A SIMPLIFIED NITROGEN MODEL

FOR SURFACE RUNOFF

By

PATRICIA K. HAAN

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1992

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
July, 1996

A SIMPLIFIED NITROGEN MODEL

FOR SURFACE RUNOFF

Thesis Approved:

G. J. Sabbagh

Thesis Adviser

Dan Storm

Thomas C. Collins

Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my advisor, Dr. George Sabbagh, for his help and guidance throughout my graduate program. I would also like to thank Dr. Dan Storm and Dr. Mike Smolen for serving on my graduate committee. Their advice and support helped to clarify many points in this study.

I would like to thank the Biosystems and Agricultural Engineering Department at Oklahoma State, especially Dr. Bill Barfield, without whose advice, understanding and guidance I would not be here.

I would like to dedicate this work to my father, Dr. Tom Haan who has been an inspiration and a tremendous help throughout my graduate program. He, my mother, Jan, and there rest of my family have provided a stable and loving environment that has allowed me thrive.

Finally, I would like to thank my best friend, Alan, who kept me on track, provided encouragement during times of difficulty, and never let things get too crazy.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table	Page

LIST OF FIGURES

Figure | Page

CHAPTER 1

INTRODUCTION

Background

Until the 1950's, agricultural land use kept pace with population growth. From 1950 to 1980 the world population increased from 3 billion to 4.5 billion and by the end of the century estimates put it at more than 6 billion (NPK, 1983). Increasing food production to meet demands can occur in one of two ways, increasing the amount of land in agricultural production, or increasing the per hectare yields of land already in production. The Food and Agriculture Organization of the United Nations (FAO) estimates that opening up more land to farming could only increase the needed food production by 25%. The other 75% must come from an increase in crop yield (FAO, 1981).

To meet the challenge of increased demand, farmers began to depend more and more on the use of chemical fertilizers to increase the per hectare yields as land for expanded crop production became increasingly scarce. Estimates of the contribution of fertilizer to increased food production in the United States range from 30 to 40% (Engelstad, 1985).

Modern farming places high demands on nitrogen (N), especially in warm and humid regions. Requirements for N exceed any other plant nutrient, and only rarely do soils have enough naturally occurring available N to produce high yields of non-legumes. World N fertilizer use has expanded more rapidly than any other primary plant nutrients because results of increased N applications are easily seen and measured in units of increased yields (Engelstad, 1985). The annual "on farm" nitrogen requirements in the United States are estimated to be 21 million tons. Of this about 11 million tons are supplied by commercial fertilizers (Jones, 1982). This amount has remained relatively constant since 1980 (Puckett, 1995).

Most soil N (>95%) is contained in soil organic matter, or in the case of ammonium ions, adsorbed by clays. In these forms, N is considered immobile and not available to plants. These immobile forms can be converted to nitrate (NO_3^-), which is highly mobile and available to plants. It can be transported by soil water into ground water (Novotny and Olem, 1994). Crop plants take up about 50% of the nitrogen that is applied during the same year that the crop is grown. Biological transformations and losses by leaching, runoff and reduction to nitrogen gas released to the atmosphere are the primary causes of this low rate utilization (Jones, 1982).

The farmer uses nitrogen fertilizers in solid form (ammonium nitrate, urea, sodium nitrate, di-ammonium phosphates), as liquid nitrogen solutions (urea, ammonium nitrate, aqua ammonia), and as a gas (anhydrous ammonia). About 40% of the nitrogen used in the U.S. is applied in the late summer and fall, mainly to cool-season grasses and grain crops. The remainder is applied during the spring and early summer.

There are essentially five major sources of agricultural pollutants: animal manures, fertilizers, irrigation residues, pesticides and sedimentation. Of these, animal manures and fertilizers along with plant residue compost contain the majority of nitrogen released into soils. Nitrates are the most common environmental form of nitrogen.

The increased use of fertilizer has been a cause of concern for both surface and ground water quality in watersheds hydrologically connected to agricultural sources. One of the main concerns about nitrate contamination is the health effects related to consuming nitrate contaminated drinking water. The primary health problem that has been linked to high nitrate concentrations is methemoglobinemia or "blue baby disease" (Busch and Meyer, 1982). Nitrate is reduced to nitrite by bacteria present in the upper gastrointestinal tract of infants. When combined with hemoglobin, nitrite inhibits the transfer of oxygen to blood cells in some infants. From 1945-1981, 2000 cases of methemoglobinemia were reported in the world literature, with a case fatality of about 8% (Fraser and Chilvers, 1981).

Other studies have linked high nitrate concentrations to impairment of the nervous system, cancer of the stomach and lungs, and hypertension. In an Australian epidemiological study of birth defects among families dependent on ground water high in nitrate (averaging 15 ppm) to those drinking nitrate-free rain water, birth defects occurred three times as frequently in the former group (Dorsch et al., 1984).

The Environmental Protection Agency (EPA) has set the standards for public wells at 10 mg/l of NO_3^--N. Public wells are by law routinely sampled, however, there is no such standard for rural wells. A study done by the United States Geological Survey (USGS) of nitrate levels in wells found that there are areas of ground water in virtually every state that exceed EPA standards (Patrick et al., 1983).

Another concern related to high nitrogen and phosphorus concentrations is eutrophication of lakes and streams. Eutrophication is a natural aging process whereby a lake or stream becomes shallower and smaller as a result of nutrient enrichment. This enrichment is accompanied by rapid plant growth, especially algae growth. When these plants begin to decay the amount of dissolved oxygen in the water decreases, and aquatic life can start to suffocate. This can be a significant problem in the ever endangered wetlands. Because ground water is a source of water for much of the flow into lakes and streams, the amount of nitrogen it contains can contribute to eutrophication. The National Eutrophication Survey estimated that 8% of the lakes and reservoirs in the northeast and north central United States are in an advanced state of eutrophication (EPA, 1975).

To gain an understanding of the relationship between N in surface water and agricultural runoff and to aid in its management, water quality models have been developed. Many of the water quality models in use today do not simulate the N processes in the soil. In more complete models where N processes are represented, the data requirements to run the model are very high.

Objectives

There are two primary objectives in this work. The first objective was to develop a simple model to determine nitrogen losses with surface runoff on a field scale. Simple in this context means using simplified algorithms to model the runoff, sediment and nitrogen soil processes while minimizing the number of inputs. The second objective was to determine whether the simplified model yielded valid results.

CHAPTER 2

LITERATURE REVIEW

Introduction

The literature was reviewed to determine the contribution of agriculture to increased N, particularly nitrates, to surface water. After it was determined that there was a correlation between agricultural runoff and higher nitrate levels in surface water, models were developed to predict how management practices impacted these losses. Five of these models are reviewed here. Finally, in order to simplify the development of this model the complex nitrogen soil processes need to be documented. A discussion of the nitrogen cycle concludes this chapter.

How Nitrogen Reaches Surface Waters

The total annual amount of N-bearing compounds entering surface waters worldwide ranges from 73 to 248 million metric tons. The largest source of N in the environment is N_2 fixation, contributing 30 to 130 million metric tons/year to freshwater and marine systems. This is followed by NH_4^+/NH_3 deposition, principally from agriculture (Moore, 1991).

Agriculture is one of the most important sources of anthropogenically derived ammonia and nitrate in surface waters. The major agricultural source is the increasing world wide use of nitrogen-based fertilizer. Other agricultural contributors include runoff from pastures, and to a lesser degree feedlots. Under aerobic conditions typical of most surface waters, ammonia is rapidly oxidized to nitrate, thereby producing relatively high nitrate residues. The main flux of N comes during rainfall, particularly after first and second runoff events after application of fertilizers and manures.

A review of the literature supports this finding. Timmons and Holt (1977) found the average annual losses of total N in surface runoff from a native prairie in central Minnesota to be 0.15 lb/acre. However, when studying the same types of soils under agriculture production, Timmons et al. (1968) found that the annual surface runoff from continuous corn, rotation corn, rotation oats, and rotation hay plots in Minnesota contained from less than 0.1 to 1.1 lb/ac mineral N. Moe et al. (1967) found that 2 to 15% of applied fertilizer N of 200 lbs N/acre, broadcast on fallow and sod plots, was lost in surface runoff for 5 inches of simulated rainfall.

Losses of nitrogen with runoff varied between agricultural fields with different field practices. Timmons et al. (1973) found that the highest N losses on a field in central Minnesota occurred when fertilizer was broadcast and disked-in. The lowest losses occurred where fertilizer was broadcast on plowed fields.

Schuman et al. (1973) found that the 3 year average annual solution N loss from a contour-planted corn watershed, fertilized 2.5 times the recommended rate, was 3.05 kg/ha. A comparable watershed, fertilized at the recommended rate, lost only 1.89 kg/ha. They found that N losses associated with sediment in runoff accounted for 92% of the total loss for a 3-year period from contour-planted corn watersheds. A large portion of the N loss for terraced watersheds was also associated with sediment. However, N loss was only one tenth that from contour-planted watersheds.

Kissel et al.(1976) found that in the Blackland Prairie of Texas concentrations of nitrate in surface runoff were usually highest just after fertilizer application when the soil was near field capacity and lowest when large amounts of water infiltrated into dry soil immediately before runoff. During runoff-producing storms just after fertilizer application, the concentrations were lowest in the initial runoff and highest near the end of the runoff event. The study indicates that a small amount of N is lost to surface waters when crops are fertilized at recommended N rates in the Texas Blackland Prairie. The mean total loss of nitrate was 3.2 kg/ha-year. Losses of sediment associated N were about 5 kg N/ha-year.

Schuman and Burwell (1974) determined that 69% of the N discharged by surface runoff from the sampled events could be accounted for by precipitation originated N on the watershed fertilized at 168 kg N/ha, whereas 53% of the N discharged from the watershed fertilized at 448 kg N/ha could be attributed to N originating in the precipitation.

Nitrates that are detected in surface waters are the effects of the cumulative practices from preceding years (Aldrich, 1980). Two generalizations can be made about nitrate concentrations in streams. The first is that nitrate concentrations tend to be at the highest levels during the spring. During the fall and winter, when there is minimal crop uptake, rain and snowfall strip nitrates from soils, which then are detected in spring stream flows. During the summer the balance of evapotranspiration with rainfall tends to minimize runoff and therefore nitrates in surface waters. In the U.S. 60% of the nitrogen-fertilizer used is applied in the spring and early summer.

The second generalization is that up to a threshold flow value, nitrate concentrations increase with increased flow. Flows greater than the threshold have a dilution effect where additional water decreases nitrate concentrations. Therefore, nitrate concentrations would be expected to be above average in a year in which total precipitation was above average and was well distributed throughout the year. Nitrate losses would also be expected to be high:

1) When fall, winter and spring precipitation is high.
2) Following a fall in which the amount of nitrate in the soil was unusually high.
3) Following a dry year in which crop removal was low.
4) After a warm fall which maximized the growth of microorganisms that decay residues and convert the resulting ammonium to nitrate.
5) From tiled fields because the pathways from the point of nitrogen application to receiving waters are much shorter and more direct.

Water Quality Models

Once it was determined that agricultural runoff was contributing to high concentrations of N in both ground and surface water, models were developed to try to predict what these losses might be under a given set of conditions. The information from these models could then be used to determine best management practices to be used on a watershed to help reduce N losses. Five of these models are discussed here. These models do not represent all of the modeling options available for runoff quality simulation, but they are some of the most notable, widely used and most operational (Donigian and

Huber, 1991).

The Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model was developed by the USDA (USDA, 1980). CREAMS is one of the most detailed operational models of agricultural runoff available at the current time. It simulates runoff, erosion, and land surface and soil profile chemical/biological processes that determine fate and transport of pesticides and nutrients. It is a field-scale model that uses separate hydrology, erosion and chemistry submodels connected by pass files. The SCS curve number method is used to simulate runoff, and the Modified USLE is used to determine sediment yield.

As a continuous simulation model, data needs are extensive. Meterologic data consisting of daily or breakpoint precipitation is required for hydrology simulation. Monthly solar radiation and air temperature data are needed. Data regarding soil type and properties along with information on crops to be grown are needed. A broad range of values for various model parameters can be obtained from the user's manual (USDA, 1980). The model has been validated by the developers along with independent experts. CREAMS has been used most extensively for field-scale agricultural runoff modeling because of its agricultural origins and ties to the agricultural research community.

Another water quality model is the Hydrologic Simulation Program-FORTRAN (HSPF) developed by Johanson et al. (1984). The focus of the model development was the ability to represent contributions of sediment, pesticides, and nutrients from agricultural areas, and evaluate resulting water quality conditions at the watershed scale considering both nonpoint contributions and instream water quality processes. The runoff quality capabilities include both simple relationships and detailed soil process options. HSPF data needs are extensive. As a continuous model, HSPF requires continuous data. Data needs include, but are not limited to, rainfall, evapotranspiration, temperature, and solar intensity.

The Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS) model was developed at Purdue University (Beasley and Huggins, 1981). It was designed primarily to simulate single storm events, and requires that the watershed be subdivided into grid elements with parameter information needed for each element. Each ANSWERS element ranges in size from 1 to 4 ha. The use of elements imposes greater computational burden and spatial data requirements, thus limiting most analyses to single 'design' storms. However, it allows for greater evaluation of source areas with a specific watershed area if required by the problem assessment. It is primarily a runoff and sediment model. The nutrient simulation is based on simple correlation between concentration and sediment yield/runoff volume. Soil processes, including nitrogen transformations are not simulated.

ANSWERS data needs are comprised of detailed descriptions of the watershed, topography, drainage network, soils and land use. The model is a storm event model and the input data file is quite complex to prepare. Most data can be obtained from USDA-SCS soil surveys and land use and cropping surveys. The model has extensive computational requirements for large watersheds.

The Agricultural Nonpoint Source Pollution (AGNPS) model was developed by the USDA Agricultural Research Service (Young et al., 1986). It is designed to simulate runoff, sediment and nutrients from watershed-scale areas for either single event or continuous periods. The watershed is divided into cells, and model computations are done at the cell level. Cells form the watershed boundaries to the outlet. It uses the SCS curve number approach combined with a unit hydrograph routing procedure, the Modified USLE, and simple correlation of extraction coefficients of nutrients in runoff and sediment. AGNPS requires both watershed data and cell data.

AGNPS was validated using field data from agricultural watersheds in Minnesota, Iowa, and Nebraska (Young et al., 1986). Lee (1987) validated the model in an Illinois watershed. The author found that the simulated and observed data for runoff volume and sediment yield were well represented when compared with observed data.

The Simulator for Water Resources in Rural Basins (SWRRB) model was developed by USDA (Williams et al., 1985; Arnold et al., 1989) for basin scale water quality modeling. SWRRB was developed by modifying CREAMS for application to large, complex, rural basins. Runoff volume is calculated using the SCS curve number method and erosion is determined by the Modified USLE. SWRRB includes channel processes and subsurface flow components to allow representation of large basin areas. It performs calculations on a daily time step and simulates hydrology, crop growth, sediment erosion, sediment transport, and nitrogen/phosphorus/pesticide movement in runoff. Its nutrient and pesticide capabilities are derived from CREAMS. SWRRB meterologic data comprised of daily precipitation and solar radiation are required for hydrology. Another set of input data are required for soils, land use, fertilizer and pesticide application.

Of the five models evaluated only three, CREAMS, HSPF and SWRRB, include nutrient soil processes. Of those three models, two, CREAMS and HSPF, have high data requirements and all three have high model complexity. Therefore, the model developed in this thesis is an attempt to simulate processes on an agricultural watershed with as few inputs as possible while adequately representing the complex processes of the nitrogen cycle in soil.

The Nitrogen Cycle

The nitrogen cycle is an extremely complex process (Brady, 1990; Aldrich, 1980 Moore, 1991). Nitrogen is an essential part of compounds contained in all living organisms. In plants these compounds include chlorophyll, providing a deep green color to leaves, and enzymes essential to plant growth. Ammonium (NH_4^+) and nitrate (NO_3^-) are the forms of nitrogen that can be taken from the soil by plant roots, however, nitrate dominates. Naturally occurring organic nitrogen compounds also occur in surface waters.

The primary sources of N in soil are commercial fertilizers, crop residues, green and farm manure, ammonium and nitrate salts and atmospheric nitrogen. The major sources of depletion of N in soil are crop removal (plant uptake), drainage and/or leaching, erosion, volatilization and transpiration.

There is a crude natural relationship between the time of release of nitrogen and other nutrients from organic matter and the time when crops need the nutrients for optimum plant growth. There is nearly always a shortage of nitrogen for optimum plant growth. Most nitrogen is found in organic matter, which is the only form in which large amounts of nitrogen can be stored in the soil. Of this only 2 to 3% is mineralized in a year under normal conditions. Nitrogen contents of surface mineral soil range from 0.02 to

0.5%, a value of 0.15% being representative. The atmosphere is 80% nitrogen, however, it is not in a form readily available to plants. Ammonium ions fixed by clay may account for up to 8% of the nitrogen in surface soils and 40% in subsoil. Clay fixed nitrogen is only slowly available to plants. The quantity of plant available N is seldom more than 1 to 2% of total soil N except where large amounts of commercial fertilizers have been applied.

Nitrate, ammonium and N attached to organic matter are the forms of N of concern when considering losses to runoff. With its negative charge, nitrate is repelled from negatively charged clay and organic material in the soil. It is soluble so it can move in any direction that water moves. NH_4^+ has a positive charge and adheres to the negatively charged soil surface. It is therefore less likely to move with water movement. Five to 20% of NH_4^+ is fixed to clay minerals, therefore, the occurrence is more likely in subsoil than topsoil. At higher soil pH values, NH_3^- in the presence of oxygen will fix to organic matter. This is the form of nitrogen most likely to be lost with sediment.

The nitrogen cycle describes the complex interactions between the various forms of nitrogen in soil, plants, and animals. Nitrogen transformations are brought about mainly by living organisms such as bacteria, fungi and earthworms. The effects of bacteria and fungi dominate. The rate of decay of the residues, the availability and the amount of available N resulting depend upon the relative proportion of carbon to nitrogen. The end product of decay is soil humus, which has a carbon to nitrogen ratio of about 10:1. High carbon residues decay slowly; narrow-ratio, low-carbon residues decay quickly. Highly carbonaceous residues always cause a deficit in available nitrogen until they are fully decayed. The major processes that act on nitrogen in the soil are immobilization, mineralization, volatilization, nitrification and denitrification.

Biological Nitrogen Fixation

An enormous amount of nitrogen is biologically fixed globally each year. Biological nitrogen fixation is a biochemical process by which elemental nitrogen is combined into organic forms. It is carried out by a number of organisms including several species of bacteria, a few actinomycetes and blue-green algae. The overall effect of the process is to reduce N gas to ammonia which is combined with organic acids to form amino acids and ultimately proteins. High levels of available nitrogen tend to depress biological nitrogen fixation.

Addition of Nitrogen to Soil in Precipitation

Atmosphere-borne nitrogen compounds are added to the soil through rain and snow. Combined N, consisting of NH_4^+, NO_2^-, NO_3^- and organically bound N are the common constituents of atmospheric precipitation. Nitrite occurs in trace amounts and is usually ignored or included with nitrate determination. Organically bound N is associated with dust and does not represent a new addition relative to the land masses of the world (Stevenson, 1982). Estimates vary as to how much nitrogen is added to the soil. Ericksson (1952) estimates total annual N deposition by precipitation to range from 0.8 to 22.0 kg/ha. Brezonik (1976) estimated bulk precipitation contributions to be 10 to 20 kg/ha annually over large areas of the U.S. Fluxes outside of 5 to 30 kg/ha-yr were considered to be unusual. Rates are higher near highly polluted areas such as cities, industrial areas and large animal feedlots.

Immobilization

The process of converting NO_3^- and NH_4^+ to organic forms is called immobilization. Immobilization occurs most commonly when plant and animal residues low in nitrogen are added to the soil. The residues are attacked by soil microorganisms which absorb the inorganic ions and convert them to organic tissue where the nitrogen is immobilized. When these organisms die some of the organic nitrogen in their bodies may be converted to forms that make up the organic matter complex. Some may be released back to NO_3^- and NH_4^+ ions in a process called mineralization.

Mineralization

Two to three percent of immobilized nitrogen is mineralized annually. Heterogeneous soil organisms simplify and hydrolyze the organic nitrogen compounds. The release of nitrogen to inorganic forms supplies a significant portion of crop needs, and may be about 60 kg N/ha per year in humid regions. In arid regions this amount would be less.

Ammonium Compounds

Ammonium compounds move in one of five directions. As discussed earlier, large amounts are appropriated by soil microorganisms and converted to organic forms. Higher plants are able to use ammonium ions, especially young plants. Ammonium is subject to interlayer fixation by vermiculite, fine-grained micas and organic matter. Some ammonia can be volatilized. Volatilized ammonia is significant when large amounts are added as fertilizer. Finally, ammonium can be oxidized by bacteria to nitrites and then to nitrates.

Ammonia Fixation

Fixed ammonium ions comprise 5 to 20% of total N found in soils. Both organic and inorganic soil forms are able to fix NH_4^+. Clay minerals having a 2:1 type structure have the capacity to fix NH_4^+ ions. The ions are the right size to fit into cavities between crystal units, becoming trapped as a rigid part of the crystal. The ions are held in nonexchangeable form, from which they are released slowly to higher plants and microorganisms. This occurs more often in the subsoil where there is a higher clay content then in the topsoil.

Anhydrous ammonia (NH_3) can react with soil organic matter to form compounds that resist decomposition. The ammonia is chemically fixed, but the exact mechanisms are not known. This process takes place most readily in the presence of oxygen and at high pH values. In organic soils with high fixing capacity, the reaction could result in a serious loss of available nitrogen and would dictate the use of fertilizers other than those that supply free ammonia.

Ammonia Volatilization

Ammonia that is present in soils from manure, residue breakdown and from fertilizers that contain or produce it can be lost in significant quantities. This is especially true in surface applications that minimize the opportunity for the ammonia to react with soil colloids. Temperatures are also higher at the surface which enhances ammonia volatilization.

Nitrification

In nitrification, ammonia is oxidized by enzymes produced by microorganisms in the soil to become nitrates. This is a two step process. First, ammonia is oxidized to nitrite, NO_2^-, by soil organisms called nitrosomonas. Next, the nitrite is further oxidized to nitrate, NO_3^-, by nitrobacter. The nitrite to nitrate oxidation happens very quickly after the ammonia to nitrite oxidation. This is necessary because high levels of nitrites in soil can be toxic to plants and microorganisms living in the soil.

Nitrate Nitrogen

Nitrate nitrogen can move in one of four directions. It can be incorporated into microorganisms or assimilated into higher plants. Both plants and soil organisms readily assimilate nitrate. If microbes have a ready food supply they use nitrates more rapidly than higher plants.

Nitrate can be lost to drainage/leaching. Because of its negative charge nitrate is not absorbed by soil colloids. This paired with the high solubility makes nitrate highly subject to leaching from the soil. Where modest fertilizer applications are made, usually 5 to 10% of dryland nitrate will be lost by leaching. Irrigation losses may be significantly higher.

Denitrification

Denitrification completes the nitrogen cycle and replenishes the supply of nitrogen in the air. It is the biochemical reduction of nitrate nitrogen to gaseous compounds. It can be carried out by common facultative anaerobic organisms. Denitrification becomes a dominant factor in nitrogen behavior under these conditions: a good supply of nitrate, a large amount of undecomposed plant residues (i.e. carbon), and a low oxygen supply which means a poorly aerated soil. This is usually caused by water saturation or standing water.

Each step of the denitrification process is catalyzed by a specific reductase enzyme. Nitrate reduces to nitrite which then reduces to NO to N_2O and finally to N_2. The transformations can stop at any point in the process and NO, N_2O and N_2 can all be released as gases into the soil air and eventually into the atmosphere. The oxygen atoms become incorporated into the bodies of the anaerobic bacteria. In flooded soils, losses by denitrification can be very high. As much as 60 to 70% of applied nitrogen can be volatilized as oxides of nitrogen or elemental nitrogen.

CHAPTER 3

NITROGEN MODEL DESCRIPTION

Introduction

The purpose of this model is to predict N loading from surface runoff. The model is composed of three primary components: hydrology, sediment and nitrogen. Each component was developed and tested independently. The three components were then combined and tested as a unit. A flowchart describing the model structure is presented in Figure 3.1. Appendix B contains the FORTRAN code for the model.

Model Assumptions

To simplify the approach the model considers only the top 1 cm of soil. Model assumptions were made both in the hydrology and nitrogen components. In the hydrology component it is assumed that there is no lateral subsurface flow. Since only the surface runoff is of concern in this analysis, leaching losses, although calculated when determining loss with runoff, are not evaluated. It is assumed that once water drains/leaches from the top 1 cm, there is no upward movement of water. It is also assumed that infiltration occurs in one time step, i.e. there is no rate component. This assumption implies well drained soils. The hydrology component ignores water uptake by plants, assuming that there is no plant uptake in the top cm of soil.

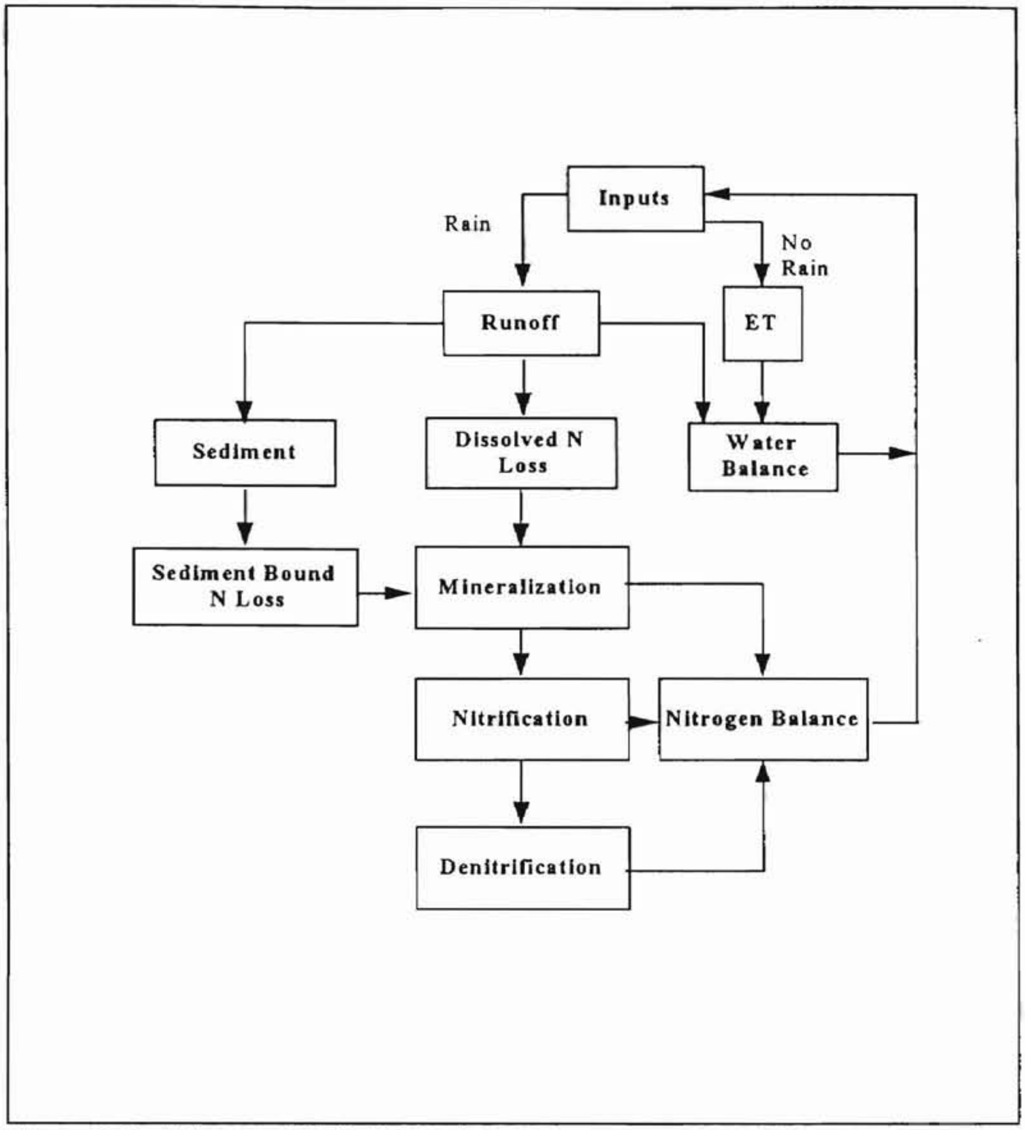

Figure 3.1. Nitrogen Model Flowchart

The nitrogen component assumes an initial source of organic matter in the top cm of soil that is steadily depleted but not replenished during the simulation. It is assumed that there is no nutrient uptake by plants in the top cm of soil. There is no upward or lateral subsurface movement of nutrients in the soil. Once nutrients leave the surface of the soil it is gone. Dissolved nitrogen losses in runoff are of nitrates only. Sediment bound losses in runoff are of organic N only.

Hydrology Component

The hydrology component models the processes of the hydrologic cycle: precipitation, runoff, infiltration, and evapotranspiration. A soil water balance is also maintained in this component. All processes are estimated on a daily time step.

Precipitation

Precipitation is the parameter that drives the hydrologic process. Precipitation is read into the model daily.

Runoff

The model uses the SCS curve number method to calculate runoff volume. This approach combines infiltration losses with initial abstractions and estimates the rainfall excess or runoff (Haan et al., 1994). This relationship is determined by (SCS, 1985):

$$V_q = \frac{\left(V_p - 0.2S\right)^2}{\left(V_p + 0.8S\right)} \tag{3.1}$$

$$S = \frac{2540}{CN} - 25.4 \tag{3.2}$$

where V_q is the runoff volume (cm), V_p is the rainfall volume (cm), S is the maximum potential difference between rainfall and runoff starting at the time the storm begins (cm), and CN is a weighted curve number based on the moisture conditions of the soil. Runoff is calculated only if V_p exceeds 0.2S. Otherwise, runoff is considered to be zero. The weighted curve number is determined by:

$$CN = W_1CN_1 + W_2CN_2 + W_3CN_3 \tag{3.3}$$

where CN_1, CN_2, and CN_3 are curve numbers for antecedent moisture conditions 1, 2 and 3 respectively and W_1, W_2 and W_3 are weighting factors. The weighting factors are determined by (Sabbagh et al., 1995):

$$W_1 = 1 \quad \text{if } V_p \leq f_1; \qquad W_1 = \frac{f_1}{V_p} \quad \text{if } V_p > f_1 \tag{3.4}$$

$$W_2 = 0 \quad \text{if } V_p \leq f_1; \qquad W_2 = \frac{V_p - f_1}{V_p} \quad \text{if } f_1 < V_p \leq f_2; \text{ and}$$

$$W_2 = \frac{f_2 - f_1}{V_p} \quad \text{if } V_p > f_2 \tag{3.5}$$

$$W_3 = 0 \quad \text{if } V_p \leq f_2; \qquad W_3 = \frac{V_p - f_2}{V_p} \quad \text{if } V_p > f_2 \tag{3.6}$$

where f_1 and f_2 are 1.25 cm and 2.75 cm during the dormant season, and 3.5 cm and 5.24 cm during the growing season, respectively (Smedema and Rycroft, 1983).

The curve numbers for antecedent moisture conditions 1 and 3 are calculated given CN_2 by (Williams et al., 1990):

$$CN_1 = CN_2 - \frac{20(100 - CN_2)}{(100 - CN_2 + \exp(2.533 - 0.0636(100 - CN_2)))} \tag{3.7}$$

$$CN_3 = CN_2 \times \exp(0.00673(100 - CN_2)) \tag{3.8}$$

Evapotranspiration

Evapotranspiration (ET) is calculated only on days that it does not rain. If there is rain, ET is set to zero. By evaluating only the top 1 cm of soil, the assumption is made that ET is essentially equal to potential evapotranspiration (PET). PET is determined by (Hargreaves, 1974):

$$PET = MF \times T \times CH \tag{3.9}$$

where MF is a monthly modifying factor dependent on latitude, T is the temperature in degrees Fahrenheit and CH is a correction factor for relative humidity to be used only for mean 24-hr relative humidity greater than 64%. For the purpose of this model it assumed that relative humidity is always below 64%, thus, CH is 1.0.

Infiltration

The amount of water that leaves the top 1 cm of soil as infiltration is calculated as:

$$F = SWC - FC, \qquad \text{if } SWC > FC;$$

$$F = 0, \qquad \text{if } SWC \le FC \qquad (3.10)$$

where F is infiltration (cm), SWC is soil water content (cm) and FC is field capacity (cm) in the top cm of soil. Drainage is not a rate controlled process in the model; all drainage takes place in one time step.

Soil Water Balance

Soil water content is determined by:

$$SWC = SWC_o + V_p - V_q - PET \qquad \text{if } F = 0;$$

$$SWC = FC \qquad \text{if } F > 0 \qquad (3.11)$$

where SWC_o is the initial soil water content (cm).

Sediment Component

The model uses the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) to estimate sediment loss by erosion. Although the USLE was developed to estimate annual average erosion losses, this model applies it on a daily basis.

The USLE is given by:

$$A_e = 2.24RKLSCP \qquad (3.12)$$

where A_e is gross annual soil loss (Mg/ha/yr), R is a rainfall factor (English units), K is a soil erosivity factor(English units), LS is the length and slope factor, C is a cover factor, and P is a practice factor. The rainfall factor for a 24-hr rainfall event can be estimated using (Cooley, 1980):

$$R = \alpha D^{-\beta} \left(\frac{P_r}{2.54} \right)^{2.119 f(D)} \tag{3.13}$$

$$f(D) = D^{0.0086} \tag{3.14}$$

where P_r is the 24-hr rainfall (cm), D is the rainfall duration (hr), 24 hours in this model, and α and β are constants for a given storm type. SCS (1973) developed storm type curves to determine precipitation patterns for different areas of the U.S. The α and β values for four storm types are given as (Cooley, 1980):

Storm Type	α	β
I	15.03	0.5780
IA	12.98	0.7488
II	17.90	0.4134
IIA	21.50	0.2811

The length factor, L, is estimated by (McCool et al., 1989):

$$m = \frac{\beta}{1+\beta} \tag{3.15}$$

$$\beta = \frac{11.6 \sin\theta}{3.0(\sin\theta)^{0.8} + 0.56} \tag{3.16}$$

$$\theta = \tan^{-1}\left(\frac{s}{100} \right) \tag{3.17}$$

$$L = \left(\frac{\lambda}{22.1} \right)^m \quad (3.18)$$

where λ is slope length (m), m is an exponent, β is a parameter, θ is field slope (degrees), and s is field slope (percent).

McCool et al. (1987) used the following equation to determine the S factor:

for slope lengths less than 4m,

$$S = 3.0(\sin\theta)^{0.8} + 0.56 \quad (3.19)$$

for slope lengths greater than or equal to 4m and field slopes less than 9%,

$$S = 10.8\sin\theta + 0.03 \quad (3.20)$$

and for slope lengths greater than or equal to 4m and field slopes greater than 9%,

$$S = 16.8\sin\theta - 0.50 \quad (3.21)$$

The erosivity factor, K, is typically determined by a nomograph developed by Wischmeier et al. (1971) based on six soil and soil profile parameters: percentage silt, percentage very fine sand, percentage sand, percentage organic matter, structure and permeability.

The practice factor, P, and the cover factor, C, are dependent on the field of interest, growing season, type of crop and soil conservation practices used (Wischmeier and Smith, 1978).

Nitrogen Component

The nitrogen component has two primary objectives:

1. To calculate the nitrogen lost with runoff, both in dissolved and sediment

attached forms, and

2. To model the nitrogen cycle processes and maintain a balance of the primary forms of nitrogen in the top 1 cm of soil.

This is accomplished in components that model dissolved nitrogen loss, sediment bound nitrogen loss, mineralization, denitrification and nitrification.

Dissolved Nitrogen Loss

The basic model assumption is that the change in concentration of the soluble nutrient in the surface active zone is proportional to the difference between the existing concentration in the zone and the concentration in the rainfall (USDA, 1980). The average nutrient concentration in the water within the surface active layer is given by (Flanagan and Foster, 1989):

$$k_f = \frac{\eta_f}{DP} \tag{3.22}$$

$$k_\sigma = \frac{\eta_\sigma}{DP} \tag{3.23}$$

$$\beta = Fk_f + Qk_\sigma \tag{3.24}$$

$$\overline{C} = C_r + \frac{1}{\beta \Delta t}\left(C_o - C_r\right)\left(1 - e^{-\beta \Delta t}\right) \tag{3.25}$$

where k_f and k_σ are constants for infiltration and runoff respectively; η_f and η_σ are extraction coefficients for infiltrating water and runoff water, 0.25 and 0.075 respectively; D is depth of the zone (cm), P is porosity (cm/cm), F is infiltration rate (cm/day), Q is runoff volume rate (cm/day), $\overline{C}$ is the average nitrate concentration in the water surface active layer (g/m^3), C_r is the nitrate concentration in the rainfall (g/m^3), C_o is the nitrate concentration in the water in the active zone at the beginning of the time interval (g/m^3), and Δt is the change in time (days). C_σ, the concentration of the soluble nitrate in the runoff water (g/m^3) is given by (Flanagan and Foster, 1989):

$$C_\sigma = C_r + \eta_\sigma\left(\overline{C} - C_r\right) \tag{3.26}$$

The weight of the soluble nitrate in the runoff, Q_{no_3}, (kg/ha) is given by:

$$Q_{no_3} = C_\sigma \times Q \times 0.10 \tag{3.27}$$

where Q is the runoff volume in cm.

Sediment Bound Nitrogen Loss

The amount of sediment bound nitrogen loss is based on the approach in CREAMS (Frere et al., 1980) with the addition of a delivery ratio as used in SIMPLE (Heatwole and Shanholtz, 1991):

$$SEDN = SOLN \times A_e \times ER \times DR \tag{3.28}$$

$$ER = \exp[a + b \ln A_e] \tag{3.29}$$

$$DR = \exp[-k_1 D_s S_f] \tag{3.30}$$

$$S_f = S_{f_{\min}} + \exp[-k_2(S + S_o)] \tag{3.31}$$

where SEDN is the organic nitrogen transported by sediment (kg/ha), SOLN is the organic nitrogen content of the soil (kg/kg), A_e is the sediment predicted by the erosion component (kg/ha), ER is a nitrogen enrichment ratio and DR is a delivery ratio developed by Heatwole and Shanholtz (1991). S is the slope (m/m), a and b are constants (Menzel, 1980), D_s is the distance to stream, k_1, k_2, S_o and S_{fmin} are constants. Based on delivery estimates from Draper et al. (1979), Heatwole and Shanholtz (1991) defined k_1=0.0161 m^{-}

[1], k_2=16.1, S_o=0.057 and S_{fmin}=0.6.

Nitrogen Transformations

The nitrogen mass balance requires that some of the complex processes of the nitrogen cycle be included in the model. This model considers the processes of mineralization, nitrification and denitrification.

Mineralization

The mineralization of organic matter to ammonium is described in Watts and Hanks (1978) by:

$$N_t = R_m N_{to} \tag{3.32}$$

where N_t is the amount of N mineralized under existing moisture conditions (kg/ha), N_{to} is the N mineralized as ammonium in time Δt at optimum soil moisture content (kg/ha) and R_m is the reduction coefficient for water content effect.

N_{to} can be calculated as (Watts and Hanks, 1978):

$$N_{to} = N_o[1 - \exp(-K_o \Delta t)] \tag{3.33}$$

$$K_o = \exp(17.753 - 6350.5 / T_a) / 168.0 \tag{3.34}$$

where N_o is the potentially mineralizable N in the soil depth increment at the beginning of the time interval, K_o is the mineralization rate coefficient (1/hrs) and T_a is the absolute soil temperature (°K). If the soil temperature exceeds 35°C then the rate constant is approximated by the 35°C value (Stanford et al., 1973).

R_m is determined by the fraction of fillable pore space (FPS) in the soil:

$$R_m = 1.111FPS; \qquad 0.0 \le FPS < 0.9 \tag{3.35}$$

$$R_m = 10.0 - 10.0FPS \qquad 0.9 \le FPS \le 1.0 \tag{3.36}$$

$$FPS = \frac{SWC}{PO} \tag{3.37}$$

where PO is the soil porosity (cm).

Nitrification

The nitrification of ammonium is calculated by (Watts and Hanks, 1978):

$$N_{no} = N_a[1 - \exp(-K_a \Delta t)] \tag{3.38}$$

$$N_n = R_m N_{no} \tag{3.39}$$

where N_{no} is the amount of ammonium converted to nitrate in time Δt at optimum water content (kg/ha), N_a is the amount of available ammonium subject to conversion at the beginning of the time interval (kg/ha), K_a is the transformation rate coefficient for the conversion of ammonium to nitrate (1/hr), and N_n is the actual amount of ammonium transformed to nitrate (kg/ha).

M.H. Frere (Watts and Hanks, 1978) determined that the rate coefficient may be calculated as:

$$K_a = (0.032T_c - 0.12)K_{35} \qquad 10^\circ C \leq T_c < 35^\circ C \tag{3.40}$$

$$K_a = (0.0105T_c + 0.00095T_c^{\,2})K_{35} \qquad 0^\circ \leq T_c < 10^\circ C \tag{3.41}$$

$$K_a = (-0.1T_c + 4.5)K_{35} \qquad 35^\circ C \leq T_c \leq 45^\circ C \tag{3.42}$$

where K_{35} is the rate constant at 35°C (1/hr) and T_c is the soil temperature (°C).

Denitrification

To calculate the amount of nitrate in the soil converted to N_2 gas, the model uses the method described in CREAMS (Frere et al., 1980):

$$DNI = NO_3 \times (1 - \exp(-DKT * T)) \tag{3.43}$$

$$DKT = \exp(0.0693 \times T_s + DB) \tag{3.44}$$

$$DB = \ln DK - 2.4255 \tag{3.45}$$

$$DK = 0.264 \times OC \times 10 + 0.06 \tag{3.46}$$

where DNI is the amount of nitrate converted to N_2 gas (kg/ha), NO_3 is the nitrate in the top cm of soil (kg/ha), DKT is the temperature adjusted rate constant and T is the number of days since the last event. T_s is the soil temperature (°C), DB and DK are denitrification rate constants and OC is the percent organic carbon in the top cm of soil.

Nitrogen Mass Balance

Calculating the nitrogen transformations and losses requires a daily update of the quantities of the various forms of nitrogen present in the soil profile. Thus, a mass balance of nitrogen is done. The total amount of nitrogen in the soil is:

$$N = MO + NOA + WNO_3 \tag{3.47}$$

Where N is the total amount of nitrogen contained in the soil (kg/ha), MO is the amount of immobilized N contained in the soil (kg/ha), NOA is the amount of ammonium N contained in the soil (kg/ha), and WNO_3 is the amount of nitrate nitrogen contained in the soil (kg/ha). The amount of immobilized nitrogen, MO (kg/ha), is determined by:

$$MO = MO_o - N_t \tag{3.48}$$

where MO_o is the amount of immobilized nitrogen at the beginning of the time interval (kg/ha) and N_t is the amount of nitrogen that has been mineralized (kg/ha).

The amount of ammonium contained in the soil, NOA (kg/ha), is determined by:

$$NOA = NOA_o + N_t + NH_4A - N_n \tag{3.49}$$

where NOA_o is the amount of ammonium subject to conversion at the beginning of the time interval (kg/ha), N_t is the amount of nitrogen that has been mineralized (kg/ha), NH_4A is the amount of nitrogen that has been applied as ammonium fertilizer (kg/ha) and N_n is amount of ammonium that has been converted to nitrate (kg/ha).

The amount of nitrate in the soil profile, WNO_3 (kg/ha), is determined by:

$$WNO_3 = WNO_{3_o} + N_n + NO_3A - DNI \tag{3.50}$$

where WNO_{3_o} is the amount of nitrate in the soil profile at the beginning of the time interval (kg/ha), N_n is the amount of ammonium that has been converted to nitrate (kg/ha), NO_3A is the amount of nitrogen applied as nitrate fertilizer (kg/ha) and DNI is the amount of nitrate that has been reduced to N_2 gas (kg/ha).

CHAPTER 4

MODEL INPUT AND OUTPUT PARAMETERS

Input Parameters

The input parameters can be divided into four categories: soil characteristics, field and practice characteristics, climatic variables and simulation specific variables. Soil characteristics relate to the inherent soil properties. Field and practice characteristics relate to the physical characteristics of the field and the agricultural practices used. Climatic variables relate to meteorological data such as daily rainfall and temperature. The simulation specific variables relate to parameters that determine the beginning and end of the simulation. They also include the time step specification. Appendix C contains a sample of the model input file.

Soil Characteristics

The soil characteristics can be separated into those characteristics relating to soil structure and moisture content and those characteristics relating to the various forms of nitrogen contained in the soil. The structure and moisture content are important when determining runoff and erosion. The forms of nitrogen in the soil are important to the biological transformations in the nitrogen cycle. Table 4.1 contains the input parameters associated with soil characteristics.

There are four inputs related to soil structure in the model. FC is the field capacity of the soil (cm of water/cm of soil). This is a measure of the percentage of water that will remain in a soil after having been saturated and after free drainage has essentially ceased

Table 4.1. Soil Characteristic Input Parameters

Parameter	Description	Units	Equation
FC	Field Capacity	cm/cm	3.10
PO	Porosity	cm/cm	3.22,3.23, 3.37
SWC	Soil Water Capacity	cm	3.10,3.37
OC	Organic Carbon	%	3.46
MO	Potentially Mineralizable N	kg/ha	3.33,3.47 3.48
NOA	NH_4^+ Available for Nitrification	kg/ha	3.38,3.47 3.49
SKN35	Nitrification Transformation Rate Coefficient	1/hr	3.40-3.42
WNO3	Weight of Soluble Nitrogen in Surface cm	kg/ha	3.43,3.47, 3.50
NF	Nitrogen Extraction Coefficient for Infiltration	-	3.22
NQ	Nitrogen Extraction Coefficient for Runoff	-	3.23
NORG	Nitrogen Associated with Sediment	kg/kg	3.28
NP1	a in Equation to Determine Enrichment Ratio	-	3.29
NP2	b in Equation to Determine Enrichment Ratio	-	3.29

(Brady, 1990). Field capacity is used to determine the amount of infiltration in the water balance portion of the model.

PO is the porosity of the soil (cm of water and air/cm of soil). Porosity is the fraction of the total soil volume that is not occupied by solids. It is a measure of the volume of the air and water contained in a soil (Brady, 1990). Porosity is used in determining soil moisture conditions for mineralization and denitrification. It is also used to convert concentrations of nitrate in water from g/cm^3 to mass in kg/ha. The model converts both field capacity and porosity from cm of water and/or air per cm of soil, to cm of water and/or air by multiplying by the depth of the soil. SWC is the soil water content (cm). This is the depth of the water contained in the top cm of soil. An initial value of SWC is input by the user. For the rest of the simulation the program calculates SWC. Soil water content is important in the balance of water in the soil. Finally, OC is the percent of organic carbon contained in the soil.

The second category of soil characteristics are those related to the forms of nitrogen contained in the soil. MO is the potentially mineralizable nitrogen in the soil (kg/ha). Potentially mineralizable nitrogen is the amount of organic nitrogen available to be converted to ammonium (NH_4^+). It is the result of the immobilization process described in the nitrogen cycle. NOA is the amount of NH_4^+ in the soil (kg/ha) available for nitrification, the process of ammonium conversion to nitrate by nitrifying bacteria. SKN35 is the transformation rate coefficient for nitrification at 35°C. It is used to determine the transformation rate at any temperature (Watts and Hanks, 1978). WNO3 is the weight of soluble nitrogen in the surface cm of soil (kg/ha). This is used as the amount of nitrate available for conversion to N_2 gas through the denitrification process.

The remaining nitrogen characteristics are related to loss of nitrogen through runoff and erosion. NF and NQ are the nitrogen extraction coefficients for infiltration and runoff respectively. They are used to determine the amount of nitrate lost with runoff (Flanagan and Foster, 1989). NORG is the nitrogen associated with sediment (kg/kg).

This is the sediment bound nitrogen that will be lost with erosion. NP1 and NP2 are constants used to determine the enrichment ratio for nitrogen with sediment (Menzel, 1980).

Field and Practice Characteristics

Field characteristics are physical characteristics related to the field being modeled. Table 4.2 contains the input parameters pertaining to field and practice characteristics. SL is the average slope of the field (%). LENGTH is the slope length from the farthest point of the field to the outlet (m). DS is the distance to stream measurement.

Table 4.2. Field and Practice Characteristic Input Parameters

Parameter	Description	Units	Equation
SL	Average Slope of the Field	%	3.17
LENGTH	Slope Length Field to the Outlet	m	3.19-3.21
DS	Distance to stream	m	3.30
SLP	Slope of the Distance to Stream	m/m	3.31
CN2	SCS Curve Number II	-	3.3,3.7,3.8
BEGIN	Beginning of the Growing Season	Julian Day	-
END	End of the Growing Season	Julian Day	-
NH4A	Fertilizer Applied as NH_4^+	kg/ha	3.49
NO3A	Fertilizer Applied as NO_3^-N	kg/ha	3.50
NCF	Number of Crop Stages	-	3.12
DCF	Beginning Date for Crop Stage	Julian Day	3.12
CF	USLE C Factor	-	3.12
KF	USLE K Factor	-	3.12
PF	USLE P Factor	-	3.12

This is a measure from the edge of the field to the point where we are determining losses (Heatwole and Shanholtz, 1991). SLP is the slope of the distance to stream (m/m). Finally, CN2 is the SCS curve number for the field for antecedent moisture condition II. The curve number is a parameter that describes the runoff potential of an area. It is described by SCS hydrologic soil groups and land use (Haan et al., 1994).

Practice characteristics are those related to the agricultural management practices of the field. Management practices include growing season, fertilizer application, and cover and practice factors used in the USLE to determine erosion losses.

BEGIN and END are the beginning and end of the growing season. They are usually determined by the type of crop and the climate. Fertilizer application is described by NH4A and NO3A. NH4A is the amount of fertilizer applied as ammonium (kg/ha) and NO3A is the amount of fertilizer applied as nitrate (kg/ha). These values are input on the day fertilization occurs and are added to the pool of nitrogen in the soil.

Three parameters are input for use in the USLE equation. CF, DCF and NCF are factors used to determine the cover (C) factor in the USLE. The C factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled continuous fallow (Wischmeier and Smith, 1978). The cover factor is based on the cover, crop sequence and management practices. It also depends on the particular stage of growth and development of the vegetal cover at the time of the rain. NCF is the number of crop stages. DCF and CF refer to the beginning date in Julian days and C factor for each crop stage. KF is the USLE K factor. The K accounts for seasonal variation in soil erodibility. It is determined by soil texture, soil organic matter, soil structure and permeability. PF is the USLE P factor. It is based on the conservation practices used on the field such as contouring, strip cropping and terracing. It is also dependent on land slope and maximum slope length.

Climatic Characteristics

Climatic characteristics are meteorological parameters. Table 4.3 contains the climatic input parameters. PR is the amount of precipitation (mm). These values are entered daily as measured values. CR is the amount of nitrogen contained in the precipitation (ppm). Typical values for nitrate contained in rainfall range from about 0.1 to 0.7 ppm (NRC, 1978). TEMP is the temperature in degrees Celsius. These values are also entered daily as measured values. MODLAT is an array of modifying factors used to calculate potential evapotranspiration (Hargreaves, 1974). These values have been tabulated monthly for different latitudes. The model converts them to daily values.

Table 4.3. Climatic Characteristic Input Parameters

Parameter	Description	Units	Equation
PR	Precipitation	mm	3.1
CR	Nitrogen in Precipitation	ppm	3.25,3.26
TEMP	Air/Soil Temperature	°C	3.9,3.34, 3.40-3.42, 3.44
MODLAT	Evapotranspiration Modifying Factor	-	3.9

Simulation Characteristics

The last type of inputs are simulation specific characteristics. Table 4,4 contains the simulation specific input parameters. NEV is the number of events in the simulation lasting for duration T. T is the time step, usually one day. DAY is the beginning date of the simulation in Julian days. DATE is the beginning year of the simulation. DATE is used to determine whether or not the year of the simulation is a leap year.

Table 4.4. Simulation Specific Input Parameters

Parameter	Description	Units
NEV	Number of Events	-
T	Time Step	days
DAY	Beginning Date of Simulation	Julian Day
DATE	Year at Beginning of Simulation	Date

Output Parameters

The output parameters of the model can be separated into two categories: those related to the runoff and erosion components of the model, and those related to the nitrogen component of the model. Table 4.5 contains the model output parameters. Appendix D contains an example of the model output file.

Q is the runoff calculated by the SCS curve number method (cm). PET is the amount of evapotranspiration calculated using Hargreaves equation (cm). F is the amount of infiltration (cm). AE is the amount of erosion loss calculated using the USLE (kg/ha). All of these values are computed daily.

QNO3 is the amount dissolved nitrogen lost with runoff (kg/ha). NSED is the amount of sediment-attached nitrogen lost with runoff (kg/ha). NH4M is the amount of organic N mineralized to ammonium (kg/ha). NA is the amount of ammonium converted to nitrate (kg/ha). NO3D is the amount of nitrate denitrified to N_2 gas (kg/ha).

Table 4.5. Model Output Parameters

Parameter	Description	Units	Equation
Q	Runoff	cm	3.1,3.11, 3.27
PET	Potential Evapotranspiration	cm	3.9, 3.11
F	Infiltration	cm	3.10, 3.11
AE	Sediment Loss	kg/ha	3.12,3.28, 3.29
QNO3	Dissolved Nitrogen Loss	kg/ha	3.27
NSED	Sediment Bound Nitrogen Loss	kg/ha	3.28
NH4M	Organic N Mineralized	kg/ha	3.32, 3.48, 3.49
NA	NH_4^+ Oxidized to NO_3^-	kg/ha	3.38, 3.49, 3.50
NO3D	NO_3^- Reduced to N_2 gas	kg/ha	3.43, 3.50

CHAPTER 5

MODEL VALIDATION

Procedure

The objective of the model validation was to test the ability of the model to predict dissolved and sediment bound N losses. One data set from Watkinsville, Georgia was used to validate the runoff, sediment, dissolved and sediment bound N loss components independently. The same data set was also used to validate the model as a whole.

Site Description

The site used for model validation was the P2 watershed of the Southern Piedmont Conservation Research Center located near Watkinsville, GA. The USDA, in a joint project with the EPA, designed an experiment to provide a database for the conceptual development and testing of operational models for describing pesticide and nutrient transport from agricultural lands (Smith et al., 1978). Since observed data were available for this location, model validation was done using the 1974, P2 watershed data.

The P2 watershed has an area of 1.3 hectares and is shaped with a drainage pattern converging to a central draw. The major soil is Cecil sandy loam with soil of alluvial origin occupying the central draw. The inputs to the model related to the soil characteristics of the P2 watershed are shown in Table 5.1.

Table 5.1. Soil Characteristic Input Values

Parameter	Value	Units	Equation
FC	0.20	cm/cm	3.10
PO	0.45	cm/cm	3.22,3.23,3.37
SWC_o	0.20	cm	3.10,3.37
OC	0.38	%	3.46
MO	47	kg/ha	3.33,3.47,3.48
NOA	47	kg/ha	3.38,3.47,3.49
SKN35	0.04	1/hr	3.40-3.42
WNO3	0.2	kg/ha	3.43,3.47,3.50
NF	0.25	-	3.22
NQ	0.075	-	3.23
NORG	0.00035	kg/kg	3.28
NP1	2.82	-	3.29
NP2	-0.16	-	3.29
CR	0.8	ppm	3.25, 3.26

Field Capacity (FC), porosity (PO), and the initial values for the various nitrogen forms in the soil and rainfall (MO, NOA, WNO3, NORG, CR), were taken from the data given in Frere et al. (1980). The organic carbon (OC) value was derived from the percent organic matter in the soil using the relationship (Frere et al., 1980):

$$OC = \%OM \times 0.58 \tag{5.1}$$

where % OM was given in the Frere et al. (1980) data set.

The nitrification rate constant at 35° C (SKN35) was derived from Hsieh et al. (1981). They estimated the K value at 21°C to be between 0.31 and 0.76 per day. K was taken as 0.5 per day for this model. Equation 3.40 yielded a value of 0.04 per hr for the K_{35} value. The extraction coefficients for infiltration and runoff, NF and NQ, were taken from Flanagan and Foster (1989). The values for the enrichment ratio regression coefficients, NP1 and NP2, were taken from Menzel (1980).

The field and practice characteristic input values for the model are given in Table 5.2. The growing season began on April 23, 1974 with disking of the field. Harvest was on October 29, 1974. Observations for this simulation began on April 4, 1974 and ended on October 16, 1974, for a total of 196 days. Corn was grown with rows nearly on the contour on plot P2. No conservation practices were used during the time of the simulation. Fertilizer was applied twice during the simulation. The first application was just prior to planting. An application of 38 kg/ha of nitrogen fertilizer was incorporated to an average depth of 10 cm. The fraction of application in the top cm of soil was 0.1. Forty-three days after planting, 101 kg/ha of N was applied to the surface soil by spray. No information was given on the fraction of NO_3-N and NH_4-N contained in the fertilizer so an assumed value of half the total amount of fertilizer was used for each.

Table 5.2. Field and Practice Characteristic Input Values

Parameter	Value	Units	Equation
SL	0.1	%	3.17
LENGTH	48.15	m	3.19-3.21
DS	0	m	3.30
SLP	0.1	m/m	3.31
CN2	81	-	3.3,3.7,3.8
BEGIN	113	Julian Day	-
END	302	Julian Day	-
KF	0.23	Mg-hr/ MJ-mm	3.12
PF	1	-	3.12

The slope percent and slope length of the field were given in Smith et al. (1978). The CN2 value was chosen based on the hydrologic soil group and land use (SCS, 1985). Cecil soils are in hydrologic soil group B (Haan et al., 1994) and the land use is cultivated land with no conservation practices (Smith et al., 1978).

The crop development was described by the C factor. Table 5.3 shows the dates and C values associated with the stages of development of corn that has been disk plowed with 3400 lb of spring residue (Wischmeier and Smith, 1978).

Table 5.3. C Factor Values Used for Model Validation

Date (Julian Day)	1	114	115	145	176	237	268	302	303	365
C Factor	.3	.3	.52	.43	.37	.24	.20	.20	.23	.23

Daily rainfall and temperature values were read into the model. Other inputs used to validate the individual components of the model were observed runoff, observed infiltration and observed sediment. The values for each of the daily inputs can be found in Appendix A.

. The modifying factors for Hargreaves' Formula to calculate evapotranspiration are based on latitude. The P2 watershed is very close to latitude 34. The modifying factors for each month are shown in Table 5.4 (Hargreaves, 1974).

Table 5.4. Potential Evapotranspiration Factor, MF

Month	MF	Month	MF
January	0.893	July	2.983
February	1.106	August	2.572
March	1.746	September	1.930
April	2.272	October	1.420
May	2.272	November	0.953
June	2.983	December	0.805

Component Validation

Frere et al. (1980) included measured values for rainfall, runoff, infiltration, sediment, dissolved N loss and sediment bound N loss. These observed values were used to validate each of the model components independently. Simple regression and standard t-tests were used as tools in validation.

Runoff Component Validation

The runoff component was validated using observed rainfall. The runoff predicted by the model was compared to the observed runoff. Table 5.5 contains the observed values for rainfall along with observed and predicted values for runoff. Table 5.6 contains summary statistics describing observed and predicted runoff. The model underpredicted the total runoff volume by 7%. The standard deviations for the observed and predicted values are also close. The predicted maximum value is approximately 25% greater than the observed maximum value.

Figure 5.1 contains a graph of the regression of observed vs. predicted runoff. Table 5.7 contains the parameters describing the regression equation. The coefficient of determination, r^2, value indicates to what degree the variability in the dependent variable can be explained by the regression line. The closer r^2 is to one, the more the regression line explains this variation (Haan, 1977). In this case, the dependent variable is predicted runoff and the independent variable is observed runoff. The r^2 of 0.75 indicates that 75% of the variability in predicted runoff is described by the regression line.

Standard t-tests were used to test two hypotheses: 1) that the slope of the regression line is equal to one, and 2) that the intercept of the regression line is equal to zero. Table 5.7 contains the t-test slope and intercept values. The significance level of the t-tests, α, was 95%. The t-slope value tests the hypothesis that the slope of the regression line is equal to one. In this case, we do not reject the hypothesis. The t-intercept value tests the hypothesis that the intercept of the regression line is equal to zero. Again, we do not reject the hypothesis. When taking into account both the r^2 value and the t-tests it appears that the runoff component of the model provides acceptable results.

Table 5.5. Observed and Predicted Values for Runoff Using Observed Rainfall

Date	Rainfall (mm)	Runoff (cm)		Date	Rainfall (cm)	Runoff (cm)	
	Observed	Observed	Model		Observed	Observed	Model
4-Apr	33	0.3	0.3	17-Jul	3	0.0	0.0
12-Apr	1	0.0	0.0	23-Jul	3	0.0	0.0
13-Apr	24	0.4	0.0	24-Jul	15	0.1	0.0
22-Apr	8	0.0	0.0	26-Jul	13	0.0	0.0
2-May	2	0.0	0.0	27-Jul	72	4.6	2.3
4-May	9	0.0	0.0	5-Aug	1	0.0	0.0
5-May	19	0.1	0.0	7-Aug	27	0.0	0.0
11-May	3	0.0	0.0	10-Aug	28	0.2	0.0
12-May	13	0.0	0.0	14-Aug	8	0.0	0.0
15-May	3	0.0	0.0	16-Aug	51	0.8	0.3
23-May	70	0.7	2.1	17-Aug	15	0.1	0.0
26-May	7	0.0	0.0	29-Aug	17	0.1	0.0
31-May	13	0.0	0.0	1-Sep	11	0.1	0.0
8-Jun	8	0.0	0.0	3-Sep	8	0.0	0.0
10-Jun	6	0.0	0.0	6-Sep	23	0.0	0.0
20-Jun	12	0.1	0.0	25-Sep	4	0.0	0.0
27-Jun	108	4.3	6.0	16-Oct	9	0.0	0.0

Table 5.6. Runoff Component Summary Statistics

	Values (cm)	
	Observed	Model
TOTAL	11.9	11.0
MEAN	0.35	0.33
MIN	0.0	0.0
MAX	4.6	6.0
STD. DEV	1.0	1.1

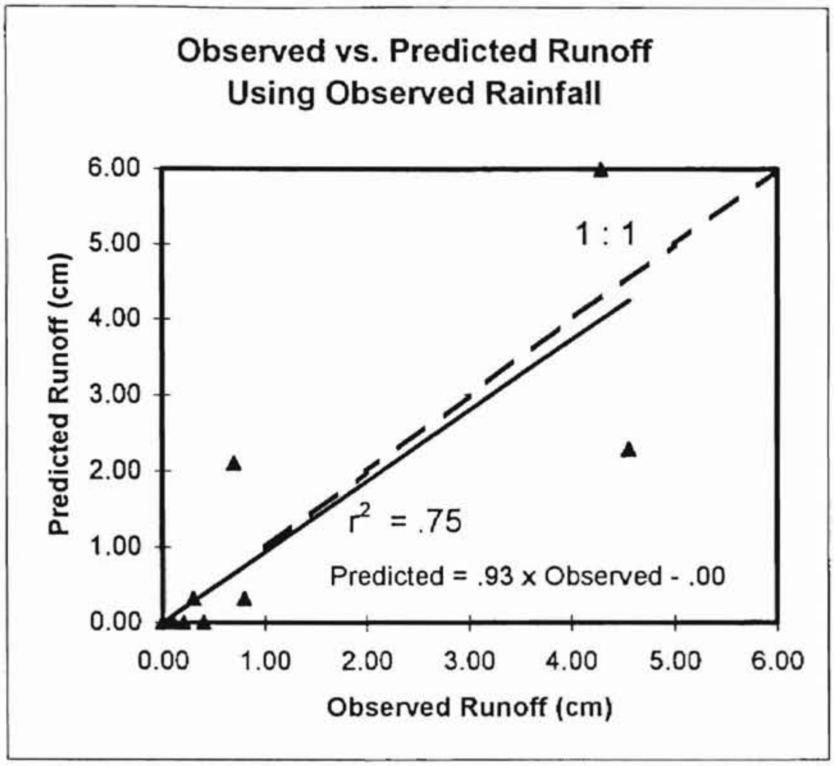

Figure 5.1. Regression of Observed vs. Predicted Runoff

Table 5.7. Runoff Regression Parameters

Regression (α = .95)		T Statistics
r^2	.75	-
slope	.93	-.72
intercept	.00	-.01
std. error	.57	-

Sediment Component Validation

The sediment component was validated with observed runoff as input into the model. The sediment predicted by the model was compared to the observed sediment. Table 5.8 contains the observed values of runoff along with observed and predicted values for sediment. Table 5.9 contains summary statistics describing observed and predicted sediment. The total predicted sediment loss is within 1% of the observed, with the model underpredicting the maximum value by 9%.

Table 5.8. Observed and Predicted Values for Sediment Using Observed Runoff

Date	Runoff (cm)	Sediment (kg/ha)		Date	Runoff (cm)	Sediment (kg/ha)	
	Observed	Observed	Model		Observed	Observed	Model
4-Apr	0.3	9.6	54.5	17-Jul	0.0	0.0	0.0
12-Apr	0.0	0.0	0.0	23-Jul	0.0	0.0	0.0
13-Apr	0.4	14.5	27.2	24-Jul	0.1	23.4	10.1
22-Apr	0.0	0.0	0.0	26-Jul	0.0	0.0	0.0
2-May	0.0	0.0	0.0	27-Jul	4.6	661.3	299.7
4-May	0.0	0.0	0.0	5-Aug	0.0	0.0	0.0
5-May	0.1	10.1	26.7	7-Aug	0.0	0.0	0.0
11-May	0.0	0.0	0.0	10-Aug	0.2	22.6	34.5
12-May	0.0	0.0	0.0	14-Aug	0.0	0.0	0.0
15-May	0.0	0.0	0.0	16-Aug	0.8	70.7	121.4
23-May	0.7	92.0	407.2	17-Aug	0.1	7.3	8.4
26-May	0.0	0.0	0.0	29-Aug	0.1	3.8	10.0
31-May	0.0	0.0	0.0	1-Sep	0.1	0.5	3.8
8-Jun	0.0	0.0	0.0	3-Sep	0.0	0.0	0.0
10-Jun	0.0	0.0	0.0	6-Sep	0.0	0.0	0.0
20-Jun	0.1	1.4	7.6	25-Sep	0.0	0.0	0.0
27-Jun	4.3	966.5	878.3	16-Oct	0.0	0.0	0.0

Table 5.9. Sediment Component Summary Statistics

	Values (kg/ha)	
	Observed.	Predicted
TOTAL	1883.7	1889.4
MEAN	55.4	55.6
MIN	0.0	0.0
MAX	966.5	878.3
STD. DEV	197.1	169.0

Figure 5.2 is the graph of the regression between observed and predicted sediment. Table 5.10 contains the parameters describing the regression equation. The r^2 value for the observed versus predicted sediment regression is 0.81, where observed sediment is the independent variable and predicted sediment is the dependent variable. The r^2 indicates that 81% of the variability in predicted sediment is explained by the

regression line.

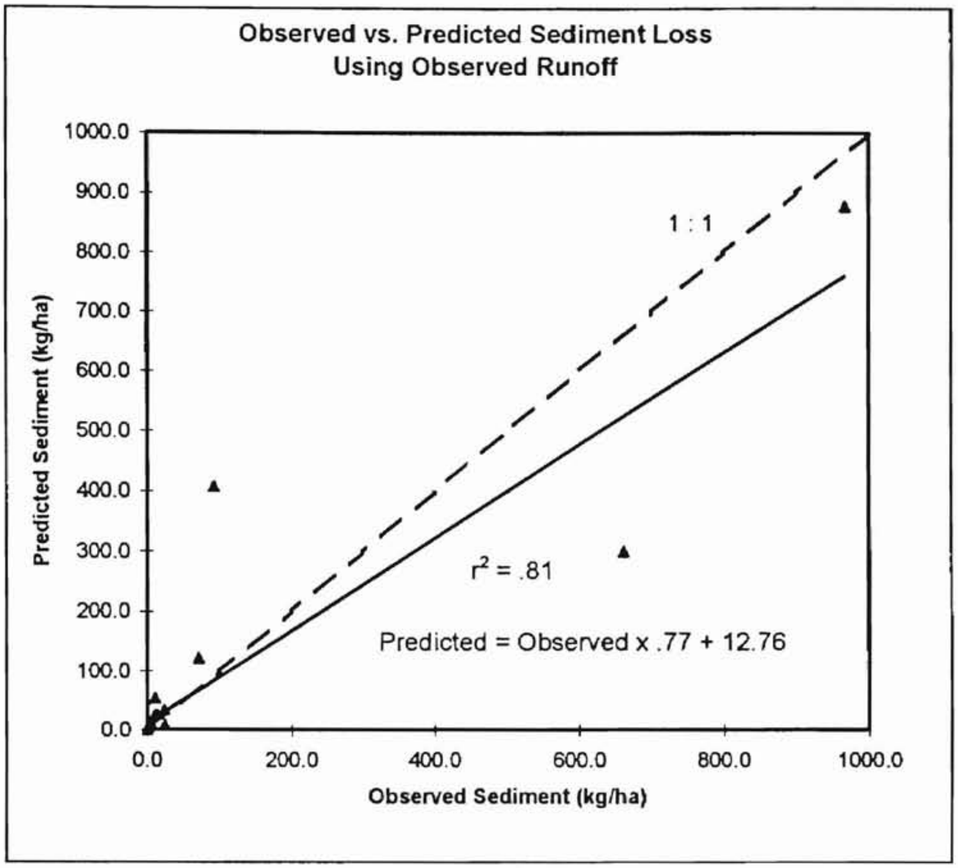

Figure 5.2. Regression of Observed vs. Predicted Sediment

Table 5.10. Sediment Regression Parameters

Regression (α = .95)		T-Statistic
r^2	.81	-
slope	.77	-3.5
intercept	12.8	.96
std. error	74.4	-

Table 5.10 contains the t-test slope and intercept values. The t-slope value testing the hypothesis that the slope equals one leads to a rejection of the hypothesis, indicating the slope is a value other than one. The t-intercept value testing the hypothesis that the

intercept equals zero leads to a conclusion of "do not reject". Taking into account both the r^2 value and the t-tests it appears that the sediment component provides acceptable sediment yield results, however, the ratio between observed and predicted runoff is not 1:1.

Dissolved N Loss Component Validation

The dissolved N loss component was validated using observed runoff. The predicted dissolved N loss was compared to observed dissolved N loss. Table 5.11 contains the observed runoff and observed and predicted values for dissolved N loss. Table 5.12 contains summary statistics for observed and predicted dissolved N loss. There is a variation of approximately 13% between the total observed and predicted values for dissolved N loss, with the model underpredicting the maximum observed value by 8%.

Figure 5.3 is a graph of the regression for observed and predicted dissolved N loss. Table 5.13 contains the parameters describing the regression. The r^2 value for the regression of observed versus predicted dissolved N loss is .99, where observed dissolved N loss is the independent variable and predicted dissolved N loss is the dependent variable. The r^2 indicates that 99% of the variation in predicted dissolved N loss is explained by the regression line.

Table 5.13 contains the t-test slope and intercept values for dissolved N loss. The t-slope value testing the hypothesis that slope equals one rejects the hypothesis, indicating the slope has a value other than one. The hypothesis that intercept is equal to zero is not rejected. The r^2 value along with the t-tests indicate that while there is a good correlation between observed and predicted dissolved N loss, it is not a 1:1 ratio. The dissolved N loss component provides acceptable results.

Table 5.11. Observed and Predicted Values for Dissolved N Loss

Date	Runoff (cm)	Dissolved N Loss (kg/ha)		Date	Runoff (cm)	Dissolved N Loss (kg/ha)	
	Observed	Observed	Model		Observed	Observed	Model
4-Apr	0.30	0.00	0.03	17-Jul	0.00	0.00	0.00
12-Apr	0.00	0.00	0.00	23-Jul	0.00	0.00	0.00
13-Apr	0.40	0.00	0.08	24-Jul	0.10	0.09	0.03
22-Apr	0.00	0.00	0.00	26-Jul	0.00	0.00	0.00
2-May	0.00	0.00	0.00	27-Jul	4.56	1.02	0.84
4-May	0.00	0.00	0.00	5-Aug	0.00	0.00	0.00
5-May	0.10	0.01	0.02	7-Aug	0.00	0.00	0.00
11-May	0.00	0.00	0.00	10-Aug	0.20	0.06	0.04
12-May	0.00	0.00	0.00	14-Aug	0.00	0.00	0.00
15-May	0.00	0.00	0.00	16-Aug	0.80	0.17	0.13
23-May	0.70	0.22	0.09	17-Aug	0.10	0.02	0.02
26-May	0.00	0.00	0.00	29-Aug	0.10	0.02	0.02
31-May	0.00	0.00	0.00	1-Sep	0.10	0.01	0.02
8-Jun	0.00	0.00	0.00	3-Sep	0.00	0.00	0.00
10-Jun	0.00	0.00	0.00	6-Sep	0.00	0.00	0.00
20-Jun	0.10	0.05	0.02	25-Sep	0.00	0.00	0.00
27-Jun	4.29	1.86	1.71	16-Oct	0.00	0.00	0.00

Table 5.12. Dissolved N Loss Summary Statistics

	Values (kg/ha)	
	Observed	Model
TOTAL	3.52	3.05
MEAN	0.10	0.09
MIN	0.00	0.00
MAX	1.86	1.71
STD. DEV.	0.36	0.32

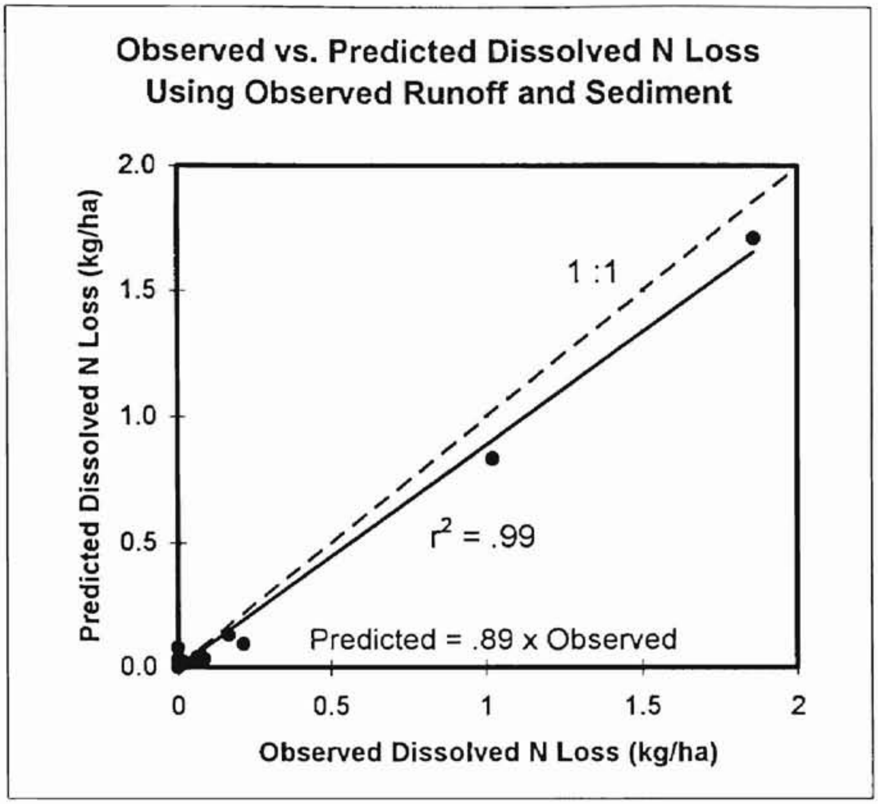

Figure 5.3. Regression of Observed vs. Predicted Dissolved N Loss

Table 5.13. Dissolved N Loss Regression Parameters

Regression (α = .95)		T-Statistic
r^2	.99	-
slope	.89	-7.46
intercept	-.00	-.48
std. error	.03	-

Sediment Bound N Loss Component Validation

The sediment bound N loss component was validated using observed sediment. The predicted sediment bound N loss was compared to observed values. Table 5.14 contains the observed sediment values along with observed and predicted values for sediment bound N loss. Table 5.15 contains summary statistics describing the sediment bound N loss component. The total sediment bound N loss is within 5% of the total observed value. The maximum observed sediment bound N loss is approximately 9% greater than the maximum predicted value.

Figure 5.4 is a graph of the regression of observed vs. predicted sediment bound N loss. Table 5.16 contains the parameters for the regression. The r^2 value for the regression is 0.94, where observed N loss is the independent variable and predicted N loss is the dependent variable. The r^2 indicates that 94% of the variation in predicted sediment bound N loss is explained by the regression line.

Table 5.16 contains the t-test slope and intercept values. The t-slope value testing the hypothesis that the slope equals one rejects the hypothesis, indicating the slope is a value other than one. The t-intercept value does not reject the hypothesis of intercept equal to zero. The r^2 value along with the t-tests indicate that while there is a good correlation between observed and predicted sediment bound N loss, the relationship is not 1:1. The sediment bound N loss component yields acceptable results.

Table 5.14. Observed and Predicted Values for Sediment Bound N Loss

Date	Sediment (kg/ha)	Sediment Bound N Loss (kg/ha)		Date	Sediment (kg/ha)	Sediment Bound N Loss (kg/ha)	
	Observed	Observed	Model		Observed	Observed	Model
4-Apr	9.6	0.00	0.04	17-Jul	0.0	0.00	0.00
12-Apr	0.0	0.00	0.00	23-Jul	0.0	0.00	0.00
13-Apr	14.5	0.00	0.06	24-Jul	23.4	0.08	0.08
22-Apr	0.0	0.00	0.00	26-Jul	0.0	0.00	0.00
2-May	0.0	0.00	0.00	27-Jul	661.3	2.07	1.37
4-May	0.0	0.00	0.00	5-Aug	0.0	0.00	0.00
5-May	10.1	0.01	0.04	7-Aug	0.0	0.00	0.00
11-May	0.0	0.00	0.00	10-Aug	22.6	0.07	0.08
12-May	0.00	0.00	0.00	14-Aug	0.0	0.00	0.00
15-May	0.0	0.00	0.00	16-Aug	70.7	0.16	0.21
23-May	92.0	0.07	0.26	17-Aug	7.3	0.02	0.03
26-May	0.0	0.00	0.00	29-Aug	3.8	0.01	0.02
31-May	0.0	0.00	0.00	1-Sep	0.5	0.01	0.00
8-Jun	0.0	0.00	0.00	3-Sep	0.0	0.00	0.00
10-Jun	0.0	0.00	0.00	6-Sep	0.0	0.00	0.00
20-Jun	1.4	0.00	0.01	25-Sep	0.0	0.00	0.00
27-Jun	966.5	1.79	1.89	16-Oct	0.0	0.00	0.00

Table 5.15. Sediment Bound N Loss Summary Statistics

	Values (kg/ha)	
	Observed	Model
TOTAL	4.30	4.09
MEAN	0.13	0.12
MIN	0.00	0.00
MAX	2.07	1.89
STD. DEV.	0.46	0.39

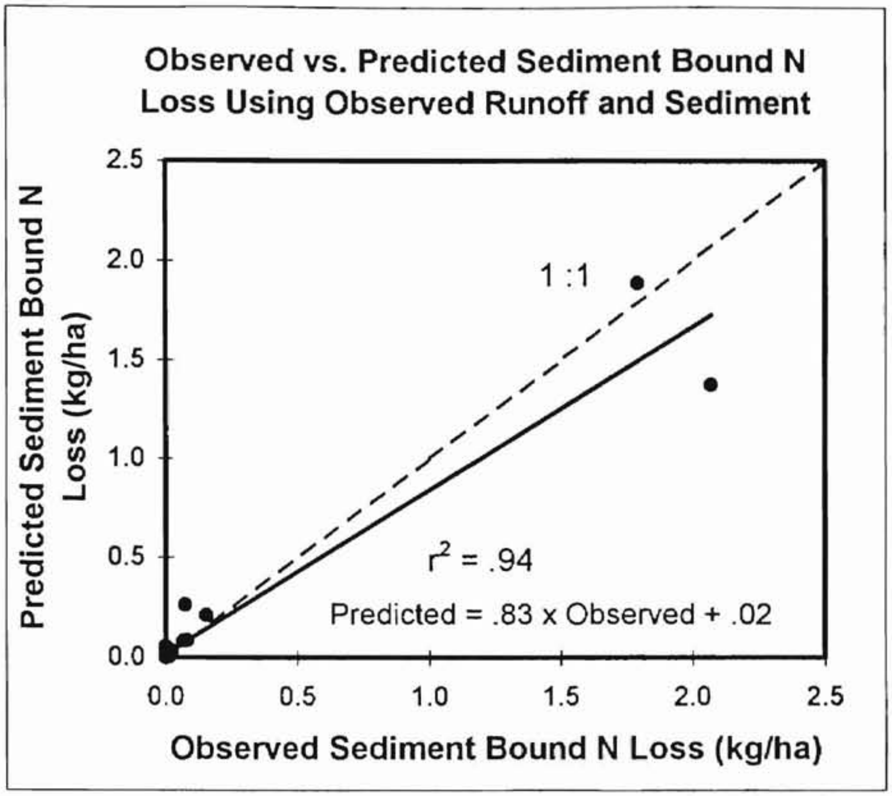

Figure 5.4. Regression of Observed vs. Predicted Sediment Bound N Loss

Table 5.16: Sediment Bound N Loss Regression Parameters

Regression (α = .95)		T-Statistic
r^2	.94	-
slope	.83	-4.57
intercept	.02	.89
std. error	.10	-

Model Validation

The model validation was done much the same as the validations for the individual components. The only observed input used was rainfall. Runoff and sediment were calculated by the model and used in the dissolved and sediment bound N loss components. These predicted values were compared to observed values. Simple linear regression and standard t-tests were used as evaluation tools for model validation. Table 5.17 contains the data for the days during the simulation that there was observed runoff, sediment, dissolved N loss, and sediment bound N loss and the corresponding model values.

Table 5.17. Observed and Predicted Values for Model Output

	Rainfall (mm)	Runoff (cm)		Sediment (kg/ha)		Dissolved N Loss (kg/ha)		Sediment Bound N Loss (kg/ha)	
Date	Observed	Observed	Model	Observed	Model	Observed	Model	Observed	Model
4-Apr	33	0.30	0.32	9.6	54.5	0.00	0.03	0.00	0.17
13-Apr	24	0.40	0.00	14.5	0.0	0.00	0.00	0.00	0.00
5-May	19	0.10	0.00	10.1	0.0	0.01	0.00	0.01	0.00
23-May	70	0.70	2.10	92.0	407.2	0.22	0.22	0.07	0.91
20-Jun	12	0.10	0.00	1.4	0.0	0.05	0.00	0.00	0.00
27-Jun	108	4.29	5.99	966.5	878.3	1.86	2.32	1.79	1.74
24-Jul	15	0.10	0.00	23.4	0.0	0.09	0.00	0.08	0.00
27-Jul	72	4.56	2.28	661.3	299.7	1.02	0.44	2.07	0.71
10-Aug	28	0.20	0.00	22.6	0.0	0.06	0.00	0.07	0.00
16-Aug	51	0.80	0.32	70.7	121.4	0.17	0.05	0.16	0.33
17-Aug	15	0.10	0.00	7.3	0.0	0.02	0.00	0.02	0.00
29-Aug	17	0.10	0.00	3.8	0.0	0.02	0.00	0.01	0.00
1-Sep	11	0.10	0.00	0.5	0.0	0.01	0.00	0.01	0.00

Table 5.18 contains the total, mean, median, maximum, minimum and standard deviation values for the model outputs. Table 5.19 contains the results of the regressions comparing observed and predicted values for each of the model outputs. Table 5.19 also contains the t-slope and t-intercept values for the model components. The t-tests were done with an $\alpha = .95$.

Table 5.18. Summary Statistics for Model Validation

	Runoff (cm)		Sediment (kg/ha)		Dissolved N Loss (kg/ha)		Sediment Bound N Loss (kg/ha)	
	Observed	Model	Observed	Model	Observed	Model	Observed	Model
TOTAL	11.85	11.00	1883.7	1761.0	3.52	3.08	4.30	3.86
MEAN	0.35	0.33	55.4	51.8	0.10	0.09	0.13	0.11
MIN	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00
MAX	4.56	5.99	966.5	878.3	1.86	2.32	2.07	1.74
MEDIAN	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00
STD. DEV.	1.05	1.13	197.1	170.0	0.36	0.40	0.46	0.35

Table 5.19. Regression Statistics for Model Validation

	Runoff	Sediment	Dissolved N Loss	Sediment Bound N Loss
r^2	0.75	0.81	0.90	0.62
slope	0.93	0.78	1.07	0.60
intercept	-0.00	8.75	-0.02	0.04
Std. Error	0.57	74.93	0.13	0.22
t-slope	-0.72	-3.37	1.07	-4.81
t-intercept	-0.01	0.66	-0.86	0.96

Runoff

The runoff results for the model are the same as those from the runoff component validation. The r^2 and t-tests show a reasonable correlation between predicted and observed runoff. Comparing the total runoff observed to the total runoff predicted indicates that the model underpredicts runoff for this data set during this simulation period.

Sediment

The total sediment yield predicted by the model is 6.5% less than the observed sediment yield. The maximum predicted sediment yield for the simulation period is 9% less than the observed sediment yield.

Figure 5.5 is a graph of the regression line for observed versus predicted sediment. The r^2 value for the regression of observed vs. predicted sediment is 0.81. The r^2 value indicates that 81% of the variation in predicted sediment is explained by the regression line. The t-slope value leads to a rejection of the hypothesis that the slope of the regression line is equal to one. The t-intercept value leads to a "do not reject" conclusion for the hypothesis that the intercept of the regression line is zero. The r^2 value along with the t-statistics indicate that the model does an acceptable job of predicting sediment however the ratio of observed to predicted sediment is not 1:1. It appears from the total, mean and maximum values that the model, for this data set, underpredicts sediment yield.

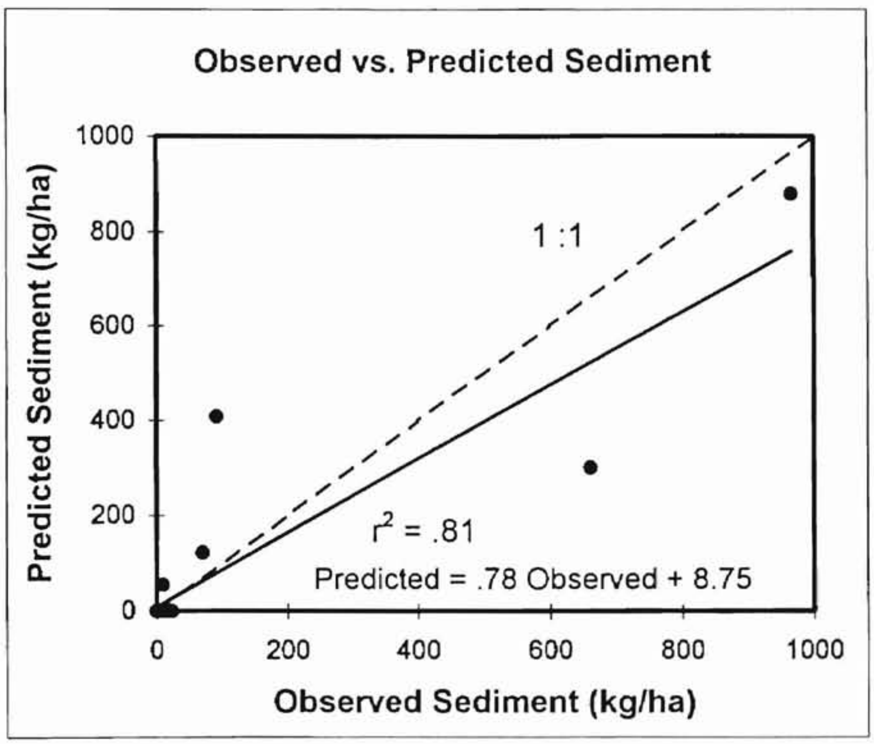

Figure 5.5. Regression of Observed vs. Predicted Sediment For Model Validation

Dissolved N Loss

The predicted total dissolved N loss value is 13% less than the observed value.

The maximum predicted dissolved N loss is 25% greater than the observed value.

Figure 5.6 is a graph of the regression between observed and predicted dissolved N loss. The r^2 value is 0.90 indicating that 90% of the variation in predicted dissolved N loss is described by the regression line. Both the hypotheses to test for slope equal to one and intercept equal to zero are not rejected. The r^2 value along with the t-tests indicates that the model does an acceptable job of predicting dissolved N loss. Totals for observed and predicted dissolved N loss indicate that the model underpredicts dissolved N loss for this data set but may overpredict for large runoff events.

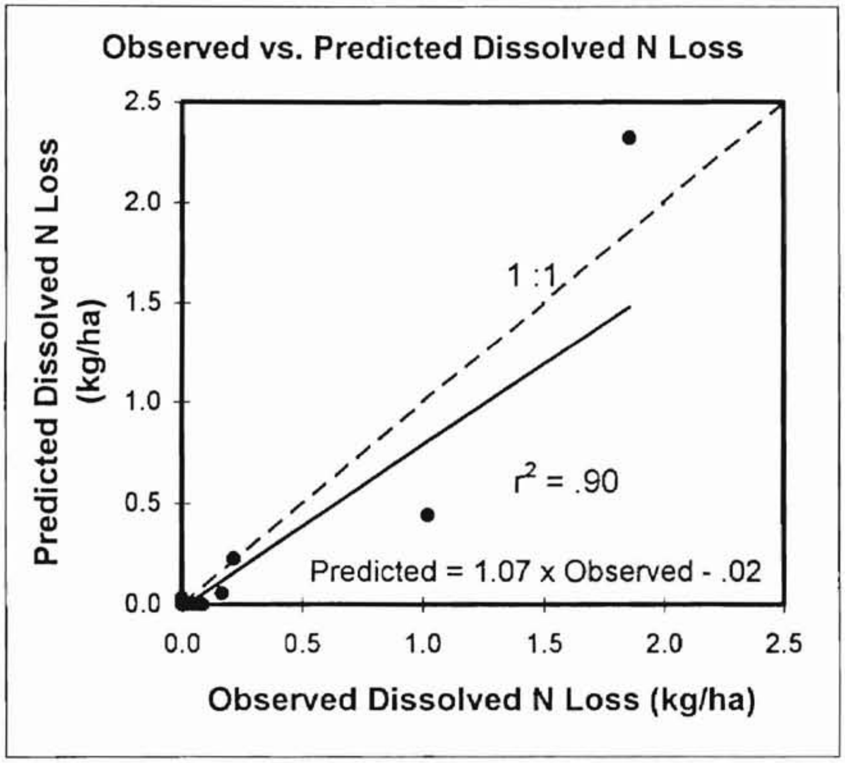

Figure 5.6. Regression of Observed vs. Predicted Dissolved N Loss For Model Validation

Sediment Bound N Loss

The total predicted sediment bound N loss was 10% less than the observed sediment bound N loss. The mean predicted sediment bound N loss is 15% less than the observed sediment bound N loss. The maximum predicted sediment bound N loss is 16% less than the observed sediment bound N loss.

Figure 5.7 is a graph of the regression between observed and predicted sediment bound N loss. The r^2 value is 0.62, which indicates that 62% of the variation in sediment bound N loss is explained by the regression line. The hypothesis to test for slope equal to one is rejected by the t-slope value. The hypothesis to test for intercept equal to zero is not rejected by the t-intercept value. Totals for observed and predicted values for sediment bound N loss indicate that the model generally underpredicts sediment bound N loss for this data set.

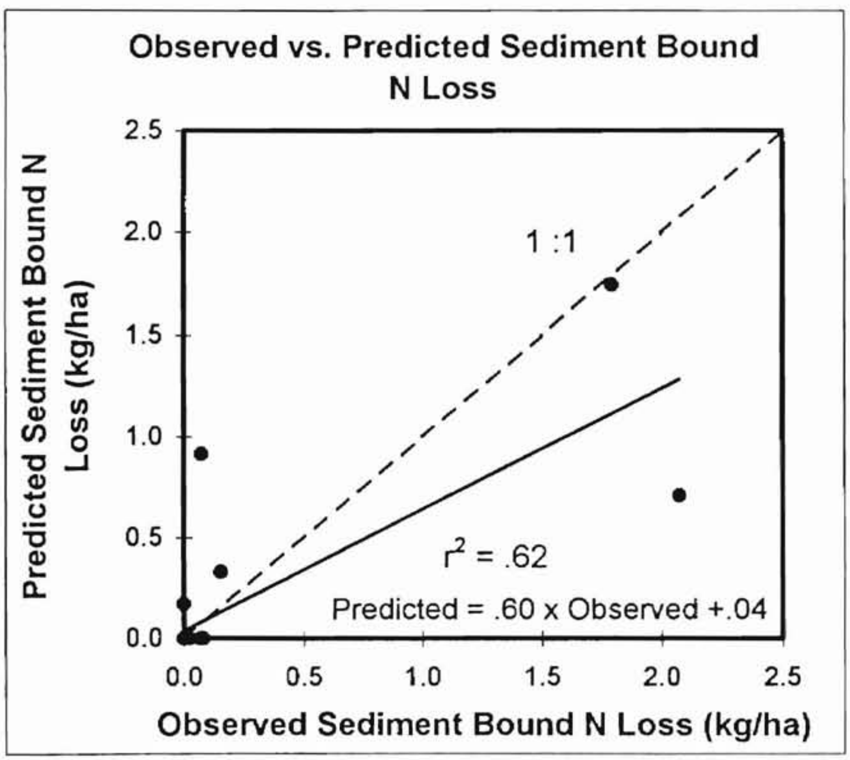

Figure 5.7. Regression of Observed vs. Predicted Sediment Bound N Loss For Model Validation

Sensitivity Analysis

In order to identify the input parameters that have the most impact on model outputs, a sensitivity analysis was done. Two types of sensitivity parameters were calculated, absolute sensitivity, S, and relative sensitivity, S_r. S gives the absolute change in output for a unit change in a input parameter while S_r gives the percent change in output for a 1% change in input parameter. Numerically these values can be calculated by (Haan, 1995):

$$S = \frac{O_2 - O_1}{P_2 - P_1} \tag{5.2}$$

$$S_r = \frac{O_2 - O_1}{P_2 - P_1}\frac{P}{O} \tag{5.3}$$

where O and P represent particular model output and input parameters respectively.

In this case each model input parameter, P, was increased by 10% to obtain P_2, and decreased by 10% to obtain P_1. The model was run once with model inputs, P, to get base values for O. The model was then run by varying one parameter at a time, holding all others at their base values. O_1 and O_2 values were outputs associated with P_1 and P_2 input parameters respectively. After all of the model runs were completed, S and S_r values were computed for each output value at a particular input parameter. Table 5.20 contains the S and S_r values from the sensitivity analysis.

Any parameter with an S_r value greater than or equal to 0.01 was considered to have a significant effect on the output parameters. It appears from the sensitivity analysis that the CN2 value has the most effect on the runoff and dissolved N loss components.

The USLE K, C, and P factors have the most effect on the sediment results. The intercept of the enrichment ratio (NP1) has the most effect on sediment bound N loss. Dissolved N loss is the output with sensitivity to the greatest number of input parameters.

Table 5.20. Sensitivity Analysis Results

	Sensitivity, S				Relative Sensitivity, S_r			
Parameter	Runoff	Sediment	Dissolved N Loss	Sediment Bound N Loss	Runoff	Sediment	Dissolved N Loss	Sediment Bound N Loss
MO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FC	0.00	0.00	3.44	0.00	0.00	0.00	0.22	0.00
PO	0.00	0.00	-2.03	0.00	0.00	0.00	-0.30	0.00
OC	0.00	0.00	-8.78	0.00	0.00	0.00	-1.08	0.00
CN2	0.61	9.24	0.18	0.03	4.48	0.43	4.77	0.67
SWC_O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	0.00	4914.55	0.00	0.63	0.00	0.28	0.00	0.02
LENGTH	0.00	0.70	0.00	0.00	0.00	0.02	0.00	0.02
KF	0.00	7656.48	0.00	14.12	0.00	1.00	0.00	0.84
PF	0.00	1760.98	0.00	3.26	0.00	0.95	0.00	0.80
NOA	0.00	0.00	0.01	0.00	0.00	0.00	0.11	0.00
WNO3	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
CR	0.00	0.00	1.08	0.00	0.00	0.00	0.28	0.00
NORG	0.00	0.00	0.00	11038.57	0.00	0.00	0.00	1.00
SKN35	0.00	0.00	15.58	0.00	0.00	0.00	0.20	0.00
NF	0.00	0.00	-5.83	0.00	0.00	0.00	-0.47	0.00
NQ	0.00	0.00	-6.68	0.00	0.00	0.00	-0.16	0.00
NP1	0.00	0.00	0.00	3.92	0.00	0.00	0.00	2.86
NP2	0.00	0.00	0.00	23.64	0.00	0.00	0.00	-0.98
FERT 1	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
FERT 2	0.00	0.00	0.04	0.00	0.00	0.00	0.60	0.00
C	0.00	5826.81	0.00	10.74	0.00	1.00	0.00	0.84
MODLAT	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00

The sensitivity analysis also indicates which parameters have little or no effect on the outputs. The initial soil water content (SWC_o) appears to have no effect on the outputs. This is expected because the SWC value changes with each time step, so initial values effect only the first time step. The initial value for potentially mineralizable N (MO), slope length (LENGTH), initial weight of the nitrate in the top cm of soil (WNO3), and modifying factors for the Hargreaves' Formula (MODLAT) appear to have very little effect on the model outputs.

The relative sensitivities of the two fertilizer applications, FERT 1 and FERT 2, indicate that the placement and amount of fertilizer effect the quantity of dissolved N loss. Dissolved N loss showed a much greater sensitivity to the larger of the two applications on the top cm of soil, FERT 2, indicating that greater amounts of N in the surface soils will result in greater amounts of N loss.

Results and Conclusions

When determining how well the model is predicting nitrogen losses with runoff, it helps to compare the individual component performance against the model performance. The dissolved N loss component when tested with observed runoff has a better correlation with runoff than when run with predicted runoff. However, the differences between observed and predicted values are about the same in each case.

The sediment bound N loss component when tested with observed sediment has a much better correlation, a slope closer to one and an intercept closer to zero than the component tested with predicted sediment. The differences between observed and predicted values are also much less in the component tested with observed sediment than in the component tested with predicted sediment.

It appears that the differences are partly due to the differences in observed and predicted runoff and sediment. The runoff component determines if there will be sediment yield, but the volume of runoff has no relation to the amount of sediment yield in this model. The dissolved N loss is directly related to the runoff volume. The sediment bound N loss volume is directly related to the amount of sediment yield. Therefore, the runoff component determines when there will be sediment yield and sediment bound N loss but does not effect their magnitudes.

The dissolved N loss component discrepancies could partly be related to the way that runoff is calculated. From the sensitivity analysis we know that the curve number, CN, has a very large effect on the runoff volume. Curve numbers for agricultural fields are difficult to estimate. If we back calculated the curve numbers from the runoff and rainfall volumes for the days of the simulation when we had both occurring we would have a wide range of curve numbers. An attempt is made to minimize the effects of soil moisture conditions on curve number by using a weighted curve number, but the runoff calculations are still very sensitive to the choice of curve number II.

The sediment bound N loss component discrepancies are harder to pin down. The sediment yield values calculated by the USLE equation are based on estimates for factors that describe a variety of soil and cropping conditions that affect erosion. The sediment bound N loss component is very sensitive to the choices for all of these parameters. However, the component shows an even greater sensitivity to the constants that are chosen for use in the enrichment ratio.

The regressions for all of the components are significantly affected by a large number of small rainfall events and a small number of large rainfall events. Over the entire simulation on this watershed there were only 13 days where runoff events occurred and only two of these runoff events were greater than 1 cm. Results would probably significantly different for a watershed receiving larger quantities of rainfall.

From the limited information given from one data set on a relatively dry, well drained soil, it appears that the model does an acceptable job of predicting N losses.

Recommendations For Further Research

Validating the model with only one data set yielded limited information. It is desirable to validate the model with a variety of data sets for a variety of conditions. In particular data sets from areas were there are more frequent high volume rainfall events would provide more detailed answers about the processes that are occurring.

Another are for research is in parameter estimation. Reducing the error in the parameters used in the model can reduce the error in the outputs to some extent. This may help to delineate the error that is inherent in the model from the error that is contained in the data themselves. It is clear that that accurate hydrology and sediment estimation is essential before accurate water quality estimations can be made for surface runoff.

One particular area that needs further research is the nitrification rate constants. The value used in this came from sewage sludge decomposition data, which provided a wide range of values. Determining the rate constants for agricultural soils with fertilizer application would help yield more accurate results in the nitrogen transformation component.

BIBLIOGRAPHY

Aldrich, S. R. 1980. *Nitrogen in Relation to Food, Environment and Energy, Special Publication 61*. Agricultural Experiment Station, College of Agriculture, University of Illinois at Urbana-Champaign.

Arnold, J.G., J.R. Williams, A.D. Nicks and N.B. Sammons. 1989. *SWRRB, A Basin Scale Simulation Model for Soil and Water Resources Management*. College Station, TX: Texas A&M Press.

Beasley, D.B. and L.F. Huggins. 1981. *ANSWERS User's Manual*. EPA-905/9-82-001, U.S. EPA, Region V. Chicago, IL.

Brady, Nyle C. 1990. *The Nature and Properties of Soils, 10th Edition*. New York: Macmillan Publishing Company.

Brezonik, P.L. 1976. "Nutrients and Other Biologically Active Substances in Atmospheric Precipitation," *Journal of Great Lakes Research 2, Supplement*, 1:166-186.

Busch, Darron and Michael Meyer. 1982. "A Case of Infantile Methemoglobinemia in South Dakota," *Journal of Environmental Health* 44(6):310-311.

Cooley, K.R. 1980. "Erosivity "R" For Individual Design Storms." In *CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*, ed. W.G. Knisel. U.S. Department of Agriculture, Conservation Research Report No. 36.

Donigian, Anthony S. and Wayne C. Huber. 1991. *Modeling of Nonpoint Source Water Quality in Urban and Non-Urban Areas*. EPA/600/3-91/039.

Dorsch, Margaret M., Robert K. R. Scragg, Anthony J. McMichael, Peter A. Baghurst, and Kenneth F. Dyer. 1984. "Congenital Malformations and Maternal Drinking Water Supply in Rural South Australia: A Case-Control Study." *Journal of Epidemiology* 119(4):473-486.

Draper, D.W., J.B. Robinson and D.R. Coote. 1979. "Estimation and management of the contribution by manure from livestock in the Ontario Great Lakes basin to the phosphorus loading of the Great Lakes." In *Best Management Practices for Agriculture and Silviculture*, ed. R.C. Loehr, et al., Ann Arbor, MI: Ann Arbor Science Publications.

Engelstad, O.P. 1985. *Fertilizer Technology and Use, 3rd Edition*. Madison, WI: Soil Science Society of America, Inc.

Ericksson, R. 1952. "Composition of Atmospheric Precipitation." *Tellus* 4:215-232.

Flanagan, D.C., and G.R. Foster. 1989. "Storm Pattern Effect on Nitrogen and Phosphorus Losses in Surface Runoff." *Transactions of the ASAE* 32(2):535-544.

Food and Agriculture Organization of the United Nations. 1981. *Agriculture: Towards 2000*. Rome: Food and Agriculture Organization of the United Nations.

Fraser, Patricia and Clair Chilvers. 1981. "Health Aspects of Nitrate in Drinking Water." In *Water Supply and Health*. Amsterdam, The Netherlands: Elsevier Scientific Publishing Company.

Frere, M.H., J.D. Ross and L.J. Lane. 1980. "The Nutrient Submodel." In *CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*. ed. W.G. Knisel. U.S. Department of Agriculture, Conservation Research Report No. 36.

Haan, Charles T. 1977. *Statistical Methods in Hydrology*. Ames, IA: Iowa State University Press.

Haan, C.T., B.J. Barfield and J.C. Hayes. 1994. *Design Hydrology and Sedimentology for Small Catchments*. San Diego, CA: Academic Press.

Haan, C.T. 1995. "Evaluation of Uncertainty in Hydrologic and Water Quality Models." A Workshop Presented to the South Florida Water Management District, West Palm Beach, FL.

Hargreaves, George H. 1974. "Estimation of Potential and Crop Evapotranspiration." *Transactions of the ASAE* 17(4):701-704.

Heatwole, C.D. and V.O. Shanholtz. 1991. "Targeting Animal Waste Pollution Potential Using a Geographic Information System." *Applied Engineering in Agriculture* 7(6):692-698.

Hsieh, Y.P., Lowell A. Douglas, and Harry L. Motto. 1981. "Modeling Sewage Sludge Decomposition in Soil: II. Nitrogen Transformations." *Journal of Environmental Quality* 10(1):59-64.

Johansen, R.C., J.C. Imhoff, J.L. Kittle and A.S. Donigian. 1984. *Hydrological Simulation Program--Fortran (HSPF). User's Manual for Release 8.* EPA-600/3-84-066. U.S. Environmental Protection Agency, Athens, GA.

Jones, Ulysses S. 1982. *Fertilizers and Soil Fertility*. Reston, Virginia: Reston Publishing Company, Inc.

Kissel, D.E., C.W. Richardson, and Earl Burnett. 1976. "Losses of Nitrogen in Surface Runoff in the Blackland Prairie of Texas." *Journal of Environmental Quality* 5(3):288-293.

Lee, M.T. 1987. "Verification and Applications of a Nonpoint Source Pollution Model." In: *Proceedings of the National Engineering Hydrology Symposium*. New York: ASCE.

McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler and L.D. Meyer. 1987. "Revised Slope Steepness Factor for the Universal Soil Loss Equation." *Transactions of the ASAE* 30(5):1378-1395.

McCool, D.K., G.R. Foster, C.K. Mutchler and L.D. Meyer. 1989. "Revised Slope Length Factor for the Universal Soil Loss Equation." *Transactions of the ASAE* 32(5):1571-1576.

Menzel, Ronald G. 1980. "Enrichment Ratios for Water Quality Modeling." In *CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*. ed. W.G. Knisel. U.S. Department of Agriculture, Conservation Research Report No. 36.

Moe, P.G., J.G. Mannering, and C.B. Johnson. 1967. "Loss of Fertilizer Nitrogen in Surface Runoff Water." *Soil Science* 6(4):369-373.

Moore, James W. 1991. *Inorganic Contaminants of Surface Water: Research and Monitoring Priorities*. New York, NY: Springer-Verlag.

National Research Council. 1978. *Nitrates: An Environmental Assessment.* Washington, D.C.: National Academy of Sciences.

Novotny, Vladimir and Harvey Olem. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*. New York: Van Nostrand Reinhold.

NPK Working Group. 1983. *Handbook on Environmental Aspects of Fertilizer Use*. The Hague: Martinus Nijhoff/Dr W. Junk Publishers.

Patrick, R., E. Ford and J. Quarles. 1987. *Groundwater Contamination in the United States, 2nd ed*. Philadelphia, PA: University of Pennsylvania Press.

Puckett, Larry J. 1995. "Identifying the Major Sources of Nutrient Water Pollution." *Environmental Science and Technology* 29(9):408A-413A.

Sabbagh, George J., Daniel E. Storm, Michael D. Smolen, C. Tom Haan, and Mark S. Gregory. 1995. "Illinois River Basin-Treatment Prioritization Final Report." submitted to the Oklahoma Conservation Commission for the U.S. Environmental Protection Agency, July 8, 1995.

Schuman, G.E. and R.E. Burwell. 1974. "Precipitation Nitrogen Contribution Relative to Surface Runoff Discharges." *Journal of Environmental Quality* 3(4):366-369.

Schuman, G.E., R.E. Burwell, R.F. Piest, and R.G. Spomer. 1973. "Nitrogen Losses in Surface Runoff from Agricultural Watersheds on Missouri Valley Loess." *Journal of Environmental Quality* 2(2):299-302.

Schwab, Glenn O. Delmar D. Fangmeier, William J. Elliott, and Richard K. Frevert. 1993. *Soil and Water Conservation Engineering, Fourth Edition*. New York, NY: John Wiley and Sons.

Smedema, L.K., and D.W. Rycroft. 1983. *Land Drainage*. Ithaca, NY: Cornell University Press.

Smith, C.N., G.W. Bailey, R.A. Leonard and G.W. Langdale. 1978. *Transport of Agricultural Chemicals From Small Upland Piedmont Watersheds*. EPA 600/3-78-056.

Soil Conservation Service. 1973. *A Method for Estimating Volume and Rate of Runoff in Small Watersheds, SCS-TP-149*. Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service.

Soil Conservation Service. 1985. "Hydrology." In *National Engineering Handbook. Section 4*. Washington, D.C.: U.S. Department of Agriculture Soil Conservation Service.

Stanford, George, M.H. Frere and D.H. Schwaninger. 1973. "Temperature Coefficient of Soil Nitrogen Mineralization." *Soil Science*, 115(4):321-323.

Stevenson, F.J. 1982. *Nitrogen in Agricultural Soils*. Madison, WI: American Society of Agronomy.

Timmons, D.R., R.E. Burwell, and R.F. Holt. 1968. "Loss of Crop Nutrients Through Runoff." *Minnesota Science* 24(4):16-18.

Timmons, D.R., R.E. Burwell, and R.F. Holt. 1973. "Nitrogen and Phosphorus Losses in Surface Runoff form Agricultural Land as Influenced by Placement of Broadcast Fertilizer." *Water Resources Research* 9(3):658-667.

Timmons, D.R. and R.F. Holt. 1977. "Nutrient Losses in Surface Runoff from a Native Prairie." *Journal of Environmental Quality* 6(4):369-373.

U.S. Department of Agriculture. 1980. *CREAMS: A Field-Scale Model for Chemicals, Runoff and Erosion from Agricultural Management Systems*. ed. W.G. Knisel. USDA Conservation Research Report No. 26, USDA-Science and Education Administration.

U.S. Environmental Protection Agency. 1975. *A Compendium of Lake and Reservoir Data Collected by the National Eutrophication Survey in the Northeast and North-Central United States*. Working Paper No. 474.

Watts, D.G. and R.J. Hanks. 1978. "A Soil-Water-Nitrogen Model for Irrigated Corn on Sandy Soils." *Soil Science Society of America Journal* 42:492-499.

Williams, J.R., C.A. Jones, and P.T. Dyke. 1990. "The Epic Model." In *EPIC--Erosion/Productivity Impact Calculator, 1. Model Documentation*. ed. A.N. Sharpley and J.R. Williams. U.S. Department of Agriculture Technical Bulletin 1768.

Williams, J.R., A.D. Nicks and J.G. Arnold. 1985. "Simulator for Water Resources in Rural Basins." *ASCE Journal of Hydraulic Engineering* 111(6):970-986.

Wischmeier, W.H., C.B. Johnson, and B.V. Cross. 1971. "A Soil Erodibility Nomograph for Farmland and Construction Sites." *Journal of Soil and Water Conservation* 26:189-193.

Wischmeier, W.H. and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses-A Guide to Conservation Planning*. U.S. Department of Agriculture, Agriculture Handbook No. 537.

Young, R.A., C.A. Onstad, D.D. Bosch and W.P. Anderson. 1986. *Agricultural Nonpoint Source Pollution Model: A Watershed Analysis Tool.* Morris, MN: Agriculture Research Service, U.S. Department of Agriculture.

APPENDICES

APPENDIX A

DAILY INPUT DATA FOR MODEL VALIDATION

Julian Day	Precipitation (mm)	Runoff (mm)	Infiltration (mm)	Temperature (°C)	Sediment (kg/ha)
94	33.0	3.0	29.11	10.00	9.60
95	0.0	0.0	29.11	10.00	0.00
96	0.0	0.0	29.11	10.00	0.00
97	0.0	0.0	29.11	10.00	0.00
98	0.0	0.0	29.11	10.00	0.00
99	0.0	0.0	29.11	10.00	0.00
100	0.0	0.0	29.11	10.00	0.00
101	0.0	0.0	29.11	10.00	0.00
102	1.0	0.0	0.00	14.83	0.00
103	24.0	4.0	13.13	15.83	14.50
104	0.0	0.0	13.13	15.83	0.00
105	0.0	0.0	13.13	15.83	0.00
106	0.0	0.0	13.13	15.83	0.00
107	0.0	0.0	13.13	15.83	0.00
108	0.0	0.0	13.13	15.83	0.00
109	0.0	0.0	13.13	15.83	0.00
110	0.0	0.0	13.13	15.83	0.00
111	0.0	0.0	13.13	15.83	0.00
112	8.0	0.0	3.26	16.67	0.00
113	0.0	0.0	3.26	16.67	0.00
114	0.0	0.0	3.26	16.67	0.00
115	0.0	0.0	3.26	16.67	0.00
116	0.0	0.0	3.26	16.67	0.00
117	0.0	0.0	3.26	16.67	0.00
118	0.0	0.0	3.26	16.67	0.00
119	0.0	0.0	0.00	17.72	0.00
120	0.0	0.0	0.00	17.72	0.00
121	0.0	0.0	0.00	17.72	0.00
122	2.0	0.0	0.00	18.17	0.00
123	0.0	0.0	0.00	18.17	0.00
124	9.0	0.0	1.55	19.28	0.00
125	19.0	1.0	17.56	19.56	10.10
126	0.0	0.0	17.56	19.56	0.00
127	0.0	0.0	17.56	19.56	0.00
128	0.0	0.0	17.56	19.56	0.00
129	0.0	0.0	17.56	19.56	0.00

Julian Day	Precipitation (mm)	Runoff (mm)	Infiltration (mm)	Temperature (°C)	Sediment (kg/ha)
130	0.0	0.0	17.56	19.56	0.00
131	3.0	0.0	0.00	20.11	0.00
132	13.0	0.0	12.02	20.67	0.00
133	0.0	0.0	12.02	20.67	0.00
134	0.0	0.0	12.02	20.67	0.00
135	3.0	0.0	0.66	21.00	0.00
136	0.0	0.0	0.66	21.00	0.00
137	0.0	0.0	0.66	21.00	0.00
138	0.0	0.0	0.66	21.00	0.00
139	0.0	0.0	0.66	21.00	0.00
140	0.0	0.0	0.66	21.00	0.00
141	0.0	0.0	0.66	21.00	0.00
142	0.0	0.0	0.66	21.00	0.00
143	70.0	7.0	58.25	21.89	92.00
144	0.0	0.0	58.25	21.89	0.00
145	0.0	0.0	58.25	21.89	0.00
146	7.0	0.0	4.54	22.94	0.00
147	0.0	0.0	4.54	22.94	0.00
148	0.0	0.0	4.54	22.94	0.00
149	0.0	0.0	4.54	22.94	0.00
150	0.0	0.0	4.54	22.94	0.00
151	13.0	0.0	9.89	23.61	0.00
152	0.0	0.0	9.89	23.61	0.00
153	0.0	0.0	9.89	23.61	0.00
154	0.0	0.0	9.89	23.61	0.00
155	0.0	0.0	9.89	23.61	0.00
156	0.0	0.0	9.89	23.61	0.00
157	0.0	0.0	9.89	23.61	0.00
158	0.0	0.0	9.89	23.61	0.00
159	8.0	0.0	3.84	24.39	0.00
160	0.0	0.0	3.84	24.39	0.00
161	6.0	0.0	4.42	24.89	0.00
162	0.0	0.0	4.42	24.89	0.00
163	0.0	0.0	4.42	24.89	0.00
164	0.0	0.0	4.42	24.89	0.00
165	0.0	0.0	4.42	24.89	0.00
166	0.0	0.0	4.42	24.89	0.00
167	0.0	0.0	4.42	24.89	0.00
168	0.0	0.0	4.42	24.89	0.00
169	0.0	0.0	4.42	24.89	0.00
170	0.0	0.0	4.42	24.89	0.00
171	12.0	10.0	4.21	25.39	1.40
172	0.0	0.0	4.21	25.39	0.00
173	0.0	0.0	4.21	25.39	0.00
174	0.0	0.0	0.00	25.58	0.00
175	0.0	0.0	0.00	25.58	0.00
176	0.0	0.0	0.00	25.58	0.00

Julian Day	Precipitation (mm)	Runoff (mm)	Infiltration (mm)	Temperature (°C)	Sediment (kg/ha)
177	0.0	0.0	0.00	25.58	0.00
178	108.0	42.9	57.82	25.83	966.50
179	0.0	0.0	57.82	25.83	0.00
180	0.0	0.0	57.82	25.83	0.00
181	0.0	0.0	57.82	25.83	0.00
182	0.0	0.0	57.82	25.83	0.00
183	0.0	0.0	57.82	25.83	0.00
184	0.0	0.0	57.82	25.83	0.00
185	0.0	0.0	57.82	25.83	0.00
186	0.0	0.0	57.82	25.83	0.00
187	0.0	0.0	57.82	25.83	0.00
188	0.0	0.0	57.82	25.83	0.00
189	0.0	0.0	57.82	25.83	0.00
190	0.0	0.0	57.82	25.83	0.00
191	0.0	0.0	57.82	25.83	0.00
192	0.0	0.0	57.82	25.83	0.00
193	0.0	0.0	57.82	25.83	0.00
194	0.0	0.0	57.82	25.83	0.00
195	0.0	0.0	57.82	25.83	0.00
196	0.0	0.0	57.82	25.83	0.00
197	0.0	0.0	57.82	25.83	0.00
198	3.0	0.0	0.00	26.33	0.00
199	0.0	0.0	0.00	26.33	0.00
200	0.0	0.0	0.00	26.33	0.00
201	0.0	0.0	0.00	26.33	0.00
202	0.0	0.0	0.00	26.33	0.00
203	0.0	0.0	0.00	26.33	0.00
204	3.0	0.0	0.00	26.56	0.00
205	15.0	1.0	2.08	26.56	23.40
206	0.0	0.0	2.08	26.56	0.00
207	13.0	0.0	12.32	26.56	0.00
208	72.0	45.6	26.30	26.56	661.30
209	0.0	0.0	26.30	26.56	0.00
210	0.0	0.0	26.30	26.56	0.00
211	0.0	0.0	26.30	26.56	0.00
212	0.0	0.0	26.30	26.56	0.00
213	0.0	0.0	26.30	26.56	0.00
214	0.0	0.0	26.30	26.56	0.00
215	0.0	0.0	26.30	26.56	0.00
216	0.0	0.0	26.30	26.56	0.00
217	1.0	0.0	0.00	26.44	0.00
218	0.0	0.0	0.00	26.44	0.00
219	27.0	0.0	18.06	26.38	0.00
220	0.0	0.0	18.06	26.38	0.00
221	0.0	0.0	18.06	26.38	0.00
222	28.0	20.0	25.03	26.33	22.60

Julian Day	Precipitation (mm)	Runoff (mm)	Infiltration (mm)	Temperature (°C)	Sediment (kg/ha)
223	0.0	0.0	25.03	26.33	0.00
224	0.0	0.0	25.03	26.33	0.00
225	0.0	0.0	25.03	26.33	0.00
226	8.0	0.0	5.95	26.28	0.00
227	0.0	0.0	5.95	26.28	0.00
228	51.0	8.0	39.47	26.17	70.70
229	15.0	1.0	13.51	26.06	7.30
230	0.0	0.0	13.51	26.06	0.00
231	0.0	0.0	13.51	26.06	0.00
232	0.0	0.0	13.51	26.06	0.00
233	0.0	0.0	13.51	26.06	0.00
234	0.0	0.0	13.51	26.06	0.00
235	0.0	0.0	13.51	26.06	0.00
236	0.0	0.0	13.51	26.06	0.00
237	0.0	0.0	13.51	26.06	0.00
238	0.0	0.0	13.51	26.06	0.00
239	0.0	0.0	13.51	26.06	0.00
240	0.0	0.0	13.51	26.06	0.00
241	17.0	1.0	2.58	25.67	3.80
242	0.0	0.0	2.58	25.67	0.00
243	0.0	0.0	2.58	25.67	0.00
244	11.0	1.0	7.82	25.06	0.50
245	0.0	0.0	7.82	25.06	0.00
246	8.0	0.0	6.86	24.89	0.00
247	0.0	0.0	6.86	24.89	0.00
248	0.0	0.0	6.86	24.89	0.00
249	23.0	0.0	21.38	24.56	0.00
250	0.0	0.0	21.38	24.56	0.00
251	0.0	0.0	21.38	24.56	0.00
252	0.0	0.0	21.38	24.56	0.00
253	0.0	0.0	21.38	24.56	0.00
254	0.0	0.0	21.38	24.56	0.00
255	0.0	0.0	21.38	24.56	0.00
256	0.0	0.0	21.38	24.56	0.00
257	0.0	0.0	21.38	24.56	0.00
258	0.0	0.0	21.38	24.56	0.00
259	0.0	0.0	21.38	24.56	0.00
260	0.0	0.0	21.38	24.56	0.00
261	0.0	0.0	21.38	24.56	0.00
262	0.0	0.0	21.38	24.56	0.00
263	0.0	0.0	21.38	24.56	0.00
264	0.0	0.0	21.38	24.56	0.00
265	0.0	0.0	21.38	24.56	0.00
266	0.0	0.0	21.38	24.56	0.00
267	0.0	0.0	21.38	24.56	0.00
268	4.0	0.0	0.00	22.78	0.00

Julian Day	Precipitation (mm)	Runoff (mm)	Infiltration (mm)	Temperature (°C)	Sediment (kg/ha)
269	0.0	0.0	0.00	22.78	0.00
270	0.0	0.0	0.00	22.78	0.00
271	0.0	0.0	0.00	22.78	0.00
272	0.0	0.0	0.00	22.78	0.00
273	0.0	0.0	0.00	22.78	0.00
274	0.0	0.0	0.00	22.78	0.00
275	0.0	0.0	0.00	22.78	0.00
276	0.0	0.0	0.00	22.78	0.00
277	0.0	0.0	0.00	22.78	0.00
278	0.0	0.0	0.00	22.78	0.00
279	0.0	0.0	0.00	22.78	0.00
280	0.0	0.0	0.00	22.78	0.00
281	0.0	0.0	0.00	22.78	0.00
282	0.0	0.0	0.00	22.78	0.00
283	0.0	0.0	0.00	22.78	0.00
284	0.0	0.0	0.00	22.78	0.00
285	0.0	0.0	0.00	22.78	0.00
286	0.0	0.0	0.00	22.78	0.00
287	0.0	0.0	0.00	22.78	0.00
288	0.0	0.0	0.00	22.78	0.00
289	9.0	0.0	0.00	18.61	0.00

APPENDIX B

FORTRAN CODE FOR MODEL

```
C     PROGRAM NITROG5b  --- 3/4/96 --
C
C
      REAL MO, FC, PO, OC, NOA, WNO3, CR, NORG,pr, Q, F, temp,SWC, AE
     +    ,NH4M, NA, NO3D,QNO3, NSED,FPS, FFPS,NH4A,NO3A,cn2,pet
c
      real nf,nq,np1,np2,cf(20),dcf(20),cval,sl,length,kf,pf,ds,slp
c
      real leap1, modlat(12)
c
      INTEGER NEV, I, T, day, date, leap2,month(0:12)
c
      INTEGER begin,end,ncf
c
      character infile1*13,infile2*13
C
c     initialize months in Julian days
c
      month(0) = 0
      month(1) = 31
      month(2) = 59
      month(3) = 90
      month(4) = 120
      month(5) = 151
      month(6) =181
      month(7) = 212
      month(8) = 243
      month(9) = 273
      month(10) = 304
      month(11) = 334
      month(12) = 365
c
c     open input file
c
```

```
      OPEN (UNIT = 1,FILE = 'nitrog5b.fil',STATUS = 'OLD')
      read(1,701) infile1,infile2
 701  format(2A13)
c
c     open output files
      OPEN (UNIT = 6,FILE = infile1, STATUS = 'UNKNOWN')
      OPEN (UNIT = 7,FILE = infile2, STATUS = 'UNKNOWN')
c
      write(6,*) '--- INPUT DATA ---'
C
C     NEV IS THE NUMBER OF EVENTS
c
      READ (1,*) NEV
c
C       MO IS THE AMOUNT OF MINERALIZABLE N (KG/HA), FC IS THE FIELD
C       CAPACITY (mm/mm), PO IS THE SOIL POROSITY(mm/mm), OC IS THE
C       % SOIL ORGANIC CARBON, CN2 is the curve number for antecedent
c      moisture condition II, and SWC is the soil water content (cm)
c
      READ (1,*) MO, FC, PO, OC,cn2,swc
c
c     sl is the field slope (%), length is the slope length (m), kf
c     is the USLE K factor, and pf is the USLE P factor.
c
      read (1,*) sl,length,kf,pf,ds,slp
c
      write(6,*)
      write(6,711) FC,PO,OC,CN2,swc
 711  format('Field Capacity = ',f5.2,/,
     *        'Porosity      = ',f5.2,/,
     *        '% Organic C   = ',f5.2,/,
     *        'CN2           = ',f5.2,/,
     *        'Initial SW    = ',f5.2)
c
C       NOA IS THE AMOUNT OF NH4 SUBJECT TO NITRIFICATION (KG/HA),
WNO3 IS
C       THE WEIGHT OF NO3 IN THE SOIL (KG/HA), CR IS THE NO3
CONCENTRATION
C       IN THE RAINFALL (ppm), NORG IS THE SEDIMENT BOUND N (KG/KG)
AND
C       skn35 is the nitrification rate constant at 35 Degrees C
c
      READ (1,*) NOA, WNO3, CR, NORG,skn35
      write(6,*)
      write(6,715) MO, NOA, WNO3, NORG,skn35
```

```
715  format('MO   (kg/ha)    =',f7.2,/,
   *      'NOA  (kg/ha)    =',f7.2,/,
   *      'WNO3 (kg/ha)    =',f7.2,/,
   *      'NORG (Kg/Kg)    =',f10.5,/,
   *      'Kn35 (1/day)    =',f10.5)
      write(6,*)
C
C     nf is the N extraction coefficient for infiltration, nq is the N
c     extraction coefficient for runoff, np1 and np2 are N enrichment
c     ratio constants.
c
      read(1,*) nf,nq,np1,np2
      write(6,720) nf,nq,np1,np2,slp,ds
 720  format('N Extraction coefficients',/,
   *       '    infiltration = ',f6.3,/,
   *       '    runoff       = ',f6.3,/,
   *       'N Enrichment Ratio Constants: ln(NER)=a+b*ln(A)',/,
   *       '    a=',f6.3,/,
   *       '    b=',f6.3,/,
   *       'Land Slope (m/m) = ',f6.3,/,
   *       'Distance To Stream (m) =',f6.3,///)
c
      write(6,*) '---- OUTPUT ----'
      write(6,*)
      write(6,*) 'day,rain,cn,runoff,sed,swc,infilt.,qno3,nsed'
      write(7,*) 't,qno3,nh4m,no3d,nsed,mo,noa,wno3'
c
c     date is the year at the start of the simulation, day is the first
c     day of the simulation (julian days), begin and end are the beginning
c     and end of the growing season (julian days)
c
      read(1,*) date,day,begin,end
c
c     modlat are the modifying factors for evapotranspiration.
c
      read(1,*) (modlat(kk),kk=1,12)
c
c     ncf, dcf and cf are factors for the USLE C factor.
c
      read(1,*) ncf,(dcf(kk),cf(kk),kk=1,ncf)
c
c     START THE SIMULATION
c
      DO 100 I = 1,NEV
C
```

```
C   T IS THE TIME PERIOD (DAYS), R IS THE RAINFALL (mm), Q IS THE
RUNOFF
C   (cm), F IS THE INFILTRATION (cm), Temp IS THE SOIL TEMPERATURE (C),
C   swc IS THE SOIL WATER CONTENT (cm), AND AE IS THE
SEDIMENT(KG/HA)
C   d0,d1, and d2 are test parameters

    READ (1,*) T, PR, d0, d1, Temp, d2, ae, NH4A,NO3A
c
c   change pr from mm to cm
c
    pr=pr/10
C
C
C   THE YEAR IS CHECKED TO DETERMINE IF IT IS A LEAP YEAR
        leapset = 0
        LEAP1 = DATE/4.0
        LEAP2 = DATE/4
        IF (LEAP1 .EQ. LEAP2) leapset=1
c
C   RUNOFF COMPONENT
C
C   IF THERE IS RAINFALL THEN WE ASSUME THERE IS NO
EVAPOTRANSPIRATION
C   AND THE PROGRAM COMPUTES RUNOFF. IF THERE IS NO RAINFALL
THEN
C   WE ASSUME THERE IS WATER LOSS ONLY THROUGH
EVAPOTRANSPIRATION.
C
        IF (PR .GT. 0) THEN
c
C       CALCULATE THE RUNOFF; EVAPOTRANSPIRATION IS ZERO
c
          CALL RUNOFF (DAY,PR,CN2,CN,Q,begin,end)
          PET = 0
        ELSE
c
c   calculate evapotranspiration; runoff is zero
c
          CALL EVAPTRAN(month,modlat,DAY,TEMP,PET,leapset)
          Q = 0
        ENDIF
C
C   SOIL WATER BALANCE
C
```

```
        SWC = SWC + pr - Q - PET
        F = SWC - FC
        IF (F .LE. 0) THEN
          F = 0
          IF(SWC .LE. 0) THEN
           SWC = 0
          ENDIF
        ENDIF
        IF (F .GT. 0) THEN
        SWC = FC
        ENDIF
         YEARQ = YEARQ + Q
         RAIN = RAIN + pr
c
c    SEDIMENT COMPONENT
c
c    If there is runoff then calculate erosion losses.
c
      if (q .gt. 0) then
       call ccalc(day,cf,dcf,ncf,cval)
       call sediment(pr,sl,length,kf,cval,pf,ae)
      else
c
c    if there is no runoff sediment is zero.
c
      ae = 0
      endif
C
c    NITROGEN COMPONENT
C
c    FFPS is a function of soil water content in nitrogen transformations
c
      FPS = SWC / PO
      IF (FPS .GE. 0 .AND. FPS .LT. 0.9)THEN
           FFPS = 1.111 * FPS
      ELSE
           FFPS = 10 - 10*FPS
      ENDIF
C
c   Begin Nitrogen Transformations
c
C    mineralization
      CALL NMIN (T,Temp,MO,FFPS,NH4M)
C
c   nitrification
```

```
      CALL NNIT (T,Temp,FFPS,NOA,NA,skn35)
C
c     denitrification
      CALL NDENIT (T,Temp,OC,WNO3,NO3D)
C
c     nitrogen balance
      MO = MO - NH4M
      NOA = NOA + NH4M + NH4A- NA
      WNO3 = WNO3 + NA + NO3A - NO3D
C
c     nitrogen loss with runoff
c
c     if there is runoff, calculate nitrogen loss with runoff
c
      IF (Q .GT. 0) THEN
       CALL NRUN (F,Q, PO, WNO3, CR, QNO3,nf,nq)
      ELSE
c
c      if there is no runoff there is no nitrogen loss with runoff.
c
       QNO3 = 0
      ENDIF
c
C      nitrogen loss with sediment
c
c     if there is sediment loss, calculate nitrogen loss with sediment.
c
      IF (AE .GT. 0) THEN
       CALL NSEDIM (NORG, AE, NSED,slp,ds,np1,np2)
      ELSE
c
c      if there is no sediment loss there is no nitrogen loss with sediment.
c
       NSED = 0
      ENDIF
c
c      OUTPUT
c
      if(pr.gt.0) then
       write(6,15) day,pr,cn,q,ae,swc,f,qno3,nsed
       WRITE (7,15) T, QNO3, NH4M, NO3D, NSED, MO, NOA, WNO3
   15  FORMAT (I3, 8F9.4,)
      endif
C
C       GO TO NEXT DAY
```

```
C
    day=day+1
c
 100 CONTINUE
C
    STOP
    END
C
c
c
    SUBROUTINE RUNOFF (DAY,PR, CN2,CN,Q,begin,end)
C
C   THIS SUBROUTINE CALCULATES RUNOFF USING THE SCS CURVE
NUMBER
C   METHOD.
C
    REAL CN2,CN,pr
    INTEGER DAY
    REAL F1, F2, W1, W2, W3,S, CN1, CN3
    INTEGER BEGIN, END
C
C   CALCULATE THE CURVE NUMBERS FOR ANTECEDENT MOISTURE
CONDITIONS 1 AND 3.
C
    CN1 = CN2 - ((20*(100-CN2))/(100 - CN2 + EXP(2.533 - 0.0636*
   +         (100 - CN2))))
C
    CN3 = CN2 * EXP( 0.00673 * (100 - CN2))
C
C   IF IT IS A LEAP YEAR THE GROWING SEASON STARTS ONE DAY LATER.
C
    IF (DAY .GT. BEGIN .AND. DAY .LT. END) THEN
        F1 = 3.5
        F2 = 5.25
    ELSE
        F1 = 1.25
        F2 = 2.75
    ENDIF
C
C   THE 5 DAY ANTECEDENT MOISTURE CONDITION IS CALCULATED TO
DETERMINE
C   THE WEIGHTS USED FOR THE AVERAGE CURVE NUMBER.
C
    IF (pr .LE. F1) THEN
        w1=1
```

```
         w2=0
         w3=0
      else if (f1 .gt. pr .and. pr .le. f2) then
         w1=f1/pr
         w2=(pr-f1)/pr
         w3=0
      else if (pr .gt. f2) then
         w1=f1/pr
         w2=(f2-f1)/pr
         w3=(pr-f2)/pr
      endif
C
C
C     THE WEIGHTED CURVE NUMBER IS CALCULATED.
C
   25 CN = W1 * CN1 + W2 * CN2 + W3 * CN3
C
C     THE S FACTOR IS CALCULATED USING THE AVERAGE CURVE NUMBER.
C
      S = 2540/CN - 25.4
C
C     IF RAINFALL IS LESS THAN .2S THAN THERE IS NO RUNOFF.  IF
C     RAINFALL IS GREATER THAN .2S THAN RUNOFF IS CALCULATED.
         IF (pr .GE. .2*S) THEN
         Q = ((pr - 0.2*S)**2)/(pr + 0.8 * S)
         ELSE
         Q = 0
         ENDIF
C
      RETURN
       END
C
c

      SUBROUTINE EVAPTRAN(month,modlat,DAY,TEMP,PET,leapset)
      REAL modlat(12),mf,temp,PET
      INTEGER DAY,z,md0,md1,month(0:12)
C
      do 400 z = 1,12
         md0=month(z-1)
         md1=month(z)
c
c     adjust for leap year
c
         if(z.gt.1.and.leapset.eq.1) md1=md1+1
```

```
      if(z.gt.2.and.leapset.eq.1) md0=md0+1
c
      if(day.gt.md0.and.day.le.md1) then
c
c  the daily modifying factor is equal to the monthly modifying factor
c  divided by the number of days in the month.
c
       mf=modlat(z)/(md1-md0)
       go to 401
      endif
 400 continue
 401 continue
   PET = (TEMP * MF)/10
   RETURN
   END
C
c
c
   SUBROUTINE CCALC (day,cf,dcf,ncf,cval)
C
C   CCALC CALCULATES THE USLE COVER FACTOR.  THE COVER FACTOR
IS KNOWN
C   AT SEVERAL DAYS DURING THE YEAR AND IS LINEARLY
INTERPOLATED FOR
C   THE OTHERS.  SUBROUTINE SLOPE IS USED TO DO THE LINEAR
INTERPOLATION.
C
   REAL Cf(20),dcf(20),cval,y1,y2
   INTEGER DAY,ncf

   INTEGER X1,X2
C
      do 20 j = 2,ncf
       if (day.gt.dcf(j-1).and.day.le.dcf(j))then
            x1 = dcf(j-1)
            x2 = dcf(j)
            y1 = cf(j-1)
            y2 = cf(j)
       call slope (x1,x2,y1,y2,day,cval)
       goto 21
      endif
  20 continue
  21 continue
   RETURN
   END
```

```
C
C
   SUBROUTINE SLOPE (X1,X2,Y1,Y2, DAY,CVAL)
C
C   THIS SUBROUTINE DOES SIMPLE LINEAR INTERPOLATION BETWEEN
TWO POINTS.
C
   REAL Y1,Y2,CVAL
   INTEGER X1,X2,DAY
   REAL LINESL
C
   LINESL = (Y2 - Y1)/(X2 - X1)
   CVAL = LINESL * (DAY - X1) + Y1
   RETURN
   END
C
C
   SUBROUTINE SEDIMENT (pr,sl,length,k,c,p,ae)
C
C   SEDIMENT CALCULATES THE DAILY SEDIMENT LOSS USING THE USLE.
C
      REAL PR,SL,K,C,P,LENGTH,R,L,S,AE
C     REAL THETA,BETA,xm
C
C     R IS THE USLE RAINFALL FACTOR
      R = 17.90 * .268794682 * (PR / 2.54)**2.178
C
      THETA = ATAN(SL/100)
      BETA = (11.16 * SIN(THETA))/(3.0 * SIN(THETA)**0.8 + 0.56)
      xm = BETA/(1 + BETA)
C     L IS THE USLE SLOPE LENGTH FACTOR.
      L = (LENGTH/22.1)**xm
C
C     S IS THE USLE SLOPING FACTOR
C
      IF (LENGTH .LT. 4) THEN
        S = 3.0 * (SIN(THETA))**0.8 + 0.56
      ELSE IF (LENGTH .GE. 4 .AND. SL .LT. 9) THEN
        S = 10.8 * SIN(THETA) + 0.03
      ELSE
        S= 16.8 * SIN(THETA) - 0.50
      ENDIF
C
C     AE IS THE DAILY SEDIMENT LOSS (kg-ha)
      AE = 2240 * R * K * L * S * C * P
```

```
C
        RETURN
      END

C
      SUBROUTINE NMIN(T,Ts,MO,FFPS,NH4M)
C
      REAL TS,MO,FFPS
      INTEGER T
      REAL KM,NH4M,TEMP

C
C   KM IS THE TRANSFORMATION RATE IN (1/HR)
      TEMP = TS
      IF (TS .GT. 35.0) THEN
       TS = 35.0
      ENDIF
C
      KM = (EXP((17.753) - (6350.5/(TS +273)))) / (168.00)
C
C   NH4M IS THE MINERALIZED AMMONIUM (KG/HA)
      NH4M = MO * (1 - EXP(-KM * T * 24)) * FFPS
C
      TS = TEMP
      RETURN
      END
C
C
C
      SUBROUTINE NNIT (T,TS,FFPS,NOA,NA,skn35)
C
C
      REAL TS,FFPS,NOA,NA
      INTEGER T
      REAL  sKN35, KN

C
C    SKN35 IS THE NITRIFICATION RATE CONSTANT AT 35 C (DAY^-1)
C
C    KN IS THE NITRIFICATION RATE CONSTANT AT TS (DAY^-1)
C
       IF (TS .LT. 0) THEN
          KN = 0
       ELSEIF (TS .GE. 0 .AND. TS .LT. 10) THEN
          KN = (0.0105 * TS + 0.00095*TS**2) * sKN35
```

```
      ELSEIF (TS .GE. 10 .AND. TS .LE. 35) THEN
         KN = (0.032 * TS - 0.12) * sKN35
      ELSEIF (TS .GT. 35 .AND. TS .LT. 45) THEN
         KN = (-0.1 * TS + 4.5) * sKN35
      ELSE
         KN = 0
      ENDIF
C
C    NA IS THE AMOUNT OF NH4 CONVERTED TO NH3- IN TIME T
      NA = (NOA * (1 - EXP(-KN * T))) * FFPS
C    RETURN
      END
C
C
C
      SUBROUTINE NDENIT (T,TS,OC,WNO3,NO3D)
C
C
      REAL TS,OC,WNO3,NO3D
      INTEGER T
      REAL DKT
C
C    DKT IS THE DENITRIFICATION RATE (1/DAY)
      dk = 0.264 * oc * 10+ 0.06
      db = log(dk)-2.4255
      DKT = EXP(0.0693 * TS + db)
C
c    write(*,*) ts, oc,dk,db,dkt
C    NO3D IS THE DENITRIFIED N (KG/HA)
      NO3D = WNO3 * (1 - EXP(-DKT * T))
C    RETURN
      END
C
C
C
      SUBROUTINE NRUN (F,Q,PO,WNO3,CR,QNO3,nf,nq)
C
      REAL F,Q,CO,CR,NF,NQ,B,KF,KQ,CE,MEANC,CQ,WNO3,PO,QNO3
C
C
C    CO IS THE INITIAL NITRATE CONCENTRATION IN THE SOIL SURFACE
C    LAYER(g/m^3)
C
      CO = (WNO3 / PO) * 10
C
```

```
C   KF IS THE RATE CONSTANT FOR DOWNWARD MOVEMENT
    KF = NF/(1*PO)
C   KQ IS THE RATE CONSTANT FOR MOVEMENT INTO RUNOFF
    KQ = NQ/(1*PO)
C
    B = (F*KF) + (Q*KQ)
C    CE IS THE NITRATE CONCENTRATION AT THE END OF THE TIME
INTERVAL
    CE = CR + (CO - CR) * (EXP(-B))
C
C    MEANC IS THE MEAN CONCENTRATION OF NITRATE IN INFILTRATION
AND
C    RUNOFF
    MEANC = CR + ((1/B)*(CO - CR) * (1 - EXP(-B)))
C
C    CQ IS THE CONCENTRATION OF SOLUABLE NUTRIENT IN THE RUNOFF
    CQ = CR + .075*(MEANC - CR)
C    CALCULATE THE WEIGHT OF NO3-N IN RUNOFF, QNO3(KG/HA)
    QNO3 = CQ * Q * 0.10
C
C    CALCULATE THE WEIGHT OF NO3-N IN THE SOIL AFTER THE
STORM,WNO3 (KG/HA)
    WNO3 = (CE * PO)/10
C   RETURN
    END
C
C
C
    SUBROUTINE NSEDIM (NORG,AE, NSED,slp,ds,np1,np2)
C
C   PROGRAM TO CALCULATE NITROGEN LOSS WITH SEDIMENT, NSED
C
    REAL NSED,NORG,AE,NER, DR, ds,SLP,SF,np1,np2

C
C   NER IS THE ENRICHMENT RATIO
    NER = EXP(NP1 + NP2*(LOG(AE)))
C
C   SLP IS THE SLOPE (M/M)
C
C   SF IS A FUNCTION OF THE SLOPE
    SF = 0.6 + EXP (-16.1 * (SLP + 0.057))
C
C   DS IS THE DISTANCE TO THE OUTLET (M)
C
```

```
C   DR IS THE DELIVERY RATIO
    DR = EXP(-0.0161 * DS * SF)
C
C   NSED IS NITROGEN LOSS WITH SEDIMENT (KG/HA)
    NSED = NORG * AE * NER * DR
C   RETURN
    END
```

APPENDIX C

MODEL INPUT FILE

```
nitrog5b.out nitrog5b.prn
196                              nev
47 0.2 0.45 0.38,75,.2           mo,fc,po,oc,cn2,swc
.1,48.15,.23,1,0,.1              sl,length,kf,pf,ds,slp
47 0.2 0.8 0.00035,.9            noa,wno3,cr,norg(kg/kg),skn35
.25,.075,2.82,-.16               NF,NQ,NP1,NP2
1974,94,113,302                  date,day,begin,end
.893,1.106,1.746,2.272,2.272,2.983,2.983,2.572,1.930,1.420,.953,.805
10,1,.30,114,.30,115,.52,145,.43,176,.37,237,.24,268,.20,302,.20,303,.23,365,.23
1   33.0  3.0  29.11  10.00  0.200  9.6   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   0.0   0.0  29.11  10.00  0.200  0.0   00.0  00.0
1   1.0   0.0  00.00  14.83  0.195  0.0   00.0  00.0
1   24.0  4.0  13.13  15.83  0.192  14.5  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  0.0   00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  0.0   00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   0.0   0.0  13.13  15.83  0.192  00.0  00.0  00.0
1   8.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  3.26   16.67  0.197  0.0   00.0  00.0
1   0.0   0.0  0.00   17.72  0.196  0.0   1.90  1.90
```

APPENDIX D

SAMPLE OUTPUT FILE

--- INPUT DATA ---

Field Capacity = .20
Porosity = .45
% Organic C = .38
CN2 = 75.00
Initial SW = .20

MO (kg/ha) = 47.00
NOA (kg/ha) = 47.00
WNO3 (kg/ha) = .20
NORG (Kg/Kg) = .00035
Kn35 (1/day) = .04000

N Extraction coefficients
infiltration = .250
runoff = .075
N Enrichment Ratio Constants: ln(NER)=a+b*ln(A)
a= 2.820
b= -.160
Land Slope (m/m) = .100
Distance To Stream (m) = .000

---- OUTPUT ----

day,rain,cn,runoff,sed,swc,infilt.,qno3,nsed

94	3.3000	70.4203	.1149	54.4627	.2000	3.1851	.0120	.1687
102	.1000	56.8628	.0000	.0000	.1000	.0000	.0000	.0000
103	2.4000	56.8628	.0000	.0000	.2000	2.3000	.0000	.0000
112	.8000	56.8628	.0000	.0000	.2000	.6000	.0000	.0000
122	.2000	56.8628	.0000	.0000	.2000	.0000	.0000	.0000
124	.9000	56.8628	.0000	.0000	.2000	.7668	.0000	.0000

125	1.9000	56.8628	.0000	.0000	.2000	1.9000	.0000	.0000
131	.3000	56.8628	.0000	.0000	.2000	.1000	.0000	.0000
132	1.3000	56.8628	.0000	.0000	.2000	1.3000	.0000	.0000
135	.3000	56.8628	.0000	.0000	.2000	.1000	.0000	.0000
143	7.0000	69.3670	1.4164	407.1597	.2000	5.3836	.1491	.9141
146	.7000	56.8628	.0000	.0000	.2000	.5000	.0000	.0000
151	1.3000	56.8628	.0000	.0000	.2000	1.1000	.0000	.0000
159	.8000	56.8628	.0000	.0000	.2000	.6000	.0000	.0000
161	.6000	56.8628	.0000	.0000	.2000	.4000	.0000	.0000
171	1.2000	56.8628	.0000	.0000	.2000	1.0000	.0000	.0000
178	10.8000	76.1843	4.9475	878.2565	.2000	5.6525	1.7776	1.7435
198	.3000	56.8628	.0000	.0000	.2000	.1000	.0000	.0000
204	.3000	56.8628	.0000	.0000	.2000	.1000	.0000	.0000
205	1.5000	56.8628	.0000	.0000	.2000	1.5000	.0000	.0000
207	1.3000	56.8628	.0000	.0000	.2000	1.1000	.0000	.0000
208	7.2000	69.9052	1.5758	299.6738	.2000	5.6242	.2932	.7066
217	.1000	56.8628	.0000	.0000	.1000	.0000	.0000	.0000
219	2.7000	56.8628	.0000	.0000	.2000	2.5000	.0000	.0000
222	2.8000	56.8628	.0000	.0000	.2000	2.6000	.0000	.0000
226	.8000	56.8628	.0000	.0000	.2000	.6000	.0000	.0000
228	5.1000	56.8628	.0757	121.4352	.2000	4.8243	.0127	.3308
229	1.5000	56.8628	.0000	.0000	.2000	1.5000	.0000	.0000
241	1.7000	56.8628	.0000	.0000	.2000	1.5000	.0000	.0000
244	1.1000	56.8628	.0000	.0000	.2000	.9000	.0000	.0000
246	.8000	56.8628	.0000	.0000	.2000	.6388	.0000	.0000
249	2.3000	56.8628	.0000	.0000	.2000	2.1000	.0000	.0000
268	.4000	56.8628	.0000	.0000	.2000	.2000	.0000	.0000
289	.9000	56.8628	.0000	.0000	.2000	.7000	.0000	.0000

VITA

Patricia Haan

Candidate for the Degree of

Master of Science

Thesis: A SIMPLIFIED NITROGEN MODEL FOR SURFACE RUNOFF

Major Field: Biosystems Engineering

Biographical:

Education: Graduated from Stillwater High School, Stillwater, Oklahoma in May 1986; received Bachelor of Science degree in Business Management from Oklahoma State University, Stillwater, Oklahoma in May 1992. Completed the requirements for the Master of Science degree with a major in Biosystems and Agricultural Engineering at Oklahoma State University in July 1996.

Experience: Employed at Caravan Books, Stillwater, Oklahoma from May 1988 to May 1994; employed by Oklahoma State University, Department of Biosystems and Agricultural Engineering as graduate research and teaching assistant, May 1992 to present.

Honorary Societies: Tau Beta Pi, Gamma Sigma Delta, Phi Kappa Phi, Alpha Epsilon.