

**RISK ASSESSMENT FORMULATION
FOR NITRATE LEACHING**

by

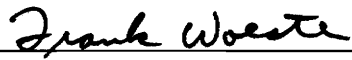
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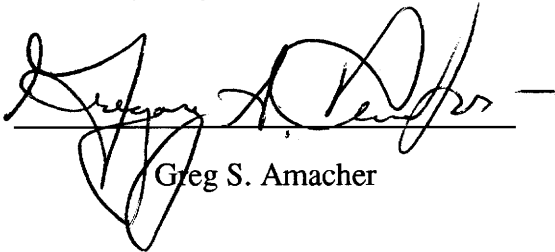
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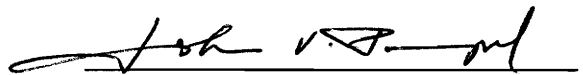
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(ABSTRACT)

A framework for evaluating the risk of water pollution from the application of liquid dairy manure to agricultural fields was developed and applied. The GLEAMS (Groundwater Loading Effects of Agricultural Management Practices) (Ver 2.1) model was used to simulate $\text{NO}_3\text{-N}$ leaching below the root zone for different land application rates of liquid dairy waste for fields in Georgia and Texas. Probability distributions of yearly-maximum nitrate concentrations were developed for each application rate at each site using the simulated nitrate concentrations. The probability of failure (exceeding 10 mg/L $\text{NO}_3\text{-N}$) for each application rate was determined from its corresponding distribution. An appropriate fine for farmers based on probability of failure for different land application rates was determined through economic analysis. The expected risk to farmers in monetary terms was determined for each application rate based on possible fines and the probability of failure. The monetary risk of nitrate leaching to ground water was compared to the social value of ground water.

The probability of failure for liquid dairy waste application rates between 200 to 800 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$ ranged from 0.0022 to 0.74 for Tifton, GA. The probability of failure for liquid dairy waste application rates between 0 and 1000 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$ ranged from 0.00 to 0.85 for Overton, TX. The maximum application rate that was environmentally acceptable

for both Texas and Georgia was 250 kg•N/ha/yr based on the probability of failure. Fines of \$1100/ha and \$700/ha for the Georgia and Texas sites, respectively, would provide farmers with economic incentives not to exceed an application rate of 250 kg•N/ha/yr. These fines resulted in risks to farmers of \$814/ha in Georgia for 800 kg•N/ha/yr application rate and \$595/ha in Texas for 1000 kg•N/ha/yr rate. This compares with a social value ranging from \$860/ha to \$1432/ha of clean ground water.

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To my dad who taught me hard work will get you anywhere.

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1.0 Introduction

Risk assessment is the estimate of the value or level of risk for a particular event where risk is defined as the chance of injury, damage, or loss to people and property. Over the last several decades, risk assessment has been used as a management tool to protect water sources from polluting industries by determining an acceptable level of risk and then setting discharge standards based on those levels. In the last decade, the focus of environmental risk assessment has shifted from industry to agriculture. However, managing risk in a formalized manner in agriculture has proven to be difficult. Unlike industry where residuals can be measured at a point, the majority of agricultural discharge can not be measured at a specific point. Agricultural discharge that enters water bodies from diffuse locations is termed nonpoint source (NPS) pollution.

Nonpoint source pollution is a major source of contamination affecting water quality. NPS pollution affects both ground and surface waters. One problem that arises with NPS pollution is identifying which fields or practices contribute the most significant amounts of pollution. To evaluate the impact a field may have on local water supplies, the potential risks associated with different land management practices need to be quantified. Risk involves both the frequency and magnitude of a hazard (Henley and Kumamoto, 1981). The frequency with which different land management practices pollute water sources can be estimated by developing probability distributions of chemical concentrations in ground and surface waters for a given time period. The magnitude or consequence per polluting event can be evaluated in monetary terms by determining the cost of damage from polluting a water source.

Probability distributions offer a straightforward approach to determining risk. Unlike many other techniques which look at initiating and critical events, failure modes, and hazards, probability distributions focus on system results or output (Henley and Kumamoto, 1981). Probability distributions work well with systems where the processes between the input and output are variable or unknown, such as nitrogen transport through the vadose zone, where there is great uncertainty as to the exact events that occur. However, there must be ample output data in order to develop a probability distribution. Modeling is often used to simulate a system and provide long-term data in order to develop probability distributions. Probability distributions also allow the risk of a system to be evaluated using data without having to fully understand the system. Many other techniques require the risk analyzer to be an expert on the systems under examination in order to study the different modes of the system. Probability distributions allow the risk analyzer to focus on the end results saving time and money. However, the cause of failure can not be determined using probability distributions.

The need for quantifying risk has increased as water resources have become more polluted. Due to the excess pollution levels in water sources, not only do the most detrimental land management practices need to be evaluated, but all land management practices need to be evaluated and alternative practices which would effectively reduce the amount of pollution entering water bodies need to be assessed. Quantification of risk could aid regulatory officials in determining acceptable land management practices, determining the amount of fertilizer, insecticide, herbicide, or other chemicals that could be applied safely, and establishing guidelines and regulations for different land management practices.

This research focused on nitrate leaching due to waste management activities on agricultural lands, specifically the application of liquid dairy waste to agricultural fields. Liquid dairy waste from feedlots, milking parlors, and stalls has had an adverse effect on water quality. Land application of liquid dairy waste has been used in an attempt to utilize and dispose of dairy waste while minimizing contamination to ground and surface waters from these sources. The impact of land application of dairy waste at a given site depends on waste forms, application rates, irrigation rates, crop cover, weather, and time of application.

Many techniques are available to quantify risk. Some of the more common techniques include preliminary hazard, failure modes and effects, criticality, fault tree, event tree, and cause-consequence analysis (Henley and Kumamoto, 1981). For this research, a technique which utilizes probability distributions and damage costs was used. The process involved in quantifying risk was the focus of this research. Dairy waste management is a large agricultural industry that presents a significant potential for ground water contamination. However, the results from this type of research are site specific and only general conclusions can be made concerning other sites. The overall goal of this research was intended to provide a framework for evaluating the risk of water pollution from agricultural land management practices.

1.1 OBJECTIVES

1. To develop probability distributions of maximum concentrations of $\text{NO}_3\text{-N}$ leaching for the study life due to land application of liquid dairy waste.
2. To estimate the probability that $\text{NO}_3\text{-N}$ leaching exceeds 10 mg/L over the study life for different application rates of liquid dairy waste.
3. To determine the magnitude of a fine for concentrations of $\text{NO}_3\text{-N}$ leaching exceeding 10 mg/L which offers economic incentives for farmers to reduce their liquid dairy waste application rates to environmentally acceptable rates.

2.0 Review of Literature

There were five major topics to this research: risk assessment, nitrate leaching, probability distributions, economics, and GLEAMS. The following sections discuss published studies related to these topics.

2.1 Risk Assessment

The major challenge in evaluating risk with respect to water quality is that natural variability in space and time of physical parameters and inputs to the system show random deviations. Risk assessment provides a general theoretical framework for dealing with randomness. Risk assessment involves the following four steps (Ganoulis et al., 1991): (1) hazard identification, (2) risk quantification, (3) consequence of failure, and (4) perception of the consequences.

Studies in the past have used risk assessment in dealing with water resources. Dahab and Lee (1991) developed a multicriterion methodology to assist decision makers in determining a nitrate risk management strategy that best satisfies the objective of reducing risk and assuring technical feasibility. This methodology consisted of defining nitrate risk management strategies, defining basic indicators, grouping basic indicators into progressively more general groups, and ranking the management strategies. This methodology is a first step in nitrate risk management. By being straightforward and well defined, this methodology allows a system to be separated and evaluated in individual components.

Nitrate risk managers can then make individual decisions for each component of a system based on the costs and risk without having to make a decision on a system as a whole. Additionally, different quantitative risk methods can be used with different components of a system. This system would work well with a dairy farm, where management could look at the environmental risk, technical feasibility, and cost of the different farm operations that could affect nitrate concentrations in ground water.

Similar to Dahab and Lee (1991), Duckstein et al. (1991) also emphasized using a multicriterion framework along with ranking strategies for risk management. They developed a system framework for defining and trading off criteria related to risk and reliability in hydrologic system design and operation with an emphasis on extreme events. Duckstein et al. measured the reliability and risk of a system using performance indices and figures of merit where the performance indices were determined from the level of service, quality of service, and ratio of resistance to load. The figures of merit were criterion functions defined over the components of the performance indices. The importance of this study is that by using performance indices, criteria related to risk and reliability can be weighted and decisions can be made accordingly.

Bobee et al. (1991) showed that flood flow data are adequately represented by Pearson type 3 or Log-Pearson type 3 distributions. Bobee et al. developed a methodology for determining the flood return period and variance from these distributions. From these parameters, confidence intervals could be determined which could be used to calculate the risk of exceeding flood flow of a given return period. Confidence intervals are useful because they give managers insight to the variance as well as the return period of floods. This study is of value to all managers, especially those in agriculture. By being

able to determine the confidence intervals and not just the return period, managers can make more informed decisions pertaining to flood risks.

2.2 Nitrate Leaching

Numerous studies have been conducted which have monitored nitrate concentrations and simulated nitrate leaching to ground water. Bruggeman et al. (1995) monitored nitrate concentrations in shallow and deep wells in a rural county in Virginia. They evaluated and demonstrated the applicability of a monitoring framework developed by Mostaghimi et al. (1993). Nitrate concentrations above the US EPA drinking water standard of 10 mg/L NO₃-N were found in 17% of the shallow and 1% of the deep wells. Additionally, nitrate above natural concentrations (0.2 mg/L) was detected in 63% of the shallow and 5% of the deep wells. Other rural well water studies (e.g., LeMasters and Doyle, 1989; Kross et al., 1990; Holden et al., 1992; Schock et al., 1992; Koterba et al., 1993) indicated the percentage of wells with nitrate levels above natural concentrations were generally above 50%. With the results from these studies confirming the widespread impact nitrate has had on rural ground water, further risk assessment formulation for nitrate in ground water needs to be addressed.

Adelman and Dahab (1993) developed a solute transport model from available data to calculate the leaching rate of nitrate. The transport model computed 50 nitrate concentrations over a 40 year time period. The probability of exceeding 10 mg/L NO₃-N was determined from the 50 nitrate concentrations. By normalizing and balancing the risk and return, they concluded that the optimal farm management practice consisted of an above average irrigation rate and a below average nitrogen fertilizer rate. This study

pointed out that the optimal farm management practice does not necessarily have to have high nitrogen fertilizer rates. Adelman and Dahab determined the risk of excessive ground water nitrate for the optimal practice was 51 percent. However, the authors assumed that normalized risk and return are equally weighted by farm managers. Return may carry a greater weight than risk for many managers.

Spalding et al. (1993) studied the effects of sludge disposal on ground water nitrate concentrations in the bottomland of the Platte River Valley in south-central Nebraska. Aerobically digested secondary sludge was injected 15 to 30 cm below the soil surface on a 32 ha field from 1980 through 1988. Concentrations in down gradient shallow monitoring wells increased from preinjection concentrations of approximately 8 to 20 mg/L $\text{NO}_3\text{-N}$ by 1983. By the late 1980's concentrations were as high as 40 mg/L $\text{NO}_3\text{-N}$ and 48 percent of down gradient shallow monitoring wells exceeded 10 mg/L $\text{NO}_3\text{-N}$. Using eight multilevel samplers and four piezometer bundles, Spalding et al. delineated a nitrate plume of contamination approximately 1.3 km by 0.3 km. They determined that the waste injected into the cornfield was responsible for the nitrate plume in the ground water. This study indicates that high rates of waste applied to agricultural fields may have adverse effects on ground water by increasing nitrate levels. There is a further need to evaluate the risk of nitrate contamination in ground water associated with different rates of land applied wastes in order to avoid similar catastrophes.

Madramootoo et al. (1995) used the CREAMS model (Knisel, 1980) to simulate nitrate leaching under a potato crop. The results showed that nitrate exceeded 10 mg/L for all simulated concentrations in which the simulated percolation exceeded zero. However, CREAMS predicted zero percolation and thus zero nitrate concentration for

several days in which the observed flow and concentrations exceeded zero. The study shows that the CREAMS model does not simulate daily nitrate concentrations and percolation depths very well. However, CREAMS underpredicted nitrate concentrations by only 7.7 and 31.7 percent for each year simulated. These values provide some degree as to the magnitude of nitrate leaching and are useful for making general nitrate leaching predictions.

2.3 Probability Distributions

Probability distribution functions (pdfs) have been used extensively in the wood industry for many decades to determine the frequency of occurrence of a failure event. In the last couple decades, pdfs have been used increasingly in agriculture. Valdes et al. (1990) derived the probability distribution for the initial moisture in a catchment based on the one-dimensional infiltration-exfiltration process of a layer of soil. Using analytical expressions for the initial and final soil moisture concentrations during a storm event, simulations were run for different combinations of soil and climate data to evaluate the average soil moisture concentration and its variance at the beginning of a storm. A beta pdf was fitted to characterize the probability distribution and a general expression for both the mean and variance was given based on climate and soil characteristics. Hydrologists could then completely characterize the pdf of the initial soil moisture concentration before a storm. In a similar study, Farago (1985) derived a stochastic model for estimation of soil moisture distribution. Using a simplified surface-water balance equation, the probability distribution of the soil moisture was expressed in a recurrence form and could be estimated effectively with limited data. These studies demonstrate the use of probability distributions as an environmental management tool. Additionally, they show

that probability distributions work well with complicated, highly variable, and stochastic variables.

The following studies show the variety of agricultural applications in which probability distributions can be utilized. Thomas and DeLorenzo (1994) fitted Weibull probability distributions to milk yield from dairy cows. Using the distributions, they were able to simulate monthly and yearly herd milk yield. Shahabasi et al. (1995) used a simulation model to calculate the allowable depth of apples stored in bulk. The model used cumulative probability distributions for the elastic modulus and the normal strain at failure and gave the percent of apples with bruises as a function of storage depth. Lewis et al. (1995) used probability distributions for rill flow and density to develop an erosion model.

2.4 Economics

Many research reports conclude with potential consequences to the environment of exceeding a nitrate threshold. However, from a regulator's viewpoint, these consequences need to be expressed in monetary terms so that the appropriate value can be placed on fines, taxes, or subsidies. Additionally, monetary values are needed so that cost-benefit analysis can be conducted for future land management uses. Bockstael et al. (1987) described three types of models used to estimate the value of water quality improvements: systems of demands, discrete choice models, and the hedonic travel cost approach. These models were contrasted and their relative usefulness in answering water quality policy questions investigated. Bockstael et al. concluded that the discrete choice model was best for decision making because of its explicit consideration of decisions and welfare. Welfare

refers to the utility or benefits people receive from an environmental good. A typical question for determining the water quality at a beach would ask how many trips a family takes a year to the beach, from which a demand function can be constructed. When placing values on water quality or any environmental commodity, care must be taken as to which model is selected and how the results should be interpreted. Often financial constraints will determine which model will be used and this may conflict with the appropriate model being selected.

Schmit and Knoblauch (1994) studied the impact of nutrient loading restrictions on dairy farm profitability. They utilized a linear programming model to determine the economically optimal dairy herd intensities, manure application rates, and crop mix for unrestricted and restricted scenarios of N loss on dairy farms. They compared a small dairy farm (60 cows) with no storage and daily manure spreading to a large dairy farm (250 cows) with 6 months storage and semi-annual spreading. Both farms were substantially affected by the imposition of restrictions on N loss. However, profitability decreases were relatively smaller on the larger farm because of better conservation and more efficient utilization of manure nutrients.

Edwards (1988) conducted a contingent valuation study to determine a household's willingness to pay to prevent uncertain, future nitrate contamination of a potable supply of ground water for Cape Cod, Massachusetts. A contingent valuation study is a survey-based approach for ascertaining how much respondents are willing to pay to preserve an environmental commodity. Edwards found that the present value of aggregate benefits for having clean ground water increased as the probability of supply and demand of having clean ground water increased. This conclusion is very important

when trying to place a value on environmental goods based on societal values. People are not willing to pay as much to prevent ground water from being contaminated if they are not certain contamination^o will be prevented or are uncertain about their own demand for the water as they are when contamination prevention and usage are certain. However, assuming the probability of supply and demand of clean ground water was certain, Edwards determined the value of clean ground water to be \$1,600 per year per household (\$133/month).

Jordan and Elnagheeb (1993) researched the social value of improved ground water for Georgia using the contingent valuation method. Values were determined by asking respondents to indicate the most they would be willing to pay above their current water bill to avoid the risk of increasing nitrate in drinking water. The average willingness to pay was \$120.84/yr (\$10.07/month) for city/county and \$148.56/yr (\$12.38/month) for private well water users. Based on these values, the aggregate willingness to pay per year was \$275.4 million for the state of Georgia.

Sun et al. (1992) developed a conceptual model for estimating the option price of ground water quality protection. Option price is an individual's maximum willingness to pay to secure the option to use a resource or commodity in the future. A contingent valuation study was utilized to measure the potential benefits of ground water contamination abatement in southwestern Georgia. The survey contained a hypothetical referendum survey designed to measure a household's willingness to pay for a new program which would definitely protect groundwater from contamination by agricultural chemicals. Hypothetical payments were a reduction in the respondent's income. The

mean option price of ground water pollution abatement was calculated as \$641 annually (\$53.42/month) per household.

Edwards (1988), Jordan and Elnagheeb (1993), and Sun et al. (1992) reported different results for households' willingness to pay to protect or improve ground water quality. Edwards' Cape Cod study and Jordan and Elnagheeb's Georgia study focused directly on nitrates while Sun et al. looked at agricultural chemicals as a whole for southwestern Georgia. Results from these three studies show that willingness to pay values for Cape Cod, Massachusetts were greater than for Georgia. One possible explanation may be that Cape Cod residents were familiar with the ground water pollution problems already faced by other coastal regions such as Long Island, New York and hoped to avoid these problems while Georgia residents were less aware of potential ground water problems. Differences in the cost of living and income levels between the two locations may also have influenced the results. Results also showed that southwest Georgia residents were willing to pay more to protect the ground water than the entire population of Georgia. These differences may be attributed to Jordan and Elnagheeb's study focusing on nitrates while Sun et al. looked at agricultural chemicals as a whole. However, differences between the studies may simply be due to different biases associated with contingent valuation studies such as hypothetical, vehicle, and information biases.

Lambert (1990) researched the economic impact of reduced nitrogen fertilizer use in agricultural production in Arizona. Lambert developed a model to measure changes in farm income and risk impacts resulting from both an input tax on fertilizer and quantitative restrictions designed to reduce nitrogen application rates. Results showed that by raising the cost of fertilizer from \$0.29/kg (\$0.13/lb) to \$2.53/kg (\$1.15/lb) of nitrogen, the

optimal nitrogen application rate was reduced from 560kg/ha (500lb/ac) to 168kg/ha (150lb/ac) for cotton. Comparisons made between the fertilizer tax and quantitative restrictions for achieving fertilizer input levels of 168kg/ha (150lb/ac) showed that the expected returns decreased by \$847/ha (\$343/ac) and \$464/ha (\$188/ac), respectively.

Taylor (1992) examined economic incentives and other mechanisms to offset nonpoint source pollution from agriculture in the Willamette Valley of Oregon. Policy options tested included a per unit tax on leached nitrates, a tax on nitrogen fertilizer, per hectare effluent standards of various levels, a requirement for use of no-till drills on small grains and grass seed production, and a ban of fall fertilizer applications to reduce winter leachate. Results showed that a 50% tax on nitrogen fertilizer, required use of no-till drills, and fall fertilizer ban cost \$62.42/ha (\$25.28/ac), \$6.07/ha (\$2.46/ac), and \$25.43/ha (\$10.30/ac), respectively. However, these policy options did not significantly reduce nitrate leaching with the latter two options increasing nitrate leaching. Per hectare effluent standards of leached $\text{NO}_3\text{-N}$ less than 34 (30), 28 (25), 22 (20), 11 (10), and 7 (6) kg/ha (lb/ac) cost the farmer \$17.65/ha (\$7.15/ac), \$34.00/ha (\$13.77/ac), \$90.07/ha (\$36.48/ac), \$140.07/ha (\$56.73/ac), and \$145.31/ha (\$58.85/ac), respectively. Finally, a tax on leached $\text{NO}_3\text{-N}$ of \$8.8/kg (\$4/lb), \$13.2/kg (\$6/lb), and \$26.4/kg (\$12/lb) cost the farmer \$148.40/ha (\$60.10/ac), \$159.47/ha (\$64.58/ac), and \$171.36/ha (\$69.40/ac), respectively.

Huang and Lantin (1993) estimated farmers' compliance associated with using different crop rotation patterns under alternative farm policy options in Iowa. The policy options considered included a nitrogen fertilizer tax option, corn sales tax option, and limiting nitrogen use option. Each policy option was employed to reduce the nitrogen

application rate to achieve zero excess nitrogen where zero excess nitrogen was defined as the difference between the amount of nitrogen applied from all sources on one acre of cropland and the amount of nitrogen present in both plants (stalks) and crops (grain) harvested and removed at the end of the growing season. Under the nitrogen fertilizer tax option, the tax was determined to be \$1.58/kg (\$0.72/lb) for continuous planting of corn and about \$0.84/kg (\$0.38/lb) for corn after soybean rotation. Under the corn sales tax option, a sales tax of \$49.71/m³ (\$1.74/bu) was estimated for continuous corn planting and \$42.86/m³ (\$1.50/bu) was calculated for the corn after soybean rotation. The market price for nitrogen fertilizer was \$0.33/kg (\$0.15/lb) and for corn was \$60.00/m³ (\$2.10/bu). Results showed that the nitrogen fertilizer tax option reduced the farmers' income by \$188/ha (\$76/ac) and \$67/ha (\$27/ac) for continuous corn and corn after soybean rotations, respectively. For the corn sales tax option, income was reduced by \$494/ha (\$200/ac) and \$279/ha (\$113/ac) for continuous corn and corn after soybean rotations, respectively. For the limiting fertilizer option, income was reduced by \$49/ha (\$20/ac) and \$0.81/ha (\$0.33/ac) for continuous corn and corn after soybean rotations, respectively. Corresponding nitrogen application rates for each policy option were not recorded.

Lambert (1990) and Huang and Lantin (1993) researched the use of policy options which targeted reducing nitrogen inputs (i.e. nitrogen fertilizer tax) while Taylor (1992) targeted reducing nitrogen output (i.e. leaching). An income reduction for utilizing the policy option of taxing nitrogen fertilizer of \$188/ha (\$76/ac) was reported by Huang and Lantin and \$847/ha (\$343/ac) was reported by Lambert. However, these values can not be compared since Huang and Lantin failed to record the corresponding nitrogen application rates. Taylor reported lower income reductions by utilizing nitrogen output

policy options. Policy options which target nitrogen output are the more direct policy option in that the problem of nitrate leaching is addressed directly while the other two policies work with indirect options. Indirect options such as nitrogen fertilizer taxes fail to address problems associated with land application of manure since manure has no market value and cannot be easily taxed. Additionally, standards or quantitative restrictions on nitrogen application rates for liquid manure are difficult to regulate and hard for farmers to comply with due to variations of nutrient levels in liquid manure. However, the direct policy options Taylor utilized focused on the mass of nitrate leached which, is nearly impossible to determine for a real farm. Direct policy options which use concentrations would be a more feasible option for monitoring nitrate leaching. By setting an upper limit nutrients are not to exceed, regulators could randomly check leachate nutrient concentrations to make sure they do not exceed that limit.

2.5 GLEAMS

A number of NPS models are available to generate data based on field conditions. One that has been applied to animal waste is the GLEAMS model. GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard et al., 1987) is a continuous, daily simulation model, developed to utilize the management-oriented physically-based CREAMS model (Knisel, 1980) and incorporate a component for vertical flux of pesticides. The components of GLEAMS include hydrology, erosion, pesticides, and nutrients (Version 2.0). GLEAMS represents land application of animal waste by creating organic ammonia, N, and P pools for mineralization. Organic N and P represent the portion that mineralizes at a higher rate than for active soil mineralizable N. A portion of the animal waste mineralizes to the active soil mineralizable N and P pools.

Yoon et al. (1994) compared N and P losses in surface and subsurface runoff following application of two rates (9 and 18 t/ha) of poultry litter at the Tennessee Valley Substation on the Alabama Agricultural Experiment Station to GLEAMS simulation results of the above scenario. The experiment was conducted for three different soil treatments. The results showed that GLEAMS simulated soluble P losses in surface runoff and $\text{NO}_3\text{-N}$ concentrations in soil layers well, but N losses in surface runoff were not simulated satisfactorily. GLEAMS simulated higher losses of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in surface runoff rather than in subsurface as indicated by field data. Also, the P leachate observed at the 1.0m depth was more than what was simulated by the model.

3.0 Methods

The major components of the research consisted of three steps: probability distributions, economics, and risk. For the first step, $\text{NO}_3\text{-N}$ leaching was simulated for different liquid dairy waste application rates using the GLEAMS model for the duration of each field study. The yearly-maximum simulated $\text{NO}_3\text{-N}$ leaching concentrations were compared with the yearly-maximum measured $\text{NO}_3\text{-N}$ concentrations in order to show that the values were close to one another and that GLEAMS predicted reasonable yearly-maximum $\text{NO}_3\text{-N}$ concentrations. A long-term GLEAMS simulation was then used to simulate 50 years of $\text{NO}_3\text{-N}$ concentrations using rainfall data generated by CLIGEN (Lane et al., 1989) for different liquid dairy waste application rates. Probability distributions were fit to the yearly maximum $\text{NO}_3\text{-N}$ concentrations from the 50 year simulation and the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate was determined for different liquid dairy waste application rates. For the second step, an economics model was used to look at the changes in farm profits from using different liquid dairy waste rates and determine a cost effective fine which offers economic incentives for farmers to reduce their liquid dairy application rates to environmentally acceptable rates. Finally, using a cost effective fine and the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate, the risk to the farmer was determined.

3.1 Probability Distributions

The first objective of this research was to develop probability distributions of maximum concentrations of $\text{NO}_3\text{-N}$ leaching for the study life due to land application of

liquid dairy waste. To achieve this objective, first, a time period of interest needed to be defined. A time period of interest was used to transform a stochastic variable into a random variable. This was accomplished by simply selecting one stochastic variable from each time period. The newly formed data points constituted a random variable. A one year time period was selected. A year represented the natural cycle of nature and eliminated any differences in nitrate due to seasonal variation. The maximum nitrate value from each year was used to develop each probability distribution.

Second, a threshold level was used to determine the probability of failure for the study life. A threshold level for nitrate concentrations of 10 mg/L $\text{NO}_3\text{-N}$, the EPA nitrate standard for drinking water, was selected. Thus the probability of failure was defined as the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate flowing to ground water. Finally, a study life was defined. Due to the high probability of failure associated with high application rates of dairy waste, the study life was also selected to be one year. Thus the probability for exceeding 10 mg/L $\text{NO}_3\text{-N}$ was evaluated yearly.

There were four main steps involved in developing probability distributions of yearly-maximum $\text{NO}_3\text{-N}$ leachate concentrations: (1) obtaining field or experimental data, (2) modeling $\text{NO}_3\text{-N}$ concentrations for the duration of the field study, (3) running long-term simulations, and (4) fitting yearly-maximum $\text{NO}_3\text{-N}$ leachate probability distributions to the simulated data.

3.1.1 Field Data

The first step involved in developing probability distributions for nitrate concentrations in leachate was obtaining field data. These data were used to develop the GLEAMS input files. The GLEAMS input files could have been developed using general soil and weather input values. However, in order to closely examine and interpret the results of this research, actual field data were used.

Data from studies in which liquid dairy waste was applied to agricultural fields at different application rates were obtained from Georgia and Texas. Dr. Donald M. Vietor supplied pertinent field data from the Texas field study from a project in which Texas A&M University (TAMU) and Virginia Polytechnic Institute and State University cooperated. Dr. Vietor was the principal investigator from TAMU. Dr. George Vellidis supplied data from a Georgia field study.

The Georgia field study involved the application of liquid dairy waste to a year-round forage production system at The University of Georgia Coastal Plain Experiment Station (CPES) near Tifton. The operational cropping system was overseeding of abuzzi rye (*Secale cereale* L.) into Tifton 44 bermudagrass (*Cynodon dactylon* L.) sod in the fall, followed by minimum tillage planting of silage corn (*Zea mays* L.) into bermudagrass and rye stubble in the spring, followed by summer crops of hay or silage from the residual bermudagrass (Vellidis et al., 1996). Liquid dairy waste was generated from flush cleaning of the CPES Research Dairy loafing areas and passed over a fixed screen to remove particulate matter before being routed to a holding lagoon (Vellidis et al., 1996). Liquid dairy waste was applied 73 times from June 1991 to October 1994, on the average

of every 16 days, to a 6.5 ha research site. The liquid dairy waste application rates were 200, 400, 600, and 800 kg • N/ha/yr. An automated 5.6 ha, 3 tower center pivot irrigation system was used to apply the liquid dairy waste. The land had not previously received any liquid manure applications. The methodology and instrumentation were described in detail by Vellidis et al. (1991).

Liquid dairy waste application rates for the Texas field study were 0, 250, 500, and 1000 kg • N/ha/yr. Liquid dairy waste applications were applied four times a year on eight 18m x 5m plots at the Texas Agricultural Experiment Station at Overton from 1992 to 1994. Dairy waste was transported in a 4500 L wagon, deposited in batches into a 1900 L galvanized steel watering tank, and manually distributed across the plots with 15 L plastic buckets (Johnson, 1995). The cropping system was overseeding of Tam-90 ryegrass (*Lolium multiflorum* Lam.) into Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.) sod in the fall. Complete details of the study were described by Johnson (1995).

Comparisons between the two sites can be made with Tables 1 and 2. Table 1 shows the mean nutrient concentration in each site's liquid dairy waste. Based on the total nitrogen concentration, the liquid waste applied at Texas was approximately 7.5 times as concentrated as the waste applied at Georgia. Table 2 shows the mean yields between the two sites. At the Georgia site, bermudagrass yields peaked at 600 kg•N/ha/yr. However, at the Texas site, bermudagrass yields increased with application rate up to 1000 kg•N/ha/yr.

TABLE 1. Mean nutrient concentrations in liquid dairy waste applied to research plots.

Site	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Tifton, GA ¹	164.4	40.4
Overton, TX ²	1230.0	232.0

¹Data obtained from Vellidis et al. (1996).

²Data obtained from Johnson (1995).

TABLE 2. Mean yields for each liquid dairy waste application rate.

Site	Rate kg•N/ha/yr	Bermudagrass -----kg / ha -----	Rye	Ryegrass	Corn Silage
Tifton, GA ¹	200	6806	2332	----	3737
	400	6700	4508	----	9599
	600	8207	4871	----	12207
	800	5697	5819	----	14936
Overton, TX ²	0	3492	----	1568	----
	250	4674	----	2209	----
	500	6161	----	2707	----
	1000	8170	----	3769	----

¹Data obtained from Vellidis (unpublished data, 1996).

²Data obtained from Johnson (1995).

3.1.2 Modeling

The GLEAMS model was used to model nitrate concentrations in leachate for each liquid dairy waste application rate for each field study. Using soil, weather, planting, harvesting, and irrigation data, the erosion, hydrology, and nutrient input files were developed. The model was run for the duration of each field study and $\text{NO}_3\text{-N}$ leachate concentrations were simulated for the different application rates. The simulated and observed nitrate concentrations were compared. Differences between the two sites included the application frequency and nutrient concentrations of the liquid dairy waste. Actual rainfall data were used for the Georgia site, while simulated rainfall data were used for Texas because measured data were unavailable.

Based on how well the observed and simulated yearly-maximum nitrate concentrations compared determined the next step of the research. For this research, yearly-maximum nitrate concentrations were the only values used from the GLEAMS simulation. It was expected that, in general, the simulated and observed yearly-maximum concentrations would be within an order of magnitude. In that case, the long-term simulation was to be the next step. However, if the observed and predicted yearly-maximum nitrate concentrations differed by more than an order of magnitude, the model was to be calibrated and rerun before any long-term simulations were run. As shown in section 4.1, the observed and predicted yearly-maximum nitrate concentrations were within an order of magnitude, so long-term simulation was the next step.

Weather data were generated stochastically to facilitate simulation of a number of weather scenarios. The CLIGEN (Lane et al., 1989) model was used to generate 50 years

of weather data. For the long-term simulations, the GLEAMS input files were set up on a one year rotation and run using the generated weather data. The rotation included parameters such as irrigation, planting, harvesting, and tillage dates as well as crop type and irrigation rates. Nitrate concentrations in leachate were obtained from these results.

Nitrate concentrations for the fifty years were obtained from the long-term GLEAMS simulation. A FORTRAN program was developed to retrieve the daily nitrate concentrations from the GLEAMS output file, select the maximum concentration from each year, and write these concentrations to a separate file. These concentrations were used to plot a yearly-maximum nitrate histogram for each land application rate for each field study. The histograms were plotted automatically by entering the yearly-maximum nitrate concentrations into VTFIT (Cooke et al., 1993). Probability distributions were overlaid on the yearly-maximum nitrate histogram. Chi square, Anderson-Darling, Kolmogorov-Smirnov, log likelihood, and visual tests were used to select the best fitting probability distribution for each application rate. Using the best fitting probability distribution, the probability of failure (exceeding 10 mg/L $\text{NO}_3\text{-N}$) was estimated for each land application rate of each field study.

3.2 Economics

In order to determine the cost effective fine to place on farms with leachate exceeding 10mg/L $\text{NO}_3\text{-N}$, an economic analysis was performed using variable costs associated with the different land application rates of liquid dairy waste. The cost effective fine was defined as a fine of adequate magnitude such that farm profits from field crops for different liquid dairy waste application rates were highest for environmentally

acceptable rates based on nitrate leaching. Imposing a fine for leachate exceeding 10 mg/L NO₃-N would give profit maximizing farmers an economic incentive to use environmentally sound land application rates of dairy waste.

The change in benefits to the farmer from using liquid dairy waste included higher yields with increased application rates and saved inorganic fertilizer costs. The inorganic fertilizer costs saved are additional benefits afforded to the farmer by using liquid dairy waste. Change in benefits were determined using the market value of crops and fertilizer, yields, and fertilizer rates. The change in benefits, B(\$/L²), were expressed as:

$$B = \sum_{i=1}^n [V_{c_i} \cdot Y_{c_i}] + (V_f \cdot A_f) \quad (1)$$

where:

V_{c_i} = Value of crop i per mass or volume, \$/M or \$/V

Y_{c_i} = Yield of crop i, M/L²

V_f = Cost of fertilizer saved per mass of nitrogen, \$/M

A_f = Amount of fertilizer used, M/L²

n = Number of crops in rotation.

Labor costs are a function of crop yield. The change in costs were determined using crop harvest times, average yield rates, and farm hand wages. The change in costs, C (\$/L²), were expressed as:

$$C = \sum_{i=1}^n [(L_{c_i} / A Y_{c_i}) \cdot W \cdot Y_{c_i}] \quad (2)$$

where:

Lc_i = Labor time of harvesting crop i per area, T/L^2

AYc_i = Average state wide yield of crop i across all growing conditions, M/L^2 or V/L^2

W = Wage rate of farm worker, $\$/T$.

The first term in equation (2), Lc_i / AYc_i , is the average harvest rate (T/M or T/V) of the crop. This value was then multiplied by the wage rate and the observed yields for the different application rates to determine the labor costs of harvesting.

The change in expected farm profits, FP ($\$/L^2$), to the farmer would be the difference between benefits and costs. Thus, the change in farm profits were then computed as:

$$FP = B - C \quad (3)$$

Farm profits were used to represent the advantages to applying different rates of liquid dairy waste and were not the total net benefits of the whole farm. Fixed costs were assumed to be equivalent across the fertilizer and dairy waste options, thus having no influence on the magnitude of the fine. Additionally, labor costs of applying liquid dairy waste were not included. For the Georgia field study, liquid dairy waste was applied through a center pivot system and additional water was added to the lower rates to make up the difference in the depth of water. Thus, there was very little change in costs to applying the different application rates. With the Texas field study, liquid dairy waste was applied using buckets. This was obviously not representative of a farm. A farm would most likely use liquid manure spreaders pulled behind a tractor or an irrigation system and this cost would be comparable to that of spreading inorganic fertilizer. Whether spreading

inorganic or organic fertilizer, the equipment used would be a fixed cost, and the time spent applying the fertilizer and thus the cost is highly dependent on the tractor speed and spreader range and not the application rate.

Expected farm profits were adjusted by imposing a fine on farms that pollute.

Thus

$$FP_f = B - C - (F \cdot P(f)) \quad (4)$$

where:

FP_f = Farm profits with fine imposed, $\$/L^2$

F = Fine, $\$/L^2$

$P(f)$ = Probability of failure (exceeding 10 mg/L NO_3-N).

Since the fine was multiplied by the probability of failure, liquid dairy waste application rates with a high probability of failure would be affected more by a fine than rates with a low probability of failure. Thus farm practices which do not pollute would not be affected by the fine.

3.3 Risk

Risk, R , was expressed as:

$$R = \begin{matrix} \text{frequency} \\ P(f) \end{matrix} \times \begin{matrix} \text{consequence} \\ F \end{matrix} \quad (5)$$

where:

$P(f)$ = Probability of failure (exceeding 10mg/L $\text{NO}_3\text{-N}$)

F = Fine, $\$/\text{L}^2$.

As shown in equation (5), the risk to the farmer is the product of the probability of failure and the fine, where the fine is constant. Equation (5) is simply the last term in equation (4).

4.0 Results and Discussion

4.1 GLEAMS Simulations

Overall, the yearly-maximum leachate $\text{NO}_3\text{-N}$ concentrations simulated by the GLEAMS model were within the range of observed concentrations for the Georgia field study (Table 3). The simulated results were compared with nitrate concentrations observed at soil depths of 1.5 and 2.0 meters. The depth for the simulated results was 1.0 meter. The GLEAMS model underpredicted the nitrate concentrations for all three years and the last two years of the field study for application rates of 200 and 400 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$, respectively. This is explained by the fact that the initial concentration rates before any dairy waste was applied were very high at 15 and 12.5 mg/L for the 200 and 400 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$ application rates, respectively. These concentrations decreased for both the simulated and observed nitrate leachate concentrations over the four years. If the study was observed over a longer period of time, it is likely that the nitrate concentrations leaching to the ground water would continue to decrease to some steady state at which the nitrate concentrations would not decrease further. GLEAMS predicted a more rapid decrease than was observed. The simulated results for the 600 and 800 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$ application rates were much closer to the observed yearly-maximum nitrate concentrations.

The predicted and observed nitrate concentrations for the Texas field site are shown in Table 4. Measured rainfall data were unavailable for the Texas field site so data were generated using CLIGEN. There is an apparent underprediction by the GLEAMS model of nitrate concentrations leaching to ground water for the 0 $\text{kg}\cdot\text{N}/\text{ha}/\text{yr}$ application

TABLE 3. Yearly-maximum concentrations of nitrate leaching for different application rates of liquid dairy manure for Tifton, GA.

APPLICATION RATE	YEAR	-----NO ₃ -N-----		
		PREDICTED	OBSERVED ^{1,2} @ 1.5m	2.0m
kg•N/ha/yr		mg/L	mg/L	mg/L
200	July 1991 - June 1992	6.4	13.0	22.0
	July 1992 - June 1993	3.0	4.5	20.5
	July 1993 - Sept. 1994	1.5	5.0	16.0
400	July 1991 - June 1992	9.7	7.5	13.5
	July 1992 - June 1993	2.6	8.0	14.0
	July 1993 - Sept. 1994	3.0	8.0	9.0
600	July 1991 - June 1992	17.8	11.5	20.0
	July 1992 - June 1993	5.3	14.0	16.5
	July 1993 - Sept. 1994	10.4	13.5	14.0
800	July 1991 - June 1992	24.6	10.5	16.5
	July 1992 - June 1993	8.2	28.0	17.0
	July 1993 - Sept. 1994	20.5	25.5	16.0

¹Mean of 24 NO₃-N concentration samples.

²Vellidis et al. (1996)

TABLE 4. Yearly-maximum concentrations of nitrate leaching for different application rates of liquid dairy manure for Overton, TX.

APPLICATION RATE	YEAR	-----NO ₃ -N-----	
		PREDICTED	OBSERVED ^{1,2}
kg•N/ha/yr		mg/L	mg/L
0	April 1992 - April 1993	0.1	8.4
	May 1993 - May 1994	0.3	10.3
250	April 1992 - April 1993	3.1	7.0
	May 1993 - May 1994	5.1	5.7
500	April 1992 - April 1993	5.8	1.7
	May 1993 - May 1994	10.4	5.2
1000	April 1992 - April 1993	15.8	12.1
	May 1993 - May 1994	19.3	33.5

¹Individual NO₃-N concentrations in the soil solution at 1.8m.

²Johnson (1995)

rate. Intuitively, it seems nitrate leaching concentrations would have been low when no liquid dairy waste was applied to the fields. These observed concentrations may suggest high initial soil nitrate concentrations or possible lateral flow through the soil layers from adjacent plots though data to prove this were not available. Yearly-maximum nitrate concentrations leaching to ground water for the 0 kg•N/ha/yr application rate of liquid dairy waste were higher than the yearly-maximum nitrate concentrations for the 250 and 500 kg•N/ha/yr application rates, although the nitrate concentrations for the 0, 250, and 500 kg•N/ha/yr application rates were tested to be statistically equal (Johnson, 1995). It may be argued that if there were high initial soil nitrate concentrations for this site, the addition of nitrate fertilizer stimulated plant growth and more nitrate was taken up than with the 0 kg•N/ha/yr application rate where plant growth was not stimulated. Additionally, nitrate concentrations below 0.2 mg/L were classified by the U.S. Geological Survey (Madison and Brunett, 1985) to represent natural background concentrations. This further suggests that nitrate was already present in the soil or there was some other source from which the nitrate flowed. Nitrate leachate concentrations simulated for the remaining three application rates for the Texas field study were within the range of observed results. GLEAMS input files and nitrate leaching results for the liquid dairy waste application rates of each field for the field study duration are shown in Appendix A.

Based on the satisfactory nitrate leaching results for the duration of the field studies, the GLEAMS model was not calibrated for either field study and long-term results were simulated using the parameters developed for evaluating GLEAMS for each field study. GLEAMS was used to simulate 50 years of nitrate leachate concentrations for the different liquid dairy waste application rates of each field study using weather data

generated by CLIGEN for each site. GLEAMS input files and nitrate leaching results for the dairy waste application rates for long-term simulations are shown in Appendix A.

4.2 Probability Distributions

VTFIT (Cooke et al., 1993) was used to fit probability distributions to the yearly-maximum nitrate concentration data of each liquid dairy waste application rate. Candidate distributions were normal, log normal, exponential, beta, gamma, two parameter Weibull, and three parameter Weibull. Based on the Chi square, Anderson Darling, Kolmogorov-Smirnov, and log likelihood, the best fitting probability distribution was selected for each liquid dairy waste application rate. These statistical tests were performed by VTFIT. A good fitting probability distribution is defined by a high log likelihood value and low values of Chi square, Anderson Darling, and Kolmogorov-Smirnov statistics. When the test statistics were similar, the visual test was used to determine the best fitting distribution. The visual test involved inspecting the yearly-maximum nitrate concentration histograms overlaid with the respective probability distributions using VTFIT. The visual test can identify discrepancies that statistical tests can not. Considering all tests, the 2 parameter Weibull was the best fitting distribution for all four liquid dairy waste application rates for both the Georgia and Texas sites. Results from the Weibull distribution for each liquid dairy waste application rate are shown in Table 5. Output files from VTFIT are shown in Appendix B.

The probability distributions with the corresponding histograms for the different liquid dairy waste application rates are shown in Figures 1 through 4 for the Georgia site

TABLE 5. Probability distribution parameters for each liquid dairy waste application rate.

SITE	APP. RATE	Weibull Scale Parameter	Weibull Shape Parameter
	kg•N/ha/yr		
Overton,TX	0	0.079	1.716
	250	3.858	1.218
	500	14.730	1.122
	1000	37.792	1.362
Tifton, GA	200	2.090	1.158
	400	8.419	1.433
	600	14.918	1.471
	800	22.221	1.526

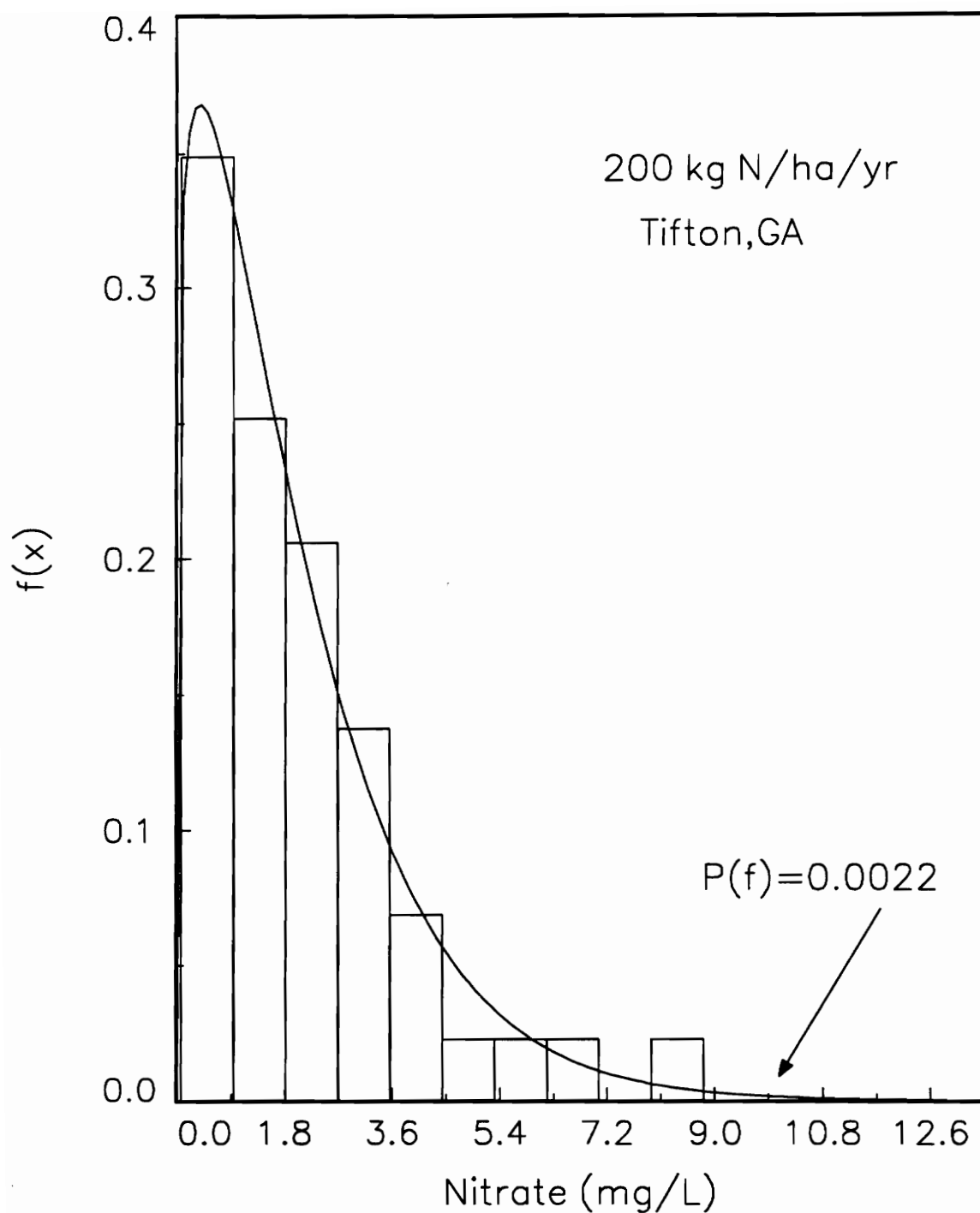


FIGURE 1. Distribution of yearly-maximum nitrate concentrations for the 200 kg•N/ha/yr application rate of liquid dairy manure at Tifton, GA. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

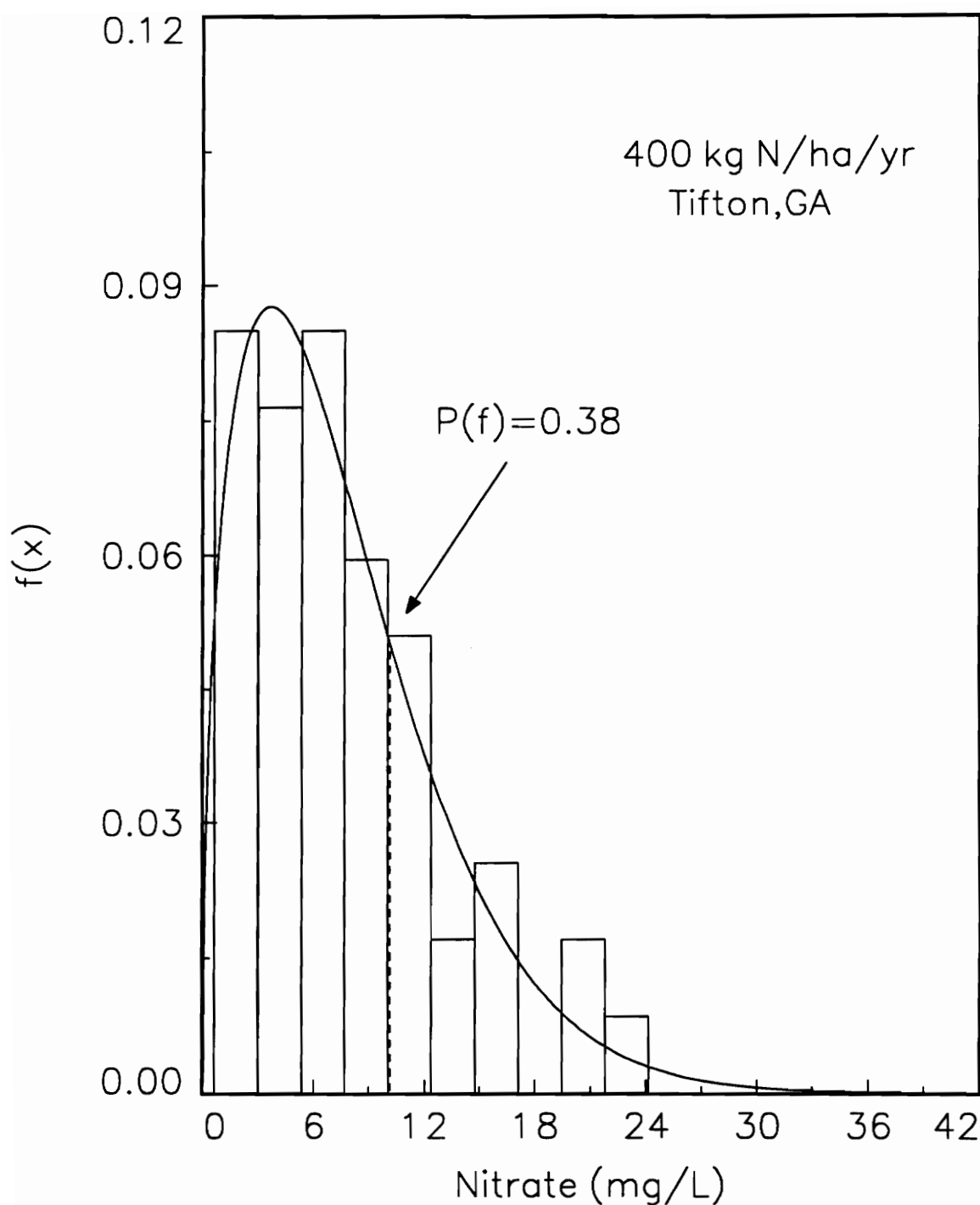


FIGURE 2. Distribution of yearly-maximum nitrate concentrations for the 400 kg•N/ha/yr application rate of liquid dairy manure at Tifton, GA. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

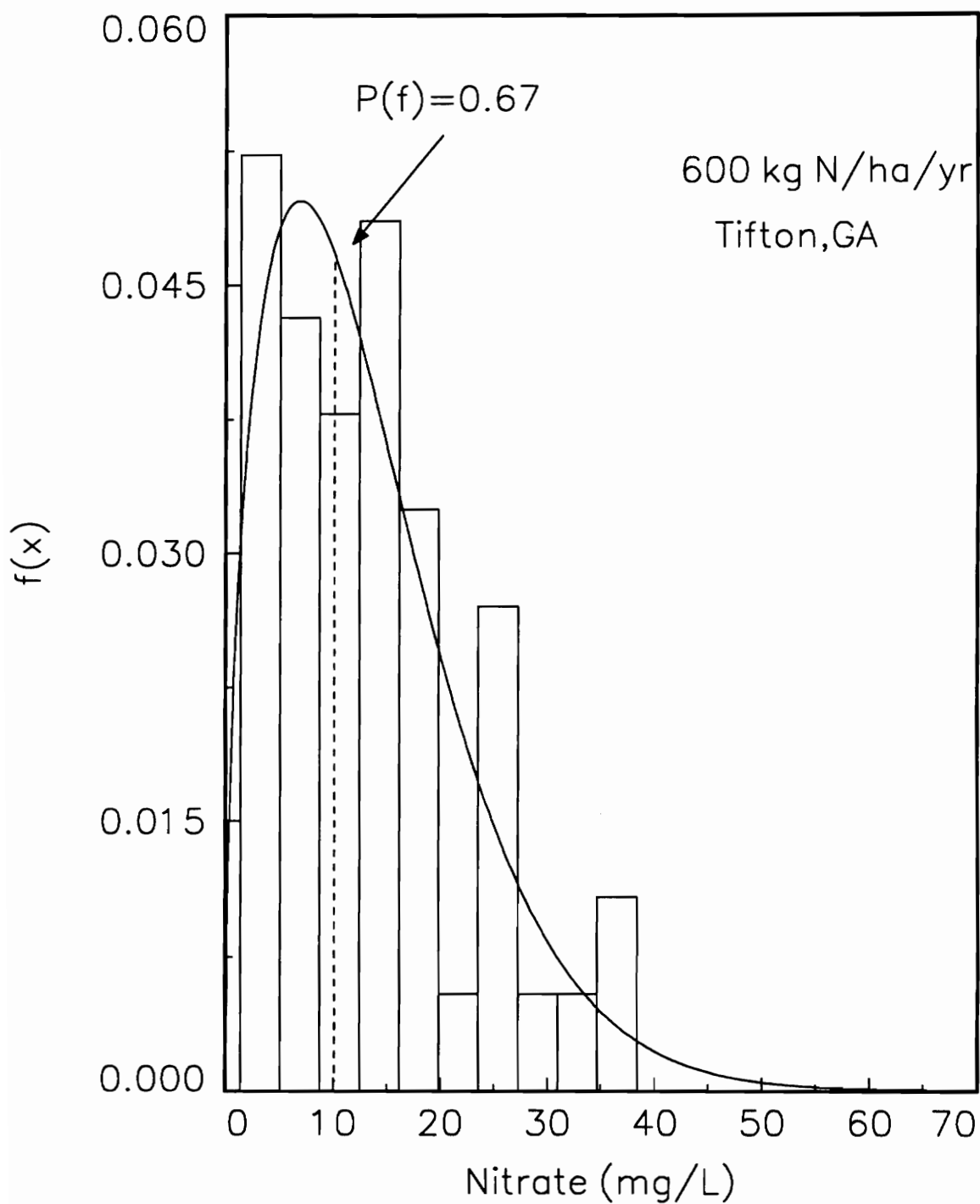


FIGURE 3. Distribution of yearly-maximum nitrate concentrations for the 600 kg•N/ha/yr application rate of liquid dairy manure at Tifton, GA. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

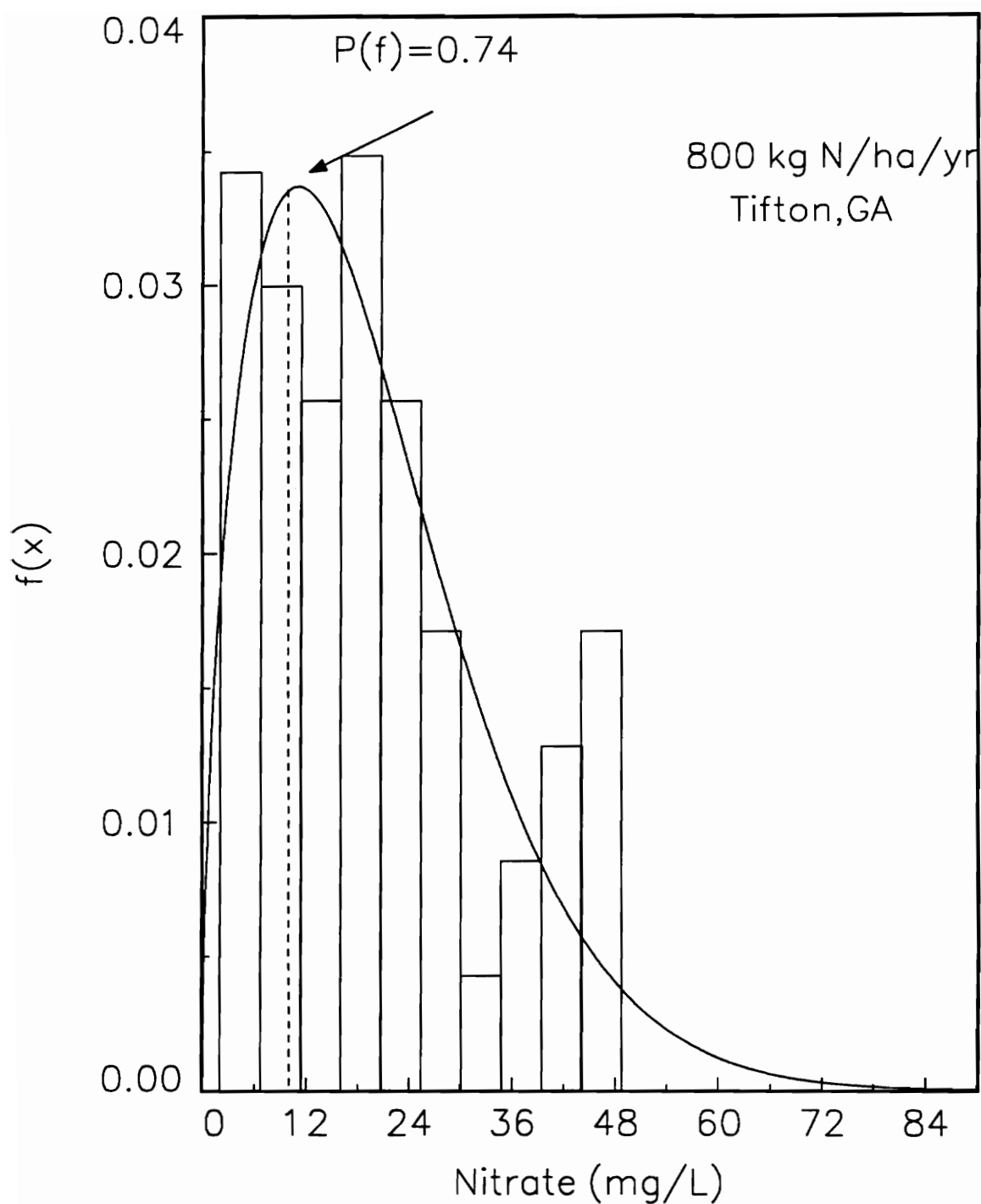


FIGURE 4. Distribution of yearly-maximum nitrate concentrations for the 800 kg•N/ha/yr application rate of liquid dairy manure at Tifton, GA. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

and in Figures 5 through 8 for the Texas site. The probability of failure of each liquid dairy waste application rate at the two sites is summarized in Table 6.

The probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ for the 200 kg•N/ha/yr application rate at the Georgia site was 0.0022 (Figure 1) indicating that there was very little chance that $\text{NO}_3\text{-N}$ leachate concentrations would contaminate the ground water when 200 kg•N/ha/yr of liquid dairy manure was applied. As expected, the probability of failure increased as the application rate increased. There was a large increase in the probability of failure from 200 to 400 kg•N/ha/yr. The probability of failure for 400 kg•N/ha/yr was 0.38 (Figure 2). This probability and the low probability for the application rate of 200 kg•N/ha/yr suggest that the environmentally acceptable liquid dairy waste application rate is between 200 and 400 kg•N/ha/yr for this site. There was also a large increase in the probability of failure (0.29) between the application rates of 400 and 600 kg•N/ha/yr (Figures 2 and 3). Finally, there was a relatively small increase (0.07) between 600 and 800 kg•N/ha/yr (Figures 3 and 4).

There was no reasonable chance that nitrate leachate concentrations would exceed 10 mg/L when no liquid dairy waste was applied at the Texas site (Figure 5). The probability of failure increased to 0.04 when 250 kg•N/ha/yr was applied (Figure 6). By doubling the application rate to 500 kg•N/ha/yr (Figure 7) and then again to 1000 kg•N/ha/yr (Figure 8), there were considerable increases in the probability of failure, to 0.52 and 0.85, respectively. The high probability of failure indicated that these rates are unreasonable when trying to limit nitrate discharges to ground water to concentrations less than 10 mg/L $\text{NO}_3\text{-N}$.

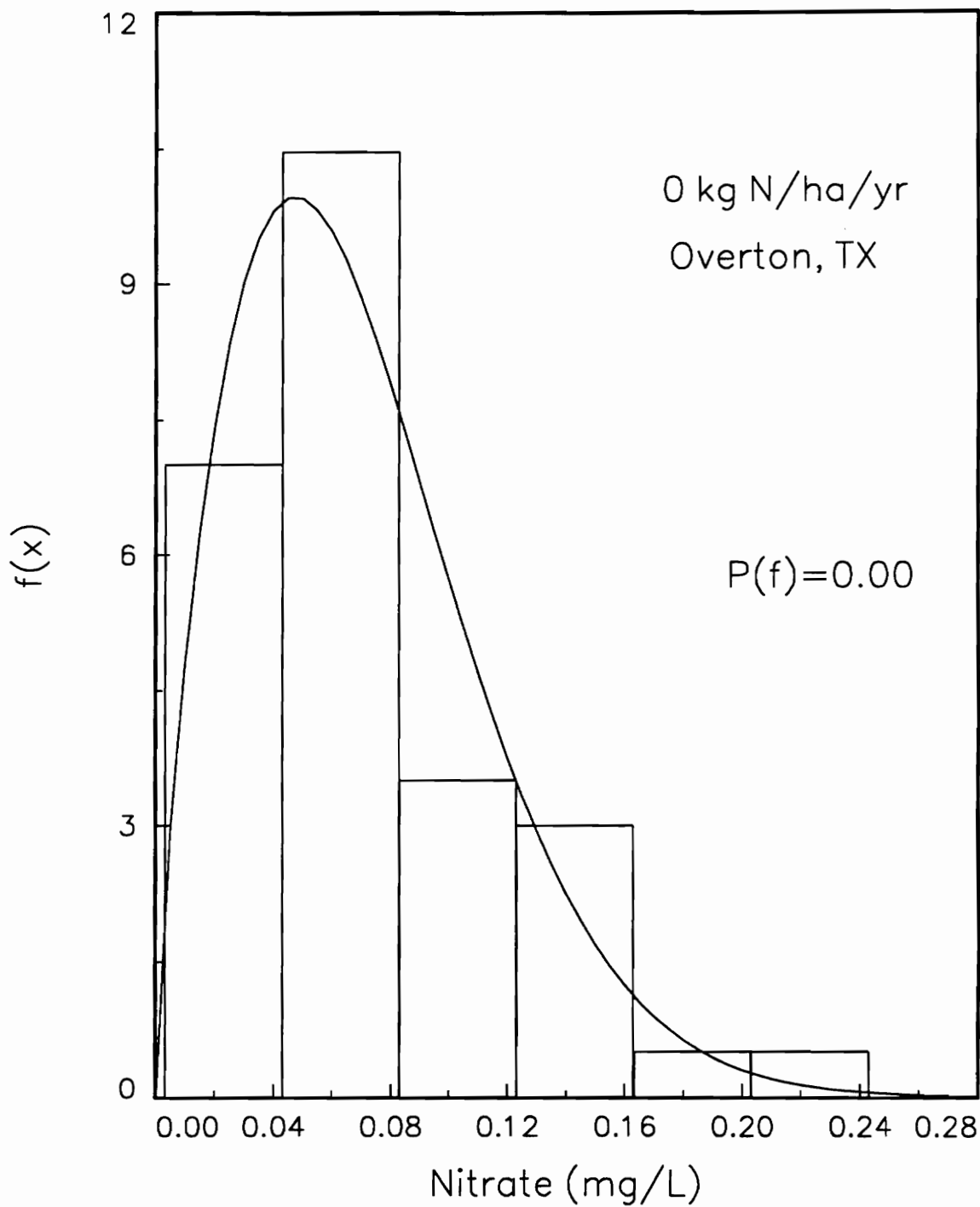


FIGURE 5. Distribution of yearly-maximum nitrate concentrations for the 0 kg•N/ha/yr application rate of liquid dairy manure at Overton, TX. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

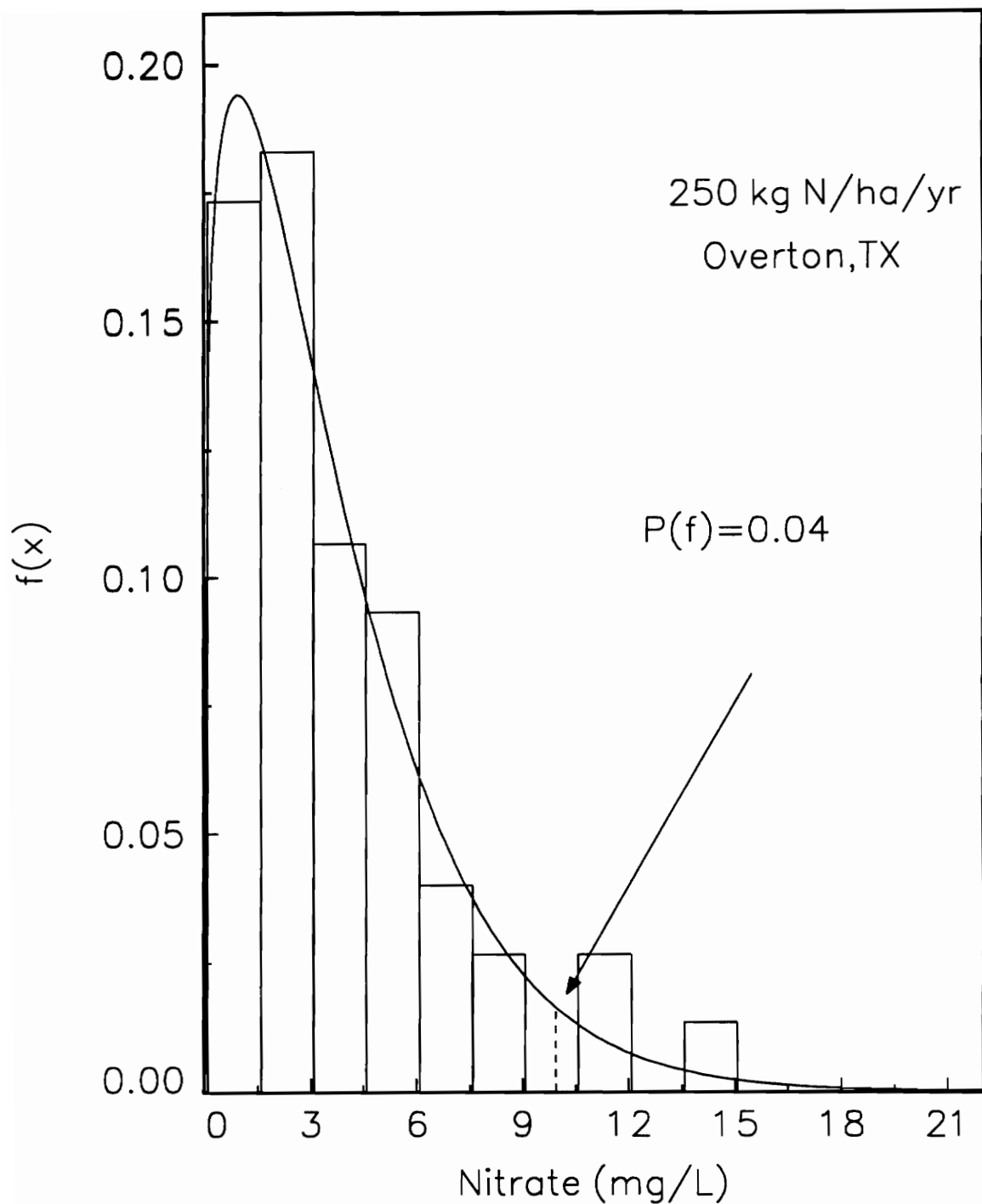


FIGURE 6. Distribution of yearly-maximum nitrate concentrations for the 250 kg•N/ha/yr application rate of liquid dairy manure at Overton, TX. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

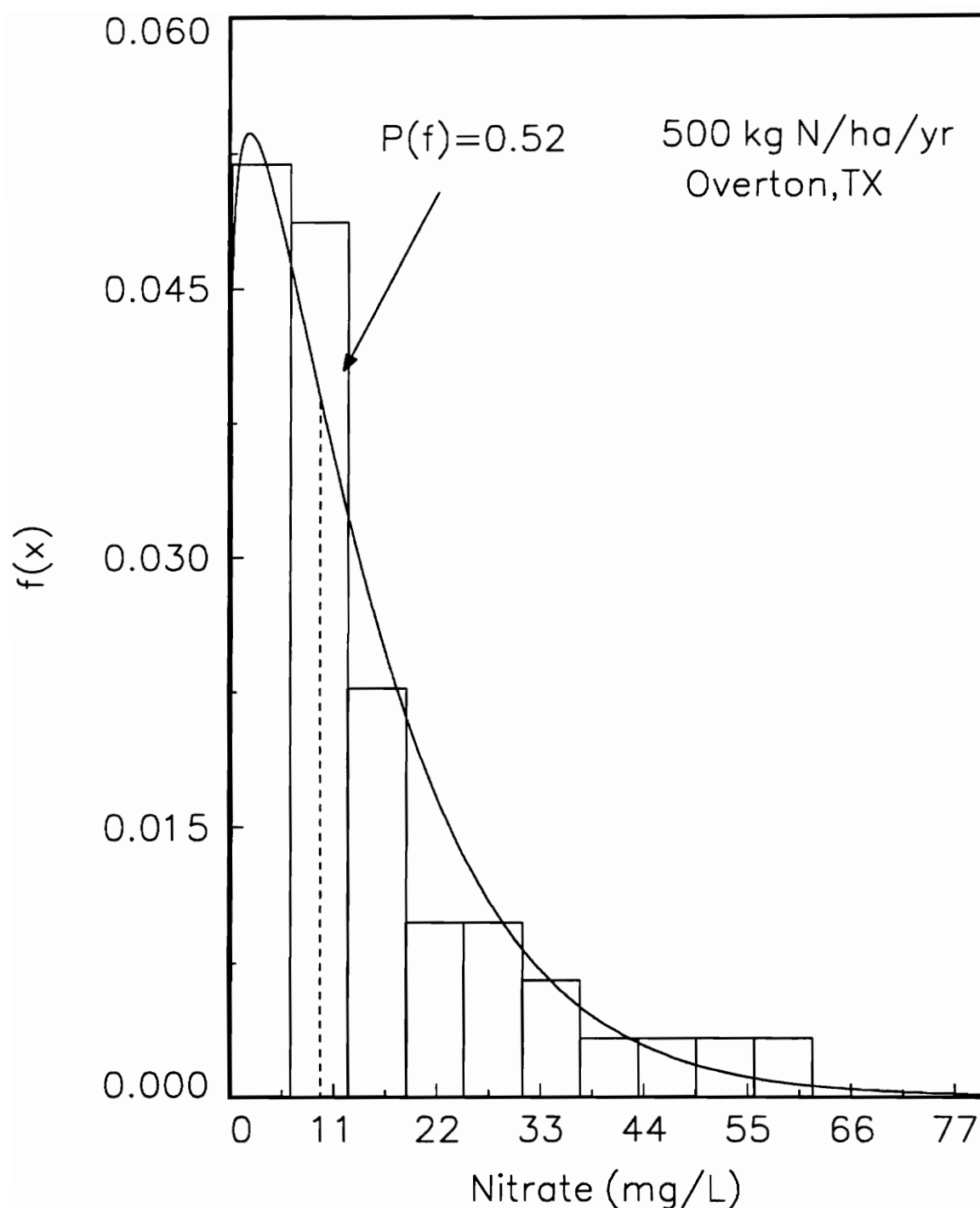


FIGURE 7. Distribution of yearly-maximum nitrate concentrations for the 500 kg•N/ha/yr application rate of liquid dairy manure at Overton, TX. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

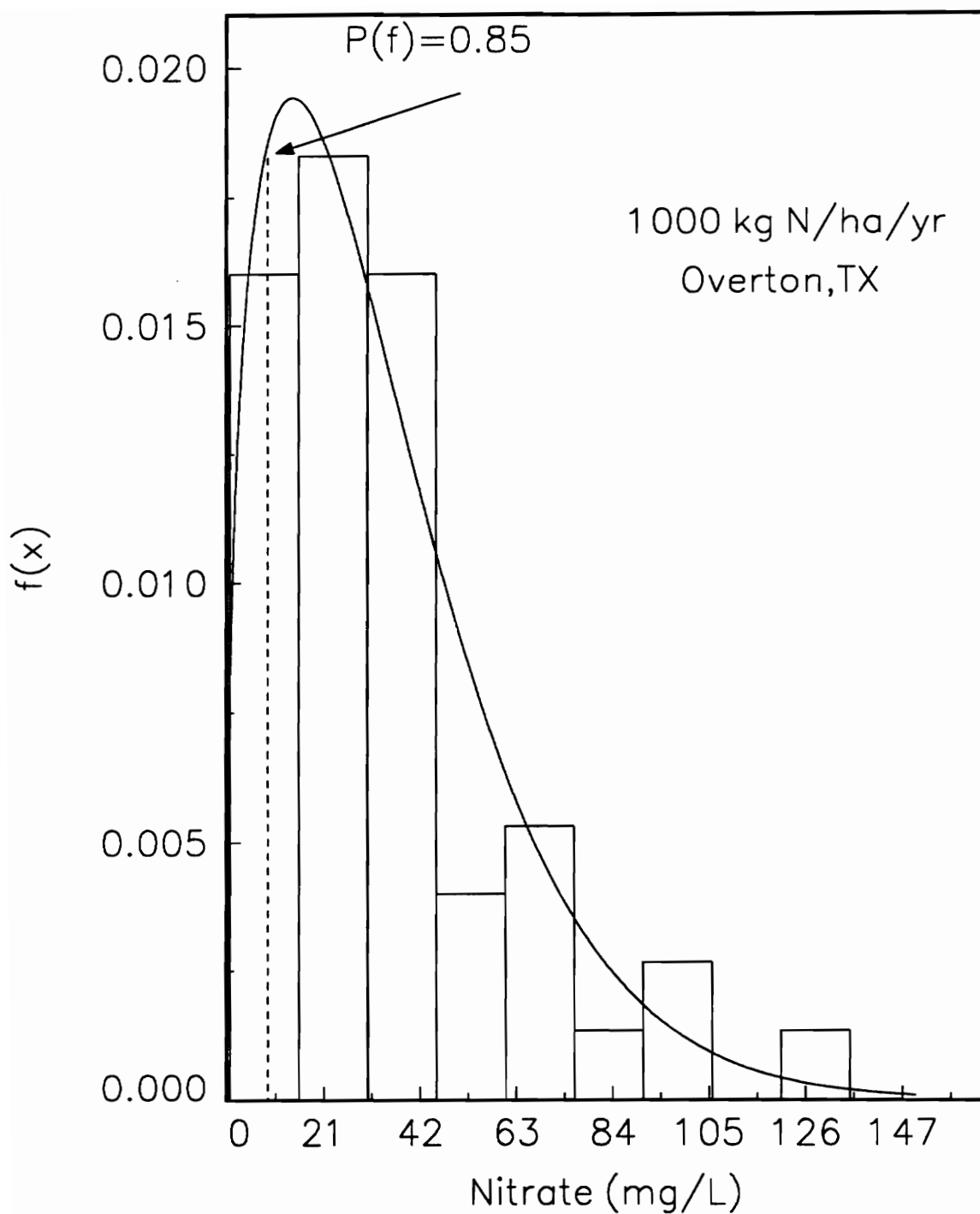


FIGURE 8. Distribution of yearly-maximum nitrate concentrations for the 1000 kg•N/ha/yr application rate of liquid dairy manure at Overton, TX. $P(f)$ is the probability of exceeding 10 mg/L $\text{NO}_3\text{-N}$ in leachate.

TABLE 6. Probability of failure, P(f), for each liquid dairy waste application rate.

SITE	APPLICATION RATE	P(f)
	kg•N/ha/yr	
Overton, TX	0	0.00
	250	0.04
	500	0.52
	1000	0.85
Tifton, GA	200	0.0022
	400	0.38
	600	0.67
	800	0.74

Determining the environmentally sound application rate of any fertilizer can be difficult and is subjective since there is no well-defined probability of failure. However, application rates with high probabilities of failure (>0.5) would not seem to be environmentally acceptable. It may be argued that the nitrate concentrations used to develop the probability distributions are yearly-maximums, and theoretically these concentrations may happen only once each year thus resulting in insignificant contributions of nitrate to the ground water. However, as with the speed limit there needs to be some upper limit which an individual is not to exceed even momentarily. The EPA has determined that this limit for nitrate in domestic drinking water is 10 mg/L. Perhaps this limit needs to be adjusted for different industries. Point sources which deliver a constant flow of water containing 9.9 mg/L of nitrate to a water source have a greater impact than a farm from which occasional runoff and leaching flows contain up to 9.9 mg/L. However, this issue is beyond the scope of this research.

The American Society of Agricultural Engineers (ASAE) has developed standards (ASAE, 1995) for components of waste management systems such as lagoons, holding ponds, and settling basins. ASAE standards require that these components be designed for a 25-year, 24-hour storm. This allows a failure rate with respect to waste management of once every 25 years or 0.04. Based on this probability of failure, the maximum environmentally acceptable liquid dairy waste application rates would be 250 kg•N/ha/yr for the Texas site and between 200 and 400 kg•N/ha/yr for the Georgia site. This would result in nitrate concentrations leaching to ground water exceeding 10 mg/L to occur on average once every 25 years.

It is interesting to note that the maximum environmentally acceptable liquid dairy waste application rate was approximately 250 kg•N/kg/ha for both sites. The results were expected to be of the same order of magnitude because the weather and topography were similar, the soil was a loamy sand, and liquid dairy waste was surface applied at both sites. Additionally, both sites had forage crops rotated with a winter cover. However, the maximum environmentally acceptable liquid dairy waste application rates were more similar than expected due to sharp contrasts in the number of applications and manure characteristics. At the Georgia site, liquid dairy waste was applied approximately 24 times a year while liquid dairy waste was applied 4 times annually for the Texas site. Liquid waste applied at the Texas site was approximately 7.5 times as concentrated with respect to nitrogen as the waste applied at the Georgia site.

4.3 Economics

Values for the economic analysis (Tables 7 and 8; equations (1) through (4)) were obtained from a variety of sources. Market prices, V_{c_j} , for crops were obtained from *Agricultural Prices* (1995). The value of liquid dairy waste, V_f , was assumed to be \$0.29/kg of nitrogen based on \$232/Mg for anhydrous ammonia, which contains 82% nitrogen fertilizer (Taylor, 1994; Thomas and Boisvert, 1995). The average farm wage rate, W , was assumed to equal \$6/hr for both Georgia and Texas (*Agricultural Statistics*, 1995). Average yields, AY_{c_j} , for each crop were obtained from *Agricultural Statistics* (1993) for each state. Labor times, L_{c_j} , i.e., the time it takes to harvest each crop, are highly variable and dependent on the yield and size of the farm and equipment. These times were calculated using typical field speeds, equipment widths, and field efficiencies (*ASAE Standards*, 1993). The crop yields, Y_{c_j} , were presented previously in Table 2.

TABLE 7. Crop yields, labor times, and market values used for Georgia.

Crop	Average GA Yield ¹ (AY _{cj})	Labor Time (L _{cj})	Market Value (V _{cj})
	-- /ha	hours/ha	dollars/---
Corn Silage	35.8 Mg	1.60	31.20 / Mg
Bermudagrass	6.3 Mg	1.56	60.64 / Mg
Rye	2.1 m ³	1.01	61.71 / m ³

¹ Average Georgia yields were obtained from *Agricultural Statistics* (1993).

TABLE 8. Crop yields, labor times, and market values used for Texas.

Crop	Average TX Yield ¹ (AY _{cj})	Labor Time (L _{cj})	Market Value (V _{cj})
	Mg/ha	hours/ha	dollars/Mg
Bermudagrass	5.6	1.56	60.64
Ryegrass	5.6	1.56	60.64

¹ Average Texas yields were obtained from *Agricultural Statistics* (1993).

Substituting the values in Table 7 in equation (3), the change in farm profits for the Georgia farm were determined for each liquid dairy waste application rate. These values are represented in Figure 9 as the \$0/ha fine curve. Additional curves represent the farm profits with a fine imposed and were calculated using equation (4). As the fine increased, the farm profits decreased. The farm profits decreased more with the higher liquid dairy waste application rates at a given fine since they have a higher probability of failure. At low fine rates, the higher the liquid dairy waste application rate the greater the profit. This is due to greater yields associated with the higher application rates. However, as the fines increased, the lower application rates became more competitive with the higher rates until finally around \$1000/ha (\$400/ac) it would be more profitable to select 600 kg•N/ha/yr than 800 kg•N/ha/yr. By increasing the fine slightly more, it would be more profitable to select 400 kg•N/ha/yr.

As stated earlier, based on the probability of failure, the desired application rate for this field was approximately 250 kg•N/ha/yr. To obtain this application rate the fine would be the line on Figure 9 where the slope of each line segment connecting the application rates beyond 250 kg•N/ha/yr is negative. Thus the minimum fine to achieve an application rate of 250 kg•N/ha/yr would be slightly less than \$1100/ha (\$440/ac) for this site. At all points on this line, it would be more profitable to use application rates below 400 kg•N/ha/yr.

Results from the economic analysis for the Texas field study are shown graphically in Figure 10. The \$0/ha fine curve represents the farm profits calculated by the economic model based on the different liquid dairy waste application rates. With no fine, a profit maximizing farmer would apply 1000 kg•N/ha/yr or more. However, as the fine is

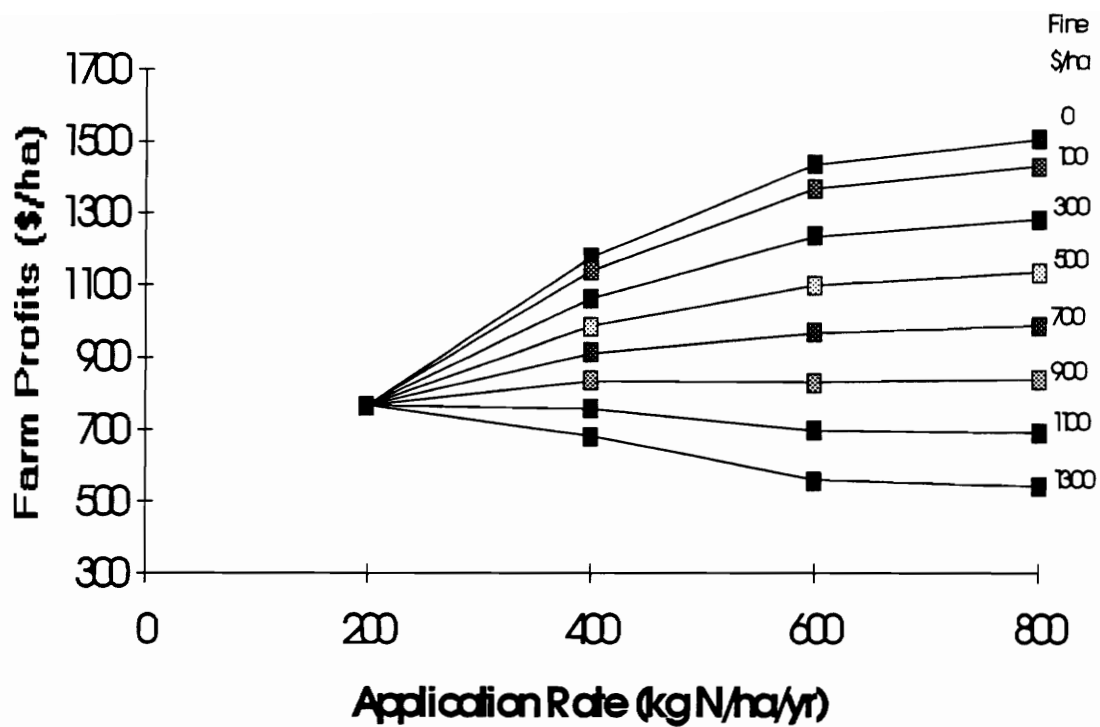


Figure 9. Farm profits for various fine and application rates for Tifton, GA.

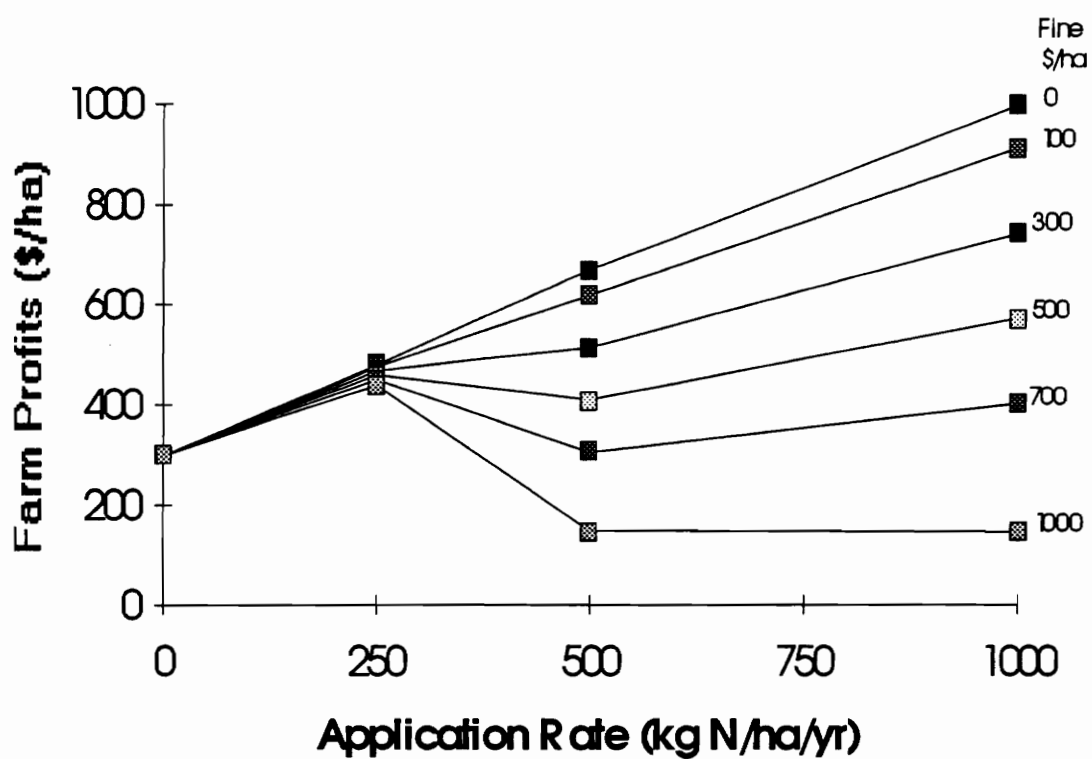


Figure 10. Farm profits for various fine and application rates for Overton, TX.

increased, the farm profits for higher liquid dairy waste application rates are decreased. Increasing the fine to around \$700/ha (\$280/ac) resulted in the 250 kg•N/ha/yr application rate having the highest farm profits. In an earlier discussion, this rate was determined to be environmentally acceptable.

It is interesting to note that the Georgia farm profit curve (Figure 9) without a fine is concave with respect to the application rate, while the Texas farm profit curve (Figure 10) without a fine is approximately linear with respect to the application rate. This difference is attributed to the bermudagrass yields decreasing after 600 kg•N/ha/yr for the Georgia site while increasing with application rate for the Texas site. As the fine is increased for the Texas site (Figure 10), the farm profit curve becomes convex with respect to the application rate because the probability of failure does not increase proportionally to increase in application rate. The convex characteristic of the farm profit versus application rate curve with a fine imposed resulted in two maximums for every curve. There is the possibility that beyond 1000 kg•N/ha/yr at the Texas site, the farm profit may be greater than for the environmentally acceptable liquid dairy waste application rate. However, rates beyond 1000 kg•N/ha/yr were not measured. For the Georgia site, as the fine is increased, the farm profit curve becomes less concave. However, since the probability of failure nearly doubles as the application rate doubles from 400 to 800 kg•N/ha/yr, the curve does not become convex for the range of fines.

Fines of \$1100/ha (\$440/ac) and \$700/ha (\$280/ac) for the Georgia and Texas sites, respectively, affect farmers differently depending on their liquid dairy waste application rates since each rate has a different probability of failure. Farmers' expected risk is simply the product of the fine and probability of failure (equation (5)).

The expected risk for each application rate is summarized in Table 9. For the Georgia site, the expected risk ranges from \$2/ha (\$0.8/ac) to \$814/ha (\$326/ac). Expected risks for the Texas site range from \$0/ha (\$0/ac) to \$595/ha (\$238/ac). These values are within the range of values from similar studies. Lambert (1990) determined that the loss in expected net return for reducing nitrogen fertilizer application rates from 560 kg•N/ha/yr to 170 kg•N/ha/yr was \$847/ha (\$343/ac) and \$464/ha (\$188/ac) for a nitrogen tax and quantity restriction policy options, respectively. Taylor (1992) determined that the expected loss in income to farmers was as high as \$175/ha (\$70/ac) for a \$5.5/kg tax on leached nitrate. Losses as high as \$494/ha (\$200/ac) was reported by Huang and Lantin (1993) when applying a corn sales tax. These losses are the costs to the farmer for pollution abatement. Taxes, standards, etc. were set so that farmers would reduce their fertilizer application rates and thus nitrate to ground water. None of these policy options were based on the social value of clean ground water.

Jordan and Elnagheeb (1993) determined the aggregate willingness to pay to avoid the risk of increasing nitrate in drinking water was \$275 million annually for the state of Georgia. Georgia has 192,000 ha of cropland, pasture, and hayland (*Agricultural Statistics*, 1993). Dividing the annual aggregate willingness to pay by the area of cropland, pasture, and hayland suggests that residents of Georgia are willing to pay as much as \$1432/ha (\$580/ac) for farmers to alter their fertilizer application rates to more acceptable application rates. The total social benefit for clean ground water of \$1432/ha is higher than any of the income losses expected by farmers for reducing their application rates mentioned earlier. However, this social value for clean ground water assumes that all of the nitrate in ground water is coming from nitrogen fertilizer applied to agricultural land. Assuming only 60% of nitrate in the ground water comes from agricultural land

TABLE 9. Farmers' risk of nitrate contamination.

Site w/ Cost Effective Fine	Application Rate	Probability of Failure	Expected Risk of NO ₃ -N Contamination
\$/ha (\$/ac)	kg•N/ha/yr	%	\$/ha (\$/ac)
Tifton, GA 1100 (440)	200	0.2	2 (0.8)
	400	38	418 (167)
	600	67	737 (295)
	800	74	814 (326)
Overton, TX 700 (280)	0	0.0	0 (0)
	250	4	28 (11)
	500	52	364 (146)
	1000	85	595 (238)

results in Georgia residents being willing to pay \$860/ha (\$348/ac) for farmers to alter their fertilizer application rates to more acceptable rates. This social value for ground water is still higher than any of the income losses expected by farmers for reducing their application rates to more environmentally acceptable rates.

When developing solutions to address water quality problems related to dairy manure management issues, either technical solutions or regulations, they must pass two tests (Grusenmeyer, 1991): will they be effective and are they affordable? In order for a solution to be effective, the solution must be imposed on the people who are polluting. Regulations and management practices have been required which do not solve the problem, exchange one problem for another, or are not practical in a dairy farm management system (Grusenmeyer, 1991). By involving dairy producers in decisions made concerning regulations, permits, fines, and best management practice development, more effective solutions are likely to be developed and people who are polluting can be identified. If the people who are polluting are not identified then solutions to preventing the pollution become more difficult.

The second test Grusenmeyer mentioned was affordability. Solutions to prevent water quality problems which put dairy farmers out of business are not very practical solutions. This certainly does not excuse the farmer from polluting. However, solutions which are economically feasible must be sought. With the profits from dairy farms shrinking, costs for preventing pollution from dairy farms must be shared between the producer and the consumers if both water quality goals are to be met and dairy farms are to operate affordably.

High application rates of liquid dairy waste which result in high levels of nitrate in ground water are unacceptable to the public. Policy options such as nitrogen fertilizer and crop taxes only work with inorganic fertilizers which the farmers have to pay for. Additionally, these policies impact all farmers and not just the farmers who pollute. Application rate standards seem to be the most reasonable approach to regulating dairy waste. However, these standards will need to be different for different regions and different crops. Additionally, this policy does not target nitrate leaching directly. Most economists advocate taxes over nonuniform standards because the incentives to innovate are higher with a tax. Perhaps a better policy would use recommended standards along with a fine system. Farmers would have the option of using the recommended application rates which are known to be environmentally sound or risk using higher application rates. However, if regulators measured leachate nitrate concentrations above 10 mg/L $\text{NO}_3\text{-N}$, then an appropriate fine would be assessed. This policy would target the nitrate leaching directly. However, a uniform monitoring system would have to be established.

5.0 Summary and Conclusions

A framework for evaluating the risk of water pollution from the application of liquid dairy manure to agricultural fields was developed and applied. The GLEAMS model was used to simulate nitrate leaching below the root zone for different land application rates of dairy waste for fields in Georgia and Texas. Probability distributions of yearly-maximum nitrate concentrations were developed for each application rate at each site using the simulated nitrate concentrations. The probability of failure (exceeding 10 mg/L $\text{NO}_3\text{-N}$) for each application rate was determined from its corresponding distribution. An appropriate fine for farmers based on the probability of failure for different land application rates was determined through economic analysis. The expected risk to the farmer was determined in monetary terms based on the fine and probability of failure. The farmer's risk was compared with the social value of clean ground water.

Conclusions from the completed research include the following:

1. The probability of failure for liquid dairy waste application rates of 200, 400, 600, and 800 kg•N/ha/yr is 0.0022, 0.38, 0.67, and 0.74 for Tifton GA, respectively. The probability of failure for liquid dairy waste application rates of 0, 250, 500, and 1000 kg•N/ha/yr is 0.00, 0.04, 0.52, and 0.85 for Overton, TX, respectively.
2. The maximum application rate that is environmentally acceptable for both Texas and Georgia is 250 kg•N/ha/yr based on the probability of failure.
3. A fine of \$1100/ha and \$700/ha is needed for Georgia and Texas, respectively, to provide farmers with economic incentives to reduce their liquid dairy manure rates

to 250 kg•N/ha/yr. These fines resulted in risks to farmers of \$814/ha in Georgia for 800 kg•N/ha/yr application rate and \$595/ha in Texas for 1000 kg•N/ha/yr rate. This compares with a social value ranging from \$860/ha to \$1432/ha.

4. The developed framework for risk quantification demonstrated advantages over other risk quantification techniques because it determines the probability of failure, $P(f)$, and consequence separately. This allows the $P(f)$ to be determined after the probability distributions have been developed. Additionally, consequences can be in any form desired.

Future Work

Before any standards are set or fines are assessed, regulating authorities must determine an acceptable threshold and failure rate for nitrate. Values were tentatively used for this research based on commonly used standards relating to nitrate and waste management. However, these values may need to be changed for different areas, soils, and/or crops. Additionally, a standard monitoring system must be established. Once these values are determined, environmentally acceptable liquid dairy waste application rates could be determined for different regions or states using the technique described in this thesis.

References

- Adelman, D.D. and M.F. Dahab. 1993. Risk versus economic return in managing groundwater nitrate contamination. *Water Science Technology* 28(3-5):55-63.
- Agricultural Prices*. 1995. USDA, National Agricultural Statistics Service, Washington, D.C.:GPO.
- Agricultural Statistics*. 1995. USDA, National Agricultural Statistics Service, Washington, D.C.:GPO.
- ASAE Standards*, 42nd Ed. 1995. EP496.1. Agricultural machinery management. St. Joseph, Michigan:ASAE.
- Bobee, B., F. Ashkar, R. Roy, and L. Perreault. 1991. Risk analysis of hydrological data using gamma family and derived distributions. *NATO ASI Series G*29:21-41.
- Bruggeman, A.C., S. Mostaghimi, G.I. Holtzman, V.O. Shanholtz, S. Shukla, and B.B. Ross. 1995. Monitoring pesticide and nitrate in Virginia's groundwater-a pilot study. *Transactions of the ASAE* 38(3):797-807.
- Cooke, R.A., S. Mostaghimi, and F.E. Woeste. 1993. VTFIT: a microcomputer-based routine for fitting probability distribution functions to data. *Applied Engineering in Agriculture* 9(4):401-408.
- Dahab, M.F. and Y.W. Lee. 1991. Risk management for nitrate-contaminated groundwater under imprecise conditions. *NATO ASI Series G*29:393-406.

- Duckstein L., B.P. Shrestha, and E.Z. Stakhiv. 1991. Multicriterion risk and reliability analysis in hydrologic system design. *NATO ASI Series G29*:363-385.
- Edwards, S.F. 1988. Option prices for groundwater protection. *Journal of Environmental Economics and Management* 15:475-487.
- Farago, T. 1985. Soil moisture content: statistical estimation of its probability distribution. *American Meteorological Society* 24:371-376.
- Ganoulis J, G., L. Duckstein, and I. Bogardi. 1991. Risk analysis of water quantity and quality problems: the engineering approach. *NATO ASI Series G29*:3-17.
- Grusenmeyer, D. 1991. Dairy manure management-an industry perspective. *National Livestock, Poultry and Aquaculture Waste Management Workshop*, 267-272. Kansas City, Missouri, 29-31 July.
- Henley, E.J. and H. Kumamoto. 1981. *Reliability Engineering and Risk Assessment*. New York, NY: The Institute of Electrical and Electronics Engineers, Inc.
- Holden, L.R., J.A. Graham, R.W. Whitmore, W.J. Alexander, R.W. Pratt, S.K. Liddle, and L.L. Piper. 1992. Results of the national alachlor well water survey. *Environmental Science Technology* 26(2):935-943.
- Huang, W. and R.M. Lantin. 1993. A comparison of farmers' compliance costs to reduce excess nitrogen fertilizer use under alternative policy options. *Review of Agricultural Economics* 15(1):51-62.
- Johnson, A.F. 1995. Forage, Soil and Water Quality Responses to Animal Waste Application. M.S. Thesis, Texas A&M University, College Station.

- Johnson, S.L., R.M. Adams, and F.M. Perr. 1991. The on-farm costs of reducing groundwater pollution. *American Agricultural Economics Association* November:1063-1071.
- Jordan, J.L. and A.H. Elnagheeb. 1993. Willingness to pay for improvements in drinking water quality. *Water Resources Research* 29:237-245.
- Knisel, W.G. 1980. CREAMS: A Field-scale model for chemicals, runoff, and erosion from agricultural management systems. U.S. Department of Agriculture, Conservation Research Report No. 26, 643.
- Koterba, M.T., W.S.L. Banks, and R.J. Shedlock. 1993. Pesticide in shallow ground water in the Delmarva peninsula. *Journal of Environmental Quality* 22(3):500-518.
- Kross, B.C., G.R. Hallberg, D.R. Bruner, R.D. Libra, K.D. Rex, L.M.B. Weih, M.E. Vermace, L.F. Burmeister, N.H. Hall, K.L. Cherryholmes, J.K. Johnson, M.I. Selim, B.K. Nations, L.S. Seigley, D.J. Wuade, A.G. Dudler, K.D. Sesder, M.A. Culp, C.F. Lynch, H.F. Nicholson, and J.P. Hughes. 1990. The Iowa state-wide rural well-water survey - water quality data: initial analysis. *Technical Information Series 19*. Iowa City: Iowa Department of Natural Resources.
- Lambert, D.K. 1990. Risk considerations in the reduction of nitrogen fertilizer use in agricultural production. *Western Journal of Agricultural Economics* 15(2):234-244.
- Lane, L.J., M.A. Nearing, J.J. Stone, and A.D. Nicks. 1989. WEPP hillslope profile erosion model user summary. USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation.

- LeMasters, G. and D.J. Doyle. 1989. Grade A dairy farm well water quality survey. Madison: Wisconsin Department of Agriculture, Trade and Consumer Protection and Wisconsin Agricultural Statistics Service.
- Leonard, R.A., W.G. Knisel, and D.A. Still. 1987. GLEAMS: Groundwater loading effects of agricultural management systems. *Transactions of the ASAE* 30(5):1403-1418.
- Lewis, S.M., B.J. Barfield, D.E. Storm, and L.E. Ormsbee. 1994. PRORIL-an erosion model using probability distribution for rill flow and density. *Transactions of the ASAE* 37(1):115- 123.
- Madison, R.J. and J.O. Brunett. 1985. Overview of the occurrence of nitrate in ground water of the United States. National water summary 1984, 93-105. U.S. Geological Survey Water Supply Paper 2275. Washington, D.C.: GPO.
- Madramootoo, C.A., K.A. Kenneth, and P. Enright. 1995. Simulating tile drainage and nitrate leaching under a potato crop. *Water Resources Bulletin* 31(3):463-473.
- Mostaghimi, S., G.I. Holtzman, V.O. Shanholtz, A.C. Bruggeman, S. Shukla, C. Desai, B.B. Ross, and M.J. Weaver. 1993. A framework for evaluating the extent of pesticide contamination in Virginia's ground water. Report No. ES1293, Commonwealth of Virginia, Department of Agriculture and Consumer Services Office of Pesticide Management, Richmond, Va. Blacksburg: Virginia Polytechnic Institute and State University.
- Schmit, T.M. and W.A. Knoblauch. 1994. The impact of nutrient loading restrictions on dairy farm profitability. *Journal of Dairy Science* 78:1267-1281.

- Schock, S.C., E. Mehnert, M.E. Caughey, G.B. Dreher, W.S. Dey, S. Wilson, C. Ray, S.F.J. Chou, J. Valkenburg, J.M. Gosar, J.R. Karny, M.L. Barnhardt, W.F. Black, M.R. Brown, and V.J. Garcia. 1992. Pilot study: Agricultural chemicals in rural private water wells in Illinois. Cooperative Ground Water Report 14. Champaign: Illinois State Geological Survey, Illinois State Water Survey, Illinois Department of Agriculture.
- Shahabasi, Y., L.J. Segerlind, and N.J. Carroll. 1995. A simulation model to determine the allowable depth for apples stored in bulk. *Transactions of the ASAE* 38(2):587-591.
- Spalding, R.F., M.E. Exner, G.E. Martin, and D.D. Snow. 1993. Effects of sludge disposal on groundwater nitrate concentrations. *Journal of Hydrology* 142:213-228.
- Sun, H. J.C. Bergstrom, and J.H. Dorfman. 1992. Estimating the benefits of groundwater contamination control. *Southern Journal of Agricultural Economics* 24:63-71.
- Taylor, H.H. 1994. Fertilizer use and price statistics, 1960-1993. USDA, Economic Research Service, Statistical Bulletin Number 893.
- Taylor, M.L. 1992. Farm-level response to agricultural effluent control strategies: the case of the Willamette valley. *Journal of Agricultural and Resource Economics*. 17:173-185.
- Thomas, C.T. and R.N. Boivert. 1995. *The bioeconomics of regulating nitrates in groundwater from agricultural production through taxes, quantity restrictions, and pollution permits*. Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, New York.

- Thomas, C.V. and M.A. DeLorenzo. 1994. Simulating individual cow milk yield for milking parlor simulation models. *Journal of Dairy Science* 77:1285-1295.
- Valdes, B.V., M. Diaz-Granados, and R.L. Bras. 1990. A derived pdf for the initial soil moisture in a catchment. *Journal of Hydrology* 113:163-176.
- Vellidis, G., S. Henry, C. Perry, and R.K. Hubbard. 1991. Methodology and instrumentation for assessing the water quality impacts of a dairy waste land application system. ASAE Paper No. 91-2598. American Society of American Engineers, St. Joseph, Mich.:ASAE.
- Vellidis, G., R.K. Hubbard, J.G. Davis, R. Lowrance, R.G. Williams, J.C. Johnson, Jr., and G.L. Newton. 1996. Nutrient concentrations in the soil solution and shallow ground water of a liquid manure land application site. *Transactions of the ASAE* (in press).
- Vellidis, G., 1996. Unpublished data. University of Georgia, Tifton.
- Yoon, K.S., K.H. Yoo, C.W. Wood, and B.M. Hall. 1994. Application of GLEAMS to predict nutrient losses from land application of poultry litter. *Transactions of the ASAE* 37(2):453-459.

Appendix A. GLEAMS Input and Output Files

GLEAMS Short-term (4yr) Input Files Tifton, GA

GLEAMS Hydrology Input File for Application Rate 200
kg-N/ha/yr (4yr) Tifton, GA

```

91001 0 0 1 0 0 0 0 1 0
926

4.44 .1 .15 3.3 72 0.02 1.45 39.0
3 3 10.0 14.0 39.0
0.40 .4 0.40
0.19 .26 0.30
0.05 .13 0.18
0.3 0.25 0.2
1.0 .8 .6
8.0 20.0 25.0
8.0 23.0 20.0
59.9 62.6 69.5 77.8 84.4 89.1 90.6 90.8 87.1
79.0
69.7 62.2
37.6 39.4 46.5 54.4 61.7 67.7 70.2 70.0 66.3
54.7
45.4 39.1
218.0 227.0 362.0 529.0 506.0 502.0 547.0 479.0
415.0 328.0
194.0 173.0
8.0 9.0 9.0 9.0 7.0 7.0 7.0 6.0 4.0 5.0
5.0 5.0
45.0 45.0 48.0 55.0 63.0 69.0 72.0 71.0 68.0
58.0
49.0 43.0
91 94 4
10 0274 1206 1177 27.0 1.3 1 074 288
0
10 1207 1259 1239 27.0 1.3 1 074 288
0
10 1240 1311 1291 27.0 1.3 1 074 288
0
52 1295 2061 2041 27.0 3.3 0 074 288
0
52 2042 2109 2089 27.0 3.3 0 074 288
0
22 2108 2224 2204 27.0 7.2 0 074 288
0
10 2205 2263 2243 27.0 1.3 1 074 288
0
10 2244 2301 2281 27.0 1.3 1 074 288
0
52 2286 3034 3014 27.0 3.3 0 074 288
0
52 3015 3101 3081 27.0 3.3 0 074 288
0
22 3096 3228 3208 27.0 7.2 0 074 288
0
10 3209 3272 3252 27.0 1.3 1 074 288
0
10 3253 3304 3284 27.0 1.3 1 074 288
0
52 3285 4051 4031 27.0 3.3 0 074 288
0
52 4032 4100 4080 27.0 3.3 0 074 288
0
22 4111 4220 4200 27.0 7.2 0 074 288
0
10 4201 4272 4252 27.0 1.3 1 074 288

```

```

0
10 4253 4304 4284 27.0 1.3 1 074 288
0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
-1 0 0 0

```

GLEAMS Nutrient Input File For Application Rate
200 kg-N/ha/yr (4yr) Tifton, GA

```

91 94 0 4 1
0.0 1.0 0.28 1.0
0.1 0.1 0.1
2.0 2.5 1.5
391.0 391.0 391.0
0.0
0.1 0.1 0.1
29.8 4.0 4.0
0.0
1001
2 1 1175
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1177 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.0010 0.0002 0.03 3
1206 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.0010 0.0002 0.03 3
1176 10 13.0
1207
3 0 1239
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1211 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1218 01 0 15
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1225 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1240
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10 17920.0 1.35 80.0 6.7 1.25 -.27
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1255 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1273 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1287 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1295
7 0 2041
52 5240.0 1.35 75.0 2.6 1.05 -.290
1301 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1317 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1336 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1348 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
2007 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
2021 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
2034 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3

```

3110	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3117	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3131	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3146	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3158	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3173	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3188	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3195	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3202	01	0	15						
2.0	0.0	0.123	0.0008	0.0032	0.001	0.0002	0.03	3	
3209									
2	0	3252							
10	17920.0	1.35	80.0	6.7	1.25	-0.29			
3222	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3237	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3253									
2	0	3284							
10	17920.0	1.35	80.0	6.7	1.25	-0.29			
3257	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3271	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3285									
5	0	4031							
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
3298	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3312	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3334	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
3354	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4011	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4032									
3	0	4080							
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
4032	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4046	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4067	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4111									
8	0	4200							
22	44800.0	1.35	75.0	2.5	.4	-0.55			
4095	01	0	15						
2.0	0.0	0.0041	0.0008	0.0032	0.001	0.0002	0.03	3	
4109	01	0	15						
2.0									

0 0 0 0
-1 0 0 0

**GLEAMS Nutrient Input File For Application Rate 400
kg-N/ha/yr (4yr) Tifton, GA**

91	94	0	4	1
0.0	1.0	0.28	1.0	
0.1	0.1	0.1		
3.0	3.0	3.5		
391.0	391.0	391.0		
0.0				
0.1	0.1	0.1		
29.8	4.0	4.0		
0.0				
1001				
2	1	1175		
10	17920.0	1.35	80.0	6.7 1.25 -0.27
1177	01	0	15	
2.00	0.0	0.0082	0.0017 0.0064	0.0020 0.0004 0.07 3
1206	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.0020 0.0004 0.07 3
1176	10	13.0		
1207				
3	0	1239		
10	17920.0	1.35	80.0	6.7 1.25 -0.27
1211	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1218	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1225	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1240				
4	00	1291		
10	17920.0	1.35	80.0	6.7 1.25 -.27
1246	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1255	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1273	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1287	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1295				
7	0	2041		
52	5240.0	1.35	75.0	2.6 1.05 -.290
1301	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1317	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1336	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
1348	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2007	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2021	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2034	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2042				
2	0	2089		
52	5240.0	1.35	75.0	2.6 1.05 -.290
2050	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2061	01	0	15	

2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2103				
7	0	2204		
22	44800.0	1.35	75.0	2.5 .4 -0.55
2112	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2119	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2131	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2145	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2159	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2174	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2194	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2205				
3	0	2243		
10	17920.0	1.35	80.0	6.7 1.25 -0.28
2222	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2230	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2239	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2244				
1	0	2281		
10	17920.0	1.35	80.0	6.7 1.25 -0.28
2252	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2286				
5	0	3014		
52	5240.0	1.35	75.0	2.6 1.05 -0.29
2300	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2314	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2322	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
2348	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3004	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3015				
4	0	3081		
52	5240.0	1.35	75.0	2.6 1.05 -.29
3019	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3032	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3053	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3061	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3096				
10	0	3208		
22	44800.0	1.35	75.0	2.5 0.4 -0.55
3103	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3110	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3117	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3
3131	01	0	15	
2.0	0.0	0.0082	0.0017 0.0064	0.002 0.0004 0.07 3

3146	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3158	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3173	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3188	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3195	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3202	01	0	15							
2.0	0.0	0.123	0.0017	0.0064	0.002	0.0004	0.07	3		
3209										
2	0	3252								
10	17920.0	1.35	80.0	6.7	1.25	-0.29				
3222	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3237	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3253										
2	0	3284								
10	17920.0	1.35	80.0	6.7	1.25	-0.29				
3257	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3271	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3285										
5	0	4031								
52	5240.0	1.35	75.0	2.6	1.05	-0.29				
3298	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3312	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3334	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
3354	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4011	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4032										
3	0	4080								
52	5240.0	1.35	75.0	2.6	1.05	-0.29				
4032	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4046	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4067	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4111										
8	0	4200								
22	44800.0	1.35	75.0	2.5	.4	-0.55				
4095	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4109	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4123	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4143	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4150	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4159	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4172	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4179	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		

4201										
2	0	4243								
10	17920.0	1.35	80.0	6.7	1.25	-0.28				
4222	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4237	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4244										
3	0	4284								
10	17920.0	1.35	80.0	6.7	1.25	-0.28				
4263	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4270	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4279	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4285										
5	0	5014								
52	5240.0	1.35	75.0	2.6	1.05	-0.29				
4291	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4299	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4312	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4334	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
4354	01	0	15							
2.0	0.0	0.0082	0.0017	0.0064	0.002	0.0004	0.07	3		
0										

GLEAMS Erosion Input File For Application Rate 400
kg-N/ha/yr (4yr) Tifton, GA

91	94	0	1	0						
100.0										
2	2.75									
0.0	.02	460.0	0.02							
1	1.0	0.19								
4										
001										
001										
001										
001										
1	1.0									
0.55										
1.0										
0.046										
.55										
1.0										
0.046										
.55										
1.0										
0.046										

GLEAMS Hydrology Input File For Application Rate 600
kg-N/ha/yr (4yr) Tifton, GA

91001	0	0	1	0	0	0	0	1	0	
926										
5.49	.1	.15	3.3	72	0.02	1.45	39.0			

3	3	10.0	14.0	39.0					
0.40	.4	0.40							
0.19	.26	0.30							
0.05	.13	0.18							
0.3	0.25	0.2							
1.0	.8	.6							
8.0	20.0	25.0							
8.0	23.0	20.0							
59.9	62.6	69.5	77.8	84.4	89.1	90.6	90.8	87.1	
79.0									
69.7	62.2								
37.6	39.4	46.5	54.4	61.7	67.7	70.2	70.0	66.3	
54.7									
45.4	39.1								
218.0	227.0	362.0	529.0	506.0	502.0	547.0	479.0		
415.0	328.0								
194.0	173.0								
8.0	9.0	9.0	9.0	7.0	7.0	7.0	6.0	4.0	5.0
5.0	5.0								
45.0	45.0	48.0	55.0	63.0	69.0	72.0	71.0	68.0	
58.0									
49.0	43.0								
91	94	4							
10	0274	1206	1177	27.0	1.3	1	074	288	
0									
10	1207	1259	1239	27.0	1.3	1	074	288	
0									
10	1240	1311	1291	27.0	1.3	1	074	288	
0									
52	1295	2061	2041	27.0	3.3	0	074	288	
0									
52	2042	2109	2089	27.0	3.3	0	074	288	
0									
22	2108	2224	2204	27.0	7.2	0	074	288	
0									
10	2205	2263	2243	27.0	1.3	1	074	288	
0									
10	2244	2301	2281	27.0	1.3	1	074	288	
0									
52	2286	3034	3014	27.0	3.3	0	074	288	
0									
52	3015	3101	3081	27.0	3.3	0	074	288	
0									
22	3096	3228	3208	27.0	7.2	0	074	288	
0									
10	3209	3272	3252	27.0	1.3	1	074	288	
0									
10	3253	3304	3284	27.0	1.3	1	074	288	
0									
52	3285	4051	4031	27.0	3.3	0	074	288	
0									
52	4032	4100	4080	27.0	3.3	0	074	288	
0									
22	4111	4220	4200	27.0	7.2	0	074	288	
0									
10	4201	4272	4252	27.0	1.3	1	074	288	
0									
10	4253	4304	4284	27.0	1.3	1	074	288	
0									
0	0	0	0						
0	0	0	0						
0	0	0	0						
0	0	0	0						
-1	0	0	0						

GLEAMS Nutrient Input File For Application Rate 600
kg-N/ha/yr (4yr) Tifton, GA

91	94	0	4	1					
0.0	1.0	0.28	1.0						
0.1	0.1	0.1							
1.0	1.0	1.5							
391.0	391.0	391.0							
0.0									
0.1	0.1	0.1							
29.8	4.0	4.0							
0.0									
1001									
2	1	1175							
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1177	01	0	15						
2.00	0.0	0.0123	0.0025	0.0097	0.0030	0.0006	0.13	3	
1206	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.0030	0.0006	0.13	3	
1176	10	13.0							
1207									
3	0	1239							
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1211	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1218	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1225	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1240									
4	00	1291							
10	17920.0	1.35	80.0	6.7	1.25	-.27			
1246	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1255	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1273	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1287	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1295									
7	0	2041							
52	5240.0	1.35	75.0	2.6	1.05	-.290			
1301	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1317	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1336	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
1348	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2007	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2021	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2034	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2042									
2	0	2089							
52	5240.0	1.35	75.0	2.6	1.05	-.290			
2050	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2061	01	0	15						
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3	
2103									
7	0	2204							
22	44800.0	1.35	75.0	2.5	.4	-0.55			

2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4237	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4244								
3	0	4284						
10		17920.0	1.35	80.0	6.7	1.25	-0.28	
4263	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4270	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4279	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4285								
5	0	5014						
52		5240.0	1.35	75.0	2.6	1.05	-0.29	
4291	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4299	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4312	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4334	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
4354	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
0								

**GLEAMS Erosion Input File For Application Rate 600
kg-N/ha/yr (4yr) Tifton, GA**

91	94	0	1	0
100.0				
2	5.49			
0.0	.02	460.0	0.02	
1	1.0	0.19		
4				
001				
001				
001				
001				
1	1.0			
0.55				
1.0				
0.046				
.55				
1.0				
0.046				
.55				
1.0				
0.046				
.55				
1.0				
0.046				

**GLEAMS Hydrology Input File For Application Rate 800
kg-N/ha/yr (4yr) Tifton, GA**

91001	0	0	1	0	0	0	0	1	0
926									
2.53	.1	.15	3.3	72	0.02	1.	39.0		
3	3	10.0	14.0	39.0					
0.40	.4	0.40							
0.19	.26	0.30							
0.05	.13	0.18							

0.3	0.25	0.2							
1.0	.8	.6							
8.0	20.0	25.0							
8.0	23.0	20.0							
59.9	62.6	69.5	77.8	84.4	89.1	90.6	90.8	87.1	
79.0									
69.7	62.2								
37.6	39.4	46.5	54.4	61.7	67.7	70.2	70.0	66.3	
54.7									
45.4	39.1								
218.0	227.0	362.0	529.0	506.0	502.0	547.0	479.0		
415.0	328.0								
194.0	173.0								
8.0	9.0	9.0	9.0	7.0	7.0	7.0	6.0	4.0	5.0
5.0	5.0								
45.0	45.0	48.0	55.0	63.0	69.0	72.0	71.0	68.0	
58.0									
49.0	43.0								
91	94	4							
10	0274	1206	1177	27.0	1.3	1	074	288	
0									
10	1207	1259	1239	27.0	1.3	1	074	288	
0									
10	1240	1311	1291	27.0	1.3	1	074	288	
0									
52	1295	2061	2041	27.0	3.3	0	074	288	
0									
52	2042	2109	2089	27.0	3.3	0	074	288	
0									
22	2108	2224	2204	27.0	7.2	0	074	288	
0									
10	2205	2263	2243	27.0	1.3	1	074	288	
0									
10	2244	2301	2281	27.0	1.3	1	074	288	
0									
52	2286	3034	3014	27.0	3.3	0	074	288	
0									
52	3015	3101	3081	27.0	3.3	0	074	288	
0									
22	3096	3228	3208	27.0	7.2	0	074	288	
0									
10	3209	3272	3252	27.0	1.3	1	074	288	
0									
10	3253	3304	3284	27.0	1.3	1	074	288	
0									
52	3285	4051	4031	27.0	3.3	0	074	288	
0									
52	4032	4100	4080	27.0	3.3	0	074	288	
0									
22	4111	4220	4200	27.0	7.2	0	074	288	
0									
10	4201	4272	4252	27.0	1.3	1	074	288	
0									
10	4253	4304	4284	27.0	1.3	1	074	288	
0									
0	0	0	0						
0	0	0	0						
0	0	0	0						
0	0	0	0						
-1	0	0	0						

**GLEAMS Nutrient Input File For Application Rate 800
kg-N/ha/yr (4yr) Tifton, GA**

91	94	0	4	1
----	----	---	---	---

2131	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2145	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2159	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2174	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2194	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2205	3	0	2243										
10	17920.0	1.35	80.0	6.7	1.25	-0.28							
2222	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2230	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2239	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2244	1	0	2281										
10	17920.0	1.35	80.0	6.7	1.25	-0.28							
2252	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2286	5	0	3014										
52	5240.0	1.35	75.0	2.6	1.05	-0.29							
2300	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2314	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2322	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
2348	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3004	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3015	4	0	3081										
52	5240.0	1.35	75.0	2.6	1.05	-.29							
3019	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3032	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3053	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3061	01	0	15										
2.0	0.0	0.0164	0.0032	0.0129	0.004	0.0008	0.13	3					
3096	10	0	3208										
22	44800.0	1.35	75.0	2.5	0.4	-0.55		</					

[illegible]

91	94	0	1	0
100.0				
2	2.53			
0.0	.02	460.0	0.02	
1	1.0	0.19		
4				
001				
001				
001				
001				
1	1.0			
0.55				
1.0				
0.046				
.55				
1.0				
0.046				
.55				
1.0				
0.046				
.55				
1.0				
0.046				

GLEAMS Long-term (50yr) Input Files Tifton, GA

GLEAMS Hydrology Input File For Application Rate 200 kg-N/ha/yr (50yr) Tifton, GA

```

1001 0 0 1 0 0 0 0 1 0
926

4.46 .1 .15 3.3 72 0.02 1.45 39.0
3 3 10.0 14.0 39.0
0.40 .4 0.40
0.19 .26 0.30
0.05 .13 0.18
0.3 0.25 0.2
1.0 .8 .6
8.0 20.0 25.0
8.0 23.0 20.0
59.9 62.6 69.5 77.8 84.4 89.1 90.6 90.8 87.1
79.0
69.7 62.2
37.6 39.4 46.5 54.4 61.7 67.7 70.2 70.0 66.3
54.7
45.4 39.1
218.0 227.0 362.0 529.0 506.0 502.0 547.0 479.0
415.0 328.0
194.0 173.0
8.0 9.0 9.0 9.0 7.0 7.0 7.0 6.0 4.0 5.0
5.0 5.0
45.0 45.0 48.0 55.0 63.0 69.0 72.0 71.0 68.0
58.0
49.0 43.0
01 50 1
52 0286 1041 1031 27.0 3.3 0 074 288
0
52 1032 1091 1081 27.0 3.3 0 074 288
0
22 1096 1228 1100 27.0 7.2 0 074 288
0
10 1101 1272 1252 27.0 1.3 1 074 288
0
10 1253 1287 1284 27.0 1.3 1 074 288
0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
-1 0 0 0

```

GLEAMS Nutrient Input File For Application Rate 200 kg-N/ha/yr (50yr) Tifton, GA

```

01 50 0 1 1
0.0 1.0 0.28 1.0
0.1 0.1 0.1
2.0 2.5 1.5
391.0 391.0 391.0
0.0
0.1 0.1 0.1
29.8 4.0 4.0
0.0
1001
1 0 1014
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1004 01 0 15

```

```

2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1015
4 0 1081
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1019 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1032 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1053 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1061 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1096
10 0 1208
22 44800.0 1.35 75.0 2.5 0.4 -0.55
1103 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1110 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1117 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1131 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1146 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1158 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1173 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1188 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1195 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1202 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1209
2 0 1252
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1222 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1237 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1253
2 0 1284
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1257 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1271 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1285
4 0 2031
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1298 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1312 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1334 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
1354 01 0 15
2.0 0.0 0.0041 0.0008 0.0032 0.001 0.0002 0.03 3
0

```

GLEAMS Erosion Input File For Application Rate 200 kg-N/ha/yr (50yr) Tifton, GA

```

01 50 0 1 0

```

100.0
2 4.46
0.0 .02 460.0 0.02
1 1.0 0.19
1
001
1 1.0
0.55
1.0
0.046

**GLEAMS Hydrology Input File For Application Rate 400
kg-N/ha/yr (50yr) Tifton, GA**

1001 0 0 1 0 0 0 0 1 0
926
2.75 .1 .15 3.3 72 0.02 1.00 39.0
3 3 10.0 14.0 39.0
0.40 .4 0.40
0.19 .26 0.30
0.05 .13 0.18
0.3 0.25 0.2
1.0 .8 .6
8.0 20.0 25.0
8.0 23.0 20.0
59.9 62.6 69.5 77.8 84.4 89.1 90.6 90.8 87.1
79.0
69.7 62.2
37.6 39.4 46.5 54.4 61.7 67.7 70.2 70.0 66.3
54.7
45.4 39.1
218.0 227.0 362.0 529.0 506.0 502.0 547.0 479.0
415.0 328.0
194.0 173.0
8.0 9.0 9.0 9.0 7.0 7.0 7.0 6.0 4.0 5.0
5.0 5.0
45.0 45.0 48.0 55.0 63.0 69.0 72.0 71.0 68.0
58.0
49.0 43.0
01 50 1
52 0286 1041 1031 27.0 3.3 0 074 288
0
52 1032 1091 1081 27.0 3.3 0 074 288
0
22 1096 1228 1100 27.0 7.2 0 074 288
0
10 1101 1272 1252 27.0 1.3 1 074 288
0
10 1253 1287 1284 27.0 1.3 1 074 288
0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
-1 0 0 0

**GLEAMS Nutrient Input File For Application Rate 400
kg-N/ha/yr (50yr) Tifton, GA**

01 50 0 1 1
0.0 1.0 0.28 1.0
0.1 0.1 0.1
3.0 3.0 3.5
391.0 391.0 391.0

0.0
0.1 0.1 0.1
29.8 4.0 4.0
0.0
1001
1 0 1014
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1004 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1015
4 0 1081
52 5240.0 1.35 75.0 2.6 1.05 -.29
1019 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1032 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1053 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1061 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1096
10 0 1208
22 44800.0 1.35 75.0 2.5 0.4 -0.55
1103 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1110 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1117 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1131 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1146 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1158 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1173 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1188 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1195 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1202 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1209
2 0 1252
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1222 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1237 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1253
2 0 1284
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1257 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1271 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1285
4 0 2031
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1298 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1312 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1334 01 0 15
2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
1354 01 0 15

2.0 0.0 0.0082 0.0017 0.0064 0.002 0.0004 0.07 3
0

**GLEAMS Erosion Input File For Application Rate 400
kg-N/ha/yr (50yr) Tifton, GA**

01 50 0 1 0
100.0
2 2.75
0.0 .02 460.0 0.02
1 1.0 0.19
1
001
1 1.0
0.55
1.0
0.046

**GLEAMS Hydrology Input File For Application Rate 600
kg-N/ha/yr (50yr) Tifton, GA**

1001 0 0 1 0 0 0 0 1 0
926

5.49 .1 .15 3.3 72 0.02 1.45 39.0
3 3 10.0 14.0 39.0
0.40 .4 0.40
0.19 .26 0.30
0.05 .13 0.18
0.3 0.25 0.2
1.0 .8 .6
8.0 20.0 25.0
8.0 23.0 20.0
59.9 62.6 69.5 77.8 84.4 89.1 90.6 90.8 87.1
79.0
69.7 62.2
37.6 39.4 46.5 54.4 61.7 67.7 70.2 70.0 66.3
54.7
45.4 39.1
218.0 227.0 362.0 529.0 506.0 502.0 547.0 479.0
415.0 328.0
194.0 173.0
8.0 9.0 9.0 9.0 7.0 7.0 7.0 6.0 4.0 5.0
5.0 5.0
45.0 45.0 48.0 55.0 63.0 69.0 72.0 71.0 68.0
58.0
49.0 43.0
01 50 1
52 0286 1041 1031 27.0 3.3 0 074 288
0
52 1032 1091 1081 27.0 3.3 0 074 288
0
22 1096 1228 1100 27.0 7.2 0 074 288
0
10 1101 1272 1252 27.0 1.3 1 074 288
0
10 1253 1287 1284 27.0 1.3 1 074 288
0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
-1 0 0 0

**GLEAMS Nutrient Input File For Application Rate 600
kg-N/ha/yr (50yr) Tifton, GA**

01 50 0 1 1
0.0 1.0 0.28 1.0
0.1 0.1 0.1
1.0 1.0 1.5
391.0 391.0 391.0
0.0
0.1 0.1 0.1
29.8 4.0 4.0
0.0
1001
1 0 1014
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1004 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1015
4 0 1081
52 5240.0 1.35 75.0 2.6 1.05 -.29
1019 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1032 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1053 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1061 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1096
10 0 1208
22 44800.0 1.35 75.0 2.5 0.4 -0.55
1103 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1110 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1117 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1131 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1146 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1158 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1173 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1188 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1195 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1202 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1209
2 0 1252
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1222 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1237 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1253
2 0 1284
10 17920.0 1.35 80.0 6.7 1.25 -0.29
1257 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1271 01 0 15
2.0 0.0 0.0123 0.0025 0.0097 0.003 0.0006 0.13 3
1285
4 0 2031

52	5240.0	1.35	75.0	2.6	1.05	-0.29		
1298	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
1312	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
1334	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
1354	01	0	15					
2.0	0.0	0.0123	0.0025	0.0097	0.003	0.0006	0.13	3
0								

**GLEAMS Erosion Input File For Application Rate 600
kg-N/ha/yr (50yr) Tifton, GA**

01	50	0	1	0
100.0				
2	5.49			
0.0	.02	460.0	0.02	
1	1.0	0.19		
1				
001				
1	1.0			
0.55				
1.0				
0.046				

**GLEAMS Hydrology Input File For Application Rate 800
kg-N/ha/yr (50yr) Tifton, GA**

1001	0	0	1	0	0	0	0	1	0
926									
2.53	.1	.15	3.3	72	0.02	1.00	39.0		
3	3	10.0	14.0	39.0					
0.40	.4	0.40							
0.19	.26	0.30							
0.05	.13	0.18							
0.3	0.25	0.2							
1.0	.8	.6							
8.0	20.0	25.0							
8.0	23.0	20.0							
59.9	62.6	69.5	77.8	84.4	89.1	90.6	90.8	87.1	
79.0									
69.7	62.2								
37.6	39.4	46.5	54.4	61.7	67.7	70.2	70.0	66.3	
54.7									
45.4	39.1								
218.0	227.0	362.0	529.0	506.0	502.0	547.0	479.0		
415.0	328.0								
194.0	173.0								
8.0	9.0	9.0	9.0	7.0	7.0	7.0	6.0	4.0	5.0
5.0	5.0								
45.0	45.0	48.0	55.0	63.0	69.0	72.0	71.0	68.0	
58.0									
49.0	43.0								
01	50	1							
52	0286	1041	1031	27.0	3.3	0	074	288	
0									
52	1032	1091	1081	27.0	3.3	0	074	288	
0									
22	1096	1228	1100	27.0	7.2	0	074	288	
0									
10	1101	1272	1252	27.0	1.3	1	074	288	
0									
10	1253	1287	1284	27.0	1.3	1	074	288	

0				
0	0	0	0	
0	0	0	0	
0	0	0	0	
0	0	0	0	
-1	0	0	0	

**GLEAMS Nutrient Input File For Application Rate 800
kg-N/ha/yr (50yr) Tifton, GA**

01	50	0	1	1
0.0	1.0	0.28	1.0	
0.1	0.1	0.1		
1.5	2.0	2.5		
391.0	391.0	391.0		
0.0				
0.1	0.1	0.1		
29.8	4.0	4.0		
0.0				
1001				
1	0	1014		
52	5240.0	1.35	75.0	2.6
1004	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1015				
4	0	1081		
52	5240.0	1.35	75.0	2.6
1019	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1032	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1053	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1061	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1096				
10	0	1208		
22	44800.0	1.35	75.0	2.5
1103	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1110	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1117	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1131	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1146	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1158	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1173	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1188	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1195	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1202	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1209				
2	0	1252		
10	17920.0	1.35	80.0	6.7
1222	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1237	01	0	15	
2.0	0.0	0.0164	0.0033	0.0129
1253				

2	0	1284							
10		17920.0	1.35	80.0	6.7	1.25	-0.29		
1257	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
1271	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
1285									
4	0	2031							
52		5240.0	1.35	75.0	2.6	1.05	-0.29		
1298	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
1312	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
1334	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
1354	01	0	15						
2.0	0.0	0.0164	0.0033	0.0129	0.004	0.0008	0.13	3	
0									

GLEAMS Erosion Input File For Application Rate 800
kg•N/ha/yr (50yr) Tifton, GA

01	50	0	1	0
100.0				
2	2.53			
0.0	.02	460.0	0.02	
1	1.0	0.19		
1				
001				
1	1.0			
0.55				
1.0				
0.046				

TABLE A1
GLEAMS YEARLY-MAXIMUM NITRATE CONCENTRATIONS (mg/L)
LEACHING BELOW THE ROOT ZONE. TIFTON, GA

Year	200 kg•N/ha/yr	400 kg•N/ha/yr	600 kg•N/ha/yr	800 kg•N/ha/yr
1	1.041468	2.078942	3.143541	3.522976
2	4.084553	9.925080	15.689220	19.558050
3	1.600133	5.600053	9.852633	12.931550
4	2.945678	10.278280	16.613320	23.543950
5	2.595306	7.818740	13.578680	18.755440
6	8.810206	24.148630	38.395470	48.751900
7	1.132123	3.375769	5.703125	8.435562
8	.824800	5.588395	13.554000	21.550310
9	.396991	.751405	1.347519	2.466766
10	1.962422	6.323679	10.897110	16.890290
11	.330414	.883413	1.752665	2.662204
12	.806205	3.713771	5.795484	8.822988
13	6.682716	12.367880	24.604760	31.942730
14	4.476213	16.324340	24.934300	40.751870
15	.888528	3.820000	6.366439	9.806156
16	2.420225	9.295775	17.207070	23.961560
17	2.044100	14.769810	29.908720	44.134280
18	1.161758	5.546545	9.900816	13.429980
19	2.942100	9.736905	16.349900	23.068650
20	.794821	7.609606	13.890890	20.386690
21	.320423	1.080931	1.748758	2.013868
22	4.377474	19.724400	33.022030	43.901150
23	.387512	1.115410	2.486558	3.788624
24	2.116039	3.823929	11.336420	29.341270
25	3.165351	10.995020	24.083840	44.840570
26	2.871606	6.681478	10.434250	14.294360
27	5.590141	15.491070	25.692570	35.813170
28	.250443	4.222906	6.282414	9.447580
29	1.149209	8.710340	14.464690	19.353110
30	1.721939	7.425506	11.761730	24.248060
31	2.072899	10.288860	18.284140	25.413040
32	.406234	2.281745	3.968248	3.571101
33	.466728	2.073332	3.985176	6.868338
34	.947837	8.769339	15.104500	21.671180
35	.351213	1.110517	2.203363	20.362250
36	1.587958	7.345224	13.666560	18.281070
37	.178497	4.697736	7.933064	12.139890
38	.890674	2.212212	2.852197	3.228451
39	1.199148	7.029419	13.304540	18.340840
40	2.298404	14.488020	25.659120	37.220000
41	1.178338	19.607700	34.776260	47.330660
42	.433916	6.169591	11.775330	15.569360
43	2.456614	5.121923	8.360049	12.745080
44	.068306	.606054	2.037061	4.693878
45	3.430331	11.002950	22.102860	40.294990
46	3.897370	11.672470	19.731450	27.132840
47	1.680088	3.863711	6.349026	8.287585
48	2.289201	8.058230	15.617540	20.415460
49	3.057378	12.409420	19.510200	28.305470
50	.281753	4.474973	7.118767	8.651424

GLEAMS Short-term (3yr) Input Files Overton, TX

GLEAMS Hydrology Input File For Application Rate 0, 250, 500, 1000 kg-N/ha/yr (3yr) Overton, TX

```

92001 0 0 1 0 0 0 0 1 0
926
.022 .1 0.1 3.3 79 0.03 3.6 45.0 700.0 31.59
3 2 3.0 45.0
0.40 0.40
0.22 0.22
0.05 0.05
0.4 0.4
1.0 0.5
8.0 8.0
8.0 8.0
53.8 59.1 67.2 76.5 82.8 89.4 93.8 93.1 86.6
78.3
66.8 58.4
31.5 35.5 43.0 52.9 60.2 67.0 70.4 68.7 63.4
51.5
42.1 34.7
244.0 310.0 412.0 473.0 561.0 618.0 601.0 570.0
472.0 386.0
288.0 231.0
240.0 240.0 264.0 264.0 264.0 240.0 216.0 216.0
192.0 216.0
240.0 240.0
37.96 40.21 43.73 53.5 62.95 69.46 70.73 69.73
64.98 55.46
44.73 40.16
92 94 1
52 0288 1083 1073 27.0 3.3 0 074 288
0
52 1074 1130 1120 27.0 3.3 0 074 288
0
10 1121 1185 1165 27.0 3.3 1 074 288
0
10 1166 1217 1197 27.0 1.3 1 074 288
0
10 1198 1245 1225 27.0 1.3 1 074 288
0
10 1226 1282 1262 27.0 1.3 1 074 288
0
0 0 0 0
0 0 0 0
-1 0 0 0

```

GLEAMS Erosion Input File For Application Rate 0, 250, 500, 1000 kg-N/ha/yr (3yr) Overton, TX

```

92 94 0 1 0
100.0
2 .022
0.0 0.03 59.4 0.03
1 1.0 .2
1
001
1 1.0
0.55
1.0
0.046

```

GLEAMS Nutrient Input File For Application Rate 0 kg-N/ha/yr (3yr) Overton, TX

```

92 94 0 3 1
0.0 1.25 1.0 1.0
0.1 .1
4.0 2.0
391.0 391.0
0.0
0.1 0.1
30.0 15.0
0.0
1001
0 0 1165
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1166
0 0 1197
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1198
0 0 1225
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1226
0 0 1262
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1263
0 0 2073
52 5240.0 1.35 75.0 2.6 1.05 -0.29
2074
0 0 2120
52 5240.0 1.35 75.0 2.6 1.05 -0.29
2121
0 0 2165
10 17920.0 1.35 80.0 6.7 1.25 -0.27
2166
0 0 2196
10 17920.0 1.35 80.0 6.7 1.25 -0.27
2197
0 0 2230
10 17920.0 1.35 80.0 6.7 1.25 -0.27
2231
0 0 2260
10 17920.0 1.35 80.0 6.7 1.25 -0.27
2261
0 0 2292
10 17920.0 1.35 80.0 6.7 1.25 -0.27
2293
0 0 3136
52 5240.0 1.35 75.0 2.6 1.05 -0.29
0

```

GLEAMS Nutrient Input File For Application Rate 250 kg-N/ha/yr (3yr) Overton, TX

```

92 94 0 3 1
0.0 1.25 1.0 1.0
0.1 .1
4.0 2.0
391.0 391.0
0.0
0.1 0.1
30.0 15.0
0.0
1001
01 0 1165

```

10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1132	01 4 15							
0.32	0.0 0.18 0.036	.06	.025	.005	.13	3		
1166								
0	0 1197							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1198								
01	0 1225							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1204	01 4 15							
0.72	0.0 0.078	.025	.05	.02	.004	.13	3	
1226								
0	0 1262							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1263								
01	0 2073							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
1273	01 4 15							
0.88	0.0 0.065	0.025	.05	.02	.004	.13	3	
2074								
01	0 2120							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
2086	01 4 15							
0.30	0.0 0.19	.06	.1	.02	.015	.13	3	
2121								
01	0 2165							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2133	01 4 15							
0.31	0.0 0.188	.06	.1	.02	.015	.13	3	
2166								
0	0 2196							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2197								
01	0 2230							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2201	01 4 15							
0.34	0.0 0.0165	.06	.1	.02	.015	.13	3	
2231								
0	0 2260							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261								
01	0 2292							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261	01 4 15							
0.38	0.0 0.15	.06	.1	.02	.015	.13	3	
2293								
01	0 3136							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
3079	01 4 15							
0.80	0.0 0.071	.03	.05	.02	.007	.13	3	
0								

GLEAMS Nutrient Input File For Application Rate 500
kg-N/ha/yr (3yr) Overton, TX

92	94	0	3	1
0.0	1.25	1.0	1.0	
0.1	.1			
4.0	2.0			
391.0	391.0			
0.0				
0.1	0.1			
30.0	15.0			
0.0				
1001				
01	0 1165			

10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1132	01 4 15							
0.63	0.0 0.18 0.036	.06	.025	.005	.13	3		
1166								
0	0 1197							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1198								
01	0 1225							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1204	01 4 15							
1.45	0.0 0.078	.025	.05	.02	.004	.13	3	
1226								
0	0 1262							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1263								
01	0 2073							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
1273	01 4 15							
1.75	0.0 0.065	0.025	.05	.02	.004	.13	3	
2074								
01	0 2120							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
2086	01 4 15							
0.6	0.0 0.19	.06	.1	.02	.015	.13	3	
2121								
01	0 2165							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2133	01 4 15							
0.61	0.0 0.188	.06	.1	.02	.015	.13	3	
2166								
0	0 2196							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2197								
01	0 2230							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2201	01 4 15							
0.69	0.0 0.0165	.06	.1	.02	.015	.13	3	
2231								
0	0 2260							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261								
01	0 2292							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261	01 4 15							
0.76	0.0 0.15	.06	.1	.02	.015	.13	3	
2293								
01	0 3136							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
3079	01 4 15							
1.59	0.0 0.071	.03	.05	.02	.007	.13	3	
0								

GLEAMS Nutrient Input File For Application Rate 1000
kg-N/ha/yr (3yr) Overton, TX

92	94	0	3	1
0.0	1.25	1.0	1.0	
0.1	.1			
4.0	2.0			
391.0	391.0			
0.0				
0.1	0.1			
30.0	15.0			
0.0				
1001				
01	0 1165			

10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1132	01 4 15							
1.26	0.0 0.18	0.036	.06	.025	.005	.13	3	
1166	0 0 1197							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1198	01 0 1225							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1204	01 4 15							
2.9	0.0 0.078	.025	.05	.02	.004	.13	3	
1226	0 0 1262							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
1263	01 0 2073							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
1273	01 4 15							
3.48	0.0 0.065	0.025	.05	.02	.004	.13	3	
2074	01 0 2120							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
2086	01 4 15							
1.19	0.0 0.19	.06	.1	.02	.015	.13	3	
2121	01 0 2165							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2133	01 4 15							
1.2	0.0 0.188	.06	.1	.02	.015	.13	3	
2166	0 0 2196							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2197	01 0 2230							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2201	01 4 15							
1.38	0.0 0.0165	.06	.1	.02	.015	.13	3	
2231	0 0 2260							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261	01 0 2292							
10	17920.0	1.35	80.0	6.7	1.25	-0.27		
2261	01 4 15							
1.51	0.0 0.15	.06	.1	.02	.015	.13	3	
2293	01 0 3136							
52	5240.0	1.35	75.0	2.6	1.05	-0.29		
3079	01 4 15							
3.19	0.0 0.071	.03	.05	.02	.007	.13	3	
0								

GLEAMS Long-term (50yr) Input Files Overton, TX

GLEAMS Hydrology Input File For Application Rates 0, 250, 500, 1000 kg-N/ha/yr (50yrs) Overton, TX

```

1000 0 0 1 0 0 0 0 1 0
926

.022 .1 0.1 3.3 79 0.03 3.6 45.0 700.0 31.59
3 2 3.0 45.0
0.40 0.40
0.22 0.22
0.05 0.05
0.4 0.4
1.0 0.5
8.0 8.0
8.0 8.0
53.8 59.1 67.2 76.5 82.8 89.4 93.8 93.1 86.6
78.3
66.8 58.4
31.5 35.5 43.0 52.9 60.2 67.0 70.4 68.7 63.4
51.5
42.1 34.7
244.0 310.0 412.0 473.0 561.0 618.0 601.0 570.0
472.0 386.0
288.0 231.0
240.0 240.0 264.0 264.0 264.0 240.0 216.0 216.0
192.0 216.0
240.0 240.0
37.96 40.21 43.73 53.5 62.95 69.46 70.73 69.73
64.98 55.46
44.73 40.16
01 50 1
52 0288 1083 1073 27.0 3.3 0 074 288
0
52 1074 1130 1120 27.0 3.3 0 074 288
0
10 1121 1185 1165 27.0 3.3 1 074 288
0
10 1166 1217 1197 27.0 1.3 1 074 288
0
10 1198 1245 1225 27.0 1.3 1 074 288
0
10 1226 1282 1262 27.0 1.3 1 074 288
0
0 0 0 0
-1 0 0 0

```

GLEAMS Erosion Input File For Application Rates 0, 250, 500, 1000 kg-N/ha/yr (50yrs) Overton, TX

```

01 50 0 1 0
100.0
2 .022
0.0 0.03 59.4 0.03
1 1.0 .2
1
001
1 1.0
0.55
1.0
0.046

```

GLEAMS Nutrient Input File For Application Rate 0 kg-N/ha/yr (50yrs) Overton, TX

```

01 50 0 1 1
0.0 1.25 1.0 1.0
0.1 .1
4.0 2.0
391.0 391.0
0.0
0.1 0.1
30.0 15.0
0.0
1001
00 0 1073
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1074
0 0 1120
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1121
0 0 1165
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1166
0 0 1197
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1198
0 0 1225
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1226
0 0 1262
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1263
0 0 2073
52 5240.0 1.35 75.0 2.6 1.05 -0.29
0

```

GLEAMS Nutrient Input File For Application Rate 250 kg-N/ha/yr (50yrs) Overton, TX

```

01 50 0 1 1
0.0 1.25 1.0 1.0
0.1 .1
4.0 2.0
391.0 391.0
0.0
0.1 0.1
30.0 15.0
0.0
1001
00 0 1073
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1074
01 0 1120
52 5240.0 1.35 75.0 2.6 1.05 -0.29
1086 01 4 15
0.3 0.0 .19 .06 .12 .025 .02 .13 3
1121
1 0 1165
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1132 01 4 15
0.32 0.0 0.18 0.036 0.06 0.025 0.005 0.13 3
1166
0 0 1197
10 17920.0 1.35 80.0 6.7 1.25 -0.27
1198
01 0 1225
10 17920.0 1.35 80.0 6.7 1.25 -0.27

```

1204	01	4	15						
.72	0.0	0.078	.025	.05	.02	.004	.13	3	
1226	0	0	1262						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1263	01	0	2073						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1273	01	4	15						
.88	0.0	0.065	0.025	.05	.02	.004	.13	3	
0									

**GLEAMS Nutrient Input File For Application Rate 500
kg-N/ha/yr (50yrs) Overton, TX**

01	50	0	1	1					
0.0	1.25	1.0	1.0						
0.1	.1								
4.0	2.0								
391.0	391.0								
0.0									
0.1	0.1								
30.0	15.0								
0.0									
1001	00	0	1073						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1074	01	0	1120						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1086	01	4	15						
0.6	0.0	.19	.06	.12	.025	.02	.13	3	
1121	1	0	1165						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1132	01	4	15						
0.63	0.0	0.18	0.036	0.06	0.025	0.005	0.13	3	
1166	0	0	1197						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1198	01	0	1225						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1204	01	4	15						
1.45	0.0	0.078	.025	.05	.02	.004	.13	3	
1226	0	0	1262						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1263	01	0	2073						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1273	01	4	15						
1.75	0.0	0.065	0.025	.05	.02	.004	.13	3	
0									

**GLEAMS Nutrient Input File For Application Rate 1000
kg-N/ha/yr (50yrs) Overton, TX**

01	50	0	1	1					
0.0	1.25	1.0	1.0						
0.1	.1								
4.0	2.0								
391.0	391.0								
0.0									
0.1	0.1								

30.0	15.0								
0.0									
1001	00	0	1073						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1074	01	0	1120						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1086	01	4	15						
1.19	0.0	.19	.06	.12	.025	.02	.13	3	
1121	1	0	1165						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1132	01	4	15						
1.26	0.0	0.18	0.036	0.06	0.025	0.005	0.13	3	
1166	0	0	1197						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1198	01	0	1225						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1204	01	4	15						
2.9	0.0	0.078	.025	.05	.02	.004	.13	3	
1226	0	0	1262						
10	17920.0	1.35	80.0	6.7	1.25	-0.27			
1263	01	0	2073						
52	5240.0	1.35	75.0	2.6	1.05	-0.29			
1273	01	4	15						
3.48	0.0	0.065	0.025	.05	.02	.004	.13	3	
0									

TABLE A2
GLEAMS YEARLY-MAXIMUM NITRATE CONCENTRATIONS (mg/L)
LEACHING BELOW THE ROOT ZONE. OVERTON, TX

Year	0 kg N/ha/yr	250 kg N/ha/yr	500 kg N/ha/yr	1000 kg N/ha/yr
1	.039225	1.617165	2.929777	6.015348
2	.123808	5.208225	11.056420	19.414780
3	.128689	5.662621	12.149270	22.139810
4	.033203	3.886832	14.773130	67.116500
5	.067514	2.175459	9.164862	29.167390
6	.033496	3.381387	25.083080	59.998970
7	.003148	2.582033	6.503006	20.454760
8	.009535	.836364	2.297482	16.002420
9	.056608	1.172625	8.148648	16.645620
10	.089759	2.467879	27.839240	45.348670
11	.108002	7.839097	23.467020	39.710530
12	.095483	10.720800	38.279650	69.087800
13	.039812	1.508768	6.221430	14.990350
14	.044176	1.753421	6.132205	25.903220
15	.058405	1.879341	12.443370	44.625030
16	.065663	1.067761	3.610370	23.937840
17	.048577	1.653135	6.708818	17.167460
18	.034874	8.839527	15.790110	29.415740
19	.052735	.645332	6.778018	32.426330
20	.047130	1.765812	4.998791	31.816880
21	.126813	4.944732	14.422590	23.588840
22	.046174	6.372391	31.192880	102.360400
23	.039801	4.742175	21.723310	127.713000
24	.040081	3.473997	6.875127	8.715071
25	.049936	2.158046	10.227340	28.272190
26	.050654	7.443066	17.804310	33.833660
27	.137682	2.775189	9.227441	62.730810
28	.149117	3.192028	6.551512	11.249010
29	.051821	4.522810	16.984840	32.346740
30	.093053	14.334480	61.889850	92.350150
31	.131573	2.868150	6.305247	14.320530
32	.081402	3.417969	7.773478	24.086590
33	.063267	5.691275	13.576950	41.669930
34	.051200	.227015	.444060	3.322376
35	.103450	5.388540	13.269720	22.741350
36	.116460	6.927045	19.137470	35.010400
37	.040080	.551911	3.978084	15.584570
38	.038652	.081286	.252440	.654362
39	.037661	.625499	2.471941	8.372212
40	.043972	1.059476	25.645120	76.641560
41	.046031	2.326050	9.607095	35.511960
42	.039239	.607604	4.550335	58.787640
43	.050465	1.083866	2.518595	6.110451
44	.041335	1.634636	3.824065	9.302037
45	.047187	1.609081	3.141899	19.511250
46	.048372	11.584190	33.276980	69.072310
47	.052984	1.275193	6.266120	14.161620
48	.170614	3.791645	43.909790	38.463150
49	.222499	4.944306	53.558500	47.467800
50	.109910	4.133261	9.671741	32.696040

Appendix B. VTFIT Output Parameters For Fitted Distributions

VTFIT Output For Fitted Distributions

200 kg•N/ha/yr Tifton, GA

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : 6.830599E-02 Probability of exceedance : .9811728

Data maximum : 8.810206 Probability of exceedance : 5.020916E-03

Scale Parameter : 2.090145 K-S D : 7.854269E-02

Shape Parameter : 1.158426 Kuiper : .1370854

Chi square: 6.8 DF: 9 p Value: .6579334

Log Likelihood: -83.34179 Cramer- von Mises: 2.962282E-02

Anderson-Darling: .2412987

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.06831	0.00000	0.31627	0.00000	0.01883
0.50540	0.54908	0.36488	0.24000	0.17560
0.94250	0.22878	0.32830	0.34000	0.32798
1.37959	0.32030	0.27971	0.48000	0.46098
1.81669	0.18303	0.23167	0.56000	0.57262
2.25378	0.18303	0.18835	0.64000	0.66420
2.69088	0.22878	0.15105	0.74000	0.73815
3.12797	0.18303	0.11985	0.82000	0.79714
3.56507	0.09151	0.09425	0.86000	0.84374
4.00216	0.04576	0.07356	0.88000	0.88025
4.43926	0.09151	0.05704	0.92000	0.90865
4.87635	0.04576	0.04398	0.94000	0.93062
5.31345	0.00000	0.03373	0.94000	0.94751
5.75054	0.04576	0.02574	0.96000	0.96043
6.18764	0.00000	0.01957	0.96000	0.97028
6.62473	0.00000	0.01481	0.96000	0.97774
7.06183	0.04576	0.01117	0.98000	0.98338
7.49892	0.00000	0.00839	0.98000	0.98763
7.93602	0.00000	0.00629	0.98000	0.99082
8.37311	0.00000	0.00469	0.98000	0.99320
8.81021	0.00000	0.00350	0.98000	0.99498

VTFIT Output For Fitted Distributions

400 kg•N/ha/yr Tifton, GA

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : .606054 Probability of exceedance : .9772301

Data maximum : 24.14863 Probability of exceedance : 1.080716E-02

Scale Parameter : 8.418604

K-S D : 6.628682E-02

Shape Parameter : 1.433103

Kuiper : .1125736

Chi square: 2 DF: 9 p Value: .9914676

Log Likelihood: -147.3743

Cramer- von Mises: 1.826829E-02

Anderson-Darling: .2000351

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.60605	0.00000	0.05322	0.00000	0.02277
1.78318	0.10194	0.07801	0.12000	0.10251
2.96031	0.06796	0.08656	0.20000	0.20038
4.13744	0.08495	0.08720	0.30000	0.30323
5.31457	0.06796	0.08315	0.38000	0.40385
6.49170	0.08495	0.07637	0.48000	0.49793
7.66883	0.08495	0.06816	0.58000	0.58308
8.84596	0.06796	0.05945	0.66000	0.65820
10.02308	0.05097	0.05084	0.72000	0.72308
11.20021	0.06796	0.04275	0.80000	0.77810
12.37734	0.03398	0.03540	0.84000	0.82401
13.55447	0.01699	0.02892	0.86000	0.86178
14.73160	0.01699	0.02333	0.88000	0.89245
15.90873	0.03398	0.01860	0.92000	0.91704
17.08586	0.01699	0.01467	0.94000	0.93656
18.26299	0.00000	0.01146	0.94000	0.95187
19.44011	0.00000	0.00886	0.94000	0.96377
20.61724	0.03398	0.00679	0.98000	0.97294
21.79437	0.00000	0.00516	0.98000	0.97993
22.97150	0.00000	0.00389	0.98000	0.98522
24.14863	0.00000	0.00290	0.98000	0.98919

VTFIT Output For Fitted Distributions

600 kg•N/ha/yr Tifton, GA

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : 1.347519 Probability of exceedance : .9713231

Data maximum : 38.39547 Probability of exceedance : 1.799029E-02

Scale Parameter : 14.9183

K-S D : 7.044077E-02

Shape Parameter : 1.471163

Kuiper : .1368269

Chi square: 7.199999 DF: 9 p Value: .6163053

Log Likelihood: -175.2291

Cramer- von Mises: 3.555927E-02

Anderson-Darling: .2979927

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
1.34752	0.00000	0.03085	0.00000	0.02868
3.19992	0.08637	0.04304	0.16000	0.09864
5.05231	0.02159	0.04831	0.20000	0.18400
6.90471	0.05398	0.04971	0.30000	0.27526
8.75711	0.03239	0.04859	0.36000	0.36663
10.60951	0.03239	0.04583	0.42000	0.45429
12.46190	0.04319	0.04206	0.50000	0.53581
14.31430	0.05398	0.03774	0.60000	0.60977
16.16670	0.04319	0.03323	0.68000	0.67551
18.01910	0.03239	0.02879	0.74000	0.73293
19.87149	0.03239	0.02457	0.80000	0.78231
21.72389	0.00000	0.02070	0.80000	0.82418
23.57629	0.01080	0.01722	0.82000	0.85923
25.42869	0.03239	0.01417	0.88000	0.88824
27.28108	0.02159	0.01153	0.92000	0.91199
29.13348	0.00000	0.00930	0.92000	0.93122
30.98588	0.01080	0.00742	0.94000	0.94666
32.83828	0.00000	0.00587	0.94000	0.95892
34.69067	0.01080	0.00461	0.96000	0.96859
36.54307	0.01080	0.00359	0.98000	0.97615
38.39547	0.00000	0.00277	0.98000	0.98201

VTFIT Output For Fitted Distributions

800 kg•N/ha/yr Tifton, GA

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : 2.013868 Probability of exceedance : .9746735

Data maximum : 48.7519 Probability of exceedance : 3.630435E-02

Scale Parameter : 22.22127 K-S D : 8.405888E-02

Shape Parameter : 1.525663 Kuiper : .1589971

Chi square: 9.2 DF: 9 p Value: .4190212

Log Likelihood: -194.2239 Cramer- von Mises: 4.530025E-02

Anderson-Darling: .4185638

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
2.01387	0.00000	0.01894	0.00000	0.02533
4.35077	0.05991	0.02681	0.14000	0.07973
6.68767	0.00856	0.03112	0.16000	0.14794
9.02457	0.04279	0.03320	0.26000	0.22345
11.36147	0.01712	0.03369	0.30000	0.30187
13.69838	0.03423	0.03301	0.38000	0.38000
16.03528	0.01712	0.03149	0.42000	0.45550
18.37218	0.02568	0.02940	0.48000	0.52674
20.70908	0.05135	0.02695	0.60000	0.59264
23.04598	0.01712	0.02432	0.64000	0.65256
25.38288	0.03423	0.02163	0.72000	0.70625
27.71979	0.01712	0.01899	0.76000	0.75370
30.05669	0.01712	0.01649	0.80000	0.79512
32.39359	0.00856	0.01415	0.82000	0.83089
34.73049	0.00000	0.01203	0.82000	0.86144
37.06739	0.00856	0.01013	0.84000	0.88729
39.40429	0.00856	0.00845	0.86000	0.90895
41.74120	0.01712	0.00699	0.90000	0.92694
44.07810	0.00856	0.00573	0.92000	0.94176
46.41500	0.01712	0.00466	0.96000	0.95388
48.75190	0.00856	0.00377	0.98000	0.96370

VTFIT Output For Fitted Distributions

0 kg•N/ha/yr Overton, TX

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : 3.14799E-03 Probability of exceedance : .9960245

Data maximum : .222499 Probability of exceedance : 2.62624E-03

Scale Parameter : 7.876872E-02 K-S D : .1826846

Shape Parameter : 1.716168 Kuiper : .345809

Chi square: 42.8 DF: 9 p Value: 2.324581E-06

Log Likelihood: 92.82461 Cramer- von Mises: .3673148

Anderson-Darling: 1.908272

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.00315	0.00000	2.16294	0.00000	0.00398
0.01412	3.64712	6.03609	0.04000	0.05097
0.02508	0.00000	8.34355	0.04000	0.13092
0.03605	5.47068	9.58393	0.10000	0.23010
0.04702	23.70630	9.96721	0.36000	0.33801
0.05799	21.88273	9.68727	0.60000	0.44631
0.06895	7.29424	8.93713	0.68000	0.54878
0.07992	0.00000	7.89713	0.68000	0.64129
0.09089	3.64712	6.72227	0.72000	0.72152
0.10186	3.64712	5.53425	0.76000	0.78870
0.11282	5.47068	4.41928	0.82000	0.84318
0.12379	1.82356	3.43039	0.84000	0.88610
0.13476	7.29424	2.59286	0.92000	0.91899
0.14573	1.82356	1.91100	0.94000	0.94354
0.15669	1.82356	1.37494	0.96000	0.96144
0.16766	0.00000	0.96664	0.96000	0.97417
0.17863	1.82356	0.66460	0.98000	0.98303
0.18960	0.00000	0.44718	0.98000	0.98906
0.20056	0.00000	0.29464	0.98000	0.99308
0.21153	0.00000	0.19021	0.98000	0.99570
0.22250	1.82356	0.12037	1.00000	0.99737

VTFIT Output For Fitted Distributions

250 kg•N/ha/yr Overton, TX

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : 8.128599E-02 Probability of exceedance : .9909526

Data maximum : 14.33448 Probability of exceedance : 7.12198E-03

Scale Parameter : 3.858316 K-S D : 5.975509E-02

Shape Parameter : 1.217803 Kuiper : .1091582

Chi square: 4.8 DF: 9 p Value: .8513826

Log Likelihood: -112.6876 Cramer- von Mises: 2.054369E-02

Anderson-Darling: .1620064

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.08129	0.00000	0.13493	0.00000	0.00905
0.79395	0.16838	0.19333	0.12000	0.13570
1.50661	0.16838	0.18709	0.24000	0.27252
2.21927	0.28064	0.16804	0.44000	0.39945
2.93192	0.14032	0.14533	0.54000	0.51119
3.64458	0.11226	0.12263	0.62000	0.60661
4.35724	0.08419	0.10164	0.68000	0.68640
5.06990	0.11226	0.08306	0.76000	0.75206
5.78256	0.11226	0.06708	0.84000	0.80540
6.49522	0.02806	0.05364	0.86000	0.84827
7.20788	0.02806	0.04253	0.88000	0.88241
7.92054	0.05613	0.03346	0.92000	0.90937
8.63320	0.00000	0.02614	0.92000	0.93051
9.34586	0.02806	0.02029	0.94000	0.94698
10.05852	0.00000	0.01566	0.94000	0.95972
10.77118	0.02806	0.01202	0.96000	0.96954
11.48384	0.00000	0.00919	0.96000	0.97705
12.19650	0.02806	0.00698	0.98000	0.98278
12.90916	0.00000	0.00529	0.98000	0.98713
13.62182	0.00000	0.00398	0.98000	0.99041
14.33448	0.00000	0.00299	0.98000	0.99288

VTFIT Output For Fitted Distributions

500 kg•N/ha/yr Overton, TX

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : .25244 Probability of exceedance : .9896365

Data maximum : 61.88985 Probability of exceedance : 6.679356E-03

Scale Parameter : 14.73007 K-S D : 7.683335E-02

Shape Parameter : 1.122412 Kuiper : .1528224

Chi square: 9.999999 DF: 9 p Value: .3504853

Log Likelihood: -181.722 Cramer- von Mises: 7.008688E-02

Anderson-Darling: .4412613

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.25244	0.00000	0.04584	0.00000	0.01036
3.33431	0.04543	0.05260	0.14000	0.17198
6.41618	0.05841	0.04644	0.32000	0.32528
9.49805	0.05841	0.03919	0.50000	0.45724
12.57992	0.03894	0.03234	0.62000	0.56729
15.66179	0.02596	0.02630	0.70000	0.65743
18.74366	0.01947	0.02116	0.76000	0.73033
21.82553	0.01298	0.01689	0.80000	0.78876
24.90740	0.00649	0.01339	0.82000	0.83523
27.98927	0.01947	0.01055	0.88000	0.87197
31.07115	0.00000	0.00828	0.88000	0.90086
34.15302	0.01298	0.00646	0.92000	0.92346
37.23489	0.00000	0.00503	0.92000	0.94109
40.31676	0.00649	0.00390	0.94000	0.95477
43.39863	0.00000	0.00301	0.94000	0.96537
46.48050	0.00649	0.00232	0.96000	0.97354
49.56237	0.00000	0.00178	0.96000	0.97983
52.64424	0.00000	0.00137	0.96000	0.98465
55.72611	0.00649	0.00104	0.98000	0.98835
58.80798	0.00000	0.00080	0.98000	0.99117
61.88985	0.00000	0.00061	0.98000	0.99332

VTFIT Output For Fitted Distributions

800 kg•N/ha/yr Tifton, GA

Weibull (Extreme value type III) for minima for 50 observations

Data minimum : .654362 Probability of exceedance : .9960143
Data maximum : 127.713 Probability of exceedance : 5.253136E-03

Scale Parameter : 37.79246 K-S D : 7.901996E-02
Shape Parameter : 1.361631 Kuiper : .150088

Chi square: 4.4 DF: 9 p Value: .8831714
Log Likelihood: -223.6563 Cramer- von Mises: 4.233797E-02
Anderson-Darling: .2738724

Variable	Observed Frequency	Fitted PDF	Observed EDF	Fitted CDF
0.65436	0.00000	0.00828	0.00000	0.00399
7.00729	0.01259	0.01771	0.08000	0.09589
13.36023	0.01259	0.01941	0.16000	0.21551
19.71316	0.02833	0.01885	0.34000	0.33783
26.06609	0.02204	0.01724	0.48000	0.45284
32.41902	0.01574	0.01514	0.58000	0.55583
38.77195	0.01889	0.01291	0.70000	0.64494
45.12489	0.00944	0.01075	0.76000	0.72004
51.47782	0.00630	0.00878	0.80000	0.78198
57.83075	0.00000	0.00705	0.80000	0.83215
64.18368	0.00944	0.00558	0.86000	0.87214
70.53661	0.00944	0.00435	0.92000	0.90357
76.88954	0.00315	0.00336	0.94000	0.92795
83.24248	0.00000	0.00256	0.94000	0.94664
89.59541	0.00000	0.00193	0.94000	0.96081
95.94834	0.00315	0.00144	0.96000	0.97145
102.30127	0.00000	0.00107	0.96000	0.97936
108.65421	0.00315	0.00078	0.98000	0.98519
115.00713	0.00000	0.00057	0.98000	0.98944
121.36007	0.00000	0.00041	0.98000	0.99253
127.71300	0.00000	0.00029	0.98000	0.99475

VITA

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A handwritten signature in black ink, reading "Edward Thomas Carter, Jr." with a stylized flourish at the end.