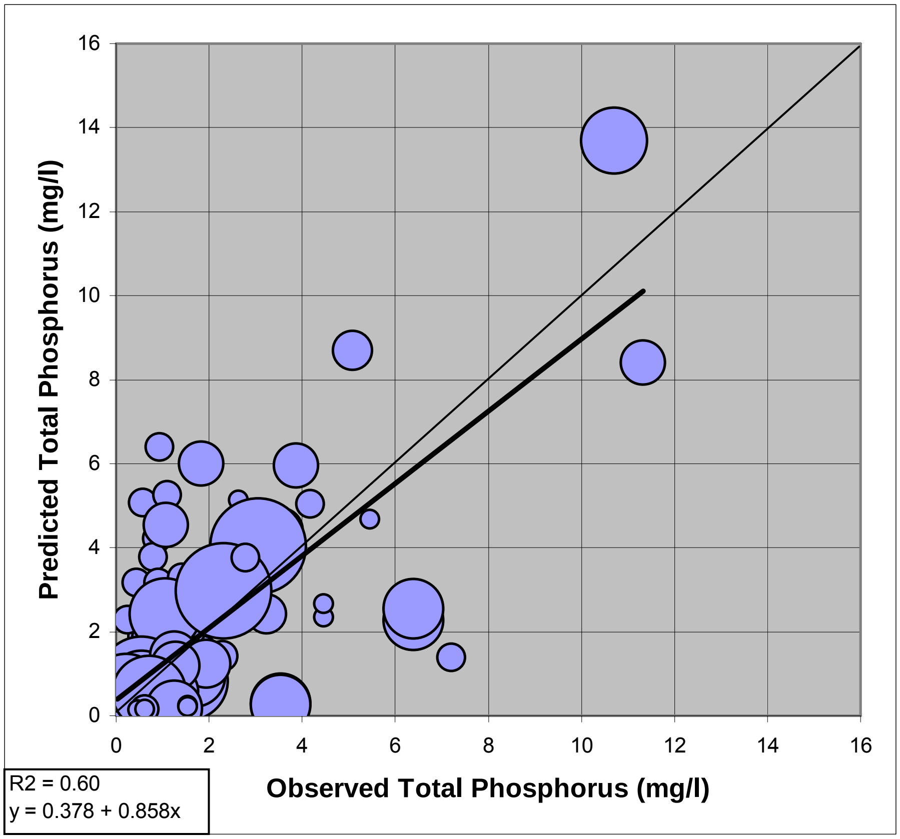


Figure 5.18 Total phosphorus validation based on flow weighted concentration for all field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Soluble P Validation

PPM Plus performed well for the validation of soluble P. The model performed better with total P than soluble P, but the results were still based on a NOF value of 1.7. EPA These results are given in Figure 5.19. There was more scatter with soluble P than total P. Soluble P is not transported in conjunction with sediments, and is less dependant upon erosion as a transport mechanism. The models apparent accuracy in sediment predictions (R^2=0.742) likely contributes significantly to total P performance.

Soluble P was evaluated separately on cultivated and grassland fields in Figure 5.20. There was little difference in fit or slope between cultivated and grassland fields. Soluble P concentration predictions are given in Figure 5.21. Model fit for soluble P as a concentration is given for cultivated and grassland fields separately in Figures 5.22 and 5.23. The model preformed well on grassland sites but there was no significant relationship with soluble P concentrations at cultivated field sites. Soluble P concentration from cultivated sites was approximately one fifth of that from grassland sites. The primary mechanism of P transport from cultivated areas is particulate not soluble.

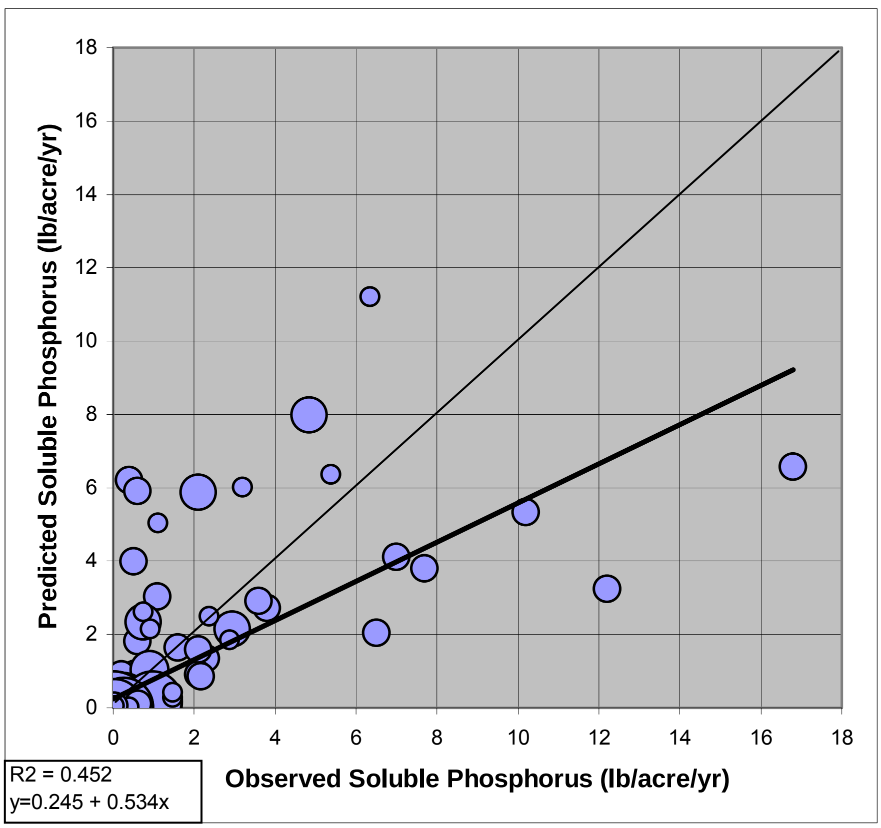
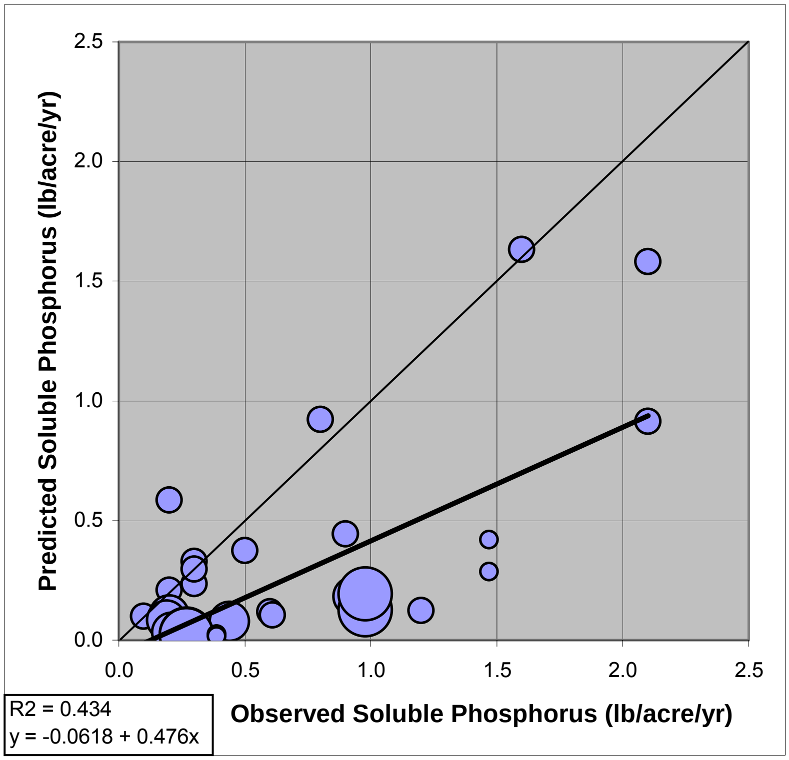


Figure 5.19 Soluble phosphorus validation for all field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.



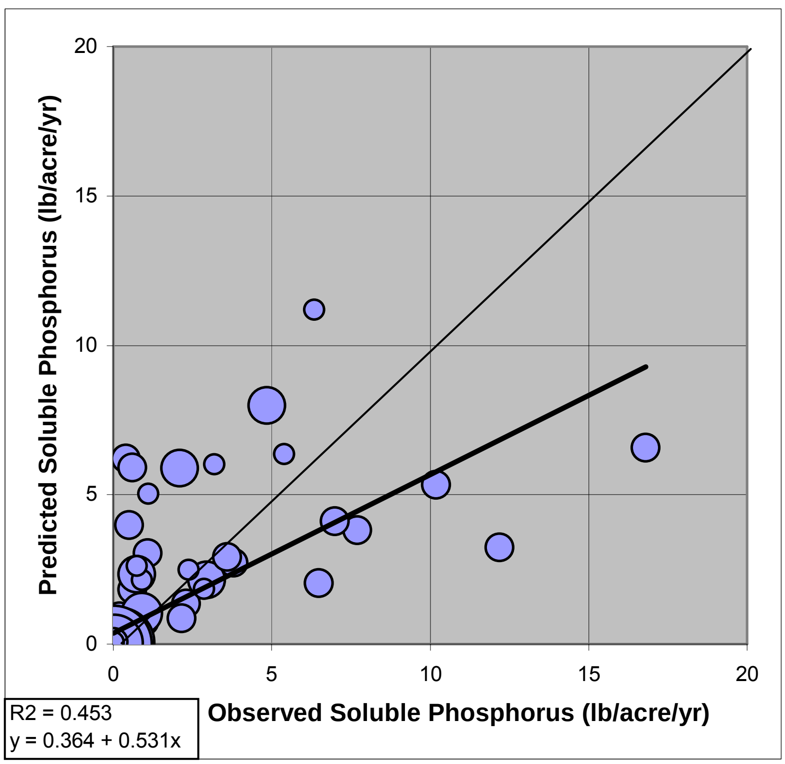


Figure 5.20 Observed and predicted soluble phosphorus for cultivated (top) and grassland (bottom) field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

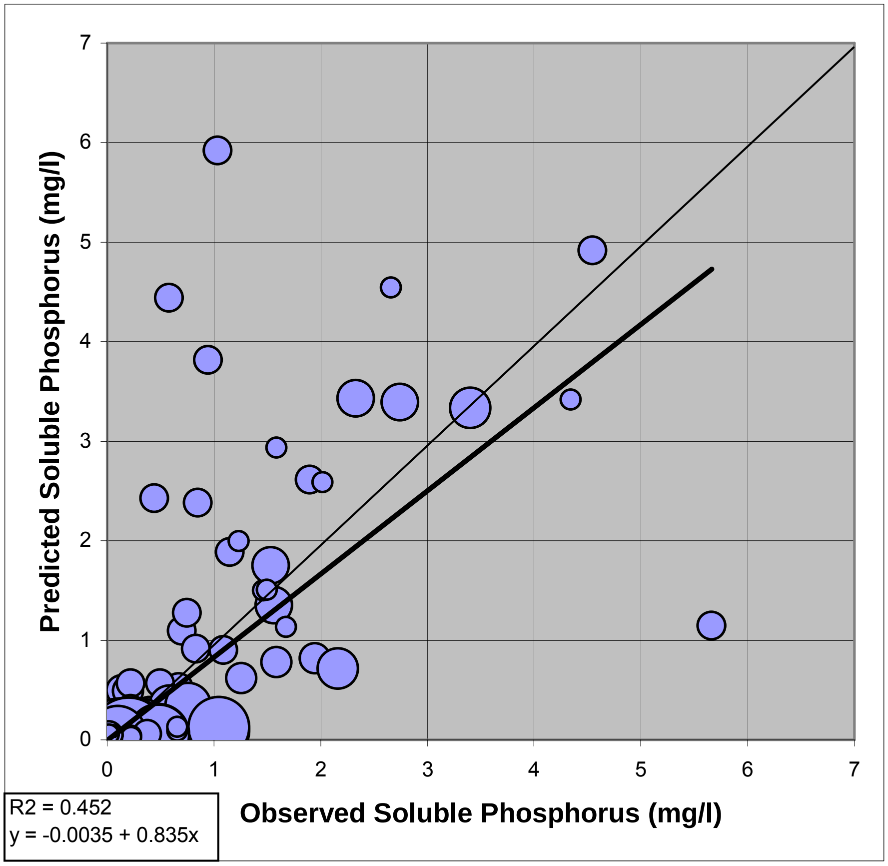


Figure 5.21 Soluble phosphorus validation as concentration for all field sites. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

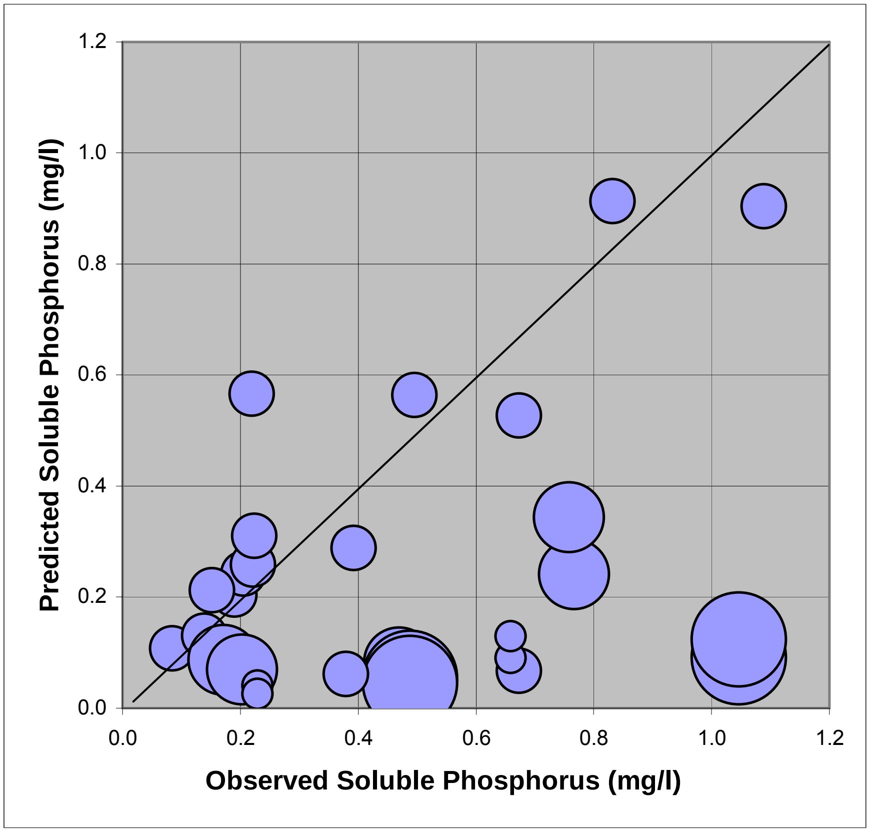


Figure 5.22 Soluble phosphorus validation as concentration for all cultivated sites only. Dot size indicates study length adjusted for overlap. No significant relationship between observed and predicted concentrations.

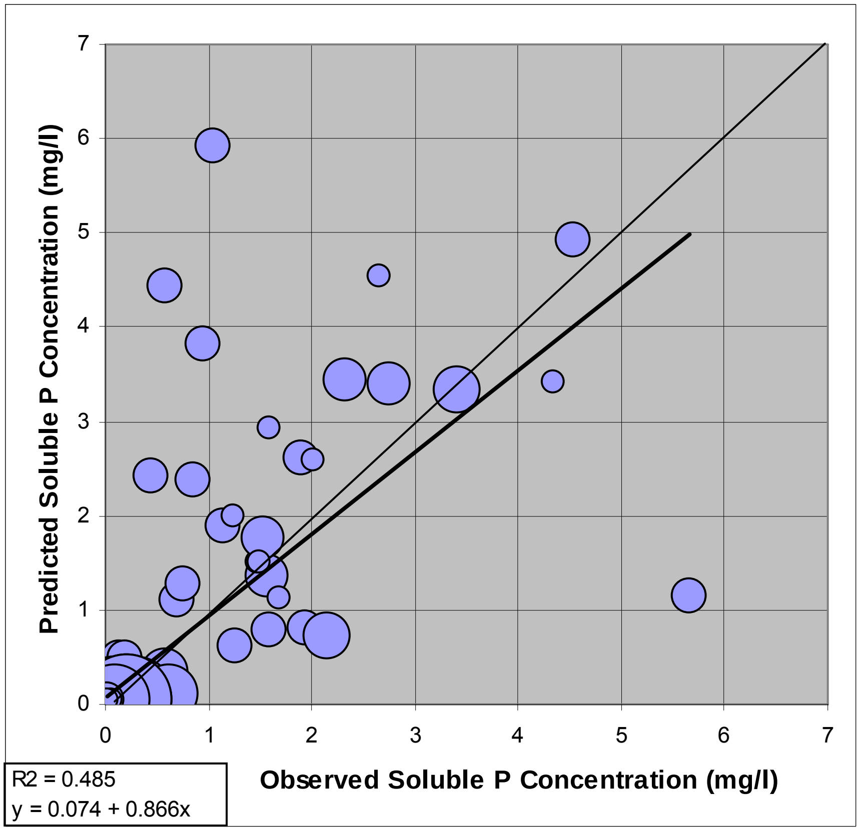


Figure 5.23 Soluble phosphorus validation as concentration for pasture field sites only. Dot size indicates study length adjusted for overlap; regression line is weighted by adjusted study length.

Dataset Variability Evaluation

This validation dataset was extremely diverse in terms of location and management. This diversity was necessary for an honest and comprehensive evaluation of model performance. The goal of this portion of the analysis was to characterize the data used in the validation of PPM Plus in terms of diversity by evaluating how individual field study or site characteristics such as STP or fertilization rates correlate with measured P loss. The significance of these relationships was contrasted with those from other studies. Data collected at a single site often exhibit a high degree of correlation between P loss and some field characteristic or fertilization rate. Harmel et al. (2005) found a high degree of correlation (R^2>0.88) between STP and orthophosphate loss on plots in Riesel, Texas when separated into cultivated and pasture landuses (these data were included in this validation). Gaston et al. (2003) found a good relationship (R^2 0.46 to 0.35) between STP and dissolved P in runoff from pastures in Union Parish, Louisiana. DeLaune et al. (2004b) found a high correlation (R^2>0.66) between soluble P in runoff water and soluble P applied in poultry litter from rainfall simulator studies on pastures in the Lake Eucha/Spavinaw watershed in northwest Oklahoma and northeast Arkansas. Given these rather good correlations, it seems as though the prediction of P loss could be very simple. Why would you need a physically based model when a regression model can explain so much of the observed variability? Unfortunately, the regression model is only good under conditions similar to those where it was developed. Many of the factors which contribute to P loss are similar throughout any study area and need not be exclusively accounted for to accurately predict P loss.

To evaluate the degree of similarity among study sites included in this validation study, these data were examined to identify simple correlations between total P loss and several casual factors. No significant correlation was observed between total P loss and STP both collectively (R^2>0.023, P =0.093) (Figure 5.24) or when separated by cultivated (R^2>0.064, P=0.146) and grassland (R^2>0.037, P=0.073) sites. There was a significant correlation (R^2>0.135, P <0.000) between total P loss and applied P (Figure 5.25), the majority of which was derived from grassland (R^2>0.217, P = 0.000) not cultivated (R^2>0.041, P = 0.248) sites. Applied fertilizer P had the highest correlation found between causal factors and P loss. Slope was not a significant factor in P loss (R^2>0.0008, P=0.760) (Figure 5.26). Precipitation was significant (R^2>0.0765, P=0.002) (Figure 5.27), but the effect could be due to the arrangement of study fields. Fields in higher rainfall regions have higher productivity and are more likely to be heavily fertilized. The combined effect of these four factors (STP, applied P, slope, and precipitation) was estimated through multiple linear regression using Minitab. Collectively these factors can account for only 15% of the variability in these data. P application accounted for the most variability of all factors examined. The difference between the correlations in these data and those reported in studies using data from a single site or group of sites illustrate the diversity present in these validation data. This diversity makes the accuracy assessment of PPM Plus very robust.

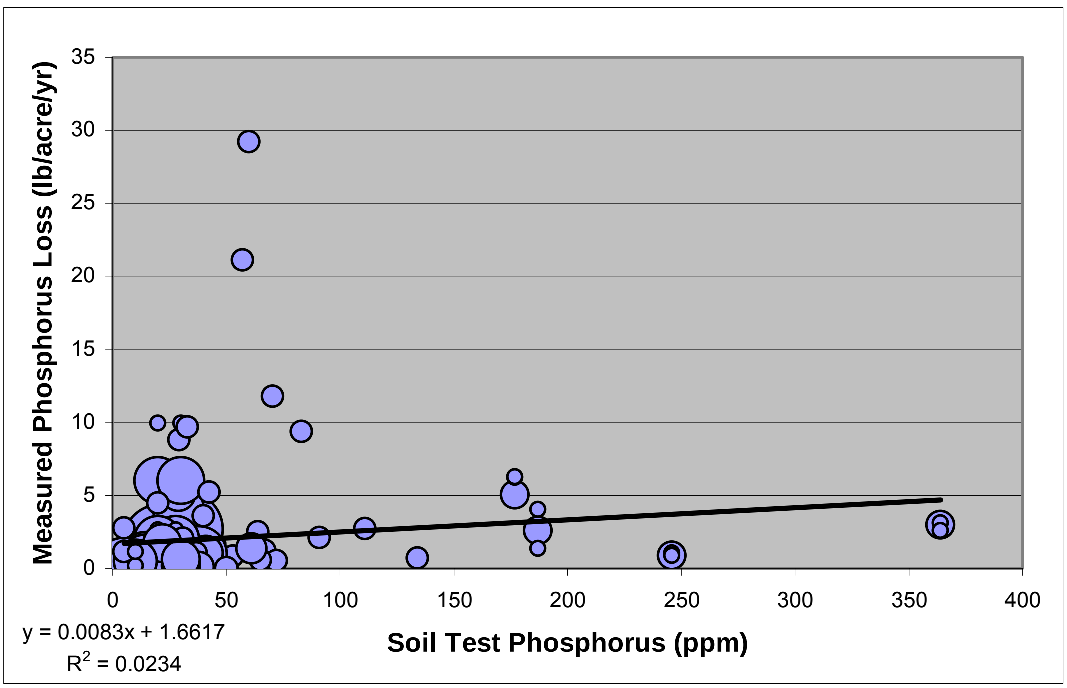


Figure 5.24 Total phosphorus loss as a function of Mehlich III soil test phosphorus at all field sites. Dot size indicates study length adjusted for overlap.

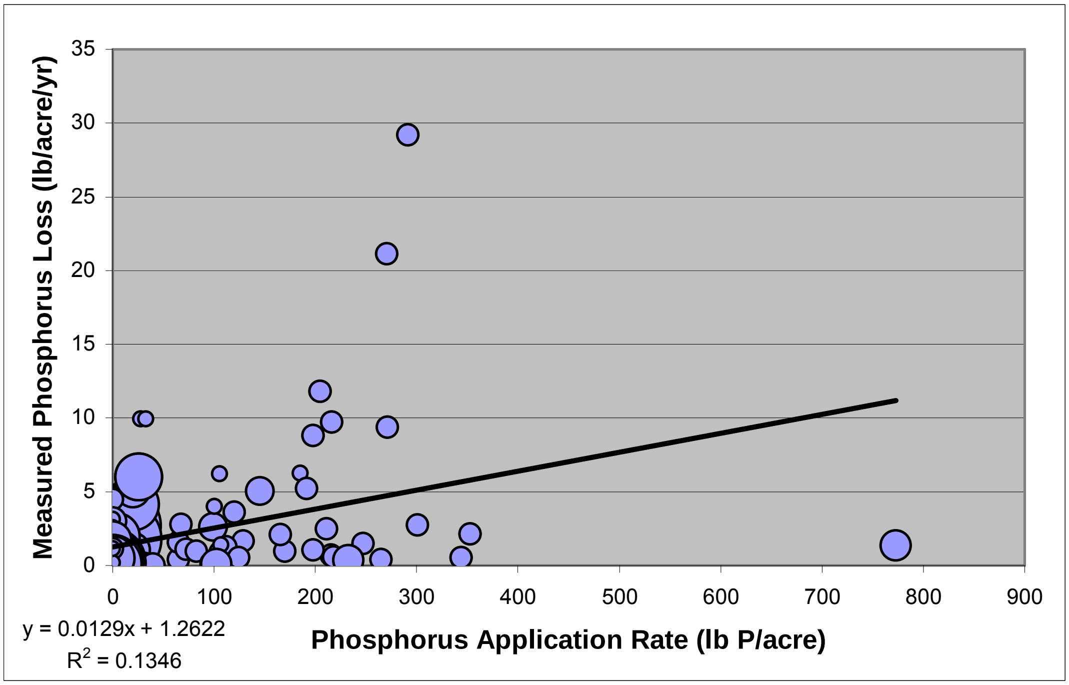


Figure 5.25 Total phosphorus loss as a function of average annual phosphorus fertilization rate at all field sites. Dot size indicates study length adjusted for overlap.

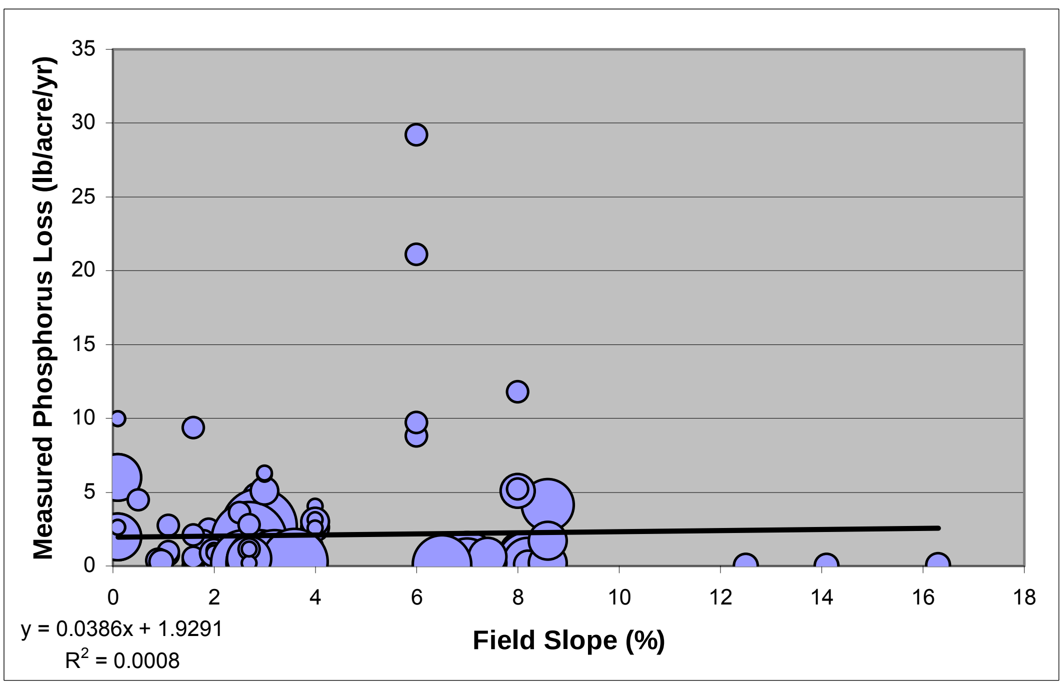


Figure 5.26 Total phosphorus loss as a function of average field slope at all field sites. Dot size indicates study length adjusted for overlap.

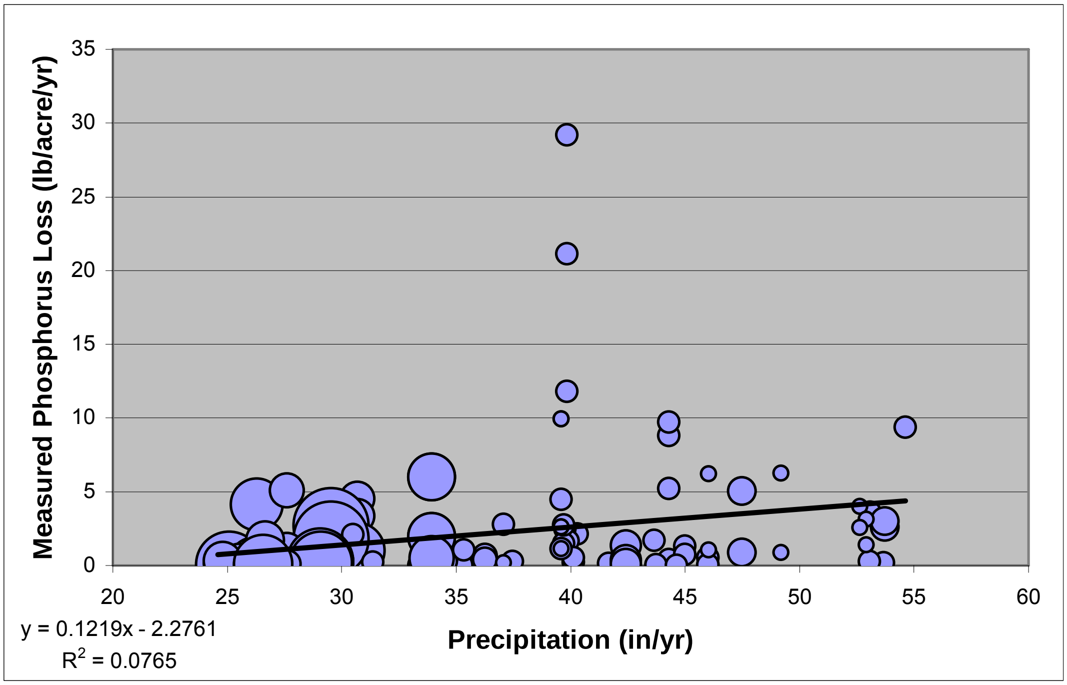


Figure 5.27 Total phosphorus loss as a function of average annual precipitation at all field sites. Dot size indicates study length adjusted for overlap.

Possible Model Limitations

There are several possible model limitations that should be noted. Model 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 neither perfect nor complete. A model by definition is a simplification of the real world. Several possible model limitations are described in the following sections:

Statewide Databases

PPM Plus includes state wide weather and soils data. Soil type is a very important factor in the prediction of P loss. Soil characteristics used in PPM Plus were derived from NRCS databases. Within the NRCS databases soils of the same series were often listed with differing parameter values. Only a single soil from each series and textural classification were included in PPM Plus. The soil parameters used in PPM Plus may not represent the full variability within a single soil series.

Weather is the driving force for any hydrologic model. Only a single weather station was selected to represent each of the nine climate regions for Oklahoma. Within each region, their may be locations with dissimilar climate not properly represented in PPM Plus.

Management Limitations

PPM Plus allows many actions a farmer to be represented in the model. The current version of PPM does not support multiple crops in a single calendar year even though double cropping is a common practice in Oklahoma. Future versions may support double crops on a limited basis. PPM Plus does not consider all possible crops grown in Oklahoma, only the six most common crops were included.

SWAT Surface Manure Application

An important perceived limitation is that SWAT simulates manure applications as simple nutrient additions applied uniformly to the top 10 mm of the soil surface. In reality, manure lies on the soil surface until rainfall moves it into the soil. In the first few rainfall events after application, the manure interacts more directly with surface runoff than simulated by SWAT. This is an often cited limitation of the SWAT model, yet the actual discrepancy in P predictions on an event basis has not been documented in literature.

Unvalidated Model Components

The primary PPM Plus model components, hydrology, erosion and P, were well validated, but the BMP components remain largely unvalidated. The primary validation did include fields with BMPs, primarily contour farming and terracing. BMP efficiencies were compared with literature values informally during model development. Unfortunately, much of the available literature on BMPs do not provide sufficient data to reconstruct the entire study site in PPM Plus. More validation of BMP components could better define the uncertainty in predicted BMP effectiveness.

Although no formal validation of BMP components was performed, process based models like SWAT are often used to estimate BMP effectiveness without validation. While validation is preferable, often little adequate data are available for that purpose. Models are often the tool of choice when data are lacking. Bracmort et al. (2006) used the SWAT model to simulate structural BMPs by modifying appropriate SWAT input parameters. SWAT was used to predict reductions in P and sediment due to BMPs. This SWAT model was calibrated and validated with measured data at the watershed scale with acceptable results. No field scale calibration or validation was performed to examine the effects of individual BMPs. The Wisconsin P Index (a regulatory tool) uses unvalidated total P delivery ratios based on the Agricultural Policy Environmental Extender (APEX) model to attenuate P delivery based on distance to stream (Good and Panuska 2007). Chu et al. (2005) used the SWAT model to simulate the effect of BMPs, again with validation at the watershed level only not at the field level where the BMPs operate. Although additional validation of the BMP components used in PPM Plus would be preferable, process based models are designed for use without validation.

Scaling Issues

SWAT is a basin scale model which PPM Plus uses to make field scale predictions. SWAT was not intended for this purpose, even though it performed well at the field scale with respect to runoff, sediment and P during the validation. The application of the subbasin components to estimate delivery from the field to the stream does not consider the characteristics of the flow path from the edge of the field to the stream.

Edge of Field Validation Data

PPM Plus predicts loads delivered to streams, yet the validation data were collected at the edge of field. The distance to stream was set to zero for all validation simulations, but the subbasin area used internally by PPM when no climate zone is specified is 120 acres (49 ha). Both the distance to stream and this subbasin area have an influence of the MUSLE predicted sediment yield, which in turn influences particulate P. Unfortunately, data were not available to validate PPM Plus loads delivered directly to streams. The significance of this possible limitation is unknown.

Chapter 6

Summary, Conclusions, and Recommended Research

Summary and Conclusions

The primary objective of this research was to put the predictive power of one of our best hydrologic water quality models into the hands of people who make daily farm management decisions which impact water quality. These decisions are often made with little or no knowledge of their true off-site water quality impact. Currently available simplistic BMP assessment tools and P Indices are based on data collected at sites which are often different from the site in question. The accuracy of these tools should be evaluated in the context of the true range of conditions under which they are applied. Comprehensive process based models like SWAT better replicate the physical mechanisms of P loss allowing accurate predictions under a wide range of conditions. SWAT is an excellent engine for a statewide P management tool.

This research demonstrates that a complex model like SWAT can be made simple in application. PPM Plus can be used by conservation planners with little or no training. Models like SWAT are complex; it's a necessity of their function. PPM Plus simplifies the operation of SWAT by translating plain language inputs into SWAT parameters. Decisions and assumptions generally made by a modeler are built into the interface. The use of more process based models allows more accurate assessment of P loss under a wide range of conditions. Traditional P indices were developed as alternatives to models with a focus on simplicity and ease of use. The process of P loss is complex, and limiting the complexity of these tools also limits their ability to accurately predict P loss under diverse conditions. This work simplifies the application of the SWAT model, not the SWAT model itself. There is no reason to limit the complexity within a model when we can limit the complexity associate with application of the model through intelligent interface designs.

PPM Plus can make accurate prediction of P losses from agricultural fields within the state of Oklahoma. PPM Plus was extensively evaluated against measured field P loss data with excellent results and can be used as a P Index or BMP evaluation tool. A tremendous amount of data was used in the validation (283 field years). All of these data were collected under natural rainfall at the field scale. The combined data were very diverse and showed little correlation with any single causal factor with simple linear regression. A process based model, like PPM Plus, was required to explain the variability in these data.

PPM Plus is useful for BMP selection and evaluation. PPM Plus was developed for use by CNMP planners and conservation district personnel. PPM can guide plan developers to select the most effective BMPs based on local conditions. At the same time the total reduction in P loss provided by BMP implementation can be quantified. BMPs effectiveness is currently based on data collected under conditions very different from the site in question; these estimates contain a tremendous amount of uncertainty. Even though the BMP portions of PPM Plus are unvalidated, its predictions are likely far more accurate than the crude BMP efficiencies being used for both BMP selection and program evaluation. PPM Plus could significantly improve both BMP selection and water quality program evaluation.

Recommended Research

Development of Endpoints

Further research is needed prior to implementation as a regulatory tool. PPM Plus still requires an endpoint, which is how much P is too much. The selection of appropriate endpoints is just as important as the P Index itself; it is the combination of the two that determine fertilization or management restrictions. P loss limits can be linked to numeric water quality standards. However, many Oklahoma water quality standards are not numeric. Where numeric standards are not available, endpoints for PPM Plus could be derived from water quality data summarized by ecoregion. Surface waters in different ecoregions have differing sensitivity to P. These endpoints should be recommended ranges with guidance as to the potential water quality impacts. The role of scientist should be to determine the water quality resulting from any particular P limit. The role of scientists is not to determine acceptable water quality for the population. The final endpoint should be selected by decision makers to better represent the values of the people of Oklahoma.

Existing qualitative indices build regulatory limits into the tool itself and in effect set P policy without stakeholder involvement. P Indices are often referred to as P risk indices, a term specifically avoided in this dissertation. The term risk, often associated with P Indices, is poorly used. There is no risk associated with the transportation of P to streams; it will be transported. Any landscape surface which generates runoff will contribute P to streams. The only risk pertains to whether or not there will be water quality impairment. Yet, there is no particular amount or concentration of P specified by the index which results in impaired water quality; no line based in science to cross which defines acceptable from unacceptable. In general, water quality does decline with increasing P concentration, but the very definition of impaired water quality is based in designated uses and societal values. Stakeholders who use the water should ideally decide what impairment means to them. Our job as scientists should be to interpret that condition into a numeric limit, not to define the limit based on our own values. The use of the term risk implies that this numeric limit is already known; it must be if you can define a risk associated with exceeding it and causing an unacceptable negative water quality impact.

Best Management Practice Validation

The validation of PPM Plus was very robust; a great deal of data were used to assess its accuracy. Data for BMP portions of the model were more limited. Some of the validation fields had BMPs in place; these were included in PPM Plus. More extensive validation of the BMP component would add additional reliability and credibility. Each of the BMP components was examined informally to confirm BMP efficiency was in the appropriate range for each BMP. Measured field data needed to make more rigorous BMP comparisons which are compatible with the input requirements of PPM Plus are limited. BMP effectiveness predicted by PPM should be better than using efficiencies established under completely different conditions. Future research should include the addition of more BMPs and further validation of existing BMPs in PPM Plus.

National P Management Tools

Each state in the US has its own method of regulating manure application; the majority of them use the P Index approach. It takes a lot of time and resources to develop 50 different P management tools. A P Index utilizing a physically based model at its core could be used nationally. We have the models to build upon; ARS has over 30 years of development vested in these models. There are plenty of existing data with which to build a national P Index. No additional field scale data are needed if models are used. Field scale P loss monitoring is very expensive and time intensive. The simple empirical design of a qualitative P Index makes it very regionally specific; these indices are applicable only to a relatively narrow range of conditions. This often means that validation data must be collected specifically for each index. There is a tremendous amount of data which have been collected across the US. Harmel et al. (2006) found more than 1,100 agricultural watershed years of data in the published literature. Models are not regionally specific and can utilize this body of existing data in a much more comprehensive validation for a nationwide tool.

The development of PPM Calculator and PPM Plus prove that a complex model can be used to power a quantitative P Index. Models like SWAT are constantly evolving and improve every year. Shortcomings in the P routines of current models can be quickly overcome to produce even better models. The P routines in SWAT were upgraded for use in this study, but additional improvements are justified. Historically, information transfer between P researchers and model developers has been too slow. This adds to the distrust of models by P researchers because they may identify flaws in the P routines. For example, the SWAT model does not simulate manure as a separate layer on the soil surface. Instead, SWAT mixes manure with the top 1 cm of soil. This often cited limitation of these models may or may not be significant or justified. These models are not entirely physically based, processes are lumped and simplifications are made; this does not imply that the results are invalid. These models are sufficiently accurate for the task today, and will continue to improve. There will be challenges in the development of a national P Index, but they can be quickly overcome.

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Appendix A

Phosphorus Management Calculator 1.0

Technical Documentation

Pasture Phosphorus Management (PPM) Calculator

Technical Documentation Version 1.0

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Table of Contents

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 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 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 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 generating model inputs and interpreting model output. By using the physically based SWAT model, the PPM Calculator can accurately simulate a variety of management options and field characteristics.

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 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 and produce erroneous 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 loading based on 15 years of observed weather data. The PPM Calculator is intended to predict long term average phosphorus loads and is not intended to predict a phosphorus load for a specific year in the future. 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 determine management practices that will minimize phosphorus loss from their field.

The PPM Calculator is a quantitative model that is superior to any qualitative Phosphorus Index. A qualitative Phosphorus Index does not accurately predict phosphorus loss, and therefore it is not possible to predict if 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. Although an endpoint is not required to run the PPM Calculator, the endpoint is required to determine the allowable phosphorus load allocation for the pastures 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.

Figure 1. 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).

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.

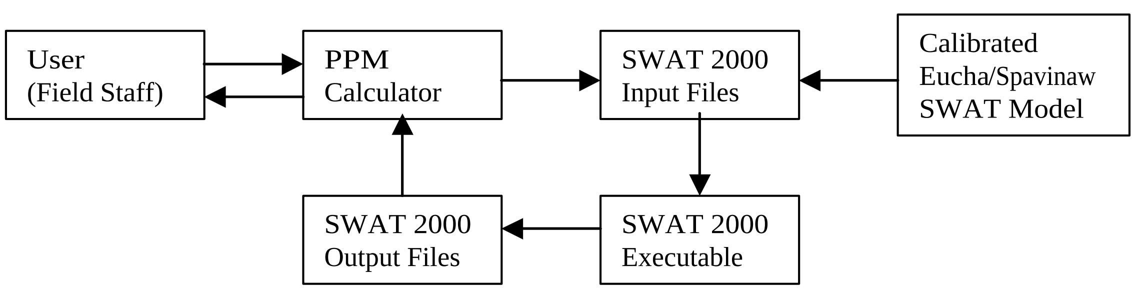

Figure 2. PPM Calculator block diagram.

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.

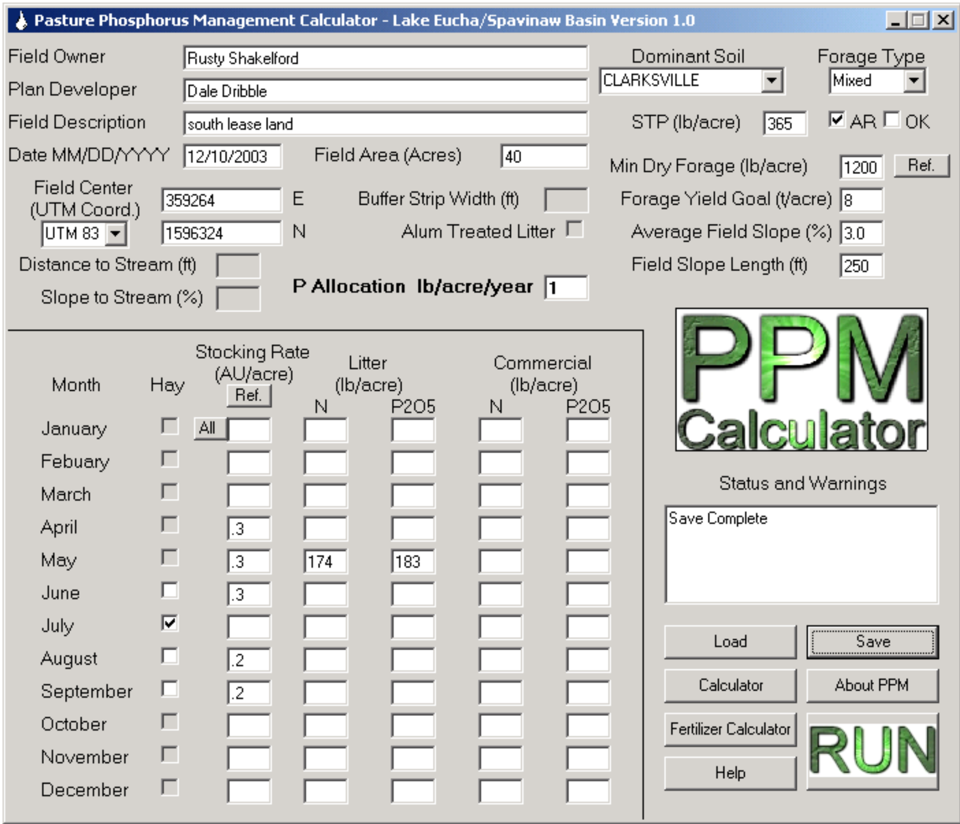

Figure 4. PPM Calculator User Interface Version 1.0. The *P Allocation* input parameter of 1.0 lb/ac/year is used ONLY for demonstration purposes and is not a proposed policy endpoint.

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 Rate (AU/acre)	Litter N ----(Lb/acre)----	Litter P2O5	Commercial N	Commercial P2O5	Precip (in)	Runoff (in)	Sediment (t/acre)	Total Phosphorus (lb/acre)	Available Forage (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 [kg/ha]	Pst in 1st soil layer [kg/ha]	Pst enrichment [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.

General Management Variables

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.
0.2	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

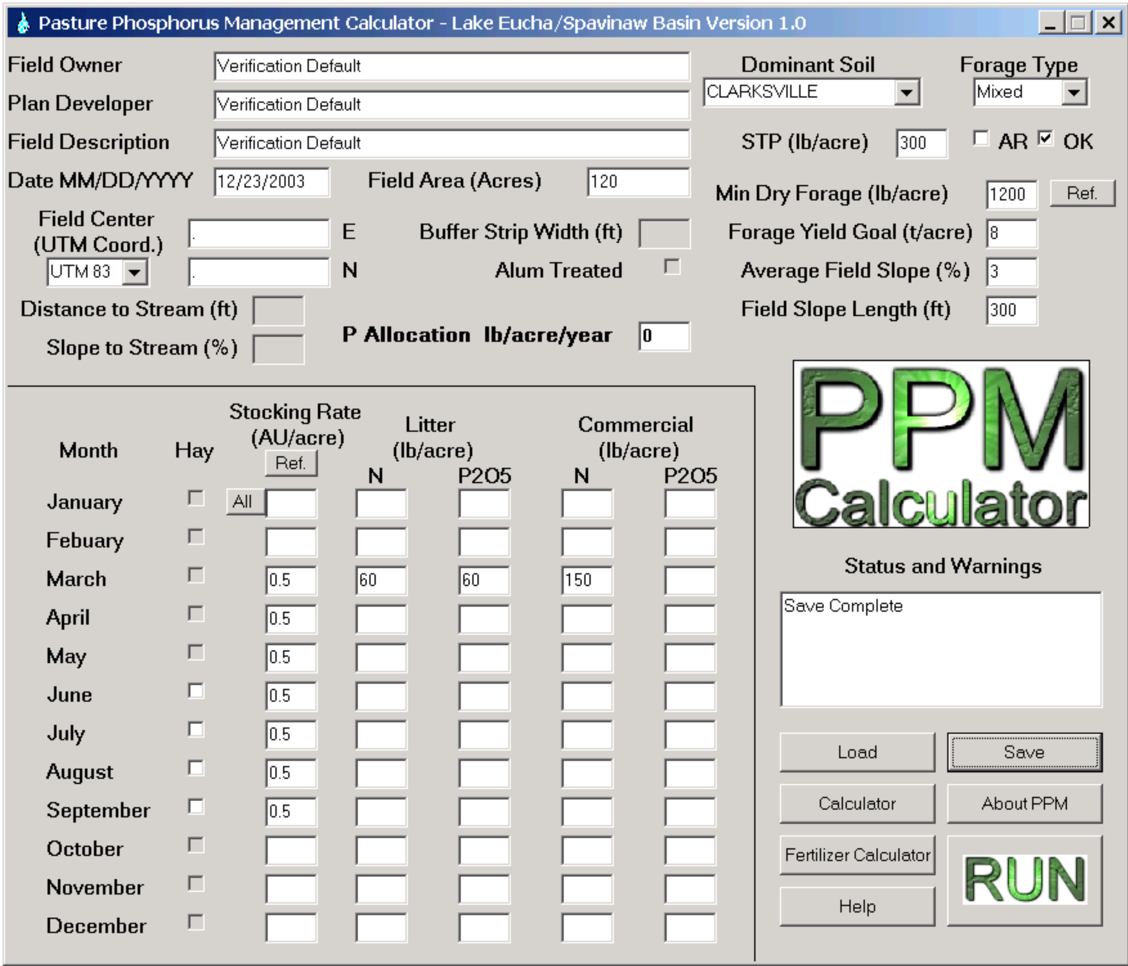

Figure 5 Default values used in verification and sensitivity analysis.

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

Parameter	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	0.00	0.01	0.92
3	4.05	0.91	0.01	0.02	0.93
5	4.05	0.91	0.01	0.03	0.96
10	4.04	0.91	0.04	0.10	1.04
Slope Length (ft)					
100	4.04	0.91	0.00	0.01	0.92
200	4.05	0.91	0.01	0.01	0.93
300	4.05	0.91	0.01	0.02	0.93
400	4.05	0.91	0.01	0.02	0.93
500	4.05	0.91	0.01	0.02	0.93
STP (lb/acre)					
65	4.05	0.73	0.01	0.01	0.75
120	4.05	0.77	0.01	0.01	0.79
300	4.05	0.91	0.01	0.02	0.93
500	4.05	1.06	0.01	0.01	1.09
1000	4.05	1.44	0.01	0.03	1.48
Min Dry Forage (lb/acre)					
400	11.41	2.27	0.44	1.33	4.01
800	4.97	1.07	0.01	0.04	1.12
1200	4.05	0.91	0.01	0.02	0.93
1600	4.02	0.91	0.01	0.02	0.93
2000	4.01	0.91	0.01	0.01	0.94
Litter P205 (lb/acre)					
0	4.05	0.55	0.00	0.01	0.56
60	4.05	0.91	0.01	0.02	0.93
120	4.05	1.27	0.01	0.02	1.30
180	4.05	1.63	0.01	0.03	1.67
240	4.05	1.99	0.02	0.03	2.04
Litter N (lb/acre)					
0	4.72	0.86	0.02	0.04	0.91
60	4.05	0.91	0.01	0.02	0.93
120	4.04	0.99	0.01	0.02	1.01
180	4.06	1.04	0.01	0.02	1.06
240	4.07	1.08	0.01	0.02	1.10
Commercial N (lb/acre)					
0	4.30	0.88	0.01	0.03	0.91
75	4.22	0.90	0.01	0.02	0.93
150	4.05	0.91	0.01	0.02	0.93
175	4.04	0.92	0.01	0.02	0.94
200	4.03	0.93	0.01	0.02	0.95

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

Parameter	Output				
	Runoff (in)	Soluble P (lb/acre)	Organic P (lb/acre)	Sediment P (lb/acre)	Total P (lb/acre)
Commercial P205 (lb/acre)					
0	4.05	0.91	0.01	0.02	0.93
25	4.05	1.13	0.01	0.02	1.15
50	4.05	1.35	0.01	0.02	1.38
75	4.05	1.57	0.01	0.02	1.60
100	4.05	1.78	0.01	0.03	1.82
Max Stocking rate (AU/acre)					
0.0	3.74	0.85	0.01	0.01	0.09
0.3	4.13	0.93	0.01	0.02	0.96
0.5	4.05	0.91	0.01	0.02	0.93
0.8	4.90	1.04	0.03	0.08	1.14
1.0	4.90	1.11	0.03	0.09	1.22
Soil Type					
Okemah (HSG C)	3.40	0.74	0.04	0.09	0.87
Clarksville (HSG B)	4.05	0.91	0.01	0.02	0.93
Dennis (HSG C)	4.07	0.89	0.05	0.11	1.05
Captina (HSG B)	5.31	1.22	0.06	0.14	1.41
Cherokee (HSG D)	6.97	1.59	0.08	0.20	1.88
Carytown (HSG D)	7.03	1.63	0.08	0.19	1.90
Nixa (HSG C)	7.95	1.66	0.00	0.01	1.67
Forage Type					
Warm	4.62	0.97	0.01	0.03	1.00
Cool	4.40	0.94	0.01	0.02	0.97
Mixed	4.05	0.91	0.01	0.02	0.93
Hay					
No hay	4.05	0.91	0.01	0.02	0.93
June	4.78	0.92	0.02	0.06	1.00
July	4.92	0.95	0.02	0.06	1.03
Aug	4.63	0.92	0.02	0.06	1.00
Sept	4.51	0.92	0.04	0.11	1.07
Grazing					
No Grazing	3.74	0.85	0.01	0.01	0.87
May-July	4.04	0.92	0.01	0.02	0.94
Apr - Aug	4.07	0.91	0.01	0.02	0.87
Mar-Sep	4.05	0.91	0.01	0.02	0.93
All year	4.05	0.92	0.01	0.02	0.94
Application Timing					
Once (March)	4.05	0.91	0.01	0.02	0.93
Once(July)	4.24	0.88	0.01	0.02	0.90
Once(October)	4.39	0.84	0.01	0.04	0.89
Twice (Mar/Oct - Split)	4.28	0.91	0.01	0.02	0.94

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	0.000	1.200	1.500	0.042
Slope Length (ft)	0.002	0.000	0.750	0.375	0.008
STP (lb/acre)	0.000	0.250	0.000	0.321	0.252
Min Dry Forage (lb/acre)	-1.370	-1.121	-32.250	-49.500	-2.476
Litter P2O5 (lb/acre)	0.000	0.567	1.000	0.500	0.569
Litter N (lb/acre)	-0.080	0.111	-0.500	-0.500	0.094
Commercial N (lb/acre)	-0.050	0.041	0.000	-0.375	0.032
Commercial P2O5 (lb/acre)	0.000	0.322	0.000	0.250	0.322
Max Stocking Rate (lb/acre)	0.143	0.143	1.000	2.000	0.609

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 Moore's 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 Moore's 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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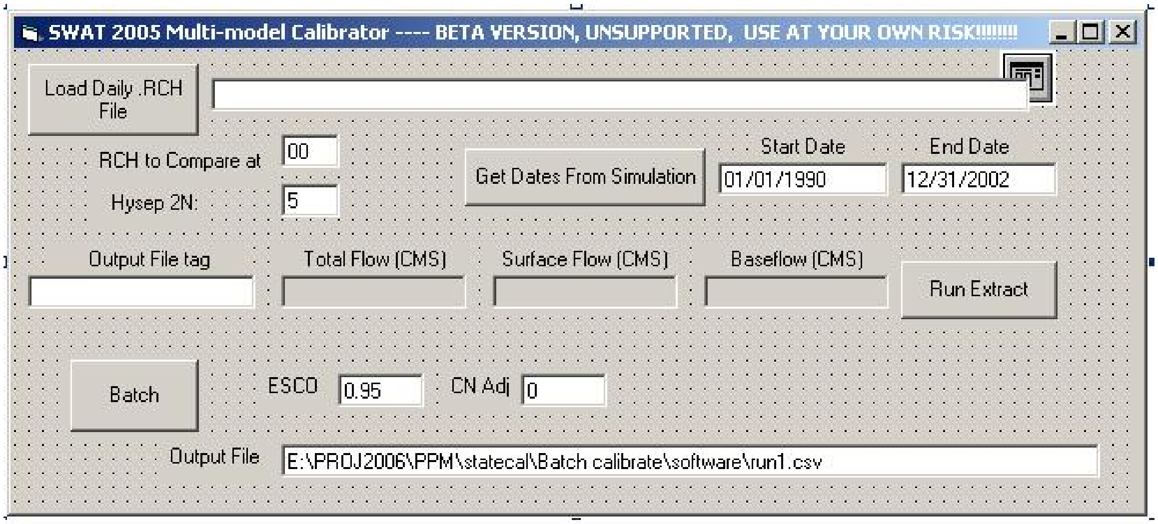
Appendix

Appendices were not included in this dissertation due to length. Full Appendices for this document are available at:
http://biosystems.okstate.edu/home/dstorm/PPM_Calculator/PPM%20Calculator%20Version%201.0%20documentation%2012-31-2003.pdf

Appendix B

Visual Basic Source code

Calibration Program Visual Basic 6 Source code



Form Code

```
Private Declare Function CopyFile Lib "kernel32" Alias "CopyFileA" ()

Sub batch_Click()
Dim cn As Single
Dim esco As Single
For e = 1 To 8
   'For T = 1 To 7
    'If T = 1 Then cn = -8
    'If T = 2 Then cn = -4
    'If T = 3 Then cn = -2
    'If T = 4 Then cn = 0
    'If T = 5 Then cn = 2
    'If T = 6 Then cn = 4
    'If T = 7 Then cn = 8
    cn = -6

    If e = 1 Then esco = 0.8
    If e = 2 Then esco = 0.9
    If e = 3 Then esco = 0.92
    If e = 4 Then esco = 0.94
    If e = 5 Then esco = 0.95
    If e = 6 Then esco = 0.97
    If e = 7 Then esco = 0.98
    If e = 8 Then esco = 1

    Call rungroup(cn, esco)
   'Next T
Next e

End Sub



Private Sub Command3_Click()

' copy all mgt files to mgo files
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fso = CreateObject("Scripting.FileSystemObject")
```

```
Set basin = fso.OpenTextFile("E:\PROJ2006\PPM\statecal\Batch calibrate\basins.txt", 1, TristateFalse)
Do While basin.AtEndOfStream = False 'work on every line in the file
mybasin = basin.readline
   MYDIRECTORY = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\"
    TMPFILE = Dir(MYDIRECTORY, vbNormal + vbHidden + vbReadOnly + vbSystem + vbArchive)
    Do While TMPFILE <> ""
        If LCase(Right(TMPFILE, 3)) = "chm" Then ' found a mgt copy it
        mgofile = Left(TMPFILE, Len(TMPFILE) - 4)
        mgofile = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\" & mgofile & ".cho"
        r = fso.CopyFile("E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\" & TMPFILE, mgofile)
        End If
        TMPFILE = Dir
    Loop
Loop
End Sub

Private Sub Command1_Click()
' copy all mgt files to mgo files
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fso = CreateObject("Scripting.FileSystemObject")
Set basin = fso.OpenTextFile("E:\PROJ2006\PPM\statecal\Batch calibrate\basins.txt", 1, TristateFalse)
Do While basin.AtEndOfStream = False 'work on every line in the file
mybasin = basin.readline
   MYDIRECTORY = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\"
    TMPFILE = Dir(MYDIRECTORY, vbNormal + vbHidden + vbReadOnly + vbSystem + vbArchive)
    Do While TMPFILE <> ""
        If LCase(Right(TMPFILE, 3)) = "chm" Then ' found a mgt copy it
        mgofile = Left(TMPFILE, Len(TMPFILE) - 4)
        mgofile = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\" & mgofile & ".chm"
        r = fso.CopyFile("E:\PROJ2006\PPM\statecal\Batch calibrate\000010001.chm", mgofile)
        End If
        TMPFILE = Dir
    Loop
Loop
End Sub

Private Sub ed_Click()
Call getsimdate
100: End Sub

Private Sub edate_Change()
If IsDate(Form1.edate.Text) = False Then MsgBox "Invalid Date"
End Sub

Private Sub Form_Load()

End Sub

Private Sub ldfile_Click()
On Error GoTo myout
    With c1
        .CancelError = True
        .Filter = "SWAT Generated .Rch File|*.rch"
        .InitDir = App.Path
        .ShowOpen
        myfile = .FileName
    End With
    Form1.simfile.Text = myfile
myout:
End Sub
```

```
Private Sub myrun_Click()
 Call Main
End Sub

Private Sub stdate_Change()
If IsDate(Form1.stdate.Text) = False Then MsgBox "Invalid Date"
End Sub
```

Distiller Module

```
Sub Main()
Form1.Show
If IsNumeric(Form1.rch.Text) = False Then MsgBox "Rch must be numeric": Exit Sub
If Form1.rch.Text < 1 Then MsgBox "Rch must greater than 0": Exit Sub
If Form1.simfile.Text = "" Then MsgBox "Must Select a .rch file to query": Exit Sub
Call distill


End Sub
Sub distill() 'DISTILL rch to only the points intrest to speed up additional queries
Dim holdit() As String
Dim cod(50) As Single
status.Show
DoEvents
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fs = CreateObject("Scripting.FileSystemObject")
' Read comparisons and COD files************************************************************************
Dim comparisons(50, 9) As Variant ' 0 =ID number, 1= RCH to compare at, 2= Constituant
(SP,TP,NO3,SED,Flow), 3= Timestep for camparison (day,mon,year) 4= Obs File name, 5= Sim file
name,6= start day ,7=endday,8 =Stat to report(NSE or RE), weight of stat in final global function
' read comparison file

'open daily data
' open rch for reading open the files as text streams
Call readcod(cod())

rchpath = Form1.simfile.Text
If Dir(rchpath) = "" Then MsgBox "Output.Rch not found": Exit Sub
'get max sub
Set myrch = fs.OpenTextFile(rchpath, ForReading, TristateFalse)
For A = 1 To 9
   rchline = myrch.readline
Next A
For A = 1 To 500
rchline = myrch.readline
reach = Mid(rchline, 7, 4) 'reach number
If maxsub < CInt(reach) Then maxsub = CInt(reach)
Next A
myrch.Close

Set myrch = fs.OpenTextFile(rchpath, ForReading, TristateFalse)
'open the output files for writing
          myoutput = App.Path & "/distill.txt"
          If Dir(myoutput) <> "" Then Kill myoutput
          Open myoutput For Output As #1
'write headder
Print #1, "Date, Flow out"
'start reading the data from the rch file
'skip to the data
For A = 1 To 9
```

```
    rchline = myrch.readline
Next A
rch = CInt(Form1.rch.Text)
stmydate = "1/1/" + CStr(cod(2))
stmydate = CDate(stmydate)
mydate = DateAdd("d", (cod(3) - 1), stmydate)
enddate = DateAdd("yyyy", (cod(1) - 1), stmydate) 'add just for end year
enddate = DateAdd("d", (cod(4) - 1), enddate) 'adjust for ending day of year
stdate = DateAdd("yyyy", cod(6), mydate)
mydate = stdate
'check dates to make sure valid dates are selected
If mydate > CDate(Form1.stdate.Text) Then MsgBox "Start Date out of Simulation Period": Unload status:
myrch.Close: Close #1: Exit Sub
If enddate < CDate(Form1.edate.Text) Then MsgBox "End Date out of Simulation Period": Unload status:
myrch.Close: Close #1: Exit Sub


40: 'start of routing loop
    'calculate completeness
    tdays = DateDiff("d", stdate, enddate)
    currentdate = DateDiff("d", stdate, mydate)
    perdone = currentdate / tdays * 100
    If Round(perdone, 1) = Round(perdone, 0) Then DoEvents
    status.status.Caption = "Distilling SWAT Output " & Format(perdone, "0") & "%"
DoEvents
    ' check to seee if any reches requested are greater than the  maximum reach
    If maxsub < rch Then MsgBox "Compare.txt refrences a rch number that is greater than the maximum
reach in basins.rch": Stop
    'read RCH file
    For A = 1 To maxsub
    'If readrch.atendofstream = True Then MsgBox "Error, Please Rerun SWAT."
        rchline = myrch.readline
        reach = CInt(Mid(rchline, 7, 4)) 'reach number
        'check to see if this is one of my rches
        If rch = reach Then ' this one of mine finsh reading and processing
            flowout = CSng(Mid(rchline, 50, 12)) 'flow out
            Print #1, mydate & "," & Format(flowout, "0.0000")
        End If ' continue if it in not one of my rches
     Next A
     mydate = DateAdd("d", mydate, 1)
If mydate = enddate Then
GoTo 60
Else
GoTo 40
End If
60: Close #1
myrch.Close
Unload status
Call baseflow
End Sub

Sub baseflow()
Dim rch(1, 25000) As Variant '0 = date 1= flow
Dim holdit() As String
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fs = CreateObject("Scripting.FileSystemObject")
status.status.Caption = "Calculating Baseflow/Surface "
DoEvents
myinterval = (CInt(Form1.hysep.Text) - 1) / 2
distillpath = App.Path & "\distill.txt"
Set distilled = fs.OpenTextFile(distillpath, 8, TristateFalse)
maxline = distilled.Line - 2
```

```
distilled.Close
'read distill to array
 Set distilled = fs.OpenTextFile(distillpath, ForReading, TristateFalse)
        distilled.readline 'skip headders
    For A = 1 To maxline
        distillline = distilled.readline
        holdit() = Split(distillline, ",")
        rch(0, A) = CDate(holdit(0))
        rch(1, A) = CSng(holdit(1))
    Next A

' write daily file
    mysurface = 0
    mytotal = 0
    mybase = 0
    mycount = 0
    montotal = 0
    monsurface = 0
    monbase = 0
    mcount = 0
daily = App.Path & "\" & Form1.mytag.Text & "_Daily.csv"
monthly = App.Path & "\" & Form1.mytag.Text & "_Monthly.csv"
annual = App.Path & "\" & Form1.mytag.Text & "_Annual.csv"
Open daily For Output As #1
Open monthly For Output As #2
Open annual For Output As #3
Print #1, "Date,Total Flow (cms),Surface Runoff (cms),Baseflow(cms)"
Print #2, "Date,Total Flow (cms),Surface Runoff (cms),Baseflow(cms)"
Print #3, "Date,Total Flow (cms),Surface Runoff (cms),Baseflow(cms)"
For A = myinterval + 1 To maxline
    'find minimum for this day
    mymin = 100000000
    For q = (A - myinterval) To (A + myinterval)
        If rch(1, q) < mymin Then mymin = rch(1, q)
    Next q

    If rch(0, A) >= CDate(Form1.stdate.Text) And rch(0, A) <= CDate(Form1.edate.Text) Then
        Print #1, rch(0, A) & "," & rch(1, A) & "," & (rch(1, A) - mymin) & "," & mymin
        mysurface = mysurface + (rch(1, A) - mymin)
        mytotal = mytotal + rch(1, A)
        mybase = mybase + mymin
        mycount = mycount + 1
        'monthly section
        montotal = montotal + rch(1, A)
        monsurface = monsurface + (rch(1, A) - mymin)
        monbase = monbase + mymin
        mcount = mcount + 1
        If rch(0, A) = GetMonthEnd(rch(0, A)) Then 'dump data to file at end of month
            Print #2, rch(0, A) & "," & montotal / mcount & "," & monsurface / mcount & "," & monbase / mcount
            montotal = 0
            monsurface = 0
            monbase = 0
            mcount = 0
        End If
        'Annual section
        antotal = antotal + rch(1, A)
        ansurface = ansurface + (rch(1, A) - mymin)
        anbase = anbase + mymin
        ancount = ancount + 1
        mmdd = Format(rch(0, A), "mmdd")
        If mmdd = "1231" Then 'dump data to file at end of year
            Print #3, rch(0, A) & "," & antotal / ancount & "," & ansurface / ancount & "," & anbase / ancount
```

```
        antotal = 0
        ansurface = 0
        anbase = 0
        ancount = 0
      End If



   End If
Next A
Form1.myt.Text = Format((mytotal / mycount), "0.000")
Form1.mys.Text = Format((mysurface / mycount), "0.000")
Form1.myb.Text = Format((mybase / mycount), "0.000")
Close #1
Close #2
Close #3

End Sub


Sub getsimdate() 'DISTILL rch to only the points intrest to speed up additional queries
If Form1.simfile.Text = "" Then MsgBox "Must Select a .rch file to query": Exit Sub
Dim holdit() As String
Dim cod(50) As Single
DoEvents
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fs = CreateObject("Scripting.FileSystemObject")
' Read comparisons and COD files***********************************************************************
Dim comparisons(50, 9) As Variant ' 0 =ID number, 1= RCH to compare at, 2= Constituant
(SP,TP,NO3,SED,Flow), 3= Timestep for camparison (day,mon,year) 4= Obs File name, 5= Sim file
name,6= start day ,7=endday,8 =Stat to report(NSE or RE), weight of stat in final global function
' read comparison file

'open daily data
' open rch for reading open the files as text streams
Call readcod(cod())
stmydate = "1/1/" + CStr(cod(2))
stmydate = CDate(stmydate)
mydate = DateAdd("d", (cod(3) - 1), stmydate)
enddate = DateAdd("yyyy", (cod(1) - 1), stmydate) 'add just for end year
enddate = DateAdd("d", (cod(4) - 1), enddate) 'adjust for ending day of year
stdate = DateAdd("yyyy", cod(6), mydate)
mydate = stdate
Form1.stdate = stdate
Form1.edate = enddate
End Sub


Private Sub readcod(cod() As Single)
Dim mypath As String
mypath = Left(Form1.simfile.Text, Len(Form1.simfile.Text) - 10)
' gets cod properties and returns an array

mypath = mypath + "File.cio"
If Dir(mypath) = "" Then MsgBox "File.cio not found in directory with output.rch file": GoTo 5000
Set fs = CreateObject("Scripting.FileSystemObject")
    'open file and read the data
   Const ForReading = 1, ForWriting = 2, ForAppending = 3
   Set f2 = fs.OpenTextFile(mypath, ForReading, TristateFalse)
   For Y = 1 To 7
   myline = f2.readline 'skip intro
   Next Y
```

```
 For d = 1 To 4
    myline = Mid(f2.readline, 1, 20)
    strresult = Empty
        For i = 1 To Len(myline)
            strCharacter = Mid(myline, i, 1)
            If strCharacter <> " " Then
                 strresult = strresult & strCharacter
            End If
        Next i
   cod(d) = CSng(strresult)
Next d
'skip some more
For Y = 1 To 47
myline = f2.readline 'skip intro
Next Y
For d = 5 To 7
    myline = Mid(f2.readline, 1, 20)
    strresult = Empty
        For i = 1 To Len(myline)
            strCharacter = Mid(myline, i, 1)
            If strCharacter <> " " Then
                 strresult = strresult & strCharacter
            End If
        Next i
   cod(d) = CSng(strresult)
Next d


If cod(5) <> 1 Then MsgBox "Control file indicates simulation is not daily timestep. Please rerun SWAT using a daily timestep."
  'NBYR :  IYR : IDAF :IDAL : IPD :NYSKIP :

5000: End Sub

Private Function GetMonthEnd(ByVal MNum As Date)
GetMonthEnd = DateAdd("d", -1, DateAdd("m", 1, ((Format$(MNum, "mm") & _
   "/01/" & Format$(MNum, "yy")))))
End Function
```

Module 1

```
Private Declare Function OpenProcess Lib "kernel32.dll" (ByVal _
    dwAccess As Long, ByVal fInherit As Integer, ByVal hObject _
    As Long) As Long
Private Declare Function WaitForSingleObject Lib "kernel32" (ByVal _
     hHandle As Long, ByVal dwMilliseconds As Long) As Long
Public Declare Sub Sleep Lib "kernel32" (ByVal dwMilliseconds As Long)
Private Declare Function CloseHandle Lib "kernel32" (ByVal _
     hObject As Long) As Long

Private strName As String
Dim AllFolders As New Collection

Sub executeall()
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fso = CreateObject("Scripting.FileSystemObject")
' this routine runs every swat model
Set basin = fso.OpenTextFile("E:\PROJ2006\PPM\statecal\Batch calibrate\basins.txt", 1, TristateFalse)
Do While basin.AtEndOfStream = False 'work on every line in the file
```

```
    myline = basin.readline
    'execute swat for this basin
    myswat = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & myline & "\swat2005_DEVELOPER.exe"
    ChDir ("E:\PROJ2006\PPM\statecal\Batch calibrate\" & myline & "\")
    LaunchApp32 (myswat)
Loop
basin.Close
End Sub
' Calls other apps and wait for them to finish before continuing
Function LaunchApp32(MYAppname As String) As Integer
 On Error Resume Next
 Const SYNCHRONIZE = 1048576
 Const INFINITE = -1&
 Dim ProcessID&
 Dim ProcessHandle&
 Dim Ret&

 LaunchApp32 = -1
 ProcessID = Shell(MYAppname, vbMinimizedFocus)
   If ProcessID <> 0 Then
      ProcessHandle = OpenProcess(SYNCHRONIZE, True, ProcessID&)
      Ret = WaitForSingleObject(ProcessHandle, INFINITE)
      Ret = CloseHandle(ProcessHandle)
     Else
       MsgBox "ERROR : Unable to start " & MYAppname
       LaunchApp32 = 0
   End If
   DoEvents
End Function
Sub rungroup(cn As Single, esco As Single)
Const ForReading = 1, ForWriting = 2, ForAppending = 3
Set fso = CreateObject("Scripting.FileSystemObject")

Dim mymodel As String
Set fs = CreateObject("Scripting.FileSystemObject")
Open "E:\PROJ2006\PPM\statecal\Batch calibrate\" & esco & "_" & cn & ".csv" For Output As #5

Set basin = fso.OpenTextFile("E:\PROJ2006\PPM\statecal\Batch calibrate\basins.txt", 1, TristateFalse)
Do While basin.AtEndOfStream = False 'work on every line in the file
    mybasin = basin.readline
    mymodel = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin
    ' make the modeifications
    Call modmodel(esco, cn, mymodel)
    'run SWAT
    myswat = "E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\SWATPPM.exe"
    ChDir ("E:\PROJ2006\PPM\statecal\Batch calibrate\" & mybasin & "\")
    LaunchApp32 (myswat)
    ' Read the output
    Form1.simfile.Text = mymodel + "\output.rch"
    Call getsimdate

    If mybasin = "skeleton" Then Form1.hysep.Text = 7
    If mybasin = "sandcrk" Then Form1.hysep.Text = 5
    If mybasin = "bigcabin" Then Form1.hysep.Text = 7
    If mybasin = "spavinaw" Then Form1.hysep.Text = 5
    If mybasin = "illinois" Then Form1.hysep.Text = 7
    If mybasin = "gaines" Then Form1.hysep.Text = 7
    If mybasin = "fourche" Then Form1.hysep.Text = 5
    If mybasin = "leecrk" Then Form1.hysep.Text = 7
    If mybasin = "blbeaver" Then Form1.hysep.Text = 3
    If mybasin = "cobbcrk" Then Form1.hysep.Text = 5
    If mybasin = "mtnfork" Then Form1.hysep.Text = 7
```

```
' get the max reach and call it the outlet
    maxsub = 0
    Set myrch = fs.OpenTextFile(Form1.simfile.Text, ForReading, TristateFalse)
    For A = 1 To 9
        rchline = myrch.readline
    Next A
    For A = 1 To 500
    rchline = myrch.readline
    reach = Mid(rchline, 7, 4) 'reach number
    If maxsub < CInt(reach) Then maxsub = CInt(reach)
    Next A
    myrch.Close
    Form1.rch.Text = maxsub
    Call Main

    Print #5, esco & "," & cn & "," & mybasin & "," & Form1.myt.Text & "," & Form1.mys.Text & "," &
Form1.myb.Text

    'save monthly data to a file for later reading
    sourcefile = "E:\PROJ2006\PPM\statecal\Batch calibrate\software\_Monthly.csv"
    destfile = "E:\PROJ2006\PPM\statecal\Batch calibrate\software\" & mybasin & "_" & esco & "_" & cn &
".csv"
    r = fso.CopyFile(sourcefile, destfile)
Loop
Close #5


End Sub

Sub modmodel(esco As Single, cn As Single, mymodel As String)
' the module sets esco and cn in the entire group of models
Dim mypath
Dim mytitle As String
Dim mytime As String
Dim mydate As String
Dim ipet As Single
Dim EPCO As Single
Dim myfile As String
Dim holdit() As String
'set esco
myfile = mymodel & "\basins.bsn"
'write the Basin file
mytime = Time
mydate = Date
'create title
mytitle = "Created " + mydate + "  " + mytime + "  PPM Plus calibration project"
mypath = mymodel
'kill the old file if it exits
If Dir(myfile) <> "" Then Kill myfile
        ' open/create the textfile
ChDir mypath
Open myfile For Output As #1
'write title
Print #1, Spc(0); mytitle
Print #1, "        Modeling Options: Land Area"
Print #1, "Water Balance:"
Print #1, "          1.000    | SFTMP : Snowfall temperature [ºC]"
Print #1, "          0.500    | SMTMP : Snow melt base temperature [ºC}"
Print #1, "          4.500    | SMFMX : Melt factor for snow on June 21 [mm H2O/ºC-day]"
Print #1, "          4.500    | SMFMN : Melt factor for snow on December 21 [mm H2O/ºC-day]"
Print #1, "          1.000    | TIMP : Snow pack temperature lag factor"
```

```
Print #1, "          1.000    | SNOCOVMX : Minimum snow water content that corresponds to 100% snow
cover [mm]"
Print #1, "          0.500    | SNO50COV : Fraction of snow volume represented by SNOCOVMX that
corresponds to 50% snow cover"
'Et Method
ipet = 0 'Default
Print #1, "          " & formater(ipet, "00000") & "    | IPET: PET method: 0=priest-t, 1=pen-m, 2=har, 3=read
into model"
Print #1, "                   | PETFILE: name of potential ET input file"
'ESCO
Print #1, "          " & formater(esco, "0.000") & "    | ESCO: soil evaporation compensation factor"
'epco
EPCO = 1
Print #1, "          " & formater(EPCO, "0.000") & "    | EPCO: plant water uptake compensation factor"
Print #1, "          3.000    | EVLAI : Leaf area index at which no evaporation occurs from water surface
[m2/m2]"
Print #1, "          0.000    | FFCB : Initial soil water storage expressed as a fraction of field capacity water
content"
Print #1, "Surface Runoff:"
Print #1, "              0    | IEVENT: rainfall/runoff code: 0=daily rainfall/CN"
Print #1, "              0    | ICRK: crack flow code: 1=model crack flow in soil"
Print #1, "          4.000    | SURLAG : Surface runoff lag time [days]"
Print #1, "         1.0000    | ADJ_PKR : Peak rate adjustment factor for sediment routing in the subbasin
(tributary channels)"
Print #1, "         1.0000    | PRF : Peak rate adjustment factor for sediment routing in the main channel"
Print #1, "         0.0010    | SPCON : Linear parameter for calculating the maximum amount of sediment that
can be reentrained during channel sediment routing"
Print #1, "         1.5000    | SPEXP : Exponent parameter for calculating sediment reentrained in channel
sediment routing"
Print #1, "Nutrient Cycling:"
Print #1, "          1.000    | RCN: nitrogen in rainfall (ppm)"
Print #1, "         0.0003    | CMN : Rate factor for humus mineralization of active organic nitrogen"
Print #1, "         20.000    | N_UPDIS : Nitrogen uptake distribution parameter"
Print #1, "         20.000    | P_UPDIS : Phosphorus uptake distribution parameter"
Print #1, "          0.200    | NPERCO : Nitrogen percolation coefficient"
Print #1, "         10.000    | PPERCO : Phosphorus percolation coefficient"
Print #1, "        175.000    | PHOSKD : Phosphorus soil partitioning coefficient"
Print #1, "          0.400    | PSP : Phosphorus sorption coefficient"
Print #1, "          0.050    | RSDCO : Residue decomposition coefficient"

'Write remainder of file as default
Print #1, "Pesticide Cycling:"
Print #1, "          0.500    | PERCOP : Pesticide percolation coefficient"
Print #1, "Algae/CBOD/Dissolved Oxygen:"
Print #1, "              0    | ISUBWQ: subbasin water quality parameter"
Print #1, "Bacteria:"
Print #1, "          0.000    | WDPQ : Die-off factor for persistent bacteria in soil solution. [1/day]"
Print #1, "          0.000    | WGPQ : Growth factor for persistent bacteria in soil solution [1/day]"
Print #1, "          0.000    | WDLPQ : Die-off factor for less persistent bacteria in soil solution [1/day]"
Print #1, "          0.000    | WGLPQ : Growth factor for less persistent bacteria in soil solution. [1/day]"
Print #1, "          0.000    | WDPS : Die-off factor for persistent bacteria adsorbed to soil particles. [1/day]"
Print #1, "          0.000    | WGPS : Growth factor for persistent bacteria adsorbed to soil particles. [1/day]"
Print #1, "          0.000    | WDLPS : Die-off factor for less persistent bacteria adsorbed to soil particles.
[1/day]"
Print #1, "          0.000    | WGLPS : Growth factor for less persistent bacteria adsorbed to soil particles.
[1/day]"
Print #1, "        175.000    | BACTKDQ : Bacteria partition coefficient"
Print #1, "          1.070    | THBACT : Temperature adjustment factor for bacteria die-off/growth"
Print #1, "          0.000    | WOF_P: wash-off fraction for persistent bacteria on foliage"
Print #1, "          0.000    | WOF_LP: wash-off fraction for less persistent bacteria on foliage"
Print #1, "          0.000    | WDPF: persistent bacteria die-off factor on foliage"
Print #1, "          0.000    | WGPF: persistent bacteria growth factor on foliage"
```

```
Print #1, "           0.000    | WDLPF: less persistent bacteria die-off factor on foliage"
Print #1, "           0.000    | WGLPF: less persistent bacteria growth factor on foliage"
Print #1, "                                                         "
Print #1, "Modeling Options: Reaches"
Print #1, "               1    | IRTE: water routing method 0=variable travel-time 1=Muskingum"
Print #1, "           0.000    | MSK_CO1 : Calibration coefficient used to control impact of the storage time
constant (Km) for normal flow"
Print #1, "           3.500    | MSK_CO2 : Calibration coefficient used to control impact of the storage time
constant (Km) for low flow"
Print #1, "           0.200    | MSK_X : Weighting factor controlling relative importance of inflow rate and outflow
rate in determining water storage in reach segment"
Print #1, "               0    | IDEG: channel degradation code"
Print #1, "               0    | IWQ: in-stream water quality: 1=model in-stream water quality"
Print #1, "   basins.wwq       | WWQFILE: name of watershed water quality file"
Print #1, "           0.000    | TRNSRCH: reach transmission loss partitioning to deep aquifer"
Print #1, "           1.000    | EVRCH : Reach evaporation adjustment factor"
Print #1, "               0    | IRTPEST : Number of pesticide to be routed through the watershed channel
network"
Print #1, "   0                | ICN: Daily curve number calculation method:"
Print #1, "   0.000            | CNCOEF: Plant ET curve number coefficient."
Print #1, "   0.000            | CDN: Denitrification exponential rate coefficient."
Print #1, "   0.000            | SDNCO: Denitrification threshold water content."
Print #1, "   0.000            | BACT_SWF: Fraction of manure applied to land areas that has active colony
forming units."
Print #1, "   0.000            | BACTMX:"
Print #1, "   0.000            | BACTMIN:"
Print #1, " "
Close #1    ' Close file.


' Write the curve number for the model by takeing all existing mgt files and rewriting them changing only the
curve number.
'the original mgt files will be designated with a
 ' find all mgt files in the target directory
  MYDIRECTORY = mymodel & "\"
  Dim MGT(50) As String
  Set fso = CreateObject("Scripting.FileSystemObject")
    TMPFILE = Dir(MYDIRECTORY, vbNormal + vbHidden + vbReadOnly + vbSystem + vbArchive)
    Do While TMPFILE <> ""
      If LCase(Right(TMPFILE, 3)) = "mgo" Then ' found a mgt file READ IT
        Set mymgt = fso.OpenTextFile(MYDIRECTORY & "\" & TMPFILE, 1, TristateFalse)
        Do While mymgt.AtEndOfStream = False 'work on every line in the file
          MGT(mymgt.Line) = mymgt.readline ' write to an array
          maxline = mymgt.Line
        Loop
        mymgt.Close
        ' get orignail CN
        holdit() = Split(MGT(12), "|")
        OCN = CSng(holdit(0))
        newcn = OCN + cn
        MGT(12) = "           " & formater(newcn, "00.00") & "    | CN2: Initial SCS CN II value"
        'write file to new mgt file
        'kill old mgt file
        myfile = Left(TMPFILE, Len(TMPFILE) - 4)
        myfile = mymodel & "\" & myfile & ".mgt"

        ' write a new file
        Open myfile For Output As #1
        For A = 2 To maxline
          Print #1, MGT(A)
        Next A
        Close #1
```

```
        End If
        TMPFILE = Dir
    Loop


End Sub


Function formater(mikesvalue, myformat)
' function to format output values for .mgt files
Dim myout As String
Dim char(10) As String
Dim A As Integer
Dim b As String
If mikesvalue = "empty" Then mikesvalue = 0
If mikesvalue = "null" Then mikesvalue = 0
If mikesvalue = "" Then mikesvalue = 0
myout = Format(mikesvalue, myformat)
For A = 1 To 10
char(A) = Mid(myout, A, 1)
If char(A) = "0" Then
Mid(myout, A, 1) = " "
Else
b = "quit"
End If
If char(A) = "." Then
Mid(myout, (A - 1), 1) = "0"
b = "quit"
End If
If char(A) = "" Then
Mid(myout, (A - 1), 1) = "0"
End If
If b = "quit" Then A = 10
Next A
formater = myout
End Function
```

Soil File (.SOL) Generator Source Code

```
Sub Main()
orders = Command ' (syntax in, out,file)
If Command = "" Then
orderme.Show
'orders = App.Path & "\MOD_DBF," & App.Path & ",ALL"
Else
Call main2(orders)
End If
End Sub
Sub main2(orders)
Dim holdit() As String
holdit() = Split(orders, ",")
myinpath = holdit(0)
myoutpath = holdit(1)
MYFILE = UCase(holdit(2))
If MYFILE = "MGT" Then Call makemgt(myinpath, myoutpath): mymake = 1
If MYFILE = "FERT" Then Call makeFERT(myinpath, myoutpath): mymake = 1
If MYFILE = "CROP" Then Call makeCROP(myinpath, myoutpath): mymake = 1
If MYFILE = "BSN" Then Call makebsn(myinpath, myoutpath): mymake = 1
If MYFILE = "SOL" Then Call makesol(myinpath, myoutpath): mymake = 1
If MYFILE = "PND" Then Call makepnd(myinpath, myoutpath): mymake = 1
If MYFILE = "RTE" Then Call makerte(myinpath, myoutpath): mymake = 1
If MYFILE = "HRU" Then Call makeHRU(myinpath, myoutpath): mymake = 1
If MYFILE = "CHM" Then Call makechm(myinpath, myoutpath): mymake = 1
If MYFILE = "SUB" Then Call makeSUB(myinpath, myoutpath): mymake = 1
If MYFILE = "GW" Then Call makegw(myinpath, myoutpath): mymake = 1
If MYFILE = "ALL" Then
Call makemgt(myinpath, myoutpath): mymake = 1
Call makeFERT(myinpath, myoutpath)
Call makeCROP(myinpath, myoutpath)
Call makebsn(myinpath, myoutpath)
Call makesol(myinpath, myoutpath)
Call makepnd(myinpath, myoutpath)
Call makerte(myinpath, myoutpath)
Call makeHRU(myinpath, myoutpath)
Call makechm(myinpath, myoutpath)
Call makeSUB(myinpath, myoutpath)
Call makegw(myinpath, myoutpath)
End If
If mymake <> 1 Or myinpath = "" Or myoutpath = "" Then MsgBox "Called without proper arguements"
Unload Status
End Sub
Sub makesol(myinpath, myoutpath)
 mcheck = myinpath & "\sol.dbf"
 If Dir(mcheck) = "" Then MsgBox "Cannot find " & mcheck: Stop
Dim con As Connection
   Dim rs As Recordset
   Set con = New Connection
   Set rs = New Recordset
   Set myn = New Recordset
With con
   .CursorLocation = adUseClient
   .Provider = "Microsoft.Jet.OLEDB.4.0"
   .ConnectionString = "Data Source=" & myinpath & ";" & "Extended Properties=dbase IV;"
   .Open
   rs.Open "sol.dbf", con, adOpenDynamic, adLockBatchOptimistic
   rs.MoveLast
   maxsub = rs.Fields(0)
```

```
    rs.MoveFirst
    'get names
    Status.Show
    Status.Label1.Caption = "Writing Soils (.sol)"
     For p = 1 To rs.RecordCount 'read a line of data and put in into an arrays
 'read a line of data and put in into an arrays
mysub = rs.Fields(0)

Status.PBar.Value = 5
Status.Refresh
myhru = rs.Fields(1)
LULC = rs.Fields(2)
soil = rs.Fields(3)
snam = rs.Fields(4)
nlayers = rs.Fields(5)
hygroup = rs.Fields(6)
zmax = rs.Fields(7)
anion = rs.Fields(8)
crk = rs.Fields(9)
texture = rs.Fields(10)
'read  LINE
Dim sol(10, 12)
For l = 1 To nlayers
    For a = 1 To 12
        z = 10 + a + (l - 1) * 12
        sol(l, a) = rs.Fields(z)
    Next a
Next l
        Dim mytime As String
        mytime = Time
        Dim mydate As String
        mydate = Date
        'create title
        mytitle = "Created " + mydate + "  " + mytime + " AWC + 0.00"

        subf = mysub

        myname = subf + ".sol"
        MYFILE = myoutpath + "\" + myname
        ' open/create the textfile
        ChDir myoutpath
        Open MYFILE For Output As #1
        'write title
        Print #1, Spc(0); mytitle
        Print #1, Spc(0); " Soil Name: " + snam
        Print #1, Spc(0); " Soil Hydrologic Group: " + hygroup
        Print #1, Spc(0); " Maximum rooting depth(m) : " + Format(zmax, "0000.00")
        Print #1, Spc(0); " Porosity fraction from which anions are excluded: " + Format(anion, "0.000")
        Print #1, Spc(0); " Crack volume potential of soil: " + Format(crk, "0.000")
        Print #1, Spc(0); " Texture 1                : " + texture

        Print #1, Spc(0); " Depth                [mm]:";
        For l = 1 To nlayers
        Print #1, formater(sol(l, 1), "000000000.00");
        Next l
        Print #1, ""

                Print #1, Spc(0); " Bulk Density Moist [g/cc]:";
        For l = 1 To nlayers
        Print #1, formater(sol(l, 2), "000000000.00");
        Next l
        Print #1, ""
```

```
        Print #1, Spc(0); " Ave. AW Incl. Rock Frag  :";
    For l = 1 To nlayers
    awc = sol(l, 3) + 0#
    Print #1, formater(awc, "000000000.00");
    Next l
    Print #1, ""
        Print #1, Spc(0); " Ksat. (est.)      [mm/hr]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 4), "000000000.00");
    Next l
    Print #1, ""
        Print #1, Spc(0); " Organic Carbon [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 5), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Clay          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 6), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Silt          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 7), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Sand          [weight %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 8), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Rock Fragments   [vol. %]:";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 9), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Soil Albedo (Moist)      :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 10), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Erosion K                :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 11), "000000000.00");
    Next l
    Print #1, ""
            Print #1, Spc(0); " Salinity (EC, Form 5)    :";
    For l = 1 To nlayers
    Print #1, formater(sol(l, 12), "000000000.00");
    Next l
    Print #1, ""
            Print #1, " "
    Close #1    ' Close file.
 rs.MoveNext
   Next p
   rs.Close
.Close
End With
Unload Status
End Sub

Function formater(mikesvalue, myformat)
```

```
' function to format output values for .mgt files
Dim myout As String
Dim char(10) As String
If mikesvalue = "empty" Then mikesvalue = 0
If mikesvalue = "null" Then mikesvalue = 0
If mikesvalue = "" Then mikesvalue = 0
myout = Format(mikesvalue, myformat)
For a = 1 To 10
char(a) = Mid(myout, a, 1)
If char(a) = "0" Then
Mid(myout, a, 1) = " "
Else
b = "quit"
End If
If char(a) = "." Then
Mid(myout, (a - 1), 1) = "0"
b = "quit"
End If
If char(a) = "" Then
Mid(myout, (a - 1), 1) = "0"
End If
If b = "quit" Then a = 10
Next a
formater = myout
End Function
```

Appendix C

SWAT 2005 Source Code Modifications

subroutine harvestop

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine performs the harvest operation (no kill)

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    auto_eff(:) |none          |fertilizer application efficiency calculated
!!                               |as the amount of N applied divided by the
!!                               |amount of N removed at harvest
!!    bio_hv(:,:,:)|kg/ha        |harvested biomass (dry weight)
!!    bio_ms(:)   |kg/ha         |land cover/crop biomass (dry weight)
!!    bio_yrms(:) |metric tons/ha |annual biomass (dry weight) in the HRU
!!    cnyld(:)    |kg N/kg yield |fraction of nitrogen in yield
!!    cpyld(:)    |kg P/kg yield |fraction of phosphorus in yield
!!    curyr       |none          |current year in simulation
!!    harveff(:,:,:)|none        |harvest efficiency: fraction of harvested
!!                               |yield that is removed from HRU; the
!!                               |remainder becomes residue on the soil
!!                               |surface
!!    hi_ovr(:,:,:)|(kg/ha)/(kg/ha)|harvest index target specified at
!!                               |harvest
!!    hru_dafr(:) |km2/km2       |fraction of watershed area in HRU
!!    hrupest(:)  |none          |pesticide use flag:
!!                               | 0: no pesticides used in HRU
!!                               | 1: pesticides used in HRU
!!    hvsti(:)    |(kg/ha)/(kg/ha)|harvest index: crop yield/aboveground
!!                               |biomass
!!    hvstiadj(:) |(kg/ha)/(kg/ha)|optimal harvest index for specific time
!!                               |during growing season
!!    icr(:)      |none          |sequence number of crop grown within the
!!                               |current year
!!    idc(:)      |none          |crop/landcover category:
!!                               |1 warm season annual legume
!!                               |2 cold season annual legume
!!                               |3 perennial legume
!!                               |4 warm season annual
!!                               |5 cold season annual
!!                               |6 perennial
!!                               |7 trees
!!    idplt(:,:,:)|none          |land cover code from crop.dat
!!    ihru        |none          |HRU number
!!    laiday(:)   |none          |leaf area index
!!    ncut(:)     |none          |sequence number of harvest operation within
!!                               |a year
!!    npmx        |none          |number of different pesticides used in
!!                               |the simulation
!!    nro(:)      |none          |sequence number of year in rotation
!!    nyskip      |none          |number of years output is not printed/
!!                               |summarized
!!    phuacc(:)   |none          |fraction of plant heat units accumulated
!!    plantn(:)   |kg N/ha       |amount of nitrogen in plant biomass
!!    plantp(:)   |kg P/ha       |amount of phosphorus in plant biomass
!!    plt_et(:)   |mm H2O        |actual ET simulated during life of plant
!!    plt_pet(:)  |mm H2O        |potential ET simulated during life of plant
!!    plt_pst(:,:)|kg/ha         |pesticide on plant foliage
!!    pltfr_n(:)  |none          |fraction of plant biomass that is nitrogen
!!    pltfr_p(:)  |none          |fraction of plant biomass that is phosphorus
!!    rwt(:)      |none          |fraction of total plant biomass that is
!!                               |in roots
!!    sol_fon(:,:)|kg N/ha       |amount of nitrogen stored in the fresh
!!                               |organic (residue) pool
!!    sol_fop(:,:)|kg P/ha       |amount of phosphorus stored in the fresh
!!                               |organic (residue) pool
!!    sol_pst(:,:,1)|kg/ha       |pesticide in first layer of soil
!!    sol_rsd(:,:)|kg/ha         |amount of organic matter in the soil
!!                               |classified as residue
!!    wshd_yldn   |kg N/ha       |amount of nitrogen removed from soil in
!!                               |watershed in the yield
!!    wshd_yldp   |kg P/ha       |amount of phosphorus removed from soil in
!!                               |watershed in the yield
!!    wsyf(:)     |(kg/ha)/(kg/ha)|Value of harvest index between 0 and HVSTI
!!                               |which represents the lowest value expected
!!                               |due to water stress
!!    yldanu(:)   |metric tons/ha |annual yield (dry weight) in the HRU
!!    yldkg(:,:,:)|kg/ha         |yield (dry weight) by crop type in the HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    bio_hv(:,:,:)|kg/ha        |harvested biomass (dry weight)
!!    bio_ms(:)   |kg/ha         |land cover/crop biomass (dry weight)
!!    bio_yrms(:) |metric tons/ha |annual biomass (dry weight) in the HRU
!!    laiday(:)   |none          |leaf area index
!!    phuacc(:)   |none          |fraction of plant heat units accumulated
!!    plantn(:)   |kg N/ha       |amount of nitrogen in plant biomass
!!    plantp(:)   |kg P/ha       |amount of phosphorus in plant biomass
!!    plt_pst(:,:)|kg/ha         |pesticide on plant foliage
!!    sol_fon(:,:)|kg N/ha       |amount of nitrogen stored in the fresh
!!                               |organic (residue) pool
!!    sol_fop(:,:)|kg P/ha       |amount of phosphorus stored in the fresh
!!                               |organic (residue) pool
!!    sol_pst(:,:,1)|kg/ha       |pesticide in first layer of soil
!!    sol_rsd(:,:)|kg/ha         |amount of organic matter in the soil
!!                               |classified as residue
!!    tnyld(:,:,:)|kg N/kg yield |modifier for autofertilization target
!!                               |nitrogen content for plant
!!    wshd_yldn   |kg N/ha       |amount of nitrogen removed from soil in
!!                               |watershed in the yield
!!    wshd_yldp   |kg P/ha       |amount of phosphorus removed from soil in
!!                               |watershed in the yield
!!    yldanu(:)   |metric tons/ha |annual yield (dry weight) in the HRU
!!    yldkg(:,:,:)|kg/ha         |yield (dry weight) by crop type in the HRU
```

```
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~
!!    clip        |kg/ha         |yield lost during harvesting
!!    clipn       |kg N/ha       |nitrogen in clippings
!!    clipp       |kg P/ha       |phosphorus in clippings
!!    clippst     |kg pst/ha     |pesticide in clippings
!!    hiad1       |none          |actual harvest index (adj for
water/growth)
!!    j           |none          |HRU number
!!    k           |none          |counter
!!    wur         |none          |water deficiency factor
!!    yield       |kg            |yield (dry weight)
!!    yieldn      |kg N/ha       |nitrogen removed in yield
!!    yieldp      |kg P/ha       |phosphorus removed in yield
!!    yldpst      |kg pst/ha     |pesticide removed in yield
!!    xx          |
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Exp, Min

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~
      use parm

      integer :: j, k
      real :: hiad1, wur, yield, clip, yieldn, yieldp, xx, clipn, clipp
      real :: yldpst, clippst, AboveGBio, AllowYield !! Mike
White Modification

      j = 0
      j = ihru

      hiad1 = 0.
      if (hi_ovr(nro(j),ncut(j),j) > 0.) then
        hiad1 = hi_ovr(nro(j),ncut(j),j)
      else
        if (plt_pet(j) < 10.) then
          wur = 100.
        else
          wur = 0.
          wur = 100. * plt_et(j) / plt_pet(j)
        endif
        hiad1 = (hvstiadj(j) - wsyf(idplt(nro(j),icr(j),j))) *          &
     &      (wur / (wur + Exp(6.13 - .0883 * wur))) +
&
     &      wsyf(idplt(nro(j),icr(j),j))
        if (hiad1 > hvsti(idplt(nro(j),icr(j),j))) then
          hiad1 = hvsti(idplt(nro(j),icr(j),j))
        end if
      end if


!! check if yield is from above or below ground
      yield = 0.
      if (hvsti(idplt(nro(j),icr(j),j)) > 1.001) then
        yield = bio_ms(j) * (1. - 1. / (1. + hiad1))
      else
        yield = (1.-rwt(j)) * bio_ms(j) * hiad1
      endif
      if (yield < 0.) yield = 0.

!! Mike White Modification Set some minimum residual
standing crop after harvest to better simulate hay cutting.

!! Exempt 1000 lb/acre of aboveground biomass from
harvest only operation

      if (hvsti(idplt(nro(j),icr(j),j)) > 1.001) then
!! if below ground yield don't change it
        Alowyield = Yield
      else
!! above ground yield
                  AboveGBio = (1.-rwt(j)) * bio_ms(j)  !!
Above ground biomass
                  Allowyield = aboveGbio - 1000
                  if (Yield > AllowYield) yield =
AllowYield
                  hiad1 = Yield/AboveGBio
      end if
!! Mike White Modification End


!! determine clippings (biomass left behind) and update yield
      clip = 0.
      clip = yield * (1. - harveff(nro(j),ncut(j),j))
      yield = yield * harveff(nro(j),ncut(j),j)
      if (yield < 0.) yield = 0.
      if (clip < 0.) clip = 0.

      if (hi_ovr(nro(j),ncut(j),j) > 0.) then
        !! calculate nutrients removed with yield
        yieldn = 0.
        yieldp = 0.
        yieldn = yield * pltfr_n(j)
        yieldp = yield * pltfr_p(j)
        yieldn = Min(yieldn, 0.9 * plantn(j))
        yieldp = Min(yieldp, 0.9 * plantp(j))
        !! calculate nutrients removed with clippings
        clipn = 0.
        clipp = 0.
        clipn = clip * pltfr_n(j)
        clipp = clip * pltfr_p(j)
        clipn = Min(clipn,plantn(j)-yieldn)
        clipp = Min(clipp,plantp(j)-yieldp)
      else
        !! calculate nutrients removed with yield
        yieldn = 0.
        yieldp = 0.
        yieldn = yield * cnyld(idplt(nro(j),icr(j),j))
        yieldp = yield * cpyld(idplt(nro(j),icr(j),j))
        yieldn = Min(yieldn, 0.9 * plantn(j))
        yieldp = Min(yieldp, 0.9 * plantp(j))
        !! calculate nutrients removed with clippings
        clipn = 0.
        clipp = 0.
        clipn = clip * cnyld(idplt(nro(j),icr(j),j))
        clipp = clip * cpyld(idplt(nro(j),icr(j),j))
        clipn = Min(clipn,plantn(j)-yieldn)
        clipp = Min(clipp,plantp(j)-yieldp)
      endif
      yieldn = Max(yieldn,0.)
      yieldp = Max(yieldp,0.)
      clipn = Max(clipn,0.)
      clipp = Max(clipp,0.)

      !! add clippings to residue and organic n and p
      sol_rsd(1,j) = sol_rsd(1,j) + clip
      sol_fon(1,j) = clipn + sol_fon(1,j)
      sol_fop(1,j) = clipp + sol_fop(1,j)

      !! remove n and p in harvested yield
      plantn(j) = plantn(j) - yieldn - clipn
      plantp(j) = plantp(j) - yieldp - clipp
      if (plantn(j) < 0.) plantn(j) = 0.
      if (plantp(j) < 0.) plantp(j) = 0.

!! adjust foliar pesticide for plant removal
      if (hrupest(j) == 1) then
        do k = 1, npmx
          !! calculate amount of pesticide removed with yield
and clippings
          yldpst = 0.
          clippst = 0.
          if (hvsti(idplt(nro(j),icr(j),j)) > 1.001) then
            yldpst = plt_pst(k,j)
            plt_pst(k,j) = 0.
          else
            yldpst = hiad1 * plt_pst(k,j)
            plt_pst(k,j) = plt_pst(k,j) - yldpst
            if (plt_pst(k,j) < 0.) plt_pst(k,j) = 0.
          endif
          clippst = yldpst * (1. - harveff(nro(j),ncut(j),j))
          if (clippst < 0.) clippst = 0.
          !! add pesticide in clippings to soil surface
```

```
        sol_pst(k,j,1) = sol_pst(k,j,1) + clippst
      end do
    end if

!! calculate modifier for autofertilization target nitrogen
content
    tnyld(nro(j),icr(j),j) = 0.
    tnyld(nro(j),icr(j),j) = (1. - rwt(j)) * bio_ms(j) * pltfr_n(j) * &
    &                                    auto_eff(j)
    if (icr(j) > 1) then
      tnyld(nro(j),icr(j)-1,j) = tnyld(nro(j),icr(j),j)
    else
      tnyld(nro(j),icr(j)+1,j) = tnyld(nro(j),icr(j),j)
    end if

!! summary calculations
    if (curyr > nyskip) then
      wshd_yldn = wshd_yldn + yieldn * hru_dafr(j)
      wshd_yldp = wshd_yldp + yieldp * hru_dafr(j)
      yldkg(nro(j),icr(j),j) = yldkg(nro(j),icr(j),j) + yield + clip
      yldanu(j) = yldanu(j) + (yield + clip) / 1000.

     ! select case (idc(idplt(nro(j),icr(j),j)))
     !   case (3, 6, 7)
     !     bio_hv(nro(j),icr(j),j) = (yield + clip) +
bio_hv(nro(j),icr(j),j)
     !     bio_yrms(j) = bio_yrms(j) + (yield + clip) / 1000.
     !   case default
          bio_hv(nro(j),icr(j),j) = bio_ms(j) + bio_hv(nro(j),icr(j),j)
          bio_yrms(j) = bio_yrms(j) + bio_ms(j) / 1000.
     ! end select
    endif

!! reset leaf area index and fraction of growing season
    xx = 0.
    xx = bio_ms(j)
    if (xx > 0.001) then
      bio_ms(j) = bio_ms(j) - yield - clip
      if (bio_ms(j) < 0.) bio_ms(j) = 0.
      laiday(j) = laiday(j) * bio_ms(j) / xx
      phuacc(j) = phuacc(j) * bio_ms(j) / xx
      rwt(j) = rwt(j) * xx / bio_ms(j)
    else
      bio_ms(j) = 0.
      laiday(j) = 0.
      phuacc(j) = 0.
    endif

!! increment harvest sequence number
    ncut(j) = ncut(j) + 1


    return
    end
```

subroutine grow

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine adjusts plant biomass, leaf area index,
and canopy height
!!    taking into account the effect of water, temperature and
nutrient stresses
!!    on the plant

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units           |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~
!!    blai(:)     |none            |maximum (potential) leaf area
index
!!    auto_nstrs(:)|none           |nitrogen stress factor which
triggers
!!                                 |auto fertilization
!!    bio_e(:)    |(kg/ha)/(MJ/m**2)|biomass-energy ratio
!!                                 |The potential (unstressed) growth
rate per
!!                                 |unit of intercepted photosynthetically
!!                                 |active radiation.
!!    bio_ms(:)   |kg/ha           |land cover/crop biomass (dry
weight)
!!    bio_targ(:,:,:)|kg/ha        |biomass target
!!    chtmx(:)    |m               |maximum canopy height
!!    co2(:)      |ppmv            |CO2 concentration
!!    curyr       |none            |current year of simulation
!!    dlai(:)     |none            |fraction of growing season when
leaf
!!                                 |area declines
!!    ep_day      |mm H2O          |actual amount of
transpiration that occurs
!!                                 |on day in HRU
!!    es_day      |mm H2O          |actual amount of
evaporation (soil et) that
!!                                 |occurs on day in HRU
!!    hru_dafr(:) |km**2/km**2     |fraction of watershed area
in HRU
!!    hru_ra(:)   |MJ/m^2          |solar radiation for the day in
HRU
!!    hvsti(:)    |(kg/ha)/(kg/ha) |harvest index: crop
yield/aboveground
!!                                 |biomass
!!    icr(:)      |none            |sequence number of crop grown
within the
!!                                 |current year
!!    idc(:)      |none            |crop/landcover category:
!!                                 |1 warm season annual legume
!!                                 |2 cold season annual legume
!!                                 |3 perennial legume
!!                                 |4 warm season annual
!!                                 |5 cold season annual
!!                                 |6 perennial
!!                                 |7 trees
!!    idorm(:)    |none            |dormancy status code:
!!                                 |0 land cover growing (not dormant)
!!                                 |1 land cover dormant
!!    idplt(:,:,:)|none            |land cover code from crop.dat
!!    igro(:)     |none            |land cover status code:
!!                                 |0 no land cover currently growing
!!                                 |1 land cover growing
!!    ihru        |none            |HRU number
!!    lai_yrmx(:) |none            |maximum leaf area index for
the year in the
!!                                 |HRU
!!    laiday(:)   |m**2/m**2       |leaf area index
!!    laimxfr(:)  |
!!    leaf1(:)    |none            |1st shape parameter for leaf
area
!!                                 |development equation.
!!    leaf2(:)    |none            |2nd shape parameter for leaf
area
!!                                 |development equation.
!!    nro(:)      |none            |sequence number of year in
rotation
!!    nyskip      |none            |number of years output
summarization
!!                                 |and printing is skipped
!!    olai(:)     |
!!    pet_day     |mm H2O          |potential evapotranspiration
on current day
!!                                 |in HRU
!!    phu_plt(:,:,:)|heat units    |total number of heat units to
bring plant
!!                                 |to maturity
!!    phuacc(:)   |none            |fraction of plant heat units
accumulated
!!    plt_et(:)   |mm H2O          |actual ET simulated during life
of plant
!!    plt_pet(:)  |mm H2O          |potential ET simulated during
life of plant
```

```
!!    strsn(:)    |none           |fraction of potential plant growth
achieved
!!                                |on the day where the reduction is
caused by
!!                                |nitrogen stress
!!    strsp(:)    |none           |fraction of potential plant growth
achieved
!!                                |on the day where the reduction is
caused by
!!                                |phosphorus stress
!!    strstmp(:)  |none           |fraction of potential plant growth
achieved
!!                                |on the day in HRU where the
reduction is
!!                                |caused by temperature stress
!!    strsw(:)    |none           |fraction of potential plant growth
achieved
!!                                |on the day where the reduction is
caused by
!!                                |water stress
!!    t_base(:)   |deg C          |minimum temperature for plant
growth
!!    tmpav(:)    |deg C          |average air temperature on
current day in
!!                                |HRU
!!    vpd         |kPa            |vapor pressure deficit
!!    wac21(:)    |none           |1st shape parameter for
radiation use
!!                                |efficiency equation.
!!    wac22(:)    |none           |2nd shape parameter for
radiation use
!!                                |efficiency equation.
!!    wavp(:)     |none           |Rate of decline in radiation use
efficiency
!!                                |as a function of vapor pressure deficit
!!    wshd_nstrs  |stress units   |average annual number of
nitrogen stress
!!                                |units in watershed
!!    wshd_pstrs  |stress units   |average annual number of
phosphorus stress
!!                                |units in watershed
!!    wshd_tstrs  |stress units   |average annual number of
temperature stress
!!                                |units in watershed
!!    wshd_wstrs  |stress units   |average annual number of
water stress units
!!                                |in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~
!!    bio_ms(:)   |kg/ha          |land cover/crop biomass (dry
weight)
!!    bioday      |kg             |biomass generated on current day
in HRU
!!    cht(:)      |m              |canopy height
!!    hvstiadj(:) |none           |harvest index adjusted for water
stress
!!    lai_yrmx(:) |none           |maximum leaf area index for the
year in the
!!                                |HRU
!!    laimxfr(:)  |
!!    olai(:)     |
!!    phuacc(:)   |none           |fraction of plant heat units
accumulated
!!    plt_et(:)   |mm H2O         |actual ET simulated during life
of plant
!!    plt_pet(:)  |mm H2O         |potential ET simulated during
life of plant
!!    rwt(:)      |none           |fraction of total plant biomass that
is
!!                                |in roots
!!    wshd_nstrs  |stress units   |average annual number of
nitrogen stress
!!                                |units in watershed
!!    wshd_pstrs  |stress units   |average annual number of
phosphorus stress
!!                                |units in watershed
!!    wshd_tstrs  |stress units   |average annual number of
temperature stress
!!                                |units in watershed
!!    wshd_wstrs  |stress units   |average annual number of
water stress units
!!                                |in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~
!!    beadj       |(kg/ha)/(MJ/m**2)|radiation-use efficiency for a
given CO2
!!                                |concentration
!!    delg        |
!!    deltalai    |
!!    f           |none           |fraction of plant's maximum leaf
area index
!!                                |corresponding to a given fraction of
!!                                |potential heat units for plant
!!    ff          |
!!    j           |none           |HRU number
!!    laimax      |none           |maximum leaf area index
!!    par         |MJ/m^2         |photosynthetically active
radiation
!!    reg         |none           |stress factor that most limits plant
growth
!!                                |on current day
!!    ruedecl     |none           |decline in radiation use
efficiency for the
!!                                |plant
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Exp, Max, Min, Sqrt
!!    SWAT: tstr, nup, npup, anfert

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: j
      real :: delg, par, ruedecl, beadj, reg, f, ff, deltalai
      real :: laimax

      j = 0
      j = ihru


       !! plant will not undergo stress if dormant
       if (idorm(j) == 1) return
       idp = idplt(nro(j),icr(j),j)

       !! update accumulated heat units for the plant
       delg = 0.
       if (phu_plt(nro(j),icr(j),j) > 0.1) then
         delg = (tmpav(j) - t_base(idp)) / phu_plt(nro(j),icr(j),j)
       end if
       if (delg < 0.) delg = 0.
       phuacc(j) = phuacc(j) + delg


       !! if plant hasn't reached maturity
       if (phuacc(j) <= 1.) then

        !! compute temperature stress - strstmp(j)
         call tstr

        !! calculate optimal biomass

         !! calculate photosynthetically active radiation
         par = 0.
         par = .5 * hru_ra(j) * (1. - Exp(-ext_coef(idp) *
&
     &        (laiday(j) + .05)))
```

```
        !! adjust radiation-use efficiency for CO2
        beadj = 0.
        if (co2(hru_sub(j)) > 330.) then
          beadj = 100. * co2(hru_sub(j)) / (co2(hru_sub(j)) +
&
    &           Exp(wac21(idp) - co2(hru_sub(j)) *
wac22(idp)))     &
        else
          beadj = bio_e(idp)
        end if

        !! adjust radiation-use efficiency for vapor pressure
deficit
        !!assumes vapor pressure threshold of 1.0 kPa
        if (vpd > 1.0) then
          ruedecl = 0.
          ruedecl = vpd - 1.0
          beadj = beadj - wavp(idp) * ruedecl
          beadj = Max(beadj, 0.27 * bio_e(idp))
        end if

        bioday = beadj * par
        if (bioday < 0.) bioday = 0.

        !! calculate plant uptake of nitrogen and phosphorus
        call nup
        call npup

        !! auto fertilization-nitrogen demand (non-legumes
only)
        select case (idc(idp))
          case (4, 5, 6, 7)
          if (auto_nstrs(j) > 0.) call anfert
        end select

        !! reduce predicted biomass due to stress on plant
        reg = 0.
!       strsw(j) = 1.
!       strsn(j) = 1.
!       strsp(j) = 1.
!       strstmp(j) = 1.
        reg = Min(strsw(j), strstmp(j), strsn(j), strsp(j))
        if (reg < 0.) reg = 0.
        if (reg > 1.) reg = 1.

        if (bio_targ(nro(j),icr(j),j) > 1.e-2) then
          bioday = bioday * (bio_targ(nro(j),icr(j),j) - bio_ms(j)) /
&
    &                             bio_targ(nro(j),icr(j),j)
          reg = 1.
        end if

        bio_ms(j) = bio_ms(j) + bioday * reg
        if (idc(idp) == 7) then
          if (mat_yrs(idp) > 0) then
            rto = float(curyr_mat(j)) / float(mat_yrs(idp))
            biomxyr = rto * bmx_trees(idp)
            bio_ms(j) = Min (bio_ms(j), biomxyr)
          else
            rto = 1.
          end if
        end if

        bio_ms(j) = Max(bio_ms(j),0.)

        !! calculate fraction of total biomass that is in the roots
        rwt(j) = .4 - .2 * phuacc(j)

        f = 0.
        ff = 0.
        f = phuacc(j) / (phuacc(j) + Exp(leaf1(idp)               &
    &             - leaf2(idp) * phuacc(j)))
        ff = f - laimxfr(j)
        laimxfr(j) = f

        !! calculate new canopy height
        if (idc(idp) == 7) then
          cht(j) = rto * chtmx(idp)
        else
          cht(j) = chtmx(idp) * Sqrt(f)
        end if

        !! calculate new leaf area index
        if (phuacc(j) <= dlai(idp)) then
          laimax = 0.
          deltalai = 0.
          if (idc(idp) == 7) then
            laimax = rto * blai(idp)
          else
            laimax = blai(idp)
          end if
          if (laiday(j) > laimax) laiday(j) = laimax
          deltalai = ff * laimax * (1.0 - Exp(5.0 * (laiday(j) -    &
    &               laimax))) * Sqrt(reg)
          laiday(j) = laiday(j) + deltalai
          if (laiday(j) > laimax) laiday(j) = laimax
          olai(j) = laiday(j)
          if (laiday(j) > lai_yrmx(j)) lai_yrmx(j) = laiday(j)
        else
          laiday(j) = olai(j) * (1. - phuacc(j)) /            &
    &               (1. - dlai(idp))
        end if
        if (laiday(j) < 0.) laiday(j) = 0.

        !! calculate plant ET values
        if (phuacc(j) > 0.5 .and. phuacc(j) < dlai(idp)) then
          plt_et(j) = plt_et(j) + ep_day + es_day
          plt_pet(j) = plt_pet(j) + pet_day
        end if

        hvstiadj(j) = hvsti(idp) * 100. * phuacc(j)           &
    &          / (100. * phuacc(j) + Exp(11.1 - 10. *
phuacc(j)))

        !! summary calculations
        if (curyr > nyskip) then
          wshd_wstrs = wshd_wstrs + (1.-strsw(j)) * hru_dafr(j)
          wshd_tstrs = wshd_tstrs + (1.-strstmp(j)) * hru_dafr(j)
          wshd_nstrs = wshd_nstrs + (1.-strsn(j)) * hru_dafr(j)
          wshd_pstrs = wshd_pstrs + (1.-strsp(j)) * hru_dafr(j)
        end if
      end if
    return
    end
```

subroutine simulate

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine contains the loops governing the
modeling of processes
!!    in the watershed

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    biomix(:)   |none          |biological mixing efficiency.
!!                               |Mixing of soil due to activity of
earthworms
!!                               |and other soil biota. Mixing is
performed at
!!                               |the end of every calendar year.
!!    hi_targ(:,:,:)|(kg/ha)/(kg/ha)|harvest index target of cover
defined at
!!                               |planting
!!    icr(:)      |none          |sequence number of crop grown
within the
!!                               |current year
```

```
!!    idaf        |julian date   |beginning day of simulation
!!    idal        |julian date   |ending day of simulation
!!    idplt(:,:,:)|none          |land cover code from crop.dat
!!    igro(:)     |none          |land cover status code:
!!                               |0 no land cover currently growing
!!                               |1 land cover growing
!!    iyr         |none          |beginning year of simulation
!!    mcr         |none          |max number of crops grown per
year
!!    nbyr        |none          |number of years in simulation
!!    ncrops(:,:,:)|
!!    nhru        |none          |number of HRUs in watershed
!!    nro(:)      |none          |sequence number of year in
rotation
!!    nrot(:)     |none          |number of years of rotation
!!    nyskip      |none          |number of years to not print output
!!    phu_plt(:,:,:)|heat units  |total number of heat units to
bring plant
!!                               |to maturity
!!    sub_lat(:)  |degrees       |latitude of HRU/subbasin
!!    tnyld(:,:,:)|kg N/kg yield |modifier for autofertilization
target
!!                               |nitrogen content for plant
!!    tnylda(:,:,:)|kg N/kg yield|estimated/target nitrogen
content of
!!                               |yield used in autofertilization
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    curyr       |none          |current year in simulation
(sequence)
!!    hi_targ(:,:,:)|(kg/ha)/(kg/ha)|harvest index target of cover
defined at
!!                               |planting
!!    hvstiadj(:) |(kg/ha)/(kg/ha)|optimal harvest index for
current time during
!!                               |growing season
!!    i           |julian date   |current day in simulation--loop
counter
!!    icr(:)      |none          |sequence number of crop grown
within the
!!                               |current year
!!    id1         |julian date   |first day of simulation in current
year
!!    iida        |julian date   |day being simulated (current julian
day)
!!    idplt(:,:,:)|none          |land cover code from crop.dat
!!    iyr         |year          |current year of simulation (eg 1980)
!!    laimxfr(:)  |
!!    leapyr      |none          |leap year flag:
!!                               |0  leap year
!!                               |1  regular year
!!    ncrops(:,:,:)|
!!    ncut(:)     |none          |sequence number of harvest
operation within
!!                               |a year
!!    ndmo(:)     |days          |cumulative number of days
accrued in the
!!                               |month since the simulation began
where the
!!                               |array location number is the number of
the
!!                               |month
!!    nro(:)      |none          |sequence number of year in
rotation
!!    ntil(:)     |none          |sequence number of tillage
operation within
!!                               |current year
!!    phu_plt(:,:,:)|heat units  |total number of heat units to
bring plant
!!                               |to maturity
!!    phuacc(:)   |none          |fraction of plant heat units
accumulated
!!    tnylda(:,:,:)|kg N/kg yield|estimated/target nitrogen
content of
!!                               |yield used in autofertilization
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    ic          |none          |counter
!!    idlst       |julian date   |last day of simulation in current
year
!!    iix         |none          |sequence number of current year in
rotation
!!    iiz         |none          |sequence number of current crop
grown
!!                               |within the current year
!!    j           |none          |counter
!!    xx          |none          |current year in simulation sequence
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Mod, Real
!!    SWAT: sim_inityr, std3, xmon, sim_initday, clicon,
command
!!    SWAT: writed, writem, tillmix

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: idlst, j, iix, iiz, ic, mon, ii
      real :: xx


      do curyr = 1, nbyr
        write (*,1234) curyr

        !! initialize annual variables
        call sim_inityr

!! MIKE WHITE reset soil P variables to previous conditions
              if (curyr == nyskip) then
                    orig_solorgp = sol_orgp
                    orig_solsolp = sol_solp
                    orig_solfop = sol_fop
                    orig_solactp = sol_actp
                    orig_solstap = sol_stap
!!            Set Initial Soil P summary based on this state

                    !! calculate nutrient levels in each
HRU
                    do j = 1, nhru
                    sumno3 = 0.
                    sumorgn = 0.
                    summinp = 0.
                    sumorgp = 0.
                    do ly = 1, sol_nly(j)
                          summinp = summinp +
sol_solp(ly,j) + sol_actp(ly,j) +
     &        sol_stap(ly,j)
                          sumorgp = sumorgp +
sol_fop(ly,j) + sol_orgp(ly,j)
                    end do
                    pbalancei(j) = summinp + sumorgp +
plantp(j)
                    end do
              endif

              if (nyskip > 0) then
                    if (curyr > nyskip) then
              !! Code added to roll back the Soil P chemical
data to intital conditions
                          sol_orgp = 0.
                          sol_orgp = orig_solorgp
                          sol_solp = 0.
                          sol_solp = orig_solsolp
                          sol_fop = 0.
                          sol_fop = orig_solfop
                          sol_actp = 0.
                          sol_actp = orig_solactp
```

```
                  sol_stap = 0.
                  sol_stap = orig_solstap
            endif
      endif

!! write header for watershed annual table in .std file
call std3


!!determine beginning and ending dates of simulation in
current year
if (Mod(iyr,4) == 0) then
  leapyr = 0   !!leap year
else
  leapyr = 1   !!regular year
end if

!! set beginning day of simulation for year
id1 = 0
if (curyr == 1 .and. idaf > 0) then
  id1 = idaf
else
  id1 = 1
end if

!! set ending day of simulation for year
idlst = 0
if (curyr == nbyr .and. idal > 0) then
  idlst = idal
else
  idlst = 366 - leapyr
end if

!! set current julian date to begin annual simulation
iida = 0
iida = id1

call xmon


do i = id1, idlst                    !! begin daily loop

  !!initialize variables at beginning of day
  call sim_initday

  if ( fcstyr == iyr .and. fcstday == i) then
    ffcst = 1
    pcpsim = 2
    tmpsim = 2
    rhsim = 2
    slrsim = 2
    wndsim = 2
    igen = igen + iscen
    call gcycl
    do j = 1, subtot
      ii = 0
      ii = fcst_reg(j)
      if (ii <= 0) ii = 1
      do mon = 1, 12
        tmpmx(mon,j) = 0.
        tmpmn(mon,j) = 0.
        tmpstdmx(mon,j) = 0.
        tmpstdmn(mon,j) = 0.
        pcp_stat(mon,1,j) = 0.
        pcp_stat(mon,2,j) = 0.
        pcp_stat(mon,3,j) = 0.
        pr_w(1,mon,j) = 0.
        pr_w(2,mon,j) = 0.
        tmpmx(mon,j) = ftmpmx(mon,ii)
        tmpmn(mon,j) = ftmpmn(mon,ii)
        tmpstdmx(mon,j) = ftmpstdmx(mon,ii)
        tmpstdmn(mon,j) = ftmpstdmn(mon,ii)
        pcp_stat(mon,1,j) = fpcp_stat(mon,1,ii)
        pcp_stat(mon,2,j) = fpcp_stat(mon,2,ii)
        pcp_stat(mon,3,j) = fpcp_stat(mon,3,ii)
        pr_w(1,mon,j) = fpr_w(1,mon,ii)
        pr_w(2,mon,j) = fpr_w(2,mon,ii)
      end do
    end do
  end if

  dtot = dtot + 1.
  nd_30 = nd_30 + 1
  if (nd_30 > 30) nd_30 = 1

  if (curyr > nyskip) ndmo(i_mo) = ndmo(i_mo) + 1

  call clicon           !! read in/generate weather

  call command          !! command loop

  !! write daily and/or monthly output
  if (curyr > nyskip) then
    call writed
    iida = i + 1
    call xmon
    call writem
  else
    iida = i + 1
    call xmon
  endif

end do                               !! end daily loop

!! perform end-of-year processes
do j = 1, nhru

  !! compute biological mixing at the end of every year
  if (biomix(j) > .001) call tillmix (j,biomix(j))

  !! store end-of-year data
  iix = 0
  iiz = 0
  iix = nro(j)
  iiz = icr(j)

  !! update sequence number for year in rotation to that
of
  !! the next year and reset sequence numbers for
operations
  if (idplt(nro(j),icr(j),j) > 0) then
    if (idc(idplt(nro(j),icr(j),j)) == 7) then
      curyr_mat(j) = curyr_mat(j) + 1
      curyr_mat(j) = Min(curyr_mat(j),
&              mat_yrs(idplt(nro(j),icr(j),j)))
    end if
  end if

  nro(j) = nro(j) + 1
  if (nro(j) > nrot(j)) then
    nro(j) = 1
  end if
  icr(j) = 1
  ncut(j) = 1
  ntil(j) = 1
  icnop(j) = 1

  !! if crop is growing, reset values for accumulated heat
units,
  !! etc. to zero in northern hemisphere
  if (igro(j) == 1) then
    if (sub_lat(hru_sub(j)) > 0.) then
      phuacc(j) = 0.
      laimxfr(j) = 0.
      hvstiadj(j) = 0.
    endif
    phu_plt(nro(j),icr(j),j) = phu_plt(iix,iiz,j)
    idplt(nro(j),icr(j),j) = idplt(iix,iiz,j)
    hi_targ(nro(j),icr(j),j) = hi_targ(iix,iiz,j)
    ncrops(iix,iiz,j) = ncrops(iix,iiz,j) + 1
  end if

  !! update target nitrogen content of yield with data from
  !! year just simulated
  do ic = 1, mcr
    xx = 0.
    xx = Real(curyr)
    tnylda(nro(j),ic,j) = (tnylda(nro(j),ic,j) *
*       xx + tnyld(nro(j),ic,j)) / (xx + 1.)
  end do
```

```
    end do

   !! update simulation year
   iyr = iyr + 1

      end do          !!     end annual loop

      return
 1234 format (1x,' Executing year ', i4)
      end
```

subroutine pminrl

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine computes p flux between the labile, active mineral
!!    and stable mineral p pools.

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name         |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    curyr        |none          |current year of simulation
!!    hru_dafr(:)  |km**2/km**2   |fraction of watershed area in HRU
!!    ihru         |none          |HRU number
!!    nyskip       |none          |number of years to skip output summarization
!!                                |and printing
!!    psp          |none          |Phosphorus availability index. The fraction
!!                                |of fertilizer P remaining in labile pool
!!                                |after initial rapid phase of P sorption
!!    sol_actp(:,:)|kg P/ha       |amount of phosphorus stored in the
!!                                |active mineral phosphorus pool
!!    sol_nly(:)   |none          |number of layers in soil profile
!!    sol_solp(:,:)|kg P/ha       |amount of phosohorus stored in solution
!!    sol_stap(:,:)|kg P/ha       |amount of phosphorus in the soil layer
!!                                |stored in the stable mineral phosphorus pool
!!    wshd_pal     |kg P/ha       |average annual amount of phosphorus moving
!!                                |from labile mineral to active mineral pool
!!                                |in watershed
!!    wshd_pas     |kg P/ha       |average annual amount of phosphorus moving
!!                                |from active mineral to stable mineral pool
!!                                |in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name         |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    rmp1tl       |kg P/ha       |amount of phosphorus moving from the labile
!!                                |mineral pool to the active mineral pool in
!!                                |the soil profile on the current day in the
!!                                |HRU
!!    roctl        |kg P/ha       |amount of phosphorus moving from the active
!!                                |mineral pool to the stable mineral pool
!!                                |in the soil profile on the current day in
!!                                |the HRU
!!    sol_actp(:,:)|kg P/ha       |amount of phosphorus stored in the
!!                                |active mineral phosphorus pool
!!    sol_solp(:,:)|kg P/ha       |amount of phosohorus stored in solution
!!    sol_stap(:,:)|kg P/ha       |amount of phosphorus in the soil layer
!!                                |stored in the stable mineral phosphorus pool
!!    wshd_pal     |kg P/ha       |average annual amount of phosphorus moving
!!                                |from labile mineral to active mineral pool
!!                                |in watershed
!!    wshd_pas     |kg P/ha       |average annual amount of phosphorus moving
!!                                |from active mineral to stable mineral pool
!!                                |in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    bk          |
!!    j           |none          |HRU number
!!    l           |none          |counter (soil layer)
!!    rmn1        |kg P/ha       |amount of phosphorus moving from the solution
!!                               |mineral to the active mineral pool in the
!!                               |soil layer
!!    roc         |kg P/ha       |amount of phosphorus moving from the active
!!                               |mineral to the stable mineral pool in the
!!                               |soil layer
!!    rto         |
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Min

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm
!! Mike White Modification
      real, parameter :: bk = .006
!! ORiginal Code
!!       real, parameter :: bk = .0006
!! END Mike White Modification

      integer :: j, l
      real :: rto, rmn1, roc, TotMinP, SSP, xx, wt1, dg
             xx = 0.
      j = 0
      j = ihru

      rto = 0.
      rto = psp / (1.-psp)

      do l = 1, sol_nly(j)
        rmn1 = 0.
        rmn1 = (sol_solp(l,j) - sol_actp(l,j) * rto)
        if (rmn1 > 0.) rmn1 = rmn1 * .1
        rmn1 = Min(rmn1, sol_solp(l,j))

!! Mike White Modification

        dg = 0.
               wt1 = 0.
               SSP = 0.
        dg = (sol_z(l,j) - xx) !! get depth of soil layer
        wt1 = sol_bd(l,j) * dg / 100.           !! mg/kg => kg/ha
               TotMinP = (sol_solp(l,j) + sol_stap(l,j) + sol_actp(l,j)) / wt1
```

```
              SSP =206.54 * (0.9996 ** (TotMinP)) *
(TotMinP ** (-0.65852))
      roc = 0.
      roc = bk * (SSP * sol_actp(l,j) - sol_stap(l,j))
              xx = sol_z(l,j)

!! ORiginal Code
!!                roc = 0.
!!        roc = bk * (4. * sol_actp(l,j) - sol_stap(l,j))

!! END Mike White Modification

      if (roc < 0.) roc = roc * .1
      roc = Min(roc, sol_actp(l,j))

      sol_stap(l,j) = sol_stap(l,j) + roc
      if (sol_stap(l,j) < 0.) sol_stap(l,j) = 0.

        sol_actp(l,j) = sol_actp(l,j) - roc + rmn1
        if (sol_actp(l,j) < 0.) sol_actp(l,j) = 0.

        sol_solp(l,j) = sol_solp(l,j) - rmn1
        if (sol_solp(l,j) < 0.) sol_solp(l,j) = 0.

        if (curyr > nyskip) then
          wshd_pas = wshd_pas + roc * hru_dafr(j)
          wshd_pal = wshd_pal + rmn1 * hru_dafr(j)
          roctl = roctl + roc
          rmp1tl = rmp1tl + rmn1
        end if

      end do

      return
      end
```

subroutine soil_chem

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine initializes soil chemical properties

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    hrupest(:)    |none          |pesticide use flag:
!!                                 | 0: no pesticides used in HRU
!!                                 | 1: pesticides used in HRU
!!    i             |none          |HRU number
!!    nactfr        |none          |nitrogen active pool fraction. The
fraction
!!                                 |of organic nitrogen in the active pool.
!!    npmx          |none          |number of different pesticides
used in
!!                                 |the simulation
!!    npno(:)       |none          |array of unique pesticides used
in watershed
!!    psp           |none          |Phosphorus availability index.
The fraction
!!                                 |of fertilizer P remaining in labile pool
!!                                 |after initial rapid phase of P sorption.
!!    skoc(:)       |(mg/kg)/(mg/L)|soil adsorption coefficient
normalized
!!                                 |for soil organic carbon content
!!    sol_bd(:,:)   |Mg/m**3       |bulk density of the soil
!!    sol_cbn(:,:)  |%             |percent organic carbon in soil
layer
!!    sol_nly(:)    |none          |number of soil layers
!!    sol_no3(:,:)  |mg N/kg soil  |nitrate concentration in soil
layer
!!    sol_orgn(:,:) |mg/kg         |organic N concentration in soil
layer
!!    sol_orgp(:,:) |mg/kg         |organic P concentration in soil
layer
!!    sol_pst(:,:,1)|kg/ha         |initial amount of pesticide in first
layer
!!                                 |read in from .chm file
!!    sol_rsd(:,:)  |kg/ha         |amount of organic matter in the
soil layer
!!                                 |classified as residue
!!    sol_solp(:,:) |mg/kg         |solution P concentration in soil
layer
!!    sol_z(:,:)    |mm            |depth to bottom of soil layer
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    basminpi      |kg P/ha       |average amount of
phosphorus initially in
!!                                 |the mineral P pool in watershed soil
!!    basno3i       |kg N/ha       |average amount of nitrogen
initially in the
!!                                 |nitrate pool in watershed soil
!!    basorgni      |kg N/ha       |average amount of nitrogen
initially in
!!                                 |the organic N pool in watershed soil
!!    basorgpi      |kg P/ha       |average amount of phosphorus
initially in
!!                                 |the organic P pool in watershed soil
!!    conv_wt(:,:)  |none          |factor which converts kg/kg soil
to kg/ha
!!    sol_actp(:,:) |kg P/ha       |amount of phosphorus stored
in the
!!                                 |active mineral phosphorus pool
!!    sol_aorgn(:,:)|kg N/ha       |amount of nitrogen stored in
the active
!!                                 |organic (humic) nitrogen pool
!!    sol_cov(:)    |kg/ha         |amount of residue on soil
surface
!!    sol_fon(:,:)  |kg N/ha       |amount of nitrogen stored in the
fresh
!!                                 |organic (residue) pool
!!    sol_fop(:,:)  |kg P/ha       |amount of phosphorus stored in
the fresh
!!                                 |organic (residue) pool
!!    sol_hum(:,:)  |kg humus/ha   |amount of organic matter in
the soil layer
!!                                 |classified as humic substances
!!    sol_kp(:,:,:) |(mg/kg)/(mg/L)|pesticide sorption coefficient,
Kp; the
!!                                 |ratio of the concentration in the solid
!!                                 |phase to the concentration in solution
!!    sol_no3(:,:)  |kg N/ha       |amount of nitrogen stored in
the
!!                                 |nitrate pool. This variable is read in as
!!                                 |a concentration and converted to
kg/ha.
!!                                 |(this value is read from the .sol file in
!!                                 |units of mg/kg)
!!    sol_orgn(:,:) |kg N/ha       |amount of nitrogen stored in
the stable
!!                                 |organic N pool NOTE UNIT CHANGE!
!!    sol_orgp(:,:) |kg P/ha       |amount of phosphorus stored
in the organic
!!                                 |P pool NOTE UNIT CHANGE!
!!    sol_pst(:,:,:)|kg/ha         |amount of pesticide in layer
NOTE UNIT
!!                                 |CHANGE!
!!    sol_solp(:,:) |kg P/ha       |amount of phosohorus stored
in solution
!!                                 |NOTE UNIT CHANGE!
!!    sol_stap(:,:) |kg P/ha       |amount of phosphorus in the
soil layer
!!                                 |stored in the stable mineral
phosphorus
!!                                 |pool
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
```

```
!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    dg          |mm            |depth of layer
!!    j           |none          |counter
!!    jj          |none          |dummy variable to hold value
!!    n           |none          |counter
!!    nly         |none          |number of soil layers
!!    soldepth    |mm            |depth from bottom of 1st soil
layer to
!!                               |the bottom of the layer of interest
!!    solpst      |mg/kg         |concentration of pesticide in soil
!!    summinp     |kg P/ha       |amount of phosphorus stored
in the mineral P
!!                               |pool in the profile
!!    sumno3      |kg N/ha       |amount of nitrogen stored in the
nitrate pool
!!                               |in the soil profile
!!    sumorgn     |kg N/ha       |amount of nitrogen stored in the
organic N
!!                               |pools in the profile
!!    sumorgp     |kg P/ha       |amount of phosphorus stored in
the organic P
!!                               |pools in the profile
!!    wt1         |none          |converts mg/kg (ppm) to kg/ha
!!    xx          |none          |variable to hold value
!!    zdst        |none          |variable to hold value
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~


!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: nly, j, jj, n
      real :: xx, dg, wt1, zdst, soldepth, sumno3, sumorgn,
summinp
!! Mike White Modification added variable declrations SSP,
MJWFRAC ,TotMinP
      real :: sumorgp, solpst, SSP, MJWFRAC , TotMinP

      nly = 0
      solpst = 0.
      sumno3 = 0.
      sumorgn = 0.
      summinp = 0.
      sumorgp = 0.
      nly = sol_nly(i)

!!    calculate sol_cbn for lower layers if only have upper
layer
      if (nly >= 3 .and. sol_cbn(3,i) <= 0) then
        do j = 3, nly
          if (sol_cbn(j,i) == 0.) then
            soldepth = 0
            soldepth = sol_z(j,i) - sol_z(2,i)
            sol_cbn(j,i) = sol_cbn(j-1,i) * Exp(-.001 * soldepth)
          end if
        end do
      end if



!!    calculate sol_kp as function of koc and sol_cbn
!!    and set initial pesticide in all layers equal to value given
for
!!    upper layer
      if (hrupest(i) == 1) then
      do j = 1, npmx
        jj = 0
        jj = npno(j)
        if (jj > 0) then
          solpst = 0.
          solpst = sol_pst(j,i,1)  !!concentration of pesticide in
soil
          do n = 1, nly
            dg = 0.
            wt1 = 0.
```

```
            dg = (sol_z(j,i) - xx)
            wt1 = sol_bd(j,i) * dg / 100.           !! mg/kg => kg/ha
            sol_kp(j,i,n) = skoc(jj) * sol_cbn(n,i) / 100.
            sol_pst(j,i,n) = solpst * wt1
          end do
        end if
      end do
      end if


!!    calculate initial nutrient contents of layers, profile and
!!    average in soil for the entire watershed
!!    convert mg/kg (ppm) to kg/ha
      xx = 0.
      sol_fop(1,i) = sol_rsd(1,i) * .0003
      sol_fon(1,i) = sol_rsd(1,i) * .0015
      sol_cov(i) = sol_rsd(1,i)
      do j = 1, nly
        dg = 0.
        wt1 = 0.
        dg = (sol_z(j,i) - xx)
        wt1 = sol_bd(j,i) * dg / 100.              !! mg/kg => kg/ha
        conv_wt(j,i) = 1.e6 * wt1                  !! kg/kg => kg/ha

        if (sol_no3(j,i) <= 0.) then
          zdst = 0.
          zdst = Exp(-sol_z(j,i) / 1000.)
          sol_no3(j,i) = 10. * zdst * .7
        end if
        sol_no3(j,i) = sol_no3(j,i) * wt1          !! mg/kg => kg/ha
        sumno3 = sumno3 + sol_no3(j,i)

        if (sol_orgn(j,i) > 0.0001) then
          sol_orgn(j,i) = sol_orgn(j,i) * wt1      !! mg/kg => kg/ha
        else
          !! assume C:N ratio of 14:1
          sol_orgn(j,i) = 10000. * (sol_cbn(j,i) / 14.) * wt1
        end if
        sol_aorgn(j,i) = sol_orgn(j,i) * nactfr
        sol_orgn(j,i) = sol_orgn(j,i) * (1. - nactfr)
        sumorgn = sumorgn + sol_aorgn(j,i) + sol_orgn(j,i) +
&
     &          sol_fon(j,i)

        if (sol_orgp(j,i) > 0.0001) then
          sol_orgp(j,i) = sol_orgp(j,i) * wt1      !! mg/kg => kg/ha
        else
          sol_orgp(j,i) = .125 * sol_orgn(j,i)
        end if

!! Mike White Modification Use STP as a Model Input ORGP
still based on OM
!! Soil Labile P input is taken as STP, and transformed here
!! in the remainer ot the program it is still Labile P not STP

        if (sol_solp(j,i) > 10.) then
          sol_solp(j,i) = sol_solp(j,i)      !! mg/kg => kg/ha
        else
          !! assume initial concentration of 30 ppm
          sol_solp(j,i) = 10.
        end if
!! estimate Total Mineral P in this soil based on data from
sharpley 2004

                        Mjwfrac = 0.0399 * (sol_solp(j,i) **
(0.3833))
                        TotMinP = sol_solp(j,i) / Mjwfrac

!! Calculate Pool Breakdown
!! from this point on, Soil Solp is back to a soil solution not
highjacked for STP

                        sol_solp(j,i) = psp * sol_solp(j,i)

                        sol_actp(j,i) = sol_solp(j,i) * (1. - psp)
/ psp

                        SSP = 206.54 * (0.9996 ** (TotMinP))
* ( TotMinP ** (-0.65852))
```

```
                        sol_stap(j,i) = SSP * (sol_actp(j,i) +
sol_solp(j,i))

!!            Convert to kg/ha
                        sol_solp(j,i) = sol_solp(j,i) * wt1

                        sol_actp(j,i) = sol_actp(j,i) * wt1

                        sol_stap(j,i) = sol_stap(j,i) * wt1

!! Original Code
!!       if (sol_solp(j,i) > 0.0001) then
!!         sol_solp(j,i) = sol_solp(j,i) * wt1      !! mg/kg => kg/ha
!!       else
!!         !! assume initial concentration of 5 mg/kg
!!         sol_solp(j,i) = 5. * wt1
!!       end if
!!       sol_actp(j,i) = sol_solp(j,i) * (1. - psp) / psp
!!       sol_stap(j,i) = 4. * sol_actp(j,i)

!! END Mike White Modification

        sol_hum(j,i) = sol_cbn(j,i) * wt1 * 17200.
        xx = sol_z(j,i)
        summinp = summinp + sol_solp(j,i) + sol_actp(j,i) +
&
   &      sol_stap(j,i)
        sumorgp = sumorgp + sol_orgp(j,i) + sol_fop(j,i)
      end do

      basno3i = basno3i + sumno3 * hru_km(i) / da_km
      basorgni = basorgni + sumorgn * hru_km(i) / da_km
      basminpi = basminpi + summinp * hru_km(i) / da_km
      basorgpi = basorgpi + sumorgp * hru_km(i) / da_km

      return
      end
```

subroutine readsol

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine reads data from the HRU/subbasin soil
properties file
!!    (.sol). This file contains data related to soil physical
properties and
!!    general chemical properties.

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    ihru          |none          |HRU number
!!    mlyr          |none          |maximum number of soil layers
!!    idplt(1,1,:)  |none          |land cover/crop identification
code for
!!                                 |first crop grown in HRU (the only crop
if
!!                                 |there is no rotation)
!!    rdmx(:)       |m             |maximum root depth of plant
!!    rsdin(:)      |kg/ha         |initial residue cover
!!    sol_no3(:,:)  |mg N/kg       |concentration of nitrate in soil
layer
!!    sol_orgn(1,:) |mg N/kg soil  |organic N concentration in
top soil layer
!!    sol_orgp(1,:) |mg P/kg soil  |organic P concentration in
top soil layer
!!    sol_solp(1,:) |mg P/kg soil  |soluble P concentration in
top soil layer
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    anion_excl(:) |none          |fraction of porosity from which
anions
!!                                 |are excluded
!!    sol_clay(:,:) |%             |percent clay content in soil
material
!!    rock(:)       |%             |percent of rock fragments in soil
layer
!!    silt(:)       |%             |percent silt content in soil material
!!    snam(:)       |NA            |soil series name
!!    sol_alb(:)    |none          |albedo when soil is moist
!!    sol_awc(:,:)  |mm H20/mm soil|available water capacity
of soil layer
!!    sol_bd(:,:)   |Mg/m**3       |bulk density of the soil
!!    sol_cbn(:,:)  |%             |percent organic carbon in soil
layer
!!    sol_crk(:)    |none          |crack volume potential of soil
!!    sol_k(:,:)    |mm/hr         |saturated hydraulic conductivity
of soil
!!                                 |layer
!!    sol_nly(:)    |none          |number of soil layers
!!    sol_no3(:,:)  |mg N/kg       |concentration of nitrate in soil
layer
!!    sol_orgn(1,:) |mg N/kg soil  |organic N concentration in
top soil layer
!!    sol_orgp(1,:) |mg P/kg soil  |organic P concentration in
top soil layer
!!    sol_rsd(:,:)  |kg/ha         |amount of organic matter in the
soil layer
!!                                 |classified as residue
!!    sol_solp(1,:) |mg P/kg soil  |soluble P concentration in
top soil layer
!!    sol_stap(:,:) |kg P/ha       |amount of phosphorus in the
soil layer
!!                                 |stored in the stable mineral
phosphorus
!!                                 |pool
!!    sol_z(:,:)    |mm            |depth to bottom of soil layer
!!    sol_zmx(:)    |mm            |maximum rooting depth
!!    usle_k(:)     |none          |USLE equation soil erodibility
(K) factor
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    flag          |none          |flag to exit do loop
!!    j             |none          |counter
!!    jj            |none          |dummy variable to hold value
!!    n             |none          |counter
!!    nly           |none          |number of soil layers
!!    plt_zmx       |mm            |rooting depth of plant
!!    sand          |%             |percent sand content of soil
material
!!    sol_ec(:)     |dS/m          |electrical conductivity of soil layer
!!    titldum       |NA            |title line/skipped line in .sol file
!!    xx            |none          |variable to hold value
!!    yy            |none          |variable to hold value
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Exp, Abs

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      character (len=80) :: titldum
      integer :: j, nly, n, jj, flag, eof
      real, dimension (mlyr) :: sol_ec
      real :: sand, xx, plt_zmx, yy

!!    initialize local variables
      nly = 0
```

```
      plt_zmx = 0.
      sand = 0.
      sol_ec = 0.

      read (107,5500) titldum
      read (107,5100) snam(ihru)
      read (107,5200) hydgrp(ihru)
      read (107,5300) sol_zmx(ihru)
      read (107,5400) anion_excl(ihru)
      read (107,5600) sol_crk(ihru)
      read (107,5500) titldum
      read (107,5000) (sol_z(j,ihru), j = 1, mlyr)

      !! calculate number of soil layers in HRU soil series
      do j = 1, mlyr
!!    khan soils
!      sol_z(j,ihru) = sol_z(j,ihru) / 5.0
        if (sol_z(j,ihru) <= 0.001) sol_nly(ihru) = j - 1
        if (sol_z(j,ihru) <= 0.001) exit
      enddo
      if (sol_nly(ihru) == 0) sol_nly(ihru) = 10
      nly = sol_nly(ihru)

      eof = 0
      do
      read (107,5000) (sol_bd(j,ihru), j = 1, nly)
      read (107,5000) (sol_awc(j,ihru), j = 1, nly)
      read (107,5000) (sol_k(j,ihru), j = 1, nly)
      read (107,5000) (sol_cbn(j,ihru), j = 1, nly)
      read (107,5000) (sol_clay(j,ihru), j = 1, nly)
      read (107,5000) silt(ihru)
      read (107,5000) sand
      read (107,5000) rock(ihru)
      read (107,5000) sol_alb(ihru)
      read (107,5000) usle_k(ihru)
      read (107,5000,iostat=eof) (sol_ec(j), j = 1, nly)
      if (eof < 0) exit
      exit
      end do

!!    set default values for sol_awc
      if (sol_awc(j,ihru) <= .01) sol_awc(j,ihru) = .01
      if (sol_awc(j,ihru) >= .80) sol_awc(j,ihru) = .80


!!    add 10mm layer at surface of soil
      if (sol_z(1,ihru) > 10.1) then
        sol_nly(ihru) = sol_nly(ihru) + 1
        nly = nly + 1
        do j = nly, 2, -1
          sol_z(j,ihru) = sol_z(j-1,ihru)
          sol_bd(j,ihru) = sol_bd(j-1,ihru)
          sol_awc(j,ihru) = sol_awc(j-1,ihru)
          sol_k(j,ihru) = sol_k(j-1,ihru)
          sol_cbn(j,ihru) = sol_cbn(j-1,ihru)
          sol_clay(j,ihru) = sol_clay(j-1,ihru)
          sol_ec(j) = sol_ec(j-1)
          sol_no3(j,ihru) = sol_no3(j-1,ihru)
          sol_orgn(j,ihru) = sol_orgn(j-1,ihru)
          sol_orgp(j,ihru) = sol_orgp(j-1,ihru)
          sol_solp(j,ihru) = sol_solp(j-1,ihru)
        end do
        sol_z(1,ihru) = 10.
      endif

!! Mike White Modification
!! Set soil Surface P concentraton to the value in layer 10.
!! By default SWAT does not allow setting the STP of the soil
surface
                  sol_solp(1,ihru) = sol_solp(10,ihru)
                  sol_solp(10,ihru) = 0.
!! Mike White Modification End


      if (isproj == 2) then
        call estimate_ksat(sol_clay(j,ihru),sol_k(j,ihru))  !!  NK
June 28, 2006
      endif

!!    compare maximum rooting depth in soil to maximum
rooting depth of
!!    plant
      if (sol_zmx(ihru) <= 0.001) sol_zmx(ihru) =
sol_z(nly,ihru)
      if (nrot(ihru) > 0) then
        plt_zmx = 1000. * rdmx(idplt(1,1,ihru))
      end if
      if (sol_zmx(ihru) > 1. .and. plt_zmx > 1.) then
         sol_zmx(ihru) = Min(sol_zmx(ihru),plt_zmx)
      else
         !! if one value is missing it will set to the one available
         sol_zmx(ihru) = Max(sol_zmx(ihru),plt_zmx)
      end if


!!    create a layer boundary at maximum rooting depth
(sol_zmx)
      if (sol_zmx(ihru) > 0.001) then
        flag = 0
        do j = 1, nly - 1
          xx = 0.
          yy = 0.
          xx = Abs(sol_zmx(ihru)-sol_z(j,ihru))
          yy = Abs(sol_zmx(ihru)-sol_z(j+1,ihru))
          !! if values are within 51 mm of one another, reset
boundary
          if (xx < 51. .and. yy > 51.) then
            sol_z(j,ihru) = sol_zmx(ihru)
            exit
          end if

          !! set a soil layer at sol_zmx and adjust all lower layers
          if (sol_z(j,ihru) > sol_zmx(ihru)) then
            flag = 1
            sol_nly(ihru) = sol_nly(ihru) + 1
            nly = nly + 1
            jj = 0
            jj = j + 1
            do n = nly, jj, -1
              sol_z(n,ihru) = sol_z(n-1,ihru)
              sol_bd(n,ihru) = sol_bd(n-1,ihru)
              sol_awc(n,ihru) = sol_awc(n-1,ihru)
              sol_k(n,ihru) = sol_k(n-1,ihru)
              sol_cbn(n,ihru) = sol_cbn(n-1,ihru)
              sol_clay(n,ihru) = sol_clay(n-1,ihru)
              sol_ec(n) = sol_ec(n-1)
              sol_no3(n,ihru) = sol_no3(n-1,ihru)
              sol_orgn(n,ihru) = sol_orgn(n-1,ihru)
              sol_orgp(n,ihru) = sol_orgp(n-1,ihru)
              sol_solp(n,ihru) = sol_solp(n-1,ihru)
            end do
            sol_z(j,ihru) = sol_zmx(ihru)
          end if
          if (flag == 1) exit
        end do
      end if



!!    set default values/initialize variables
      if (sol_alb(ihru) < 0.1) sol_alb(ihru) = 0.1
      if (anion_excl(ihru) <= 0.) anion_excl(ihru) = 0.5
      if (anion_excl(ihru) >= 1.) anion_excl(ihru) = 0.99
      if (rsdin(ihru) > 0.) sol_rsd(1,ihru) = rsdin(ihru)
      do j = 1, nly
        a = 50.0
        b = 20.0
        c = 5.0
        d = 2.0
        nota = 10.
        if (sol_k(j,ihru) <= 0.0) then
          if (hydgrp(ihru) == "A") then
            sol_k(j,ihru) = a
                else
          if (hydgrp(ihru) == "B") then
            sol_k(j,ihru) = b
                else
          if (hydgrp(ihru) == "C") then
            sol_k(j,ihru) = c
```

```
            else
        if (hydgrp(ihru) == "D") then
          sol_k(j,ihru) = c
        else
          sol_k(j,ihru) = nota
        endif
        endif
        endif
        endif
       endif
      if (sol_bd(j,ihru) <= 1.e-6) sol_bd(j,ihru) = 1.3
      if (sol_bd(j,ihru) > 2.) sol_bd(j,ihru) = 2.0
      if (sol_awc(j,ihru) <= 0.) sol_awc(j,ihru) = .005
      end do

      close (107)
      return
 5000 format (27x,10f12.2)
 5100 format (12x,a16)
 5200 format (24x,a1)
 5300 format (28x,f12.2)
 5400 format (51x,f5.3)
 5500 format (a80)
 5600 format (33x,f5.3)
      End
```

subroutine readchm

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    This subroutine reads data from the HRU/subbasin soil chemical input
!!    file (.chm). This file contains initial amounts of pesticides/nutrients
!!    in the first soil layer. (Specifics about the first soil layer are given
!!    in the .sol file.) All data in the .chm file is optional input.

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    ihru        |none          |HRU number
!!    mlyr        |none          |maximum number of soil layers
!!    mpst        |none          |maximum number of pesticides used in
!!                               |watershed
!!    nope(:)     |none          |sequence number of pesticide in NPNO(:)
!!    npmx        |none          |number of different pesticides used in
!!                               |the simulation
!!    npno(:)     |none          |array of unique pesticides used in
!!                               |watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    hrupest(:)    |none          |pesticide use flag:
!!                                 | 0: no pesticides used in HRU
!!                                 | 1: pesticides used in HRU
!!    nope(:)       |none          |sequence number of pesticide in NPNO(:)
!!    npmx          |none          |number of different pesticides used in
!!                                 |the simulation
!!    npno(:)       |none          |array of unique pesticides used in
!!                                 |watershed
!!    plt_pst(:,:)  |kg/ha         |pesticide on plant foliage
!!    sol_pst(:,:,1)|mg/kg         |pesticide concentration in soil
!!    pst_enr(:,:)  |none          |pesticide enrichment ratio
!!    sol_no3(:,:)  |mg N/kg       |concentration of nitrate in soil layer
!!    sol_orgn(1,:) |mg N/kg soil  |organic N concentration in top soil layer
!!    sol_orgp(1,:) |mg P/kg soil  |organic P concentration in top soil layer
!!    sol_solp(1,:) |mg P/kg soil  |soluble P concentration in top soil layer
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    eof         |none          |end of file flag
!!    j           |none          |counter
!!    k           |none          |counter
!!    newpest     |none          |new pesticide flag
!!    pltpst      |kg/ha         |pesticide on plant foliage
!!    pstenr      |none          |pesticide enrichment ratio
!!    pstnum      |none          |pesticide number
!!    solpst      |mg/kg         |pesticide concentration in soil
!!    titldum     |NA            |title line for .chm file
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~


      use parm

      character (len=80) :: titldum
      integer :: j, eof, k, newpest, pstnum
      real :: pltpst, solpst, pstenr

      eof = 0

      do
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5100,iostat=eof) (sol_no3(j,ihru), j = 1, mlyr)
      if (eof < 0) exit
      read (106,5100,iostat=eof) (sol_orgn(j,ihru), j = 1, mlyr)
      if (eof < 0) exit
      read (106,5100,iostat=eof) (sol_solp(j,ihru), j = 1, 10) !! Mike White mod
      if (eof < 0) exit
      read (106,5100,iostat=eof) (sol_orgp(j,ihru), j = 1, mlyr)
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      read (106,5000,iostat=eof) titldum
      if (eof < 0) exit
      do j = 1, mpst
        pstnum = 0
        pltpst = 0.
        solpst = 0.
        pstenr = 0.
        read (106,*,iostat=eof) pstnum, pltpst, solpst, pstenr
        if (pstnum > 0) then
          hrupest(ihru) = 1
          newpest = 0
          do k = 1, npmx
            if (pstnum == npno(k)) then
              newpest = 1
              exit
            endif
          end do
          if (newpest == 0) then
```

```
      npno(npmx) = pstnum
      nope(pstnum) = npmx
      npmx = npmx + 1
    end if

    k = 0
    k = nope(pstnum)
    plt_pst(k,ihru) = pltpst
    sol_pst(k,ihru,1) = solpst
    pst_enr(k,ihru) = pstenr
  end if
```

```
      if (eof < 0) exit
      end do
      exit
      end do

      close (106)

      return
 5000 format (a)
 5100 format (27x,10f12.2)
      End
```

subroutine readfert

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine reads input parameters from the
fertilizer/manure
!!    (i.e. nutrient) database (fert.dat)

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    mfdb        |none           |maximum number of fertilizers in
!!                                |database
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    bactkddb(:) |none           |bacteria partition coefficient:
!!                                |1: all bacteria in solution
!!                                |0: all bacteria sorbed to soil particles
!!    bactlpdb(:) |# cfu/g manure |concentration of less
persistent
!!                                |bacteria in manure(fertilizer)
!!    bactpdb(:)  |# cfu/g manure |concentration of persistent
bacteria
!!                                |in manure(fertilizer)
!!    fertnm(:)   |NA             |name of fertilizer
!!    fminn(:)    |kg minN/kg fert |fraction of mineral N (NO3 +
NH3)
!!    fminp(:)    |kg minP/kg fert |fraction of mineral P
!!    fnh3n(:)    |kg NH3-N/kg minN|fraction of NH3-N in
mineral N
!!    forgn(:)    |kg orgN/kg fert |fraction of organic N
!!    forgp(:)    |kg orgP/kg fert |fraction of organic P
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    eof         |none           |end of file flag
!!    it          |none           |counter which represents the array
!!                                |storage number of the pesticide data
!!                                |the array storage number is used by
the
!!                                |model to access data for a specific
!!                                |fertilizer
!!    ifnum       |none           |number of fertilizer/manure.
reference
!!                                |only
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
```

```
!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: it, ifnum, eof
      real :: ffminn, ffminp, fforgn, fforgp, ffnh3n, bctpdb,
bctlpdb
      real :: bctkddb, ffstab !! Mike White Modification
      character (len=8) :: fnm

      ifnum = 0
      eof = 0

      do
        !! initialize local variables
        bctkddb = 0.
        bctlpdb = 0.
        bctpdb = 0.
        ffminn = 0.
        ffminp = 0.
        ffnh3n = 0.
        fforgn = 0.
        fforgp = 0.
              ffstab = 0. !! Mike White Modification
        fnm = ""

        read (107,5000,iostat=eof) it, fnm, ffminn, ffminp,
fforgn,     &
    &     fforgp, ffnh3n, bctpdb, bctlpdb, bctkddb, ffstab !! Mike
White Mod

        if (eof < 0) exit

        if (it == 0) exit

        fertnm(it) = fnm
        fminn(it) = ffminn
        fminp(it) = ffminp
        forgn(it) = fforgn
        forgp(it) = fforgp
        fnh3n(it) = ffnh3n
        bactpdb(it) = bctpdb
        bactlpdb(it) = bctlpdb
        bactkddb(it) = bctkddb
              mjwfstabp(it) = ffstab !! Mike White Modification

      end do

      close (107)
      return
!! format changed for prem - last two bacteria inputs ok for all
 !!  Mike White Modeification
 !! 5000 format (i4,1x,a8,6f8.3,2f11.0)
 5000 format (i4,1x,a8,9f8.3)
      End
```

subroutine hrumon

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine writes monthly HRU output to the
output.hru file
```

```
!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name         |units        |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
```

```
!!    bio_ms(:)     |kg/ha         |land cover/crop biomass (dry
weight)
!!    cpnm(:)       |NA            |four character code to represent
crop name
!!    deepst(:)     |mm H2O        |depth of water in deep aquifer
!!    hru_km(:)     |km^2          |area of HRU in square
kilometers
!!    hru_sub(:)    |none          |subbasin in which HRU is
located
!!    hrugis(:)     |none          |GIS code printed to output
files(output.hru,.rch)
!!    hvstiadj(:)   |(kg/ha)/(kg/ha)|optimal harvest index for
current time
!!                                 |during growing season
!!    icr(:)        |none          |sequence number of crop grown
within the
!!                                 |current year
!!    idplt(:,:,:)  |none          |land cover code from crop.dat
!!    ipdvas(:)     |none          |output variable codes for
output.hru file
!!    isproj        |none          |special project code:
!!                                 |1 test rewind (run simulation twice)
!!    itots         |none          |number of output variables printed
(output.hru)
!!    mo_chk        |none          |current month of simulation
!!    mhruo         |none          |maximum number of variables
written to
!!                                 |HRU output file (output.hru)
!!    nhru          |none          |number of HRUs in watershed
!!    nmgt(:)       |none          |management code (for GIS
output only)
!!    nro(:)        |none          |sequence number of year in
rotation
!!    rwt(:)        |none          |fraction of total plant biomass that
is
!!                                 |in roots
!!    shallst(:)    |mm H2O        |depth of water in shallow
aquifer
!!    sol_sw(:)     |mm H2O        |amount of water stored in the
soil profile
!!                                 |on any given day
!!    hrumono(1,:)  |mm H2O        |precipitation in HRU during
month
!!    hrumono(2,:)  |mm H2O        |amount of precipitation
falling as freezing
!!                                 |rain/snow in HRU during month
!!    hrumono(3,:)  |mm H2O        |amount of snow melt in
HRU during month
!!    hrumono(4,:)  |mm H2O        |amount of surface runoff to
main channel
!!                                 |from HRU during month (ignores
impact of
!!                                 |transmission losses)
!!    hrumono(5,:)  |mm H2O        |amount of lateral flow
contribution to main
!!                                 |channel from HRU during month
!!    hrumono(6,:)  |mm H2O        |amount of groundwater
flow contribution to
!!                                 |main channel from HRU during month
!!    hrumono(7,:)  |mm H2O        |amount of water moving
from shallow aquifer
!!                                 |to plants or soil profile in HRU during
month
!!    hrumono(8,:)  |mm H2O        |amount of water recharging
deep aquifer in
!!                                 |HRU during month
!!    hrumono(9,:)  |mm H2O        |total amount of water
entering both aquifers
!!                                 |from HRU during month
!!    hrumono(10,:) |mm H2O        |water yield (total amount of
water entering
!!                                 |main channel) from HRU during
month
!!    hrumono(11,:) |mm H2O        |amount of water
percolating out of the soil
!!                                 |profile and into the vadose zone in
HRU
!!                                 |during month
!!    hrumono(12,:) |mm H2O        |actual evapotranspiration
in HRU during month
!!    hrumono(13,:) |mm H2O        |amount of transmission
losses from tributary
!!                                 |channels in HRU for month
!!    hrumono(14,:) |metric tons/ha|sediment yield from HRU
for month
!!    hrumono(17,:) |kg N/ha       |amount of nitrogen applied
in continuous
!!                                 |fertilizer operation during month in
HRU
!!    hrumono(18,:) |kg P/ha       |amount of phosphorus
applied in continuous
!!                                 |fertilizer operation during month in
HRU
!!    hrumono(23,:) |mm H2O        |amount of water removed
from shallow aquifer
!!                                 |in HRU for irrigation during month
!!    hrumono(24,:) |mm H2O        |amount of water removed
from deep aquifer
!!                                 |in HRU for irrigation during month
!!    hrumono(25,:) |mm H2O        |potential
evapotranspiration in HRU during
!!                                 |month
!!    hrumono(26,:) |kg N/ha       |monthly amount of N
(organic & mineral)
!!                                 |applied in HRU during grazing
!!    hrumono(27,:) |kg P/ha       |monthly amount of P
(organic & mineral)
!!                                 |applied in HRU during grazing
!!    hrumono(28,:) |kg N/ha       |monthly amount of N
(organic & mineral)
!!                                 |auto-applied in HRU
!!    hrumono(29,:) |kg P/ha       |monthly amount of P
(organic & mineral)
!!                                 |auto-applied in HRU
!!    hrumono(31,:) |stress days   |water stress days in HRU
during month
!!    hrumono(32,:) |stress days   |temperature stress days in
HRU during month
!!    hrumono(33,:) |stress days   |nitrogen stress days in
HRU during month
!!    hrumono(34,:) |stress days   |phosphorus stress days in
HRU during month
!!    hrumono(35,:) |kg N/ha       |organic nitrogen in surface
runoff in HRU
!!                                 |during month
!!    hrumono(36,:) |kg P/ha       |organic phosphorus in
surface runoff in HRU
!!                                 |during month
!!    hrumono(37,:) |kg N/ha       |nitrate in surface runoff in
HRU during month
!!    hrumono(38,:) |kg N/ha       |nitrate in lateral flow in HRU
during month
!!    hrumono(39,:) |kg P/ha       |soluble phosphorus in
surface runoff in HRU
!!                                 |during month
!!    hrumono(40,:) |kg N/ha       |amount of nitrogen removed
from soil by plant
!!                                 |uptake in HRU during month
!!    hrumono(41,:) |kg N/ha       |nitrate percolating past
bottom of soil
!!                                 |profile in HRU during month
!!    hrumono(42,:) |kg P/ha       |amount of phosphorus
removed from soil by
!!                                 |plant uptake in HRU during month
!!    hrumono(43,:) |kg P/ha       |amount of phosphorus
moving from labile
!!                                 |mineral to active mineral pool in HRU
during
!!                                 |month
!!    hrumono(44,:) |kg P/ha       |amount of phosphorus
moving from active
!!                                 |mineral to stable mineral pool in HRU
during
!!                                 |month
!!    hrumono(45,:) |kg N/ha       |amount of nitrogen applied
to HRU in
!!                                 |fertilizer and grazing operations during
!!                                 |month
!!    hrumono(46,:) |kg P/ha       |amount of phosphorus
applied to HRU in
```

```
!!                       |fertilizer and grazing operations during
!!                       |month
!!    hrumono(47,:) |kg N/ha       |amount of nitrogen added to
soil by fixation
!!                       |in HRU during month
!!    hrumono(48,:) |kg N/ha       |amount of nitrogen lost by
denitrification
!!                       |in HRU during month
!!    hrumono(49,:) |kg N/ha       |amount of nitrogen moving
from active organic
!!                       |to nitrate pool in HRU during month
!!    hrumono(50,:) |kg N/ha       |amount of nitrogen moving
from active organic
!!                       |to stable organic pool in HRU during
month
!!    hrumono(51,:) |kg P/ha       |amount of phosphorus
moving from organic to
!!                       |labile mineral pool in HRU during
month
!!    hrumono(52,:) |kg N/ha       |amount of nitrogen moving
from fresh organic
!!                       |to nitrate and active organic pools in
HRU
!!                       |during month
!!    hrumono(53,:) |kg P/ha       |amount of phosphorus
moving from fresh
!!                       |organic to the labile mineral and
organic
!!                       |pools in HRU during month
!!    hrumono(54,:) |kg N/ha       |amount of nitrogen added to
soil in rain
!!    hrumono(61,:) |metric tons/ha|daily soil loss predicted
with USLE equation
!!    hrumono(63,:) |# bacteria/ha |less persistent bacteria
transported to main
!!                       |channel from HRU during month
!!    hrumono(64,:) |# bacteria/ha |persistent bacteria
transported to main
!!                       |channel from HRU during month
!!    hrumono(65,:) |kg N/ha       |nitrate loading from
groundwater in HRU to
!!                       |main channel during month
!!    hrumono(66,:) |kg P/ha       |soluble P loading from
groundwater in HRU to
!!                       |main channel during month
!!    hrumono(67,:) |kg P/ha       |loading of mineral P
attached to sediment
!!                       |in HRU to main channel during month
!!    laiday(:)     |none          |leaf area index for HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~
!!    days        |none          |number of days in month
!!    dmt         |metric tons/ha|land cover/crop biomass (dry
weight)
!!    ii          |none          |counter
!!    j           |none          |HRU number
!!    pdvas(:)    |varies        |array to hold HRU output values
!!    pdvs(:)     |varies        |array to hold selected HRU output
values
!!                               |when user doesn't want to print all
!!    sb          |none          |subbasin number
!!    yldt        |metric tons/ha|land cover/crop yield (dry weight)
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: j, sb, ii, days, iflag
      real :: dmt, yldt, dg, wt1, wt2
      real, dimension (mhruo) :: pdvas, pdvs
      character (len=4) :: cropname

      days = 0
      select case(mo_chk)
        case (9, 4, 6, 11)
          days = 30
        case (2)
          days = 29 - leapyr
        case default
          days = 31
      end select

      do j = 1, nhru
        sb = 0
        sb = hru_sub(j)

        iflag = 0
        do ii = 1, itoth
          if (ipdhru(ii) == j) iflag = 1
        end do


        if (iflag == 1) then

        pdvas = 0.
        pdvs = 0.

        dmt = 0.
        yldt = 0.
        dmt = bio_ms(j) / 1000.
        yldt = (1. - rwt(j)) * dmt * hvstiadj(j)

        pdvas(1) = hrumono(1,j)
        pdvas(2) = hrumono(2,j)
        pdvas(3) = hrumono(3,j)
        pdvas(4) = hrumono(22,j)
        pdvas(5) = hrumono(25,j)
        pdvas(6) = hrumono(12,j)
        pdvas(7) = hrumono(21,j) / Real(days)
        pdvas(8) = sol_sw(j)
        pdvas(9) = hrumono(11,j)
        pdvas(10) = hrumono(9,j)
        pdvas(11) = hrumono(8,j)
        pdvas(12) = hrumono(7,j)
        pdvas(13) = hrumono(23,j)
        pdvas(14) = hrumono(24,j)
        pdvas(15) = shallst(j)
        pdvas(16) = deepst(j)
        pdvas(17) = hrumono(19,j)
        pdvas(18) = hrumono(4,j)
        pdvas(19) = hrumono(13,j)
        pdvas(20) = hrumono(5,j)
        pdvas(21) = hrumono(6,j)
        pdvas(22) = hrumono(10,j)
        pdvas(23) = hrumono(20,j) / Real(days)
        pdvas(24) = hrumono(57,j) / Real(days)
        pdvas(25) = hrumono(55,j) / Real(days)
        pdvas(26) = hrumono(56,j) / Real(days)
        pdvas(27) = hrumono(30,j) / Real(days)
        pdvas(28) = hrumono(58,j) / Real(days)
        pdvas(29) = hrumono(14,j)
        pdvas(30) = hrumono(61,j)
        pdvas(31) = hrumono(45,j)
        pdvas(32) = hrumono(46,j)
        pdvas(33) = hrumono(28,j)
        pdvas(34) = hrumono(29,j)
        pdvas(35) = hrumono(26,j)
        pdvas(36) = hrumono(27,j)
        pdvas(37) = hrumono(17,j)
        pdvas(38) = hrumono(18,j)
        pdvas(39) = hrumono(54,j)
        pdvas(40) = hrumono(47,j)
        pdvas(41) = hrumono(52,j)
        pdvas(42) = hrumono(49,j)
        pdvas(43) = hrumono(50,j)
        pdvas(44) = hrumono(53,j)
        pdvas(45) = hrumono(51,j)
        pdvas(46) = hrumono(43,j)
        pdvas(47) = hrumono(44,j)
        pdvas(48) = hrumono(48,j)
        pdvas(49) = hrumono(40,j)
        pdvas(50) = hrumono(42,j)
        pdvas(51) = hrumono(35,j)
```

```
      pdvas(52) = hrumono(36,j)
      pdvas(53) = hrumono(67,j)
      pdvas(54) = hrumono(37,j)
      pdvas(55) = hrumono(38,j)
      pdvas(56) = hrumono(41,j)
      pdvas(57) = hrumono(65,j)
      pdvas(58) = hrumono(39,j)
      pdvas(59) = hrumono(66,j)
      pdvas(60) = hrumono(31,j)
      pdvas(61) = hrumono(32,j)
      pdvas(62) = hrumono(33,j)
      pdvas(63) = hrumono(34,j)
      pdvas(64) = dmt
      pdvas(65) = laiday(j)

!!      pdvas(66) = yldt
!!      pdvas(67) = hrumono(63,j)
!! Mike White modification hijack persestiant bacteria as my
output for STP
!!      pdvas(68) = hrumono(64,j) Original Line
!! calculate nutrient levels in each HRU
                  sumno3 = 0.
                  sumorgn = 0.
                  summinp = 0.
                  sumorgp = 0.
                  do ly = 1, sol_nly(j)
                           summinp = summinp +
sol_solp(ly,j) + sol_actp(ly,j) +
     &      sol_stap(ly,j)
                           sumorgp = sumorgp +
sol_fop(ly,j) + sol_orgp(ly,j)
                  end do
                  pbalanceF(j) = summinp + sumorgp +
plantp(j)
           pdvas(68) = pbalancef(j) - pbalancei(j)

!!      hijack Less persestiant bacteria and yield as my output
for STP surface and layer 2
         pdvas(66) = (sol_solp(1,j) + sol_actp(1,j))
         pdvas(67) = (sol_solp(2,j) + sol_actp(2,j))
         pdvas(66) = pdvas(66)/ conv_wt(1,j) * 1000000
         pdvas(67) = pdvas(67)/ conv_wt(2,j) * 1000000


!! END Mike White modification

      if (ipdvas(1) > 0) then
       do ii = 1, itots
        pdvs(ii) = pdvas(ipdvas(ii))
       end do

       idum = idplt(nro(j),icr(j),j)
       if (idum > 0) then
        cropname = cpnm(idum)
       else
        cropname = "NOCR"
       endif

       if (iscen == 1 .and. isproj == 0) then
!      write (3,1000) cpnm(idplt(nro(j),icr(j),j)), j, hrugis(j),
sb,&
       write (3,1000) cropname, j, hrugis(j), sb,              &
     &      nmgt(j), mo_chk, hru_km(j), (pdvs(ii), ii = 1,
itots)
       else if (isproj == 1) then
!      write (21,1000) cpnm(idplt(nro(j),icr(j),j)), j, hrugis(j),
&
       write (21,1000) cropname, j, hrugis(j),                 &
     &    sb, nmgt(j), mo_chk, hru_km(j), (pdvs(ii), ii = 1,
itots)
       else if (iscen == 1 .and. isproj == 2) then
       write (3,2000) cropname, j, hrugis(j), sb,              &
     &  nmgt(j), mo_chk, hru_km(j), (pdvs(ii), ii = 1, itots), iyr
       end if
      else
       if (iscen == 1 .and. isproj == 0) then
!      write (3,1000) cpnm(idplt(nro(j),icr(j),j)), j, hrugis(j),
sb,&
       write (3,1000) cropname, j, hrugis(j), sb,              &
     &      nmgt(j), mo_chk, hru_km(j), (pdvas(ii), ii = 1,
mhruo)
       else if (isproj == 1) then
!      write (21,1000) cpnm(idplt(nro(j),icr(j),j)), j, hrugis(j),
&
       write (21,1000) cropname, j, hrugis(j),                 &
     &    sb, nmgt(j), mo_chk, hru_km(j), (pdvas(ii), ii = 1,
mhruo)
       else if (iscen == 1 .and. isproj == 2) then
       write (3,2000) cropname, j, hrugis(j), sb,              &
     &  nmgt(j), mo_chk, hru_km(j), (pdvas(ii), ii = 1, mhruo),
iyr
       end if
      end if
      end if
    end do

    return
 1000 format (a4,i4,1x,i8,1x,i4,1x,i4,1x,i4,e10.5,69f10.3)
 2000 format
(a4,i4,1x,i8,1x,i4,1x,i4,1x,i4,e10.5,68f10.3,1x,i4)
    End
```

subroutine filter

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine calculates the reduction of pollutants in surface runoff
!!    due to an edge of field filter or buffer strip

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    bactrolp    |# colonies/ha |less persistent bacteria transported to main
!!                               |channel with surface runoff
!!    bactrop     |# colonies/ha |persistent bacteria transported to main
!!                               |channel with surface runoff
!!    bactsedlp   |# colonies/ha |less persistent bacteria transported with
!!                               |sediment in surface runoff
!!    bactsedp    |# colonies/ha |persistent bacteria transported with
!!                               |sediment in surface runoff
!!    curyr       |none          |current year of simulation
!!    fsred(:)    |none          |reduction in bacteria loading from filter
!!                               |strip
!!    hru_dafr(:) |none          |fraction of watershed area in HRU
!!    hrupest(:)  |none          |pesticide use flag:
!!                               | 0: no pesticides used in HRU
!!                               | 1: pesticides used in HRU
!!    ihru        |none          |HRU number
!!    npmx        |none          |number of different pesticides used in
!!                               |the simulation
!!    nyskip      |none          |number of years to skip output summarization
!!                               |and printing
!!    pst_sed(:,:)|kg/ha         |pesticide loading from HRU sorbed onto
!!                               |sediment
!!    pst_surq(:,:)|kg/ha        |amount of pesticide type lost in surface
!!                               |runoff on current day in HRU
!!    sbactrolp   |# colonies/ha |average annual number of less persistent
!!                               |bacteria transported to main channel
!!                               |with surface runoff in solution
!!    sbactrop    |# colonies/ha |average annual number of persistent bacteria
!!                               |transported to main channel with surface
!!                               |runoff in solution
!!    sbactsedlp  |# colonies/ha |average annual number of less persistent
!!                               |bacteria transported with sediment in
!!                               |surface runoff
!!    sbactsedp   |# colonies/ha |average annual number of persistent bacteria
!!                               |transported with sediment in surface runoff
!!    sedminpa(:) |kg P/ha       |amount of active mineral phosphorus sorbed to
!!                               |sediment in surface runoff in HRU for day
!!    sedminps(:) |kg P/ha       |amount of stable mineral phosphorus sorbed to
!!                               |sediment in surface runoff in HRU for day
!!    sedorgn(:)  |kg N/ha       |amount of organic nitrogen in surface runoff
!!                               |in HRU for the day
!!    sedorgp(:)  |kg P/ha       |amount of organic phosphorus in surface runoff
!!                               |in HRU for the day
!!    sedyld(:)   |metric tons   |daily soil loss caused by water erosion
!!    surqno3(:)  |kg N/ha       |amount of NO3-N in surface runoff in HRU for
!!                               |the day
!!    surqsolp(:) |kg P/ha       |amount of soluble phosphorus in surface runoff
!!                               |in HRU for the day
!!    trapeff(:)  |none          |filter strip trapping efficiency (used for
!!                               |everything but bacteria)
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
!!    bactrolp    |# colonies/ha |less persistent bacteria transported to main
!!                               |channel with surface runoff
!!    bactrop     |# colonies/ha |persistent bacteria transported to main
!!                               |channel with surface runoff
!!    bactsedlp   |# colonies/ha |less persistent bacteria transported with
!!                               |sediment in surface runoff
!!    bactsedp    |# colonies/ha |persistent bacteria transported with
!!                               |sediment in surface runoff
!!    pst_sed(:,:)|kg/ha         |pesticide loading from HRU sorbed onto
!!                               |sediment
!!    pst_surq(:,:)|kg/ha        |amount of pesticide type lost in surface
!!                               |runoff on current day in HRU
!!    sbactrolp   |# colonies/ha |average annual number of less persistent
!!                               |bacteria transported to main channel
!!                               |with surface runoff in solution
!!    sbactrop    |# colonies/ha |average annual number of persistent bacteria
!!                               |transported to main channel with surface
!!                               |runoff in solution
!!    sbactsedlp  |# colonies/ha |average annual number of less persistent
!!                               |bacteria transported with sediment in
!!                               |surface runoff
!!    sbactsedp   |# colonies/ha |average annual number of persistent bacteria
!!                               |transported with sediment in surface runoff
!!    sedminpa(:) |kg P/ha       |amount of active mineral phosphorus sorbed to
!!                               |sediment in surface runoff in HRU for day
!!    sedminps(:) |kg P/ha       |amount of stable mineral phosphorus sorbed to
!!                               |sediment in surface runoff in HRU for day
!!    sedorgn(:)  |kg N/ha       |amount of organic nitrogen in surface runoff
!!                               |in HRU for the day
!!    sedorgp(:)  |kg P/ha       |amount of organic phosphorus in surface runoff
!!                               |in HRU for the day
!!    sedyld(:)   |metric tons   |daily soil loss caused by water erosion
!!    surqno3(:)  |kg N/ha       |amount of NO3-N in surface runoff in HRU for
!!                               |the day
!!    surqsolp(:) |kg P/ha       |amount of soluble phosphorus in surface runoff
!!                               |in HRU for the day
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
```

```
!!    j           |none          |HRU number
!!    k           |none          |counter
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: j, k

      j = 0
      j = ihru

!! compute filter strip reduction
      bactrop = bactrop * fsred(j)
      bactrolp = bactrolp * fsred(j)
      bactsedp = bactsedp * fsred(j)
      bactsedlp = bactsedlp * fsred(j)
      sedorgn(j) = sedorgn(j) * (1. - trapeff(j))

!!              Mike White Modification
!!     surqno3(j) = surqno3(j) * (1. - trapeff(j))
              surqno3(j) = surqno3(j)
!!              Mike White Modification

      return
      end
```

```
      sedorgp(j) = sedorgp(j) * (1. - trapeff(j))
      sedminpa(j) = sedminpa(j) * (1. - trapeff(j))
      sedminps(j) = sedminps(j) * (1. - trapeff(j))

!!              Mike White Modification
!!     surqsolp(j) = surqsolp(j) * (1. - trapeff(j))
              surqsolp(j) = surqsolp(j)
!!              Mike White Modification

      sedyld(j) = sedyld(j) * (1. - trapeff(j))
      if (hrupest(j) == 1) then
       do k = 1, npmx
        pst_surq(k,j) = pst_surq(k,j) * (1. - trapeff(j))
        pst_sed(k,j) = pst_sed(k,j) * (1. - trapeff(j))
       end do
      end if

!! summary calculations
      if (curyr > nyskip) then
       sbactrop = sbactrop + bactrop * hru_dafr(j)
       sbactrolp = sbactrolp + bactrolp * hru_dafr(j)
       sbactsedp = sbactsedp + bactsedp * hru_dafr(j)
       sbactsedlp = sbactsedlp + bactsedlp * hru_dafr(j)
      end if
```

subroutine fert

```
!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this subroutine applies N and P specified by date and
!!    amount in the management file (.mgt)

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    bactkddb(:)   |none          |fraction of bacteria in solution (the
!!                                 |remaining fraction is sorbed to soil
!!                                 |particles)
!!    bactlp_plt(:) |# cfu/m^2     |less persistent bacteria on foliage
!!    bactlpdb(:)   |# cfu/g   frt |concentration of less persistent
bacteria
!!                                 |in fertilizer
!!    bactpdb(:)    |# cfu/g   frt |concentration of persistent
bacteria in
!!                                 |fertilizer
!!    bactlpq(:)    |# cfu/m^2     |less persistent bacteria in soil
solution
!!    bactlps(:)    |# cfu/m^2     |less persistent bacteria attached
to soil
!!                                 |particles
!!    bactp_plt(:)  |# cfu/m^2     |persistent bacteria on foliage
!!    bactpq(:)     |# cfu/m^2     |persistent bacteria in soil solution
!!    bactps(:)     |# cfu/m^2     |persistent bacteria attached to
soil
!!                                 |particles
!!    curyr         |none          |current year of simulation
!!    fertn         |kg N/ha       |total amount of nitrogen applied to
soil
!!                                 |in HRU on day
!!    fertp         |kg P/ha       |total amount of phosphorus applied
to soil
!!                                 |in HRU on day
!!    fminn(:)      |kg minN/kg frt|fraction of fertilizer that is mineral
N
!!                                 |(NO3 + NH4)
!!    fminp(:)      |kg minP/kg frt|fraction of fertilizer that is mineral
P
!!    fnh3n(:)      |kgNH3-N/kgminN|fraction of mineral N in
fertilizer that
!!                                 |is NH3-N
!!    forgn(:)      |kg orgN/kg frt|fraction of fertilizer that is organic
N
!!    forgp(:)      |kg orgP/kg frt|fraction of fertilizer that is organic
P
!!    frt_kg(:,:,:) |kg/ha         |amount of fertilizer applied to HRU
!!    frt_surface(:,:,:)|none      |fraction of fertilizer which is
applied to
!!                                 |the top 10 mm of soil (the remaining
!!                                 |fraction is applied to first soil layer)
!!    hru_dafr(:)   |km2/km2       |fraction of watershed area in
HRU
!!    ihru          |none          |HRU number
!!    laiday(:)     |m**2/m**2     |leaf area index
!!    nfert(:)      |none          |sequence number of fertilizer
application
!!                                 |within the year
!!    nro(:)        |none          |sequence number of year in rotation
!!    nyskip        |none          |number of years to not
print/summarize output
!!    sol_aorgn(:,:)|kg N/ha       |amount of nitrogen stored in the
active
!!                                 |organic (humic) nitrogen pool
!!    sol_bd(1,:)   |Mg/m^3        |bulk density of top soil layer in
HRU
!!    sol_fon(:,:)  |kg N/ha       |amount of nitrogen stored in the
fresh
!!                                 |organic (residue) pool
!!    sol_fop(:,:)  |kg P/ha       |amount of phosphorus stored in
the fresh
!!                                 |organic (residue) pool
!!    sol_nh3(:,:)  |kg N/ha       |amount of nitrogen stored in the
ammonium
!!                                 |pool in soil layer
!!    sol_no3(:,:)  |kg N/ha       |amount of nitrogen stored in the
nitrate pool
!!                                 |in soil layer
!!    sol_orgp(:,:) |kg P/ha       |amount of phosphorus stored in
the organic
!!                                 |P pool
!!    sol_solp(:,:) |kg P/ha       |amount of inorganic phosohorus
stored in
!!                                 |solution
!!    sol_z(:,:)    |mm            |depth to bottom of soil layer
!!    wshd_fminp    |kg P/ha       |average annual amount of
mineral P applied
!!                                 |in watershed
!!    wshd_fnh3     |kg N/ha       |average annual amount of NH3-
N applied in
!!                                 |watershed
```

```
!!    wshd_fno3     |kg N/ha       |average annual amount of NO3-
N applied in
!!                          |watershed
!!    wshd_orgn     |kg N/ha       |average annual amount of
organic N applied
!!                          |in watershed
!!    wshd_orgp     |kg P/ha       |average annual amount of
organic P applied
!!                          |in watershed
!!    wshd_ftotn    |kg N/ha       |average annual amount of N
(mineral &
!!                          |organic) applied in watershed
!!    wshd_ftotp    |kg P/ha       |average annual amount of P
(mineral &
!!                          |organic) applied in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    bactlp_plt(:) |# cfu/m^2     |less persistent bacteria on foliage
!!    bactlpq(:)    |# cfu/m^2     |less persistent bacteria in soil
solution
!!    bactlps(:)    |# cfu/m^2     |less persistent bacteria attached to
soil
!!                                 |particles
!!    bactp_plt(:)  |# cfu/m^2     |persistent bacteria on foliage
!!    bactpq(:)     |# cfu/m^2     |persistent bacteria in soil solution
!!    bactps(:)     |# cfu/m^2     |persistent bacteria attached to soil
!!                                 |particles
!!    fertn         |kg N/ha       |total amount of nitrogen applied to
soil
!!                                 |in HRU on day
!!    fertp         |kg P/ha       |total amount of phosphorus applied
to soil
!!                                 |in HRU on day
!!    nfert(:)      |none          |sequence number of fertilizer
application
!!                                 |within the year
!!    sol_aorgn(:,:)|kg N/ha       |amount of nitrogen stored in the
active
!!                                 |organic (humic) nitrogen pool
!!    sol_fon(:,:)  |kg N/ha       |amount of nitrogen stored in the
fresh
!!                                 |organic (residue) pool
!!    sol_fop(:,:)  |kg P/ha       |amount of phosphorus stored in the
fresh
!!                                 |organic (residue) pool
!!    sol_nh3(:,:)  |kg N/ha       |amount of nitrogen stored in the
ammonium
!!                                 |pool in soil layer
!!    sol_no3(:,:)  |kg N/ha       |amount of nitrogen stored in the
nitrate pool
!!                                 |in soil layer
!!    sol_orgp(:,:) |kg P/ha       |amount of phosphorus stored in
the organic
!!                                 |P pool
!!    sol_solp(:,:) |kg P/ha       |amount of inorganic phosohorus
stored in
!!                                 |solution
!!    wshd_fminp    |kg P/ha       |average annual amount of
mineral P applied
!!                                 |in watershed
!!    wshd_fnh3     |kg N/ha       |average annual amount of NH3-
N applied in
!!                                 |watershed
!!    wshd_fno3     |kg N/ha       |average annual amount of NO3-
N applied in
!!                                 |watershed
!!    wshd_orgn     |kg N/ha       |average annual amount of
organic N applied
!!                                 |in watershed
!!    wshd_orgp     |kg P/ha       |average annual amount of
organic P applied
!!                                 |in watershed
!!    wshd_ftotn    |kg N/ha       |average annual amount of N
(mineral &
!!                                 |organic) applied in watershed
!!    wshd_ftotp    |kg P/ha       |average annual amount of P
(mineral &
!!                                 |organic) applied in watershed
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name          |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~
!!    frt_t         |
!!    gc            |
!!    gc1           |
!!    j             |none          |HRU number
!!    l             |none          |counter (soil layer #)
!!    rtof          |none          |weighting factor used to partition the
!!                                 |organic N & P content of the fertilizer
!!                                 |between the fresh organic and the active
!!                                 |organic pools
!!    xx            |none          |fraction of fertilizer applied to layer
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    SWAT: Erfc

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      real, parameter :: rtof=0.5
      integer :: j, l, ifrt
      real :: xx, gc, gc1, swf, frt_t, mjtemp !! Mike White
Modification

      j = 0
      j = ihru

      ifrt = 0
      ifrt = ifrttyp(nro(j),nfert(j),j)

      do l = 1, 2
        xx = 0.
        if (l == 1) then
          xx = frt_surface(nro(j),nfert(j),j)
        else
          xx = 1. - frt_surface(nro(j),nfert(j),j)
        endif

        sol_no3(l,j) = sol_no3(l,j) + xx * frt_kg(nro(j),nfert(j),j) *  &
     &       (1. - fnh3n(ifrt)) * fminn(ifrt)

        sol_fon(l,j) = sol_fon(l,j) + rtof * xx *                      &
     &       frt_kg(nro(j),nfert(j),j) * forgn(ifrt)

        sol_aorgn(l,j) = sol_aorgn(l,j) + (1. - rtof) * xx *          &
     &       frt_kg(nro(j),nfert(j),j) * forgn(ifrt)

        sol_nh3(l,j) = sol_nh3(l,j) + xx * frt_kg(nro(j),nfert(j),j) *  &
     &       fnh3n(ifrt) * fminn(ifrt)

        sol_solp(l,j) = sol_solp(l,j) + xx * frt_kg(nro(j),nfert(j),j) *&
     &       fminp(ifrt)

        sol_fop(l,j) = sol_fop(l,j) + rtof * xx *                      &
     &       frt_kg(nro(j),nfert(j),j) * forgp(ifrt)

        sol_orgp(l,j) = sol_orgp(l,j) + (1. - rtof) * xx *            &
     &       frt_kg(nro(j),nfert(j),j) * forgp(ifrt)

!! Mike White Modification  Add FERT to stable pool for alum
simulation
              mjtemp = rtof * xx * frt_kg(nro(j),nfert(j),j) *
mjwfstabp(ifrt)
              sol_stap(l,j) = sol_stap(l,j) + mjtemp
```

```
!! Mike White Modification
      end do


!! add bacteria - #cfu/g * t(manure)/ha * 1.e6g/t * ha/10,000m^2
= 100.
!! calculate ground cover
      gc = 0.
      gc = (1.99532 - Erfc(1.333 * laiday(j) - 2.)) / 2.1
      if (gc < 0.) gc = 0.

      gc1 = 0.
      gc1 = 1. - gc


      frt_t = 0.
      frt_t = bact_swf * frt_kg(nro(j),nfert(j),j) / 1000.

      bactp_plt(j) = gc * bactpdb(ifrt) * frt_t * 100. + bactp_plt(j)
      bactlp_plt(j) = gc * bactlpdb(ifrt) * frt_t * 100. + bactlp_plt(j)

      bactpq(j) = gc1 * bactpdb(ifrt) * frt_t * 100. + bactpq(j)
      bactpq(j) = bactkddb(ifrt) * bactpq(j)

      bactps(j) = gc1 * bactpdb(ifrt) * frt_t * 100. + bactps(j)
      bactps(j) = (1. - bactkddb(ifrt)) * bactps(j)

      bactlpq(j) = gc1 * bactlpdb(ifrt) * frt_t * 100. + bactlpq(j)
      bactlpq(j) = bactkddb(ifrt) * bactlpq(j)

      bactlps(j) = gc1 * bactlpdb(ifrt) * frt_t * 100. + bactlps(j)
      bactlps(j) = (1. - bactkddb(ifrt)) * bactlps(j)


!! summary calculations
      fertn = fertn + frt_kg(nro(j),nfert(j),j) *                    &
     &   (fminn(ifrt) + forgn(ifrt))

      fertp = fertp + frt_kg(nro(j),nfert(j),j) *                    &
     &   (fminp(ifrt) + forgp(ifrt) + mjwfstabp(ifrt)) !! Mike White
Mod

      tfertn(j) = tfertn(j) + fertn
      tfertp(j) = tfertp(j) + fertp

      if (curyr > nyskip) then
      wshd_ftotn = wshd_ftotn + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) &
     &   * (fminn(ifrt) + forgn(ifrt))

      wshd_forgn = wshd_forgn + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) &
     &   * forgn(ifrt)

      wshd_fno3 = wshd_fno3 + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) * &
     &   fminn(ifrt) * (1. - fnh3n(ifrt))

      wshd_fnh3 = wshd_fnh3 + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) * &
     &   fminn(ifrt) * fnh3n(ifrt)

      wshd_ftotp = wshd_ftotp + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) &
     &   * (fminp(ifrt) + forgp(ifrt)+ mjwfstabp(ifrt))  !! Mike White
Mod

      wshd_fminp = wshd_fminp + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) &
     &   * (fminp(ifrt)+ mjwfstabp(ifrt)) !! Mike White Mod

      wshd_forgp = wshd_forgp + frt_kg(nro(j),nfert(j),j) *
hru_dafr(j) &
     &   * forgp(ifrt)

      end if


!! increase fertilizer sequence number by one
      nfert(j) = nfert(j) + 1

      return
      end
```

subroutine graze

```
!!    ~ ~ ~ PURPOSE ~ ~ ~

!!    this subroutine simulates biomass lost to grazing

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name          |units          |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    bactkddb(:)  |none           |bacteria partition coefficient:
!!                                 |1: all bacteria in solution
!!                                 |0: all bacteria sorbed to soil particles
!!    bactlp_plt(:)|# cfu/m^2      |less persistent bacteria on foliage
!!    bactlpdb(:)  |# cfu/g        |concentration of less persistent
!!                                 |bacteria in manure(fertilizer)
!!    bactlpq(:)   |# cfu/m^2      |less persistent bacteria in soil
solution
!!    bactlps(:)   |# cfu/m^2      |less persistent bacteria attached to
soil
!!                                 |particles
!!    bactp_plt(:) |# cfu/m^2      |persistent bacteria on foliage
!!    bactpdb(:)   |# cfu/g        |concentration of persistent bacteria
!!                                 |in manure(fertilizer)
!!    bactpq(:)    |# cfu/m^2      |persistent bacteria in soil solution
!!    bactps(:)    |# cfu/m^2      |persistent bacteria attached to soil
particles
!!    bio_min(:)   |kg/ha          |minimum plant biomass for grazing
!!    bio_ms(:)    |kg/ha          |land cover/crop biomass (dry
weight)
!!    bio_eat(:,:,:) |(kg/ha)/day  |dry weight of biomass removed
by grazing
!!                                 |daily
!!    bio_trmp(:,:,:)|(kg/ha)/day  |dry weight of biomass removed
by
!!                                 |trampling daily
!!    curyr        |none           |current year of simulation
!!    fminn(:)     |kg minN/kg frt|fraction of mineral N (NO3 + NH3)
in
!!                                 |fertilizer/manure
!!    fminp(:)     |kg minP/kg frt|fraction of mineral P in
fertilizer/manure
!!    fnh3n(:)     |kg NH3-N/kg minN|fraction of NH3-N in mineral
N in
!!                                 |fertilizer/manure
!!    forgn(:)     |kg orgN/kg frt|fraction of organic N in
fertilizer/manure
!!    forgp(:)     |kg orgP/kg frt|fraction of organic P in
fertilizer/manure
!!    grazn        |kg N/ha        |total amount of nitrogen applied to
soil
!!                                 |during grazing in HRU on day
!!    grazp        |kg P/ha        |total amount of phosphorus applied
to soil
!!                                 |during grazing in HRU on day
!!    hru_dafr(:)  |km**2/km**2    |fraction of watershed area in
HRU
!!    icr(:)       |none           |sequence number of crop grown
within the
!!                                 |current year
!!    iida         |julian date    |day being simulated (current julian
day
```

```
!!    manure_id(:,:,:)|none         |manure (fertilizer) identification
!!                                  |number from fert.dat
!!    igraz(:,:,:) |julian date   |date grazing operation begins
!!    igrz(:)      |none          |grazing flag for HRU:
!!                                  |0 HRU currently not grazed
!!                                  |1 HRU currently grazed
!!    ihru         |none          |HRU number
!!    laiday(:)    |m**2/m**2     |leaf area index
!!    grz_days(:,:,:)|none          |number of days grazing will be
simulated
!!    ngr(:)       |none          |sequence number of grazing
operation
!!                                  |within the year
!!    nro(:)       |none          |sequence number of year in rotation
!!    nyskip       |none          |number of years to skip output
summarization
!!                                  |and printing
!!    phuacc(:)    |none          |fraction of plant heat units
accumulated
!!    phug(:,:,:)  |none          |fraction of plant heat units at which
!!                                  |grazing begins
!!    plantn(:)    |kg N/ha       |amount of nitrogen in plant
!!    plantp(:)    |kg P/ha       |amount of phosphorus in plant
!!    pltfr_n(:)   |none          |fraction of plant biomass that is
nitrogen
!!    pltfr_p(:)   |none          |fraction of plant biomass that is
phosphorus
!!    sol_bd(:,:)  |Mg/m**3       |bulk density of the soil
!!    sol_fon(:,:) |kg N/ha       |amount of nitrogen stored in the
fresh
!!                                  |organic (residue) pool
!!    sol_fop(:,:) |kg P/ha       |amount of phosphorus stored in the
fresh
!!                                  |organic (residue) pool
!!    sol_nh3(:,:) |kg N/ha       |amount of nitrogen stored in the
ammonium
!!                                  |pool in soil layer
!!    sol_no3(:,:) |kg N/ha       |amount of nitrogen stored in the
nitrate pool
!!                                  |in soil layer
!!    sol_rsd(:,:) |kg/ha         |amount of organic matter in the soil
!!                                  |classified as residue
!!    sol_solp(:,:)|kg P/ha       |amount of phosohorus stored in
solution
!!    sol_z(:,:)   |mm            |depth to bottom of soil layer
!!    manure_kg(:,:,:)|(kg/ha)/day  |dry weight of manure
deposited on HRU
!!                                  |daily
!!    wshd_fminp   |kg P/ha       |average annual amount of
mineral P applied
!!                                  |in watershed
!!    wshd_fnh3    |kg N/ha       |average annual amount of NH3-
N applied in
!!                                  |watershed
!!    wshd_fno3    |kg N/ha       |average annual amount of NO3-
N applied in
!!                                  |watershed
!!    wshd_orgn    |kg N/ha       |average annual amount of
organic N applied
!!                                  |in watershed
!!    wshd_orgp    |kg P/ha       |average annual amount of
organic P applied
!!                                  |in watershed
!!    wshd_ftotn   |kg N/ha       |average annual amount of N
(mineral &
!!                                  |organic) applied in watershed
!!    wshd_ftotp   |kg P/ha       |average annual amount of P
(mineral &
!!                                  |organic) applied in watershed
!!    yldkg(:,:,:) |kg/ha         |yield (dry weight) by crop type in the
HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name         |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    bactlp_plt(:)|# cfu/m^2     |less persistent bacteria on foliage
!!    bactlpq(:)   |# cfu/m^2     |less persistent bacteria in soil
solution
!!    bactlps(:)   |# cfu/m^2     |less persistent bacteria attached to
soil
!!                                  |particles
!!    bactp_plt(:)|# cfu/m^2      |persistent bacteria on foliage
!!    bactpq(:)    |# cfu/m^2     |persistent bacteria in soil solution
!!    bactps(:)    |# cfu/m^2     |persistent bacteria attached to soil
particles
!!    bio_ms(:)    |kg/ha         |land cover/crop biomass (dry
weight)
!!    grazn        |kg N/ha       |total amount of nitrogen applied to
soil
!!                                  |during grazing in HRU on day
!!    grazp        |kg P/ha       |total amount of phosphorus applied
to soil
!!                                  |during grazing in HRU on day
!!    igrz(:)      |none          |grazing flag for HRU:
!!                                  |0 HRU currently not grazed
!!                                  |1 HRU currently grazed
!!    laiday(:)    |m**2/m**2     |leaf area index
!!    ndeat(:)     |days          |number of days HRU has been
grazed
!!    ngr(:)       |none          |sequence number of grazing
operation
!!                                  |within the year
!!    phuacc(:)    |none          |fraction of plant heat units
accumulated
!!    plantn(:)    |kg N/ha       |amount of nitrogen in plant
!!    plantp(:)    |kg P/ha       |amount of phosphorus in plant
!!    sol_fon(:,:)|kg N/ha        |amount of nitrogen stored in the
fresh
!!                                  |organic (residue) pool
!!    sol_fop(:,:)|kg P/ha        |amount of phosphorus stored in the
fresh
!!                                  |organic (residue) pool
!!    sol_nh3(:,:)|kg N/ha        |amount of nitrogen stored in the
ammonium
!!                                  |pool in soil layer
!!    sol_no3(:,:)|kg N/ha        |amount of nitrogen stored in the
nitrate pool
!!                                  |in soil layer
!!    sol_rsd(:,:)|kg/ha          |amount of organic matter in the soil
!!                                  |classified as residue
!!    sol_solp(:,:)|kg P/ha       |amount of phosohorus stored in
solution
!!    wshd_fminp   |kg P/ha       |average annual amount of
mineral P applied
!!                                  |in watershed
!!    wshd_fnh3    |kg N/ha       |average annual amount of NH3-N
applied in
!!                                  |watershed
!!    wshd_fno3    |kg N/ha       |average annual amount of NO3-N
applied in
!!                                  |watershed
!!    wshd_orgn    |kg N/ha       |average annual amount of
organic N applied
!!                                  |in watershed
!!    wshd_orgp    |kg P/ha       |average annual amount of
organic P applied
!!                                  |in watershed
!!    wshd_ftotn   |kg N/ha       |average annual amount of N
(mineral &
!!                                  |organic) applied in watershed
!!    wshd_ftotp   |kg P/ha       |average annual amount of P
(mineral &
!!                                  |organic) applied in watershed
!!    yldkg(:,:,:)|kg/ha          |yield (dry weight) by crop type in the
HRU
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name         |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    dmi          |kg/ha         |biomass in HRU prior to grazing
```

```
!!    dmii        |kg/ha         |biomass prior to trampling
!!    frt_t       |
!!    gc          |
!!    gc1         |
!!    it          |none          |manure/fertilizer id number from fert.dat
!!    j           |none          |HRU number
!!    l           |none          |number of soil layer that manure is
applied
!!    swf         |
!!    xx          |
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: Max
!!    SWAT: Erfc

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm

      integer :: j, l, it
      real :: dmi, dmii, gc, gc1, swf, frt_t, xx

      j = 0
      j = ihru

!! if HRU currently not grazed, check to see if it is time
!! to initialize grazing
      if (igrz(j) == 0) then
        if (igraz(nro(j),ngr(j),j) > 0 .and.                         &
     &                       iida >= igraz(nro(j),ngr(j),j)) then
          igrz(j) = 1
          ndeat(j) = 1
        else if (phuacc(j) > phug(nro(j),ngr(j),j)) then
          igrz(j) = 1
          ndeat(j) = 1
        else
          return
        end if
      else
        !! if not first day of grazing increment total days of grazing
by one
        ndeat(j) = ndeat(j) + 1
      end if

!! graze only if adequate biomass in HRU
      if (bio_ms(j) > bio_min(j)) then

        !! determine new biomass in HRU
        dmi = 0.
        dmi = bio_ms(j)
        bio_ms(j) = bio_ms(j) - bio_eat(nro(j),ngr(j),j)
        if (bio_ms(j) < bio_min(j)) bio_ms(j) = bio_min(j)

        !! adjust nutrient content of biomass
        plantn(j) = plantn(j) - (dmi - bio_ms(j)) * pltfr_n(j)
        plantp(j) = plantp(j) - (dmi - bio_ms(j)) * pltfr_p(j)
        if (plantn(j) < 0.) plantn(j) = 0.
        if (plantp(j) < 0.) plantp(j) = 0.

        !! remove trampled biomass and add to residue
        dmii = 0.
        dmii = bio_ms(j)
        bio_ms(j) = bio_ms(j) - bio_trmp(nro(j),ngr(j),j)
        if (bio_ms(j) < bio_min(j))  then
          sol_rsd(1,j) = sol_rsd(1,j) + dmii - bio_min(j)
          bio_ms(j) = bio_min(j)
        else
          sol_rsd(1,j) = sol_rsd(1,j) + bio_trmp(nro(j),ngr(j),j)
        endif
        sol_rsd(1,j) = Max(sol_rsd(1,j),0.)
        bio_ms(j) = Max(bio_ms(j),0.)

        !! adjust nutrient content of residue and biomass for
        !! trampling
        plantn(j) = plantn(j) - (dmii - bio_ms(j)) * pltfr_n(j)
        plantp(j) = plantp(j) - (dmii - bio_ms(j)) * pltfr_p(j)
        if (plantn(j) < 0.) plantn(j) = 0.
        if (plantp(j) < 0.) plantp(j) = 0.
        if (dmii - bio_ms(j) > 0.) then
          sol_fon(1,j) = (dmii - bio_ms(j)) * pltfr_n(j) + sol_fon(1,j)
          sol_fop(1,j) = (dmii - bio_ms(j)) * pltfr_p(j) + sol_fop(1,j)
        end if


        !! apply manure
        it = 0
        it = manure_id(nro(j),ngr(j),j)
        if (manure_kg(nro(j),ngr(j),j) > 0.) then
          l = 1

          sol_no3(l,j) = sol_no3(l,j) + manure_kg(nro(j),ngr(j),j) *
     &
     &                 (1. - fnh3n(it)) * fminn(it)
          sol_fon(l,j) = sol_fon(l,j) + manure_kg(nro(j),ngr(j),j) *    &
     &                 forgn(it)
          sol_nh3(l,j) = sol_nh3(l,j) + manure_kg(nro(j),ngr(j),j) *
     &
     &                 fnh3n(it) * fminn(it)
!! mike white modifications
!! set P in manure to what was consumed in forage that day
                      sol_solp(l,j) = sol_solp(l,j) +
     &   (dmi - bio_ms(j)) * pltfr_p(j) * 0.36

                      sol_fop(l,j) = sol_fop(l,j) +
     &   (dmi - bio_ms(j)) * pltfr_p(j) * 0.64


!!        sol_solp(l,j) = sol_solp(l,j) + manure_kg(nro(j),ngr(j),j) *
&
!!   &              fminp(it)
!!      sol_fop(l,j) = sol_fop(l,j) + manure_kg(nro(j),ngr(j),j) *
&
!!   &              forgp(it)

!! add bacteria - #cfu/g * t(manure)/ha * 1.e6 g/t * ha/10,000
m^2 = 100.
!! calculate ground cover
          gc = 0.
          gc = (1.99532 - Erfc(1.333 * laiday(j) - 2.)) / 2.1
          if (gc < 0.) gc = 0.

          gc1 = 0.
          gc1 = 1. - gc

          swf = .15

          frt_t = 0.
          frt_t = bact_swf * manure_kg(nro(j),ngr(j),j) / 1000.

          bactp_plt(j) = gc * bactpdb(it) * frt_t * 100. + bactp_plt(j)
          bactlp_plt(j) = gc * bactlpdb(it) * frt_t * 100.+bactlp_plt(j)

          bactpq(j) = gc1 * bactpdb(it)  * frt_t * 100. + bactpq(j)
          bactpq(j) = bactkddb(it) * bactpq(j)

          bactps(j) = gc1 * bactpdb(it) * frt_t * 100. + bactps(j)
          bactps(j) = (1. - bactkddb(it)) * bactps(j)

          bactlpq(j) = gc1 * bactlpdb(it) * frt_t * 100. + bactlpq(j)
          bactlpq(j) = bactkddb(it) * bactlpq(j)

          bactlps(j) = gc1 * bactlpdb(it) * frt_t * 100. + bactlps(j)
          bactlps(j) = (1. - bactkddb(it)) * bactlps(j)

        endif

        !! reset leaf area index and fraction of growing season
        if (dmi > 1.) then
          laiday(j) = laiday(j) * bio_ms(j) / dmi
          phuacc(j) = phuacc(j) * bio_ms(j) / dmi
        else
          laiday(j) = 0.05
          phuacc(j) = 0.
        endif
```

```
!! summary calculations
grazn = grazn + manure_kg(nro(j),ngr(j),j) *                &
&            (fminn(it) + forgn(it))
grazp = grazp + manure_kg(nro(j),ngr(j),j) *                &
&            (fminp(it) + forgp(it))
tgrazn(j) = tgrazn(j) + grazn
tgrazp(j) = tgrazp(j) + grazp

if (curyr > nyskip) then
  wshd_ftotn = wshd_ftotn + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * (fminn(it) + forgn(it))
  wshd_forgn = wshd_forgn + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * forgn(it)
  wshd_fno3 = wshd_fno3 + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * fminn(it) * (1. - fnh3n(it))
  wshd_fnh3 = wshd_fnh3 + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * fminn(it) * fnh3n(it)
  wshd_ftotp = wshd_ftotp + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * (fminp(it) + forgp(it))
  wshd_fminp = wshd_fminp + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * fminp(it)
  wshd_forgp = wshd_forgp + manure_kg(nro(j),ngr(j),j) *
&
&            hru_dafr(j) * forgp(it)
  yldkg(nro(j),1,j) = yldkg(nro(j),1,j) + (dmi - bio_ms(j))
  !yldkg(nro(j),icr(j),j) = yldkg(nro(j),icr(j),j) + (dmi -
bio_ms(j))
    end if
  end if

!! check to set if grazing period is over
  if (ndeat(j) == grz_days(nro(j),ngr(j),j)) then
    igrz(j) = 0
    ndeat(j) = 0
    ngr(j) = ngr(j) + 1
  end if


  return
  end
```

Subroutine Main

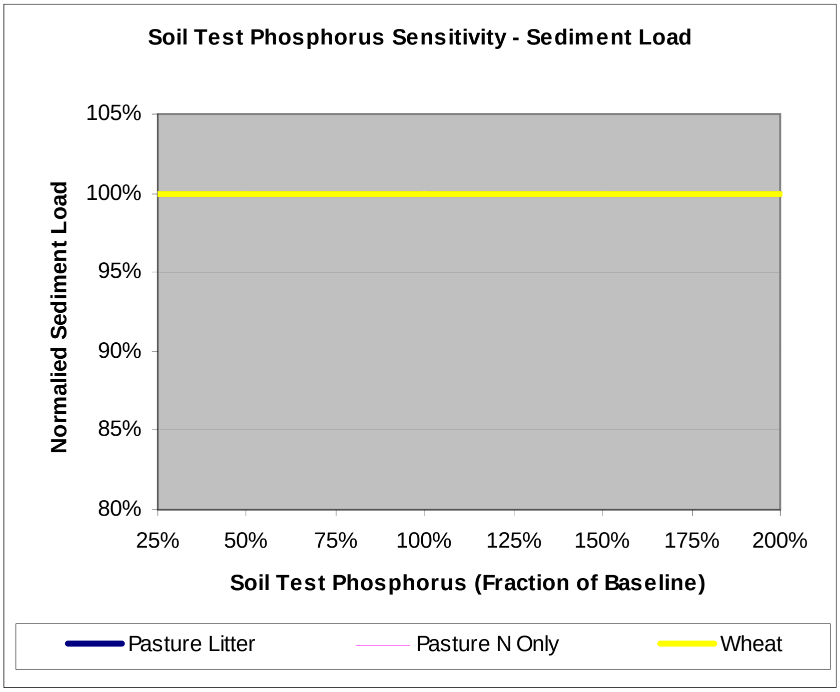
```
include 'modparm.f'
program main

!!    ~ ~ ~ PURPOSE ~ ~ ~
!!    this is the main program that reads input, calls the main
simulation
!!    model, and writes output
!!    comment changes to test merging with trunk and
c:\branch_test code
!!    two lines added to c:\branch_test code

!!    ~ ~ ~ INCOMING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    date        |NA            |date simulation is performed where
leftmost
!!                               |eight characters are set to a value of
!!                               |yyyymmdd, where yyyy is the year, mm is
the
!!                               |month and dd is the day
!!    isproj      |none          |special project code:
!!                               |1 test rewind (run simulation twice)
!!    time        |NA            |time simulation is performed where
leftmost
!!                               |ten characters are set to a value of
!!                               |hhmmss.sss, where hh is the hour, mm is
the
!!                               |minutes and ss.sss is the seconds and
!!                               |milliseconds
!!    values(1)   |year          |year simulation is performed
!!    values(2)   |month         |month simulation is performed
!!    values(3)   |day           |day in month simulation is performed
!!    values(4)   |minutes       |time difference with respect to
Coordinated
!!                               |Universal Time (ie Greenwich Mean Time)
!!    values(5)   |hour          |hour simulation is performed
!!    values(6)   |minutes       |minute simulation is performed
!!    values(7)   |seconds       |second simulation is performed
!!    values(8)   |milliseconds  |millisecond simulation is
performed
!!    zone        |NA            |time difference with respect to
Coordinated
!!                               |Universal Time (ie Greenwich Mean Time)
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ OUTGOING VARIABLES ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    prog        |NA            |program name and version
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~

!!    ~ ~ ~ LOCAL DEFINITIONS ~ ~ ~
!!    name        |units         |definition
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~
!!    i           |none          |counter
!!    ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~
~ ~ ~ ~ ~


!!    ~ ~ ~ SUBROUTINES/FUNCTIONS CALLED ~ ~ ~
!!    Intrinsic: date_and_time
!!    SWAT: getallo, allocate_parms, readfile, readfig
!!    SWAT: readbsn, std1, readwwq, readinpt, std2, storeinitial
!!    SWAT: openwth, headout, simulate, finalbal, writeaa, pestw

!!    ~ ~ ~ ~ ~ ~ END SPECIFICATIONS ~ ~ ~ ~ ~ ~

      use parm
      implicit none
      prog = "SWAT PPM Modified 5-11-2007"

      write (*,1000)
 1000 format(1x,"       SWAT2005 for PPM 5-14-2007     ",/,
&
&         "     Soil & Water Assessment Tool    ",/,              &
!  &         "            UNIX Version            ",/,            &
&         " Based on Developer Version 5-11-2007  ",/,
&
&         " Program reading from file.cio . . . executing",/)

!! process input


      call getallo
```

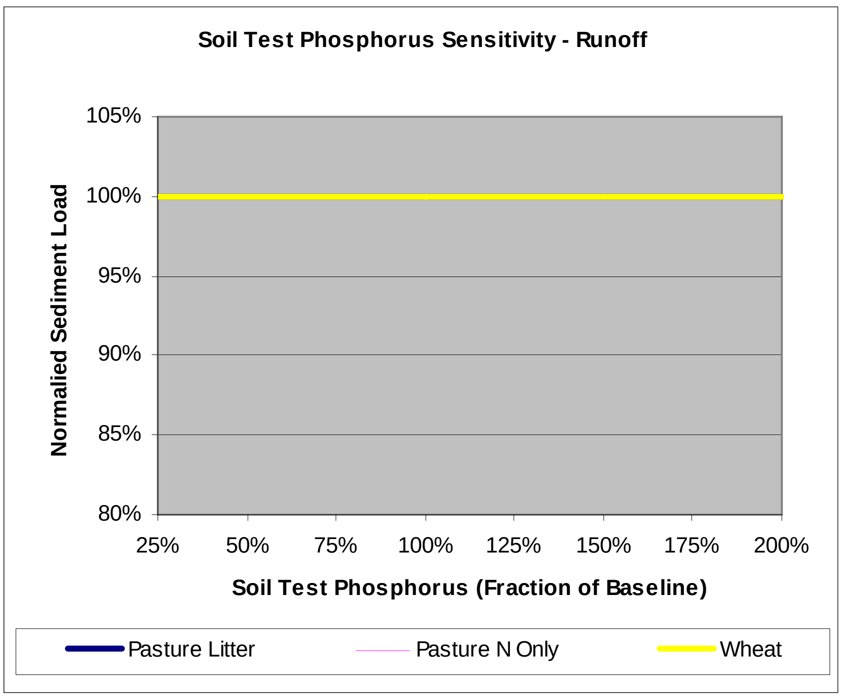
```
      call allocate_parms
      call readfile
      call readbsn
      call readwwq
      if (fcstyr > 0 .and. fcstday > 0) call readfcst
      call readcrop            !! read in the landuse/landcover
database
      call readtill            !! read in the tillage database
      call readpest            !! read in the pesticide database
      call readfert            !! read in the fertilizer/nutrient
database
      call readurban           !! read in the urban land types
database
      call readfig
      call readatmodep
      call readinpt
      call std1
      call std2
      call openwth
      call headout

      if (isproj == 2) then
        hi_targ = 0.0
      end if

!! save initial values
      if (isproj == 1) then
        scenario = 2
        call storeinitial
      else if (fcstcycles > 1) then
        scenario =  fcstcycles
        call storeinitial
      else
        scenario = 1
      endif
        if (iclb /= 4) then
      do iscen = 1, scenario


        !! simulate watershed processes
        call simulate

        !! perform summary calculations
        call finalbal
        call writeaa
        call pestw

        !!reinitialize for new scenario
        if (scenario > iscen) call rewind_init
      end do
         end if
      do i = 1, 9
        close (i)
      end do
      write (*,1001)
 1001 format (/," Execution successfully completed ")


        iscen=1
        if (iclb > 0) call automet
                stop
      end
```

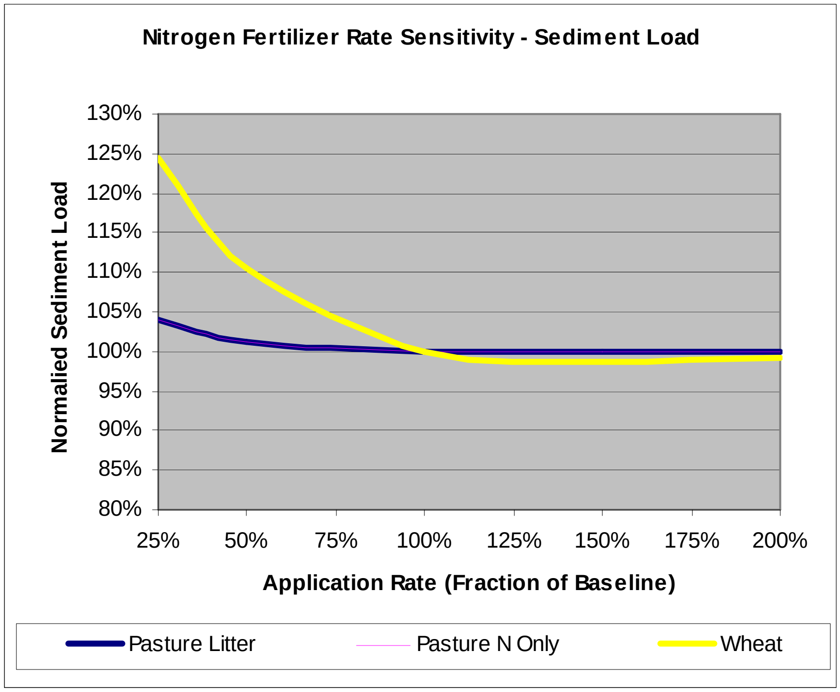
Appendix D

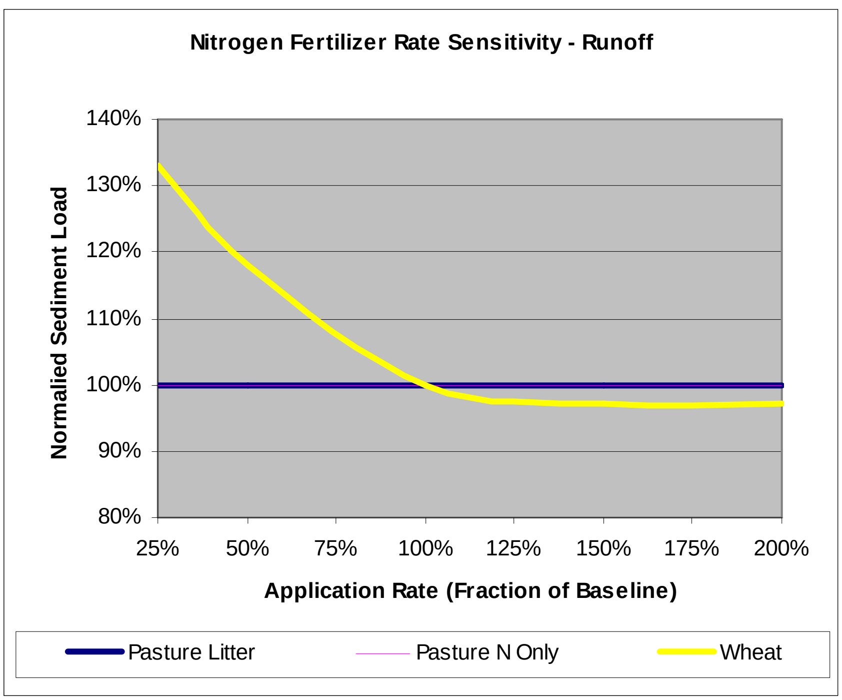
PPM Plus

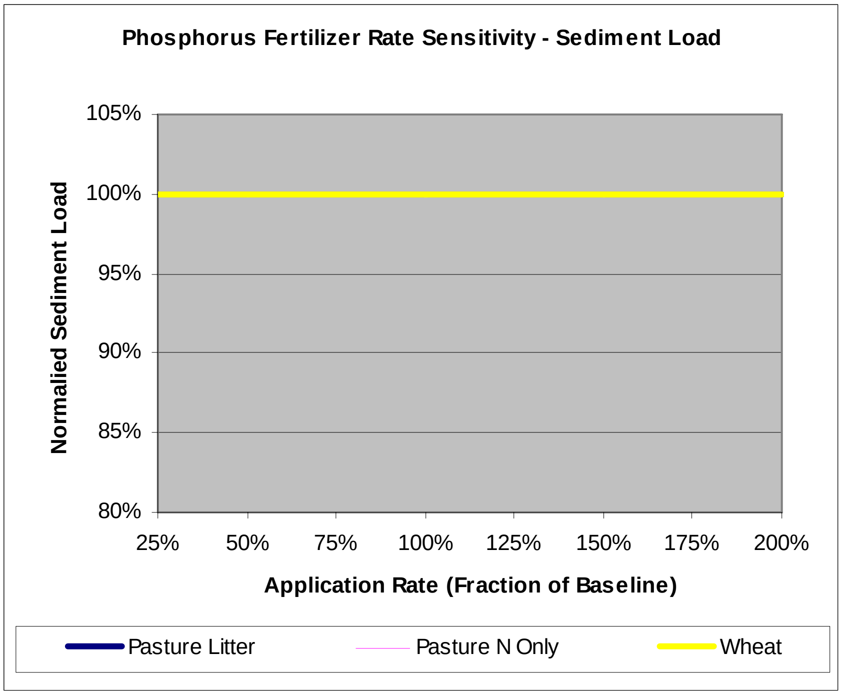
Parameter Sensitivity Graphs

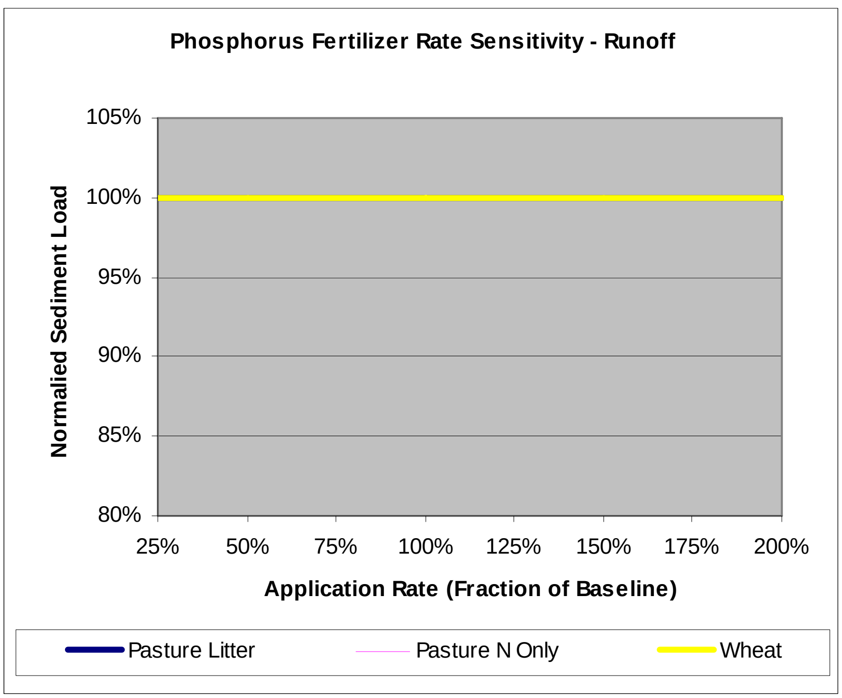

Soil Test Phosphorus Sensitivity - Sediment Load
Normalied Sediment Load
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Soil Test Phosphorus (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

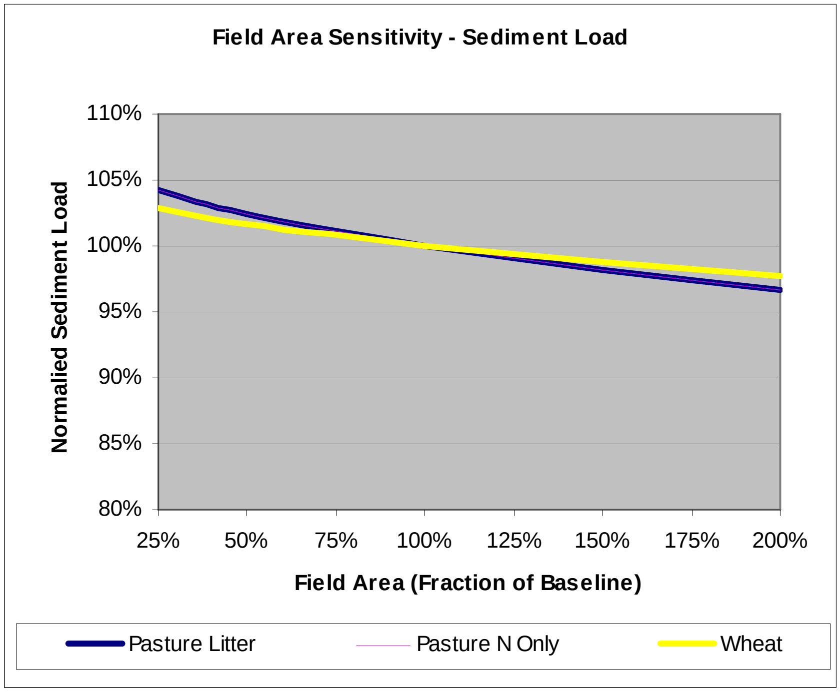

Soil Test Phosphorus Sensitivity - Runoff
Normalied Sediment Load
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Soil Test Phosphorus (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

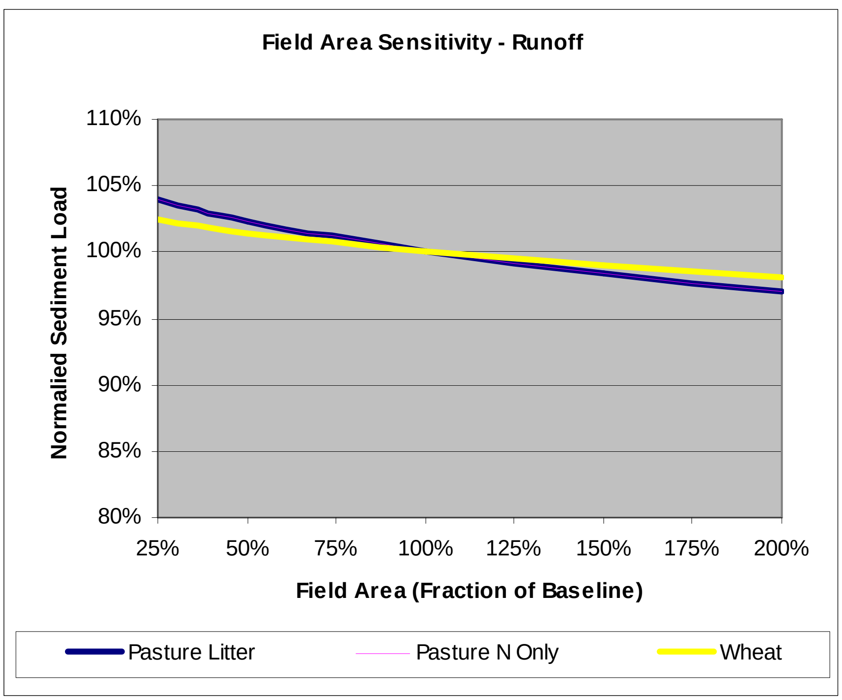

Nitrogen Fertilizer Rate Sensitivity - Sediment Load
130%
125%
120%
115%
110%
105%
100%
95%
90%
85%
80%
Normalied Sediment Load
25%
50%
75%
100%
125%
150%
175%
200%
Application Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

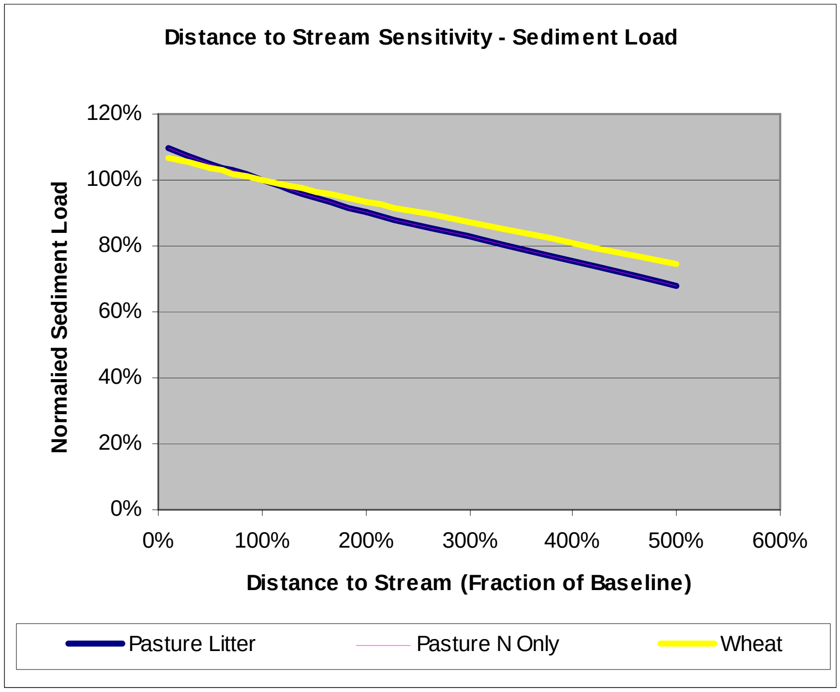

Nitrogen Fertilizer Rate Sensitivity - Runoff
140%
130%
120%
110%
100%
90%
80%
Normalied Sediment Load
25%
50%
75%
100%
125%
150%
175%
200%
Application Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

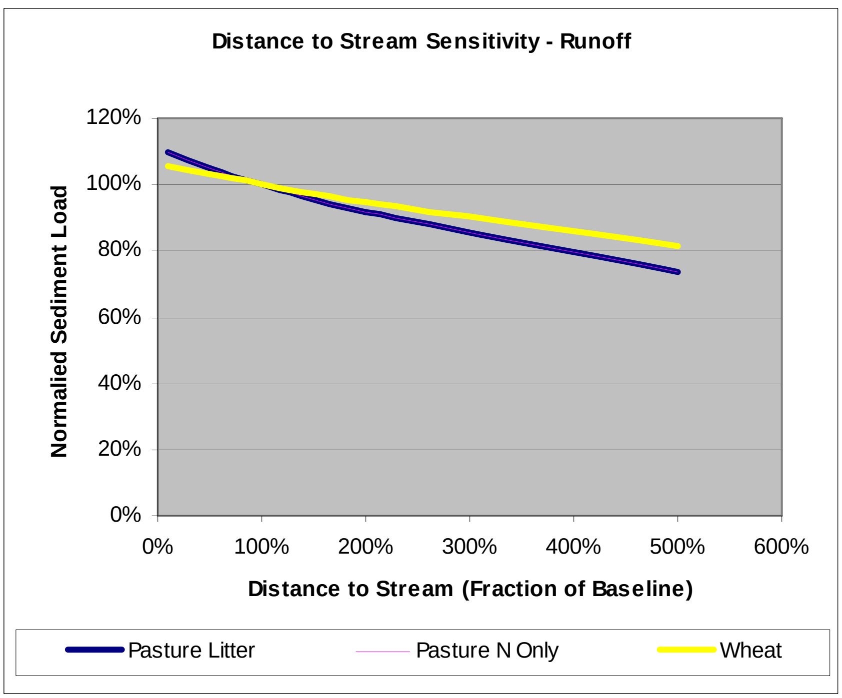

Phosphorus Fertilizer Rate Sensitivity - Sediment Load
Normalied Sediment Load
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Application Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

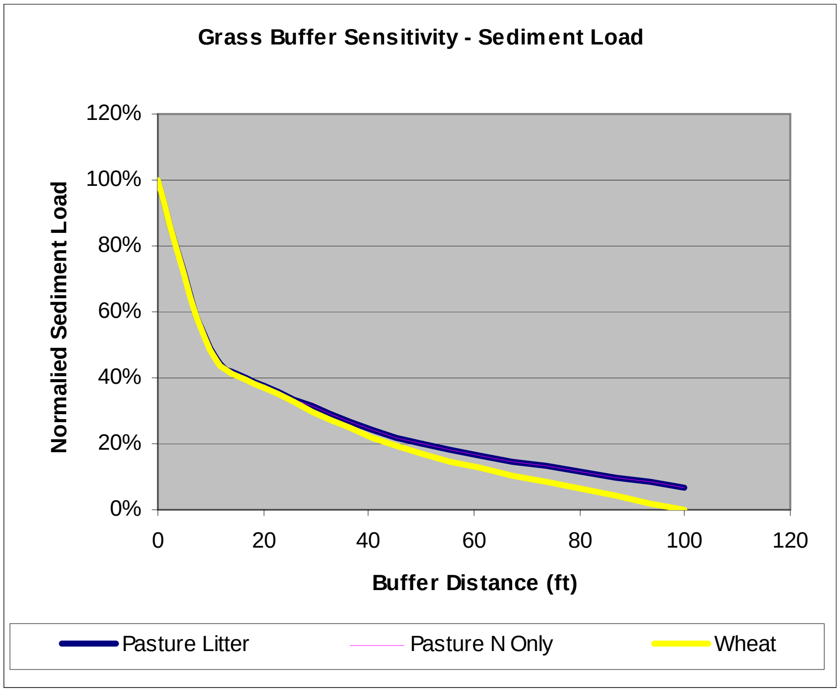

Phosphorus Fertilizer Rate Sensitivity - Runoff
Normalied Sediment Load
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Application Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

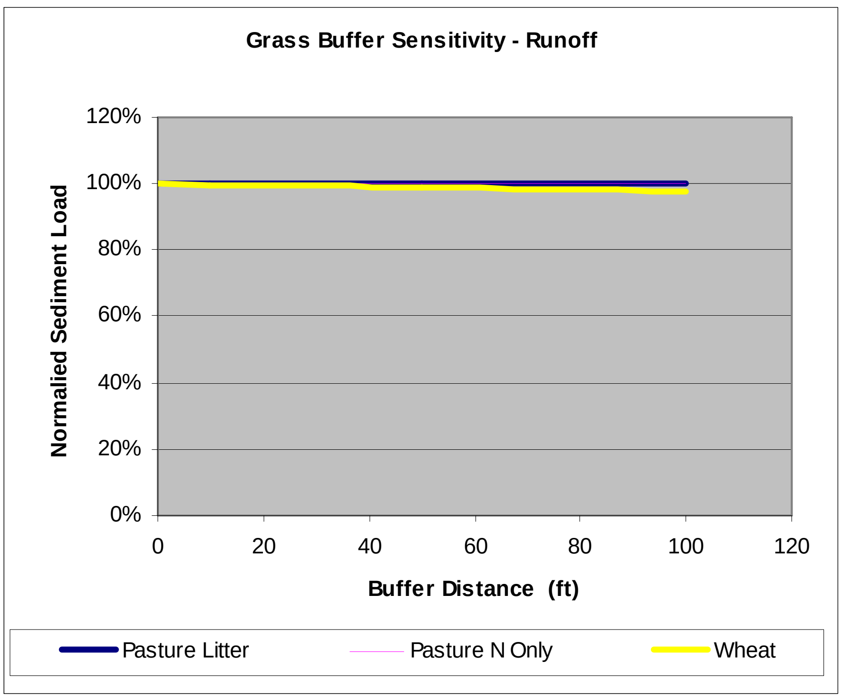

Field Area Sensitivity - Sediment Load
Normalied Sediment Load
110%
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Field Area (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

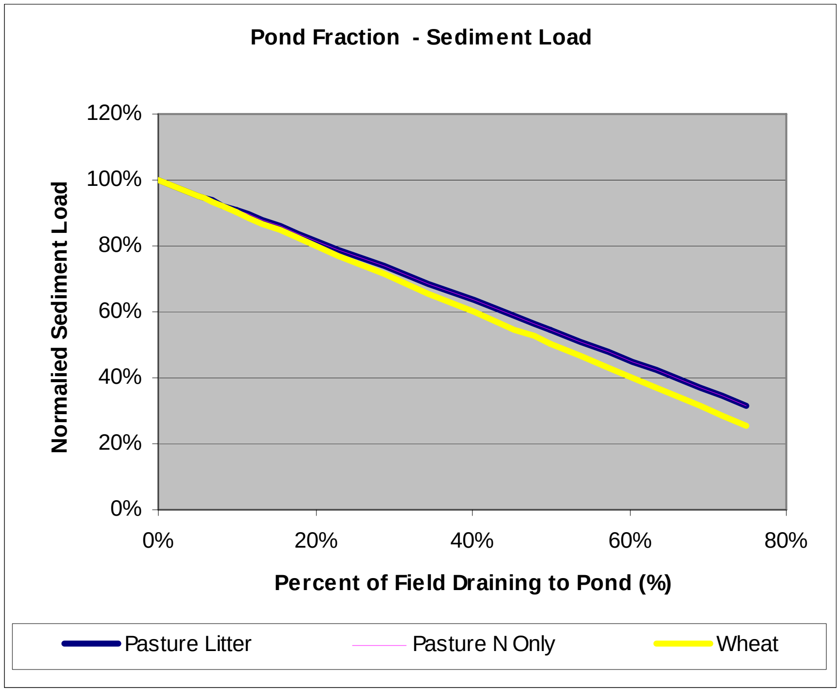

Field Area Sensitivity - Runoff
Normalied Sediment Load
110%
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Field Area (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

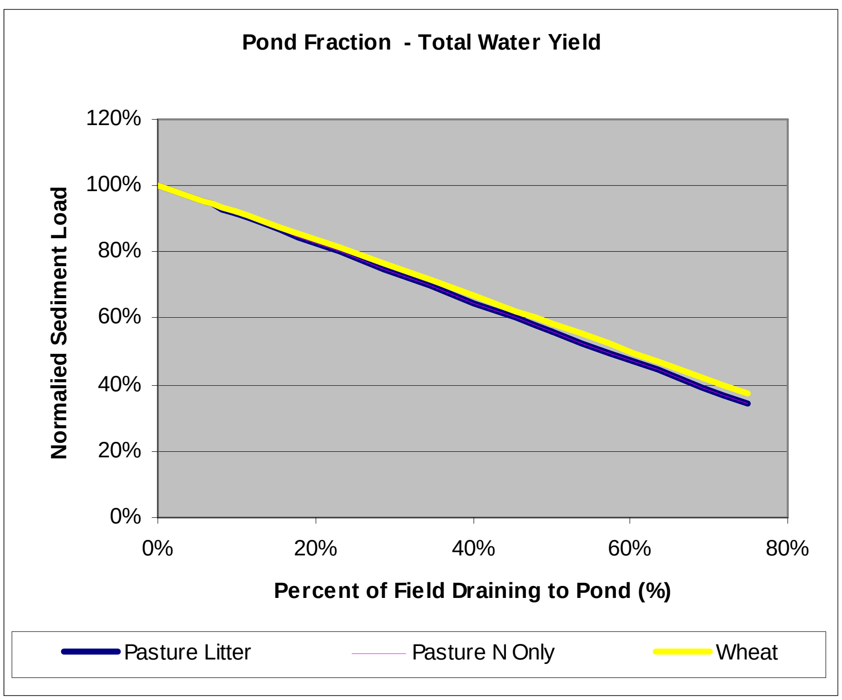

Distance to Stream Sensitivity - Sediment Load
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0%
100%
200%
300%
400%
500%
600%
Distance to Stream (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

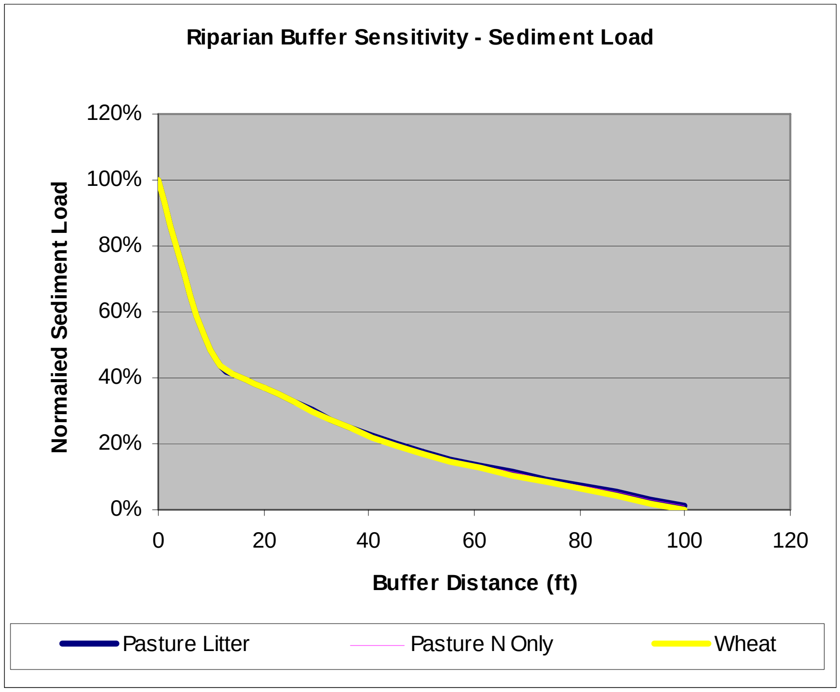

Distance to Stream Sensitivity - Runoff
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0%
100%
200%
300%
400%
500%
600%
Distance to Stream (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

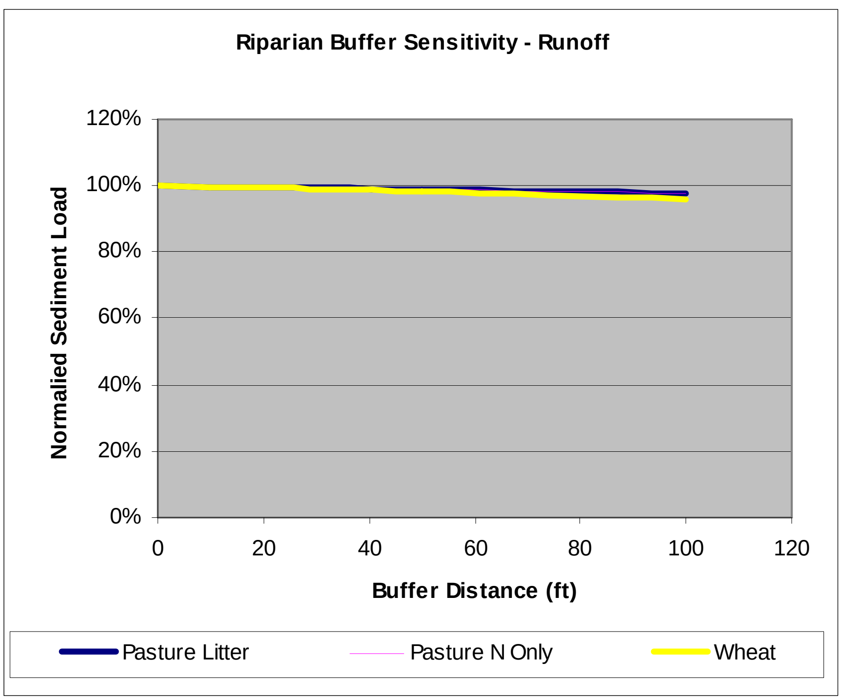

Grass Buffer Sensitivity - Sediment Load
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0
20
40
60
80
100
120
Buffer Distance (ft)
Pasture Litter
Pasture N Only
Wheat

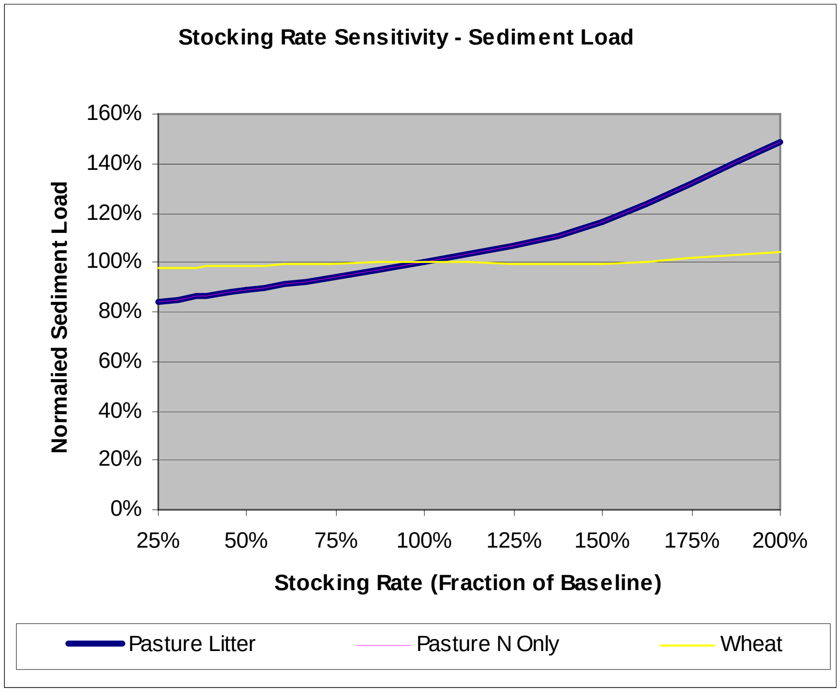

Grass Buffer Sensitivity - Runoff
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0
20
40
60
80
100
120
Buffer Distance (ft)
Pasture Litter
Pasture N Only
Wheat

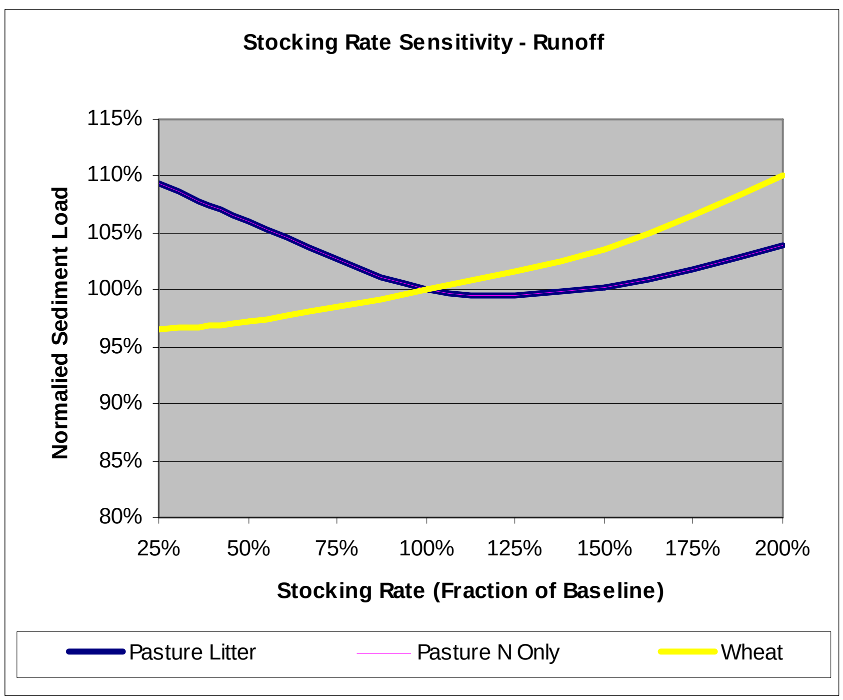

Pond Fraction - Sediment Load
120%
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
Normalied Sediment Load
Percent of Field Draining to Pond (%)
Pasture Litter
Pasture N Only
Wheat

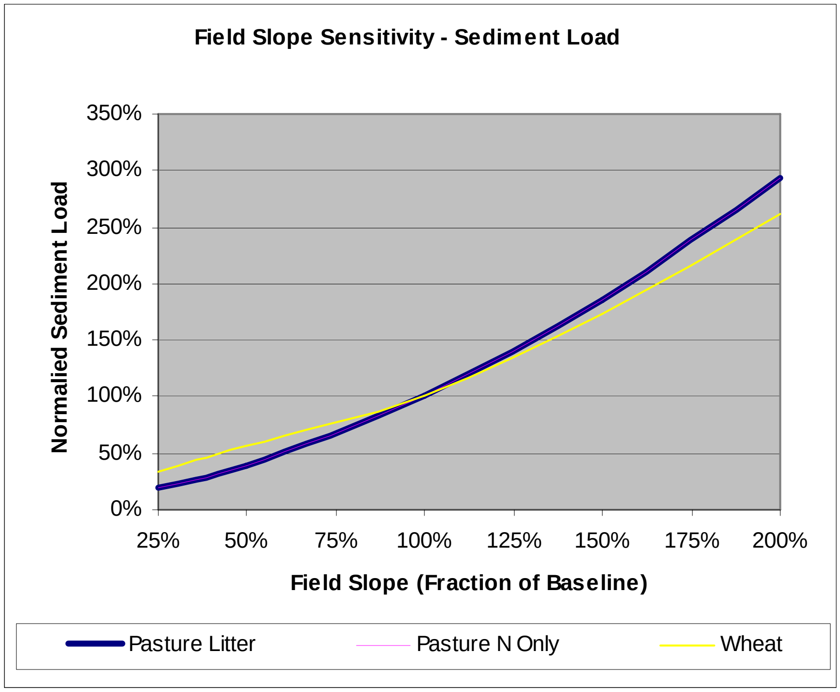

Pond Fraction - Total Water Yield
120%
100%
80%
60%
40%
20%
0%
0%
20%
40%
60%
80%
Normalied Sediment Load
Percent of Field Draining to Pond (%)
Pasture Litter
Pasture N Only
Wheat

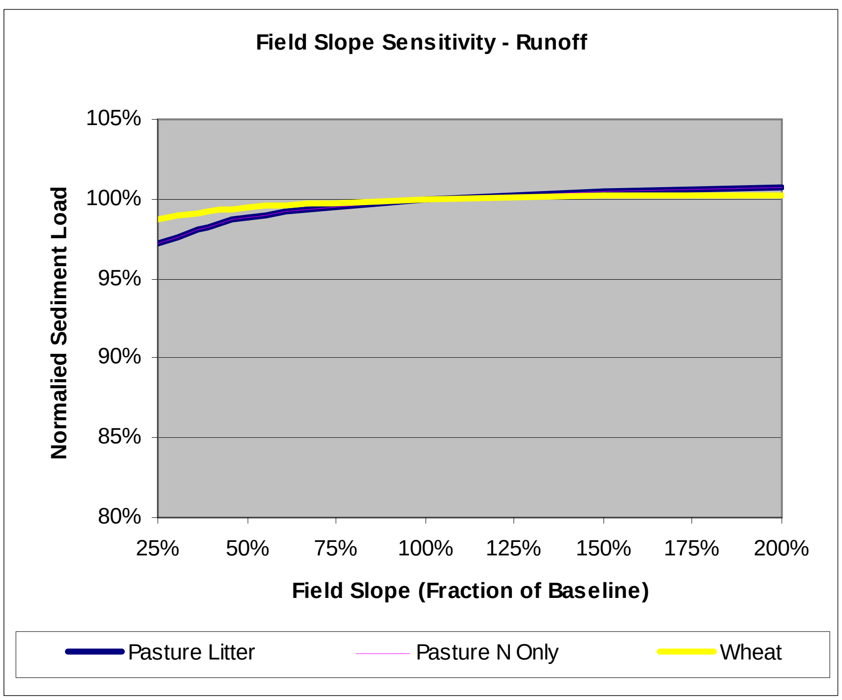

Riparian Buffer Sensitivity - Sediment Load
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0
20
40
60
80
100
120
Buffer Distance (ft)
Pasture Litter
Pasture N Only
Wheat

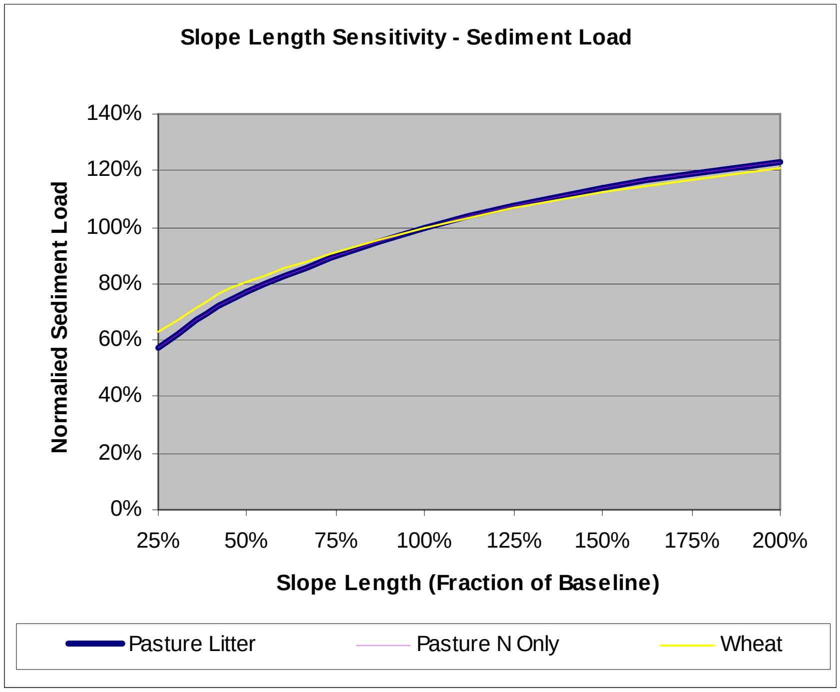

Riparian Buffer Sensitivity - Runoff
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
0
20
40
60
80
100
120
Buffer Distance (ft)
Pasture Litter
Pasture N Only
Wheat

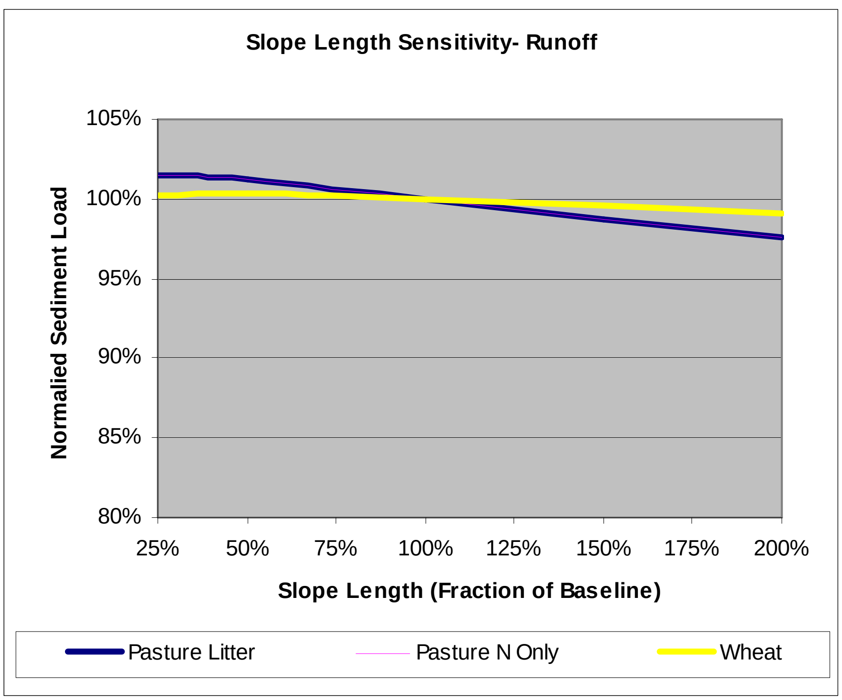

Stocking Rate Sensitivity - Sediment Load
160%
140%
120%
100%
80%
60%
40%
20%
0%
25%
50%
75%
100%
125%
150%
175%
200%
Normalied Sediment Load
Stocking Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

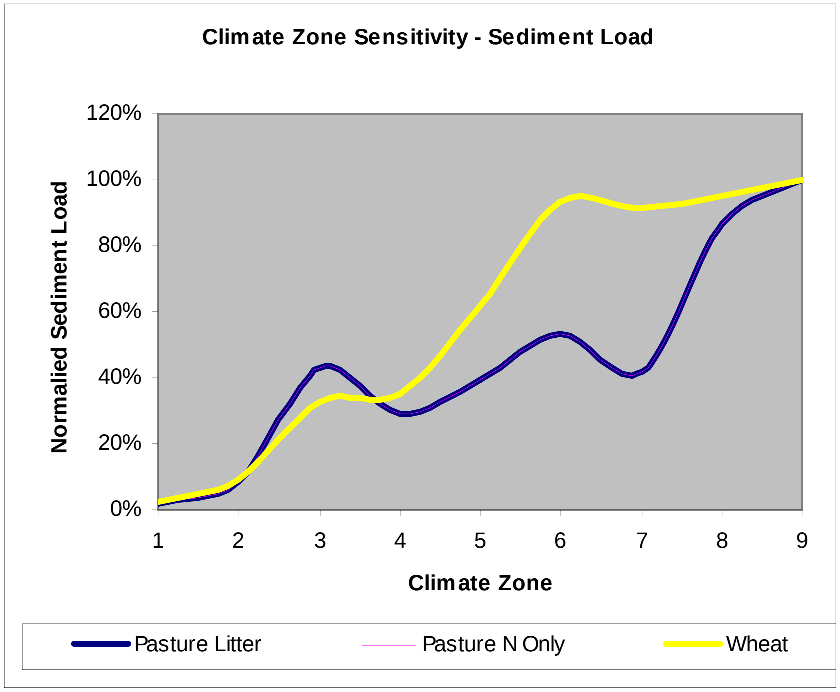

Stocking Rate Sensitivity - Runoff
115%
110%
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Normalied Sediment Load
Stocking Rate (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

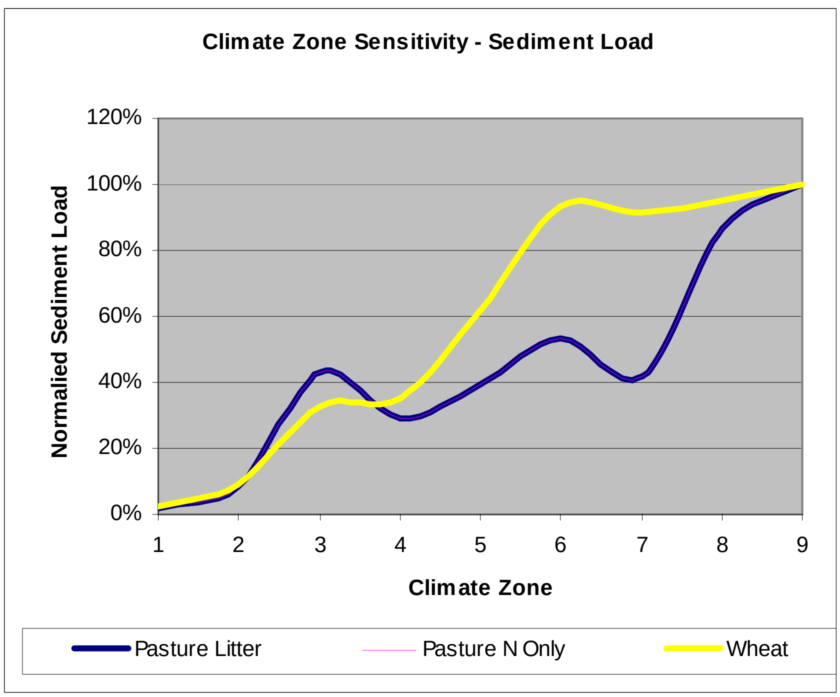

Field Slope Sensitivity - Sediment Load
Normalied Sediment Load
350%
300%
250%
200%
150%
100%
50%
0%
25%
50%
75%
100%
125%
150%
175%
200%
Field Slope (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

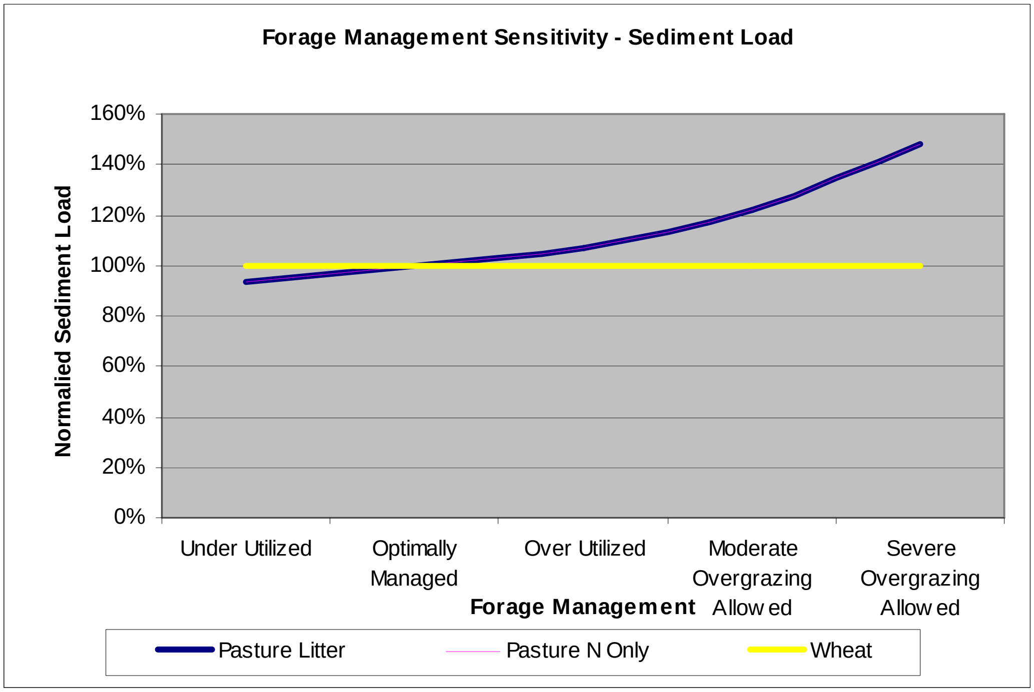

Field Slope Sensitivity - Runoff
Normalied Sediment Load
105%
100%
95%
90%
85%
80%
25%
50%
75%
100%
125%
150%
175%
200%
Field Slope (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat

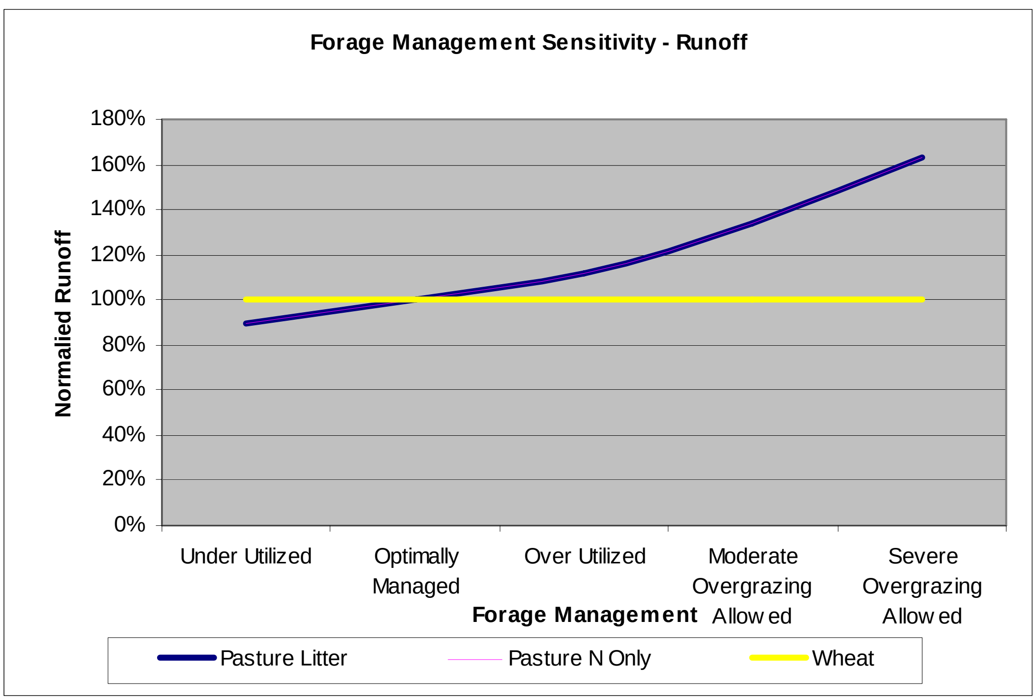

Slope Length Sensitivity - Sediment Load
140%
120%
100%
80%
60%
40%
20%
0%
Normalied Sediment Load
25%
50%
75%
100%
125%
150%
175%
200%
Slope Length (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat


Slope Length Sensitivity- Runoff
105%
100%
95%
90%
85%
80%
Normalied Sediment Load
25%
50%
75%
100%
125%
150%
175%
200%
Slope Length (Fraction of Baseline)
Pasture Litter
Pasture N Only
Wheat


Climate Zone Sensitivity - Sediment Load
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
Climate Zone
Pasture Litter
Pasture N Only
Wheat


Climate Zone Sensitivity - Sediment Load
Normalied Sediment Load
120%
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
Climate Zone
Pasture Litter
Pasture N Only
Wheat


Forage Management Sensitivity - Sediment Load
160%
140%
120%
100%
80%
60%
40%
20%
0%
Normalied Sediment Load
Under Utilized
Optimally Managed
Over Utilized
Moderate Overgrazing Allow ed
Severe Overgrazing Allow ed
Forage Management
Pasture Litter
Pasture N Only
Wheat


Forage Management Sensitivity - Runoff
180%
160%
140%
120%
100%
80%
60%
40%
20%
0%
Normalied Runoff
Under Utilized
Optimally Managed
Over Utilized
Moderate Overgrazing Allow ed
Severe Overgrazing Allow ed
Forage Management
Pasture Litter
Pasture N Only
Wheat

Appendix E

PPM Plus Validation

Field Site Characteristics and Management

################ File Name: 1 Mundy west #####################

Field Owner: Mundy west
Plan Developer: validation
Field Description: Field ID1
Climate Region: Eucha_Mundy Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description mundy farm 2
Plan Date: 09/10/2007 Field Area (acres): 2.2
Field Slope (%): 1.75 Slope Length (ft): 400
Soil Test P (ppm): 22.5
Soil #1 (100.0%): Choteau_silt loam Hy. Group C CN2: 79

Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 10
Forage Over Utilized

------------------------------Pasture Management -------------------------------
Date Description

01/01 Continious Grazing 2 Animal Units per Acre for 30 Days (With suplemental feed as needed.)
02/01 Continious Grazing .2 Animal Units per Acre for 59 Days (With suplemental feed as needed.)
04/02 Continious Grazing 1.5 Animal Units per Acre for 104 Days (With suplemental feed as needed.)
04/20 Manure Fertilization (Phosphorus Only) 40.0 lb/acre of P2O5
04/20 Manure Fertilization (Nitrogen Only) 50.0 lb/acre of N
04/25 Commercial Fertilization (Phosphorus Only) 0 lb/acre of P2O5
04/25 Commercial Fertilization (Nitrogen Only) 45.0 lb/acre of N
08/15 Continious Grazing 1.8 Animal Units per Acre for 78 Days (With suplemental feed as needed.)

################ File Name: 2 Mundy East #####################

Field Owner: Mundy east
Plan Developer: validation
Field Description: Field ID2
Climate Region: Eucha_Mundy Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description Mundy farm 1
Plan Date: 09/10/2007 Field Area (acres): 2.2
Field Slope (%): 2.4 Slope Length (ft): 300
Soil Test P (ppm): 22.5
Soil #1 (100.0%): Newtonia_silt loam Hy. Group B CN2: 69

Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 10
Forage Over Utilized

------------------------------Pasture Management -------------------------------
Date Description

01/01 Continious Grazing 2 Animal Units per Acre for 30 Days (With suplemental feed as needed.)
02/01 Continious Grazing .2 Animal Units per Acre for 59 Days (With suplemental feed as needed.)
04/02 Continious Grazing 1.5 Animal Units per Acre for 104 Days (With suplemental feed as needed.)
04/20 Manure Fertilization (Nitrogen Only) 50.0 lb/acre of N
04/20 Manure Fertilization (Phosphorus Only) 40.0 lb/acre of P2O5
04/25 Commercial Fertilization (Phosphorus Only) 0 lb/acre of P2O5
04/25 Commercial Fertilization (Nitrogen Only) 45.0 lb/acre of N
08/15 Continious Grazing 1.8 Animal Units per Acre for 78 Days (With suplemental feed as needed.)

################ File Name: 3 Demo South East #####################
Field Owner: Demo South East
Plan Developer: validation
Field Description: Field ID 3
Climate Region: Eucha_Demo_S Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum

Legal Description demo farms south 2
Plan Date: 09/10/2007 Field Area (acres): 1.1
Field Slope (%): 16.3 Slope Length (ft): 60
Soil Test P (ppm): 12.5
Soil #1 (100.0%): Clarksville_gravelly silt loam Hy. Group B CN2: 69
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

03/01 Continious Grazing .7 Animal Units per Acre for 30 Days (With suplemental feed as needed.)
05/15 Manure Fertilization (Nitrogen Only) 27.0 lb/acre of N
05/15 Manure Fertilization (Phosphorus Only) 70.0 lb/acre of P2O5
06/01 Continious Grazing .7 Animal Units per Acre for 60 Days (With suplemental feed as needed.)
10/01 Continious Grazing .6 Animal Units per Acre for 60 Days (With suplemental feed as needed.)

################ File Name: 4 Demo south West ######################
Field Owner: Demo South West
Plan Developer: validation
Field Description: Field ID 4
Climate Region: Eucha_Demo_S Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description demo south 1
Plan Date: 09/10/2007 Field Area (acres): 1.1
Field Slope (%): 14.1 Slope Length (ft): 80
Soil Test P (ppm): 12.5
Soil #1 (100.0%): Clarksville_gravelly silt loam Hy. Group B CN2: 69

Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

03/01 Continious Grazing .7 Animal Units per Acre for 30 Days (With suplemental feed as needed.)
05/15 Manure Fertilization (Nitrogen Only) 27.0 lb/acre of N
05/15 Manure Fertilization (Phosphorus Only) 70.0 lb/acre of P2O5
06/01 Continious Grazing .7 Animal Units per Acre for 60 Days (With suplemental feed as needed.)
10/01 Continious Grazing .6 Animal Units per Acre for 60 Days (With suplemental feed as needed.)

################ File Name: 5 Demo North ######################
Field Owner: Demo North
Plan Developer: validation
Field Description: Field ID 5
Climate Region: Eucha_Demo_N Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description
Plan Date: 09/10/2007 Field Area (acres): 4.8
Field Slope (%): 12.5 Slope Length (ft): 80
Soil Test P (ppm): 50.0
Soil #1 (100.0%): Clarksville_gravelly silt loam Hy. Group B CN2: 69
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

02/01 Continious Grazing .7 Animal Units per Acre for 27 Days (With suplemental feed as needed.)
05/01 Continious Grazing .5 Animal Units per Acre for 60 Days (With suplemental feed as needed.)
06/15 Manure Fertilization (Phosphorus Only) 90.0 lb/acre of P2O5
06/15 Manure Fertilization (Nitrogen Only) 80.0 lb/acre of N
07/01 Continious Grazing .2 Animal Units per Acre for 29 Days (With suplemental feed as needed.)
08/01 Continious Grazing .65 Animal Units per Acre for 60 Days (With suplemental feed as needed.)

################ File Name: 6 Colcord Hay ######################

Field Owner: Colcord Hay
Plan Developer: validation
Field Description: Field ID 6
Climate Region: Eucha_Colcord Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description
Plan Date: 09/10/2007 Field Area (acres): 5.4
Field Slope (%): 1.7 Slope Length (ft): 400
Soil Test P (ppm): 31.5
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 82.5
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Moderate Overgrazing Allowed
-----------------------------Pasture Management ------------------------------
Date Description

03/15 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/15 Commercial Fertilization (Nitrogen Only) 50.0 lb/acre of N
06/15 Cutting Hay
07/01 Continious Grazing .5 Animal Units per Acre for 152 Days (With suplemental feed as needed.)

################ File Name: 7 Colcord West ######################
Field Owner: Colcord West
Plan Developer: validation
Field Description: Field ID 7
Climate Region: Eucha_Colcord Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description cc grazing field 2
Plan Date: 09/10/2007 Field Area (acres): 1.7
Field Slope (%): .9 Slope Length (ft): 400
Soil Test P (ppm): 7.5
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 82.5
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Moderate Overgrazing Allowed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Continious Grazing .5 Animal Units per Acre for 364 Days (With suplemental feed as needed.)

################ File Name: 8 Colcord East ######################
Field Owner: Colcord East
Plan Developer: validation
Field Description: Field ID 8
Climate Region: Eucha_Colcord Ecoregion:Ouachita Mountains
Start Date 05/01/2006 End Date: 6/30/2007
UTM Coordinates: E N Datum
Legal Description cc grazing field 1
Plan Date: 09/10/2007 Field Area (acres): 1.7
Field Slope (%): .96 Slope Length (ft): 400
Soil Test P (ppm): 7.5
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 82.5
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 10
Moderate Overgrazing Allowed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Continuous Grazing .5 Animal Units per Acre for 364 Days (With supplemental feed as needed.)

################ File Name: Riesel W10 2000 ######################

Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W10 - 2000
Climate Region: Riesel-W10 Ecoregion:default

Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 16
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

04/27 Commercial Fertilization (Phosphorus Only) 12.0 lb/acre of P2O5
04/27 Commercial Fertilization (Nitrogen Only) 78.0 lb/acre of N

################ File Name: Riesel W10 2001 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W10 - 2001
Climate Region: Riesel-W10 Ecoregion:default
Start Date 01/01/2001 End Date: 12/31/2001
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 38
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

05/22 Cutting Hay
07/13 Manure Fertilization (Nitrogen Only) 284.0 lb/acre of N
07/13 Manure Fertilization (Phosphorus Only) 284.0 lb/acre of P2O5
10/04 Cutting Hay

################ File Name: Riesel W10 2002 ######################

Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W10 - 2002
Climate Region: Riesel-W10 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 37
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

07/12 Cutting Hay
09/06 Manure Fertilization (Phosphorus Only) 450.0 lb/acre of P2O5
09/06 Manure Fertilization (Nitrogen Only) 450.0 lb/acre of N

################ File Name: Riesel W10 2003 ######################
Field Owner: Riesel

Plan Developer: Mike White
Field Description: Watershed W10 - 2003
Climate Region: Riesel-W10 Ecoregion:default
Start Date 01/01/2003 End Date: 12/31/2003
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 16
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

06/23 Cutting Hay
09/25 Manure Fertilization (Nitrogen Only) 189.0 lb/acre of N
09/25 Manure Fertilization (Phosphorus Only) 189.0 lb/acre of P2O5
10/20 Cutting Hay

################ File Name: Riesel W10 2004 ######################

Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W10 - 2004
Climate Region: Riesel-W10 Ecoregion:default
Start Date 01/01/2004 End Date: 12/31/2004
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 40
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78

Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed

------------------------------Pasture Management -------------------------------
Date Description

05/17 Cutting Hay
07/21 Cutting Hay
09/02 Manure Fertilization (Nitrogen Only) 274.0 lb/acre of N
09/02 Manure Fertilization (Phosphorus Only) 274.0 lb/acre of P2O5

################ File Name: Riesel W10 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W10 - 2005
Climate Region: Riesel-W10 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 19.8
Field Slope (%): 2.5 Slope Length (ft): 300
Soil Test P (ppm): 35
Soil #1 (91.0%): HOUSTON BLACK_clay Hy. Group D CN2: 78
Soil #2 (9.0%): Heiden_clay Hy. Group D CN2: 78
Soil #3 (0.0%): Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed

------------------------------Pasture Management -------------------------------
Date Description

05/20 Cutting Hay
08/05 Cutting Hay
09/01 Manure Fertilization (Nitrogen Only) 222.0 lb/acre of N
09/01 Manure Fertilization (Phosphorus Only) 222.0 lb/acre of P2O5
09/22 Cutting Hay

################ File Name: Riesel SW12 2000 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2000
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 18
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

06/28 Cutting Hay

################ File Name: Riesel SW12 2001 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2001
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2001 End Date: 12/31/2001
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 16
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

07/10 Cutting Hay

################ File Name: Riesel SW12 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2002
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 5
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78

Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

06/28 Cutting Hay

################ File Name: Riesel SW12 2003 ######################

Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2003
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2003 End Date: 12/31/2003
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 6
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

06/28 Cutting Hay

################ File Name: Riesel SW12 2004 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2004
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2004 End Date: 12/31/2004
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 10
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

07/22 Cutting Hay

################ File Name: Riesel SW12 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW12 - 2005
Climate Region: Riesel-SW12 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 3.8 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

06/28 Cutting Hay

################ File Name: Riesel SW17 2000 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2000
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 16

Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84
Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing .46 Animal Units per Acre for 364 Days

################ File Name: Riesel SW17 2001 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2001
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2001 End Date: 12/31/2001
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 13
Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84
Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

03/01 Rotational or flash Grazing .46 Animal Units per Acre for 117 Days
07/05 Rotational or flash Grazing .46 Animal Units per Acre for 102 Days

################ File Name: Riesel SW17 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2002
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 6
Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84
Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

03/15 Rotational or flash Grazing 1 Animal Units per Acre for 112 Days
10/15 Rotational or flash Grazing .46 Animal Units per Acre for 77 Days

################ File Name: Riesel SW17 2003 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2003
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2003 End Date: 12/31/2003
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 6
Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84

Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

01/02 Rotational or flash Grazing .46 Animal Units per Acre for 30 Days
04/01 Rotational or flash Grazing 1 Animal Units per Acre for 187 Days
12/01 Rotational or flash Grazing .5 Animal Units per Acre for 29 Days

################ File Name: Riesel SW17 2004 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2004
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2004 End Date: 12/31/2004
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 8
Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84
Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

01/02 Rotational or flash Grazing .46 Animal Units per Acre for 30 Days
03/01 Rotational or flash Grazing 1 Animal Units per Acre for 214 Days
12/01 Rotational or flash Grazing .5 Animal Units per Acre for 29 Days

################ File Name: Riesel SW17 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed SW17 - 2005
Climate Region: Riesel-SW17 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3
Field Slope (%): 1.8 Slope Length (ft): 400
Soil Test P (ppm): 14
Soil #1 (35.0%): HOUSTON BLACK_clay Hy. Group D CN2: 84
Soil #2 (65.0%): Heiden_clay Hy. Group D CN2: 84
Soil #3 (0.0%): Hy. Group D CN2: 84
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

01/02 Rotational or flash Grazing .5 Animal Units per Acre for 30 Days
03/18 Rotational or flash Grazing .5 Animal Units per Acre for 31 Days
04/20 Rotational or flash Grazing 1 Animal Units per Acre for 140 Days
11/22 Rotational or flash Grazing .5 Animal Units per Acre for 38 Days

################ File Name: Riesel Y14 2000 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2000
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 11

Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management -------------------------------
Date Description

04/27 Commercial Fertilization (Nitrogen Only) 78.0 lb/acre of N
04/27 Commercial Fertilization (Phosphorus Only) 12.0 lb/acre of P2O5
06/20 Cutting Hay

################ File Name: Riesel Y14 2001 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2001
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2001 End Date: 12/31/2001
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 67
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management -------------------------------
Date Description

06/05 Cutting Hay
07/13 Manure Fertilization (Nitrogen Only) 603.0 lb/acre of N
07/13 Manure Fertilization (Phosphorus Only) 603.0 lb/acre of P2O5
10/03 Cutting Hay

################ File Name: Riesel Y14 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2002
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 72
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management -------------------------------
Date Description

06/05 Cutting Hay
09/05 Manure Fertilization (Nitrogen Only) 782.0 lb/acre of N
09/05 Manure Fertilization (Phosphorus Only) 782.0 lb/acre of P2O5
10/03 Cutting Hay

################ File Name: Riesel Y14 2003 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2003
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2003 End Date: 12/31/2003
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 31
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized

-----------------------------Pasture Management ------------------------------
Date Description

05/29 Cutting Hay
09/25 Manure Fertilization (Nitrogen Only) 377.0 lb/acre of N
09/25 Manure Fertilization (Phosphorus Only) 377.0 lb/acre of P2O5
10/20 Cutting Hay

################ File Name: Riesel Y14 2004 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2004
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2004 End Date: 12/31/2004
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 83
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

05/26 Cutting Hay
07/22 Cutting Hay
09/01 Manure Fertilization (Phosphorus Only) 617.0 lb/acre of P2O5
09/01 Manure Fertilization (Nitrogen Only) 617.0 lb/acre of N

################ File Name: Riesel Y14 2005 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y14 - 2005
Climate Region: Riesel-Y14 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 5.7
Field Slope (%): 1.6 Slope Length (ft): 400
Soil Test P (ppm): 65
Soil #1 (100.0%): Heiden_clay Hy. Group D CN2: 78
Forage Type: Bermudagrass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

05/19 Cutting Hay
08/05 Cutting Hay
08/31 Manure Fertilization (Phosphorus Only) 497.0 lb/acre of P2O5
08/31 Manure Fertilization (Nitrogen Only) 497.0 lb/acre of N
09/21 Cutting Hay

################ File Name: Riesel Y6 2000 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y6 - 2000
Climate Region: Riesel-Y6 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 16.3
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 20
Soil #1 (45.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (55.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80

Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Fertilization with 435 lb/acre of Ammonium Nitrate 34-00-00
02/28 Performing Conservation tillage (Primary)
03/01 Planting Corn
08/05 Harvest Corn
08/14 Performing Incorporate Material (Secondary)
10/02 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y6 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y6 - 2002
Climate Region: Riesel-Y6 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 16.3
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 21
Soil #1 (45.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (55.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Fertilization with 435 lb/acre of Ammonium Nitrate 34-00-00
02/28 Performing Conservation tillage (Primary)
03/06 Planting Corn
08/23 Harvest Corn
08/30 Performing Incorporate Material (Secondary)
09/26 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y6 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y6 - 2005
Climate Region: Riesel-Y6 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 16.3
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 16
Soil #1 (45.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (55.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Performing Conservation tillage (Primary)
03/17 Commercial Fertilization (Nitrogen Only) 155.0 lb/acre of N
03/17 Commercial Fertilization (Phosphorus Only) 31.0 lb/acre of P2O5
03/18 Planting Corn
08/23 Harvest Corn
08/30 Performing Incorporate Material (Secondary)
10/05 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y8 2002 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y8 - 2002
Climate Region: Riesel-Y8 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 20.8
Field Slope (%): 2.2 Slope Length (ft): 300
Soil Test P (ppm): 91
Soil #1 (83.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (17.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Performing Conservation tillage (Primary)
03/06 Planting Corn
08/24 Harvest Corn
09/05 Manure Fertilization (Nitrogen Only) 803.0 lb/acre of N
09/05 Manure Fertilization (Phosphorus Only) 803.0 lb/acre of P2O5
09/06 Performing Incorporate Material (Secondary)
09/25 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y8 2005 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y8 - 2005
Climate Region: Riesel-Y8 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 20.8
Field Slope (%): 2.2 Slope Length (ft): 300
Soil Test P (ppm): 134
Soil #1 (83.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (17.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Performing Conservation tillage (Primary)
03/17 Planting Corn
08/24 Harvest Corn
08/31 Manure Fertilization (Nitrogen Only) 491.0 lb/acre of N
08/31 Manure Fertilization (Phosphorus Only) 491.0 lb/acre of P2O5
09/01 Performing Incorporate Material (Secondary)
10/04 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y10 2002 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y10 - 2002
Climate Region: Riesel-Y10 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 18.5
Field Slope (%): 1.9 Slope Length (ft): 400
Soil Test P (ppm): 64
Soil #1 (76.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80

Soil #2 (24.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Performing Conservation tillage (Primary)
03/06 Planting Corn
08/20 Harvest Corn
09/05 Manure Fertilization (Nitrogen Only) 480.0 lb/acre of N
09/05 Manure Fertilization (Phosphorus Only) 480.0 lb/acre of P2O5
09/06 Performing Incorporate Material (Secondary)
09/23 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y10 2005 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y10 - 2005
Climate Region: Riesel-Y10   Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007   Field Area (acres): 18.5
Field Slope (%): 1.9   Slope Length (ft): 400
Soil Test P (ppm): 53
Soil #1 (76.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (24.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/16 Performing Conservation tillage (Primary)
03/16 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/16 Commercial Fertilization (Nitrogen Only) 74.9 lb/acre of N
03/17 Planting Corn
08/23 Harvest Corn
08/29 Manure Fertilization (Phosphorus Only) 241.0 lb/acre of P2O5
08/29 Manure Fertilization (Nitrogen Only) 241.0 lb/acre of N
08/30 Performing Incorporate Material (Secondary)
10/05 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y13 2002 #####################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y13 - 2002
Climate Region: Riesel-Y13   Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007   Field Area (acres): 11.4
Field Slope (%): 2.3   Slope Length (ft): 300
Soil Test P (ppm): 45
Soil #1 (29.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (71.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/20 Performing Conservation tillage (Primary)
03/07 Planting Corn

08/21 Harvest Corn
09/04 Manure Fertilization (Phosphorus Only) 293.0 lb/acre of P2O5
09/04 Manure Fertilization (Nitrogen Only) 293.0 lb/acre of N
09/05 Performing Incorporate Material (Secondary)
09/27 Performing Incorporate Material (Secondary)

################ File Name: Riesel Y13 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed Y13 - 2005
Climate Region: Riesel-Y13 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 11.4
Field Slope (%): 2.3 Slope Length (ft): 300
Soil Test P (ppm): 39
Soil #1 (29.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (71.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/16 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/16 Commercial Fertilization (Nitrogen Only) 99.2 lb/acre of N
03/17 Planting Corn
03/18 Performing Conservation tillage (Primary)
08/22 Harvest Corn
08/30 Manure Fertilization (Phosphorus Only) 166.0 lb/acre of P2O5
08/30 Manure Fertilization (Nitrogen Only) 166.0 lb/acre of N
08/31 Performing Incorporate Material (Secondary)
10/04 Performing Incorporate Material (Secondary)

################ File Name: Riesel W12 2000 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W12 - 2000
Climate Region: Riesel-W12 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 9.9
Field Slope (%): 2 Slope Length (ft): 400
Soil Test P (ppm): 22
Soil #1 (64.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (36.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
02/28 Commercial Fertilization (Nitrogen Only) 200.0 lb/acre of N
03/01 Performing Conservation tillage (Primary)
03/02 Planting Corn
08/04 Harvest Corn
08/15 Performing Incorporate Material (Secondary)
10/03 Performing Incorporate Material (Secondary)

################ File Name: Riesel W12 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W12 - 2002

Climate Region: Riesel-W12 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 9.9
Field Slope (%): 2 Slope Length (ft): 400
Soil Test P (ppm): 63
Soil #1 (64.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (36.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description

----------------------------Cropland Management ------------------------------
Date Description

02/20 Commercial Fertilization (Nitrogen Only) 73.9 lb/acre of N
02/20 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
02/21 Performing Conservation tillage (Primary)
03/07 Planting Corn
08/22 Harvest Corn
09/03 Manure Fertilization (Phosphorus Only) 562.0 lb/acre of P2O5
09/03 Manure Fertilization (Nitrogen Only) 562.0 lb/acre of N
09/04 Performing Incorporate Material (Secondary)
09/24 Performing Incorporate Material (Secondary)

################ File Name: Riesel W12 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W12 - 2005
Climate Region: Riesel-W12 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 9.9
Field Slope (%): 2.0 Slope Length (ft): 400
Soil Test P (ppm): 67
Soil #1 (64.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (36.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/16 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/16 Commercial Fertilization (Nitrogen Only) 69.1 lb/acre of N
03/17 Performing Conservation tillage (Primary)
03/18 Planting Corn
08/24 Harvest Corn
08/29 Manure Fertilization (Nitrogen Only) 254.0 lb/acre of N
08/29 Manure Fertilization (Phosphorus Only) 254.0 lb/acre of P2O5
08/30 Performing Incorporate Material (Secondary)
10/06 Performing Incorporate Material (Secondary)

################ File Name: Riesel W13 2000 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W13 - 2000
Climate Region: Riesel-W13 Ecoregion:default
Start Date 01/01/2000 End Date: 12/31/2000
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 11.4
Field Slope (%): 1.1 Slope Length (ft): 400
Soil Test P (ppm): 20

Soil #1 (96.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (4.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

03/06 Commercial Fertilization (Nitrogen Only) 200.0 lb/acre of N
03/06 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/07 Performing Conservation tillage (Primary)
03/09 Planting Corn
08/04 Harvest Corn
08/15 Performing Incorporate Material (Secondary)
10/03 Performing Incorporate Material (Secondary)

################ File Name: Riesel W13 2002 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W13 - 2002
Climate Region: Riesel-W13 Ecoregion:default
Start Date 01/01/2002 End Date: 12/31/2002
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 11.4
Field Slope (%): 1.1 Slope Length (ft): 400
Soil Test P (ppm): 111
Soil #1 (96.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (4.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

02/20 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
02/20 Commercial Fertilization (Nitrogen Only) 53.8 lb/acre of N
02/21 Performing Conservation tillage (Primary)
03/07 Planting Corn
08/22 Harvest Corn
09/03 Manure Fertilization (Nitrogen Only) 685.0 lb/acre of N
09/03 Manure Fertilization (Phosphorus Only) 685.0 lb/acre of P2O5
09/04 Performing Incorporate Material (Secondary)
09/24 Performing Incorporate Material (Secondary)

################ File Name: Riesel W13 2005 ######################
Field Owner: Riesel
Plan Developer: Mike White
Field Description: Watershed W13 - 2005
Climate Region: Riesel-W13 Ecoregion:default
Start Date 01/01/2005 End Date: 12/31/2005
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 11.4
Field Slope (%): 1.1 Slope Length (ft): 400
Soil Test P (ppm): 63
Soil #1 (96.0%): HOUSTON BLACK_clay Hy. Group D CN2: 80
Soil #2 (4.0%): Heiden_clay Hy. Group D CN2: 80
Soil #3 (0.0%): Hy. Group D CN2: 80
Terraced and Planted on Contour
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

03/16 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5

03/16 Commercial Fertilization (Nitrogen Only) 24.0 lb/acre of N
03/17 Performing Conservation tillage (Primary)
03/17 Planting Corn
08/24 Harvest Corn
08/30 Manure Fertilization (Nitrogen Only) 387.0 lb/acre of N
08/30 Manure Fertilization (Phosphorus Only) 387.0 lb/acre of P2O5
08/31 Performing Incorporate Material (Secondary)
10/06 Performing Incorporate Material (Secondary)

################ File Name: Moors Creek 1 (R Litter) Entire #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with litter application
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 09/01/1991 End Date: 3/30/1994
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3.04
Field Slope (%): 3.0 Slope Length (ft): 450
Soil Test P (ppm): 177
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 79

Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

05/15 Manure Fertilization (Nitrogen Only) 350.0 lb/acre of N
05/15 Manure Fertilization (Phosphorus Only) 331.0 lb/acre of P2O5
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek 1 (R Litter) 1992 #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with litter application
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 01/01/1992 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3.04
Field Slope (%): 3.0 Slope Length (ft): 450
Soil Test P (ppm): 177
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 79
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

03/15 Manure Fertilization (Nitrogen Only) 296.0 lb/acre of N
03/15 Manure Fertilization (Phosphorus Only) 240.0 lb/acre of P2O5
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek 1 (R Litter) 1993 #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with litter application
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 01/01/1993 End Date: 12/31/1993
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3.04
Field Slope (%): 3.0 Slope Length (ft): 450
Soil Test P (ppm): 177
Soil #1 (100.0%): Captina_silt loam Hy. Group C CN2: 79
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

07/13 Manure Fertilization (Phosphorus Only) 422.0 lb/acre of P2O5
07/13 Manure Fertilization (Nitrogen Only) 402.0 lb/acre of N
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek (R Com N) Entire #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with Commercial N
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 09/01/1991 End Date: 3/30/1994
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 1.41
Field Slope (%): 2.0 Slope Length (ft): 465
Soil Test P (ppm): 246
Soil #1 (100.0%): TADLOCK_fine sandy loam Hy. Group B CN2: 69
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized

------------------------------Pasture Management ------------------------------
Date Description

04/01 Commercial Fertilization (Nitrogen Only) 86.0 lb/acre of N
04/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
08/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
08/01 Commercial Fertilization (Nitrogen Only) 86.0 lb/acre of N
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek (R Com N) 1992 #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with Commercial N
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 1/1/1992 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 1.41
Field Slope (%): 2.0 Slope Length (ft): 465
Soil Test P (ppm): 246
Soil #1 (100.0%): TADLOCK_fine sandy loam Hy. Group B CN2: 69
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized
------------------------------Pasture Management ------------------------------
Date Description

03/23 Commercial Fertilization (Nitrogen Only) 60.0 lb/acre of N
03/23 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
08/14 Commercial Fertilization (Nitrogen Only) 60.0 lb/acre of N
08/14 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek (R Com N) 1993 #####################
Field Owner: Moors Creek RU RA
Plan Developer: Mike White
Field Description: R group with Commercial N
Climate Region: Moors_RU_RM Ecoregion:Ozark Highlands
Start Date 1/1/1993 End Date: 12/31/1993
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 1.41
Field Slope (%): 2.0 Slope Length (ft): 465
Soil Test P (ppm): 246
Soil #1 (100.0%): TADLOCK_fine sandy loam Hy. Group B CN2: 69
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

03/23 Commercial Fertilization (Nitrogen Only) 103.0 lb/acre of N
03/23 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
07/14 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
07/14 Commercial Fertilization (Nitrogen Only) 121.0 lb/acre of N
08/15 Continious Grazing .56 Animal Units per Acre for 243 Days (With suplemental feed as needed.)

################ File Name: Moors Creek 3 (W Litter) Entire ######################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with litter application
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 09/01/1991 End Date: 3/30/1994
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 2.62
Field Slope (%): 4 Slope Length (ft): 590
Soil Test P (ppm): 187
Soil #1 (100.0%): ALLEGHENY_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

01/01 Continious Grazing .32 Animal Units per Acre for 364 Days (With suplemental feed as needed.)
04/01 Manure Fertilization (Nitrogen Only) 160.0 lb/acre of N
04/01 Manure Fertilization (Phosphorus Only) 123.0 lb/acre of P2O5
08/01 Manure Fertilization (Phosphorus Only) 123.0 lb/acre of P2O5
08/01 Manure Fertilization (Nitrogen Only) 160.0 lb/acre of N

################ File Name: Moors Creek 3 (W Litter) 1992 ######################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with litter application
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 1/1/1992 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description 1992
Plan Date: 05/07/2007 Field Area (acres): 2.62
Field Slope (%): 4 Slope Length (ft): 590
Soil Test P (ppm): 187
Soil #1 (100.0%): ALLEGHENY_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

01/01 Continious Grazing .32 Animal Units per Acre for 364 Days (With suplemental feed as needed.)
03/23 Manure Fertilization (Nitrogen Only) 194.0 lb/acre of N
03/23 Manure Fertilization (Phosphorus Only) 123.0 lb/acre of P2O5
08/13 Manure Fertilization (Nitrogen Only) 128.0 lb/acre of N
08/13 Manure Fertilization (Phosphorus Only) 120.0 lb/acre of P2O5

################ File Name: Moors Creek 3 (W Litter) 1993 ######################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with litter application
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 1/1/1993 End Date: 12/31/1993
UTM Coordinates: E N Datum
Legal Description 1993
Plan Date: 05/07/2007 Field Area (acres): 2.62
Field Slope (%): 4 Slope Length (ft): 590
Soil Test P (ppm): 187
Soil #1 (100.0%): ALLEGHENY_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
------------------------------Pasture Management ------------------------------

Date Description

01/01 Continious Grazing .32 Animal Units per Acre for 364 Days (With suplemental feed as needed.)
04/13 Manure Fertilization (Nitrogen Only) 141.0 lb/acre of N
04/13 Manure Fertilization (Phosphorus Only) 86.0 lb/acre of P2O5
07/20 Manure Fertilization (Phosphorus Only) 143.0 lb/acre of P2O5
07/20 Manure Fertilization (Nitrogen Only) 173.0 lb/acre of N

################ File Name: Moors Creek 3 (W Com N) Entire #####################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with Com N
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 09/01/1991 End Date: 3/30/1994
UTM Coordinates: E N Datum
Legal Description
Plan Date: 05/07/2007 Field Area (acres): 3.61
Field Slope (%): 4 Slope Length (ft): 635
Soil Test P (ppm): 364
Soil #1 (100.0%): Linker_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

04/01 Commercial Fertilization (Nitrogen Only) 90.0 lb/acre of N
04/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
07/20 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
07/20 Commercial Fertilization (Nitrogen Only) 60.0 lb/acre of N
08/01 Continious Grazing .2 Animal Units per Acre for 242 Days (With suplemental feed as needed.)

################ File Name: Moors Creek 3 (W Com N) 1992 #####################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with Com N
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 1/1/1992 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description 1992
Plan Date: 05/07/2007 Field Area (acres): 3.61
Field Slope (%): 4 Slope Length (ft): 635
Soil Test P (ppm): 364
Soil #1 (100.0%): Linker_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

03/23 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/23 Commercial Fertilization (Nitrogen Only) 123.0 lb/acre of N
08/01 Continious Grazing .2 Animal Units per Acre for 242 Days (With suplemental feed as needed.)

################ File Name: Moors Creek 3 (W Com N) 1993 #####################
Field Owner: Moors Creek
Plan Developer: Mike White
Field Description: W group with Com N
Climate Region: Moors_WU_WM Ecoregion:Ozark Highlands
Start Date 1/1/1993 End Date: 12/31/1993
UTM Coordinates: E N Datum
Legal Description 1993
Plan Date: 05/07/2007 Field Area (acres): 3.61
Field Slope (%): 4 Slope Length (ft): 635
Soil Test P (ppm): 364
Soil #1 (100.0%): Linker_loam Hy. Group B CN2: 65
Forage Type: Cool Season (Fescue, Rye) Yield Goal (t/acre): 6
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

04/13 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
04/13 Commercial Fertilization (Nitrogen Only) 91.0 lb/acre of N
07/20 Commercial Fertilization (Nitrogen Only) 91.0 lb/acre of N
07/20 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
08/01 Continious Grazing .2 Animal Units per Acre for 242 Days (With suplemental feed as needed.)

################ File Name: Georgia Peach W1 (Excessive Litter) #####################
Field Owner: Georgia Peach Watersheds
Plan Developer: W1- IX+C
Field Description: 4.5 ton Litter Plus 45 ton compost
Climate Region: Georgia Peach Ecoregion:default
Start Date 03/01/1995 End Date: 2/28/1997
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.1
Field Slope (%): 2.75 Slope Length (ft): 300
Soil Test P (ppm): 61
Soil #1 (100.0%): ESTO_sandy loam Hy. Group B CN2: 58
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

04/10 Fertilization with 322 lb/acre of Organic Phosphorus as P
04/10 Fertilization with 535 lb/acre of Manure Nitrogen (80% Organic)
04/10 Fertilization with 28 lb/acre of Elemental Phosphorous as P2O5
04/30 Cutting Hay
06/30 Cutting Hay
08/30 Cutting Hay
09/25 Fertilization with 500 lb/acre of Manure Nitrogen (80% Organic)
09/25 Fertilization with 411 lb/acre of Organic Phosphorus as P
09/25 Fertilization with 64 lb/acre of Elemental Phosphorous as P2O5
10/30 Cutting Hay

################ File Name: Georgia Peach W2 (2x Litter) #####################
Field Owner: Georgia Peach Watersheds
Plan Developer: W2- 2X
Field Description: 9.0 ton Litter
Climate Region: Georgia Peach Ecoregion:default
Start Date 03/01/1995 End Date: 2/28/1997
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.1
Field Slope (%): 2.75 Slope Length (ft): 300
Soil Test P (ppm): 11
Soil #1 (75.0%): ESTO_sandy loam Hy. Group B CN2: 58
Soil #2 (25.0%): FACEVILLE_sandy loam Hy. Group B CN2: 58
Soil #3 (0.0%): Hy. Group B CN2: 58
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

04/10 Fertilization with 278 lb/acre of Manure Nitrogen (80% Organic)
04/10 Fertilization with 7.3 lb/acre of Elemental Phosphorous as P2O5
04/10 Fertilization with 85.7 lb/acre of Organic Phosphorus as P
04/30 Cutting Hay
06/30 Cutting Hay
08/30 Cutting Hay
09/25 Fertilization with 135 lb/acre of Organic Phosphorus as P
09/25 Fertilization with 20.4 lb/acre of Elemental Phosphorous as P2O5
09/25 Fertilization with 338 lb/acre of Manure Nitrogen (80% Organic)
10/30 Cutting Hay

################ File Name: Georgia Peach W3 (1x Litter) #####################
Field Owner: Georgia Peach Watersheds
Plan Developer: W3- IX

Field Description: 4.5 ton Litter
Climate Region: Georgia Peach Ecoregion:default
Start Date 03/01/1995 End Date: 2/28/1997
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.1
Field Slope (%): 2.75 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): FACEVILLE_sandy loam Hy. Group B CN2: 58
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

04/10 Fertilization with 142 lb/acre of Manure Nitrogen (80% Organic)
04/10 Fertilization with 16.5 lb/acre of Elemental Phosphorous as P2O5
04/10 Fertilization with 39.5 lb/acre of Organic Phosphorus as P
04/30 Cutting Hay
06/30 Cutting Hay
08/30 Cutting Hay
09/25 Fertilization with 10.3 lb/acre of Elemental Phosphorous as P2O5
09/25 Fertilization with 51 lb/acre of Organic Phosphorus as P
09/25 Fertilization with 180 lb/acre of Manure Nitrogen (80% Organic)
10/30 Cutting Hay

################ File Name: Georgia Putnam Plot 2 1995 #####################
Field Owner: Georgia Putnam Plot 2
Plan Developer: Plot 2 1995
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1995 End Date: 12/31/1995
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.95
Field Slope (%): 8 Slope Length (ft): 328
Soil Test P (ppm): 42.6
Soil #1 (27.0%): ALTAVISTA_fine sandy loam Hy. Group C CN2: 79
Soil #2 (36.0%): CECIL_sandy loam Hy. Group B CN2: 69
Soil #3 (37.0%): SEDGEFIELD_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 1 Animal Units per Acre for 364 Days
03/16 Manure Fertilization (Nitrogen Only) 241.0 lb/acre of N
03/16 Manure Fertilization (Phosphorus Only) 221.0 lb/acre of P2O5
05/20 Cutting Hay
10/30 Manure Fertilization (Nitrogen Only) 235.0 lb/acre of N
10/30 Manure Fertilization (Phosphorus Only) 215.0 lb/acre of P2O5

################ File Name: Georgia Putnam Plot 2 1996 #####################
Field Owner: Georgia Putnam Plot 2
Plan Developer: Plot 2 1996
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1996 End Date: 12/31/1996
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.95
Field Slope (%): 8 Slope Length (ft): 328
Soil Test P (ppm): 70.5
Soil #1 (27.0%): ALTAVISTA_fine sandy loam Hy. Group C CN2: 79
Soil #2 (36.0%): CECIL_sandy loam Hy. Group B CN2: 69
Soil #3 (37.0%): SEDGEFIELD_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management -------------------------------

Date Description

01/01 Rotational or flash Grazing 1.25 Animal Units per Acre for 364 Days
03/05 Manure Fertilization (Nitrogen Only) 430.0 lb/acre of N
03/05 Manure Fertilization (Phosphorus Only) 312.0 lb/acre of P2O5
09/25 Manure Fertilization (Nitrogen Only) 230.0 lb/acre of N
09/25 Manure Fertilization (Phosphorus Only) 154.0 lb/acre of P2O5

################ File Name: Georgia Putnam Plot 4 1995 ######################
Field Owner: Georgia Putnam Plot 4
Plan Developer: Plot 4 1995
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1995 End Date: 12/31/1995
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.87
Field Slope (%): 6 Slope Length (ft): 328
Soil Test P (ppm): 29.3
Soil #1 (6.0%): ALTAVISTA_fine sandy loam Hy. Group C CN2: 79
Soil #2 (86.0%): CECIL_sandy loam Hy. Group B CN2: 69
Soil #3 (8.0%): HELENA_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 1.0 Animal Units per Acre for 364 Days
03/16 Manure Fertilization (Phosphorus Only) 207.0 lb/acre of P2O5
03/16 Manure Fertilization (Nitrogen Only) 241.0 lb/acre of N
05/20 Cutting Hay
10/30 Manure Fertilization (Phosphorus Only) 243.0 lb/acre of P2O5
10/30 Manure Fertilization (Nitrogen Only) 235.0 lb/acre of N

################ File Name: Georgia Putnam Plot 4 1996 ######################
Field Owner: Georgia Putnam Plot 4
Plan Developer: Plot 4 1996
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1996 End Date: 12/31/1996
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.87
Field Slope (%): 6 Slope Length (ft): 328
Soil Test P (ppm): 57.1
Soil #1 (6.0%): ALTAVISTA_fine sandy loam Hy. Group C CN2: 79
Soil #2 (86.0%): CECIL_sandy loam Hy. Group B CN2: 69
Soil #3 (8.0%): HELENA_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 1.25 Animal Units per Acre for 364 Days
03/05 Manure Fertilization (Phosphorus Only) 366.0 lb/acre of P2O5
03/05 Manure Fertilization (Nitrogen Only) 430.0 lb/acre of N
09/25 Manure Fertilization (Phosphorus Only) 249.0 lb/acre of P2O5
09/25 Manure Fertilization (Nitrogen Only) 230.0 lb/acre of N

############### File Name: Georgia Putnam Plot 6 1995 ######################
Field Owner: Georgia Putnam Plot 6
Plan Developer: Plot 6 1995
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1995 End Date: 12/31/1995
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.78

Field Slope (%): 6 Slope Length (ft): 328
Soil Test P (ppm): 32.9
Soil #1 (14.0%): HELENA_sandy loam Hy. Group C CN2: 79
Soil #2 (86.0%): SEDGEFIELD_sandy loam Hy. Group C CN2: 79
Soil #3 (0.0%): HELENA_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 1 Animal Units per Acre for 364 Days
03/16 Manure Fertilization (Phosphorus Only) 184.0 lb/acre of P2O5
03/16 Manure Fertilization (Nitrogen Only) 241.0 lb/acre of N
05/20 Cutting Hay
10/30 Manure Fertilization (Phosphorus Only) 308.0 lb/acre of P2O5
10/30 Manure Fertilization (Nitrogen Only) 235.0 lb/acre of N

################ File Name: Georgia Putnam Plot 6 1996 ######################
Field Owner: Georgia Putnam Plot 6
Plan Developer: Plot 6 1996
Field Description:
Climate Region: Georgia Putnam Ecoregion:default
Start Date 01/01/1996 End Date: 12/31/1996
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/25/2007 Field Area (acres): 1.78
Field Slope (%): 6 Slope Length (ft): 328
Soil Test P (ppm): 60.1
Soil #1 (14.0%): HELENA_sandy loam Hy. Group C CN2: 79
Soil #2 (86.0%): SEDGEFIELD_sandy loam Hy. Group C CN2: 79
Soil #3 (0.0%): HELENA_sandy loam Hy. Group C CN2: 79
Forage Type: Mixed Warm and Cool GrassesYield Goal (t/acre): 500
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 1.25 Animal Units per Acre for 364 Days
03/05 Manure Fertilization (Phosphorus Only) 452.0 lb/acre of P2O5
03/05 Manure Fertilization (Nitrogen Only) 430.0 lb/acre of N
09/25 Manure Fertilization (Phosphorus Only) 211.0 lb/acre of P2O5
09/25 Manure Fertilization (Nitrogen Only) 230.0 lb/acre of N

################ File Name: elrenonativeFR1 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1977-1989
Field Description: El Reno, OK FR1
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 3.0 Slope Length (ft): 300
Soil Test P (ppm): 13
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 84
Forage Type: Native Grass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

06/01 Rotational or flash Grazing 0.33 Animal Units per Acre for 91 Days

################ File Name: ElrenonativeFR11977to80 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977-1980
Field Description: El Reno native FR1
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum

Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.0 Slope Length (ft): 300
Soil Test P (ppm): 13
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 84
Forage Type: Native Grass Yield Goal (t/acre):
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.33 Animal Units per Acre for 364 Days

################ File Name: elrenonativeFR2 ######################

Field Owner: Smith and Sharpley
Plan Developer: 1977-1989
Field Description: El Reno, OK FR2
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 84
Forage Type: Native Grass Yield Goal (t/acre): 3
Forage Over Utilized
-----------------------------Pasture Management ------------------------------
Date Description

06/01 Rotational or flash Grazing 0.33 Animal Units per Acre for 91 Days

################ File Name: ElrenonativeFR21977to80 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977-1980
Field Description: El Reno FR2 native pasture
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days
05/01 Commercial Fertilization (Nitrogen Only) 25.0 lb/acre of N
05/01 Commercial Fertilization (Phosphorus Only) 4.0 lb/acre of P2O5

################ File Name: elrenonativeFR31977-1989 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1977-1989
Field Description: El Reno Native FR3
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 14
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed

------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeFR31977to80 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977-1980
Field Description: El Reno Native FR3
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 14
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeFR41977to80 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977 to 1980
Field Description: El Reno Native FR3
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.6 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days
05/01 Commercial Fertilization (Nitrogen Only) 28.0 lb/acre of N
05/01 Commercial Fertilization (Phosphorus Only) 4.5 lb/acre of P2O5

################ File Name: elrenonativeFR41977-1989 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1977-1989
Field Description: El Reno Native FR4
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.6 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeFR51977to78 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977 - 1978
Field Description: El reno Native FR5 1977-1978

Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1978
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 3.5 Slope Length (ft): 300
Soil Test P (ppm): 22
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeFR61977to78 #####################
Field Owner: Smith and Menzel
Plan Developer: 1977-1978
Field Description: El Reno Native Pasture FR6
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1978
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 32
Soil # (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenowheatFR6 #####################
Field Owner: Smith and Sharpley
Plan Developer: 1984-1988
Field Description: El Reno FR6 Wheat
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1984 End Date: 12/31/1988
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 32
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 87
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/15 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/15 Commercial Fertilization (Nitrogen Only) 67.8 lb/acre of N
06/16 Harvest Small Grains
09/13 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/13 Commercial Fertilization (Phosphorus Only) 24.3 lb/acre of P2O5
09/14 Performing Conventional tillage (Primary)
09/15 Planting Small Grains

################ File Name: elrenonativeFR71977to78 #####################
Field Owner: Smith and Menzel
Plan Developer: 1977-1978
Field Description: El Reno, OK native pasture FR6
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1978
UTM Coordinates: E N Datum
Legal Description

Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 38
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenowheatFR7 #####################
Field Owner: Smith and Sharpley
Plan Developer: 1984-1988
Field Description: El Reno wheat FR7
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1984 End Date: 12/31/1988
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 38
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 79.8
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

03/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/01 Commercial Fertilization (Nitrogen Only) 67.8 lb/acre of N
06/16 Harvest Small Grains
09/14 Commercial Fertilization (Phosphorus Only) 26.4 lb/acre of P2O5
09/14 Performing No-till (Primary)
09/14 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/15 Planting Small Grains

################ File Name: elrenowheatFR8 #####################
Field Owner: Smith and Sharpley
Plan Developer: 1984-1988
Field Description: El Reno wheat FR8
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1984 End Date: 12/31/1988
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 21
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 87
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

03/01 Commercial Fertilization (Nitrogen Only) 67.8 lb/acre of N
03/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
06/16 Harvest Small Grains
09/14 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/14 Performing Conventional tillage (Primary)
09/14 Commercial Fertilization (Phosphorus Only) 26.4 lb/acre of P2O5
09/15 Planting Small Grains

################ File Name: elrenonativeFR81977to78 #####################
Field Owner: Smith and menzel
Plan Developer: 1977 to 1978
Field Description: El Reno, OK native FR8
Climate Region: 4 Ecoregion:Central Great Plains

Start Date 01/01/1977 End Date: 12/31/1978
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 4.0
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 21
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeE1 ######################
Field Owner: Sharpley
Plan Developer: 1977-1992
Field Description: El Reno, OK E1
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.6 Slope Length (ft): 300
Soil Test P (ppm): 13
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 84
Forage Type: Native Grass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

06/01 Rotational or flash Grazing 0.33 Animal Units per Acre for 91 Days

################ File Name: elrenonativeE2 ######################
Field Owner: Sharpley
Plan Developer: 1977-1992
Field Description: El Reno, OK E2
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 84

Forage Type: Native Grass Yield Goal (t/acre):
Forage Over Utilized
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.33 Animal Units per Acre for 364 Days

################ File Name: elrenonativeE3 ######################
Field Owner: Sharpley
Plan Developer: 1977-1992
Field Description: El Reno, OK E3
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 3.2 Slope Length (ft): 300
Soil Test P (ppm): 14
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------

Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenonativeE4 #####################
Field Owner: Sharpley
Plan Developer: 1977-1992
Field Description: El Reno, OK E4
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 3.6 Slope Length (ft): 300
Soil Test P (ppm): 15
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 82
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: elrenowheatE6 #####################
FieldOwner: Sharpley
Plan Developer: 1979-1992
Field Description: El Reno E6 Wheat
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1979 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 32
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 87
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management ------------------------------
Date Description

06/16 Harvest Small Grains
09/13 Commercial Fertilization (Phosphorus Only) 24.3 lb/acre of P2O5
09/13 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/14 Performing Conventional tillage (Primary)
09/15 Planting Small Grains

################ File Name: elrenowheatE7 #####################
Field Owner: Sharpley
Plan Developer: 1984-1992
Field Description: El Reno E7 Wheat
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1984 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.9 Slope Length (ft): 300
Soil Test P (ppm): 38
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 79.8
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management ------------------------------
Date Description

06/16 Harvest Small Grains
09/13 Commercial Fertilization (Phosphorus Only) 26.4 lb/acre of P2O5

09/13 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/14 Performing No-till (Primary)
09/15 Planting Small Grains

################ File Name: elrenowheatE8 #####################
Field Owner: Sharpley
Plan Developer: 1979-1992
Field Description: El Reno E8 Wheat
Climate Region: 4 Ecoregion:Central Great Plains
Start Date 01/01/1979 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 4.0
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 21
Soil #1 (100.0%): Kirkland_silt loam Hy. Group D CN2: 87
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
-----------------------------Cropland Management -------------------------------
Date Description

06/16 Harvest Small Grains
09/13 Commercial Fertilization (Phosphorus Only) 26.4 lb/acre of P2O5
09/13 Commercial Fertilization (Nitrogen Only) 51.7 lb/acre of N
09/14 Performing Conventional tillage (Primary)
09/15 Planting Small Grains

################ File Name: woodwardnativeW1 #####################
Field Owner: Sharpley, Andrew
Plan Developer: 1977-1992
Field Description: Woodward Native grass W1
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 11.7
Field Slope (%): 7 Slope Length (ft): 200
Soil Test P (ppm): 14
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeW2 #####################
Field Owner: Sharpley, Andrew
Plan Developer: 1977-1992
Field Description: Woodward, OK W2
Climate Region: 3 Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1992
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 13.8
Field Slope (%): 8.2 Slope Length (ft): 200
Soil Test P (ppm): 15
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre): 3
Forage Optimally Managed
------------------------------Pasture Management -------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardwheatW3 #####################
Field Owner: Sharpley, Andrew

Plan Developer: 1979-1986
Field Description: Woodward wheat W3
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1979 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 6.7
Field Slope (%): 8.6 Slope Length (ft): 200
Soil Test P (ppm): 29
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
03/01 Commercial Fertilization (Nitrogen Only) 49.0 lb/acre of N
06/16 Harvest Small Grains
09/13 Commercial Fertilization (Nitrogen Only) 50.0 lb/acre of N
09/13 Commercial Fertilization (Phosphorus Only) 46.6 lb/acre of P2O5
09/14 Performing Conventional tillage (Primary)
09/15 Planting Small Grains

################ File Name: woodwardwheatW4 #####################
Field Owner: Sharpley, Andrew
Plan Developer: 1982-1986
Field Description: Woodward, OK
Climate Region: 3 Ecoregion:Central Great Plains
Start Date 01/01/1982 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description W4 (wheat)
Plan Date: 07/18/2007 Field Area (acres): 7.17
Field Slope (%): 7.4 Slope Length (ft): 200
Soil Test P (ppm): 41
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 68.4
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/01 Commercial Fertilization (Nitrogen Only) 49.0 lb/acre of N
03/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
06/16 Harvest Small Grains
09/14 Commercial Fertilization (Phosphorus Only) 46.6 lb/acre of P2O5
09/14 Performing No-till (Primary)
09/14 Commercial Fertilization (Nitrogen Only) 50.0 lb/acre of N
09/15 Planting Small Grains

################ File Name: woodwardnativeww11977to80 #####################
Field Owner: Smith and Menzel
Plan Developer: 1977 to 1980
Field Description: Woodward Native WW1
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 11.6
Field Slope (%): 7 Slope Length (ft): 200
Soil Test P (ppm): 14
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww11977to89 ######################
Field Owner: Simth and Sharpley
Plan Developer: 1977-1989
Field Description: Woodward Native WW1
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 11.6
Field Slope (%): 7.0 Slope Length (ft): 200
Soil Test P (ppm): 14
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww21977to80 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977 to 1980
Field Description: Woodward Native pasture WW2
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1980
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 13.8
Field Slope (%): 8.2 Slope Length (ft): 200
Soil Test P (ppm): 15
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days
05/01 Commercial Fertilization (Nitrogen Only) 8.9 lb/acre of N
05/01 Commercial Fertilization (Phosphorus Only) 4.5 lb/acre of P2O5

################ File Name: woodwardnativeww21977to89 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1977-1989
Field Description: Woodward Native WW2
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 13.8
Field Slope (%): 8.2 Slope Length (ft): 200
Soil Test P (ppm): 15
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65

Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww21982to86 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1982-1986
Field Description: Woodward Native WW2
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1982 End Date: 12/31/1986
UTM Coordinates: E N Datum

Legal Description
Plan Date: 07/19/2007 Field Area (acres): 13.8
Field Slope (%): 8.2 Slope Length (ft): 200
Soil Test P (ppm): 15
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww31977to79 ######################
Field Owner: Smith and Menzel
Plan Developer: 1977 to 1979
Field Description: Woodward NAtive WW3
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1980 End Date: 12/31/2004
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 6.7
Field Slope (%): 8.6 Slope Length (ft): 200
Soil Test P (ppm): 22
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww31987to89 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1987-1989
Field Description: Woodward Native WW3
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1987 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 6.7
Field Slope (%): 8.6 Slope Length (ft): 200
Soil Test P (ppm): 22
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

############### File Name: woodwardwheatww31982to86 ######################
Field Owner: Smith and Sharpley
Plan Developer: 1982-1986
Field Description: Woodward wheat WW3
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1982 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 6.7
Field Slope (%): 8.0 Slope Length (ft): 200
Soil Test P (ppm): 29
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

06/16 Harvest Small Grains
09/13 Commercial Fertilization (Phosphorus Only) 46.6 lb/acre of P2O5
09/13 Commercial Fertilization (Nitrogen Only) 50.0 lb/acre of N
09/14 Performing Conventional tillage (Primary)
09/15 Planting Small Grains

################ File Name: woodwardnativeww41977to79 #####################
Field Owner: Smith and Menzel
Plan Developer: 1977-1979
Field Description: Woodward Native WW4
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1979
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 7.2
Field Slope (%): 7.4 Slope Length (ft): 200
Soil Test P (ppm): 30
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardnativeww41987to89 #####################
Field Owner: Simth and sharpley
Plan Developer: 1987-1989
Field Description: Woodward native WW4
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1987 End Date: 12/31/1989
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/19/2007 Field Area (acres): 7.2
Field Slope (%): 7.4 Slope Length (ft): 200
Soil Test P (ppm): 30
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 364 Days

################ File Name: woodwardwheatww41982to86 #####################
Field Owner: Smith and Sharpley
Plan Developer: 1982-1986
Field Description: Woodward wheat WW4
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1982 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/18/2007 Field Area (acres): 7.2
Field Slope (%): 8.0 Slope Length (ft): 200
Soil Test P (ppm): 41
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 68.4
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

06/16 Harvest Small Grains
09/13 Commercial Fertilization (Phosphorus Only) 46.6 lb/acre of P2O5
09/13 Commercial Fertilization (Nitrogen Only) 50.0 lb/acre of N
09/14 Performing No-till (Primary)
09/15 Planting Small Grains

################ File Name: woodwardnograze #####################
Field Owner: Berg
Plan Developer: 1977-1979
Field Description: Woodward No Graze pasture
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1977 End Date: 12/31/1979
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/24/2007 Field Area (acres): 13.8
Field Slope (%): 6.5 Slope Length (ft): 200
Soil Test P (ppm): 5
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.0 Animal Units per Acre for 364 Days

################ File Name: woodwardgraze #####################
Field Owner: Berg and smith
Plan Developer: 1980-1986
Field Description: Woodward Grazed pasture
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1980 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/24/2007 Field Area (acres): 11.6
Field Slope (%): 6.5 Slope Length (ft): 200
Soil Test P (ppm): 5
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

01/01 Rotational or flash Grazing 0.111 Animal Units per Acre for 364 Days

################ File Name: woodwardduration #####################
Field Owner: Berg and smith
Plan Developer: 1980-1986
Field Description: Woodward short duration pasture
Climate Region: Woodward Ecoregion:Central Great Plains
Start Date 01/01/1980 End Date: 12/31/1986
UTM Coordinates: E N Datum
Legal Description
Plan Date: 07/24/2007 Field Area (acres): 13.6
Field Slope (%): 6.5 Slope Length (ft): 200
Soil Test P (ppm): 5
Soil #1 (100.0%): Woodward_loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

06/01 Rotational or flash Grazing 0.111 Animal Units per Acre for 91 Days

################ File Name: chickashacottonC31972to76 #####################

Field Owner: Menzel et al.
Plan Developer: July 1972 to June 1976
Field Description: Chickasha C3 Cotton plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 44.2

Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 20
Soil #1 (57.0%): McLain_silt loam Hy. Group C CN2: 85
Soil #2 (30.0%): McLain_silty clay loam Hy. Group C CN2: 85
Soil #3 (13.0%): Reinach_silt loam Hy. Group B CN2: 78
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Commercial Fertilization (Phosphorus Only) 59.5 lb/acre of P2O5
02/28 Commercial Fertilization (Nitrogen Only) 28.4 lb/acre of N
03/01 Performing Conventional tillage (Primary)
05/15 Planting Cotton
05/16 Irrigate Cotton as needed througout crop cycle
11/02 Harvest Cotton

################ File Name: chickashacottonC41972to76 ######################
Field Owner: Menzel et al.
Plan Developer: July 1972 to June 1976
Field Description: Chickasha C4 Cotton plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 29.9
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 30
Soil #1 (20.0%): McLain_silt loam Hy. Group C CN2: 85
Soil #2 (77.0%): McLain_silty clay loam Hy. Group C CN2: 85
Soil #3 (3.0%): Reinach_silt loam Hy. Group B CN2: 78
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Commercial Fertilization (Phosphorus Only) 59.5 lb/acre of P2O5
02/28 Commercial Fertilization (Nitrogen Only) 28.4 lb/acre of N
03/01 Performing Conventional tillage (Primary)
05/15 Planting Cotton
05/16 Irrigate Cotton as needed througout crop cycle
11/02 Harvest Cotton

################ File Name: chickashawheatC51972to76 ######################
Field Owner: Menzel et al.
Plan Developer: July 1972 to June 1976
Field Description: Chickasha C5 wheat plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 12.8
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 28
Soil #1 (42.0%): McLain_silty clay loam Hy. Group C CN2: 83
Soil #2 (34.0%): McLain_silt loam Hy. Group C CN2: 83
Soil #3 (24.0%): Reinach_silt loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description

----------------------------Cropland Management ------------------------------
Date Description

01/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
01/01 Commercial Fertilization (Nitrogen Only) 27.8 lb/acre of N

06/16 Harvest Small Grains
10/01 Commercial Fertilization (Nitrogen Only) 27.7 lb/acre of N
10/01 Commercial Fertilization (Phosphorus Only) 9.3 lb/acre of P2O5
10/02 Performing Conventional tillage (Primary)
10/03 Planting Small Grains

################ File Name: chickashawheatC61972to76 #####################
Field Owner: Menzel et al.
Plan Developer: July 1972 to June 1976
Field Description: Chickasha C6 wheat plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 13.1
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 20
Soil #1 (49.0%): McLain_silt loam Hy. Group C CN2: 83
Soil #2 (32.0%): McLain_silty clay loam Hy. Group C CN2: 83
Soil #3 (19.0%): Reinach_silt loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

01/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
01/01 Commercial Fertilization (Nitrogen Only) 27.8 lb/acre of N
06/16 Harvest Small Grains
10/01 Commercial Fertilization (Nitrogen Only) 27.7 lb/acre of N
10/01 Commercial Fertilization (Phosphorus Only) 9.3 lb/acre of P2O5
10/02 Performing Conventional tillage (Primary)
10/03 Planting Small Grains

################ File Name: ChickashanativeR61972to76 #####################
Field Owner: Menzel et al.
Plan Developer: July 1972 to June 1976
Field Description: Chickasha R6
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of chickasha
Plan Date: 07/25/2007 Field Area (acres): 27.2
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 10
Soil #1 (53.0%): Grant_silt loam Hy. Group B CN2: 65
Soil #2 (42.0%): Renfrow_silt loam Hy. Group D CN2: 82
Soil #3 (5.0%): Kingfisher_silt loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

06/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 213 Days

################ File Name: chickashacottonC11972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha C1 Cotton plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 17.8
Field Slope (%): 0.5 Slope Length (ft): 400
Soil Test P (ppm): 20
Soil #1 (66.0%): McLain_silt loam Hy. Group C CN2: 85
Soil #2 (19.0%): Reinach_loam Hy. Group B CN2: 78

Soil #3 (15.0%): McLain_silty clay loam Hy. Group C CN2: 85
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

03/01 Performing Conventional tillage (Primary)
05/15 Planting Cotton
11/02 Harvest Cotton

################ File Name: chickashacottonC31972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha C3 Cotton plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 44.2
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 20
Soil #1 (57.0%): McLain_silt loam Hy. Group C CN2: 85
Soil #2 (30.0%): McLain_silty clay loam Hy. Group C CN2: 85
Soil #3 (13.0%): Reinach_silt loam Hy. Group B CN2: 78
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Commercial Fertilization (Phosphorus Only) 63.7 lb/acre of P2O5
02/28 Commercial Fertilization (Nitrogen Only) 37.0 lb/acre of N
03/01 Performing Conventional tillage (Primary)
05/15 Planting Cotton
05/16 Irrigate Cotton as needed througout crop cycle
11/02 Harvest Cotton

################ File Name: chickashacottonC41972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha C4 Cotton plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 29.9
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 30
Soil #1 (20.0%): McLain_silt loam Hy. Group C CN2: 85
Soil #2 (77.0%): McLain_silty clay loam Hy. Group C CN2: 85
Soil #3 (3.0%): Reinach_silt loam Hy. Group B CN2: 78
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management ------------------------------
Date Description

02/28 Commercial Fertilization (Phosphorus Only) 74.1 lb/acre of P2O5
02/28 Commercial Fertilization (Nitrogen Only) 37.0 lb/acre of N
03/01 Performing Conventional tillage (Primary)
05/15 Planting Cotton
05/16 Irrigate Cotton as needed througout crop cycle
11/02 Harvest Cotton

################ File Name: chickashawheatC51972to73 #####################

Field Owner: Olness et al.

Plan Developer: July 1972 to June 1973
Field Description: Chickasha C5 wheat plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 12.8
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 28
Soil #1 (42.0%): McLain_silty clay loam Hy. Group C CN2: 83
Soil #2 (34.0%): McLain_silt loam Hy. Group C CN2: 83
Soil #3 (24.0%): Reinach_silt loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management -------------------------------
Date Description

06/16 Harvest Small Grains
10/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
10/01 Commercial Fertilization (Nitrogen Only) 33.4 lb/acre of N
10/02 Performing Conventional tillage (Primary)
10/03 Planting Small Grains

################ File Name: chickashawheatC61972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha C6 wheat plot
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha
Plan Date: 07/25/2007 Field Area (acres): 13.1
Field Slope (%): 0.1 Slope Length (ft): 400
Soil Test P (ppm): 20
Soil #1 (49.0%): McLain_silt loam Hy. Group C CN2: 83
Soil #2 (32.0%): McLain_silty clay loam Hy. Group C CN2: 83
Soil #3 (19.0%): Reinach_silt loam Hy. Group B CN2: 75
Planted in Strait Rows
Interface Type: Advanced
Description: Please Enter a Description
----------------------------Cropland Management -------------------------------
Date Description

06/16 Harvest Small Grains
10/01 Commercial Fertilization (Phosphorus Only) 0.0 lb/acre of P2O5
10/01 Commercial Fertilization (Nitrogen Only) 33.4 lb/acre of N
10/02 Performing Conventional tillage (Primary)
10/03 Planting Small Grains

################ File Name: ChickashanativeR51975to76 #####################
Field Owner: Olness et al.
Plan Developer: May 1975 to May 1976
Field Description: Chickasha R5
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 05/01/1975 End Date: 4/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha, OK
Plan Date: 07/25/2007 Field Area (acres): 23.7
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 5
Soil #1 (43.0%): Grant_silt loam Hy. Group B CN2: 65
Soil #2 (51.0%): Renfrow_silt loam Hy. Group D CN2: 82
Soil #3 (6.0%): Kingfisher_silt loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed

-----------------------------Pasture Management ------------------------------

Date Description

05/19 Commercial Fertilization (Phosphorus Only) 153.6 lb/acre of P2O5
05/19 Commercial Fertilization (Nitrogen Only) 77.6 lb/acre of N
09/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 121 Days

################ File Name: ChickashanativeR51972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha R5
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha, OK
Plan Date: 07/25/2007 Field Area (acres): 23.7
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 5
Soil #1 (43.0%): Grant_silt loam Hy. Group B CN2: 65
Soil #2 (51.0%): Renfrow_silt loam Hy. Group D CN2: 82
Soil #3 (6.0%): Kingfisher_silt loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

04/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 274 Days

################ File Name: ChickashanativeR61975to76 #####################
Field Owner: Olness et al.
Plan Developer: May 1975 to May 1976
Field Description: Chickasha R6
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 05/01/1975 End Date: 4/30/1976
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha, OK
Plan Date: 07/25/2007 Field Area (acres): 27.2
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 10
Soil #1 (53.0%): Grant_silt loam Hy. Group B CN2: 65
Soil #2 (42.0%): Renfrow_silt loam Hy. Group D CN2: 82
Soil #3 (5.0%): Kingfisher_silt loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
------------------------------Pasture Management ------------------------------
Date Description

06/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 213 Days

################ File Name: ChickashanativeR61972to73 #####################
Field Owner: Olness et al.
Plan Developer: July 1972 to June 1973
Field Description: Chickasha R6
Climate Region: Chickasha Ecoregion:Central Great Plains
Start Date 07/01/1972 End Date: 6/30/1973
UTM Coordinates: E N Datum
Legal Description 14 km east and 4 km north of Chickasha, OK
Plan Date: 07/25/2007 Field Area (acres): 27.2
Field Slope (%): 2.7 Slope Length (ft): 300
Soil Test P (ppm): 10
Soil #1 (53.0%): Grant_silt loam Hy. Group B CN2: 65
Soil #2 (42.0%): Renfrow_silt loam Hy. Group D CN2: 82
Soil #3 (5.0%): Kingfisher_silt loam Hy. Group B CN2: 65
Forage Type: Native Grass Yield Goal (t/acre):
Forage Optimally Managed
-----------------------------Pasture Management ------------------------------
Date Description

04/01 Rotational or flash Grazing 0.125 Animal Units per Acre for 274 Days

VITA

Michael White
Candidate for the Degree of
Doctor of Philosophy

Dissertation: Development of and Validation of a Quantitative Phosphorus Loss Assessment Tool

Major Field: Biosystems Engineering

Biographical:

Personal: Native Oklahoman born July 20, 1975

Education: Received a Bachelor of Science degree in Biosystems Engineering from Oklahoma State University in Stillwater, Oklahoma in 1999; received Master of Science degree with a major in Biosystems Engineering at Oklahoma State University in 2001. Completed the requirements for the degree of Doctor of Philosophy degree with a major in Biosystems Engineering at Oklahoma State University in 2007.

Experience: Employed as a research engineer by Oklahoma State University, Biosystems Engineering Department from 2001 to present.

Professional Memberships: American Society of Agricultural Engineers

Selected Reports and Publications:

White, M., D. Storm, T. Demissie, H. Zhang, and M. Smolen. 2003. Pasture Phosphorus Management (PPM) Calculator technical documentation version 1.0. http://storm.okstate.edu/PPM_Calculator/PPM%20Calculator%20Version%201.0%20documentation%2012-31-2003.pdf. Last accessed 12/6/2007

White, M., D. Storm, and S. Stoodley. 2002. A strategy for using SWAT to target critical sediment source areas, Total Maximum Daily Load (TMDL) Environmental Regulations–, ASAE Publication Number 701P1503, Albuquerque, New Mexico USA.

White, M., D.E. Storm, and M.D. Smolen. 2001. Hydrologic modeling of the Great Salt Plains basin. Oklahoma State University, Biosystems and Agricultural Engineering Department., Stillwater. http://biosystems.okstate.edu/home/dstorm/reports/Saltfork_report_rev_14.pdf. Last accessed 12/6/2007.

White, M.J. 2001. Evaluation of management practices and examination of spatial detail effects using the SWAT model. http://storm.okstate.edu/eucha/modeling/white_thesis.pdf. Last accessed 12/6/2007.

Ancev, T., A. Stoecker, D. Storm, and M. White. 2006. The economics of efficient phosphorus abatement in a watershed. *Journal of Agricultural and Resource Economics*. 31: 529-548.

Engel, B., D. Storm, M. White, J. Arnold, and M. Arabi. 2007. A hydrologic/water quality model application protocol. *Journal of the American Water Resources Association.* 43: 1223-1236.

Storm, D.and M. White. 2005. Development of guidelines for TMDLs with nonpoint source components using SWAT. http://www.okcc.state.ok.us/WQ/WQ_reports/report0114.pdf. . Last accessed 12/6/2007

Storm, D.E., M. White, M.D. Smolen, and H. Zhang. 2001. Modeling phosphorous loading for the Lake Eucha basin. http://biosystems.okstate.edu/home/dstorm/eucha/modeling/OSU_EuchaReport_110101.pdf. . Last accessed 12/6/2007

Storm, D.E., M.J. White, M.B. Armstrong, L.E. Christianson, and P.R. Busteed. 2005a. Targeting high non-point source contributing areas in the Turkey Creek basin. http://biosystems.okstate.edu/home/dstorm/reports/Turkey%20Creek%2012-1-2005%20DRAFT.pdf. Last accessed 12/6/2007

Storm, D.E., M.J. White, and P.R. Busteed. 2005b. Targeting high phosphorus loss areas in the Spavinaw Creek basin. http://biosystems.okstate.edu/home/dstorm/reports/Spavinaw%20Targeting%2011-2-2005.pdf. . Last accessed 12/6/2007

Storm, D.E., M.J. White, and M.D. Smolen. 2006c. Illinois River upland and in-stream phosphorus modeling Oklahoma State University, Department of Biosystems and Agricultural Engineering. http://www.crossroads.odl.state.ok.us/cgi-in/showfile.exe?CISOROOT=/stgovpub&CISOPTR=562. . Last accessed 12/6/2007

Other reports and publications available by request.

Name : Michael James White | Date of Degree: December 2007

Institution Oklahoma State University | Location: Stillwater, Oklahoma

Title of Study: Development and Validation of a Quantitative Phosphorus Loss Assessment Tool

Pages in Study: 302 | Candidate for the Degree of Doctor of Philosophy

Major Field: Biosystems Engineering

Abstract:

Conservation planners need an assessment tool to accurately predict phosphorus loss from agricultural lands to evaluate the impact of management decisions on water quality. Available tools to predict phosphorus loss were either qualitative indices with limited capability to quantify offsite water quality impacts or quantitative process based models which were prohibitively complex for most conservation planners. To address the need for a simple quantitative tool, PPM Plus was developed. PPM Plus is a vastly simplified interface for the Soil and Water Assessment Tool (SWAT) model, a powerful comprehensive hydrologic and water quality model which can predict the average annual phosphorus and sediment losses. It is simple enough for use by farmers and conservation planners, supports both cultivated crops and pastures, and can applied throughout the state of Oklahoma. PPM Plus can make predictions using a wide variety of management options and Best Management Practices (BMPs). It can be used to predict site specific impacts of many BMPs prior to implementation and aid in the evaluation of state and federally sponsored BMP implementation projects. When combined with numeric water quality standards, it can be used to predict allowable animal manure or commercial fertilizer application by field to ensure that water quality standards are met. A detailed sensitivity analysis and extensive validation was conducted on PPM Plus. The validation used 283 years of field scale data collected under natural rainfall throughout Oklahoma and the southern United States. These extremely diverse data included pasture, small grains, and row crop fields with rainfall ranging from 630 to 1390 mm/yr, with and without manure application. The validation included average annual runoff, total and soluble phosphorus, and sediment. PPM Plus explained 68% of the variability in measured total phosphorus losses. This tool performed extremely well compared to other field scale phosphorus assessment tools. PPM Plus puts the predictive power of one of the best hydrologic water quality models into the hands of people who make daily farm management decisions which impact water quality.

Advisors Approval: ______ Daniel E. Storm ______