APPLICATION AND EVALUATION OF THE GLEAMS MODEL TO A CATTLE GRAZING PASTURE FIELD IN NORTH ALABAMA

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Abstract: The GLEAMS (Groundwater Loading Effects of Agricultural Management System, version 3.0) water quality model was used to predict hydrology and water quality and to evaluate the effects of soil types from a cattle-grazed pasture field of Bermuda-Rye grass rotation with poultry litter application as a fertilizer in North Alabama. The model was applied and evaluated by using four years (1999-2002) of field-measured data to compare the simulated results for the 2.71- ha Summerford watershed. R^2 values between observed and simulated runoff, sediment yields, TN, and TP were 0.91, 0.86, 0.95, and 0.69, respectively. EI (Efficiency Index) of these parameters were 0.86, 0.67, 0.70, and 0.48, respectively. The statistical parameters indicated that GLEAMS provided a reasonable estimation of the runoff, sediment yield, and nutrient losses at the studied watershed.

The soil infiltration rates were compared with the rainfall events. Only high intensity rainfall events generated runoff from the watershed. The measured and predicted infiltration rates were higher during dry soil conditions than wet soil conditions. The ratio of runoff to precipitation was ranging from 2.2 % to 8.8 % with average of 4.3 %. This shows that the project site had high infiltration and evapotranspiration which generated the low runoff. The ratio of runoff to precipitation according to soil types by the GLEAMS model appeared that Sa (Sequatchie fine sandy loam) soil type was higher and Wc (Waynesboro fine sandy loam, severely eroded rolling phase) soil type relatively lower than the weighted average of the soil types in the watershed.

The model under-predicted runoff, sediment yields, TN, and TP in Wb (Waynesboro fine sandy loam, eroded undulating phase) and Wc soil types. General tendency of the predicted data was similar for all soil types. The model predicted the highest runoff in Sa soil type by 105 % of the weighted average and the lowest runoff in Wc soil type by 87 % of the weighted average

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Keywords: GLEAMS, water quality, soil, pasture field, runoff, sediment, TN, TP, grass

1. INTRODUCTION

The contamination of surface and ground water from non-point sources is being addressed by many national and state agencies, as well as private and public institutions (Tucker et. al., 2000A). Computer models can simulate numerous management scenarios without actual implementation in order to compare management practices and their effects on NPS pollution. Several models have been developed to predict and assess runoff, sediment yield, and nutrient movements within an agricultural field or a watershed. These models are also used to develop Best Management Practices (BMPs) and other pollution prevention practices.

Models are typically either on a watershed-scale such as the AGNPS (Agricultural Non-point Source) model or a field-scale model such as the GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model. In most NPS models, the hydrology component is the main driving force of the transport of pollutants, sediments, nutrients and pesticides. Therefore, if the hydrology simulation of a model functions reasonably well, the pollutant components are more likely to provide reasonable results.

A field-scale model, GLEAMS that is used for evaluating the impacts of agricultural management practices on water quality was developed by Knisel (1980). The model is a modification of the CREAMS model to simulate edge-of-field and bottom-of-root-zone loading of water, sediment, pesticides, and plant nutrients from the complex climate-soil-management interactions (Knisel, 1993). As a field-scale water quality model that has sediment/erosion yield, hydrology, and chemical submodels, GLEAMS has been validated under different conditions and management practices with varied results (Yoon et al., 1994; Shirmohammadi et al., 1998; Stone et al., 1998; Bakhsh et al., 2000).

Carter et al. (1996) used the GLEAMS model and probability distributions of nitrate concentration to determine appropriate fines for management practices that fail to comply with the water quality standard of 10 mg/l NO_3-N in leached water. The model was also used by Minkara et al. (1995) to predict nitrate concentrations in subsurface water and in the soil profile for an experiment involving poultry litter application treatments to pine seedlings. Sabbagh et al. (1991) developed the EPIC-PST model with the GLEAMS pesticide routines in order to simulate agricultural management practices. In Richmond County of Virginia, Diebel et al. (1992) evaluated low-input agriculture with GLEAMS-estimated nitrate and chemical leaching from the crop root zone. CREAMS-PADDY, a CREAMS based model was developed by Seo et al. (2002) and Chin et al. (2002) to simulate water quality from paddy fields in Korea.

The GLEAMS-IR model was developed by Wedwick et al. (2001) which simulates water quality from surface-irrigated cotton fields in Marana, Arizona. Tucker et al. (2000A & 2000B) used the hydrology components of GLEAMS and REMM (Riparian Ecosystem Management Model) models in a cascaded format to assess the model's capabilities to simulate runoff from upland crop fields through the downslope riparian zone. Chinkuyu and Kanwar (2001) calibrated the GLEAMS model with field data measured by suction lysimeters to predict NO_3-N losses in subsurface drainage under the poultry manure applied fields of continuous corn. Bakhsh and Kanwar (2001) calibarated the nutrient component of the GLEAMS (ver. 2.10) model and validated the model for simulating tillage effects on subsurface drainage water quality.

Although computer models are useful tools for solving water, soil, and field management problems, they need to be validated with field data. This paper presents application and evaluation of the GLEAMS model for simulation of hydrology, sediment yield, and losses of plant nutrients from a pasture field. The specific objectives of this study were to apply the GLEAMS model for prediction of hydrology and water quality, and to evaluate the effects of soil types from a cattle-grazed pasture field of Bermuda-Rye grass rotation with poultry litter application as a fertilizer in north Alabama.

2. THE GLEAMS MODEL

The GLEAMS model is a mathematical, computer-based model developed for use with field-size areas to assess agricultural management effects on water and chemical movements in surface runoff and through the plant root zone (Leonard et al., 1987). The GLEAMS model simulates edge of field and bottom of root zone loadings of water, sediment, pesticides, and plant nutrients from the complex climate soil management interactions. It has evolved through several versions from its inception in 1984 to the present, and has been evaluated in numerous climatic and soil regions of the world (Knisel & Davis, 2000). The model consists of four input components; hydrology, sediment yield, pesticides, and nutrients. The hydrologic component of GLEAMS establishes the foundation for assessing pesticide and/or nutrient movement. The model has been used to develop and assess Best Management Practices (BMPs) and their effects on water quality improvement from agricultural areas.

GLEAMS model allows the input of parameter data and the output of model analysis through the DOS format (Knisel et al., 1993). Input parameters include information on soil profile characteristics, daily rainfall amounts, climatic data, crop cover, field geometry, and land management practices. The model allows the user to specify the frequency of model output and changes in input over the designated simulation period. During a prolonged model run, parameters that affect hydrology dynamics, such as crop rotations and irrigation applications, can be updated. Hydrologic outputs can be assessed over days, months, years, or individual storm events. The GLEAMS model is being used extensively around the world and has been verified under many different physiographic conditions and compared to many other models (Reyes and Cecil, 1997; Smith et al., 1991; Ma et al., 1998; Shirmohammadi and Knisel, 1994; Tucker et al., 2000A and 2000B). However, there are limited applications of the model to cattle-grazing pasture fields in the southeastern USA.

3. MATERIALS AND METHODS

3.1 Project Watershed

This study was conducted at the Summerford watershed, a cattle-grazing pasture field located near the Danville City, Morgan County in north Alabama, USA (Figure 1). The total watershed area is about 2.71ha. The watershed is covered with perennial pastures that include: Bermudagrass and Ryegrass. The soil types were Abernathy fine sandy loam (Aa), Sequatchie fine sandy loam (Sa), Waynesboro fine sandy loam eroded undulating phase (Wb) and Waynesboro fine sandy loam severely eroded rolling phase (Wc). The watershed is currently under Best Management Practices (BMPs) that include:

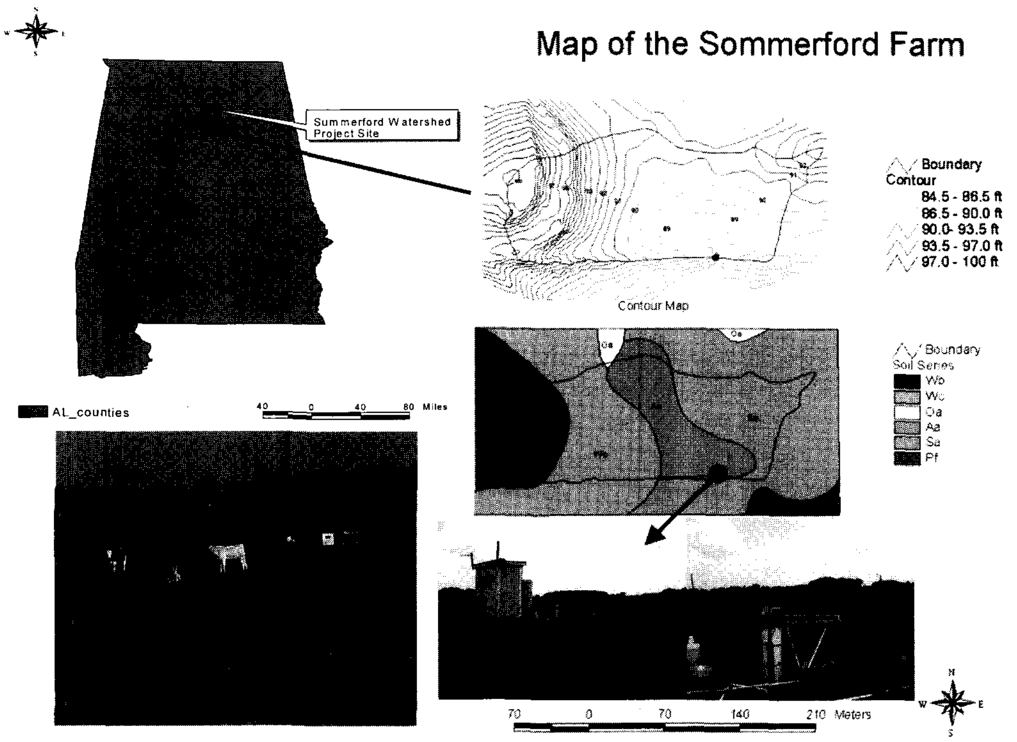

Figure 1. Location map and cattle grazing pasture of the Summerford watershed

stream line fencing, rotational grazing, haying, fertilization (chicken litter), and vegetation.

The instrumentation site was located near the channel outlet of the watershed (Figure 1). Two rain gages (1/100th inch and 1/10th mm sensors) were installed and connected to a CR10X datalogger (CSI, Logan, Utah). Two rain gages were used to collect rainfall data with the idea that when one rain gage fails the other one collects back up data. The wind-blowing dusts, and grass cutting activities in the watershed often clog the orifice of the rain gages. The CR10X datalogger was programmed to collect 15-minute interval rainfall. The CR10X was also programmed to collect daily ambient temperatures. The Palm m105 series PDA (Palm, Inc. Santa Clara, CA) was used to download data from the CR10X datalogger.

The runoff from the watershed was diverted through a 60-cm H-flume (Figure 1). The CR10X datalogger records the water level changes in the flume by sensing the rotational position of a potentiometer. The potentiometer rotates according to the position of a float in the stilling well which maintains the same water level as that in the flume. Once the runoff passes through the H-flume, it is routed through a small trapezoidal shape basin where a suction tube is connected to the ISCO 3700 sampler (ISCO, Inc. Lincoln, NE). After a rainfall is detected by the datalogger and the potentiometer reading reaches greater than the standard level in the flume (potentiometer reading at the bottom of the flume) the sampler starts pumping. The sampler was programmed to collect 20 ml per sample every three-minute interval during runoff events. The runoff collected in the ISCO sampler was vigorously stirred and collected in a 1-litter bottle and brought to a local chemistry laboratory (ENERSOLV, Decatur, AL). The laboratory determined water quality parameters that include; Total Suspended Solids (TSS), Ammonia Nitrogen (NH_3N), Nitrate and Nitrite (NO_3+NO_2), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), and Total Nitrogen (TN).

3.2 Hydrologic Characteristics

There were about one hundred and ninety one storm events recorded which were greater than 5 mm per event. However, only eleven runoff events were recorded at the Summerford watershed. Runoff events which were not recorded due to a system failure were not included in this number. Therefore, for analyzing hydrologic characteristics of the project site, infiltration rates in the watershed were evaluated because low runoff events were observed from the project site.

Infiltration tests at three randomly selected locations in the watershed were conducted during wet and dry soil conditions using double ring infiltrometers. Each site of infiltration test had three replications. The tests followed the ASTM standard (ASTM, 1990) of the double ring infiltrometers. Nine data sets were used in the infiltration rate prediction using a regression analysis based on the Kostiakov's infiltration equation. The soil samples were taken from the nine locations to determine the soil moisture conditions. The soil infiltration rates were compared with the rainfall events as shown in Figure 2. It shows that only high intensity rainfall events generated runoff from the watershed. The high infiltration rates in the watershed have been due to the mature pasture condition, good water holding capacity of the soil and mild slope of the watershed.

Surface runoff (about 102.16 m^3 discharge)

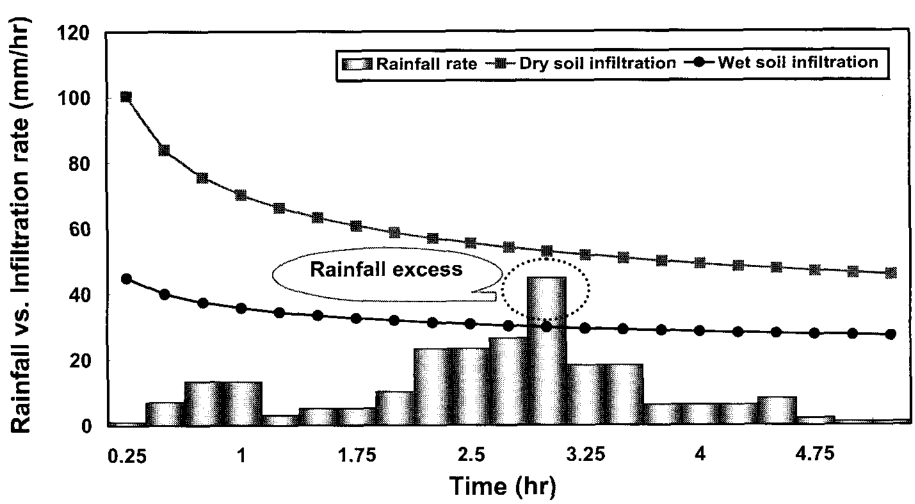

Figure 2. Rainfall vs predicted infiltration rates for 09/09/2001 storm event under the wet and dry soil conditions (total amount of rainfall was 60.71 mm).

was recoded during the wet soil condition in rainfall intensity vs. infiltration rate. The observed data showed about 22.86 m^3 discharge for this storm event. When compared with the average of wet and dry soil conditions the discharge was estimated as 23.24 m^3 which was very close to the observed data. The total 5 days antecedent rainfall was 0.00 mm. However, the 9 days antecedent rainfall was 91.44 mm. The infiltration tests were conducted right after about 26.92 mm (wet soil condition) and 1.01 mm (dry soil condition) of 5 days antecedent rainfall condition. The soil moisture contents during the infiltration tests were 17.15 % and 13.18 % for wet and dry soil moisture condition, respectively. The recorded average water holding capacities of the soil at the test site were 30.64 % and 32.38 % for the two tests respectively (Prem, 2003).

3.3 Model Parameters

The GLEAMS model requires daily precipitation and mean temperature to determine whether precipitation is rain or snow (Bakhsh & Kanwar, 2001). The hydrology parameters require mean monthly maximum temperature, minimum temperature, solar radiation, wind speed, and dew point temperature data. Temperature data measured at the study site were used in this simulation. Mean monthly data for solar radiation, dew point, and wind speed were obtained from a National Weather Service site in Cullman, north Alabama, which locates 30 km from the project site. The period from 1999 through 2002 was chosen for the simulation.

Combination of Bermudagrass-Ryegrass is the current pasture management practice. The parameter values for Bermudagrass-Ryegrass rotation were selected from GLEAMS user's

Table 1. Soil properties for hydrology parameter file at the project site

Soil Name (Area,%)	Texture	Soil Depth (in)	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	Porosity (in^3/in^3)	Field Capacity (in^3/in^3)	Wilting Point (in/in)	Saturated Conductivity (in/hr)	K factor
Aa	SIL[1]	16	9.05	64.45	26.50	2.50	0.43	0.32	0.12	1.10	0.37
(26.4)	SICL[2]	28	7.16	65.34	27.50	0.00	0.47	0.36	0.20	1.10	0.37
	SICL	60	7.65	56.35	36.00	0.00	0.47	0.36	0.20	1.10	0.37
Sa	FSL[3]	10	63.15	19.35	17.50	2.00	0.36	0.27	0.08	1.10	0.32
(25.0)	L[4]	54	39.03	36.97	24.00	0.25	0.40	0.26	0.11	1.10	0.24
	L	60	42.96	38.54	18.50	0.25	0.40	0.26	0.11	1.90	0.24
Wb	FSL	7	61.61	18.89	19.50	1.25	0.36	0.27	0.08	1.10	0.28
(12.4)	SCL[5]	27	53.94	17.06	29.00	1.25	0.40	0.30	0.18	1.10	0.28
	SC	60	49.82	7.68	42.50	1.25	0.40	0.28	0.20	1.10	0.28
Wc	FSL	7	61.61	18.89	19.50	1.25	0.36	0.27	0.08	1.10	0.28
(36.2)	SC[6]	60	49.82	7.68	42.50	1.25	0.40	0.28	0.20	1.10	0.28
Weighted		10	48.12	31.03	20.85	1.77	0.38	0.28	0.09	1.10	0.31
Average		34	37.86	34.78	27.36	0.67	0.42	0.31	0.17	1.10	0.29
(WA)		60	36.97	28.24	34.79	0.67	0.42	0.30	0.18	1.30	0.29

[1)-6)] denote silt loam, silt clay loam, fine sandy loam, loam, sandy clay loam, and sandy clay.

manual for the hydrology input parameter. A runoff Curve Number (CN) of 69 was used for non-contoured pasture considering the soil texture of the project site.

As stated above, the soils in the watershed are Aa, Sa, Wb and Wc. The parent materials for these soils are described as: Aa (Local colluvium and alluvium from uplands under-lain by limestone and sandstone), Sa (General alluvium derived mainly from land underlain by sandstone but some shale), and Wc (General alluvium from uplands underlain chiefly by sandstone). However, the GLEAMS model uses only a single soil type. Thus, the soil parameters of the model used weighted average (WA) of the four soil types. The parameter values for the soil layers used in the hydrology input file are shown in Table 1.

The nutrient component of GLEAMS and the associated parameters allow users to make a generalized application with model-initialized values or to use site-specific user-defined parameter values (Yoon et al., 1994). Nutrient parameters were selected from the GLEAMS user's manual. The rate of poultry litter application as a fertilizer was 2,242 kg/ha at the study site.

4. RESULTS AND DISCUSSION

4.1 Application of the GLEAMS model

Measured hydrologic and water quality data were used to compare the model simulation of runoff, sediment yield, TN, and TP as daily basis from 1999 through 2002 depending on availability of the observed data. The weighted average values of soil types were selected as soil parameters and Bermudagrass-Ryegrass was used as an existing annual pasture vegetation type. Parameters of the GLEAMS model were calibrated using RMSE (Root Mean Square error) and RMAE (Root Mean Absolute Error), and verified with the measured hydrologic and water quality data.

Figure 3 shows comparison between the observed and the simulated runoff according to hydrologic conditions from the runoff curve numbers for hydrologic soil-cover complexes of antecedent moisture condition Ⅱ (CN2). The runoff curve numbers used for poor, fair, and good hydrologic conditions of the studied site

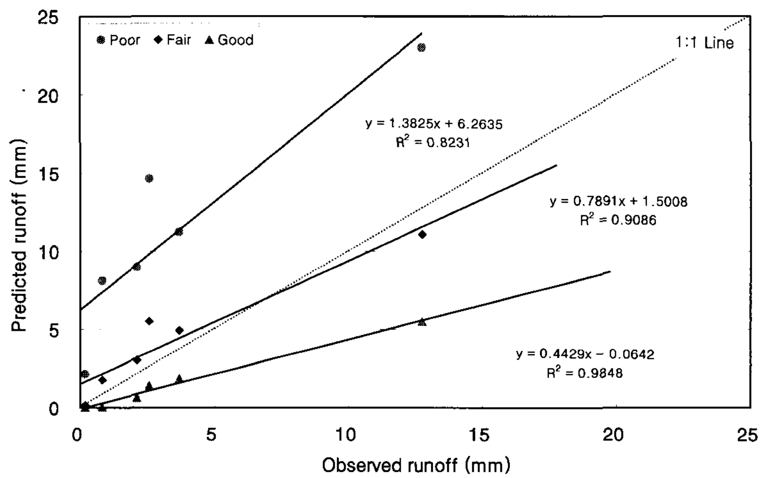

Figure 3. Comparison between the observed and the simulated runoff at the project site

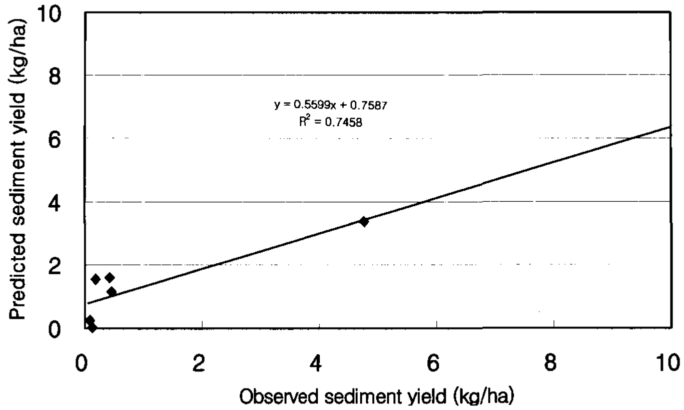

Figure 4. Comparison between the observed and the simulated sediment yield

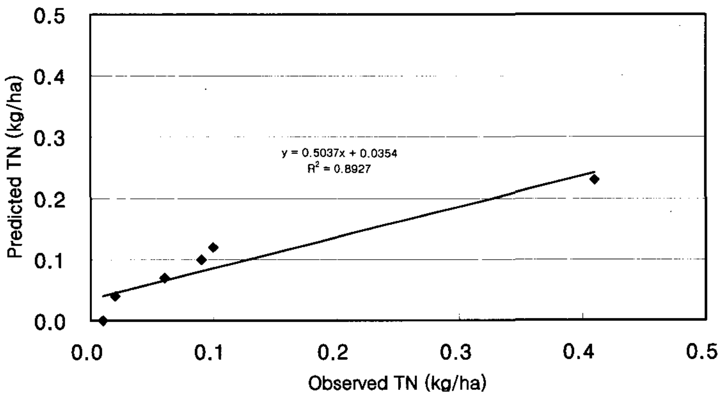

Figure 5. Comparison between the observed and the simulated TN

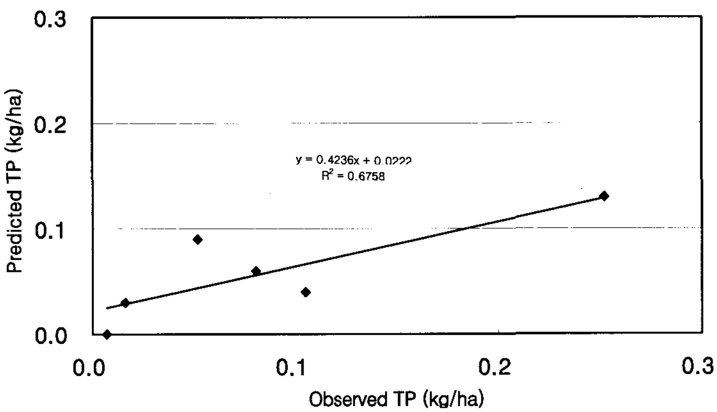

Figure 6. Comparison between the observed and the simulated TP

were 79, 69, and 61, respectively. R^2 values between the observed and simulated results were 0.82, 0.91, and 0.98, respectively. The high R^2 values indicate that the hydrology of GLEAMS model was reasonably simulated for all hydrologic conditions. The fair hydrologic condition in this study was selected to apply the model.

Comparisons between the observed and the simulated sediment yields and nutrient losses for application periods are shown in Figures 4 to 6. The model adequately represented the daily variations of sediment yield, TN, and TP. R^2 values of sediment yield, TN, and TP were 0.75, 0.89, and 0.68, respectively between the observed data and simulation. The results shown in Figures 4 to 6 indicate that the GLEAMS model underestimated sediment yield, TN, and TP under high runoff conditions, and overestimated under low runoff conditions.

4.2 Evaluation of the GLEAMS model

The statistical measures such as RB (Relative Bias), RMSE (Root Mean Square error), RMAE, EI (Nash-Suttcliffe Efficiency Index, Nash and Suttciffe, 1970) and R^2 (coefficient of determination) were used to evaluate the model simulation.

RB is a measure of systematic error in the forecast. It measures the degree to which the prediction is consistently above or below the actual values. RMSE and RMAE are measures that incorporate both systematic and random errors. R^2 is the square of the correlation coefficient between the observed and predicted values. If the R^2 and EI values are less than or very close to 0.0, the model prediction is considered unacceptable or poor. If the values are 1.0, then the model prediction is perfect (Santhi et al., 2001). Ramanarayanan et al. (1997) suggested that model prediction is acceptable or satisfactory if R^2 and EI values are greater than 0.6 and 0.5, respectively.

Although R^2 is widely used as a measure of prediction accuracy, care must be taken if appreciable bias is present since R^2 evaluates the accuracy of a prediction with respect to random error only (Maidment, 1993). For this reason the prediction accuracy was assessed by using RB, RMSE, RMAE, and EI together.

Table 2 summarizes RB, RMSE, RMAE, EI and R^2 values between the observed and the simulated runoff, sediment yield, and nutrient losses during the study period. RB values between the observed and the simulated runoff,

Table 2. Summary of daily results of runoff, sediment yield, and nutrient.

Item	RB [1] (%)	RMSE[2] (kg/ha)	RMAE[3] (kg/ha)	EI[4]	R^2
Runoff (mm)	19.70	1.56	0.35	0.86	0.91
SY[5] (kg/ha)	31.46	0.98	0.81	0.67	0.75
TN[6] (kg/ha)	-18.84	0.07	0.36	0.70	0.89
TP[7] (kg/ha)	-31.37	0.06	0.51	0.48	0.68

[1] Relative bias, [2] Root mean square error, [3] Root mean absolute error

[4] Efficiency index, [5] Sediment yield, [6] Total nitrogen, [7] Total phosphorus

Table 3. GLEAMS simulated runoff, sediment yield, TN, and TP in different soil type conditions

Items	Observed	Simulated				
		WA	Aa	Sa	Wb	Wc
Runoff (mm)	2.10	3.36	2.70	3.36	3.48	3.53
	0.18	0.25	0.10	0.22	0.17	0.03
	12.75	12.02	11.35	11.75	11.05	8.97
	3.68	5.44	5.02	5.29	4.89	3.73
	2.56	5.60	5.86	5.50	5.28	4.76
	0.81	1.79	2.15	1.72	1.62	1.32
Sediment yield (kg/ha)	0.45	1.16	0.49	1.51	1.30	1.31
	0.13	0.05	0.01	0.04	0.02	0.00
	4.77	3.41	3.14	3.79	3.32	3.30
	0.42	1.90	0.55	1.99	1.71	1.15
	0.18	1.62	0.92	1.62	1.44	1.14
	0.09	0.25	0.35	0.24	0.22	0.20
TN (kg/ha)	0.06	0.08	0.07	0.08	0.08	0.08
	0.01	0.00	0.00	0.00	0.00	0.00
	0.41	0.24	0.23	0.24	0.21	0.17
	0.09	0.11	0.10	0.11	0.09	0.07
	0.10	0.12	0.13	0.12	0.11	0.10
	0.02	0.10	0.05	0.04	0.03	0.03
TP (kg/ha)	0.10	0.04	0.03	0.03	0.03	0.03
	0.01	0.00	0.00	0.00	0.00	0.00
	0.25	0.14	0.12	0.14	0.13	0.11
	0.08	0.07	0.04	0.06	0.06	0.05
	0.05	0.10	0.09	0.09	0.09	0.07
	0.02	0.03	0.03	0.03	0.03	0.03

Table 4. The average GLEAMS annual prediction during the study period (1999-2002) for different soil types (Average, minimum, and maximum rainfall were 1131, 919, and 1258 mm, respectively).

Soil type	Item	Runoff (mm)	Ratio of runoff to rainfall (%)	Sediment (kg/ha)	TN (kg/ha)	TP (kg/ha)
WA	Average	49.6 (100)*	4.40 (100)	13.4 (100)	0.91 (100)	0.60 (100)
	Min/Max	20.9/96.4	2.3/8.4	4.5/26.8	0.30/1.74	0.19/1.06
Aa	Average	50.1 (101)	4.44 (101)	11.2 (83)	0.91 (100)	0.53 (89)
	Min/Max	20.3/94.2	2.2/8.4	4.5/22.3	0.27/1.72	0.15/0.17
Sa	Average	51.9 (105)	4.60 (105)	15.6 (117)	0.93 (103)	0.64 (108)
	Min/Max	21.8/98.8	2.4/8.8	4.5/31.2	0.29/1.82	0.17/1.18
Wb	Average	49.6 (100)	4.40 (100)	13.4 (100)	0.86 (95)	0.56 (95)
	Min/Max	21.6/95.5	2.4/8.5	4.5/26.8	0.27/1.69	0.16/1.03
Wc	Average	43.0 (87)	3.80 (87)	11.2 (83)	0.74 (82)	0.48 (80)
	Min/Max	20.7/84.9	2.3/7.6	4.5/22.3	0.26/1.50	0.15/0.89

A blacketed passage means the rate of WA soil type condition.

sediment yield, TN, and TP were 19.7, 31.46, -18.84, and –31.37, respectively. The minus RB values of TP and TN indicate that the GLEAMS model underestimated nutrient losses as a whole. The RMSE and RMAE values between the observed and simulated items range from 0.06 to 1.56 and from 0.35 to 0.81, respectively. EI values of runoff, sediment yield, TN, and TP were 0.86, 0.67, 0.70, and 0.48, respectively. The predicted runoff and water quality parameters appeared to be reasonable compared to the observed data.

4.3 Effects of Soil Types

Effects of soil types on the water quality parameters simulated by the GLEAMS model were evaluated for the five soil types (WA, Aa, Sa, Wb, and Wc). The model predicted results for each soil type in different storm events and their comparisons with observed data were analyzed as summarized in Table 3. The model under-predicted runoff and other components in Wb and Wc soil types. General tendency of the predicted data was similar to all soil types.

Table 4 shows the average runoff, sediment yields, TN, and TP of the GLEAMS annual prediction during the study period (1999 to 2002) for different soil types. Average predicted runoff rates were 49.6, 50.1, 51.9, 49.6, and 43.0 mm in WA, Aa, Sa, Wb, and Wc soil types, respectively. Sa soil type predicted the highest runoff by 105 % of that of WA and the lowest runoff by 87 % in Wc soil type condition. The ratio of simulated runoff to precipitation ranged from 2.2 % to 8.8 % with the average of 4.3 %. This demonstrates that the project site had high infiltration and evapotranspiration which generated the low runoff. The simulation results follow the low runoff characteristics of the study site. The ratio for Sa soil type was higher than that for the weighted average (WA) of the soil types. It is reverse for Wc soil type. The magnitudes for sediment yields, TN and TP followed those of runoff.

5. CONCLUSIONS

The GLEAMS water quality model was used to predict hydrology and water quality parameters and to evaluate the effects of soil types from a cattle-grazed pasture watershed of Bermuda-Rye grass rotation with poultry litter application as a fertilizer in north Alabama. The model was applied and evaluated by using four years (1999-2002) of field-measured data to compare the simulated results for the 2.71 ha Summerford watershed.

The soil infiltration rates were compared with the rainfall events. It seems that only high intensity rainfall events can generate runoff from the watershed. The measured and predicted infiltration rates were higher during dry soil conditions than wet soil conditions. The high infiltration rates in the watershed may have been due to the good pasture condition, good water holding capacity of the soil and mild slope of the watershed.

Evaluation of the model simulation used the following statistical parameters; Relative Bias (RB), RMSE, RMAE, Nash-Suttcliffe Efficiency Index (EI) and coefficient of determination (R^2). The results of R^2 for runoff, sediment yield, TN, and TP were 0.91, 0.86, 0.95, and 0.69, respectively. EI of runoff, sediment yield, TN, and TP were 0.86, 0.67, 0.70, and 0.48, respectively. The statistical parameters indicated that GLEAMS provided a reasonable prediction of the runoff, sediment yield, and nutrient losses from the studied watershed.

Yearly ratio of runoff to precipitation according to soil types such as Aa, Sa, Wb, Wc, and weight average of the soil types (WA) was predicted by the GLEAMS model. The ratios ranged from 2.2 % to 8.8 % with the average of 4.3 %. This shows that the project site had high infiltration and evapotranspiration which generated the low runoff. The ratio for Sa soil type was higher and that for Wc soil type was relatively lower than that of the weighted average (WA).

The predicted results for each soil type in different storm events and their comparison with observed data are presented. The model under-predicted runoff and other parameters for Wb and Wc soil types. General tendency of the predicted data was similar to all soil types. The model predicted the highest runoff for Sa soil type by 105 % of the weighted average (WA) and the lowest runoff by 87 % for Wc soil type. The magnitudes for sediment yields, TN, and TP followed those of runoff.

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