To the Graduate Council:

I am submitting herewith a thesis written by Diane Rios Erb entitled "Estimating Nonpoint Source Pollution Loading From Animal Wastes". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Engineering Science.

Jack H. Hansen

Jack Hansen, Major Professor

We have read this thesis and recommend its acceptance:

Charles T. N. Paludan

Basil N. Antar

Accepted for the Council:

C W Minkel

Associate Vice Chancellor and Dean of The Graduate School

Estimating Nonpoint Source Pollution Loading From Animal Wastes

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Diane Rios Erb

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DEDICATION

This thesis is dedicated to my beautiful and loving mother, Estela Lewis, who always believed in me and who always encouraged me to pursue all that life has to offers.

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Most importantly, I'd like to acknowledge my Father in Heaven, who is the strength in my heart and only through him, are all things are possible.

ABSTRACT

Water is valuable because of its many uses. As the quality of water degrades, so does its value and usefulness. For this study, the water quality impacts from livestock wastes and grazing activities are estimated. A hydrologic model, Soil and Water Assessment Tool, is used to estimate the pollution loading from a watershed. The Big Shoal Creek watershed located in Alabama is selected as the study area. The analysis consists of simulating the sediment and nutrient impacts from four pastureland conditions; pastureland only, the application of animal wastes (manure), and grazing activities for 180 days and 365 days. The study clearly demonstrated the large increases in pollution loading due to animal wastes. The addition of grazing activities increased the pollutant loads to over 100% as compared to manure additions only. However, the pollutant loads were significantly reduced during controlled grazing operations (180 days) as compared to unmanaged grazing operations (365 days).

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CHAPTER I

INTRODUCTION

The cholera epidemic of 1854 in London, England firmly established the relationship between polluted water and diseases. (Henry et al, 1989) The protection of public health was then set as the primary purpose of water pollution control. After World War II, dramatic increases in urban population and industrialization came about and water pollution problems intensified across the world. Today, nations in North America and across the world are cooperating with each other to improve water quality. Since the 1970's, the United States (US) and Canada have agreed to reduce the discharge of contaminants to the Great Lakes. For most of the last decade, the US has been constructing one of the world's largest water treatment plants to reduce pollutants in the Colorado River before it enters Mexico. Similarly, European nations in the Rhine River watershed have agreed to reduce the discharge of pollutants into the river.

Even with these national efforts to improve water quality, there is still a lot of work to be done to restore and maintain the nation's lakes, rivers, and streams. Water pollutants come from many sources and these sources must first be identified and understood in order to begin restoration processes.

Water pollutants can be categorized into eight types: 1) physical pollutants are any materials that settle in the bottom of a lake or stream and cut off the transfer of food or oxygen between organisms; 2) organic pollutants consist of organic matter which degrades in water, consumes oxygen and can lead to eutrophication; 3) inorganic pollutants are inorganic nutrients that promote aquatic life and can cause foul odors and/or eutrophication; 4) bacterial pollutants are pathogenic organisms from animal and human wastes; 5) thermal pollutants are process waters that are heated by a process and then dumped into the waters; thermal pollutants change the ecology and adversely affect aquatic organisms; 6) radioactive pollutants (radioactive wastes) are a potential source of radiation exposure to aquatic organisms and humans; 7) oil pollutants such as oil spills are toxic to marine organisms. Finally, aesthetic pollutants involve anything which looks bad to the general public. (Dalrymple, 1972)

Sources of water pollutants are generally classified as either point sources or nonpoint sources. Point sources of pollution include the end of discharge pipes, outfalls, liquid-waste injection wells, or any other recognizable origin of contaminants. Nonpoint sources of pollution implies that the origin of the pollutants can not be traced to a particular point. For example, runoff from the land and animal wastes are nonpoint sources of pollution.

Water Quality Problems from Nonpoint Sources

Modern agriculture has been recognized as a major source of water pollution. The water quality of streams and rivers has been adversely affected by eroded soil, sediments, pesticides, fertilizers, and agricultural animal wastes. In 1990, the Environmental Protection Agency's (EPA) national water quality report stated that agriculture was the most widespread nonpoint source of pollution. (US EPA, 1990)

Sedimentation and soil erosion is a natural geologic process. It is the acceleration of these processes by human activities that causes water quality problems. Major concerns for sediment related problems are: habitat alteration and contamination of aquatic life; filling of watercourses and reservoirs; increased costs and complex treatment systems for municipalities and industries; and a diminished recreational value of water. Agricultural lands and livestock grazing in particular, contribute significant amounts of sediment to surface waters. Furthermore, agricultural lands erode at an average annual rate of 20 tons/ha, twice the rate considered acceptable by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS). (Duttweiler et al, 1983)

Pesticides were introduced in the 1940s and water quality problems due to pesticides appeared shortly afterwards. Soon, farmers noticed sudden death of their farm pond fish following rains that caused runoff from treated croplands. Fish kills were also apparent in nearby streams and rivers. By the 1950s, the effects of pesticides were being researched by the USDA and the Public Health Service. Runoff from agricultural lands was shown to be the major source for polluting surface waters.

The first nitrogen (N) fertilizers were introduced in the US in the 1920's. As agriculture reached an unprecedented productivity in 1977, over 900 million tons of N fertilizer was being applied annually. (Duttweiler et al, 1983) Nitrogen and Phosphorous (P) are the major nutrients in fertilizers and are also the main contaminants. Since only a relatively small amount of N and P are required to produce normal flora and fauna, excess amounts of these nutrients create large growths of algae and aquatic weeds. These growths can restrict navigation, produce undesirable tastes and odors in water supplies, and deplete the dissolved oxygen content and cause fish kills. Excessive nitrate (NO_3^-) levels contaminate groundwater to toxic levels and harm animals and humans.

With the advent of cheap chemical fertilizers, the use of animal wastes as a fertilizer declined. Confined livestock production in feedlots and poultry houses grew. Soon the accumulation of huge amounts of wastes for disposal became a problem. It has been estimated that the farm animal population in the US is over three times that of the human population, and the manure generated is more than ten times that of human wastes. (Dalrymple, 1972)

Agricultural animal wastes adversely impact watercourses by affecting the surface water quality and the groundwater. The initial signal of the impacts came when a series of dramatic fishkills downstream of concentrated cattle in the Midwest appeared. The fishkills were reported in rural areas remote from traditional industrial waste discharges. The rivers were noted to be depleted of dissolved oxygen, high in dissolved ammonia, black in color, and emitting a strong odor characteristic of decomposing cattle manure. After investigating upstream, a cattle feedlot alongside a major tributary was found to be contributing manure laden runoff. (Overcash et al, 1983) Contamination from animal wastes had so significantly affected so many watercourses that it became necessary to subject large modern feedlots with thousands of animals to pollution control regulations like other major industries. Discharges from these feedlots must now meet EPA water quality criteria as summarized in Table 1.1.

Water Quality Legislation

With the continued population increases and the associated increasing demands for products and services, the measurement and assessment of water quality has become the norm to our society. Water pollution control has also evolved into a complex process where regulatory controls range from best management practices (BMP's) to fines and surcharges. Concern over nonpoint source water pollution reached a peak in the mid-1970's as several water acts and environmental laws were passed. At the same time,

Table 1.1: Water Quality Criteria.

Nitrate (NO_3)	For health reasons domestic water supplies should not have nitrate nitrate concentrations exceeding 10 mg/l.
Nitrite (NO_2)	For health reasons domestic water supplies to be used by infants should not have nitrite concentrations exceeding 1 mg/l.
Phosphorous	For aesthetic purposes, phosphorus concentrations in excess of 0.10 μg/l (0.0001 mg/l) are associated with accelerated eutrophication.
Solids and turbidity	For freshwater fish and other aquatic life, settleable and suspended solids should not reduce the depth of the zone of photosynthetic. oxygen production by more than 10 % from the seasonally established norm.

Source: US EPA. 1986. Quality criteria for water. EPA 440/5-86-001, Wash., DC.

Canada, Great Britain, Europe, Japan and other industrialized countries developed legislation to deal with their water quality problems.

Federal legislation for water quality began with the Rivers and Harbors Act of 1886 and 1889. By 1970, a national policy of prevention, control, and abatement of water pollution was set. In 1972, the Federal Water Pollution Control Act, Public Law 92-500, was passed to hasten the implementation of water pollution control. The Federal role increased as standards were established and enforcement was utilized. The goal was to restore the physical, chemical, and biological integrity of the Nation's water. (USDA SCS, 1992) In 1977, the Clean Water Act, Public Law 95-217, amended the 1972 Act to allow for more easily attainable objectives and schedules. Section 208 called for comprehensive state and local area plans which emphasized nonpoint sources. The amendment also authorized long-term federal financial support for farmers who installed and maintained BMP's to control agricultural nonpoint source pollution under an approved Section 208 plan.

Although legislation for years has required animal waste treatment and disposal plans by animal waste producers, unconfined animal systems have been overlooked. Over 75% of the beef cattle in the US are in unconfined systems. Farmers that have less than 1,000 cows are not regulated and thus are not required to maintain managed livestock operations. Water quality problems arise when large numbers of these animals graze in close proximity to watercourses.

Objective

The purpose of this thesis is to estimate the water quality impacts from livestock wastes and grazing activities. The transport of sediments and nutrients (N and P) in a watershed are very complex hence a hydrologic model was required to simulate the watershed processes. Land management practices, and other key processes such as precipitation, infiltration, runoff, erosion, sedimentation, adsoprtion and desorption, and chemical transformations all affect the transport of pollutants. The Soil and Water Assessment Tool (SWAT) was selected to model these processes and aid in estimating the sediment and nutrient loads on the watershed. For this study, SWAT was modified by the SWAT program developer to incorporate the effects of grazing such as trampling, waste application, and the removal of biomass by the livestock.

A watershed located in Lawrence County, Alabama was selected for estimating the livestock waste impacts on a creek. The study area has a particularly large unconfined beef cattle population that grazes year round and has access to the creeks. The analysis includes simulating the natural hydrological processes of the pastureland and then adding the effects of livestock activity. The results of the study are then compared to previous studies.

Following the description of the study area, chapters are organized to develop an understanding of the processes that affect the transport of nutrients and sediments in a watershed. First a description of the pollution potential and cycling of nutrients is presented in Chapter II. Next, a description of various nonpoint source measuring methods is discussed in Chapter III. Chapter IV provides a discussion on the development, operation, components, and inputs of the SWAT model. The results generated by the model and a discussion of the results are presented in Chapter V. Finally, Chapter VI contains the conclusion, recommendations, and future work.

Description of study area

The geographic area selected for this study is the Big Shoal Creek watershed located in Lawrence County, Alabama and is shown in Figure 1.1. The watershed area is 5,157 ha (12,743 acres). The general land use in the watershed is 72% pastureland, 25% forest land, and less than 1% each of crops, residential, and water use. (Morgan County SCS, 1995) The elevation of the watershed ranges from 608 m (1, 994 ft.) to 708 m (2,322 ft.) above sea level.

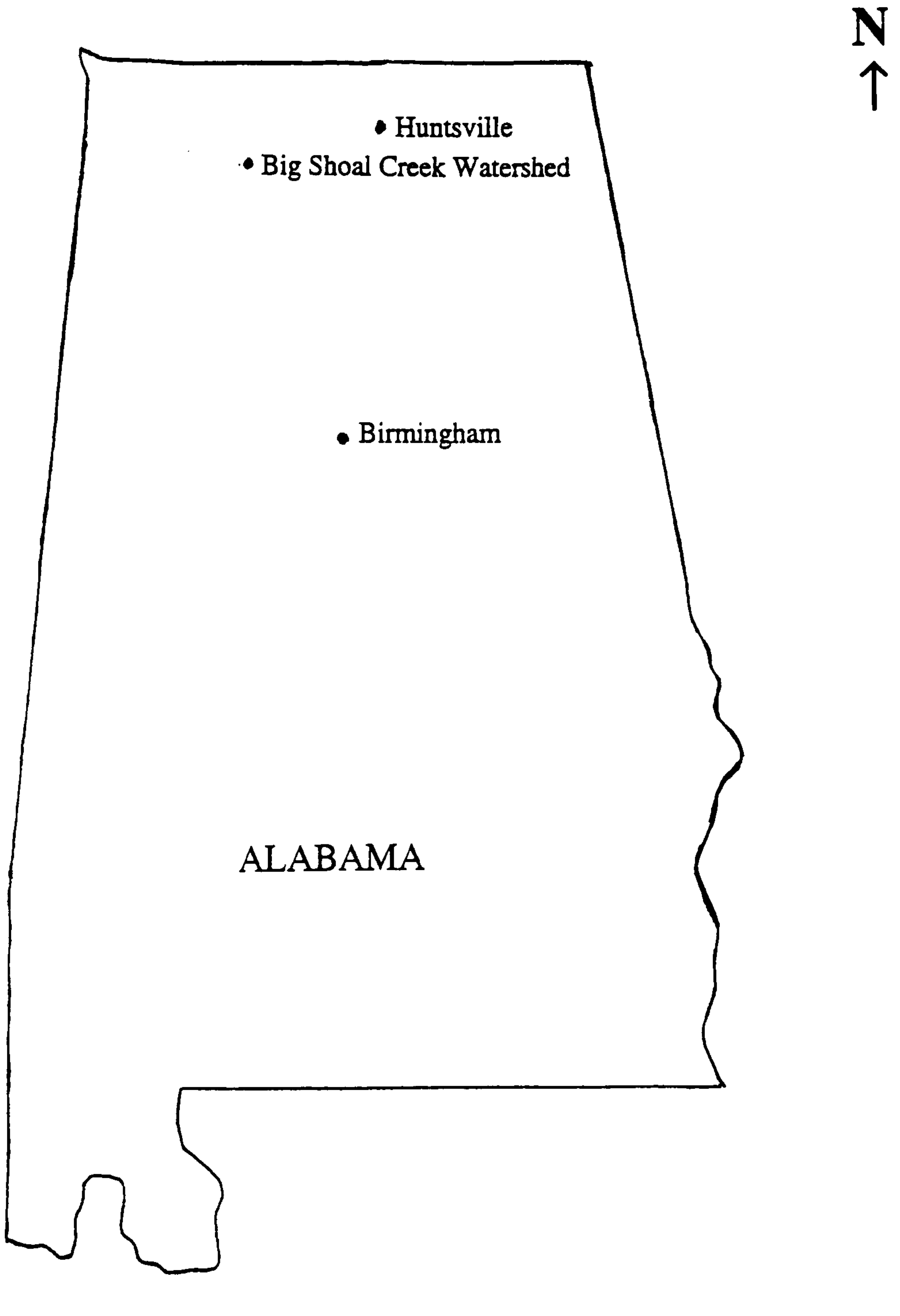

Figure 1.1: Big Shoal Creek Watershed Location

The major aquifer beneath the watershed is the Hartselle Sandstone formation and ranges form 10.6 m (35 ft) to 50 m (165 ft) in thickness below surface. The rock character is sandstone, colored light gray, medium to coarse grained with beds of shale and limestone in the lower part. The aquifer yields less than 10 gallons per minute (gpm) to wells and springs. (Harris et al, 1965)

The climate is humid and temperate with average temperatures for the winter, spring, summer, and fall at 44 °F, 61.6°F, 79.2°F, and (62.4) °F, respectively. Although precipitation is distributed fairly evenly throughout the year, the hazard from runoff and flooding is greater late in winter and early in spring. (USDA, 1959)

The soils in the study area are characteristic of silt loam to clay loam soils. The dominant soil associations are Tilsit, Linker, and Muskingum. (USDA, 1959)

CHAPTER II

POLLUTION POTENTIAL AND CYCLING OF NUTRIENTS

In photosynthesis, carbon dioxide and water are converted to organic matter and oxygen by green plants in the presence of sunlight. This involves the uptake of dissolved carbon dioxide, phosphate, and nitrogen and the production of oxygen. The overall process of photosynthesis in lakes and rivers can be represented by the following reaction (Berner, 1987):

$$16NO_3^- + HPO_4^{2-} + 18H^+ + 106CO_2 + 122H_2O \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138O_2,\ \text{or}$$

"nutrients + carbon dioxide + water → organic matter + oxygen".

The reaction illustrates that relatively small amounts of nutrients can produce relatively large amounts of organic matter. For example, to synthesize 100 g (dry weight) of algae, only 7 g of N and 1 g of P are required. (Berner, 1987) This explains why the addition of these nutrients could lead to excessive biological productivity and eutrophication. As more organic matter is produced, more oxygen is required, thus depleting the dissolved oxygen content in waters. The system is sensitive and to control it requires an understanding of how nutrients react with the environment.

Nitrogen

Nitrogen (N) is found in the soil, water, rain, and the surrounding air. During the decay process of plants and animals, nitrogen returns to the environment and is cycled back in various forms. Nitrogen exists in the gaseous, aqueous and solid (organic matter and sediment bound) forms. Most nitrogen transformations are a result of bacterial processes and are summarized in the nitrogen cycle (Figure 2.1). Mineralization occurs when organic nitrogen (Org-N) is transformed to ammonia (NH_3) and ammonium (NH_4^+).

Ammonia and ammonium usually exist in equilibrium concentrations. Ammonium is relatively immobile and attaches itself to clay particles until further conversion. Ammonia is toxic and the EPA has established a recommended allowable limit of 0.02 mg/l to protect aquatic life. During lower temperatures (5-10 °C), runoff from over-fertilized pastures can exceed the EPA limit by 3,000 times. Depending on the temperature, wind, and humidity, as much as 25% of ammonia can be lost to the air through volatilization. Under aerobic conditions (via bacterial oxidation), nitrification occurs when ammonia is converted to nitrite and then to nitrate.

Nitrite is usually a transitory phase in the nitrification and denitrification course. Only very small amounts of nitrite are ever detected in natural waters or soils. Nitrites usually occur in significant concentrations in commercial and farm ponds during a fall overturn. If the bottom of the pond is enriched with nutrients due to animal wastes, as the nitrites surface the concentrations can cause nitrite poisoning to fish and humans. If digested, nitrite bonds with hemoglobin in the blood to restrict the transfer of oxygen from the lungs. The effect is called *methemoglobinemia* or the Blue Baby syndrome (because of the bluish color of deoxygenated blood).

The nitrate form is the end product of the nitrification process. Nitrate is highly

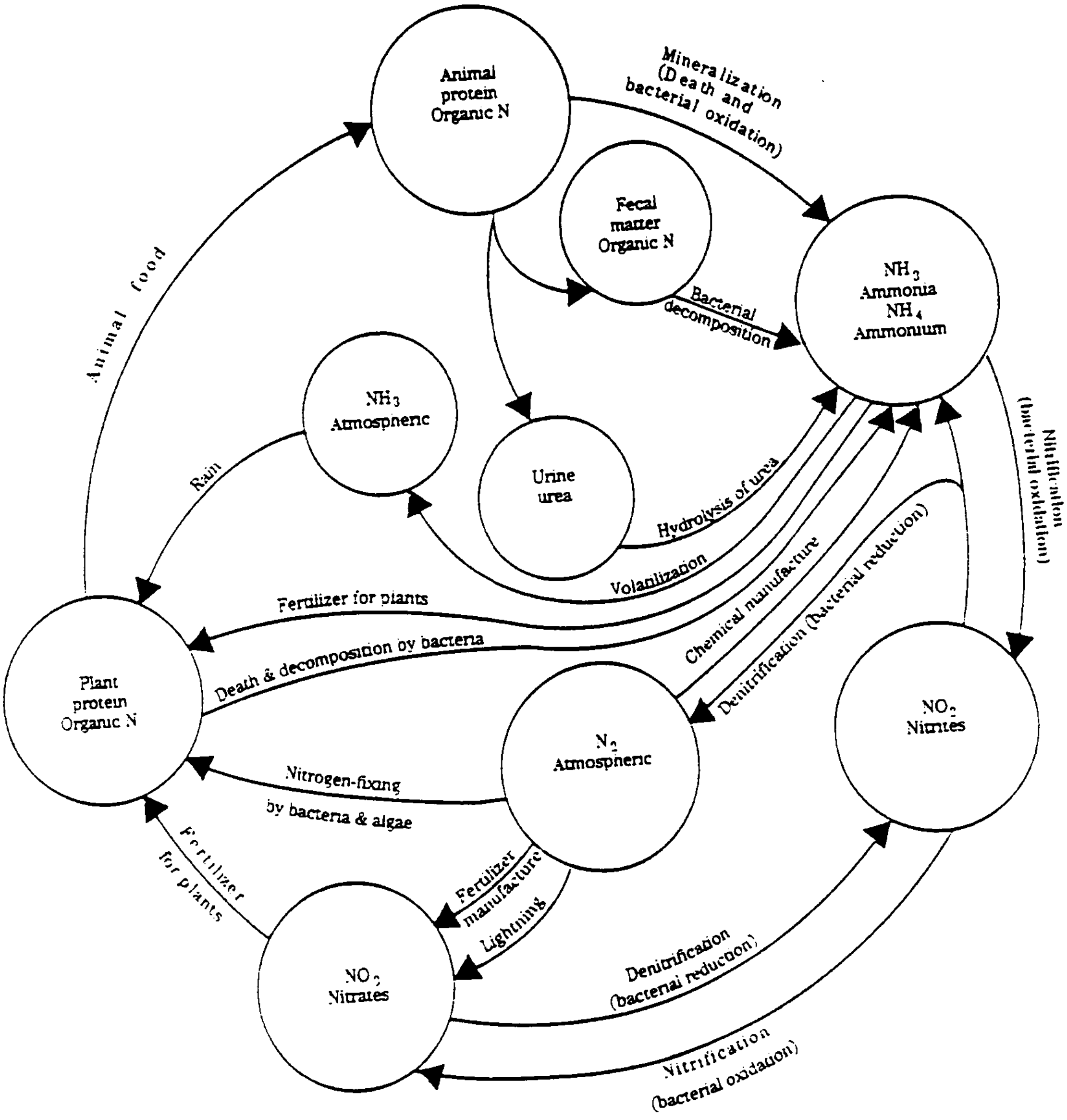

Figure 2.1 The Nitrogen Cycle

Source: USDA SCS, 1992. National Engineering Handbook, Part 651. Agricultural Waste Management Field Handbook. Washington D. C.

water soluble and is readily available to crops and plants. Nitrate is an anion and thus is repelled by the net negative charge in most soils. It does not form strong chemical bonds with mineral surfaces like P does. Therefore, nitrate is highly mobile and is more likely to be a contaminant in groundwater than in surface water. Under anaerobic conditions, nitrate can convert to a gaseous form of N through the denitrification process. Nitrates derived from animal wastes can leach through the soil, encounter an anaerobic zone, and then be denitrified. The resultant gaseous form will be lost to the surface. Nitrates are easily removed by runoff from feedlots, cropland, and pastures.

In beef cattle fresh manure, Org-N is 60-80% of the total nitrogen. The solid form of Org-N is in a complex form with digested food and the liquid part is in the form of urea. Depending on the temperature, within 4 to 5 months, 40 to 90% of the Org-N is converted to ammonia through nitrification. Organic nitrogen is not taken up by plants and is only carried away by its adsorbed constituents (organic matter and sediments) through runoff.

In water quality analysis, total nitrogen includes organic nitrogen (Org-N), total ammonia ($NH_4 + NH_3$) , nitrate (NO_3) and nitrite (NO_2). Total N removed via runoff is highly complex and depends on factors such as geographical region, slope, amount and age of waste, and rain input. Total Kjeldahl nitrogen (TKN) is comprised of the organic and the total ammonia forms of nitrogen. TKN measurements are taken to asses water quality since most of the nitrogen contamination comes in these forms.

Phosphorous

Phosphorous (P) is a naturally occurring element in soil with typical total P concentrations of 300 to 1200 mg/kg. Phosphorous promotes growth in aquatic and terrestrial life. Since 73 % of fresh cattle waste is in the organic P form, P is a high source for pollution. Total phosphorus is made up of organic, soluble, and the attached forms. Understanding the relationship between the P forms is essential for understanding the methods for controlling it. The P cycle, including inputs, losses, and soil transformations, is illustrated in Figure 2.2.

Phosphorous primarily enters the cycle from animal wastes and crop residue. Organic P (Org-P) is the principal form found in the metabolic byproducts of most animals. In the soil, P is composed of solid (99%) and solution phases. In the solid phase, P can be found in the compounds of anionic P forms that attach themselves to cations such as iron, aluminum, and calcium. Solid P can also be found in the labile (loosely bound), and adsorbed (fixed) forms that are tightly adsorbed to soil particles. The solution phase is comprised of mostly orthophosphate ($H_2PO_4^-$) and some dissolved Org-P or P bound to colloidal organic matter and iron (Fe) oxide. Soluble P is called dissolved or available because it is available for use by all plants and it is subject to leaching. In most soils, soluble P makes up less than 15 % of the total P. Soluble P exists in equilibrium with labile P; therefore, when soluble P is taken up by plants, some labile P converts to soluble P to maintain the equilibrium.

The movement of P to surface and ground waters depends on several factors. In addition to the chemical form of P, the principal factors include the degree of contact with

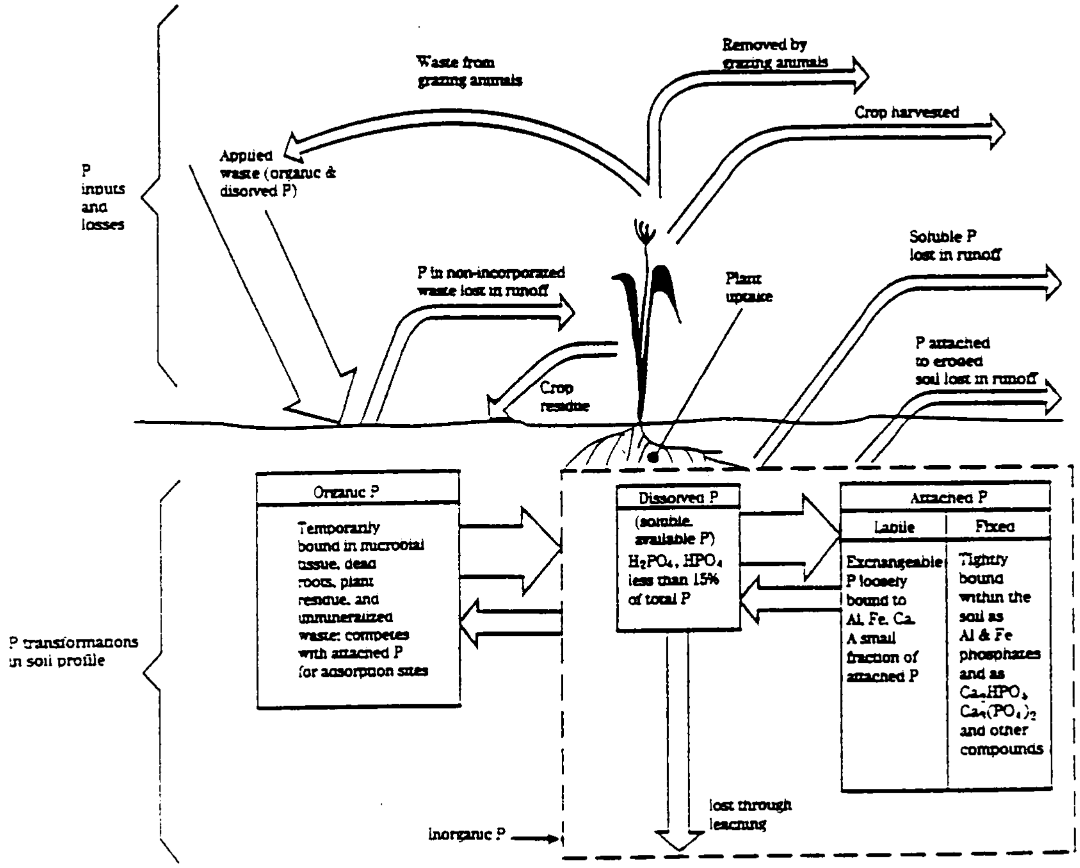

Figure 2.2 The Phosphorous Cycle

Source: USDA SCS, 1992. National Engineering Handbook, Part 651. Agricultural Waste Management Field Handbook. Washington D. C.

the soil, soil pH, soil texture, amount of waste, erosion control measures, P entrapment, P retention, aerobic conditions and harvesting practices. For example, manure that is on the surface generally has a higher potential for loss in surface runoff, especially during high-intensity storms. Also, soluble P can leach downward or be carried off in runoff water.

Once P has made contact with the soil, it will change forms relatively quickly. Usually, within a few hours equilibrium is established between the bound and solution forms. However, as time goes on, most of the P will convert to the bound form and the pollution potential of the sediment P form increases largely. The major environmental problem associated with P in water is eutrophication brought about by the accelerated growth of phytoplankton (suspended and rooted algae) in ponds, rivers, and lakes.

Sediments

Sediment are the most significant of all surface water pollutants because they form major transport mechanisms for other pollutants. Sediment is generated in a watershed as a result of erosion. Eroded soil is deposited on the land surface, stream channels and flood plains.

The sediment deposition process includes the selective removal of clay-sized particles and organic matter. Since these are the most chemically reactive materials in soil, sediment often has higher concentration of chemicals such as P than the soil in place. The concentration of the chemical in the sediment to that in the soil is called the enrichment ratio. As the sediment load increases, the enrichment ratio decreases approaching 1.0. The enrichment ratio is greatest for coarser textured soils and smaller for soils that are high in clay content.

Once entrained in the stream system, suspended sediments can act as either a source or sink for chemicals. When sediment, enriched by nutrients such as P, enters the stream system, the nutrients dissolve into the water. On the other hand, sediment has been shown to react with dissolved chemicals discharged into the stream as point sources. (Ward et al., 1995) Sediment-bound chemicals may be permanently stored in sediments as flood plain deposits or as buried sediment in stream or lake bottoms. Much of these bottom sediments are then resuspended during larger storm events and transported downstream.

Organic Matter (Biochemical Oxygen Demand)

Any substance made up from animal or vegetable origin that contains carbon compounds is organic matter. When plants and animals die, they start to decay. This process is simply the act of breaking down the organic matter (plant and body tissue) to simpler compounds. These compounds can be other forms of organic matter such as proteins and lipids or can be nonorganic compounds such as nitrates and gases (ammonia). The decay process also occurs when animal wastes or other organic materials are added to water. The bacterial organisms consume dissolved oxygen as they consume the organic matter. As the organic matter content in the water increases, more free oxygen is consumed and the bacterial population continues to grow. This cycle depletes the waters of oxygen and devastates the aquatic life by driving the fish out of the polluted area or causing them to simply die of lack of oxygen. Organic matter can be measured by the amount of oxygen required by microorganisms to biologically degrade the organic matter, thus the biochemical oxygen demand (BOD) or the BOD in a five day period at 68 °F (BOD_5). Concentrations of BOD_5 for selected sources are listed in Table 2.1. The table illustrates BOD_5 values for a sampling of sewage waste, stormwater, and livestock lagoon influents.

Table 2.1: BOD_5 Concentrations

Source	Concentration (mg/l)
Domestic sewage	190-300
Industrial sewage	0-1200 (depends on process)
Stormwater	14 (annual runoff)
Beef runoff	6,700
Swine runoff	12,800
Poultry runoff	9,800

Sources: USDA SCS, 1992. National Engineering Handbook, Part 651. Agricultural Waste Management Field Handbook. Washington D. C. and US EPA, 1990. National water quality inventory. 1988 Rep. to Congress. Office of Water. U. S. Gov. Print. Office, Washington, D. C.

CHAPTER III

NONPOINT SOURCE MEASUREMENT METHODS

Ever since the relationship of water quality and agricultural practices became a concern, the need to predict the transport and fate of agricultural pollutants was evident. During the era of environmental awareness (1960s), transport process such as runoff, leaching, and volatilization began to receive research attention. During this time, predictive equations for soil loss and sedimentation, water yield from fields; and water and sediment routing through watersheds were developed. These methods range in complexity from simple loading functions to physical process algorithms requiring simulation of chemical reaction, transformation, and dynamic transport.

Loading Function Parameters

It became evident early on that substances (such as P) strongly adsorb to sediments. Hence, a good correlation between the two parameters was determined. Assuming the pollutant is linearly correlated with the sediment loss from a watershed, an appropriate multiplier (potency factor) is all that is required. The empirical equation is: (Dean, 1980)

$$L_n = P_n \times S$$

where L_n is the load of pollutant delivered to the receiving body of water (mass/time), P_n is a factor that relates the load of pollutant n associated with each unit load of sediment ($mass_{pollutant}/mass_{sediment}$), and S is the load of sediment delivered to the receiving body of water (mass/time). This expression is a loading function and P is called the potency factor. This expression can be used to simulate loading from any pollutant from agricultural runoff. However, not all pollutants physically bind themselves to the sediment with the same strength. Nitrates do not attach themselves as strongly to sediments as phosphate ions do. Thus, the loading function is more accurate for phosphorous than nitrogen.

An empirical approximation for the potency factor (P_n) shows the relation to enrichment ratios: (Dean, 1980)

$$P_n = E_n \times C_{sn} \times R$$

where E_n is the enrichment ratio of pollutant n ($m_{\text{pollutant in eroded sediment}}/m_{\text{pollutant in surface soil}}$), C_{sn} is the average concentration of pollutant n in the surface layer of the soil ($m_{\text{pollutant}}/m_{\text{surface soil}}$), and R is the ratio of the mean particle density of the surface soil to the mean particle density of eroded sediment (dimensionless).

The enrichment ratio is the concentration of a chemical in the sediment to that in the surface soil. It represents the effects of processes such as the detachment and transport of fine particles. The selective removal of these fine particles and organic matter during runoff is inversely related to the energy of the runoff. As kinetic energy in the form of runoff velocity and turbulence increases, progressively larger and heavier particles are entrained in the runoff. In the limit, all particles in the surface soil are transported. As sediment load increases, the enrichment ratio decreases, approaching 1.0. Since the particles easily interact with dissolved substances, pollutants will be carried off and eventually adsorbed by these substances. Therefore, enrichment ratios are higher at the streams edge than at the source.

Potency factors and enrichment ratios have been the source of many studies. As with other hydrological processes, variations in soils, slope, and ground cover result in different values for each condition. Most enrichment ratios observed for N and P have values between 1 and 5. (Dean, 1980) Despite the varying numbers, some general trends have been established. For nutrients such as nitrogen (N) and phosphorous (P), the following empirical equation has been developed:

$$Ln\ (E_n) = \quad 2\text{-}0.2 \times Ln\ (SED)$$

where E_R is the enrichment ratio, and SED is the eroded soil (kg/ha). This formula can be used for both N and P since there is not enough information available to justify separate equations for nitrogen and phosphorus enrichment. (Menzel, 1980)

Universal Soil Loss Equation

Traditionally, sediment yield has been predicted by applying a delivery ratio to gross sediment production (erosion). Gross sediment production is determined by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) which uses several factors:

$$A = R \times K \times L \times S \times C \times P$$

where, A is the average annual soil loss in tons/acre, R is the rainfall and runoff erosivity index for a geographic location, K is the soil-erodibility factor, LS is the slope steepness and length factor, C is the cover management factor, and P is the conservation practice factor. The factors can all be obtained from data developed by the USDA Agricultural Research Service (ARS) and the Soil Conservation Service (SCS). The USLE computes upland erosion from small watersheds on an average annual basis. It includes the detachment and transport component but not the deposition component. To determine the sediment yield (amount of sediment delivered at the stream's edge) the gross sediment production is multiplied by a sediment delivery ratio that varies from 0 to 1.

The delivery ratio is defined as the ratio of sediment delivered at a location in the stream system to the gross erosion from the drainage area above that point. The ratio varies with the size of area, steepness, density of drainage network, and many other factors. Sediment delivery ratios can be estimated from obtaining sediment surveys from the area in question. In the absence of actual measurement, delivery ratios can be predicted by using statistical analysis to develop regional regression equations. The simplest delivery ratio prediction equation is that based solely on drainage area (Renfro, 1975):

$$\log DR = 1.87680 - 0.14191 \times \log (10 \times A)$$

where DR is the sediment delivery ratio (in percent of annual erosion), and A is the drainage area in square miles ($A < 100$ mi^2). Basically, the greater the drainage area, the smaller the catchment relief and the greater the chances for sediment deposition within the catchment. Thus larger areas would give smaller delivery ratios.

Delivery ratios are required by the USLE because the rainfall factor represents energy used in detachment only. The USLE was modified (MUSLE) by Williams and Berndt, 1977 and does not need sediment delivery ratios. The MUSLE replaced the rainfall energy factor in the USLE with a runoff factor. The runoff factor represents energy used in detaching and transporting sediment. Consequently, no sediment delivery ratio is needed. The MUSLE increases sediment yield prediction accuracy and is applicable to single event storms. The MUSLE is used in water quality modeling because shorter time intervals less than a year are required and both runoff and sediment are needed to determine pollutant transport.

Runoff Curve Number

The main components of the hydrological cycle which are important in determining surface runoff are precipitation, infiltration, interception, surface storage, and detention, overland flow, interflow and subsurface drainage, and channel storage and streamflow. In addition, surface runoff is also affected by the watershed size, topography, shape, geology, soil, and land use. Determining surface runoff is important because, like sediment, it is a major conveyor of chemicals and nutrients. The most commonly used method is the USDA SCS curve number procedure. (USDA SCS, 1972).

Surface runoff (or rainfall) excess is determined from the following equation (Ward, 1995):

$$Q = (P-I_a)^2 / (P-I_a + S)$$

where Q is the accumulated runoff in inches, P is the rainfall depth in inches, and S is a parameter given by S = (1000/CN) - 10 where CN is the curve number. The term I_a is the initial abstractions in inches and includes surface storage, interception, and infiltration prior to runoff. I_a is approximated as 0.2S and Q becomes:

$$Q = (P-0.2 \times S)^2 / P+0.88 \times S).$$

The curve number is a function of the ability of soils to infiltrate water, land use and the soil water conditions at the start of a rainfall event (antecedent soil water condition). The USDA SCS has divided soils into four hydrologic soils groups depending on the runoff potential. For example Group A soils have high infiltration rates while Group B soils have slow infiltration rates. (USDA SCS, 1984)

The measurement methods discussed here represent a fraction of the many processes involved in the transport of nonpoint source pollution. Estimates are built on estimates and the results are only as good as the tools used to obtain the estimates. The accuracy of loading functions are based on the accuracy of predicting sediment loads, enrichment ratios, and pollutant concentrations. Predicting sediment loads can be a problem because they are highly sensitive to storm events. Thus predictions are generally better for longer periods. Although enrichment ratios have been well documented, only recently has the impact of watershed variables or their magnitude been investigated. Comprehensive studies to identify important variables and their relationship to enrichment ratios should be conducted for each study area. Predicting watershed concentrations of pollutants and surface runoff are best obtained by using computer simulations. Whether hand calculated or simulated in a model, predicting these parameters continues to be a challenge.

Modeling

By the 1970's, researchers had learned that nonpoint source pollution was the result of a combination of complex factors including chemical and soil properties, watershed characteristics, agricultural management practices, and climate. Although models for soil loss, water yields, and routing of sediments and water had been developed, they had not been coupled. Soon afterwards, it became apparent that analyzing nonpoint source pollution required the complete understanding of agro-environmental systems which could only be accomplished by modeling.

Models are an abstraction, not a description, of the real world. (Baily and Swank, 1980) They provide for simplifications of complex processes. In addition to calculating pollution loads, watershed based models can be used as a tool for decision making impacts. For this study, the Soil and Water Assessment Tool (SWAT) was selected to aid in estimating the water quality impacts from nonpoint sources (livestock wastes).

CHAPTER IV

THE SWAT MODEL

SWAT Model Development

In the 1970's, in response to the Clean Water Act, the USDA ARS put together a team of interdisciplinary scientists to develop a process-based, nonpoint source simulation model. The result was a model called CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980) that simulated the impact of land management on water sediment, nutrients, and pesticides leaving the edge of a field. From CREAMS, other models were developed in the 1980's. These include GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987) which simulates pesticide and nutrient groundwater loading, and EPIC (Erosion Productivity Impact Calculator) (Williams et al., 1985) which simulates comprehensive agricultural management effects.

Models developed from CREAMS were capable of simulating complex watersheds with varying soils, land use, and agricultural management. In 1987, AGNPS (Agricultural Nonpoint Source) (Young et al.,1989) was developed for single events and was capable of dividing the watershed into grids; this allowed for spatially detailed modeling. A model called SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al, 1990) was developed for simulation of entire watersheds over a continuous daily time step and allowed the watershed to be divided into a maximum of ten subwatersheds.

The major change from CREAMS to SWRRB was that the daily rainfall hydrology model was applied to larger, complex rural watersheds. In addition, changes included an expansion to allow for simultaneous computations on several subbasins, sediment routing, a weather simulation component (rainfall, solar, radiation and temperature), and other major changes. The need to add a weather simulator was evident after studies showed that effects of pollutants could not be evaluated by a single storm event. (Frere et al, 1980)

In the late 1980's, the Bureau of Indian Affairs needed to estimate the downstream impact of water management from Indian reservation lands in Arizona and New Mexico. The SWRRB model was used for small watersheds but was not capable of simulating larger basins (up to 1000 km^2). This limitation would require the watershed to be divided into several hundred subwatersheds. Unfortunately, SWRRB was limited to only 10 subwatersheds. Another fallback was that SWRRB had a simplistic routing structure that routed outputs from the subwatershed outlets directly to the watershed outlet. A model called ROTO (Routing Outputs to Outlet) was developed to take the output from multiple SWRRB runs and route the flows through channels and reservoirs. This proved to be effective but quite cumbersome because all SWRRB runs had to be made independently, and then input to ROTO for routing. Finally, ROTO and SWRRB were merged and the Soil and Water Assessment Tool (SWAT) was developed. The SWAT model is a distributed parameter, continuous time model that can simulate hundreds of subwatersheds and/or grid cells. It is the result of years of research in nonpoint source pollution modeling.

Model Operation

The SWAT model is used to predict the impact of management on water, sediment and agricultural chemical yields in large ungaged watersheds. The model is physically based and can not be calibrated because the subwatershed is ungaged. The model is intended to use readily available inputs and is capable of simulating large, complex watersheds over several years. The routing component allows flow to be routed through streams and reservoirs, adding flows, and inputting measured data, or point sources. Also, output from other hydrologic models can be inputted to SWAT.

The model is divided into three major components: subbasin (subwatershed), routing, and reservoir routing. These major components, along with other hydrological processes simulated by SWAT are illustrated in Figure 4.1. Essentially, the SWAT reads the input data and initializes parameters. For each annual loop, the model begins with day 1 (user input) and simulates each day's processes. For each subwatershed, SWAT reads or generates precipitation and the maximum and minimum temperatures; generates solar radiation, wind speed, and humidity; computes soil temperatures, snowfall, and snowmelt; computes surface runoff, peak rate, transmission losses, sediment yields, nutrient and pesticide yields; computes soil water routing, evapotranspiration, crop growth; and computes pond, reservoir, and ground water flow and height. In addition, the daily loop involves routing water, sediments, and pollutants through stream channels and reservoirs; transferring water from any reach or reservoir to another; adding water, sediments, and nutrients from any two hydrographs; and incorporating other designated model outputs in the loop. The process is repeated for each year of simulation.

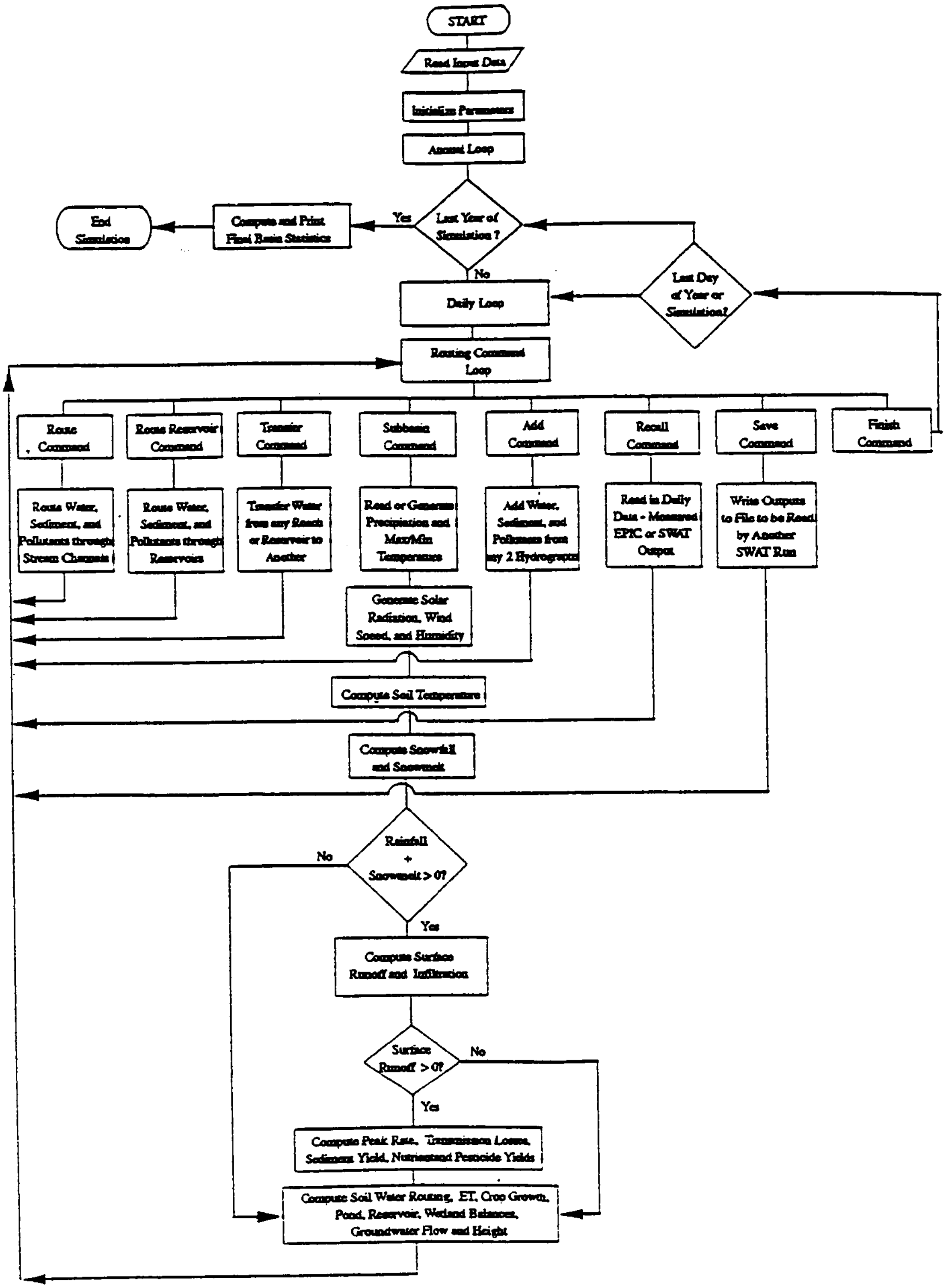

Figure 4.1: SWAT Model Components

Source: Arnold, J.G., J.R. Williams, R. Srinivasan, and K.W. King, 1996. SWAT Soil and Water Assessment Tool. USDA ARS Grassland, Soil and Water Research Laboratory.

Subwatershed Components

The subwatershed components consists of the following eight major divisions: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. Figure 4.2 illustrates how SWAT simulates these processes for each subwatershed.

Hydrologic processes. The hydrological processes simulated by SWAT include surface runoff, percolation, lateral subsurface flow, groundwater flow, evaporation, snow melt, transmission losses, and ponds. The surface runoff from daily rainfall is predicted by estimating the runoff volume with a modification of the SCS curve number method (USDA SCS, 1972). The curve number varies non-linearly from the 1 (dry) condition at permanent wilting point to the wet conditions at field capacity and approaches 100 at saturation. Runoff can also simulated from frozen soil.

The percolation component uses a storage routing technique to predict flow through each soil layer in the root zone. When the field capacity of a soil layer is exceeded, downward flow occurs. Upward flow occurs when a lower layer exceeds field capacity. No percolation is allowed from a layer if the temperature of a soil layer is 0 °C or below. Lateral subsurface flow is predicted using a kinematics storage model and is calculated simultaneously with percolation. The variation in conductivity, slope, and soil water content in each soil layer also is taken into account.

For groundwater flow contribution, a shallow aquifer storage is created. (Arnold et al, 1993) Flow is added to the aquifer from the above root zone percolate. This flow is

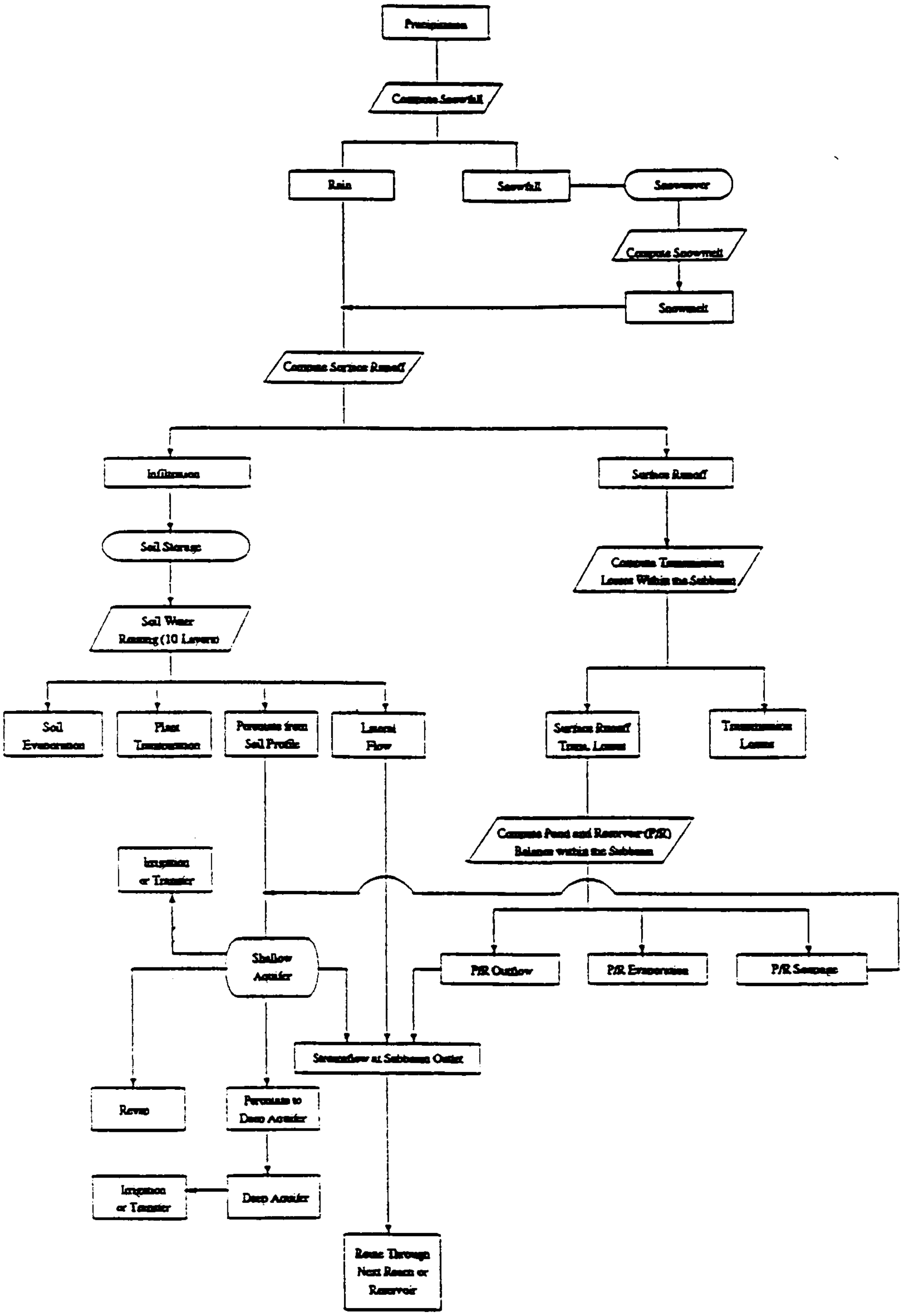

Figure 4.2: Subwatershed Components

Source: Arnold, J.G., J.R. Williams, R. Srinivasan, and K.W. King, 1996. SWAT Soil and Water Assessment Tool. USDA ARS Grassland, Soil and Water Research Laboratory.

the recharge for the aquifer. Other components include a recession constant to lag flow from the aquifer to the stream, evaporation, pumping withdrawals, and seepage to the deep aquifer.

The model offers three options for simulating the potential evapotranspiration (ET). These methods may require wind speed, relative humidity, and solar radiation inputs. Potential soil water evaporation is estimated as a function of potential ET and the area of plant leaves relative to the soil surface area (leaf area index). The actual soil water evaporation is simulated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET and leaf area index. (Ritchie, 1972)

If snow is present, a linear function of temperature is used to melt it when the maximum temperature exceeds 0 °C. For the surface runoff and percolation, the melted snow is treated the same as rainfall.

Transmission losses occur when semiarid watersheds have alluvial channels and large volumes of streamflow are abstracted. These transmission losses reduce runoff volumes and the peak runoff rate. Transmissions losses are simulated using Lane's method. (USDA SCS, 1983)

Farm ponds are small structures in a subwatershed used to store surface runoff. The model assumes the ponds have only emergency spillways. Pond storage is simulated as a function of capacity, daily inflows and outflows, seepage, and evaporation. When the surface area is less than capacity, it is estimated as a non-linear function of storage.

Weather. The weather component includes precipitation, air temperature, solar radiation, wind speed, and relative humidity. The model accepts daily minimum and maximum temperature data and daily precipitation data. If the data is not available, the weather generator simulates these inputs. Solar radiation, wind speed, and relative humidity are always simulated by the model. The model is flexible in that one set of weather data may be used for the entire watershed or different weather may be simulated for each subwatershed.

The precipitation model is based on a first-order Markov chain model. (Nicks, 1974) This requires inputs of monthly probabilities of receiving precipitation if the previous day was dry or if the previous day was wet. If the previous day was dry, the model determines stochastically if precipitation occurs or not. When precipitation occurs, the amount that falls is determined from a skewed normal daily precipitation distribution.

Daily maximum and minimum air temperature and solar radiation data is generated from a normal distribution that is corrected for the wet-dry probability state. The correction factor provides more deviation in temperatures and radiation for rainy days than for dry days. These correction factors are calculated to insure that long-term standard deviations of daily variables are maintained.

The daily wind speed is simulated using a modified exponential equation which requires the mean monthly wind speed as input. The daily relative humidity is simulated from the monthly average by using a triangular distribution. The mean daily relative humidity is also adjusted with a correction factor to account for wet-day and dry-day effects.

Sedimentation. The MUSLE is used to estimate the sediment yield for each subwatershed. It uses the USLE parameters which include surface runoff and peak flow rate (supplied by model simulation), crop (C) management, soils erodibility (K), erosion control practice (P), and the slope length and steepness factors (LS) (supplied by user).

Crop Growth Model. The crop growth model simulates crop yield and potential growth for over 30 crops. These crops and their characteristics are contained in the model's database. Heat units (thermal time) are used to estimate the rate of crop development. Also, in scheduling crop management operations, the model will accept a calendar date or the fraction of crop maturity in terms of the heat units. The crop growth model also accounts for growth constraints, and water, nutrient, and temperature stresses.

Nutrients. The nutrient submodel calculates nitrogen (N) and phosphorous (P) yields for each subwatershed. The nutrients, along with water and sediment, are also routed from the subwatershed outlets to the watershed outlet.

The nitrogen processes simulated by the model include nitrate loss in surface runoff, nitrate leaching, organic N transported by sediment, denitrification, mineralization, immobilization, rainfall input, and crop uptake. Most of these processes are discussed in Chapter II and are illustrated in Figure 2.1. The amounts of nitrate contained in surface runoff, lateral flow, and percolation are estimated as the products of the volume of water and the average nitrate concentration.

A loading function is used to estimate organic N loss and transport by sediment. (McElroy et al, 1976) The loading function estimates the daily organic N loss based on the concentration of organic N in the top soil layer, sediment yield, and the enrichment ratio. The amount of N contribution from rainfall is estimated as the product of rainfall amount and N concentration. The amount of N crop uptake is estimated using a supply and demand approach.

The P processes simulated by SWAT include soluble P loss in surface runoff, P transported by sediment, mineralization, and immobilization. These processes are determined in the same manner as the N processes are.

Pesticides. The pesticide model simulates the transport of pesticides in runoff, percolate, soil evaporation, and sediments. Pesticides can be applied to the subwatersheds at any time, any rate, and on the plant foliage or below the soil surface. The model accounts for losses to the atmosphere, by infiltration, by leaching, or through transformation and degradation. The SWAT model contains a database of over 100 common pesticides and their characteristics.

Agricultural Management. Agricultural management in SWAT includes tillage systems and residue, application of irrigation, fertilizer, and pesticides and grazing systems In addition, SWAT allows unlimited years of crop rotations with up to three crops each year.

The tillage and residue component is designed to partition the above-ground biomass at harvest. Part of the biomass is removed as yield, part is incorporated into the soil, and the rest is left as residue on the soil surface. The day of the tillage operation and the tillage implement are input by the user. The model contains a database with over 100 tillage implements.

Irrigation applications may be scheduled by the user or the model may irrigate automatically. For user directed irrigation, the amounts and dates of application are required. For automatic irrigation, the application efficiency and a plant water stress level to trigger irrigation are required as inputs. The option for no irrigation is also available.

Fertilizer applications can also be user directed or automatic. For the user scheduled option, the application date, total amount of N and P, the fraction of organic and inorganic N and P, and the soil layer of application are required as inputs. The model adds the N and P to the organic or inorganic pools and the soil layer indicated. For the automatic option, the plant nitrogen stress level to trigger fertilization, the amount of nitrate that can be applied in one year, and minimum time between the fertilizer applications are required as inputs.

Grazing. The SWAT model simulates livestock grazing as part of a daily harvest operation. The daily grazing rate (amount of biomass removed) and the period of grazing are required as inputs.

Routing Components

The routing components consist of channel flood routing, channel sediment routing, reservoir water balance and routing, reservoir sediment routing, and reservoir chemicals (nutrients and pesticides) routing. Currently, no routing of nutrients or pesticides in channels is available.

A variable storage coefficient method is used for channel routing. (Williams, 1969) Inputs required include reach length, channel slope, stream width and depth, subwatershed slope, and the roughness coefficient for the channel and the floodplain. The model accounts for channel outflow from transmission losses, evaporation, diversions, and return flow.

The sediment routing submodel has two components, deposition and degradation, which are simulated simultaneously. The deposition of sediments in the channel from the subwatershed outlets is based on sediment particle fall velocity. Degradation in the channel is predicted by stream power (product of water density, flow rate, and water surface slope). (Bagnold, 1977) Available stream power reentrains loose and deposited sediments until all of the material is removed by the fluid flow. The excess stream power causes bed degradation which is then adjusted by the USLE soil erodibility and cover factors of the channel and floodplain.

Reservoir / pond routing is controlled by a reservoir / pond water balance. The water balance includes inflow, outflow, rainfall on the surface, evaporation, seepage from the reservoir / pond bottom, diversions and return flow. Sediment yields to the ponds and reservoirs is calculated using MUSLE. Sediment concentrations in the outflow is the product of outflow volume and sediment concentration. The initial reservoir / pond sediment concentration is a required input.

Nutrients and pesticides in a reservoir / pond are also simulated. A phosphorous mass balance model which can assume different trophis status is used to simulate P in the reservoir / pond. (Thomann and Mueller, 1987) Variables in the mass balance equation include the reservoir / pond inflow, outflow, and overall loss rate. The toxic model assumes well mixed conditions and simulates pesticide loading, outflow, reactions, volatilization, settling, diffusion, resuspension, and burial. (Chapra, 1989)

Description of Model Inputs

There are 13 data files that SWAT reads in order to obtain input data. The files are summarized in Table 4.1. For this study, ponds, reservoirs, pesticides, automatic management use, and lake water quality were not simulated, thus the respective files were not utilized. Inputs for a sample run are found in Appendix A.

Control Code File (Appendix A1). The control code file contains inputs for the number of years of simulation, number of subwatersheds, and other control codes. The model allows the watershed to be divided into many subwatersheds. For this study, the watershed was divided into 24 subwatersheds based on the natural drainage patterns. Figure 4.3 illustrates the 24 subwatershed divisions.

Table 4.1: SWAT Input Data Files

File no.	File extension	Description
1	.cod	Control code file
2	.bsn	Basin data
3	.wgn	Weather data
4	.sub	Subbasin data
5	.rte	Routing configuration data
6	.pnd	Pond data
7	.res	Reservoir data
8	.chm	Pesticide data
9	.sol	Soils data
10	.mgt	Management data
11	.mco	Automatic management /water use
12	.gw	Groundwater data
13	.lwq	Lake water quality data

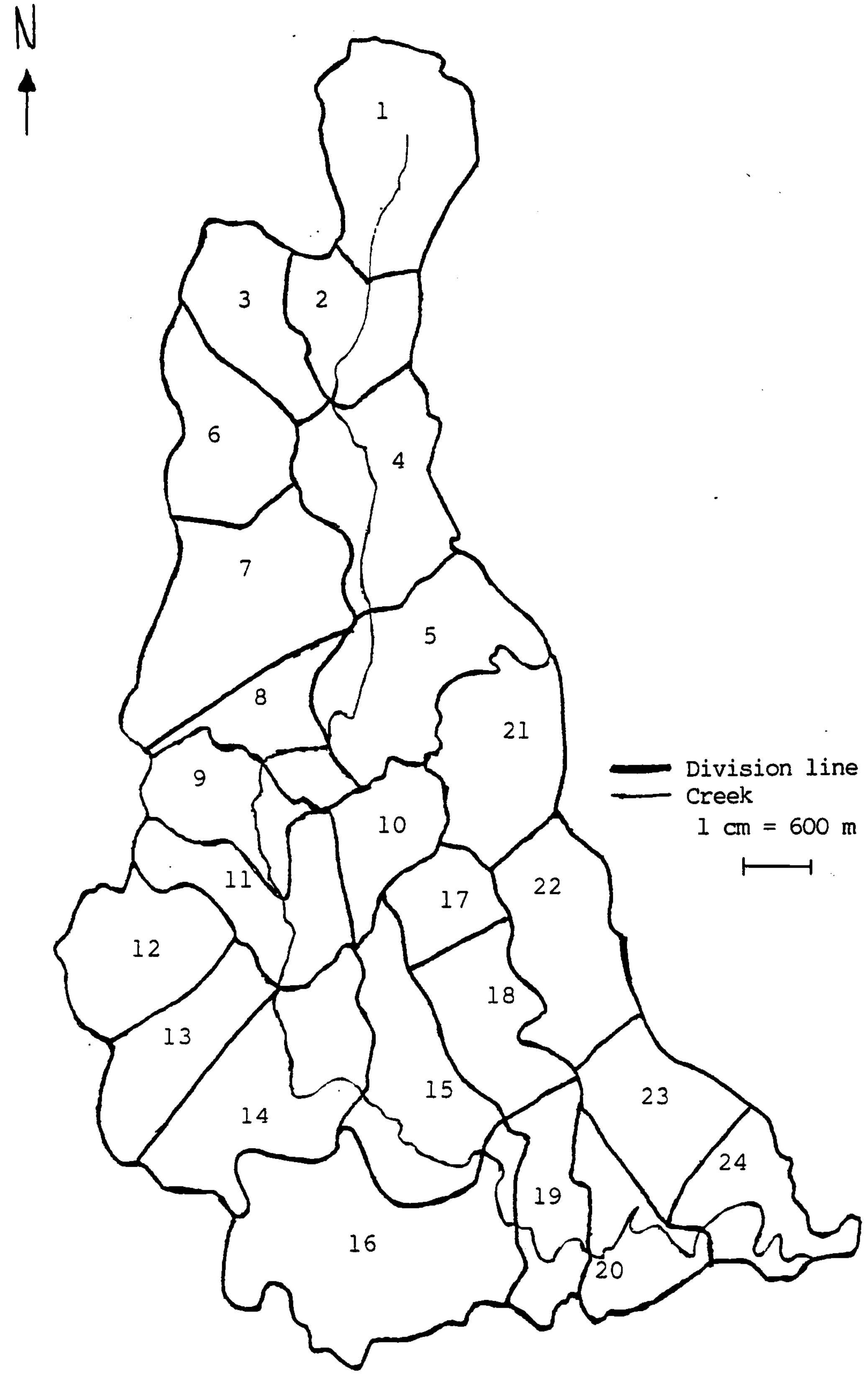

Figure 4.3: Watershed Subdivisions

Basin Data (Appendix A2). The basin data file contains inputs that are common to the entire watershed. The watershed area is 51.57 km^2 (20 mi^2). The creek is perennial so the baseflow factor was set at 1. The basin lag time was calculated to 0.23 days using the following equation:

$$t_L = L^{0.8} (S+1)^{0.7} / 1900\ Y^{0.5}$$

where t_L is the lag time (days), L is the hydraulic length of the watershed (ft), S is a function of the SCS curve number , Y is the average land slope in %, and S = (1000/curve number) - 10. (Ward, 1995) The initial soil water storage - fraction of field capacity was set at 0 so that SWAT could estimate it.

Weather Data (Appendix A3). The weather data was obtained from SWAT's database. The weather station selected was in Huntsville, Alabama. SWAT automatically reads in the file with all the data once the weather station number is input. The same weather data was used for all the subwatersheds.

Subbasin Data (Appendix A4). The subbasin data files are specific to each subwatershed, thus 24 subbasin files were created. The area for each subwatershed was determined by superimposing a grid on the topographic map of the watershed. The runoff curve number was based on the land use (pasture or rangeland, good condition) and the infiltration characteristics of the soil (group B). The carbon dioxide concentration and the initial water content of snow were not known so they were set at default values. The channel length, average channel slope, and the average slope steepness were obtained from topographic maps. The average main channel width was measured during a site visit. The effective hydraulic conductivity in the channel alluvium is based on the bed material characteristics. The channel bed consists of sand and gravel with significant amounts of silt-clay content. The channel N value is Mannings's "n" value and is determined for a natural (earth) channel flow characterized as winding and sluggish. The surface roughness factor (overland flow N value) was based on land use (rangeland). The return flow travel time and the sediment concentration in return flow were set at the default values. The USLE erosion control practice factor P was based on the land slope. The average slope length was determined as suggested by Jimmy Williams, Hydrologist USDA ARS Blackland Research Center, via telephone conversation. (Williams, 1996) The average slope length of a subwatershed is

$$L = LC/2E$$

Where L is the average slope length (m), LC is the length of the contour (m), and E is the number of extreme points in the contour. The initial residue cover at the start of simulation was set at the suggested value by Jeff Arnold, Agricultural Engineer, USDA ARS Blackland Research Center via telephone conversation (Arnold, 1996). Finally, temperature, radiation, humidity, and carbon dioxide monthly adjustments were not simulated.

Routing Data (Appendix A5). The routing data is specific for each subwatershed, thus 24 routing files were created. The average channel width and depth were measured during a site visit. The channel slope and channel length was obtained from the topographic map. The USLE soil factor K and C for the channel were determined during the site visit.

Pond, Reservoir, and Pesticide Data (Appendix A6, A7, and A8). These processes were not simulated due to the limited amount of information available.

Soils Data (Appendix A9). Once the soil association for the study area is determined, information required by the data file is obtained from the SWAT soils database. To determine the soil association name, the SCS Lawrence county soils maps were investigated. The association map indicated that the county was primarily of the Tilsit - Linker - Muskingum association. To show that the study area is representative of the county soils association, a frequency analysis was conducted. The watershed was arbitrarily divided into three areas and the 13 dominant soil series were counted. Figures 4.4, 4.5, and 4.6 illustrate the frequency of the soils for the top, middle, and bottom portions of the watershed. The total count for the soils is illustrated in Figure 4.7. Table 4.2 contains the soil series legend for the figures. The characteristics of the soils that made up 80% of each section were averaged and deemed the soil for that section. For example, the "top" soil is the non-weighted average of Tilsit, Linker, and Muskingum. Thus three soil data files were created: top.sol, mid.sol, and bot.sol.

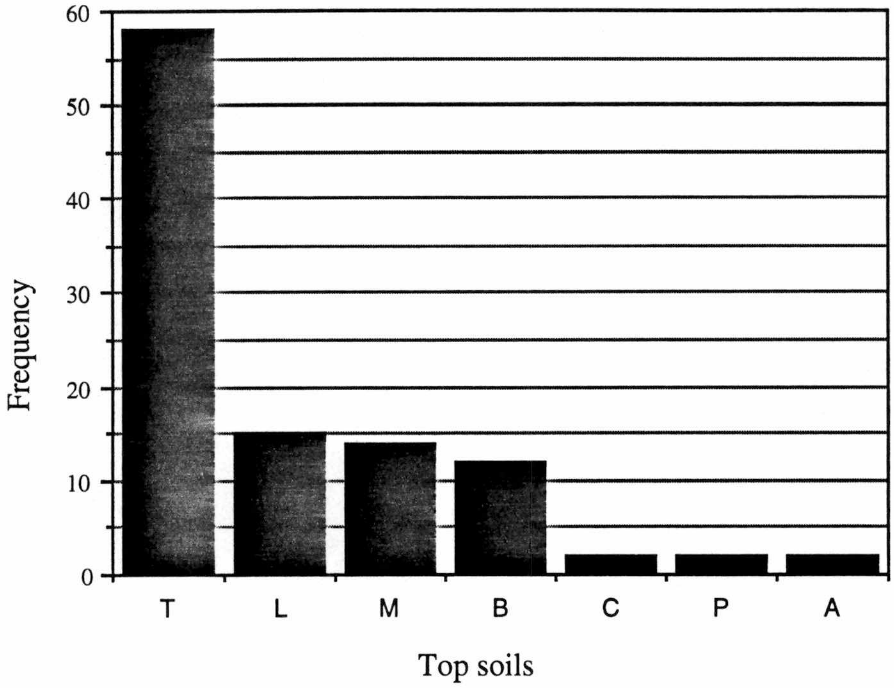

Figure 4.4: Frequency of Soil Series - Top.

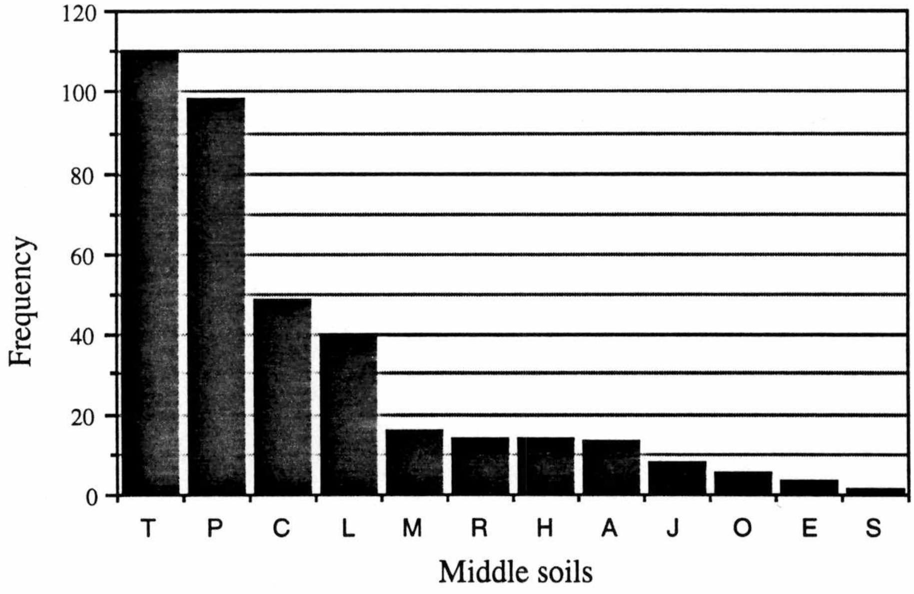

Figure 4.5: Frequency of Soil Series -Mid.

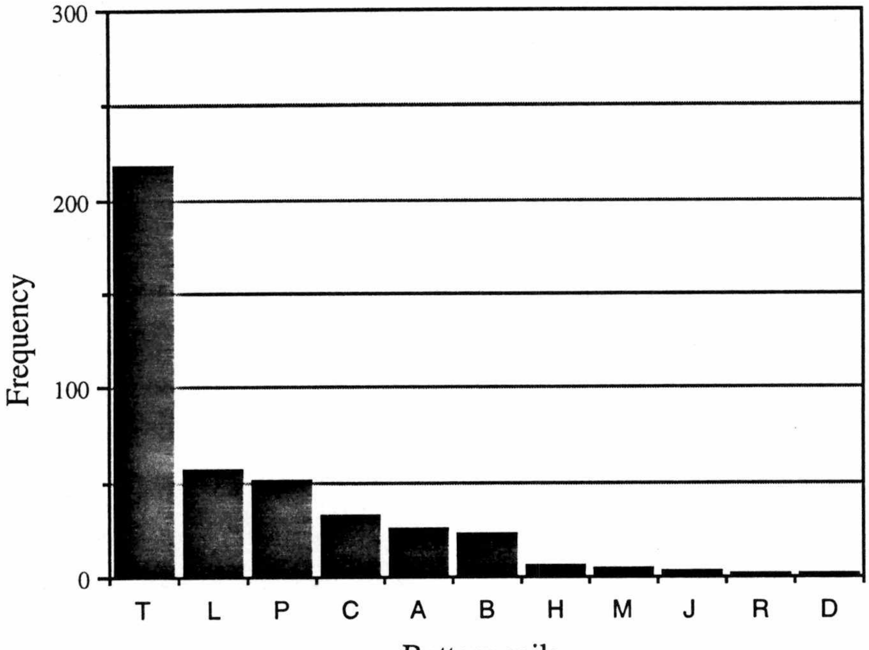

Figure 4.6: Frequency of Soil Series - Bot.

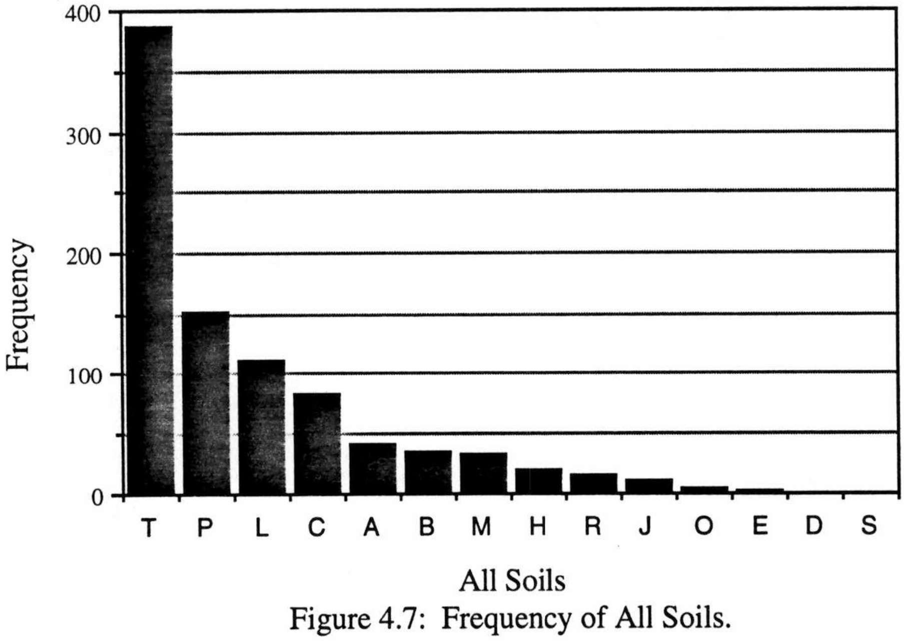

Figure 4.7: Frequency of All Soils.

Table 4.2: Soil Series Legend

A - Atkins	H - Hartsells	P - Lawrence and Colbert
B - Barbourville	J - Jefferson	R - Robertsville
C- Cumberland	L - Linker	T - Tilsit
D - Decatur	M - Muskingum	
E - Etowah	O - Oltewah	

Management Data (Appendix 10). The management data file is specific for each subwatershed, thus 24 files were created. To simulate pasture or rangeland growing on the land, this "crop" was selected from the SWAT crop database. To simulate grazing, the user inputs required were the daily biomass consumed (kg/ha/day) and the number of days of grazing. The amount consumed daily was determined by multiplying the number of cows in the subwatershed times the average cow consumption rate (45 lb/day) and dividing by the area of the subwatershed. Animal wastes were simulated using the fertilizer application. The user inputs included the date of application, type of fertilizer (beef cattle - fresh) selected from the SWAT data base and the amount applied (kg/ha/day). The amount was determined by multiplying the number of cows in the subwatershed times the application rate and dividing by the area. The following example illustrates the fertilizer calculations for subwatershed 1:

> Area = 316.9 ha, 305 cows,
> 1 cow produces 59.1 lb. manure/day/1000 lb. live wt.
> 1 cow applies 0.18 kg manure/ha/day
> 305 cows x 0.18 kg manure/ha/day = 56.8 kg manure/ha/day applied in the subwatershed. (Data obtained from TVA maps deduced from aerial photographs and Morgan County Soil & Water Conservation District, 1995)

The model works on a daily time step with one management data entry per day. Yet the model could only handle 20 entries (20 days) not 365 so the amount applied every 18 days was determined instead:

> 18 days x 59.1 lb./ day = 1063 lb. = 482.5 kg produced per cow
> 482.5 kg / 316.9 ha = 1.52 kg/ha every 18 days
> 305 cows x 1.52 kg/ha = 463.6 kg manure/ha applied in the subwatershed 1 every 18 days.

Reluctant with this methodology, the SWAT model author, Mr. Jeff Arnold, was consulted. Mr. Arnold responded by changing the code and modifying the grazing component to simulate grazing and manure effects simultaneously. User inputs to the modified version include the starting date of activity, the daily biomass removed (kg/ha), the number of days of grazing, the amount of biomass trampled per day (approximately 80% of the amount consumed), amount of manure applied (kg/ha/day), and the type of manure applied (beef cattle - fresh).

Automatic Management Data (Appendix A11) This data file was not utilized since no irrigation is conducted in the study area .

Groundwater Data (Appendix A12). The groundwater data obtained was used for all the subwatersheds. The Alabama Geological Survey graciously helped in identifying sources to obtain the required data. The data inputs and their source are listed in the appendix.

Lake Water Quality Data (Appendix A13). This data file was not utilized since there were no lakes in the study area.

CHAPTER V

RESULTS

One of the most important attributes of the SWAT model is the ability to provide reasonable outputs in cases where ungaged watershed data is input. The model uses readily available inputs and several studies have certified a goodness of fit coefficient between 0.7 and 0.8. (Arnold et al, 1996) The program is effective because it is physically based but this incurs the cost that no calibrations are possible when researching ungaged watersheds. Since a calibration was not possible for the Big Shoal Creek site, the modified program was run using a well documented watershed to ensure proper program operation.

Analysis of the watershed was separated into three categories: natural pastureland processes, the application of grazing effects, and the application of livestock wastes. The pastureland hydrologic processes of the watershed were simulated to obtain precipitation, surface runoff, and the pastureland nutrient and sediment loads. Note that all the results shown are due to cumulative effects for a single year. Also, the same weather pattern was used for all of the categories.

The watershed precipitation and surface runoff are illustrated in Figure 5.1. The watershed receives steady amounts of rain each month with slightly more during the winter months. An average of 1,377 mm (54 in.) of rain per year is received by the watershed. Although runoff is affected by several factors, it similarly follows the

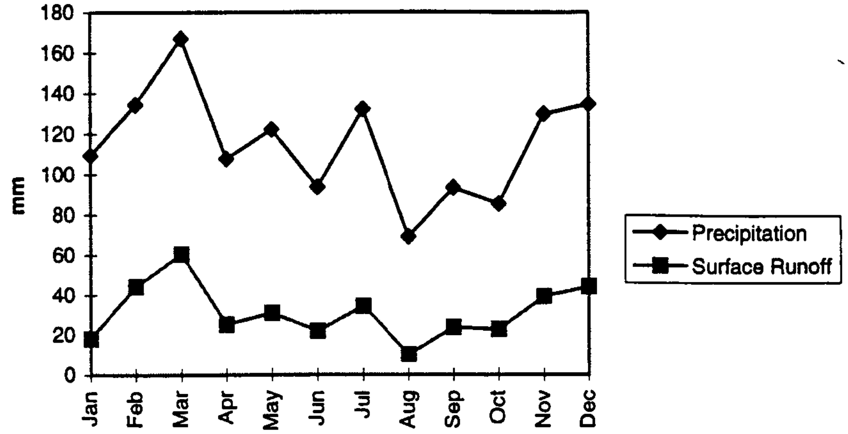

Figure 5.1: Watershed Precipitation and Surface Runoff.

increasing and decreasing trends of precipitation. The average annual surface runoff of the basin is 374 mm (14.7 in).

Erosion and sedimentation of the pastureland occurs naturally in the watershed as shown in Figure 5.2. The erosion and sedimentation process begins as the surface soil is impacted by rain. After continued rain impact, soil is ultimately detached from the land and transported by overland flow, all along causing more erosion and sedimentation. The annual average sediment load from the pastureland is 36.92 mm (1.45 in.).

Big Shoal Creek also receives nutrients from the surrounding land. Figure 5.3 shows the amount of total N and total P obtained throughout the year from pastureland, residue. The average annual yields for total N and total P are 2.81 kg/ha and 2.12 kg/ha, respectively. To obtain the annual load, the yield is multiplied by the watershed area.

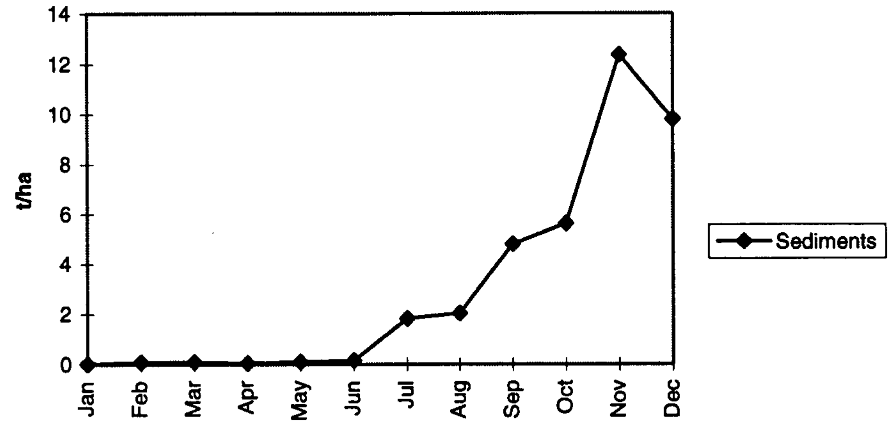

Figure 5.2: Pastureland Sediment Yield.

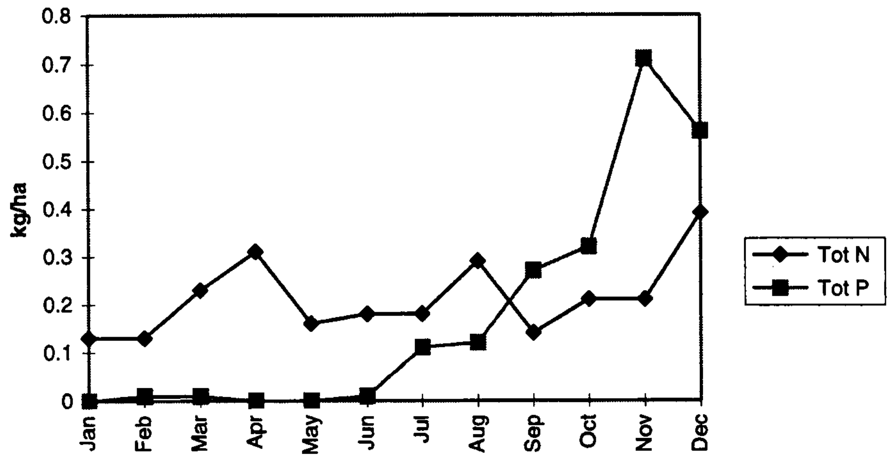

Figure 5.3: Pastureland Nutrient Yields.

Table 5.1 summarizes the annual sediment and nutrient loads, and the precipitation and surface runoff for the pastureland.

The next scenario involved simulating the effects of livestock grazing. As livestock graze throughout the pasture, several activities that occur are affecting the land. First of all, while biomass is being consumed, the land surface becomes more susceptible to erosion and sedimentation because the protective cover is being removed. In addition, the trampling upon the land also detaches much of the vegetative cover. Finally, livestock wastes are added to the surface and eventually decompose to organic matter, nutrients, and residue. The modified SWAT version incorporates all these grazing activities in the model.

Since cattle in the watershed graze year round, grazing effects were simulated for 365 days. The effects of grazing on sediments, total N, and total P as compared to the pastureland processes are illustrated in Figures 5.4, 5.5, and 5.6 respectively. Grazing activities vastly increased the amount of pollutants due to the removal of vegetative cover.

Table 5.1: Watershed Parameters due to Pastureland Processes

Precipitation	1377 mm/yr	(54 in./yr)
Surface Runoff	374 mm/yr	(14.7 in/yr)
Total N	14, 486 kg/yr	(15.9 tons/yr)
Total P	10,999 kg /yr	(12.1 tons/yr)
Sediments	190,417 t/yr	(209,898 tons/yr)

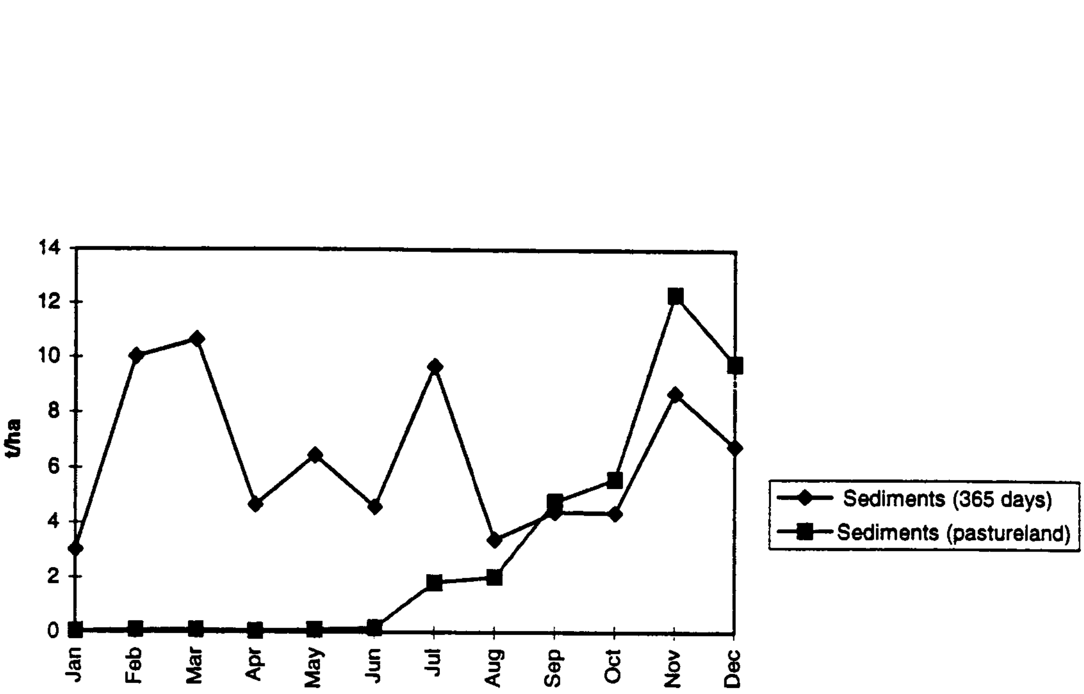

Figure 5.4: 365 Days- Grazing Effects on Sediments.

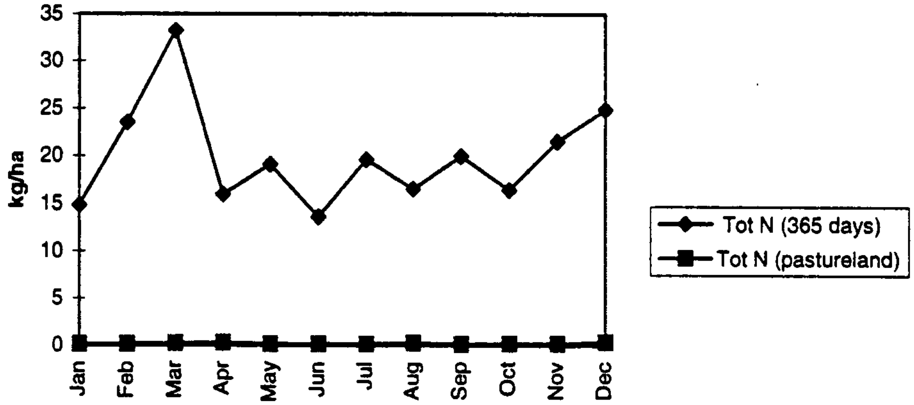

Figure 5.5: 365 Days - Grazing Effects on Total N Yields.

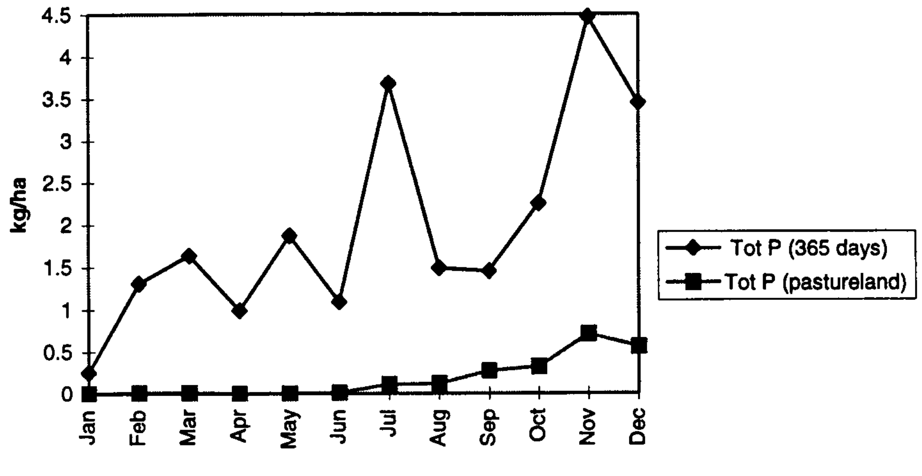

Figure 5.6: 365 Days - Grazing Effects on Total P.

Under managed conditions, livestock graze in a roughly 4 month period (April - October). Grazing was simulated for these months only and the effects on sediments and nutrients were also obtained. Figure 5.7 compares the sediment yields for the 180 day grazing period to the pastureland sediment yields. Total N and total P yields are also compared to pastureland nutrient yields in Figures 5.8 and 5.9. Table 5.2 displays the average annual loads for 365 and 180 days of grazing (includes pastureland loads). In each case, the loads are reduced by at least one-half when grazing was limited to the 4 month season.

The final analysis concerned simulating the application of livestock wastes without incorporating the grazing effects of trampling and biomass removal. This

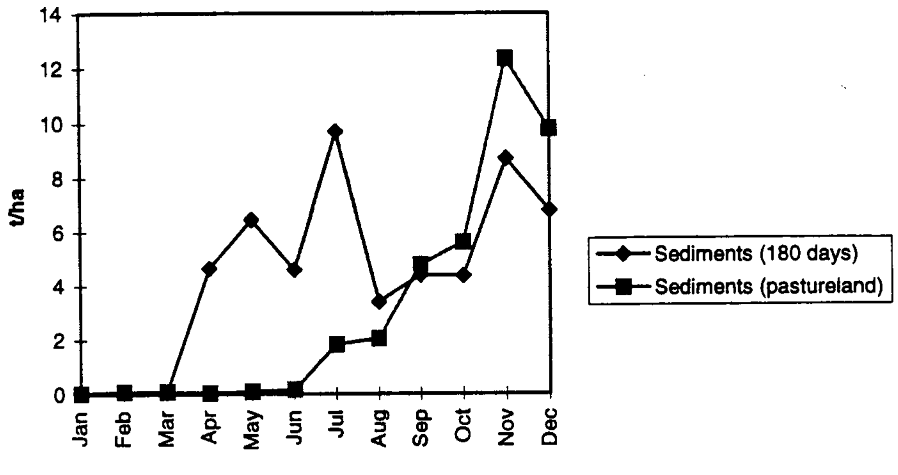

Figure 5.7: 180 Days - Grazing Effects on Sediments.

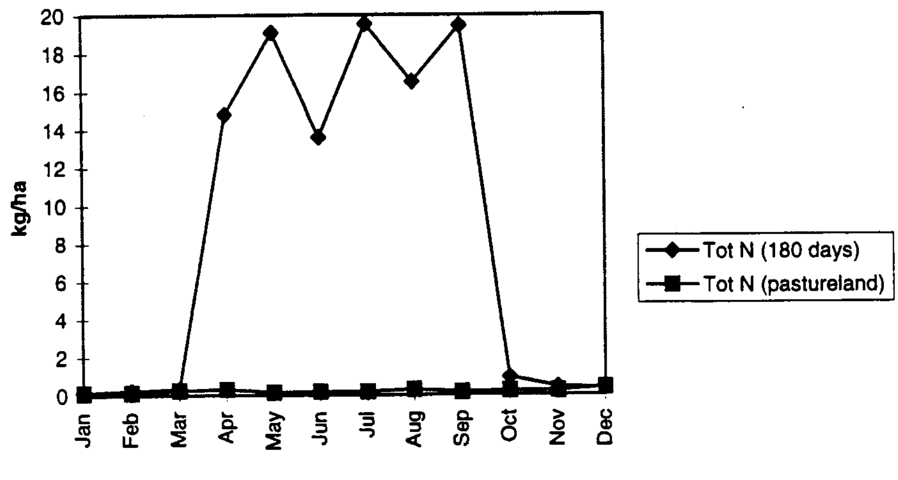

Figure 5.8: 180 Days - Grazing Effects on Total N Yields.

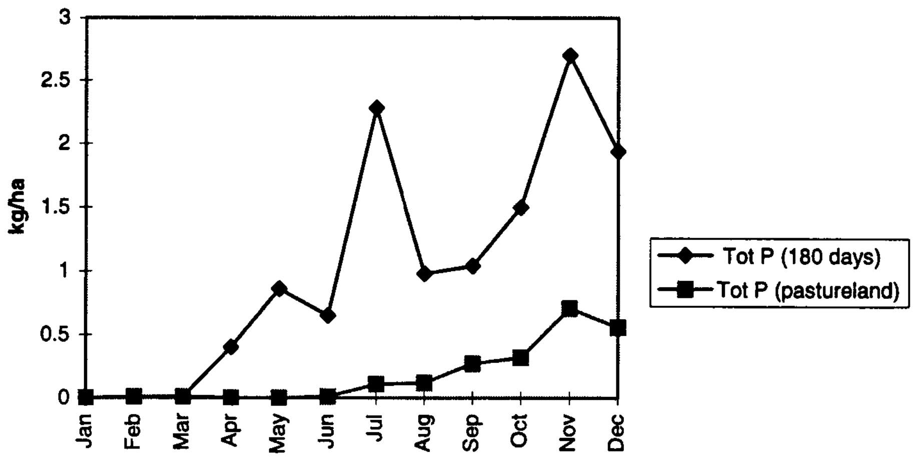

Figure 5.9: 180 Days - Grazing Effects on Total P.

Table 5.2: Big Shoal Creek Annual Nutrient and Sediment Loads For Grazing

	365 Days		180 days	
Total N	1,233,848 kg/yr	(1,360 tons/yr)	543,310 kg/yr	(598 tons/yr)
Total P	123,525 kg/yr	(136 tons/yr)	63,761 kg/yr	(70 tons/yr)
Sediments	395,846 t/yr	(436,345 tons/yr)	274,744 t/ha	(302,853 tons/yr)

involved using the fertilizer option of the model (unmodified version of SWAT) where fresh manure was applied to the land as fertilizer. As shown in Figure 5.10, manure application effects on sediments were virtually none as compared to the pastureland sediment yield. Figure 5.11 illustrates the immediate increase in total N yields as compared to the natural yields. On the other hand, Figure 5.12 reveals that the total P yields did not change from the pastureland yields. Table 5.3 summarizes the average annual loads of sediments and nutrients from manure applications (including pastureland loads).

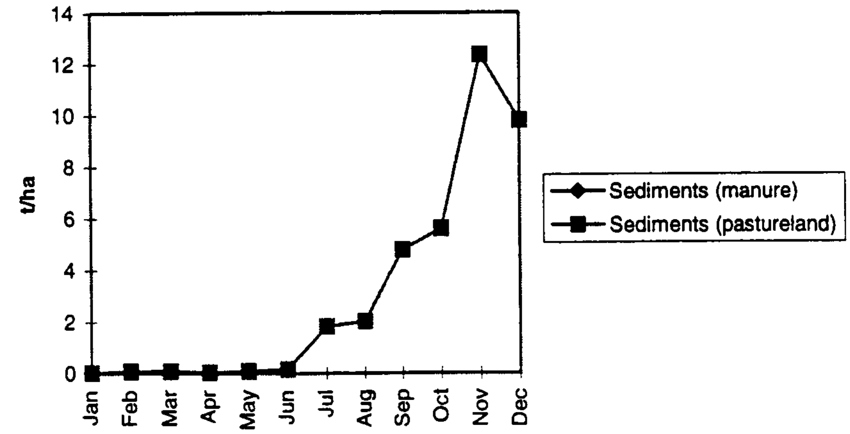

Figure 5.10: Manure Application Effects on Sediments.

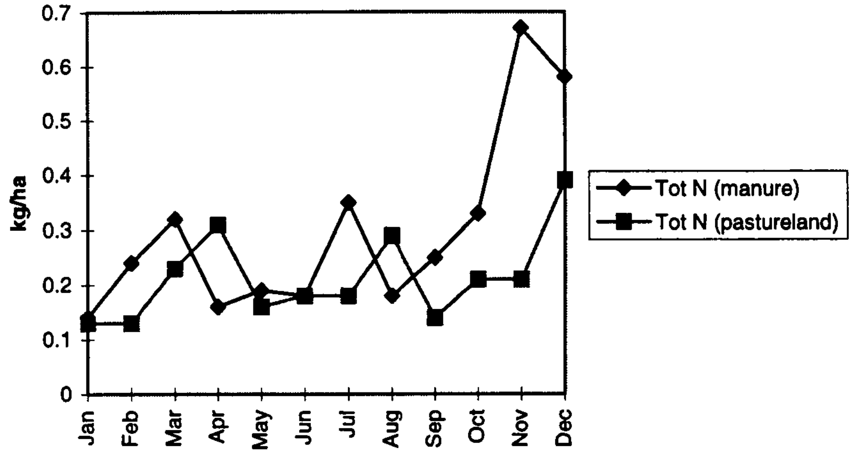

Figure 5.11: Manure Application Effects on Total N.

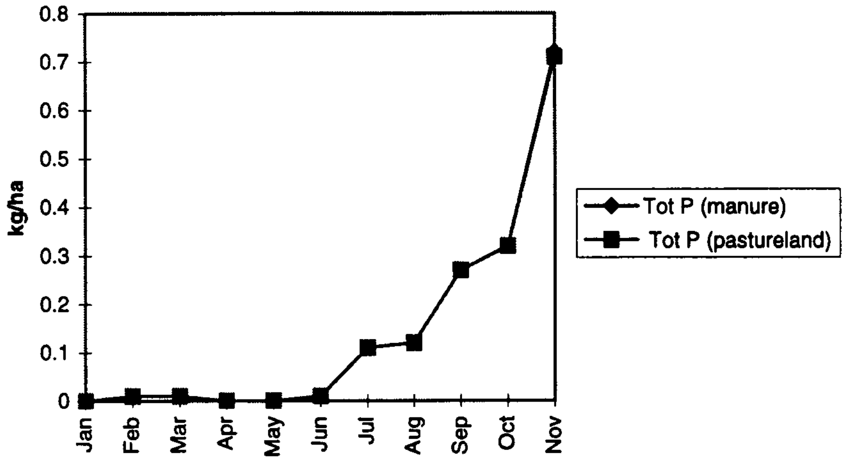

Figure 5.12: Manure Application Effects on Total P.

Table 5.3: Big Shoal Creek Annual Loads For Manure Applications

Total N	18,389 kg/yr	(20.2 tons/yr)
Total P	11,025 kg/yr	(12.1 tons/yr)
Sediments	190,417 t/yr	(209,898 tons/yr)

Discussion of Results

Clearly the effects of grazing significantly increased the amount of pollution loading. Trampling on the land and removal of residue destroy the land cover which directly leads to increased erosion and sedimentation. In all cases, P yields closely followed sediments because the larger Org-P components adsorb onto soil particles. Nitrogen yields varied more because the larger nitrate component is highly mobile and does not form strong chemical bonds with particle surfaces. When simulating grazing for 180 days, the annual loads were reduced by over 50% as shown in Table 5.2

The simulation of manure application, not including grazing effects, resulted in nutrient loads reduced by over 300% for 365 days and over 100% for 180 days (Table 5.3). This clearly shows the effect that sedimentation has on pollution loading since the manure results include no sediment loads.

The model simulated the pollution loading trends as expected. To determine the validity of the estimates, the results were compared to a previous study on the watershed. In 1994, local, State, and Federal organizations determined pollution loading estimates for Big Shoal Creek as part of the Flint Creek Watershed Project (FCWP). (Morgan County Soil & Water Conservation District, 1995) Table 5.4 compares the different results obtained from the studies.

The results obtained from SWAT were much larger than those determined by the FCWP. One of the reasons for this is the methodology used by the FCWP. The

Table 5.4: Comparison of Annual Pollution Loading Estimates

	FCWP	SWAT Pastureland	SWAT Manure*	SWAT 180 days*	SWAT 365 days*
Sediments	379 t	190,417 t	190,417 t	274,744 t	395,846 t
TKN	8,454 kg	3,395 kg	7,663 kg	8,168 kg	13,387 kg
Tot P	2,870 kg	10,999 kg	11,025 kg	63,761 kg	123,525 kg

* Includes pastureland loads.

following equation was used for pollution loading estimates (Morgan County Soil & Water Conservation District, 1995):

$$M = (CSt1 \times PC1) + ... + (CStn \times PCn)$$

where M = pollutant loading (tons/yr.), CSt1 = no. of cattle sites of type 1 (type), CStn = no. of cattle sites of type n (type), PC1 = pollution coefficient type 1 (ton pollutant/year/type), and PCn = pollutant coefficient type n (ton pollutant/year/type). The number and type of cattle site was obtained by TVA using aerial remote sensing techniques. Cattle sites were identified as small (15 cows), medium (50 cows), and large (110 cows).

The pollutant coefficient for each type of cattle site was determined by the following equation :

$$PCn = NA \times WT \times PR \times DR\ 0.1825$$

where PCn = pollutant coefficient (tons/site/yr.) and (n = P, TKN, etc.), NA = number of animals (number/site), WT = animal wt, PR = production rate (lb/day/1000 lb. live wt), DR = delivery ratio, and 0.1825 = unit conversion factor. The average beef cow was estimated to weigh 1000 pounds. The following (as excreted) production rates were used:

Manure production = 59.1 lb/day/1000 lb. live wt
Total Nitrogen = 1.6 lb./day /1000 lb. live wt
Phosphorus = 0.11 lb/day/1000 lb. live wt
Total solids = 6.78 lb/day/1000 lb. live wt

The delivery ratio was based on: (1) where the cattle are in the watershed and (2) the fate of the pollutant once it is introduced into the environment (i.e., movement, adsorption, volatilization). The delivery ratio was calculated by summing the products of the time spent in the general areas (in stream, in pastures, etc.) (in %) and the respective fates (in %) and dividing by 100.

This technique estimates the pollution loading without taking into effect grazing, consumption of biomass, continuous precipitation, groundwater, and other hydrological parameters which affect the transport of pollutants. On the other hand, the results determined by SWAT can be overly estimated (especially for P) due to several factors.

First of all, the model is simulating a watershed that is covered by 100% pastureland when in fact, the watershed is about 72% pastureland and 25% forest. To incorporate the forest land or to designate areas where no grazing occurs, the watershed would have to be divided into more subwatersheds and/or use a grid descrectization scheme. Both would require a multitude of additional information which could be obtained by extensive field work and/or the use of the SWAT model coupled with a geographical information system. The addition of forest land would significantly reduce the amount erosion and sedimentation, despite the grazing effects. For example, the watershed was simulated at 100% forest land and the model predicted the sediment yield to be 34.4 t/ha. By increasing the ground cover (residue) from 2,000 kg/ha to 10,1000 kg/ha, the sediment yield reduced even further to 15.7 t/ha.

Secondly, the FCWP values were low because the calculations do not include the cumulative effects of precipitation. Sedimentation is directly related to runoff which is directly related to precipitation. The transport of sediments and nutrients are both directly related to runoff in SWAT. Finally, the delivery ratio used by the FCWP was based on animal behavior and the fate of the pollutant once it was introduced into the environment. SWAT estimates a sediment delivery ratio for each runoff event using the equation (Arnold, 1996):

$$DR = (q_p/r_{ep})^{0.56}$$

where DR is the sediment delivery ratio, q_p is the peak runoff rate (mm/hr), and r_{ep} is the peak rainfall excess rate (mm/hr). Again, runoff (directly related to precipitation) is a driving factor in the calculating the pollution loads.

Figures 5.13 and 5.14 illustrate the relationship between precipitation and pollutants nutrients. The nitrogen component closely follows the rain while phosphorous slightly trails rain. This occurs because P transport must first rely on the sediment build up and then being transported through runoff.

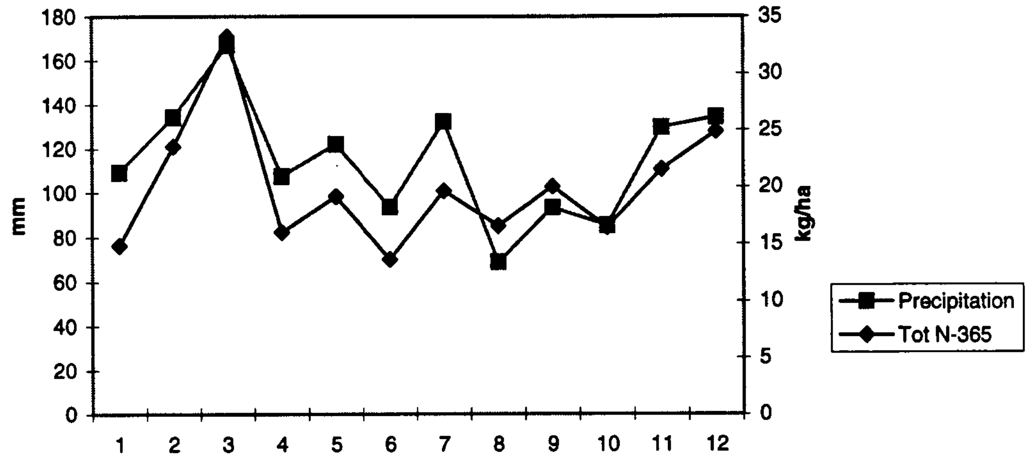

Figure 5.13: Precipitation and Total N.

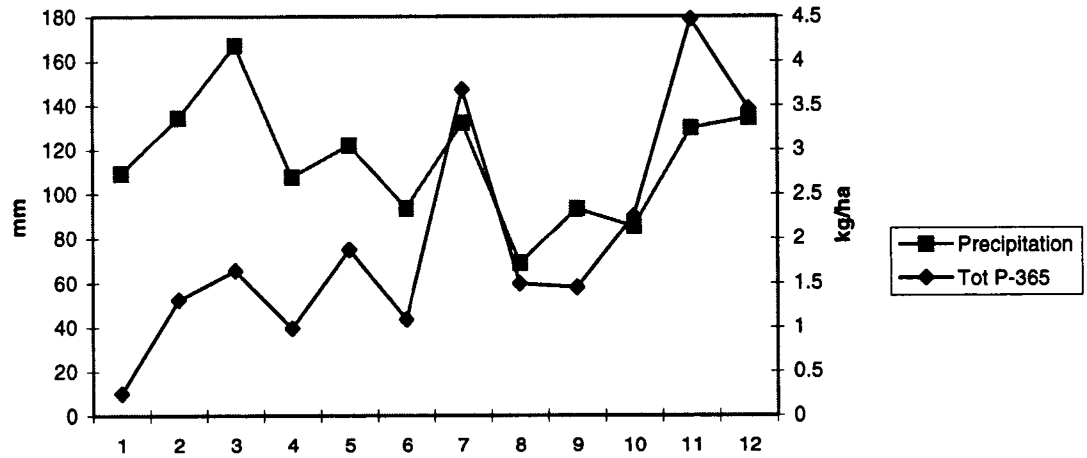

Figure 5.13 Precipitation and Total P.

CHAPTER VI

CONCLUSIONS

Conclusions

Water pollution potential from livestock waste are of sufficient magnitude to make it critically important to all citizens, and in particular, farmers, pollution control officials, and design engineers. SWAT clearly demonstrated the vast increases in pollution loading due to animal wastes. Pollutant loads were also shown to adversely impact water quality most severely during or after a storm event. Precipitation and runoff also proved to directly influence the transport of pollutants.

Grazing activities, in addition to animal waste application, accelerated pollution loading to over 100%. The adverse impacts of grazing exemplified in the study are related to changes in soil structure. Compaction of soils can lead to decreased infiltration, which in turn leads to decreased plant (cover) yields. As the vegetative cover decreases, the tendency for soil erosion and sedimentation increases. Ultimately more soil particles and sediments and available to transport pollutants and contaminate surface waters.

With the best agricultural management practices, pollution loading in pastures can be significantly reduced. Studies have shown that pollution loading is not entirely due to the number of animals but due to the runoff, sedimentation, and agricultural practices. (Khaleel et al, 1980)

Recommendations

Like any other problem, in order to be resolved, the problem itself must be identified and recognized. A study was conducted to determine the attitudes and practices of animal producers relative to the treatment and disposal of animal wastes. (Molner, and Litchie, 1989) The study found that while recognizing the value of animal waste as a feed and a fertilizer, most farmers tended to discount the extent to which animal waste is a source of pollution to groundwater, rivers, and streams. Few farmers acknowledged the necessity of making changes in the way they handle animal wastes. Consequently, they exhibited little commitment to improving this part of their operations. Once farmers and the general public recognize the problem, then they can move towards ameliorating the impacts of animal wastes on the environment by voluntarily complying with The Clean Water Act Section 208 programs.

Section 208 programs stress the education and implementation of best management practices (BMPs). Best management practices can be defined as a practice or combination of practices determined to be the most effective, practicable means of preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with water quality goals. (USDA SCS, 1992) They include agronomic and environmental effectiveness, economic feasibility, and social acceptability. Because BMP's are site specific they require the knowledge and cooperation from both the land-owner and the agricultural experts. The list of practices has evolved over the years and are generally available from Agricultural Extension Centers and Soil Conservation Districts. BMP's for managing animals include: controlling erosion and drainage;

rotational grazing; supplying water from a source other than streams and restrict access to streams; and stocking animals at no more than two cows per acre. (Vaigneur, H.O.)

Future Work

Opportunities exists to refine the methodologies used in determining the pollution loading in this study. For example, the waterhsed can be divided up into grid cells (or more subwatersheds) to better define the land use. This would significantly increase the amount and time required to obtain the inputs for the model. Just recently, an interface was developed for SWAT using a public domain geographical information system (GIS) called Graphical Resources Analysis Support Systems (GRASS) (US Army, 1988). The SWAT GRASS interface will automatically subdivide a watershed and then extract model input data from map layers and the associated relational databases for each subwatershed (or grid). (Arnold, et al, 1994). Both GRASS and the SWAT-GRASS interface (Srinivasan and Arnold, 1993) are readily available including a manual from the USDA ARS Agricultural Blackland Research Center in Temple, Texas.

SWAT and other hydrologic / agricultural models are tools used in assessing pollution loads. These tools can only be utilized by those who recognize the need to implement alternative land management practices. Changing waste disposal practices will depend on awareness and recognition of the problem and the availability of the solution. Many farmers rely on streams and rivers for stock watering and this can only be overcome through education and readily available technical and financial assistance.

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APPENDIX

SWAT INPUT FILES

Program Control Codes

Number of years of runoff simulation ___1___		NBYR
Beginning year of runoff simulation ___1996___		IYR
Number of subareas in basin ___24___		LU
Printout frequency- Monthly(0); Daily(1); Annual(2); ___0___		IPD
Will the rainfall be:		
Read in single rain gage for entire basin	(1) ______	NSIM
Simulated single rain gage for entire	(2) ___x___	
Read in one rain gage for entire basin	(3) ______	
Simulated for multiple rain gages	(4) ______	
Will the max & min temperatures be:		
Read in single max & min for entire basin	(1) ______	MSIM
Simulated single max & min for entire basin	(2) ___x___	
Read in max & min for each subbasin	(3) ______	
Simulated for each subbasin	(4) ______	
Number of times random number generator cycles before simulation begins ___2___		IGN
Code for stat collection on monthly water yield		
Skip collection (0) ___x___	Collect (1) ______	IWST
Code for stat collection on monthly sediment yield		
Skip collection (0) ___x___	Collect (1) ______	ISST
Reservoir code		IRES
Reservoir simulation for each subbasin ______		
Reservoir at basin outlet______		
Lake water quality inputs		IRESQ
Do not call lake water quality inputs (0) ___0___		
Call (1) ______		
Beginning day of simulation ___0___		IDAF
Last day of simulation ___0___		IDAL
Print code		IPRN
To print to .std file(0) ___0___		
Not to print to .std file(1) ______		
Print code for pesticide output file		IPRP
To print to .pst file(0) ___0___		
Not to print to .pst file(1) ______		
Reach number used for comparing with measured streamflow data___0___		IOPT
Statistics for comparing predicted (outflow from reach iopt) vs. measured streamflow (from the *.sta file).		
Code for potential ET option		IPET
Priestley-Taylor method(0) ______		
Penman-Monteith method(1) ___1___		
Hargreaves method(2) ______		
Streamflow adjustment		ILOG
Input [0] Do not take log of stramflow		
Input [1] Take log of streamflow		

When selecting ILOG=1, the base 10 log of reach outflow is performed before it it written to the .rch file. This is done for very large basins (i.e. Mississippi) where flows are extremely high.

A1: Control Code File

General Basin Data

Basin area (km^2) 51.57	DA
Rainfall correction factor 0.8	P2
Baseflow factor 1	BFF
Basin lag time (days) 0.23	BRT
Initial soil water storage--fraction of field capacity 0 (entering 0. allows SWAT to estimate it)	FFC
Pesticide numbers used in simulation (from database, max. 10)	NPNO(1-10)

0 0 0 0 0 0 0 0 0 0

A2: Basin Data

General Weather Data*

If automatic entry is used, enter:

Weather station number (Appendix II) 7

Weather station name (Appendix II) Huntsville and skip to Section 4.

If not, continue.

TP-40 10-year frequency 0.5 hour rainfall (mm)	67.56	TP5
TP-40 10-year frequency 6.0 hour rainfall (mm)	142.75	TP6
Number of years for maximum monthly 0.5 hour rainfall record	25	TP24
Latitude of watershed (deg)	34.50	YLT

Monthly Temperature Data*

Average monthly maximum air temperature(°C) — OBMX(1-12)

9.1	11.7	16.8	22.8	26.6	30.4	31.9	31.6	28.4	23	16.6	11.3

Average monthly minimum air temperature(°C) — OBMN(1-12)

-1.5	0.1	4.6	9.8	14.1	18.5	20.6	20	16.7	9.7	4.3	0.6

Coefficient of variation for monthly temperature (°C) — CVT(1-12)

0.31	0.25	0.21	0.15	0.11	0.07	0.06	0.05	0.10	0.14	0.20	0.26

Radiation Data*

Monthly average daily solar radiation (ly) — OBSL(1-12)

191	262	340	460	531	554	542	497	427	340	241	180

Rainfall Data*

Monthly maximum 0.5 h rainfall for period of record (mm) — WI(1-12)

20.07	16.0	28.5	26.7	35.3	26.7	43.2	33.0	31.8	16.5	20.6	20.8

Precipitation Generation Parameter Table* (Enter PRD and PRW or WVL)

Monthly probability of wet day after dry day — PRD(1-12)

0.29	.30	.32	.25	.27	.24	.31	.24	.2	.16	.26	.28

Monthly probability of wet day after wet day — PRW(1-12)

.49	.42	.44	.48	.45	.48	.42	.43	.46	.37	.45	.48

Days prec — WVL(1-12)

0	0	0	0	0	0	0	0	0	0	0	0

*These data will be brought in with the GETWEAT command, if used.

A3: Weather Data

Weather Data (.wgn continued)

Mean RMN(1-12)

11.7 12.0 15.8 13.5 12.7 10.16 11.4 8.89 12.0 12.4 12.0 13.2

Standard deviation RST(1-12)

14.5 14.2 21.3 16.3 17.5 14.2 16.5 12.5 15.5 16.5 15.0 17.2

Skew coefficient RSK(1-12)

1.58 .64 1.85 1.10 2.15 2.33 2.13 1.97 1.28 2.01 [illegible] 1.49

Dew point DEWPT(1-12)

1.31 1.76 3.88 8.94 14.3 18.7 20.4 20.0 16.5 10.4 4.29 1.11

Wind speed UAVM(1-12)

4.08 4.3 4.5 4.06 3.29 3.09 2.76 2.67 3.11 3.17 3.62 4.07

*These data will be brought in with the GETWEAT command if used.

A3: (continued)

4. Subbasin Data (For Subwatershed #1)

Fraction of basin in each subarea .062	FLU
SCS runoff curve number - Condition II 61	CN2
CO2 concentration (ppmv) 302	CO2
Water content of snow on ground at start of simulation (mm) 0	SNO
Main channel length in each subbasin (km) 1.067	CHL1
Average channel slope in each subbasin (m/m) 0.014	CHS
Average main channel width (m) 5.5	CHW1
Effective hydraulic conductivity of channel alluvium (mm/hr) 7	CHK1
Channel N value 0.05	CHN
Overland flow N value 0.06	OVN
Main elevation of the subbasin (m) 240	ELEV
Return flow travel time(days) 0	RT
Sediment concentration in return flow 500	CSS
USLE erosion control practice factor P 0.6	ECP
Average slope length(m) 209	SL
Average slope steepness(m/m) 0.076	STP
Initial residue cover(kg/ha) 2000	RSDIN
Monthly precipitation increment (%)	RFINC(1-12)
Monthly temperature increment (°C)	TMPINC(1-12)
Monthly solar radiation increment (lys)	RADINC(1-12)

A4: Subbasin Data

Subbasin Data (.sub continued)

Monthly relative humidity increment (%) HUMINC(1-12)

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

Monthly CO2 increment (ppm) CO2INC(1-12)

_____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____ _____

A4: (continued)

5. **Routing Data**

Average channel width(m) 5.48	CHW2
Average channel depth(m) 0.61	CHD
Channel slope(m/m) 0.014	CHSS
Channel length(km) 1.067	CHL
Channel N value(mm/hr) 0.05	CHNN
Effective hydraulic conductivity of alluvium (mm/hr) 7	CHK2
Channel USLE K factor 0.5	CHXK
Channel USLE C factor 0.8	CHC

A5: Routing Configuration Data

6. **Reservoirs with a Subbasin Data**

Fraction of each subbasin that flows into ponds________ FP

Total surface area of all ponds in each subbasin(ha)________ SAX

Runoff volume from pond catchment area required to fill empty ponds at principle spillway(ha-m)________ VMX

Total surface area of all ponds in subbasin at emergency spillway(ha)________ SAE

Runoff volume from pond catchment area required to fill empty ponds at emergency spillway(ha-m)________ VME

Initial pond volumes(ha-m)________ V

Seepage through dam(m^3/day)________ SEPP

Initial sediment concentration in ponds(ppm)________ CS

Normal sediment concentration in ponds(ppm)________ CFP

Hydraulic conductivity of pond bottoms(mm/hr)________ HC

Beginning month of "non-flood" season for reservoir routing________ IFLOD1

Ending month of "non-flood" season for reservoir routing________ IFLOD2

No. of days to reach target storage from current reservoir storage________ NDTARG

Fraction of subbasin that flows into wetlands________ FW

Total surface area of all wetlands in subbasin to principle spillway(ha)________ SAXW

Runoff volume from wetlands catchment area required to fill empty ponds at principle spillway(mm)________ VMXW

Total surface area of all wetlands in subbasin at emergency spillway(ha)________ SAEW

Runoff volume from wetlands catchment area required to fill empty ponds at emergency spillway(mm)________ VMEW

Initial wetlands volumes(mm)________ VW

Seepage through dam (contributes to flow) (m^3/day)________ SEPW

A6: Pond Data

Pond Data (.pnd continued)

Initial sediment concentration in wetlands(ppm)_______	CSW
Normal sediment concentration in wetlands(ppm)_______	CFW
Hydraulic conductivity of wetlands bottoms(mm/hr)_______	HCW

A6: (continued)

7. **Reservoir in the Routing Network**

Month the reservoir became operational_____	MORES
Year the reservoir became operational_____	IYRES
Simulate with principle outflow(no control-old method)(0)_______ Use measured outflow(1)_______ Simulate controlled outflow-target release(2)_______ Simulated inflow-outflow regression method(3)_______	IRESCO
Total reservoir surface area at emergency spillway(ha)_______	SAF
Runoff volume from reservoir catchment area required to fill to emergency spillway(ha-m)_______	VRF
Total reservoir surface area at principal spillway(ha)_______	SAS
Runoff required to fill to principle spillway(ha-m)	VRS
Initial reservoir volumes(ha-m)_______	VR
Average principal spillway release rate($m^3/s/km^2$)_______	RRR
Seepage through dam(m^3/day)_______	SEPD
Initial sediment concentration in reservoirs(ppm)_______	CSR
Normal sediment concentration in reservoirs(ppm)_______	CFR
Hydraulic conductivity of reservoir bottoms(mm/hr)_______	HCR
Size classification-IRESCO=3_______	LS
Subbasin water withdrawn from reservoir returns to_______	IRTNSN
Fraction of water withdrawn that returns_______	WURTNF
Average monthly water withdrawn from reservoir in network(ha/m)	WURESN

Measured outflow(entered if IRESCO=1)	RESOUT

A7: Reservoir Data

8. **Pesticide Data**

Pesticide	Initial pesticide on foliage(kg/ha) FFP	Initial pesticide on ground(kg/ha) GP	Enrichment ratio for pesticides ERP
1	______	______	______
2	______	______	______
3	______	______	______
4	______	______	______
5	______	______	______
6	______	______	______
7	______	______	______
8	______	______	______
9	______	______	______
10	______	______	______

Organic N concentration (g/m^3) WN	Phosphorus concentration (g/m^3) WPO	Concentration of labile (soluble) P (g/m^3) AP
______	______	______

A8: Pesticide Data

9. **Soils Data***

Number of soil layers 4 — NS
K-Factor 0.4 — EK
Pass #200 sieve ______ — SIL
Soils series name top.soil — SNAM

Layer #	1	2	3	4	5	6	7	8	9	10	
Depth to bottom layer(mm)	228.6	495.3	1244.6	1765.3							Z
Bulk density	1.36	1.48	1.53	1.53							POR
Available water capacity(mm/mm)	0.2	0.18	0.125	0.12							AWC
Saturated conductivity(mm/h)	33.02	33.02	18.16	20.7							SC
Organic carbon content(%)	1.31	.05	.05	.05							CBN
Clay content(%)	20.5	29.5	36.5	44.5							CLA
Sand content(%)											SAN
Rock fragments(%)											ROCK
Moist soil albedo											SALB
Dry soil albedo											SALBD
Salinity											SALEC
Initial NO3 concentration(g/t)	10	5	5	5							WNO3

Maximum rooting depth(mm) ______ — ZMX

*These data will be retrieved with the "RUNSOIL" program and entered into UTIL with the "LOAD" command.

A9: Soils Data

10. Management Data

Number of years of rotation 1 NROT

Number of pesticides used in simulation 0 NPTOT

MON	DAY	HUSC	ITILL	$HU^{1,5}$ $BMEAT^{9}$	$NCRP^{1,5}$ $ITIL^{6}$ $NDGRAZ^{9}$	$AIRG^{2}$ $ALAI^{8}$ $HITAR^{6}$	$ANTI^{8}$ DM^{8} $DMTAR^{6}$	$PHOS^{3}$	$INPEST^{4}$ $IFERT^{3}$	$PAMT^{4}$ $FRORGN^{3}$	$CN2UP^{1,6}$ $FRORGP^{3}$
1	1		1		36						75
1	1		9	19.5	365	15.6		25.8	1		

The following table includes the operation and code number for ITILL to be input in the SWAT model.

ITILL - Operation Code Number

1=plant operation
2=irrigation operation
3=fertilizer operation
4=pesticide operation
5=harvest and kill operation
6=tillage operations
7=harvest only
8=kill only
9=grazing

The superscript numbers stands for inputting the variable if ITILL is equal to this number, e.g., if ITILL=9, then the variable BMEAT (Daily biomass removed by grazing in kg/ha) should be input.

A10: Management Data

11. **Automatic Management and Water Use**

Auto irrigation(1), input dates and amounts(-1), no irrigation(0) 0 ______ IRR

If IRR=1, input water stress factor______ WSF

Irrigation runoff ratio______ EFI

Nitrogen stress factor to trigger fertilization______ ANSF

Soil N level to fertilize to(kg/ha)______ FNMX

Maximum amount of N that can be applied in one year(kg/ha)______ ANMX

Minimum interval between fertilizations(days)______ IDMN

P fertilizer management for auto fertilization IPMAN
High management-restores P level in upper 2 layers to 30 ppm(3)______
Medium management-restores P level in upper 2 layers to 20 ppm(2)______
Low management-restores P level in upper layers to 10 ppm(1)______

Soil layer that fertilizer is applied to______ LAFERT

Fraction of organic N in fertilizer______ FORGN

Fraction of organic P in fertilizer______ FORGP

Average daily water use from the reservoir by month(ha-m) WURES

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average daily water use from the reach by month(ha-m) WURCH

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average daily water use from the shallow aquifer by month(ha-m) WUSHAL

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average daily water use from the deep aquifer storages by month(ha-m) WUDEEP

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

A11: Automatic Management /Water Use

12. **Groundwater Data**

Initial groundwater height(m) 1.59	GWHT
Initial groundwater flow contribution to streamflow 3	GWQ
Alpha factor for groundwater 0.6 (Arnold, 1996)	ABF
Specific yield 0.2 (Zheng et al, 1995)	SYLD
Groundwater delay(days) 1	DELAY
Revap coefficient-fraction of recharge (root zone that goes to revap) 0.1 (Arnold, 1996)	REVAPC
Fraction(0-1) of root zone perc that percolates past shallow gw into deep gw 0.1 (Arnold, 1996)	RCHRGC
Revap storage 250	REVAPMN
Initial deep aquifer storage(mm) 1590	DEEPST

A12: Groundwater Data

13. **Lake Water Quality Data**

Initial pesticide concentration(mg/m³)_______	CPEST1
Reaction coefficient(1/day)_______	VREAC
Volatilization coefficient(m/day)_______	VVOL
Partition coefficient(m³/day)_______	VPART
Settling velocity(m/day)_______	VSETL
Resuspension velocity(m/day)_______	VRSUP
Mixing velocity(diffusion)(m/day)_______	VMIX
Initial pesticide concentration in bottom sediments(mm/m³)_______	CPEST2
Reaction coefficients(1/day)_______	VREACT2
Burial velocity(m/day)_______	VBURY
Depth of active sediment layer(m)_______	DACT
Phosphorus settling rate(m/day)_______	VSETLP
Initial total phosphorus concentration in lake (mg/L)_______	PHOSL
Subbasins weather to use in lake balance_______	ISUBL

Average monthly wind speed(m/s) — UMW

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average daily effluent flow (m³/day) — EFFLQ

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average temperature of effluent(°C) — EFFLT

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average temperature of natural inflow(°C) — FLOWT

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

Average monthly dewpoint temperature(°C) — TD

____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____ ____

A13: Lake Water Quality Data

VITA

Diane Rios Erb was born on December 27, 1968 in Los Angeles, California. She has an older brother, Robert, and a sister sixteen years younger named Desiree. Diane grew up in the greater Los Angeles area and attended St. Paul High in Santa Fe Springs for three years. She then moved to Ontario, Ca. where she graduated from Ontario High in 1987. She went on to pursue an education in engineering at California State Polytechnic University in Pomona. During her school years Diane participated in several internships including, The Gas Company, NASA, and the South Coast Air Quality Management District. Diane graduated in June, 1994 with her Bachelor's in Mechanical Engineering.

Diane continued with her education at the Florida Institute of Technology in Melbourne, Florida. After one semester she married her fiancee, Daniel Erb, and moved to Tullahoma, Tennessee where she finished her graduate studies at the University of Tennessee. Diane graduated from the University of Tennessee Space Institute in December 1996 with a Master's in Engineering Science and Mechanics, with an emphasis in Environmental Engineering.