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APPLICATION OF WEPP AND AGNPS TO A CATTLE GRAZING PASTURE WITH POULTRY LITTER APPLICATION AS A FERTILIZER

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Water quality impairment in many streams and water bodies in the United States is primarily the result of non-point source pollution from agricultural watersheds. Water quality computer simulation models can assess the impact of cattle grazing pasture management practices on water quality. This study applied the single-event mode of the Agricultural Non-Point Source (AGNPS) and the Water Erosion Prediction Project (WEPP) models to simulate surface runoff and sediment yields from a grazed watershed (2.71 ha) in north Alabama. The models were used to evaluate three pasture vegetation types (Bermuda grass, fescue, and ryegrass) to recommend the best pasture vegetation type used in this study. Runoff samples collected from eleven storm events from January 1999 to September, 2003 were analyzed and compared with the antecedent moisture condition for AGNPS and initial saturation level for WEPP based model prediction. The AGNPS and WEPP models reasonably predicted surface runoff and sediment yields in this study.

INTRODUCTION

Non-point source pollution (NPS) is usually influenced by several factors including rainfall, runoff and infiltration. Runoff from rainfall picks up and carries diffuse sources of pollutants resulting from human activities and ultimately discharges them into streams and rivers. The potential of sediment delivered to streams from agricultural watersheds is still a challenge for many scientists (EPA, 2005). In 1997, it was estimated that about 1.9 billion metric tons of soil were lost in the United States each year through the processes of wind and water erosion. About 70% of the total soil loss was eroded from agricultural land (USDA-SCS, 1987).

Alabama is one of the largest poultry producing states in the U.S. (Moore et al., 1995). More than 4 million broilers and layers are produced annually by the poultry industry in Alabama (USDA-NASS, 2005). Approximately 2 million metric tons of poultry litter are produced each year. One major use of poultry litter is to apply in to pastureland (Donald et al., 2005). Land application of poultry litter may increase soil quality, water holding capacity and crop yield. However, litter application also increases nutrient losses from pastureland that may pollute surface waters. Computer simulation models that predict soil erosion and nutrient losses from pasture and agricultural fields are effective tools used for soil conservation planning and design (USDA-ARS, 2002). It is not easy to monitor the influence of agricultural management practices in all ecosystems and climatic conditions. Erosion prediction tools are mainly used to rank alternative agricultural practices with regard to their impact on water quality. Modeling soil erosion is a process of mathematically describing detachment, transport, and deposition of soil on land surfaces (Laflen et al., 1991).

The WEPP (Water Erosion Prediction Project) model contains various input options to simulate different watershed conditions. The model requires detailed input for soil, slope, management, and climate and uses a steady-state sediment continuity equation to describe the movement of sediments. The hydrologic processes of the WEPP model include infiltration, runoff routing, soil evaporation, plant transpiration, snowmelt, and seepage. The model maintains a continuous water balance on a daily basis.

The current version of the AGNPS (Agricultural Non Point Source) model is an ArcView-GIS Interfaced water quality simulation model. This is an advanced version of the AGNPS model which was originally developed for single storm-based simulation of runoff, sediment and nutrient losses. The AGNPS model can extract data from the digital elevation model (DEM) and the AGNPS Input Editor allows users to directly import the extracted data. The hydrology of the AGNPS model is based on a water balance equation, which is based on a simple bookkeeping of daily inputs and outputs of water movement. The model uses the Natural Resources Soil Conservation Service (NRCS) curve number (CN) method (USDA, 1972) to calculate runoff based on a function of water input to soil and maximum potential difference between rainfall and runoff. The amount of soil moisture is used to determine the effects of the NRCS curve number on runoff and is thus the basis for the surface and subsurface runoff simulation in the model. The surface runoff calculated in each grid cell is routed through the watershed based on flow directions from one grid cell to the next until it reaches the drainage outlet. Soil erosion is calculated by the RUSLE (Revised Universal Soil Loss Equation) which is based on whether there has been any runoff in each day. The nutrient losses are calculated using a chemical routing equation.

The WEPP and AGNPS models require input parameters be specified in detail to predict results more accurately. Input data including vegetation and soil types may not be readily found to describe specific field conditions in the models. In many cases the models use interpretations from other measurable data. As a consequence, crop data, vegetation data and soil archives have been developed in these models. The cover crop management conditions allow users the flexibility to hypothesize different alternative crops and field operations to assess the effectiveness of different vegetation types and to select the Best Management Practices (BMPs).

The AGNPS model has been applied and validated in many parts of the United States. Validation of the AGNPS model for sediment and runoff was shown by Koelliker and Humbert (1989) for five watersheds in Kansas. Hession and Huber (1989) evaluated the AGNPS model (v. 3.51) for its reliability in assessing BMP effectiveness on a monitored watershed by comparing pre-BMP, post-BMP and 100% forested conditions. Evaluation was not performed on specific storm events, but by using design storms ranging from 25.40 mm to 152.40 mm for 1, 2, 5 and 10-year events. Input parameters were selected to reflect average conditions. The 1,157 ha watershed contained five livestock producers, with only one using an animal waste storage facility, and excessive field applications of manure for pre-BMP conditions. Post-BMP included waste facilities for all animal operations and nutrient management plans to reduce fertilization to recommended application rates. The model was not validated using field monitored data, but simulation showed that the state program's 40% nutrient reduction goal could be met with full implementation of BMPs.

Bingner et al. (1989) tested the AGNPS model in three small watersheds and presented variable results. The predicted total annual runoff was varied from 65% to 151% of observed. Mitchell et al. (1993) studied the model for 50 rainfall-runoff events in which 25 events were used for calibration and 25 events for validation. The arithmetic mean values of observed and predicted data were about 87% deviated. However, individual event values were deviated as high as 1400%. Srinivasan and Engel (1994) compared 13 observed and predicted rainfall-runoff events with the AGNPS model and found that the predicted runoff volumes were underestimated for all events. Grunwald and Norton (1999) applied the AGNPS model to two watersheds (120 ha and 160 ha) in Germany. A poor Nash Sutcliffe coefficient of efficiency (EI) of 0.25 for small watershed runoff and 0.24 for large watershed runoff were reported. The EI values of the predicted sediment yield were found higher (0.57) for the large watershed than that of the small watershed (0.26).

Kirnak (2001) compared the erosion and runoff predicted by the WEPP and AGNPS models using a GIS. The study was conducted for the Rock Creek watershed located in Seneca County, Ohio. The WEPP and AGNPS models produced reasonable results with average surface runoff with R^2 of 0.9 and 0.925, respectively and average sediment yield with R^2 of 0.92 and 0.935, respectively. The AGNPS model under-predicted average runoff and sediment yields by 17.50% and 17%, respectively, whereas the WEPP model over-predicted the same parameters by 19.22% and 37.25%, respectively, when compared to the average observed runoff and sediment yields of 17.95 m^3 s^{-1}, and 911.61 metric tons, respectively. The t-test showed that there were no statistically significant differences between model predictions and observed data at the 5 % level.

Bhuyan et al. (2003) applied the single event AGNPS model to the Red Rock Creek watershed in Kansas. The Curve Number (CN) method CN_{II} used in the AGNPS model overestimated (overall average >54%) the runoff depth for 19 out of 23 runoff events. The antecedent moisture condition (AMC_2) used in the model was not a reasonable assumption for the watershed and storm events. The actual AMC conditions were estimated and used to develop model prediction for all 23 storm events. The overall average model overestimation was reduced to about 4%. Leon et al. (2004) applied the AGNPS model to the Duffins Creek watershed in Southern Ontario, Canada. The single event mode of the model was found to be highly sensitive to antecedent moisture conditions in predicting surface runoff and sediment yields from the watershed. However, the model appeared to be well suited for application in Southern Ontario.

OBJECTIVES

The objectives of this study were to; 1) measure runoff, sediment, and nutrient losses from the watershed, 2) simulate single-storm based runoff and sediment losses using the WEPP and AGNPS water quality simulation models, and 3) compare the simulation results with the observed data to evaluate the model performance.

MATERIALS AND METHODS

Study Area

This study was done at the Summerford watershed located near the city of Danville in Morgan County in North Alabama (Figure 1). The Summerford watershed (2.7 ha) is a cattle grazing field with the average slope of approximately three percent as determined by the digital elevation model (DEM). The elevation of the watershed ranges from 179 m to 187 m above mean sea level.

Watershed Management

The watershed has been covered by perennial grasses for more than 20 years. The watershed is managed as perennial grassland with rotational grazing practices for about 135 days yr^{-1} during the growing season (July to November). The stocking rate at the watershed was 3 heads ha^{-1} on average.

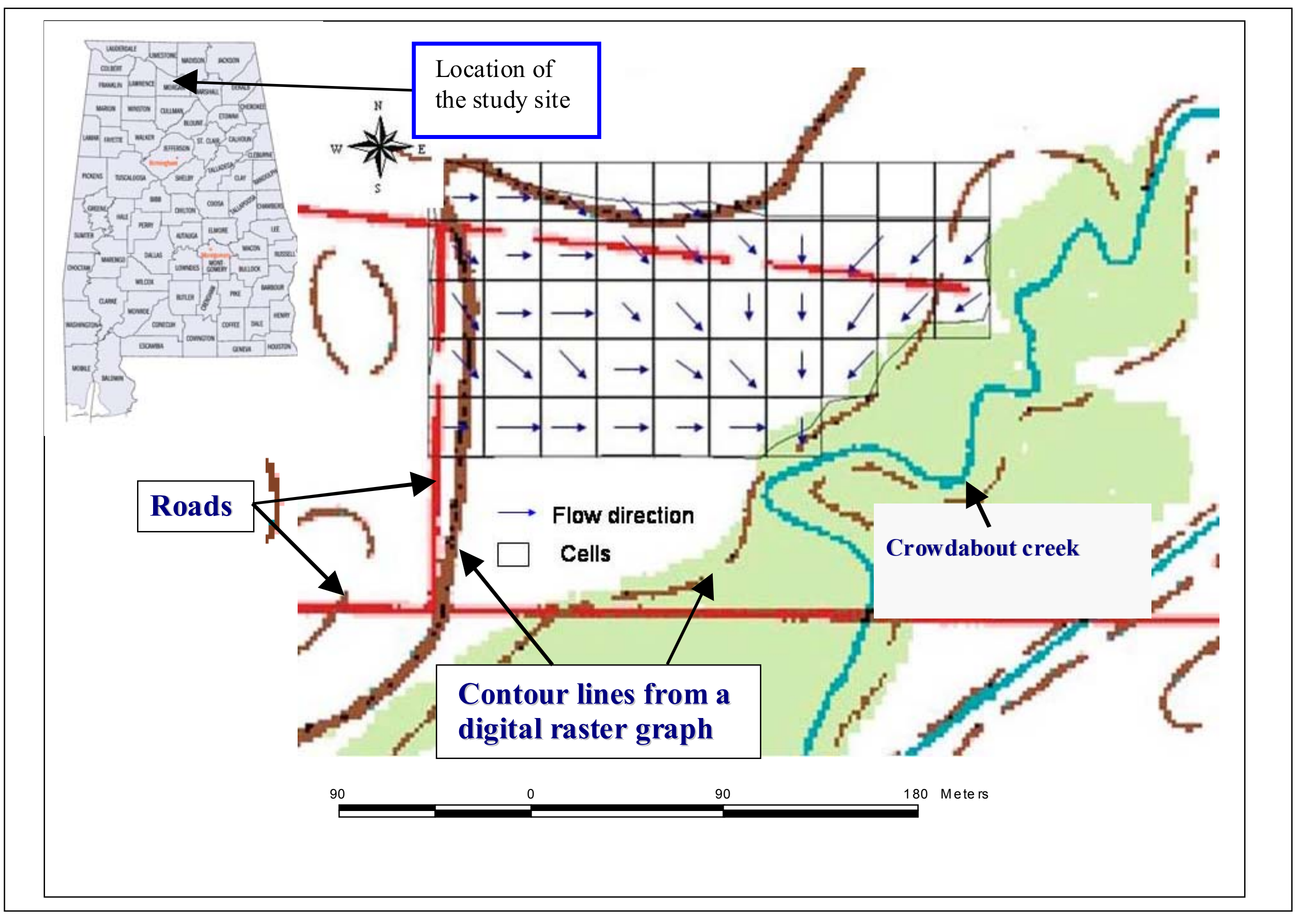

Figure 1. Location of the study area overlaid on a digital raster graph map of the watershed.

The manure deposition due to cattle grazing in the pastureland was not considered in this study for modeling. The poultry manure is broadcast applied in the watershed at about 2,242 kg ha^{-1} two times per year. The combination of Bermuda grass and ryegrass are the existing pasture grasses in the watershed that produces about 51,870 kg $ha^{-1}year^{-1}$ of hay yield (Summerford , 2003).

The soil orders and suborders of the watershed in Soil Taxonomy are Ultisols and most likely Udults, respectively. The soil series are Abernathy Fine Sandy Loam (Aa), Sequatchie Fine Sandy Loam (Sa), and Waynesboro Fine Sandy Loam (Wc) severely eroded undulating phase (USDA, NRCS, 1958).

Instrumentation and Data Collection

The runoff from the study watershed drains into the Crowdabaut Creek, a tributary of the Flint Creek. The instrumentation site was located near the channel outlet of the watershed before it drains into the stream. The runoff from the watershed was directed through a 0.60-m H-Flume with a stilling well. A potentiometer attached to the pulley observed the position of a float, which changed according to the flow depth through the flume and recorded these data on a CR10X datalogger (Campbell Scientific, Inc., Logan, Utah). The data were later analyzed to calculate flow rates. Runoff was routed through a small bucket (200 mm by 50 mm metal box) where a liquid actuator (ISCO model 1640, ISCO, Lincoln, Nebraska) was placed. When the liquid actuator sensed runoff water in the bucket, the ISCO 3700 runoff sampler was activated to collect runoff samples. Two rain gages (0.01 inch and 0.1 mm sensors) were installed and connected with the CR10X datalogger. There were 196 precipitation events which were greater than 5mm from January, 1999 to September, 2003, but only eleven runoff events were recorded. Some runoff events were not recorded due to system failures and other uncontrollable problems in the field. The ISCO sampler was checked after every storm event for collecting a runoff sample. The collected runoff in the ISCO sampler was well mixed before sampling up to 1.0 L in a sampling bottle for laboratory analysis. The samples were kept in a cooler box and then taken to a chemistry lab (ENERSOLV, Decatur, Alabama) nearby the watershed site. Runoff samples were analyzed by ENERSOLV (Table 1). The water quality parameters analyzed included; TSS (total suspended solids), NH_3-N (ammonia nitrogen), NO_2+NO_3-N (nitrite and nitrate), TKN (total Kjeldahl nitrogen), TP (total phosphorus), and TN (total nitrogen). The samples were analyzed according to the method recommended by the U.S. EPA (U.S. EPA, 1983) and the laboratory maintains the EPA approved QA/QC program.

Simulation of WEPP and AGNPS

The WEPP model includes soil and crop management input data. The soil archives of the WEPP model provide soils data, including soil name, soil texture, albedo, initial saturation level, erodibility, depth of each soil layer and % clay, sand and rock. The WEPP management data provide crop management data including crop type, grass type, tillage systems and tillage depth. Three hill slopes were used for the Summerford watershed. The WEPP model contains the CLIGEN climate generator computer model, but break-point rainfall data collected at the field were used for simulation of single storm events. Since the WEPP model does not predict nutrient losses, the results were compared only with the observed surface runoff and sediment yields.

The Summerford watershed was too small to extract an accurate watershed boundary from the DEM data. In this study, the required data to layout the watershed boundary were built into the Input Editor (v. 3.42) of the AGNPS model to run the single storm event mode of the AGNPS model.

Table 1. Observed water quality parameters.

Sampling Dates	TSS[a]	NH_3N[b]	TKN[c]	NO_3N+NO_2N[d]	TP[e]	TN[f]
M/D/Y	mg/L					
01/15/1999	20.00	0.32	2.40	0.24	4.60	2.64
01/24/1999	56.00	0.34	3.20	0.25	3.20	3.45
05/06/1999	60.00	0.78	3.60	0.65	7.00	4.25
12/16/2000	72.00	1.40	5.60	0.23	3.60	5.83
01/21/2001	36.00	0.63	2.90	0.23	1.90	3.13
03/21/2001	11.00	0.21	2.20	0.15	2.10	2.35
08/10/2001	7.00	0.22	3.20	0.65	2.00	3.85
09/09/2001	10.50	0.53	1.80	0.72	1.90	2.52
12/13/2001	11.00	0.23	1.50	0.28	1.50	1.50
08/31/2003	18.00	NA	NA	NA	2.72	2.64
09/21/2003	8.00	0.10	1.40	0.29	1.70	1.69

a	TSS = Total Suspended Solids	b	NH_3N = Ammonia Nitrogen
c	TKN = Total Kjeldahl Nitrogen	d	NO_3N+NO_2N = Nitrate and Nitrite
e	TP = Total Phosphorus	f	TN = Total Nitrogen

This is another way to use the current version of the Input Editor when the watershed size is small and the model is not able to accurately delineate watershed boundaries (Bingner R., personal communication, 2003). Forty data cells (26m x 26m each) were developed to describe the watershed boundary in the Input Editor with each cell containing 0.0676 ha (Figure 1). Average elevation and soil information for each cell were provided based on the DEM and the SSURGO (Soil Survey Geographic Database) soil data. Time of concentration for runoff, average slope and LS factor of the RUSLE model for each cell were also calculated and input to the Input Editor. Data for three soil types (Aa, Sa, Wc) were extracted from the SSURGO soil database using MUFF (map unit user's file) tool to input to the Input Editor based on the guidelines provided by Baumer et al. (1994).

Data Analysis and Evaluation

The AGNPS and WEPP model response was evaluated based on 11 observed runoff events data from the watershed. The statistical analysis of data will include: (a) mean, (b) standard deviation, (c) coefficient of determination (R^2), and (d) Nash Sutcliffe Efficiency Index (EI) (Nash and Sutcliffe, 1970). The mean and standard deviation describe the average value, and range of variation respectively. The R^2 value indicates how consistently observed vs. predicted values follow a best fit line. If the R^2 values are less than or very close to zero, the model prediction is considered unacceptable or poor. If the value is 1.0, the model prediction is perfect (Santhi et al., 2001). The Nash-Sutcliffe Efficiency Index indicates how consistently observed values match predicted values and follow a linear best-fit line (Nash and Sutcliffe, 1970). Therefore, using R^2 values and EI values together will assess the model prediction accuracy. The EI defines the degree to which the model predicted variations agree and will be calculated as

$$EI = 1 - \left(\frac{\Sigma(P_i - O_i)^2}{\Sigma(|P_{i'}| + |O_{i'}|)^2} \right) \quad (1)$$

where

$P_{i'} = (P_i - \overline{P})$, $O_{i'} = (O_i - \overline{O})$, $\overline{P}$ = mean predicted value, and $\overline{O}$ = mean observed value.

RESULTS AND DISCUSSION

The observed and model predicted water quality parameters of the Summerford watershed were compared. The mean and median levels of observed water quality parameters were compared with the general water quality standards (Table 2) of the U.S. EPA; NH_3-N and TP should not be greater than 0.25 mg/L and 0.50 mg/L, respectively in surface waters. The concentration of water quality parameters higher than the general standards is common in polluted waters (Boyd, 2000).

Surface runoff

The observed surface runoff for the eleven runoff events were compared with the AGNPS and WEPP predicted results (Table 3). Both models used in the study showed low fit of coefficient of

Table 2. Comparison of water quality parameters for the Summerford watershed.

Parameters	TSS	NH_3N	NO_3N+NO_2N	TP
	mg/L			
General standards	25.00	0.25	0.30	0.50
Mean observed	28.14	0.48	0.37	2.93
Median observed	18.00	0.33	0.27	2.10

Table 3. Comparison of observed and predicted runoff using CN, AMC_{II} for AGNPS and ISL 75% for WEPP.

Dates	Rainfall		Runoff, mm			Sediment yield, kg/ha		
	Depth	Intensity	Observed	Predicted		Observed	Predicted	
	mm	mm/hr		WEPP	AGNPS	Observed	WEPP	AGNPS
01/15/1999	46.22	16.25	2.27	0.97	6.61	0.45	1.18	0.50
01/24/1999	15.74	1.52	6.49	0.00	0.00	3.64	0.00	0.00
05/06/1999	72.39	16.76	16.68	14.78	20.80	10.01	9.69	9.40
12/16/2000	24.63	9.65	0.17	0.00	0.50	0.13	0.00	0.20
01/21/2001	70.87	8.12	13.20	6.47	19.54	4.77	5.74	4.80
03/21/2001	69.09	14.22	3.81	6.47	16.19	0.42	1.71	0.50
08/10/2001	71.37	67.06	2.57	16.99	19.55	0.18	4.72	0.10
09/09/2001	60.45	35.56	0.84	7.77	13.71	0.09	0.91	1.00
12/13/2001	57.91	14.73	0.54	2.60	12.26	0.06	0.07	0.90
8/31/2003	40.64	38.54	0.03	1.00	5.18	0.01	1.11	0.40
9/21/2003	110.99	54.35	11.40	31.23	50.00	0.98	4.37	4.40

* Average model prediction in three management conditions

correlation and Nash Sutcliffe efficiency index (AGNPS; R^2 = 0.31 and EI = 0.27 and WEPP; R^2 = 0.28 and EI = 0.44) when compared with observed values. The AGNPS model over-predicted average surface runoff by 161% whereas WEPP did by 52% considering the average of all pasture vegetation types. It was partially because of the small size of watershed (2.71 ha) and errors due to the single event mode of the model application to estimate initial abstraction. In a separate study, the infiltration rate at the watershed was found to be high, as a result of which the surface runoff prediction by the AGNPS and WEPP models was highly variable (Parajuli, 2003). The AGNPS model uses curve number (CN), average antecedent moisture condition (AMC_{II}) and WEPP considers 75% initial saturation level (ISL) by default to estimate surface runoff.

The CN and AMC that needed to match the observed surface runoff may be less or greater than the watershed average CN_{II} conditions which is an important input to the AGNPS model (SCS, 1968; Koelliker et al., 1981; Koelliker, 1987). CN values for each AGNPS cell are affected by both canopy and AMC, which were estimated by individual storm events. There was generally an increasing trend in the relationship between antecedent moisture condition and 5-day antecedent rainfall (Figure 2). Daily soil moisture was estimated in the top 30.5 cm on the day prior to each storm event from weather and soil data using the water balance method as described by Bhuyan et al. (2003).

The single event AGNPS model was adjusted with estimated AMC whereas the WEPP model was adjusted calibrating the range of initial saturation levels (50% to 90%). The adjustment of these parameters greatly improved model performance (Table 4). When compared to observed surface runoff data with adjusted model predicted surface runoff, results showed a very good coefficient of correlation and Nash Sutcliffe efficiency index (AGNPS; R^2 = 0.82 and EI = 0.72 and WEPP; R^2 = 0.81 and EI = 0.80) (Figure 3). The AGNPS model predicted similar amounts of surface runoff in all three pasture vegetations whereas in the WEPP model prediction, Bermuda grass pasture vegetation had a higher coefficient of correlation and EI (R^2=0.82 and EI=0.81), followed by fescue and ryegrass when compared with observed data.

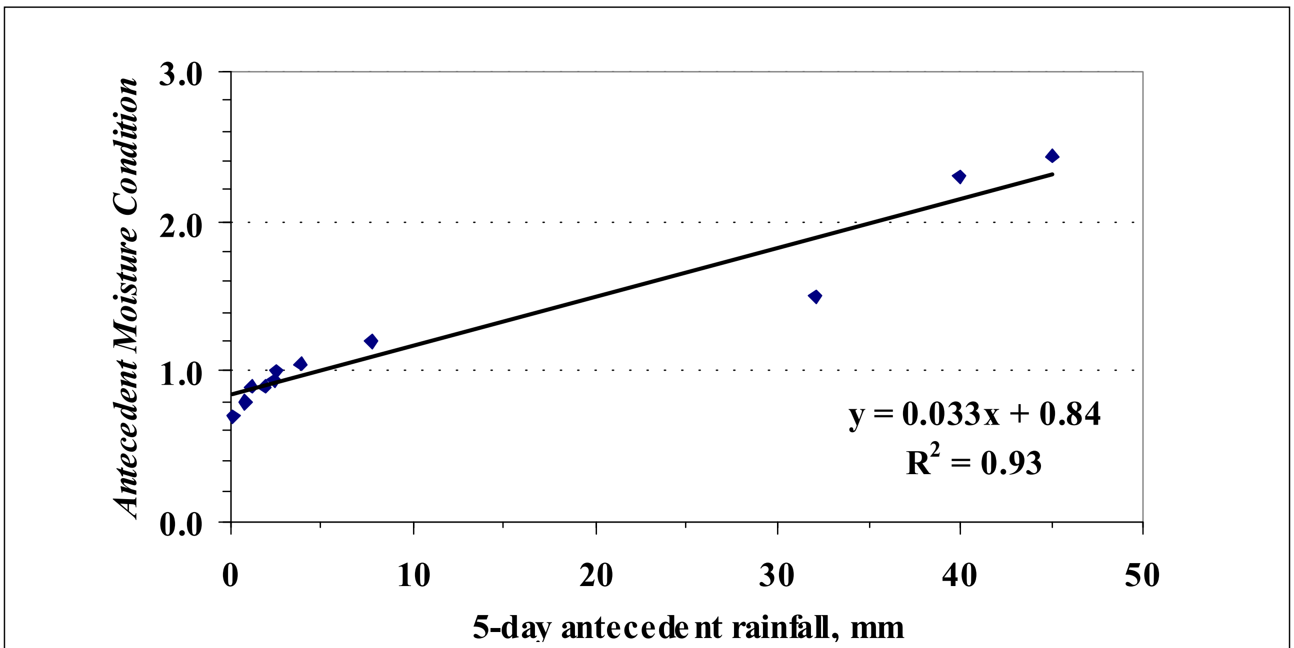

Figure 2. Relationship between 5-day antecedent rainfall and estimated AMC.

Table 4. Comparison of observed and predicted runoff using CN and AMC for AGNPS and varied ISL (50-90%) for WEPP.

No. of Storm Events	Date	Observed runoff, mm	Predicted runoff, mm	
			AGNPS	WEPP
1	1/15/1999	2.27	3.80	0.93
2	1/24/1999	6.49	0.00	0.00
3	5/6/1999	16.68	21.35	17.57
4	12/16/2000	0.17	0.50	0.00
5	1/21/2001	13.20	14.45	10.74
7	3/21/2001	2.57	7.80	5.50
6	8/10/2001	3.81	3.80	3.43
8	9/9/2001	0.84	2.20	2.29
9	12/13/2001	0.54	2.10	2.09
10	8/31/2003	0.03	2.30	1.00
11	9/21/2003	11.40	13.20	14.40

Sediment yields

When observed sediment yield data are compared with adjusted model predicted sediment yield, the result is a very good coefficient of correlation and Nash Sutcliffe efficiency index (AGNPS; $R^2 = 0.84$ and EI = 0.86 and WEPP; $R^2 = 0.73$ and EI = 0.68) as shown in Figure 4. The AGNPS model predicted similar sediment yields in all three pasture vegetations whereas in the WEPP model prediction, Bermuda grass pasture vegetation had higher coefficient of correlation

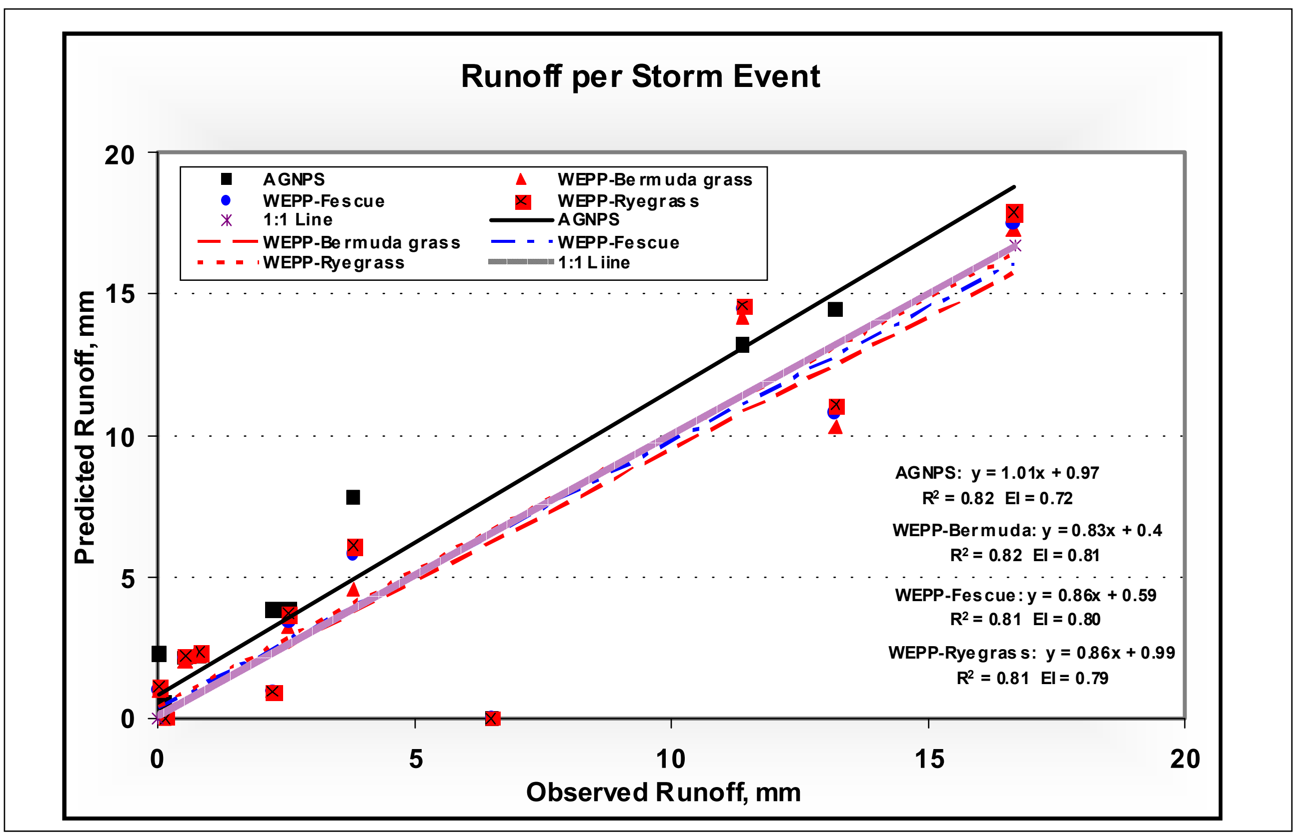

Figure 3. Predicted and observed surface runoff under different pasture management conditions.

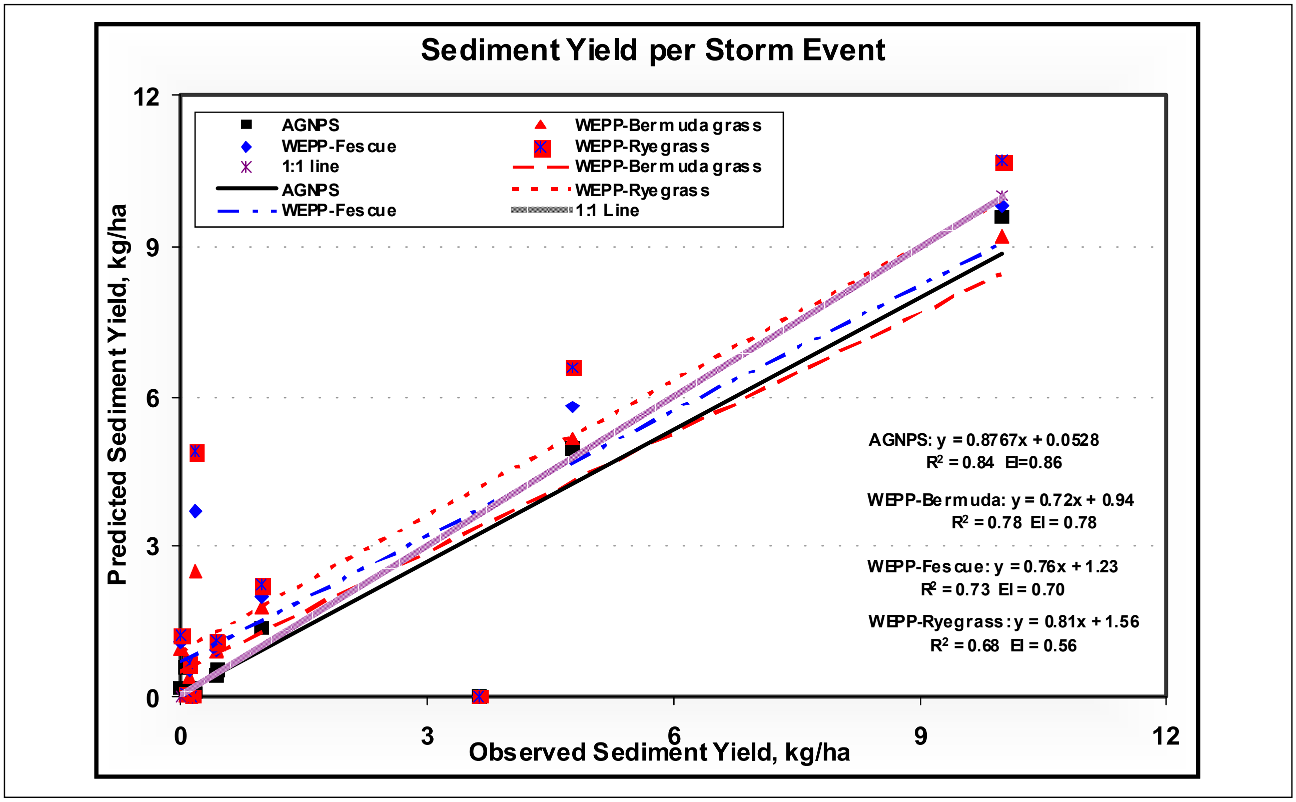

Figure 4. Predicted and observed sediment yields under different pasture management conditions.

and EI (R^2=0.78 and EI=0.78), followed by fescue and ryegrass when compared with observed data.

The observed average TP (0.19 kg/ha) was found to be greater than TN (0.17 kg/ha) from this watershed. It is common that TP losses are often greater than TN from the watershed where poultry litter is applied (Saleh et al., 2000). Nitrogen can be dissipated from various sources but phosphorus may either attach to soil and remain in place or be transported with soil particles, or it can flow from the field in dissolved forms.

SUMMARY AND CONCLUSION

The field-observed water quality in the Summerford watershed (a cattle grazing pasture with poultry litter application as a fertilizer) failed to meet the general water quality standards defined by the U.S. EPA on several occasions. The water quality parameters that often failed to meet the standards were TSS, NH_3-N, NO_2 + NO_3-N and TP. Since pesticides and commercial fertilizer were not applied to the field (Summerford , 2003), the primary nutrient (nitrogen and phosphorus) sources were the poultry litter applied as a fertilizer. Reduction in the amount of chicken litter applied in the watershed would contribute to reducing the level of NPS pollution from the watershed.

After the adjustment of AMC for AGNPS and initial saturation levels for WEPP, single event modes of both water quality models were able to simulate watershed conditions with high model efficiency. However, overall AGNPS model efficiency was found to be better than WEPP, especially in predicting sediment yields.

The models were used to evaluate three pasture vegetation types (Bermuda grass, fescue, and ryegrass) and to recommend the Best Management Practices (BMPs). Based on the model prediction and the observed data, the combined pasture practice of Bermuda grass and fescue reduced the surface runoff and sediment losses more than that of either the Bermuda grass and ryegrass or the fescue and ryegrass practices. The Bermuda grass and fescue combination assures good ground covers throughout the year.

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