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# Suggested Procedures for Modeling Phosphorus Runoff in Central Illinois Farm Scale Watersheds

Timothy J. Freeman
tfree@siu.edu

# SUGGESTED PROCEDURES FOR MODELING PHOSPHORUS RUNOFF IN CENTRAL ILLINOIS FARM SCALE WATERSHEDS


by

Timothy J. Freeman

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Submitted in Partial Fulfillment of the Requirements for the
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Approved by:

Leslie A. Duram, Chair

Jonathan Remo

Samuel Adu-Prah

Graduate School
Southern Illinois University Carbondale
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# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Non-point Source Pollution is described as pollution from a distributed source. Most pollution in an agricultural setting is considered a non-point source, since activities are usually practiced over the extent of the agricultural plot. Agriculture is one of the major contributors to non-point source pollution (EPA, 2002). Two forms of agricultural non point source pollution are water and the dissolved contaminates within it, and sediment and the nutrients attached to the particles.

Phosphorus is a nutrient associated with agricultural practices. Seventy-six percent of Phosphorus in surface water of the U.S. is contributed from Agricultural activities (Carpenter, 1998). This is especially important in Illinois where there is a high ratio of Phosphorus contribution to the Mississippi River when compared with flow contributed by Illinois. Twelve percent of Mississippi Phosphorus loads are from Illinois, while Illinois only contributes 9.6% of flow (David and Gentry, 2000). After decades of fertilizer application a surplus of Phosphorus has been retained in the soil. This excess phosphorus could remain in soils, runoff, or leech into local aquifers. Phosphorus is more bio-available in its dissolved form, but it is commonly a sediment attached nutrient (Carpenter, 1998). Quantification of sediment loads is important because phosphorus is commonly a growth limiting nutrient in freshwater systems and can be retained in sediments for long periods of time (Meals, 2010: Alexander, 2005).

Excess sediment and nutrients like phosphorus and nitrogen can cause algal blooms, turbidity, and depleted dissolved oxygen (EPA, 2000). The concentrations of these nutrients in surface waters often limit growth of algae and bank-side vegetation. Increased concentrations of nutrients leads to accelerated primary productivity in freshwater and coastal ecosystems. The resulting eutrophication causes fish kills, biodiversity loss, and degradation of aquatic ecosystems (Carpenter, 1998). Increase of bacterial activity from eutrophication can cause bad taste and odor in drinking water supplies (Carpenter, 1998). Nitrogen and phosphorus are hard to regulate and measure due to weather variations and large areas (David and Gentry, 2000). Since non-point sources are difficult to quantify, models are typically used to predict non-point source loads (Borah, 2003). Quantification of attached and soluble phosphorus is especially critical in Illinois agricultural watersheds because of the amount of P stored in the soil that will eventually become bioavailable (Carpenter, 1998). One model capable of partitioning phosphorus into its dissolved and attached forms is the AGNPS (Agricultural Non-Point Source) model.

The recently updated AGNPS 5.0, developed by Agricultural Research Service scientist and engineers, is a hydrologic simulation model used widely by land owners, consultants, practitioners, and farm operators. This model is typically used to estimate water, sediment, nutrient, and pesticide runoff. This model can be used for either real world or hypothetical storm events. The model can be used to evaluate effects of BMP's (Best Management Practices) or other management decisions (Bartholic, 1995). Farmers continue to make management decisions for phosphorus application based on simulations from the AGNPS model. Many different studies have used AGNPS for runoff prediction measures. Yet, few validation studies have been done on the nutrient movement simulation and partitioning into dissolved (soluble) phosphorus and attached (sediment bound) phosphorus. The validation studies reviewed for this paper were in Kansas, Quebec, and Michigan, but scale, soils, and topography are different at the study site in Macon County, Illinois. Confirmation and precision studies are still needed on the updated 5.0 AGNPS model (Bosch, 1998). These previous validation studies used older versions of AGNPS that lacked important ephemeral gully, winter modeling, sub-surface flow components, and tile drainage simulation features. AGNPS 5.0 enhanced features increases its predictive ability for soils that freeze annually and are tilled, which can cause restrictive layers, leading to lateral subsurface flow.

The Buffett Foundation purchased agricultural land for the purpose of paired watershed experiments. This experimental agricultural plot has three complete thirty to forty acre watersheds. The agricultural plot is located ten miles south of Decatur in Macon County, Illinois. These watersheds are being analyzed for the first four years to develop a relationship between them. During the calibration period all three watersheds have the same management practices after four years a statistical relationship will be developed between them (U.S. EPA, 1993). The long-term focus of the study is to research what impact different farming practices, such as tilling and buffers, have on fertilizer and sediment runoff. This will be done by keeping one control watershed and employing different BMP's on the other two. Sediment and nutrient runoff will be collected and compared to the control watershed to determine what effects these BMP's have nutrient and sediment loads.

For these three watersheds the AGNPS Model coupled with ArcGIS will be used to predict conditions in these experimental watersheds. By comparing the model’s predicted condition to actual conditions, the predictive abilities of the model will be tested. This model will allow other researchers working on this project to experiment with different input parameters such as seasons, fertilizer types, application amounts, precipitation amounts, and antecedent moistures in a computer model. The AGNPS model can be used to calculate runoff amounts on all three watersheds to analyze the effect of different variables or BMP’s on runoff. Practitioners will be able to use this individual AGNPS model to simulate management decisions on the Buffet Foundation experimental watersheds. They will be able to employ a management decision into AGNPS then simulate a rain event to see what effect the management decision had on runoff.

Studies like this could also give insight on reasonable TMDL's (Total Maximum Daily Loads) for individual farms. Models aid development of TMDL Standards from Clean Water Act (Borah, 2003). These standards would limit damage to water bodies as a result of agricultural runoff. If we can accurately quantify sediment and nutrient loads and account for their sources, regional TMDL's for agricultural lands could be formed to reduce loads. The viability of a watershed model to mimic processes is tested through the calibration and validation process (White and Chaubey, 2005).

**1.2 Problem Statement**

The AGNPS model is a widely used agricultural model employed to simulate water, sediment, nutrient, and pesticide movement from cell to cell through a watershed for any given time period. Many data sources and statistics can be used for the model validation process. The purpose of this paper is to describe data and procedures needed to estimate actual conditions for water, sediment, and nutrients in small Central Illinois (30-40 acre) watersheds using the AGNPS 5.0 model. The AGNPS output data should be compared to the actual conditions on an event basis in order to calibrate and validate use of the model. A Central Illinois farm-scale watersheds validation study needs to be performed.

**1.3 Project Description**

This paper describes procedures to test if the AGNPS model can accurately predict real world conditions for water, sediment, and nutrients at field scale. Over the course of the calibration period the three watersheds will have identical treatments. All three watersheds at the Decatur site will have the same input parameters. These inputs will be soil, land use, climactic, and topographical data. The AGNPS model should be calibrated using the first two-thirds of the rain events. Based on the results of a relative sensitivity analysis, sensitive parameters should be adjusted in order to reduce relative error between model predicted values and observed. After the model is calibrated the AGNPS output data should be compared to the actual conditions for each watershed. AGNPS output should be tested for accuracy through statistical comparison of the simulated and observed data. The Nash-Sutcliffe efficiency coefficient should be used for comparison of observed and predicted runoff, sediment, and Phosphorus over the study period's average. Relative error will be used to calculate error for individual storms. Correlation of the model predicted and observed values depend on the accuracy of the AGNPS Model. Suggested procedures for model selection, data collection, and statistical analysis should create an accurate model, useful for predicting runoff, sediment, and nutrient transport under different management scenarios. By utilizing suggested statistical procedures, model accuracy can be compared to model accuracy in other studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Literature Review Summary

The following review summarizes previous literature about: Non-Point Source Pollution, sources and environmental consequences of Phosphorus pollution, different hydrological models used to estimate Phosphorus runoff, AGNPS model specifications, and previous AGNPS model use. Other sources reviewed include examples of common statistical methods used and field data collected to validate hydrological models, which can be found in the suggested procedures chapter of the paper.

## 2.2 Agriculture and Non-Point Source Pollution

Carpenter (1998) reports about non-point source pollution of surface waters. Non point Source Pollution is described as pollution from a distributed source. Most pollution in an agricultural setting is considered a non-point source since activities are usually practiced over the extent of the agricultural plot. Agriculture is one of the major contributors to non-point source pollution. Intensive agricultural activities contribute to excess nutrients and siltation in lakes and streams (Carpenter, 1998). Water and the dissolved chemicals within it, and sediment and the contaminants attached to the particles are the two primary forms of agricultural non-point source pollution. High concentration of nutrients like phosphorus is one of the major sources of non-point source pollution from agricultural land. In Illinois thirty-eight percent of phosphorus is dissolved, while 62% is attached to soil particles, while Nitrogen tends to be more soluble (David and Gentry, 2000). Phosphorus from agricultural-non point source pollutants effect can ecosystems at a regional and global level.

**Global Phosphorus Pollution**

The main cause of phosphorus being considered a non-point source pollutant is the surplus of Phosphorus that is retained in the soil (Carpenter, 1998). Globally, 600 X $10^6$ Mg of phosphorus was applied between 1950 and 1995. Only 250 X $10^6$ Mg was removed through harvest produce, and 50 X $10^6$ Mg was reapplied through manure. This leaves 400 X $10^6$ Phosphorus addition over 55 years, a 25% increase from the natural condition of 950 X $10^6$ Mg. This excess phosphorus could remain in soils, runoff, or leech into local aquifers (Carpenter, 1998). Three to twenty percent of phosphorus leaves through surface water. This results in a large amount of phosphorus retained in soils. In the U.S., this surplus of Phosphorus in soils impairs river and stream systems.

**U.S. Phosphorus Pollution**

Phosphorus is a nutrient associated with agricultural practices. Agricultural activities contribute seventy-six percent of Phosphorus entering the surface waters of the U.S. (EPA, 2002). Since nutrient input onto farms exceeds output of harvest yield in the U.S., there is a surplus of nutrients in the soil causing non-point source pollution (Carpenter, 1998). In an EPA assessment of the nation's water quality, 19% of U.S. river and stream miles were assessed. Agriculture was the leading source of river and stream impairment, accounting for 18% (128,859 miles) of pollutant sources in the miles of streams assessed, and 48% of the impaired streams. The second leading cause of impairment was hydrologic modification at 53,850 miles (EPA, 2002). Sedimentation impairs 12% of assessed streams and rivers, and 31% of impaired streams. Sedimentation can increase stream turbidity, decrease available oxygen, and suffocate fish eggs and bottom dwelling organisms (Illinois EPA, 2002). Eleven thousand kilometers of streams and

55,440 hectares of lakes are impaired by agricultural chemicals and sediment in Illinois (Illinois EPA, 2002).

**Illinois Phosphorus Pollution**

With use of the SPARROW model, 9 states in the Mississippi River Basin were found to contribute seventy-five percent of Nitrogen and Phosphorus to annual loads, while only making up thirty-three percent of the Mississippi River watershed (Alexander, 2005). Of these nine states Illinois contributed most to the seventy-five percent. In Illinois, there is a high ratio of Phosphorus contribution to the Mississippi River when compared with flow contributed by Illinois. Twelve and eighteen percent of the Mississippi river's Nitrogen and Phosphorus loads are from Illinois , while Illinois only contributes 9.6% of discharge (David and Gentry, 2000). Nitrogen and phosphorus are difficult to measure and regulate due to weather variations and large scale operations.  Illinois phosphorus inputs from 1945-1998 suggests a surplus of 2.2 million Mg of phosphorus (230 Kg P/ha) in row crop land covers. Most of this phosphorus still remains in Illinois soils after riverine export and crop uptake (David and Gentry, 2000).

**Problems Caused by Agricultural Non-Point Source Pollution**

Excess sediment and nutrients like phosphorus and nitrogen can cause nuisance algal blooms, turbidity, and depleted dissolved oxygen (EPA, 2000). The concentrations of these nutrients in surface waters often limit growth of algae and bank-side vegetation. Increased concentrations of nutrients can cause eutrophication of surface waters. The resulting eutrophication causes fish kills, biodiversity loss, and degradation of aquatic ecosystems (Carpenter, 1998). Increase of bacterial activity from eutrophication can cause bad taste and odor in drinking water supplies (Carpenter, 1998). Nitrogen has recently exceeded levels of10 mg./L in Decatur Lake, resulting in methemoglobinemia (Borah, 2003). Nitrogen and phosphorus are hard to regulate and measure due to weather variations and large areas (David and Gentry, 2000). Since non-point sources are difficult to quantify, models are typically used to predict non-point source loads (Borah, 2003). Modeling attached and soluble phosphorus is especially critical in Illinois agricultural watershed because of the amount of Phosphorus stored in the soil that will eventually become bioavailable (Carpenter, 1998).

**2.3 Review of Hydrological Models**

There have been many hydrological models developed to estimate non-point source pollution on different spatial and temporal scales (Borah, 2003). Hydrologic models are commonly intended to analyze current conditions, and predict future situations for BMP analysis (Wang, 2005). Models are our most practical way to analyze flow, sediment runoff and pollutant movement on a watershed scale. Models also allow users to locate high priority areas and analyze the effects of treatments prior to spending (Borah, 2003). There are continuous and single event simulation models in the temporal scale. Models can be intended for larger rivers to ephemeral gullies. There are many differences between the data input parameters for different hydrological models, as well as model output. In a 2005 Kansas lake eutrophication study, Wang based his criteria for model selection on: input parameters and the data output, model limitations, use history, and limitations of data collection (Wang, 2005).

The difference between single-event and continuous modeling is continuous models simulate runoff processes between events, and are usually used for long term studies (Borah, 2003). AnnAGNPS, ANSWERS-Continuous, HSPF, and SWAT are continuous simulation models useful for analyzing long-term effects of hydrological changes and watershed management practices. AGNPS, ANSWERS, DWSM, and KINEROS are single rainfall event models used to analyze severe actual or design single-event storms and evaluating watershed management practices. CASC2D, MIKE SHE, and PRMS long term and single event able (Suir, 2002: Borah, 2003). Two of the most commonly used models were SWAT and AGNPS. Single-event models with nutrient modeling capabilities were DWSM and AGNPS (Borah, 2003).

SWAT is a continuous simulation model suited for studying long term effects on large watersheds. The SWAT model is not well suited for single event modeling due to the use of the daily time step. Modeling intense short term events accurately is critical because of their ability to transport large amounts of sediment and nutrients (Borah, 2003). AnnAGNPS is also a continuous long term simulation model, but output can be set for single event accounting. Many different versions of AGNPS have been released. Some were released in the 1980's and others were released more recently. The initial versions of AGNPS were only suited for event modeling, and was not intended for winter time applications (Bosch, 1998). Updated versions of the model also include subsurface flow components that previous models lacked (Yuan, 2006). AGNPS 5.0 has been updated with many new modeling features and new validation studies are needed.

AGNPS and DWSM are both event suitable models with nutrient modeling capabilities (Borah, 2003). Borah presented a good review of eleven models and partitions them into long term and single event models. Out of the six of the major single event-models only AGNPS and DWSM had chemical runoff simulation capabilities. KINEROS and ANSWERS lack chemical and nutrient simulation capabilities. The ANSWERS model requires considerable amounts of data input. DWSM was developed at University of Illinois Champaign. DWSM is a computationally intensive model with sub-surface flow components good for the mild topography of Midwestern agricultural land that is commonly tile-drained (Borah, 2003).

**AGNPS Model**

AGNPS is a widely distributed, simple to use model, equipped with all three major modeling components (hydrology, sediment, chemical). AGNPS was original developed by the NRCS and the Minnesota Agricultural Research Service. The single event model of AGNPS used the event duration for its time step (Borah, 2003). This model was developed to estimate runoff from watersheds a couple hectares to 20,000 ha in size. The AGNPS 5.0 system now includes the original single event modeling and an AnnAGNPS component for continuous modeling for long term studies. The AGNPS 5.0 model is a distributed parameter, batch processed model (Bosch, 1998)

AGNPS model output includes fate and transport of chemicals. Source accounting locates areas contributing large loads to the watershed outlet. Source accounting output estimates total sediment, water, and nutrients each cell is contributing to the watershed outlet. For the event accounting output, the AGNPS model calculates loads passing through a selected cell on the stream reach for any given time period (event, monthly, or annual). These cells are usually chosen at the location of the watershed outlet (Wang and Ciu, 2005). The AGNPS model is suitable for primarily agricultural land cover, and adequate for small watersheds. Varying time-steps for different storms became difficult to analyze for long term simulations with multiple events. The AGNPS model is a widely used model across the world, but there were major limitations in the single event model. The AnnAGNPS was created in order to better simulate long term watershed processes.

The AnnAGNPS model is a continuous simulation model released in 1998. This means that the AnnAGNPS considers multiple events for one simulation. AnnAGNPS requires more parameters for data input than the single event AGNPS in order to model in between storm events (Borah, 2003). The original AGNPS was developed in the early 1980's. This version of AGNPS only had 22 input parameters compared to the 34 parameter required for AnnAGNPS. AnnAGNPS requires more input data parameters for forecasting future climate with weather generators, and antecedent soil moisture considerations between events. AnnAGNPS had many features upgraded from the original AGNPS. The 1998 AnnAGNPS was updated to include modeling features for pesticides, source accounting, sediment settling, winter applications, ephemeral gullies and groundwater (Bosch, 1998). The AnnAGNPS model uses a time step of one day. Water and the resulting runoff movement is simulated through the entire watershed before the next day is modeled. This is a limitation when looking at individual storms. Depending on study focus and data limitations either the AGNPS single event or AnnAGNPS must be chosen. AGNPS 5.0 single event model has been updated with many of the same features as AnnAGNPS (Bosch, 1998).

Some sub-models of AGNPS are CCHE1D, CONCEPTS, SNTEMP, CREAMS, and GLEAMS. CCHE1D is the stream network analysis an AGNPS. CONCEPTS is the stream corridor model in AGNPS. SNTEMP is the in-stream temperature model in AGNPS. CREAMS is the Chemicals, Runoff, and Erosion for Agricultural Systems used to calculate sediment and nutrients in the AGNPS model. This sub-model includes the Revised Universal Soil Loss Equation for sediment calculation. GLEAMS is the Groundwater Loading Effects of Agricultural Management Systems, used to calculate effects of agricultural management on groundwater (Bosch, 1998).

## 2.4 Previous AGNPS Model Use

### Introduction

There have been many studies that use the AGNPS model. The AGNPS model has been broadly and successfully used in U.S. (Wang, 2005). While many studies have used the AGNPS Model for its predictive abilities, few AGNPS validations have been presented. Some AGNPS studies use the single event simulation and others are annual studies. These models are used on a variety of landscapes and scales. The validation studies reviewed are Kansas, Quebec, and Michigan. The Kansas study utilizes the continuous annual simulation version of AGNPS, AnnAGNPS.

### Kansas Lake Eutrophication (Wang, 2005)

This study uses the AnnAGNPS model for annual simulation of nutrient loadings into Kansas lakes. The AnnAGNPS model was used to simulate effects of watershed BMP's on nutrient levels and plant biomass increases in Central Plains lakes in Osage County, Kansas (Wang, 2005). This analysis would allow users to collect information about different nutrient loads and their effect on lakes trophic conditions. The methods used in this analysis consisted of measuring total Nitrogen and Phosphorus and chlorophyll levels in a deep clear, deep turbid, shallow clear, and shallow turbid reservoir. Streams discharging to the reservoir were monitored and used for AnnAGNPS calibration and validation. In this study, the AnnAGNPS model was calibrated and validated for partitioning dissolved and attached phosphorus (Wang, 2005).

This paper reviewed criteria for model selection. Wang based his criteria for model selection on: input parameters, the data output, model limitations, use history, and limitations of data collection. Hydrologic models are commonly intended to analyze current conditions, and predict future situations for BMP analysis (Wang, 2005).

Modeling is one of the most effective management strategies. Critical loading levels can be identified through modeling to aid in TMDL development. The quantification of nutrient and sediment loads will give inferences on critical areas contributing to loads (Wang, 2005). The study of effects of nutrient levels on reservoir eutrophication is in itself significant for water quality.

In particular this study discussed nutrient loads in terms of lake/reservoir eutrophication. The measurement of stream/tributary data follows a good methodology for observed water quality data collection. This study is also using 5 events for calibration and 4 events for validation. There are a limited number of events being collected for this study due to time restrictions (Wang, 2005). The watersheds used in this study were also relatively large. Watershed sizes ranged from 881 to 95,320 hectares (Wang, 2005). The AGNPS model is better suited for small scale studies, with primarily agricultural land.

**Michigan (Bartholic, 1995)**

Another study that utilized the AGNPS model was in Saginaw Bay, Michigan. The purpose of this study was to locate critical source areas, choose BMP's, and validate effects of management strategies. Over the course of this study different BMP's were used to decrease sediment and nutrient concentrations to improve water quality and maintain soil quality. Bartholic did not use the nutrient accounting portion of the model. Also, in this study, the model was not validated with field measurements.

In this case the AGNPS model was used to target critical source areas, and analyze the effect different BMP's have on these areas. The model was used to pinpoint which watersheds or areas need most attention in Saginaw Bay, Michigan (Bartholic, 1995). Once these critical areas were located AGNPS could be used to examine tradeoffs between different management practices. BMP's used in these critical areas are analyzed to determine how they affect runoff when compared to another BMP.

This study found that the factors that have the highest effect on non-point source pollution in agricultural watersheds were slope, soil erodibility, row crops, and reach lengths (Bartholic, 1995). The clustering of these factors would locate areas vulnerable to erosion. By comparing runoff between individual cells, critical source areas can be identified. Locating and treating these identified areas ensure that areas of greatest erosion potential will be treated (Bartholic, 1995). The Cass River, a sub-watershed of Saginaw Bay was analyzed in this study. The AGNPS model was used to estimate impact of agricultural runoff. The model estimated sediment mass and attached and soluble phosphorus in pounds per acre. This study found that the Cass River introduces large amounts sediment and nutrients into Saginaw Bay. A 25 year frequency storm of 3.7 inches over 24 hours created 145 tons of runoff per acre at the mouth of the watershed (Bartholic, 1995).

**Quebec (Perrone, 1997)**

A similar study in Quebec tested the predictability of AGNPS for simulating runoff, peak flow, and sediment yields 26 km$^2$ watershed (Perrone, 1997). This study was intended to test if the AGNPS Model is suitable for Quebec soils and topography. In the Quebec study, data availability created an opportunity to study a small scale farm (Perrone, 1997). Event simulation at a number of scales is critical (Perrone, 1997). In Perrone's study on Quebec watersheds seven events were used for calibration and five events were used for validation, for a total of twelve events. This data was collected over the course of two years. Perrone also used the model to locate areas susceptible to NPS pollution. After these critical areas are located BMP’s can be applied, and their effectiveness can be monitored. In this study the St. Esprit watershed in Montreal was intensely monitored for water quality.

This study was significant in that small rural watersheds are rarely gauged. Commonly only large watersheds are monitored by government agencies. The St Esprit watershed is 64% cropland and 38% is un-cropped. This study found that the AGNPS model was reliable for predicting runoff and sediment yields, but predicted poorly for peak flow. High correlation in runoff and sediment indicated that the AGNPS model may predict well for partitioning Phosphorus, since Phosphorus yield depends highly on sediment yield. Also using this previous version of AGNPS, Peronne reported poor performance of the model in winter months. The AGNPS model has been updated with new wintertime modeling features to better predict snow-melt (Bosch, 1998).

# CHAPTER 3

# SUGGESTED PROCEDURES

## 3.1 Study Area

The study area is in Macon County, IL. It is located 10 miles south of Decatur, Illinois on State Highway 51. On this agricultural plot there are three individual watersheds, each one is thirty to forty acres. The Buffett Foundation purchased this agricultural land for the purpose of paired watershed experiments. These watersheds are being compared for the first four years to develop a relationship between them. The three watersheds should have the same management practices during the calibration period. The AGNPS model should be calibrated and validated for all three watersheds on the agricultural site by comparing model predictions with observed field data.

The three watersheds on the Buffet Site are mainly composed of two different soil series. Drummer silty clay loam 0-2% slopes and Flanagan silt loam 0-2% slopes are the two dominant soil series within the watersheds, based on a USDA Web Soil Survey. Drummer silty clay loam is found near drainage areas, while Flanagan silt loam is found on rises. Both soils are mollisols, which have a relatively high organic content. The Drummer soil series is Illinois State Soil, covering more than 1.5 million acres in Illinois. Drummer soils are found mostly in the north-central area of the state coinciding with areas of high commercial corn and soybean production. With restrictive features at 80 inches, mild slopes, and poorly drained soils at lower elevations, there are increased chances for lateral sub-surface flow. NCDC Normals from 1971 to 2000 show monthly and annual average precipitation (Table 1) and temperature (Table 2) for the Buffet Study area (2007).

1971-2000 NCDC Normals (Table 1)

| Element | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Prec. (in) | 2.05 | 1.95 | 3.20 | 3.58 | 4.47 | 3.90 | 4.54 | 4.14 | 2.98 | 2.74 | 3.32 | 2.87 | 39.74 |

1971-2000 NCDC Normals (Table 2)

| Element | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| High °F | 34.5 | 40.5 | 52.6 | 65.3 | 76.1 | 84.5 | 87.8 | 85.8 | 79.9 | 67.8 | 52.0 | 39.2 | 63.8 |
| Low °F | 17.1 | 22.1 | 31.9 | 41.8 | 51.6 | 60.6 | 64.6 | 62.8 | 54.9 | 43.9 | 33.5 | 22.6 | 42.3 |
| Mean °F | 25.8 | 31.3 | 42.3 | 53.6 | 63.9 | 72.6 | 76.2 | 74.3 | 67.4 | 55.9 | 42.8 | 30.9 | 53.1 |

(Illinois State Water Survey, 2007)

### 3.2 Field Data Collection

Water quality samples should be taken at all three flumes, located at the watershed outlet, using auto-samplers. The purpose of the flume is to accurately record discharge in a fixed channel, based on stage and velocity. An auto-sampler consists of 16 bottles that are filled with runoff water at different time intervals during a storm event. The auto-sampler will start at the onset of the storm. The auto-sampler will take a concentration sample every 30 minutes after the first sample is taken. Since these are ephemeral streams, there will be no base-flow, and therefore little need to make continuous predictions. After the storm event the bottles are collected, and replaced with clean empty bottles. The samples should then be analyzed for total phosphorus concentration of the water.

Total Phosphorus is measured by the persulfate digestion procedure. This procedure consists of heating and acidifying the sample to convert all forms of Phosphorus to orthophosphate. The orthophosphate or Total Phosphorus is then measured using the ascorbic acid method. The ascorbic acid method uses an ascorbic acid and ammonium molybdate compound. When this compound is mixed with the orthophosphate in the sample, the sample turns a shade of blue. Total orthophosphate in the sample is directly proportional to the intensity of the blue. The water sample from the event should also be passed through a 45 micron Phosphorus-free filter and measured using the persulfate digestion procedure for total dissolved phosphorus. The phosphorus attached to the solids collected by the filter is considered total attached phosphorus. This value can be found by subtracting the dissolved Phosphorus from the Total Phosphorus (EPA, 1993). Discharge and water samples should be collected for all events occurring within the study period. Once runoff volumes (discharge) are collected sediment and phosphorus loads are calculated by multiplying concentration by discharge in 30 minute intervals for the entire storm.

### 3.3 AGNPS Input Data

The input data for the AGNPS model has four different subcategories for data entry. These categories are soils, topography, land management, and climate. There are 34 different parameters divided into the subcategories. The data for these 34 parameters will come from many different sources. Data should be collected from the site, land owners, and computer databases.

#### Land Management Data

Land management data can be collected from landowners and Landsat land cover maps. Land Management data include Crop Data, Fertilizer Reference Data, Landuse Reference Data, Feedlot Operations, Point Sources and Gully Information. Because the entire study area is agricultural row crop, only Crop Data and Fertilizer Reference Data will be needed. This data can be collected from land owner records.

## Topographical Data

Topographical data can be derived from a 30 meter DEM from the USGS. The AGNPS topographic parameters are flow direction, receiving cell number, land slope, slope shape, slope length, and channel type (Wang and Ciu, 2005). These values can be generated in AGNPS by adding the DEM to the input module.

## Soils Dataset

Soils data will be derived from both SSURGO data and soil samples taken in a one acre grid by the SIUC Forestry Department. The Soils Dataset contains soil identifier, hydrologic soil group, K-factor, albedo, time to consolidation, impervious depth, specific gravity, soil name, soil texture data, layer depth, bulk density, and the following layer specific data: clay, silt, clay, rock, and very fine sand ratios, calcium carbonate, saturation conductivity, field capacity, wilting point, base saturation, unstable aggregate ratio, pH, organic matter, organic N, inorganic N, organic P, inorganic P ratios and soil structure code (Suir, 2002).

## Climate Data

The climate data will be derived from a weather station set up on-site. Due to the small scale of the study area, the assumption that one station will be sufficient is made. Climate will be assumed uniform for the entire study area. Input climate data consists of daily precipitation, maximum and minimum temperatures, and solar radiation, daily dew point temperature, sky cover, and wind speed (Suir, 2002). A Climate input file will be created in the input editor for each day that produced a runoff event.

### AGNPS Input Data Processing

ArcView GIS linked with AGNPS 5.0 can be used to process climate, soils, topography, and land-use data into a file format accepted by AGNPS 5.0. Text ASCII files are stacked and all 34 parameter are added to individual 30 m grid cells. After data parameters are collected and processed a sensitivity analysis will be done to identify the parameters that have the greatest effect on model output.

### 3.4 Calibration and Validation of the AGNPS Model

Single event calculations in the AGNPS model should be used to predict sediment, nutrient and water runoff in three agricultural watersheds in Central Illinois. The first two thirds of the events should be used to calibrate the model. Once the model is calibrated, the last one third of storm events that caused runoff should be modeled to predict runoff amount values for the last one third of the runoff events. In-situ data collected on the three watersheds will be the observed values, and estimates generated by the model will be the predicted values. An accuracy assessment between predicted and observed values will either validate the model or show that it is insufficient for this scale and type of landscape. If the model is shown to be sufficient, it could potentially be used by the Forestry Department and the Buffet Foundation to calculate sediment and nutrient runoff from these three watersheds for the duration of the study. Identification of critical source areas could aid in management decisions. Use of the model to calculate runoff amounts on all three watersheds to analyze the effect different BMP's have on runoff.

Calibration is defined as parameter modification to achieve a given function (White and

Chaubey, 2005). The parameters that will be modified are identified through sensitivity analysis (Equation 3). The model is calibrated by modifying the parameters for the first two thirds of the events to match observed data for the first two-thirds of the events. The purpose of this modification is to make the model match the processes of the watershed. This is a multivariable model calibration. The model will be best calibrated to predict, sediment, water, and nutrients. The calibration process must be done in a particular order (Perrone, 1997).

The model must be initially calibrated for runoff/flow, then sediment, then nutrients (White and Chaubey, 2005). In previous studies sensitive parameter for runoff were found to be SCS curve and antecedent soil moisture (Perrone, 1997). For example, if the SCS Curve number is found to be the most sensitive parameter and the model is under predicting observed runoff, then the SCS curve number needs to be adjusted until the model output closely matches observed runoff. An SCS Curve value of thirty indicates high infiltration and low runoff, while one hundred means low infiltration and high runoff (NRCS). So if the model is under predicting the SCS Curve number would need to be increased in order to calibrate the model and match model predicted to the observed value. During the calibration stages the model will be calibrated to reduce relative error to fifteen percent. Sensitive runoff parameters must be modified for calibration first, since sediment loads and concentration depend on runoff amount. After the sensitive parameter is modified for flow, calibration for sediment can start. Sensitive parameters for sediment have been found to be the soil erodibility value (K), and slope (Perrone, 1997). Sediment sensitive parameters must be modified for calibration before nutrient sensitive parameters, since dissolved and attached phosphorus loads depend on sediment concentration and runoff. After runoff and sediment have been calculated, nutrient sensitive parameters can be modified. Initial soil nutrient concentrations have been collected on a one acre grid. The initial soil nutrient will be used as input parameter into the AGNPS model. This parameter has been found to be sensitive in past studies (Wang, 2005). All identified parameters will be modified to create the most holistic model possible (White and Chaubey, 2005). It is easiest to select single most influent parameter, but using multiple variables creates a more comprehensive useful model. This multivariable calibrated model will consider other processes, unlike a single variable calibrated model.

The calibration of the model necessitates modifying variables to make model output match observed data to a maximum level. The degree in which model output matches observed output can be measure through similar statistical measures. Many different statistical measures can be used in the calibration process. The purpose of the calibration process is to reduce relative error (Equation 2) and optimize the Nash-Sutcliffe efficiency coefficient (Equation 1). The Nash-Sutcliffe coefficient is sensitive to outliers so $R^2$ is commonly used. The coefficient of determination ($R^2$) and the Nash-Sutcliffe efficiency coefficient are both statistical measures accounting for multiple events. O represents the observed values and P represents the predicted values. O(average) and P(average) represent the mean of O and P, respectively. Calibration should also minimize mean square error and absolute error. N corresponds to the number of events in the mean square error equation. Absolute Error and Relative are single event statistical methods. Error is minimized in calibration through relative sensitivity analysis.

**Nash-Sutcliffe Efficiency Coefficient:**

$$1\text{-}(\mathrm{SUM}(\mathrm{O\text{-}P})^{2})/\mathrm{SUM}(\mathrm{O\text{-}Oaverage})^{2} \qquad \text{(Equation 1)}$$

**Relative Error:**

$$(\mathrm{P\text{-}O})/\mathrm{O}*100 \qquad \text{(Equation 2)}$$

**3.5 AGNPS Model Validation**

Model output can be analyzed by cell or for the entire watershed transport of Phosphorus, water, and sediment for any time period. In this case the model output will be for single events in the event accounting portion of AGNPS, and also over the entire study period. The source accounting feature can also be run to locate critical source areas contributing to sediment and nutrient loads. ArcView GIS is also useful for output processing. AGNPS creates a text file either for amounts of water, sediment, and chemicals passing through a given cell or a file accounting what amount of sediment or chemicals each cell lost or contributed to runoff. ArcView GIS can process these text files into raster formats for visualization and statistical procedures

Similar statistical procedures for model calibration will be used for validation the only difference is the validation will be done on the remainder of the storm events in the study period (Wang, 2005). For calibration the first two-thirds of events will be used. In validation, the last one-third of events will be used. By comparing model predicted and observed results, validation will test if the model was calibrated to represent the modeled watershed. The validation process reduces uncertainty and increases user confidence in the models predictive ability (White and Chaubey, 2005). Each watershed will be calibrated and validated individually in the model. This should identify differences in their watershed processes. The statistical measure that will be used for calibration and validation for single events will be relative error. Single site calibrations most often presented (White and Chaubey, 2005). However, a single site does not consider how well the model predicts watershed response at other watershed locations (White and Chaubey, 2005). In order to analyze watershed model responses at multiple locations all three watersheds should be also validated together.

The AGNPS model was chosen due to its widespread use, simplicity, lack of validations, data availability, output, suitability for high intensity, single event storms, small watersheds, and primarily agricultural land. Model selection should be based on input/output, limitations, use history, time limitations, data limitations (Wang, 2005). The AGNPS model is "widely used," "untested," and "considerable testing must be done before considered reliable and accurate" (Bosch, 1998). Given the study area and data availability a suitable model had to be identified. The Macon County Study area is suitable for this model due to it small scale, availability of weather, soils, stream-flow, and nutrient data, and being primarily agricultural land without tile drains. The AGNPS model was developed to estimate runoff from watersheds a couple hectares to 20,000 ha in size (Bosch, 1998).

AGNPS is adequate for small watersheds (Borah, 2003); yet small rural watersheds are rarely gauged. In the Quebec study, data availability created an opportunity to study a small scale farm (Perrone, 1997). Although the Buffett site watersheds are much smaller than the Quebec study, the AGNPS model is suitable. Event simulation at a number of scales is critical (Perrone, 1997). Runoff volumes, sediment and nutrient concentrations, including attached and soluble Phosphorus should be collected for storm events occurring within the study period. The number of events that occur in the validation period will be analyzed individually and as a whole. Correlation between the sum of the events that occur in the study period and the sum of the model predicted events will be calculated with the Nash- Sutcliffe Coefficient.

A few different studies reviewed used a similar number of events that will occur within this given time period. In Perrone's study on Quebec watersheds seven events were used for calibration and five events were used for validation, for a total of twelve events. In the Decatur Lake study only two events were calibrated, and the calibrated model was used to make long term estimates of nutrient and sediment loss from the watershed. At Decatur Lake no validation was done for the large watershed (Demissie and Keefer, 1996). As for the Kansas Lake eutrophication study, four calibration and five validation events were used for analysis. The AGNPS model should be validated for individual event predictions and over the study period average. By comparing the observed and predicted runoff, sediment, and nutrients the viability of the model for this setting will be tested. If the model predicts accurately, less than 15% relative error, the model could be used as a practical tool for testing effects of BMPs.

### 3.6 Sensitivity Analysis

Sensitivity is described as the effect an input parameter has on model output. This effect is commonly measured through relative sensitivity analysis,

$$Sr=(x/y)((y2-y1)/(x2-x1) \qquad \text{(Equation 3)}$$

where x is the parameter and y is the predicted output. x1, x2 and y1, y2 correspond to plus and minus 10% of the initial parameter and modeled output values, respectively (White and Chaubey, 2005). The greater the relative sensitivity (Sr), the more sensitive the output is to that variable (White and Chaubey, 2005). All input parameters will be tested to find to what degree each parameter affected outputs for runoff, sediment, and nutrient concentrations. The parameters that effect model output most will be modified in the calibration process. Different parameters are commonly found to be sensitive for runoff, sediment, and nutrient simulations. Many studies found the SCS curve number to be the most sensitive variable for runoff simulations. The soil erodability factor is commonly sensitive for sediment calculations. Initial soil nutrient concentrations are found to be sensitive in nutrient modeling. The sensitive parameter found for runoff, sediment, and nutrient modeling will be calibrated respectively.

# CHAPTER 4

# CONCLUSION

## 4.1 Significance of Proposed Model

This research is unique in that it outlines procedures needed to validate the use of the updated AGNPS 5.0 model for partitioning attached and soluble phosphorus in farm scale watersheds. This is important because this small scale use aids farmers in use of BMPs, and to assess current runoff scenarios. Larger scale models of larger watersheds would possibly include different land covers or another farmer's property. It is critical that farm/field-scale models are used in order for them to be useful to farmers and land owners. Practitioners will be able to use this individual AGNPS model to simulate management decisions on the Buffet Foundation experimental watersheds. They will be able to employ a management decision into AGNPS then simulate a rain event to see what effect the management decision had on runoff. Studies like this could also give inquires to reasonable TMDL's for individual farms contribution to larger water bodies (Y. Yuan, R. L. Bingner, J. Boydston, 2006).

The AGNPS model also tracks pollutants back to their sources (Bosch, 1998). The source tracking output can be used to locate critical areas contributing to sediment and Phosphorus loads. Once these critical source areas are located management practices could focus on those areas. Models aid in development of TMDL Standards from Clean Water Act (Borah, 2003). These standards would limit damage to water bodies. If we can accurately quantify sediment and nutrient loads and account for their sources, regional TMDL's for agricultural lands could be formed to reduce loads.

Due to the small scale of the study area, detailed data available from the SIUC Department of Forestry input data and observed event data for the three watersheds will create a more accurate model from calibration, and accurate data to compare for model validation. Since there are three watersheds this will be a multisite validation. This will allow for comparison of results between different watersheds on different storm events, or over the entire study period.

The models for these three watersheds will be calibrated individually for each watershed for multiple variables. When only one calibration site is considered, does not give inferences of how well the model predicts watershed response at other watershed locations. Multivariable means that the model will be calibrated for different parameters to achieve the best function for predicting multiple variables (White and Chaubey, 2005). A single model will predict flow, sediment, and nutrients. The AGNPS 5.0 model should be calibrated separately for each variable, first discharge, then sediment, and finally nutrients. Running all three in one model creates a more complete holistic model. This multivariable model will allow for more accurate prediction of runoff, sediment, and Phosphorus partitioning.

The partitioning of Phosphorus is important because of the high amount of phosphorus stored in Illinois soils. Since phosphorus is a primarily sediment attached nutrient, the partitioning of P loads is critical. Dissolved phosphorous is the most bioavailable but the sediment attached portion must be accounted for.

Once observed runoff data is able to be collected, and the AGNPS model is validated for use in these settings. This study will allow other researchers in similar settings to use the AGNPS model. Depending on the results of the AGNPS model validation, researchers will gain knowledge of the viability of use of the AGNPS model in similar settings. If the AGNPS model produces sufficient results, it will be able to produce accurate runoff estimates for similar settings. Data and procedures suggested in this paper were chosen based on the accuracy of the sources and procedures used in other studies for comparison of statistics. By utilizing the data and procedures outlined above an accurate and comprehensive model should be produced for the Buffet Experimental Agricultural units.

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# VITA

Graduate School

Southern Illinois University

Timothy J. Freeman

tfree@siu.edu

Southern Illinois University Carbondale

Bachelor of Science, Geography & Environmental Resources, December 2009

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Major Professor: Dr. Leslie A. Duram