A Quantitative Phosphorus Index for Conservation and Nutrient Management Plan Development

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Abstract

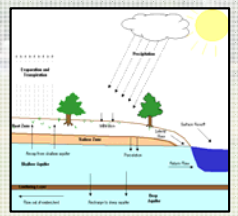
The primary goal of this work was to develop and test a quantitative phosphorus prediction tool, PPM+. This tool acts as an interface to Soil and Water Assessment Tool (SWAT) model, a powerful comprehensive hydrologic and water quality model. PPM+ vastly simplifies the operation of SWAT, allowing its use by conservation and nutrient management plan developers. PPM+ predicts the average phosphorus lost from a single agricultural field which is transported to the nearest stream. PPM+ offers a host of Best Management Practice (BMP) options to allow the users to predict the impact of a BMP on a particular field before establishment. This information can be used to pick more appropriate BMPs or to identify fields contributing excessive phosphorus. This tool can be used to estimate P losses at different fertilizer or animal manure application rates. When combined with numeric water quality standards, PPM+ can function as a quantitative phosphorus index. Allowable animal waste applications can be determined by field to ensure that overall water quality standards are met. PPM+ was extensively validated on 283 field years of data with very good results, and is sufficiently reliable to serve as a phosphorus index or to aid in BMP evaluation and selection.

Introduction

Phosphorus is a pollutant of concern in Oklahoma's waters. Excess phosphorus in lakes and streams accelerates algal growth. Phosphorus is often the limiting nutrient for algal growth, and reducing its concentration is often the most effective method of control. Much of the phosphorus in Oklahoma's waters originates from agricultural activities. Predicting the impact of various management scenarios or the adoption of Best Management Practices (BMPs) on phosphorus loss is very important. This information can be used to select the most appropriate BMPs for a particular site or limit the application of animal manures on high phosphorus loss fields. The primary goal of this research is to develop an easy to use tool which can predict phosphorus loss from a single agricultural field, anywhere in the state of Oklahoma.

The SWAT Model

PPM+ is an interface for the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1996). SWAT is a widely accepted model which has been used extensively by hydrologists and engineers since 1994 in the United States and 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. PPM+ 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 watershed or basin scale. Models like SWAT have been used for many years to make predictions of phosphorus loss, but models have one primary weakness, they are complex. These models require a great deal of specialized knowledge, and data not readily available to phosphorus index users; farmers and conservation agents require a simpler tool (Veith et al., 2005).



SWAT Hydrologic Cycle

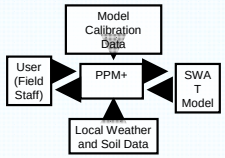
Improvements to PPM+

Previous versions of PPM+ (White et al., 2003) were only applicable to pasture systems in the Lake Eucha/Spavinaw Basin. The latest version is applicable to the entire state of Oklahoma, and includes common agricultural crops. The latest version has not yet been officially released, but has a significant number of improvements over previous versions.

- **Updated SWAT 2005 engine**
- **Expanded to cover the entire state of Oklahoma**
- **More flexible operation scheduling**
- **Handles row crops and small grains**
- **Includes irrigated crops**
- **Supports rotational grazing and supplemental feed**
- **Predicts average annual STP change**
- **Predicts cattle in streams impacts**
- **Includes riparian and grass buffers**
- **Pond effects**
- **Allows alum amended animal waste**
- **Contour planting and terraces**
- **Multiple soils allowed within a single field**
- **Expanded validation and testing**

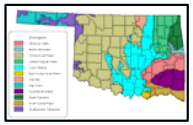
PPM+ - A Field Level Phosphorus Management Tool

Models like SWAT are generally too complex for use by conservationists and farmers, but they don't have to be. PPM+ was designed to be easy to use; the user does not see, nor directly interact with the SWAT model. An intelligent model interface takes relatively simple user data and generates the complex SWAT model inputs using internal database for weather, soils, and management. The SWAT model is executed in the background, after which PPM+ summarizes the output in a simple table that is easy to interpret. All the information entered by the user is listed in the output, along with monthly average precipitation, runoff, sediment, soluble and total phosphorus, and estimated annual Soil Test Phosphorus (STP) increase.



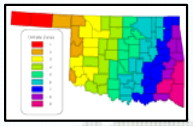
PPM+ Structure

PPM+ was developed for the state of Oklahoma, and includes databases describing weather and soils across the state. Oklahoma has tremendous differences in annual rainfall, ranging from 15 in/yr in the northwest panhandle to 55 in/yr in the mountains of the southeast. This tremendous difference must be accounted for in a statewide phosphorus management tool. Climatic and geologic diversity has given Oklahoma a wide variety of soil types, over 3,200 were represented in PPM+. Hydrologic calibration parameters were developed by calibrating the SWAT model to observed stream flow data in watersheds across Oklahoma.



Oklahoma Ecoregions

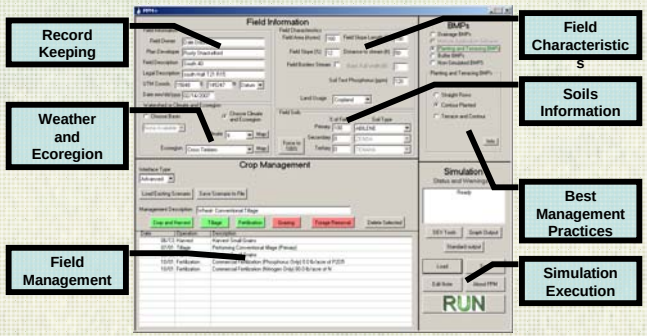
Calibration Watersheds



Climate Zones

PPM+ User Interface

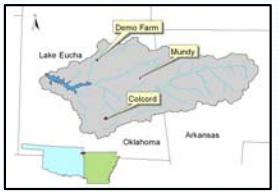
The PPM+ interface is shown below. PPM+ has been extensively tested and validated. Final beta testing is in progress; release is scheduled for December 2007. A description of the interface is also given below.



Record Keeping – Important documentation not used in model predictions.
Weather and Ecoregions – Enter precipitation and ecoregion from map.
Field Management – Actual field operations including harvest, planting, tillage, fertilization, hay cutting, and grazing.
Field Characteristics – Field topographical parameters, STP and land use.
Soils Information – Fraction of field occupied by each soil type.
Best Management Practices – BMPs selection, inappropriate BMPs are disabled.
Simulation Execution – Save, load, execute and other functions for generating predictions.

PPM+ Validation Data

Validation is the process of testing a model with data not used in calibration or model development. Data for the validation of PPM+ were collected from eight fields in the Eucha/Spavinaw Basin. These data were supplemented with data from other field scale phosphorus studies in Oklahoma, Arkansas, Texas, and Georgia. These data include pasture, small grains, and row crop fields. Fertilization rates varied, and many fields received large applications of animal manures. A total of 283 field years of data are used in the validation of PPM+. It is important that any P prediction tool be validated on a very diverse set of data to ensure its accuracy under varying conditions.

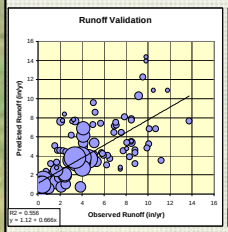


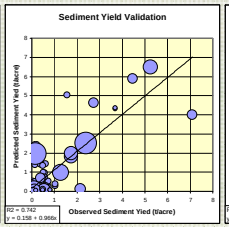
Field Sites in the Eucha/Spavinaw Basin

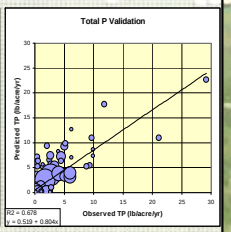
Field Sites across the Southern US

PPM+ Validation Performance

PPM+ was validated on runoff, sediment yield, and phosphorus loss. Although phosphorus loss was the primary concern, runoff and sediment yield are also important. The US Environmental Protection Agency's 303d lists more waters impaired due to sediment (10.7%) than for nutrients (8.8%) (USEPA 2005). PPM+ performed very well during the validation for all constituents, especially given the diversity of data. PPM+ was not calibrated to any field data prior to validation. Measured and predicted values are given in the scatterplots below. These data contained field studies of differing lengths. Using weighted least square regression, longer studies were given greater weight (larger dots) in the analysis. PPM+ is sufficiently accurate for the purpose of predicting phosphorus and sediment loss from Oklahoma's agricultural fields.







Conclusions

PPM+ performed very well during the validation, and made reliable predictions of runoff, sediment and phosphorus loss without calibration. PPM+ can be used for BMP selection and evaluation, enabling conservation planners to put right BMPs in the right locations. In addition, it can evaluate phosphorus reduction associated with government sponsored BMP implementation programs. We can quantify how much phosphorus loss is prevented per dollar spent. PPM+ can also be used as a phosphorus index to determine allowable animal manure application. This will require a specified maximum allowable P loss rate, which will allow water quality standards to be met; a task not addressed by this research. PPM+ is simple enough to be used with little or no training. It puts the predictive power of one of our best hydrologic models in the hands of conservation and nutrient management plan developers.

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