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USING GLEAMS AND REMM TO ESTIMATE NUTRIENT MOVEMENT FROM A SPRAY FIELD AND THROUGH A RIPARIAN FOREST

by

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Summary: With the increase of large animal facilities in Eastern North Carolina, nutrient accumulation in surface waters and groundwater is becoming a problem. To protect these water sources, computer models are being used to evaluate management practices to reduce nutrient movement or accumulation. This project used Groundwater Loading Effects of Agricultural Management Systems model (GLEAMS) and a pre-release version of Riparian Ecosystem Management Model (REMM) to estimate nitrogen and phosphorus transport of nutrients from an agricultural field that received swine lagoon effluent and through a riparian buffer zone. Two simulations were conducted with annual application rates of effluent equivalent at 560 and 1000 kg N/ha. The GLEAMS output provided the weather data and nutrient concentrations in the soil, sediment, and leachate as input into REMM.

Both GLEAMS and REMM provided an adequate estimation of the nitrogen transport through the system. In the GLEAMS output, few differences between the simulations for both the leachate and soil phosphorus concentrations did not seem to significantly impair REMM's ability to estimate PO_4 - P leachate concentrations. The pre-release version of REMM provided good estimates of the nutrient transport, but still needs some improvement. Some of these improvements should include more variable documentation, allow for the use of more soil layers and vegetation types per zone, and include typical laboratory soil and water analysis results as inputs. With a few improvements, future versions of REMM have the potential to provide better estimates of the nutrient movement through the riparian buffer zone.

Keywords: GLEAMS, REMM, modeling, nutrients, riparian.

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With the rapid growth of the swine industry in the Southeast, animal waste management must be taken seriously. As the industry grows, larger amounts of swine waste are being stored in lagoons. To reduce the accumulation of animal waste in lagoons, the effluent can be applied to field crops as fertilizer. If the effluent is over applied, groundwater and surface water pollution may occur. To reduce potential pollution of these waters, riparian buffer zones can be used as a buffer between the application fields and waterways. The riparian buffer zone can remove some of these contaminates before reaching these waters. Thus reducing the potential for pollution.

A riparian forest is a complex ecosystem consisting of soils, vegetation, hydrology, and organisms. These forests can stabilize streambanks, provide wildlife habitat, dissipate water and wind energy, increase sedimentation and hydraulic resistance to flow, and provide long- and short-term nutrient storage (Lowrance et al., 1985 and Schultz et al., 1995). In agriculture, riparian forests are typically located between row crops, pasture, or animal facilities and waterways (Lowrance et al., 1985). Schultz et al. (1995) suggested that riparian ecosystems consist of three zones: a grass strip next to agricultural fields, then a shrub strip, and finally several rows of trees. The grass zone aids in reducing the flow velocity of surface water. The shrub strip and trees aid in soil stability with a permanent root system, increases the bio-diversity and wildlife habitats (Schultz et al., 1995), and captures agricultural non-point source pollutants before entering surface waters and groundwater.

Nitrogen and phosphorus were the non-point nutrients of the most concern for surface water and groundwater contamination. Two primary removal pathways of nitrogen were denitrification and storage in woody vegetation. Lowrance et al. (1984) also concluded that denitrification was a significant factor in the removal of nitrogen in a riparian forest. The loss of nitrogen due to denitrification could be twice the amount of nitrogen exiting the riparian forest. Lowrance (1992) found that in the first 10 m of the riparian forest, there was an 8 to 9 fold decrease of the NO_3^- concentration in the shallow groundwater. In the next 40 m of the forest, there was only an additional 1 mg/L decrease of the NO_3^- concentration. Phosphorus can bind to the soil or be stored in woody vegetation (Lowrance et al., 1985).

In two other riparian zones, Haycock and Pinay (1993) studied the change in groundwater NO_3^- concentrations during the winter months. The two riparian zones evaluated were a grass (*Lolium perenne L.*) vegetated zone and a poplar (*Populus italica*) riparian zone. Within the first 5 m of the poplar riparian zone, approximately 100% of the applied NO_3^- was captured. The grass riparian zone retained approximately 84% of the NO_3^- applied. In both riparian zones, increases in groundwater flow rates did not cause a significant change in the width of the maximum retention zone (Haycock and Pinay, 1993).

Lowrance et al. (1983) estimated that 96% of the water moved into a riparian zone as subsurface flow, while less than 20% of the nutrients applied to the upland fields entered the riparian forest through the subsurface flow. Of these nutrients, 79% of the nitrogen entering the riparian forest was NO_3-N. Only 18% of the NO_3-N exited the riparian forest. This denoted a net loss of 9153 kg NO_3-N in the water passing through the 472-ha riparian forest. The amount of land devoted to forest, pasture, and fields affected the nutrient inputs and the filtering capacity of the riparian forest (Lowrance et al., 1983).

Peterjohn and Correll (1984) investigated the movement of nitrogen and phosphorus through a riparian forest. The majority of the nitrogen was removed from the groundwater flow (75%). The riparian forest retained approximately 89% of the nitrogen that entered. The majority of phosphorus entered the riparian forest through the surface runoff (94%) from cropland. The riparian forest retained 80% of the phosphorus that entered. The majority of the total nutrient concentration changes occurred within the first 19 m of the riparian forest (Peterjohn and Correll, 1984).

GLEAMS was designed to evaluate the movement of nutrients and pesticides within agricultural management areas. GLEAMS was a continuation of Chemicals Runoff and Erosion from Agricultural Management Systems (CREAMS) (Knisel, 1993). It had a more advanced plant nutrient component, improved climate-soil-management interactions, vertical flux of pesticides, and an improved hydrology program. Three of GLEAMS main calculation components used in this project were the hydrology, erosion, and nutrient (nitrogen and phosphorus) components. Some field management alternatives were crops grown, fertilizers used, application schedules, and planting and harvesting dates. Most importantly, GLEAMS estimated the NPS pollution caused by a field management plan.

REMM was designed to simulate the biological, chemical, and physical processes of a riparian buffer zone. The model had four main calculation components: hydrology, plant growth, nutrient dynamics, and sedimentation and erosion. Due to the model's versatility, numerous management scenarios for a riparian buffer zone could be evaluated. Some management alternatives that can be investigated are vegetation types, buffer width, and site characteristics. Most importantly, REMM can also estimate the reduction of NPS pollution over time for given site criteria.

The main objective of this project was to use GLEAMS in combination with REMM to estimate the transport of nutrients from an agricultural field that received swine lagoon effluent and through a riparian buffer zone. The second pre-release version of REMM was also evaluated for its usefulness and practicality as a model.

METHODS AND MATERIALS

The project site was a feeder to finishing swine farm located in northern Duplin County, NC. The 1600-head swine facility generated approximately 2758 t of waste per year, including 1670 kg of plant available N per year. The site consisted of the swine facility, a waste application field and a riparian buffer zone (figure 1). The waste application field had approximately 2.4 ha of usable area. The field was planted with Coastal Bermuda grass (*Cynodon dactylon*), which was cut three times a year. Table 1 describes the characteristics of the swine lagoon effluent as used in GLEAMS from Barker et al. (1990) and NCDA Agronomic Division Waste Analysis Reports.

Table 1. Characteristics of Swine Lagoon Effluent

Characteristics of Waste	%
Total N	0.0462
Organic N	0.0083
Ammonia	0.0377
Phosphorus	0.00881
Organic P	0.00176
Organic Matter	0.1

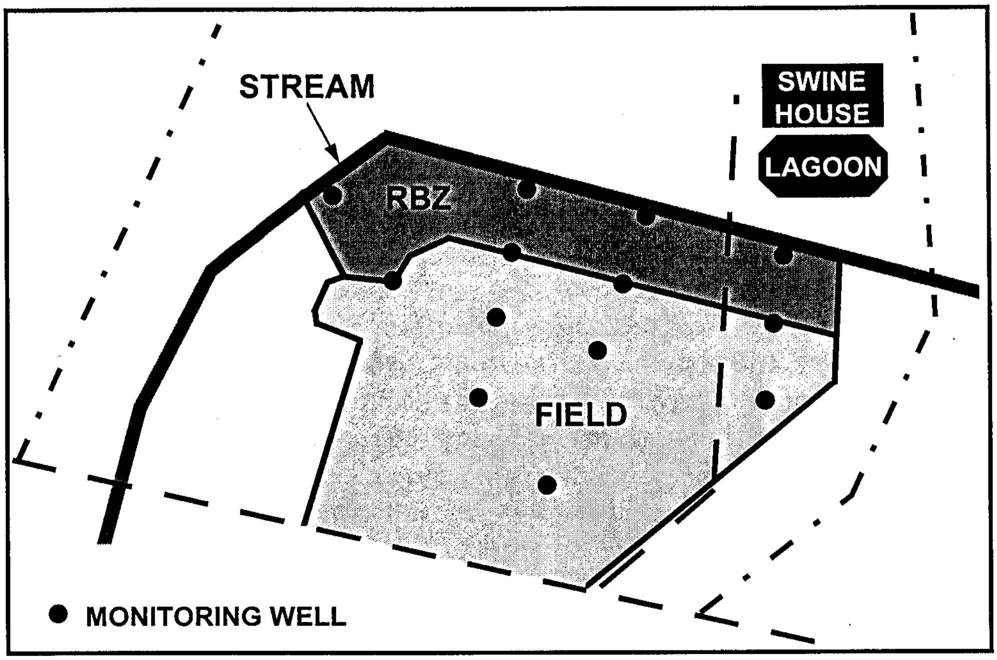

Figure 1-Project Site, Plan View (not to scale)

The riparian buffer zone (RBZ) in REMM was based on the recommendations of the U.S. Forest Service and USDA-Natural Resources Conservation Service (Altier et al., 1996 and Welsch, 1991). The riparian buffer zone was approximately 0.7 ha with a length of 304.8 m and an average slope of 4.6 percent. The riparian buffer zone contained three zones delineated by vegetation management (figure 2). Zone 1 was a non-managed, undisturbed forest at the edge of the stream comprised of Water Oak (*Quercus nigra*) trees along the edge of stream and was 3 m wide. Zone 1 was intended to protect the integrity of the stream bank. Zone 2 was a managed timber forest (20.5 m wide) constructed of Bald Cypress (*Taxodium distichum*), Red Maple (*Acer rubrum*), Sycamore (*Platanus occidentalis*), and Green Ash (*Fraxinus pennsylvanica*) trees. The trees in zones 1 and 2 were planted in April of 1993. The trees in zone 2 were designed to remove nutrients from runoff and groundwater. Zone 3 was a Coastal Bermudagrass strip at the edge of field, approximately 3 m wide. Zone 3 was designed to slow runoff flow and increase sedimentation. At the project site, the trees in zones 2 and 1 were planted in April 1993. For simplicity of the simulation, the trees were assumed to be present for the entire simulation period. It was recommended that only one vegetation type be used in each zone. The profile soil was divided into three layers (figure 2). In REMM, the depth of the water table in each zone determined the bottom of the soil profile. Soil samples and the soil survey provided most of the soil characteristic data.

Weather data was collected for 1990-1997 from several sources and locations near the project site. This was due to partial data sets at some locations. Monthly solar radiation was provided by GLEAMS data bank (Knisel, 1993). The location used for solar radiation was Elizabethtown, NC, which is approximately 50miles southwest of the project site. Dew point temperature, wind velocity, precipitation, and maximum and minimum temperatures were provided by the National Climatic Data Center and the NC State Climate Office. Dew point temperature and wind velocity were an average of data from Raleigh and Wilmington, NC.

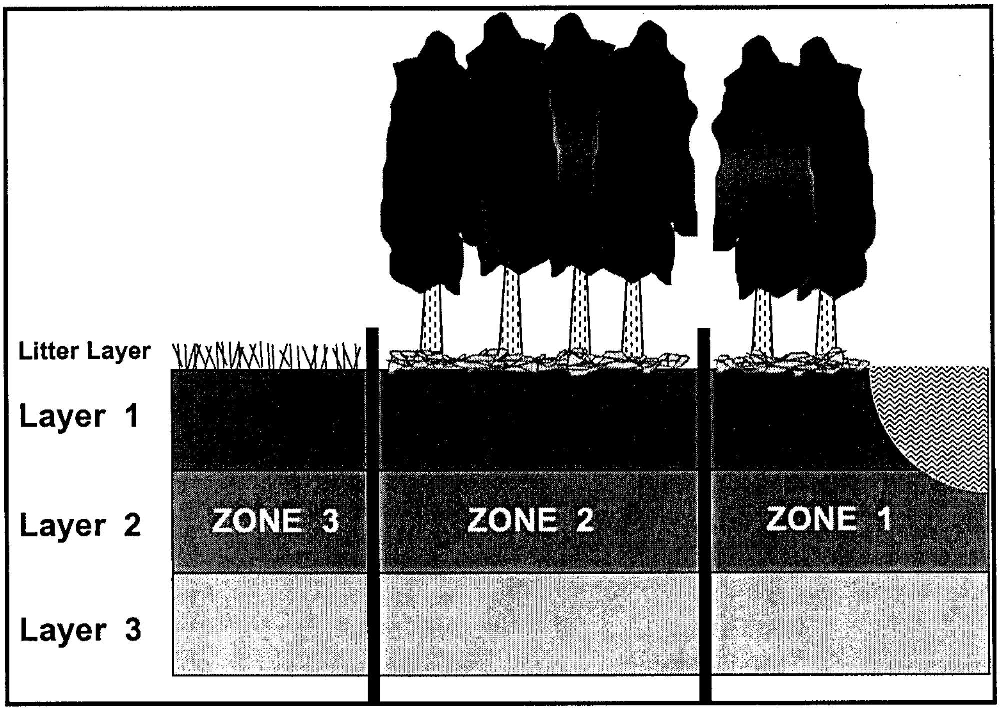

Figure 2-REMM's Riparian Buffer Zone with Zones and Layers (not to scale)

Minimum temperature was an average of data from Warsaw and Clinton, NC. Precipitation and maximum temperature were from the Clinton, NC weather station. All of the weather data used in GLEAMS, except precipitation and mean daily temperature, were averaged on a monthly basis from six years of weather data. Daily precipitation and mean daily temperature was used for the simulation period. All weather data for REMM were required on daily basis and were generated by GLEAMS output for each year of simulation.

The soil at the project site was Autryville fine sand (Loamy, thermic, siliceous, Arenic Paleudults). Soil samples from the application field were taken in August 1991 and in March, June, and July 1997. All soil samples were analyzed for the following parameters: total Kjeldahl nitrogen (TKN), and total phosphorus (TP) concentrations, the percentage of sand, silt, and clay in the soil. The Nelson and Sommers (1972) method was used to digest the samples. Determination of TKN and TP concentrations was accomplished with a Technicon Auto Analyzer (Bran Luebbe, Buffalo Grove, IL). TKN analyses followed the automated phenate method. TP analyses followed the automated ascorbic acid reduction method (Greenberg et al, 1992).

Well samples were collected monthly since October 1991 from 18 wells in the application field and the riparian buffer zone. The well samples were analyzed for nitrate-N (NO_3-N), ammonium-N (NH_4-N), total Kjeldahl nitrogen (TKN), ortho-phosphate (PO_4-P), and total phosphorus (TP). Filtered samples were digested with a sulfuric acid digestion using a sulfuric acid:mercuric sulfate:potassium sulfate (100:10:1, w/w/w) catalyst. Determination of nutrient concentrations was accomplished with a TRAACS analyzer (Model 800, Bran Luebbe, Buffalo Grove, IL). The EPA Methods used for the analysis of NO_3-N, NH_4-N, TKN, PO_4-P, and TP were methods 353.2, 350.1, 351.2, 365.1, and 365.4, respectively (U.S. EPA, 1983). The phosphorus data from November 1993 to August 1994 was considered bad as a result of changes in sample handling.

GLEAMS was used to evaluate the movement of nutrients within agricultural management area. Four files were required to run GLEAMS: a hydrology, an erosion, a nutrient, and a precipitation file. The hydrology file contained the following information: site parameters, weather data, soil data, and the planting and harvesting schedule. The nutrient file contained the following information: initial nitrogen and phosphorus concentrations in the soil, fertilizer characteristics, and fertilizer application schedule. The erosion file contained Manning's n and soil loss ratios. The precipitation file contained the amounts of rain received daily during the period of simulation (Knisel, 1993). Observed field data were used when available. Other required data were supplied by the GLEAMS database.

The actual application rate of the swine lagoon effluent was unknown until a management plan was developed. Based on previous work (Gerwig, 1998), the application rate was estimated to be between 500 and 1000 kg N ha^{-1} yr^{-1}. Two simulations were developed, each with a different application schedule. Simulation 1 had an application rate of 500 kg N ha^{-1} yr^{-1}, not to exceed 1.2 cm per application. Simulation 2 had an application rate of 1000 kg N ha^{-1} yr^{-1}, not to exceed 2.4 cm per application. Both simulations had 12 applications of waste per year, with an equal number of applications between each planting and cutting. Three plantings and cuttings were completed between January and October. Although grass is a perennial and was not planted 3 times a year, GLEAMS required a planting date for growth reference. Simulations were conducted for the time period between January 1, 1990 and December 31, 1997. The first two years of simulation were used as a buffer to allow parameters to equilibrate in GLEAMS and REMM and were not used in the data evaluation.

Three soil layers were used in GLEAMS input files. Table 2 contains the soil properties used in GLEAMS. The soil layers in GLEAMS were determined from the Duplin County soil survey (Goldston et al., 1959). However, GLEAMS further divided these layers into ten computational layers within the soil profile.

Table 2. Soil Characteristics of the Spray Field as Used in GLEAMS

GLEAMS	*Bot. of Layer (cm)*	*Porosity (cm^3/cm^3)*	*FC* (cm/cm)*	*WP (cm/cm)*	*Silt (%)*	*Clay (%)*	*OM (%)*
Layer 1	66	0.38	0.18	0.03	6.6	2.0	1.0
Layer 2	104	0.435	0.18	0.03	8.4	6.5	0.5
Layer 3	150	0.38	0.18	0.03	6.2	15.2	0.1

* FC is field capacity, WP is wilting point, and OM is organic matter.

Simulated nutrient concentrations from GLEAMS were compared to the measured nutrient concentrations in soil and well samples from the project site. The well samples from the wells at the edge of the field were averaged and compared to GLEAMS monthly leachate data leaving the field. The nutrient concentrations in the soil were compared through the soil profile at the beginning and end of the simulation period. The 1991 and 1997 field soil data were compared to a five-day average around the dates on which the soil samples were taken.

The results of the GLEAMS simulations were evaluated graphically and mathematically. The GLEAMS output was evaluated for similar nutrient concentration trends with the observed data during the simulation period and within the soil profile. The average monthly nutrient concentration (Y_A) was calculated to aid in the determination of the actual application rate of the swine lagoon effluent. The average monthly nutrient concentration was calculated as:

$$Y_A = (\sum C_M) / n \tag{1}$$

where C_M is the observed or simulated monthly nutrient concentration and n is the number of months. The percent difference (%Δ) of the total soil and leachate nutrient concentrations from the field edge to the stream was calculated. The percent difference is calculated as:

$$\%\Delta = \left[(Zo - Zs)/Zo\right]100 \qquad (2)$$

where Z_S and Z_O are the simulated and observed nutrient concentration in the leachate, respectively.

REMM was used to estimate the nutrient transport within a riparian buffer zone. REMM required four input files to run a simulation successfully. The first file, *.CN1, contained the site geometry, initial nutrient levels, litter and soil properties, and plant types. The second file, *.CN2, contained detailed information about each of the 12 plant types. Much of the detailed vegetation information data was not available for the project site. The third file, *.FIN, contained upland inputs, including surface and subsurface nutrient and water loadings. The fourth file, *.WEA, contained all the weather information common to all zones. The last two files, *.Fin and *.WEA, were constructed almost entirely of user defined output from GLEAMS. This output provided the following data for these two files: daily precipitation, runoff, percolation, maximum and minimum temperatures, radiation, sediment yield, runoff loss concentrations (NO_3-N, NH_4-N, PO_4-P), sediment loss concentrations (NO_3-N, NH_4-N, PO_4-P), leachate concentrations (NO_3-N, NH_4-N, PO_4-P), and nutrient concentrations by soil layer (NO_3-N, NH_4-N, TKN, TP, PO_4-P) (Altier et al., 1996). Where project site data were unvailable, default data were from sites in the Coastal Plains near Tifton, Georgia (Bocsh et al., 1996, Lowrance et al., 1998, Sheridan et al., 1998). Changes were made where possible to better estimate the project information.

Three soil layers per zone were used in REMM input files. Table 3 contains the soil properties used in REMM. The data were collected from the Duplin County soil survey (Goldston et al., 1959) and the soil samples taken within each zone.

Table 3. Soil Characteristics for Each Zone as Used in REMM

REMM	Bot. of Layer (cm)	Porosity (cm^3/cm^3)	FC* (cm/cm)	WP (cm/cm)	Sand (%)	Silt (%)	Clay (%)
			ZONE 1				
Layer 1	9	0.35	0.15	0.09	91.77	7.60	0.63
Layer 2	17	0.38	0.15	0.09	91.63	7.39	0.99
Layer 3	26	0.40	0.15	0.09	90.77	6.10	3.14
			ZONE 2				
Layer 1	15	0.35	0.15	0.07	97.13	2.71	0.16
Layer 2	46	0.38	0.15	0.07	94.86	4.99	0.15
Layer 3	66	0.40	0.15	0.07	95.05	4.38	0.58
			ZONE 3				
Layer 1	66	0.38	0.18	0.03	91.4	6.6	2.0
Layer 2	104	0.435	0.18	0.03	85.1	8.4	6.5
Layer 3	150	0.38	0.18	0.03	78.6	6.2	15.2

* FC is field capacity and WP is wilting point.

REMM's leachate data were compared to the observed data. The REMM output was evaluated for trend similarities with the observed data from 1992 to 1997. For comparison with REMM, wells at the field and stream edges of the riparian zone were compared to the leachate data of Zone 1. The nitrate-nitrogen leachate concentrations from REMM and the well samples were compared. The observed PO_4-P concentration in the leachate was compared to the labile phosphorus (LP) leachate concentrations from REMM. There was a linear relationship between PO_4-P and LP in leachate (Paul and Clark, 1989).

The results of the REMM simulations were evaluated graphically and mathematically. The majority of the graphical analysis was a comparison of the simulation results within each zone or layer. The Y_A and %Δ were also used to evaluate the REMM data.

RESULTS AND DISCUSSION

GLEAMS ANALYSIS

When the observed and simulated leachate data were compared, few similarities resulted (figure 3). As the application rate increased, the simulated peak NO_3-N concentrations increased in magnitude. The observed concentrations leveled out between simulations 1 and 2 after January 1994. Simulations 1 and 2 represented lagoon effluent application rates of 580 and 1000 kg N ha^{-1} yr^{-1}, respectively.

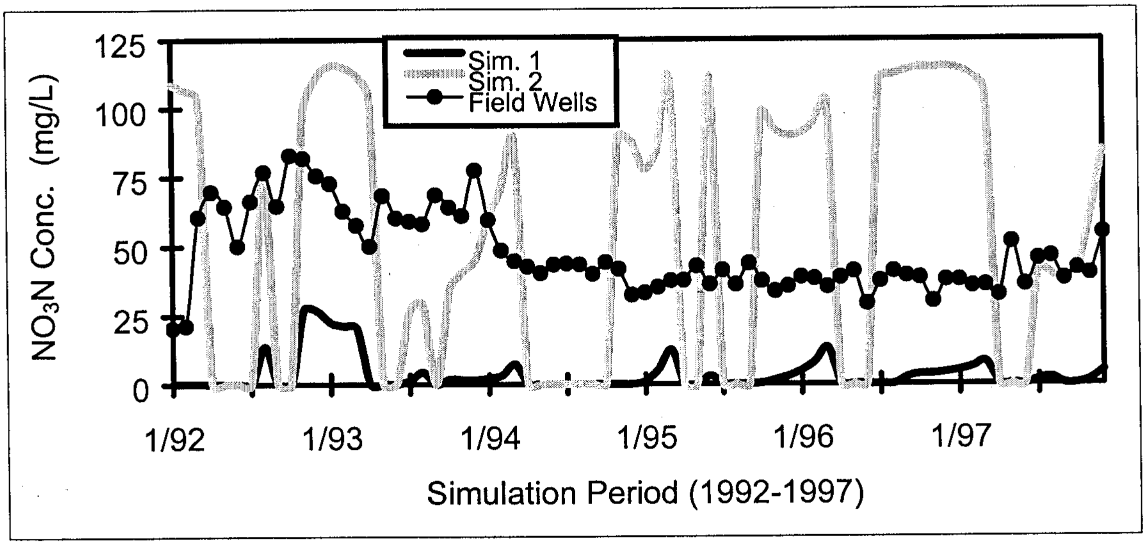

Figure 3-GLEAMS NO_3-N Leachate Data versus Observed NO_3-N Leachate Data

For a better estimation of the application rate, the average monthly NO_3-N leachate concentrations were compared (table 4). The observed average concentration was between simulations 1 and 2, as expected, but closer to simulation 2 than simulation 1. The percent difference between the observed average NO_3-N concentration and simulation 1 was 92 percent. The percent difference between the observed and simulation 2 was 14 percent. This indicated that the actual application rate was closer to 1000 kg N ha^{-1} yr^{-1}.

Table 4. Average Monthly NO_3N Concentrations

GLEAMS	Y_A (mg/L)	%Δ
Sim. 1	3.5	92.6
Sim. 2	54.0	-14.2
Field Wells	47.3	

The comparison of the 1991 and 1997 TKN data with the observed TKN data were favorable (figure 4). In the 1991 and 1997 data, differences between the simulations occurred only within the top 20 cm of the soil profile. This was primarily due to the high TKN concentrations in the litter layer. Below 20 cm, the data for each simulation were almost identical in shape and magnitude. Both simulated data sets estimated decrease in concentration at 66 cm. However, the decrease did not occur at the same depth as the observed data. In the 1997 data comparison, GLEAMS simulated the increase of TKN concentrations in the last soil layer. GLEAMS estimated the trends of the TKN concentrations within the soil profile relatively well.

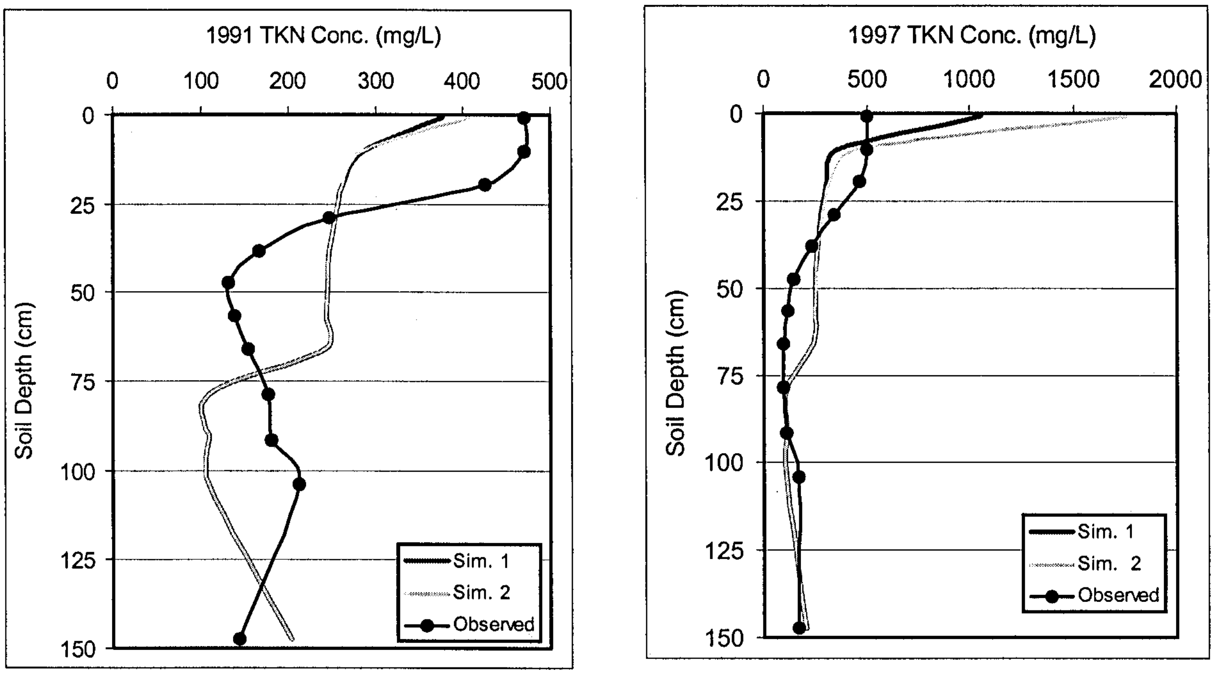

Figure 4-GLEAMS TKN Soil Data versus Observed TKN Soil Data for 1991 and 1997

When the observed and simulated PO_4-P leachate concentrations were compared, the results were favorable (figure 5). Prior to November 1993, there were no similarities between the simulated and the observed data. After August 1994, GLEAMS estimated the observed PO_4-P concentrations more precisely. The observed and simulated peak concentrations began occurring simultaneously during the later part of the simulation period. GLEAMS estimated the peak PO_4-P leachate concentrations would remain relatively constant over time. Both simulations overestimated the observed average PO_4-P leachate concentration (table 5).

Table 5. Average Monthly PO_4-P Concentrations

GLEAMS	Y_A (mg/L)	%Δ
Sim. 1	0.043	-98.8
Sim. 2	0.043	-98.4
Field Wells	0.021	

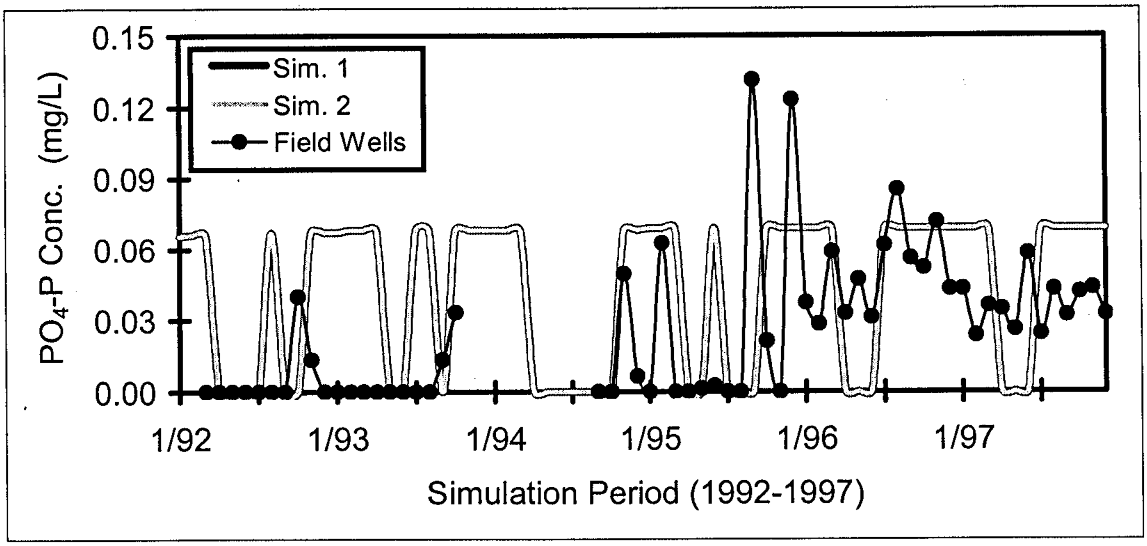

Figure 5-GLEAMS PO_4-P Leachate Data versus Observed PO_4-P Leachate Data

In 1991 and 1997, the total phosphorus (TP) soil data showed the most difference between the simulations within the top 20 cm (figure 6). In both data sets, the TP concentrations of the simulations remained relatively constant below 20 cm in the soil profile. This was consistent with the observed data. In 1997, the litter layer had a greater effect on the comparison of the simulations and the observed data. Below 20 cm, there was almost no detectable difference between the observed and simulated concentrations.

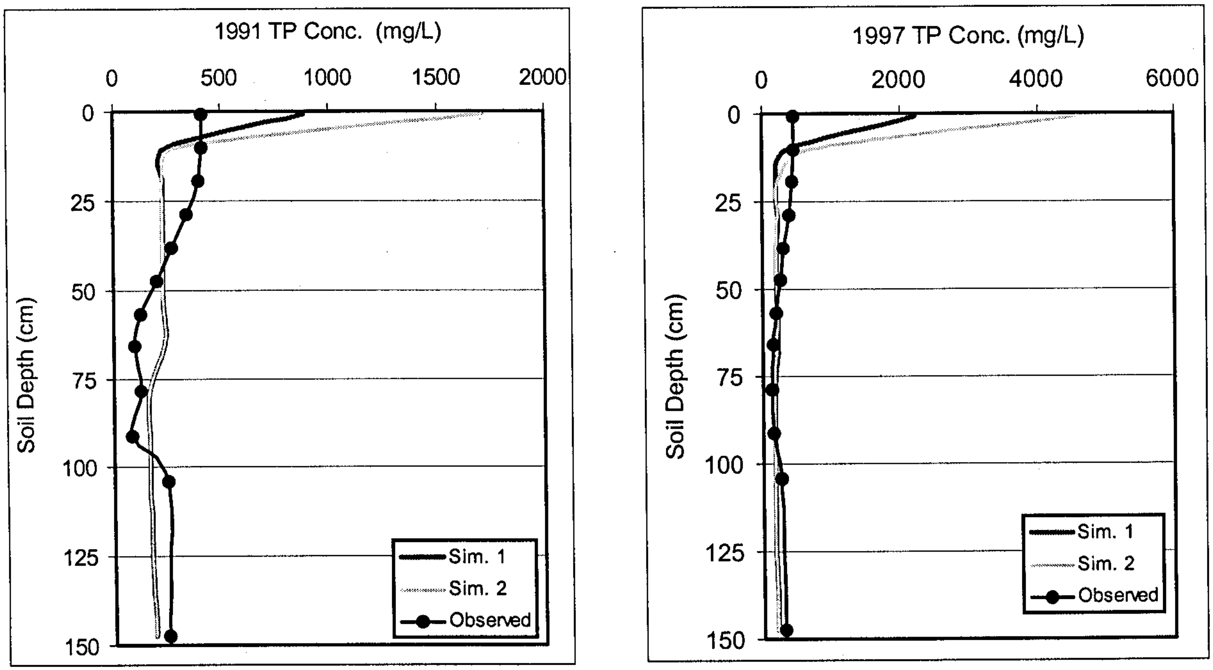

Figure 6-GLEAMS TP Soil Data versus Observed TP Soil Data for 1991 and 1997

MODEL EVALUATION

GLEAMS had some limitations. First, the estimation of phosphorus in the soil and the leachate was inadequate. There was little difference in the phosphorus concentrations between the simulations. With increased application rate, the phosphorus concentrations within the soil and leachate should have increased over time. All of the peak PO_4-P concentrations in the leachate were the same, regardless of simulation or time. In conjunction with this, the TP concentrations in the soil at depths below 20 cm did not differ between simulations. Some differences were expected between simulation 1 and simulation 2 due to the different application rates. The lack of differences in the phosphorus data caused REMM to be less accurate in its estimation of the phosphorus concentrations within the riparian buffer zone.

GLEAMS was a relatively easy model to use being well documented and having an easy to use and understand interface for each input file. The use of the file builders made it easy to construct the input files with confidence. The variable definitions and expected ranges for the variables were available within each of the file builders and the model documentation. The data banks were useful when a data set was incomplete. Also, the required input information was easy to obtain from reference manuals or laboratory analysis.

COMPARISON WITH PUBLISHED WORKS

The trends of the NO_3-N leachate data from Hubbard et al. (1987) study were comparable to those simulated by GLEAMS in this project. That study compared the NO_3-N leachate concentrations of fields applied with dairy wastewater at rates similar to simulations 1 and 2 (Hubbard et al., 1987). The first similarity was the seasonal variations of the NO_3-N leachate concentrations in both data sets. The NO_3-N leachate concentrations were higher in the winter than summer months. The observed project data did not show seasonal influences in NO_3-N leachate concentrations. Second, over time, there was little or no increase in the NO_3-N leachate concentrations for either application rate. GLEAMS estimated no increase of the NO_3-N leachate concentrations due to simulation 1 application rate. There was a small increase over time of the NO_3-N concentrations due to simulation 2 application rate. The observed project data showed a decrease in the NO_3-N leachate concentrations over time. Thus, overall, GLEAMS estimated similar trends of the NO_3-N leachate concentrations as in the study data. This may indicate the observed data did not follow typical trends.

The trends of a GLEAMS simulation by Yoon et al. (1994) were also similar to those simulated by the project. The study compared observed and simulated nutrient concentrations from two application rates of poultry litter. The first similarity was the higher nitrogen concentrations within the top 20 cm of the soil profile. The majority of the difference between the two application rates occurred in the top 20 cm. The remaining profile depth had a fairly constant concentration. Also, the increase of the nitrogen concentrations from the beginning to the end of the simulation period was greater for the higher application rate. The difference in the simulated nitrogen concentrations between the applications rates became more significant over time. Both the thesis project and the study simulations resulted in an underestimation of the nitrogen concentrations when compared to the observed concentrations. Second, both the project and the study simulations estimated the phosphorus leachate concentrations to be very low and almost constant over time. The observed phosphorus leachate data from the Yoon study and this project had more fluctuations than the simulated concentrations. Thus, the GLEAMS project estimations had similar trends as the estimations from the study by Yoon et al. (1994).

REMM ANALYSIS

The comparison of the observed and the simulated NO_3-N leachate concentrations over time resulted in a better estimation of the trends (figure 7 and 8). The observed leachate data at the edge of the field and the edge of the stream were compared to the simulated leachate concentrations in Zone 1. All of the simulations indicated a larger decrease of the total NO_3-N concentrations than the observed data. The decrease of the total NO_3-N concentrations in the observed leachate may have been reduced by flow from the stream entering the last zone. The observed NO_3-N data showed a significant decrease in concentration beginning in January of 1994. This could be the result of the planting of the riparian trees in April 1993. The simulated data did not show this trend because the model assumed the trees were planted for the entire simulation period for simplicity. The percent difference between the observed average NO_3-N concentration and simulation 1 was 99 percent (table 6). The percent difference between the observed and simulation 2 was 5 percent. This indicated that the actual application rate was even closer to 1000 kg N ha^{-1} yr^{-1} than GLEAMS had estimated.

Table 6. Average Monthly NO_3N Concentrations

REMM	Y_A (mg/L)	%Δ
Sim. 1	0.45	99.0
Sim. 2	46.7	-5.4
Stream Wells	44.3	

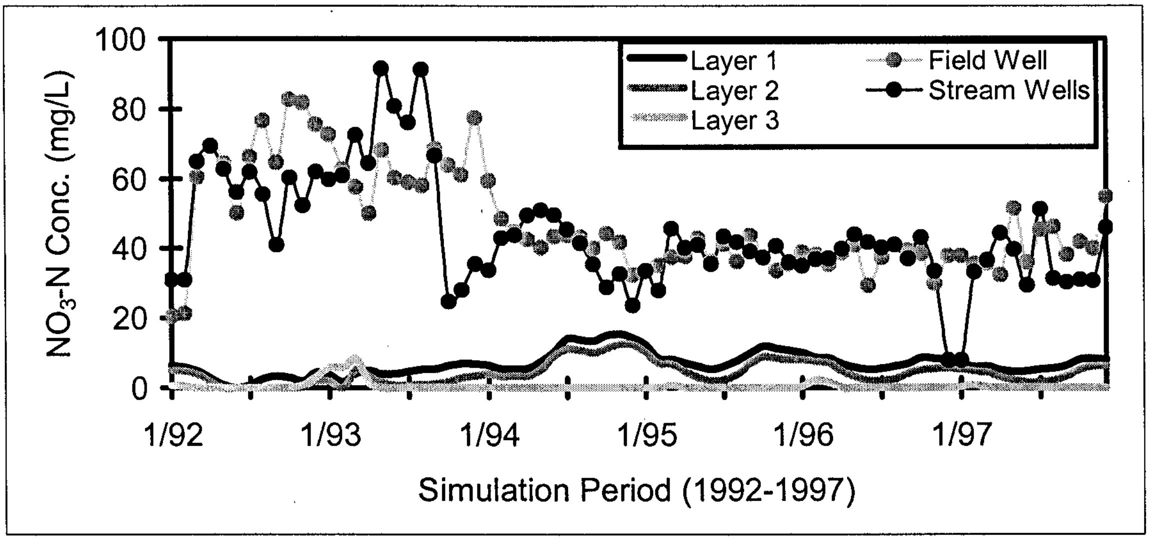

Figure 7-REMM's NO_3-N Leachate Data versus Observed NO_3-N Leachate Data for Sim. 1

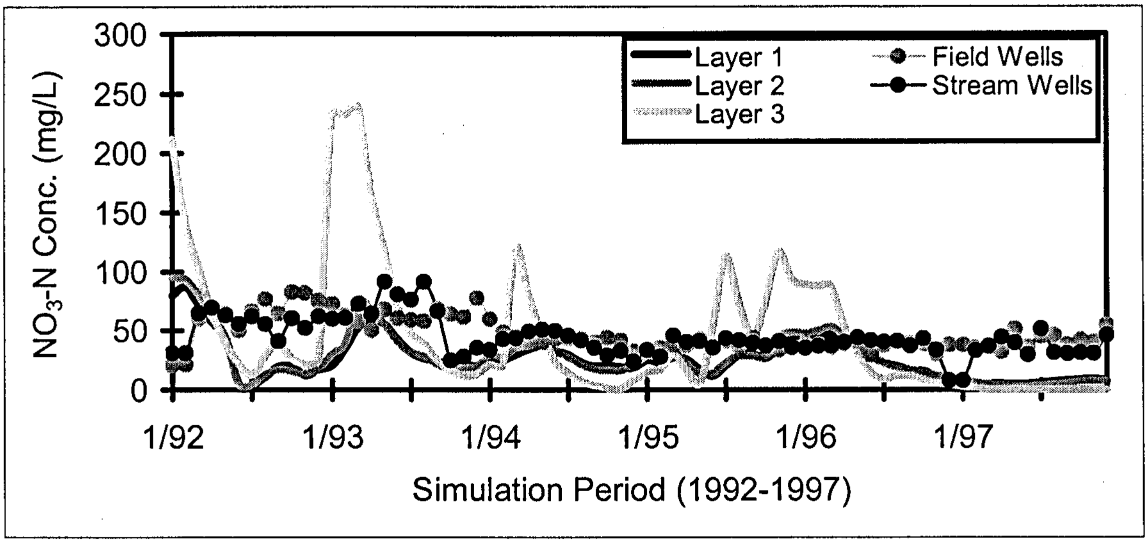

Figure 8-REMM's NO_3-N Leachate Data versus Observed NO_3-N Leachate Data for Sim. 2

REMM's phosphorus leachate results were an improvement from the previous version of REMM. The simulated dissolved labile phosphorus (LP) concentrations were compared to the ortho-phosphorus (PO_4-P) concentrations measured in the well samples (figure 9 and 10). The LP concentrations of the two simulations were almost identical for each layer. Both simulations over-estimated the observed average monthly PO_4-P concentration. The LP concentrations were fairly constant over time with only minor fluctuations. The average monthly concentration in Layer 3 was compared to the model's monthly concentrations (table 7). The model over-estimated the phosphorus concentrations. However, there was a general agreement concerning the low range of the phosphorus concentrations.

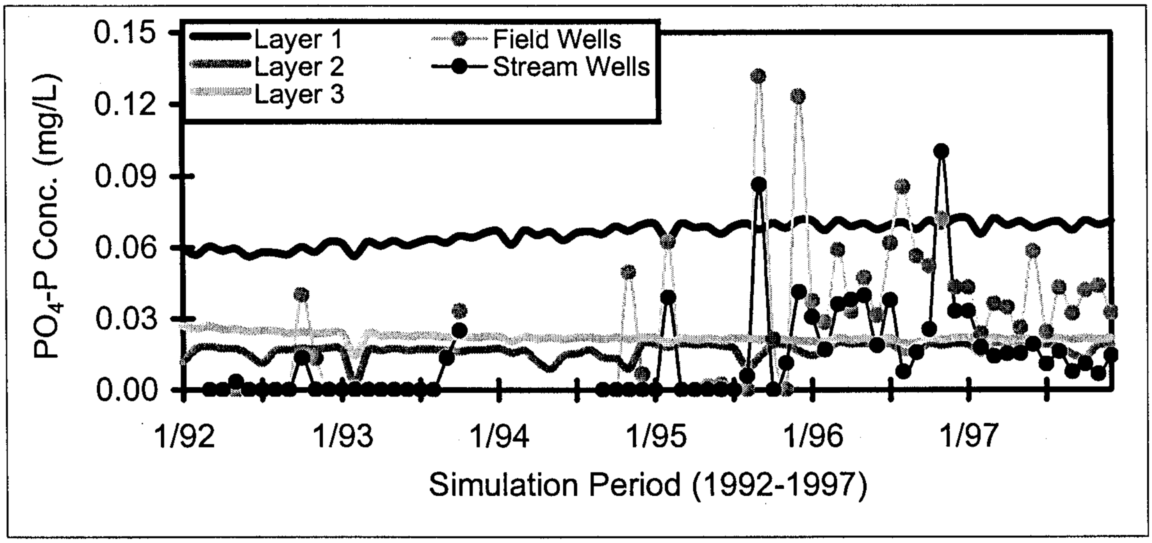

Figure 9-REMM's LP Leachate Data for Sim. 1

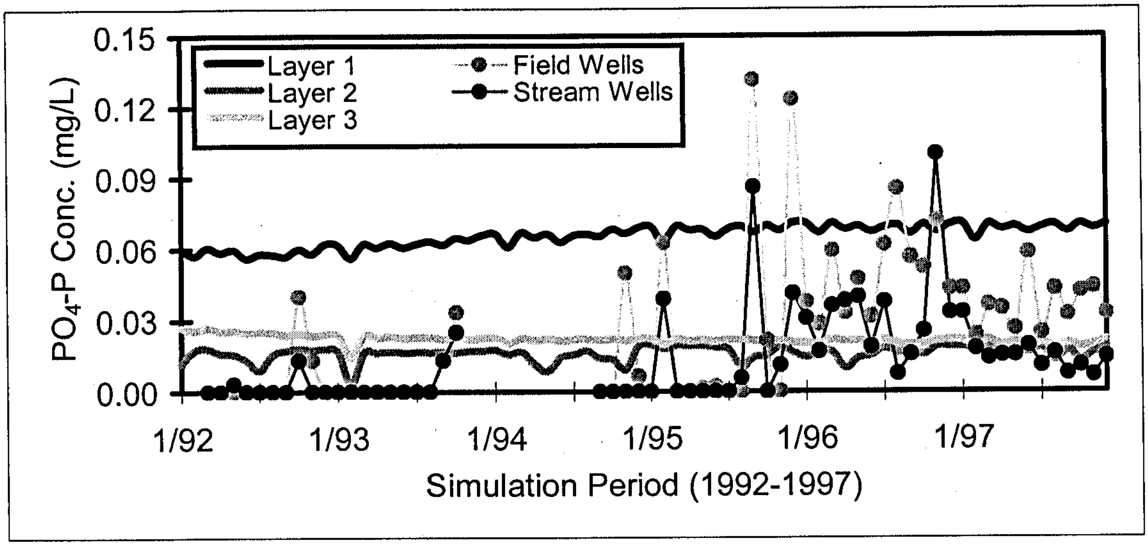

Figure 10-REMM's LP Leachate Data for Sim. 2

Table 7. Average Monthly PO_4-P / LP Concentrations

REMM	Y_A (mg/L)	%Δ
Sim. 1	0.022	-62.0
Sim. 2	0.022	-60.2
Stream Wells	0.014	

MODEL EVALUATION

While some improvements have been made in the second pre-release version of REMM, there were still a few limitations of the model's structure. First, a user interface has been designed, but the interface does not aid in construction of input files. The type of output can be chosen only from a list of predetermined output files; unlike GLEAMS, the user cannot choose specific variables for output. The output does not include units of variables, only abbreviated names of the variables. A users manual is needed that describes input and output files. Second, only one vegetation type per zone was suggested, since multiple vegetation types had not yet been tested. This limited the accuracy of the output because the project site had multiple vegetation types in Zones 1 and 2. Also, only three soil layers per zone were available, which generalized the soil profile characteristic. A soil input structure similar to that used in GLEAMS would provide a better relationship between the two models. Third, it was not practical to obtain all the required data. This pertained primarily to various forms of carbon, nitrogen, and phosphorus in the soil and vegetation. The soil samples were not typically analyzed for these additional forms of nutrients. The soil nutrient inputs should also include TP, TN NO_3-N, NH_4-N, PO_4-P, and total carbon. These limitations should be considered for improvements to future versions of REMM.

The calculations of phosphorus leachate concentrations have been improved since the first version of REMM. Differences in the PO_4-P concentrations were seen between the two trials, whereas previously no differences were seen. Also, the PO_4-P leachate concentrations display a more realistic trend and similar to GLEAMS phosphorus output, whereas previously the PO_4-P concentrations decreased exponentially over time.

CONCLUSIONS AND RECOMMENDATIONS:

The first objective of this project was to use GLEAMS in combination with REMM to estimate the transport of nutrients through a riparian buffer zone from an agricultural field that received swine lagoon effluent. GLEAMS estimations of the nutrient concentrations leaving the spray field were first evaluated. The results of the evaluation indicated GLEAMS provided an adequate estimation of the average nitrogen concentrations leaving the field. The phosphorus leachate data revealed a limitation of GLEAMS ability to estimate the phosphorus concentration differences between the simulations. The limitations of the phosphorus estimations affected REMM's ability to accurately estimate the phosphorus movement within the riparian buffer zone.

REMM's ability to estimate the nutrient transport through the riparian buffer zone was evaluated second. The model was able to effectively estimate the NO_3-N leachate concentrations. The estimations of the phosphorus movement were limited by the GLEAMS input phosphorus data. REMM's estimations were partially limited by the inability to acquire more real input data.

The second objective was to evaluate the second pre-release version of REMM. Some recommendations for improvements to this version of REMM would allow the model to be a useful tool in the development of the agricultural management plans for groundwater and surface water pollution reduction. An expansion of the user interface would be beneficial. Some suggestions for improvement would be an input file creation tool, user-selected output file, and variable definitions and units. Also, the use of more soil layers within each zone would be useful to better describe the soil profile. In the future, default soil files would helpful for general use of the model where soil data is not available. More research on the use of multiple vegetation types per zone should be done to allow for a better representation of project site. This would also provide a means of comparison between different types of buffer strips. This would be helpful in determining the most suitable buffer strip for a given location.

Some suggestions for the user to consider for improvement of model's outputs would be more soil samples with a more complex soil analysis. More samples from the spray field and riparian buffer zone should be taken at least yearly for comparison with models. These samples should also be taken at the depths, which correlate to those used in the models. Also, a more complex soil analysis should be done to supply more input information. Analysis resulting in the following data would beneficial to the development of input files: total humus, slow, active, and passive C, N, and P concentrations. This would allow the model to better estimate the nutrient concentrations within the system.

With these improvements to future versions of REMM, this model would be a useful tool in the development of agricultural management plans for pollution reduction. Varying the zones' widths and vegetation types would be helpful to minimize the size of a riparian buffer zone. This would prevent land from being unnecessarily removed from production. Estimations of this type could further reduce the amount of land removed from production. A comparison could be made between different types of buffer strips. This versatility would be helpful in determining the most suitable buffer strip for a given location.

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