GLEAMS Simulation of Groundwater Nitrate-N from Row Crop and Swine Wastewater Spray Fields in the Eastern Coastal Plain

K. C. Stone, P. G. Hunt, M. H. Johnson, S. W. Coffey

Abstract. *Nonpoint source pollution of surface and groundwater resulting from agricultural management practices is a major water quality problem. This problem was assessed on a demonstration watershed in the Cape Fear River Basin of North Carolina, during a five-year study. Groundwater was monitored in a row crop field (corn/wheat/soybean) and a swine waste spray field (Coastal bermuda grass). Groundwater nitrate-N concentrations averaged 6.5 mg/L in the row crop field. Nitrate-N concentrations in groundwater at the swine waste spray field exceeded 80 mg/L. Nitrate-N concentrations were simulated in both fields with the GLEAMS model. The GLEAMS model simulated groundwater nitrate-N concentrations with mean residuals (simulated-observed) ±1.3 mg/L and ±19 mg/L, respectively, for the row crop and the swine waste spray field. Groundwater nitrate-N concentrations have been reduced in the spray field by using improved management practices and the GLEAMS model simulated this nitrate-N concentration reduction. These simulation results show that the GLEAMS model can be used to predict nitrate-N loading of groundwater of these agricultural management systems.* ***Keywords.*** *Groundwater, Water quality, GLEAMS.*

The USA public is concerned about nonpoint source pollution of surface and groundwater. These concerns are especially critical in the eastern Coastal Plain because shallow groundwater tables and coastal estuaries can be affected by nonpoint source pollution (NCDEHNR, 1992; Hubbard et al., 1989). In this region, nonpoint source pollution from agriculture has been identified as a significant problem (North Carolina Division of Water Quality, 1996; Jacobs and Gilliam, 1985). This problem and its associated economic loss can be reduced using appropriate nutrient management plans. One of the most important management plans is to apply the correct amount of nutrients (Jackson et al., 1987).

This problem is particularly acute in watersheds with concentrated animal production. In these watersheds, it is difficult to fully utilize the quantity of nutrients produced, and excess application of animal waste to field sites can result in contamination of shallow groundwater (Hunt et al., 1995). Suitable application rates for animal waste are calculated based upon anticipated crop nutrient uptake (Zublena et al., 1993). These criteria determine application rates and area needed to prevent loss of excess nutrients from the soil profile. In cases where operations have expanded production but not expanded the land area to compensate for the increased effluent load, contamination of groundwater is likely to occur.

Such concerns have resulted in the need to evaluate the effects of management practices on chemical movement in the soil. This need appears best met using computer simulation models. Models have been successfully used to evaluate nonpoint source pollution in surface runoff and in groundwater loading from agricultural operations (Nicks et al., 1984; Leonard et al., 1987; Williams and Renard, 1985; Stone et al., 1989). They are useful when evaluating alternative management practices and can provide a basis for guiding management and regulatory decisions. Phillips et al. (1993) used the Erosion Productivity Impact Calculator (EPIC, Williams and Renard, 1985) model to simulate responses of soil erosion and nutrient exports on several different tillage and crop rotation practices in Illinois. Wu et al. (1997) used the EPIC model to evaluate nitrogen runoff and leaching potential over the Ogallala aquifer in the High Plains. Both CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems, Knisel, 1980) and GLEAMS (Groundwater Loading Effects of Agricultural Management Systems, Leonard et al., 1987) were used by Thomas et al. (1989) to simulate potential leaching and runoff of pesticides and nutrients from alternative cropping systems in Georgia. The CREAMS model was used by Cooper et al. (1989) to simulate the effects of buffer strips on runoff water quality in New Zealand. Reck (1994) used the GLEAMS model to determine the potential effects of BMP implementation to poultry and dairy waste applications on reducing nitrate leaching in northern Florida. Yoon et al. (1994) used the GLEAMS model to predict nutrient losses in surface and subsurface runoff from application of poultry litter on conventionally tilled corn plots. Poultry litter applications to pine seedlings were simulated with the GLEAMS model

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by Minkara et al. (1995). These simulation models have been instrumental in investigating the potential impact of implementing alternative management practices.

The GLEAMS model referred to above is a mathematical model developed for field-size areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone (Leonard et al., 1987). It uses soil input data by soil horizon and can accommodate depth-specific parameters. The GLEAMS nutrient component simulates the major processes and transformations of nitrogen and phosphorus and considers surface and subsurface pathways to estimate edge-of-field and bottom-of-root zone loadings. The nutrient component includes land application of animal waste as well as inorganic fertilizers and nitrogen fixation by legumes.

The objectives of this research were to measure the levels of groundwater nitrate-N in two fields in an eastern Coastal Plain watershed and to evaluate the ability of the GLEAMS model to simulate groundwater nitrate-N concentrations at these fields.

BACKGROUND

A water quality demonstration project involving private industry; local land owners; and federal, state, and local agencies was initiated in 1990 on a watershed in the Cape Fear River Basin in Duplin County, North Carolina. The 2044-ha demonstration watershed, Herrings Marsh Run (HMR), is located within the Goshen Swamp Watershed Hydrologic Unit Area Project (United States Department of Agriculture and Cooperating State Agencies, 1989). Duplin County is typical of an intensive agricultural county in the eastern Coastal Plain of the USA. It has the highest agricultural revenue of any county in North Carolina, with intense poultry and swine production (North Carolina Department of Agriculture, 1996; USDA-NASS, 1995).

Agricultural management practices on the watershed are typical for the eastern Coastal Plain and include about 1100 ha of cropland and 700 ha of woodlands. The major agricultural crops on the watershed include cotton, corn, soybeans, vegetables, tobacco, and wheat (Stone et al., 1995). Conventional management practices typically use commercial fertilizers as their main source of nutrients. Some alternative management practices replace many of these commercial fertilizers with animal waste to use nutrients on the watershed better.

METHODS

GROUNDWATER MONITORING

Groundwater was monitored on two fields in the HMR watershed. The fields are located approximately latitude 35°05′North, longitude 77°57′West, and elevation 40 m. One field was row crop, and the other was a swine wastewater spray field. The row crop (RC) field had corn, wheat, and soybean in a two-year rotation; planting dates and nutrient inputs are defined in table 1. Our investigation of the RC field began in 1992 with corn. The previous crop was cucumber. Crops received nutrient inputs from both poultry litter and conventional fertilizers. The crops received 212 and 84 kg N/ha, respectively, in 1992 and 1993. The RC field was 1.7 ha of a Norfolk sand (Fine-loamy, siliceous, thermic *Typic Kandiudults*). The soil was conventionally tilled with a disk, and planting was done with row crop planters and conventional grain drills. Rainfall patterns for the monitoring period are shown in figure 1. The RC field represented a field that was in compliance with a nutrient management plan developed by NRCS. It was monitored from January 1992 to December 1993 with two groundwater monitoring wells.

Table 1. Cropping practices for row crop field with Norfolk soil used to validate the GLEAMS model

Year 1	Year 2
March: Applied 9 kg N/ha starter	Feb: Applied 84 kg N/ha
March: Applied 4667 kg litter (84 kg N)/ha	June: Harvested wheat
March: Planted corn	June: Planted soybeans
May: Sidedressed with 112 kg N/ha	Nov: Harvested soybeans
Sept: Harvested corn	
Nov: Planted wheat	

The swine wastewater spray field (SWS) soil was an Autryville sand (Loamy, siliceous, thermic *Arenic Paleudults*). Rainfall patterns at the SWS field were similar to those of the RC field. However, nutrient management of the two fields was very different. Initial nutrient management at the SWS field was not in compliance with NRCS developed plans for nutrient management. Initially, the spray field (~1 ha) had no permanent cover, and swine waste was applied in excess of crop needs (approximately 2500 kg N/ha). When our study began, a nutrient management plan was implemented at the SWS field. The SWS field was expanded to approximately 2 ha and planted with Coastal bermuda grass (*Conodon dactylon* L.). Nutrient application rates were reduced to approximately 250 kg N/ha, and nutrients were removed by harvesting the Coastal bermuda hay. Groundwater at the SWS field was sampled at two locations and at two depths at each location.

Groundwater monitoring wells were installed to minimize their influence on normal farming activities in the two fields using local topography and interaction with the landowners and farmers. Local topography was assumed to be a guide for determining groundwater flow gradients. Groundwater monitoring wells were installed in the SWS field in August 1991 and the RC field in March 1992. Two wells at the RC field (fig. 2) were located on the perimeter of the field. Monitoring well locations in the SWS field are shown in figure 3.

Groundwater monitoring wells were installed using a SIMCO 2800 trailer-mounted drill rig equipped with 108-mm i.d. hollow-stem augers. The well casings and screens were 50-mm i.d. threaded schedule 40 PVC, and well screens were 1.5 m in length. Well bottoms were placed on an impermeable layer or to a depth of 7.6 m if the impermeable layer was not located above that depth. Water table depths in the watershed are generally 1.5 to 3 m below the soil surface. Monitoring wells (fig. 4) were constructed according to North Carolina Division of Environmental Management regulations (NCDEHNR, 1993). A filter pack of coarse sand was placed around well screens. An annular seal of bentonite was placed above the filter sand. Concrete grout was then placed from above the bentonite to the soil surface to prevent contamination from the surface. Locking well covers were installed to prevent unauthorized access. WaTerra foot valves (model D-25)

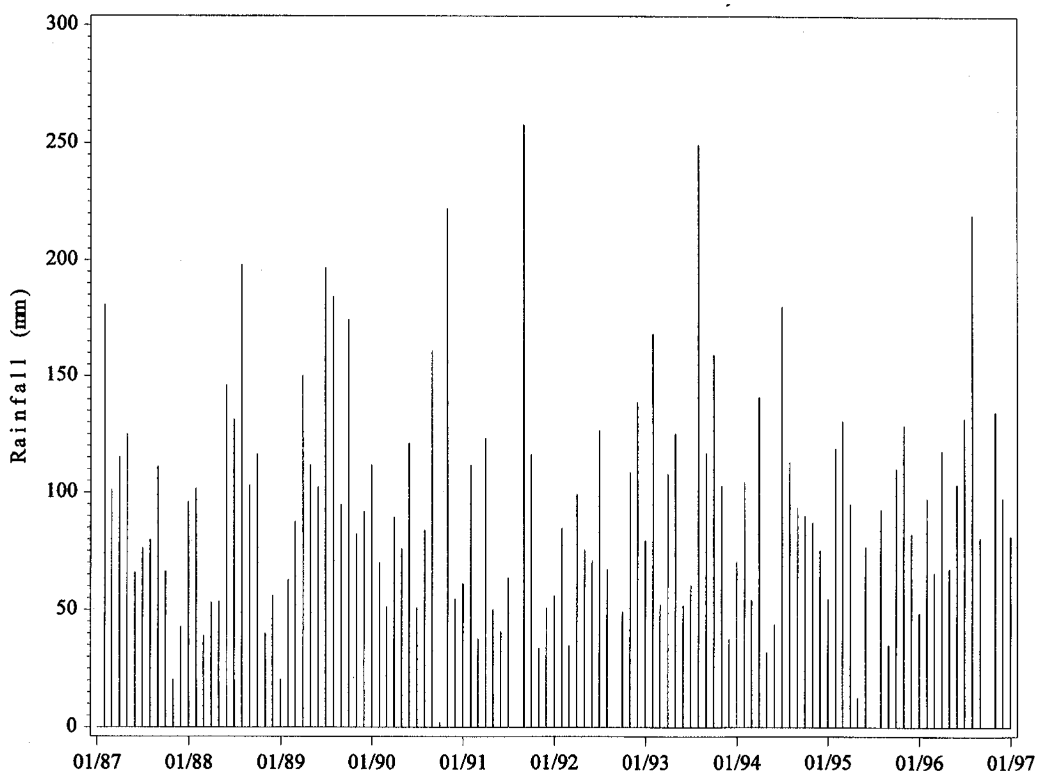

Figure 1–Monthly rainfall for Clinton, N.C.

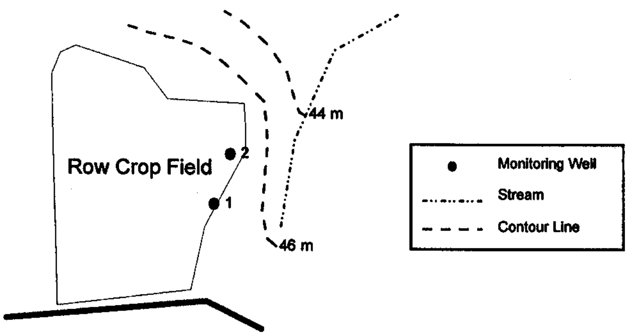

Figure 2–Monitoring well layout for row crop field.

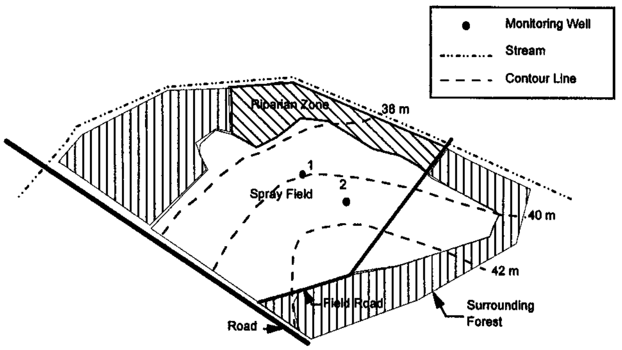

Figure 3–Monitoring well layout for swine wastewater spray field.

and high density polyethylene tubing were installed in each well to provide dedicated samplers.

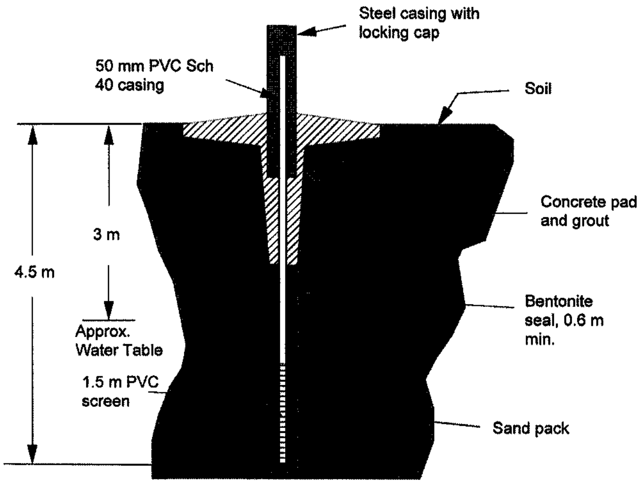

Figure 4–Schematic of groundwater monitoring well construction details.

Wells were sampled monthly. Before samples were collected, the static well water depths were measured, and one to three well volumes were purged. Glass sample collection bottles were rinsed with the well water before sample collection, filled with sample, packed in ice, and transported to the USDA-ARS, Soil, Water, and Plant Research Center in Florence, South Carolina, for analyses. Water samples were analyzed using a TRAACS 800 Auto-Analyzer for nitrate-N using EPA Methods (U.S. EPA, 1983). EPA-certified quality control samples were routinely analyzed to verify results. All statistical analyses of the data were accomplished using SAS version 6.07 (SAS, 1990).

GLEAMS Simulations

The GLEAMS model was used to simulate two monitored fields in the HMR watershed. Climatological inputs for simulations were obtained from the Warsaw and Clinton, North Carolina, weather stations (20 and 40 km from watershed, respectively) for the simulation period.

The GLEAMS model was validated on the RC field. Cropping practices used in the field system were obtained from farm surveys (NCSU, 1993) and are shown in table 1. Soil and land use data were obtained from the county soil survey and annual reports of the water quality demonstration project (USDA-SCS, 1959; NCSU, 1993). Additional parameters for development of input data for the GLEAMS model were obtained from the GLEAMS manual. The soil profile simulated with the GLEAMS model was set equal to the depth of the groundwater monitoring wells. Percolation from the rooting zone was restricted by assigning a very small hydraulic conductivity value to the soil zone immediately below the simulated soil profile. Simulated GLEAMS nitrate-N concentrations for the bottom soil layer were assumed to be an estimate of groundwater nitrate-N concentrations. GLEAMS simulation results were compared to observed nitrate-N concentrations from the groundwater monitoring wells. No prior calibration of the GLEAMS model was performed.

The swine wastewater spray field (SWS) was modeled to determine the GLEAMS model's ability to simulate an overloaded spray field and to determine the spray field's recovery if the rates were reduced. Input parameters for the spray field were determined from annual project reports, farm surveys, and the landowner. Actual application rates for the site were unknown prior to installation of monitoring wells. The spray field was initially undersized because of expansion of the operation since its original design. After initial monitoring indicated elevated nitrate-N in groundwater, the spray field was enlarged to meet current guidelines and recommendations (NRCS, 1995, personal communication; Zublena et al., 1993). The previously fallow spray field was sprigged with a Coastal bermuda grass cover after enlargement. Recommended nitrogen application rates for the soil and bermuda grass were 280 kg/ha (250 lbs/ac) (Zublena et al., 1993). This rate was used as model inputs after spray field expansion implementation of recommended nutrient applications. A five-year simulation (prior to BMP implementation) study was conducted to determine the potential swine waste application rates that could produce groundwater nitrate-N concentration in groundwater similar to initial observed values. To determine the potential application rate, a series of simulations was performed at various application rates from 280 to 3500 kg/ha (250 to 3100 lbs/ac) to determine the potential application rates that best agreed with the average infield groundwater nitrate concentrations.

Statistical procedures were utilized to determine the model's ability to predict the observed values as described by Reckhow et al. (1990). The first statistical method was a regression analysis in which the predicted values were regressed with the observed values. In this method, the model would be considered to provide a good agreement between predicted and observed values if the regression produced an intercept and slope equal to zero and one, respectively. The second method used the nonparametric Wilcoxon Test to determine if the center of two distributions, simulated and observed, were the same. The third statistical method was a t-test on the residuals from the predicted and observed values. A series of t-values was calculated to determine an acceptable agreement between the observed and predicted values at the $P \leq 0.05$ level. The null hypothesis used was that the mean of the absolute value of the residuals would be less than an acceptable value.

Results and Discussion

Groundwater Monitoring

In the RC field, groundwater nitrate-N concentrations averaged 6.8 mg/L (std = 1.8), which was below the 10 mg/L level for safe drinking water (USEPA, 1992). Nitrate-N concentrations were relatively stable for the first year, varying from 5 to 7 mg/L (fig. 5). However in the first six months of 1993, nitrate-N concentrations for well no. 2 began to increase, but then returned to approximately 5 to 7 mg/L. During this same time period, well no. 1 nitrate-N concentrations varied from 5 to 9 mg/L. No explanation for these variations could be determined from the information available.

Nitrate-N concentrations in the swine waste spray field averaged 87 mg/L (std = 63). These elevated nitrate-N concentrations are believed to be directly related to the over application of swine wastewater and to the undersized spray field. Also prior to 1991, the spray field had no permanent grass cover; weed served as the ground cover. In 1992, the wastewater spray field was expanded, application rates were reduced to recommended rates, and a permanent grass cover of Coastal bermuda was established. It was anticipated that lower wastewater application rates, the expanded application area, and the Coastal bermuda grass uptake of nitrogen would assist in reclaiming this site. Groundwater nitrate-N concentrations have been reduced from initial observations (fig. 6). We believe this decrease in nitrate-N concentration is a result of the reduced application rates, expanded spray field, and permanent grassed cover. However, the site still has elevated nitrate-N

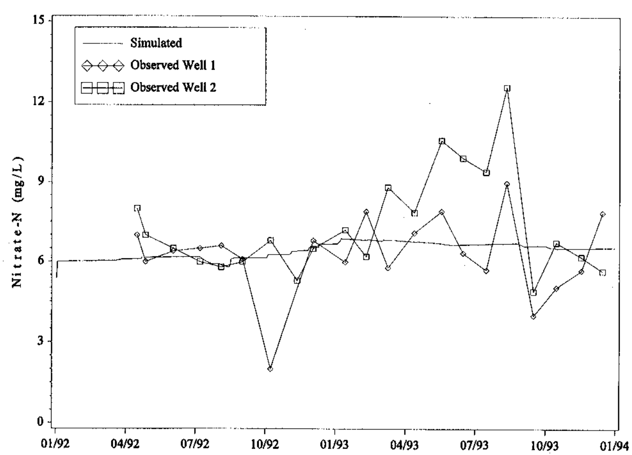

Figure 5–Comparison of GLEAMS row crop simulated to measured groundwater nitrate-N in a Norfolk loamy sand. Cropping sequence was corn/wheat/soybeans with commercial and poultry litter used as nutrient sources.

concentrations, and continued management and monitoring of this site would be needed to reduce the groundwater nitrate-N concentrations to the 10 mg/L safe drinking water standard.

GLEAMS Simulations

The GLEAMS simulations of both sites are plotted with observed nitrate-N concentrations in figures 5 and 6. For the RC field, GLEAMS predicted more uniform nitrate-N concentrations over time than were observed. The regression analysis was performed on the simulated and observed data. The regression null hypothesis compared whether the slope equaled one and the intercept equaled zero. Using the regression analysis, calculated F values were much higher than the acceptable F value at the $P \leq 0.05$ level for both wells, and the null hypothesis was rejected. The Wilcoxon test results determined that the simulated distribution center was not statistically different from the observed distribution center for either well. Calculated z values using the Wilcoxon test were 0.72 and 0.83, respectively, for wells numbers 1 and 2. A t-test on the absolute values of the residuals (predicted-observed) was conducted for both monitoring wells at the RC field. The observed distribution of the individual residual values between 5% and 95% was 0.1 to 3.4 for well no. 1 and 0.08 to 3.9 for well no. 2. The mean of the residuals was 1.1 (std = 1.0) and 1.3 mg/L (std = 1.5), respectively, for wells no. 1 and 2. The 95% confidence interval for the mean residuals was 0.7 to 1.4 for well no. 1 and 0.8 to 1.8 for well no. 2. For a t-test null hypothesis that the true mean of residuals was 1 mg/L, the calculated t-statistics (0.27 and 1.0 for wells no. 1 and 2, respectively) were accepted at the $P \leq 0.05$ confidence level. Using results from these statistical analyses, one can conclude that the GLEAMS model can be used to simulate nitrate-N concentrations with a mean residual of ±1.3 mg/L for the entire simulation period. Using sensitivity analysis and parameter estimation methods, the model could provide even better estimates.

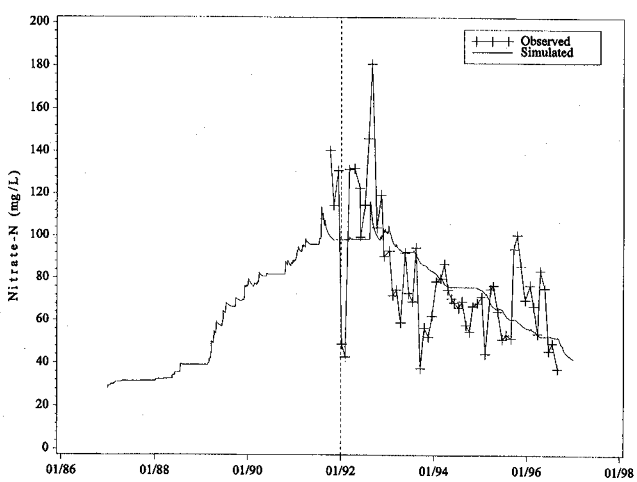

Figure 6–Comparison of GLEAMS spray field simulated to measured groundwater nitrate-N in swine waste spray field on an Autryville fine sand. Simulation prior to 1/1/92 with over 10-times the recommended application rate (3500 kg/ha N) for nitrogen, and after 1/1/92 application rates were reduced to recommended rate (280 kg/ha N).

GLEAMS simulations of the swine waste spray field and comparison with mean observed values are shown in figure 6. The GLEAMS simulation of the SWS field started with a five-year simulation prior to our installation of groundwater monitoring wells. For this five-year period, the anaerobic lagoon and the spray field were undersized, the spray field had no continuous cover crop, and loading rates were estimated to be approximately 3500 kg/ha. This rate is over 10 times the recommended rates of 280 kg N/ha for Coastal bermuda grass. The initial simulation period shows that the GLEAMS model predicted a similar groundwater loading pattern as was observed for a heavily overloaded spray field. GLEAMS was then used to simulate the next five years after the lagoon and spray field were expanded, the spray field had a permanent bermuda grass cover established, and the applications rates were reduced to recommended levels. With the improvements in management at this site, the simulated trends were similar to the observed groundwater nitrate-N concentrations. Yet, even with these improvements, it will take several more years for the groundwater nitrate-N concentrations to be reduced to acceptable levels.

GLEAMS simulations of the groundwater nitrate-N concentrations in the spray field were compared statistically to the observed concentrations using the same statistical methods as for the RC field. Using the regression technique, the calculated F value was much higher than the $P \leq 0.05$ level ($F = 3.0$) of acceptance. For this analysis, the slope and intercept were statistically different from 0 and 1, respectively. The Wilcoxon test results ($z = 1.9$) determined that the simulated distribution center was not statistically different from the observed distribution center for the spray field at $P \leq 0.05$. Using the t-test, the mean residual (predicted-observed) nitrate-N concentration was 19 mg/L. At the $P \leq 0.05$ level, a confidence limit on the mean residual was from 17.5 to 21 mg/L for the entire simulation period. The calculated distribution of the residuals between 5% and 95% was 0.4 to 50 mg/L. Considering the mean nitrate-N concentration for the spray field and variation in the data (mean = 86 mg/L, std = 63 mg/L), this level of agreement would be acceptable. If more pre-observation data were available, a much lower agreement level would be appropriate.

The GLEAMS model simulated more uniform results compared to observed nitrate-N concentration for simulations of both the row crop and swine waste spray field. This is partially a result from variation in the observed data and from the GLEAMS model structure. GLEAMS was developed to investigate long-term comparisons of different management systems (Leonard et al., 1987). Additionally, other factors not included in the model, such as preferential flow, could help to explain the differences in the observed and simulated concentrations.

Conclusions

Groundwater nitrate-N concentrations were monitored on both a row crop field and swine wastewater spray field in the HMR watershed. Groundwater nitrate-N concentrations in the row crop field with a corn/wheat/soybean crop rotation averaged 6.5 mg/L.

Groundwater nitrate-N concentration at the swine wastewater spray field averaged 87 mg/L. The high nitrate-N concentration in the spray field exceeded the safe drinking water standards of 10 mg/L. However, high nitrate-N concentrations in the spray field have been reduced by expanding the spray field and reducing application rates. After three years of reduced application rates, groundwater nitrate-N concentrations reduced from 120 to 70 mg/L.

The GLEAMS model was used to simulate nitrate-N loading in shallow groundwater on the two monitored fields. The row crop field was simulated with a mean groundwater nitrate-N residual of ±1.3 mg/L. The swine waste spray field was simulated with a mean groundwater nitrate-N residual of ±19 mg/L. These results were very encouraging because the GLEAMS model was not calibrated or fine tuned through sensitivity analysis to produce these results. These simulation results show that the GLEAMS model can be used to predict results for moderately and highly contaminated systems. Long-term impacts of various nutrient management alternatives can be investigated, and acceptable practices can be implemented that help reduce potential contamination of both surface and groundwaters. Continued use of the improved nutrient management plans at the spray field could further reduce nitrate-N concentration in the groundwater in the spray field and assist in the recovery of the site. These results indicate that improvements in specific agricultural management practices on the watershed, especially at the swine wastewater spray field, have produced measurable improvements in water quality. It also points out that lack of, or failure to follow, a nutrient plan can cause extensive groundwater contamination that would take many years to mitigate.

REFERENCES

Cooper, A. B., C. M. Smith, and A. B. Bottcher. 1989. Using CREAMS for predicting runoff of water, sediment and nutrients from a New Zealand grazed pasture. In *Proc. CREAMS/GLEAMS Symp.*, 170-178, 27-29 Sept. 1989, Athens, Ga.

Hubbard, R. K., R. G. Williams, and M. D. Erdman. 1989. Chemical transport from Coastal Plain soils under simulated rainfall: I. Surface runoff, percolation, nitrate, and phosphate movement. *Transactions of the ASAE* 32(6):1239-1249.

Hunt, P. G., K. C. Stone, F. J. Humenik, and J. M. Rice. 1995. Impact of animal waste on water quality in an eastern Coastal Plain watershed. In *Animal Waste and the Land-Water Interface*, Proc. ed. K. Steele, 257-264. Boca Raton, Fla.: Lewis Publishers.

Jackson, G., D. Keeney, D. Curwen, and B. Webendorfer. 1987. *Agricultural Management Practices to Minimize Groundwater Contamination,* 114. Madison, Wis.: Environ. Resources Center, Univ. of Wis., Wis. Dept. Nat. Resources.

Jacobs, T. J., and J. W. Gilliam. 1985. Riparian losses of nitrate from agricultural drainage waters. *J. Environ. Qual.* 14(4):472-478.

Knisel, W. G., ed. 1980. CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. USDA, Conservation Research Report No. 26. Washington, D.C.: USDA-Agric. Research 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.

Minkara, M. Y., J. H. Wilhoit, C. W. Wood, and K. S. Yoon. 1995. Nitrate monitoring and GLEAMS simulation for poultry litter application to pine seedlings. *Transactions of the ASAE* 38(1):147-152.

NCDEHNR. 1993. *North Carolina Well Construction Regulations and Standards.* Raleigh, N.C.: North Carolina Environmental Management Commission, Department of Environment, Health and Natural Resources.

_________. 1992. Water quality progress in North Carolina 1990-1991 305(b) Report. Report No. 92-06. Raleigh, N.C.: North Carolina Dept. of Environment, Health, and Natural Resources.

NCSU. 1993. Annual progress report for USDA Water Quality Demonstration Project in Herrings Marsh Run, Duplin County, North Carolina. Raleigh, N.C.: North Carolina Cooperative Extension Service, N. C. State University.

Nicks, A. D., J. B. Burt, W. G. Knisel, and G. A. Gander. 1984. Application of a field-scale water quality model for evaluation of a watershed land treatment project. ASAE Paper No. 84-2633. St. Joseph, Mich.: ASAE.

North Carolina Department of Agriculture. 1996. *Annual Agricultural Survey.* Raleigh, N.C.

North Carolina Division of Water Quality. 1996. Neuse River Nutrient Sensitive Waters (NSW) management strategy. Raleigh, N.C.

Phillips, D. L., P. D. Hardin, V. W. Benson, and J. V. Bagilo. 1993. Nonpoint source pollution impacts of alternative agricultural management practices in Illinois: A simulation study. *J. Soils and Water Cons.* 48(5):449-457.

Reck, W. R. 1994. GLEAMS modeling of BMPs to reduce nitrate leaching in Middle Suwannee River Area. In *Environmentally Sound Agriculture,* Proc. 2nd Conf., 361-367. St. Joseph, Mich.: ASAE.

Reckhow, K. H., J. T. Clemets, and R. C. Dodd. 1990. Statistical evaluation of mechanistic water quality models. *J. Environ. Engng.* 116(2):250-268.

SAS Institute Inc. 1990. *SAS Stat Users Guide*, ver. 6.07, vol. 1 and 2. Cary, N.C.: SAS Institute.

Stone, K. C., P. G. Hunt, S. W. Coffey, and T. A. Matheny. 1995. Water quality status of a USDA water quality demonstration project in the eastern Coastal Plain. *J. Soil and Water Conserv.* 50(5):567-571.

Stone, K. C., K. L. Campbell, and L. B. Baldwin. 1989. A microcomputer model of agricultural stormwater management systems in Florida's flatwoods. *Transactions of the ASAE* 32(2):545-550.

Thomas, D. L, M. C. Smith, M. A. Breve, and R. A. Leonard. 1989. Alternate production systems. In *Proc. CREAMS/ GLEAMS Symp.*, 149-160, 27-29 September 1989, Athens, Ga.: University of Georgia.

U.S. EPA. 1983. Methods for chemical analysis of water and wastes. USEPA-600/4-79-020. eds. J. F. Kopp and G. D. McKee. Cincinnati, Ohio: Environmental Monitoring and Support Lab. and Office of Research and Development.

_________. 1992. *Drinking Water Regulations and Health Advisories.* Office of Water. Washington, D.C.: U.S. EPA.

United States Department of Agriculture and Cooperating State Agencies. 1989. Water quality program plan to support the President's water quality initiative. Washington, D.C.: U.S. GPO.

USDA-NASS. 1995. *Agricultural Statistics.* Washington, D.C.: U.S. GPO.

USDA-SCS. 1959. Soil survey of Duplin County, North Carolina. Washington, D.C.: Soil Conservation Service.

Williams, J. R. and K. G. Renard. 1985. Assessment of soil erosion and crop productivity with process models (EPIC). In *Soil Erosion and Crop Productivity*, 67-103, eds. R. F. Follett and B. A. Stewart. Madison, Wis.: ASA/CSSA/SSSA.

Wu, J. J., D. J. Bernardo, H. P. Mapp, S. Geleta, M. L. Teague, K. B. Watkins, G. J. Sabbagh, R. L. Elliot, and J. F. Stone. 1997. An evaluation of nitrogen runoff and leaching potential in the High Plains. *J. Soil and Water Cons.* 52(1):73-80.

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.

Zublena, J. P., J. C. Barker, J. W. Parker, and C. M. Stanislaw. 1993. Swine manure as a fertilizer source. North Carolina Cooperative Extension Service, Publication Number: AG-439-4. Raleigh, N.C.: North Carolina State Univ.