MODEL SIMULATION OF RUNOFF AND NUTRIENT LOSSSES FROM THREE ADJACENT ROW-CROP WATERSHEDS IN THE CLAYPAN REGION

Anomaa Senaviratne
Graduate Student

Ranjith Udawatta
Research Assistant Professor

Stephen Anderson
Professor

Watershed models have become useful and necessary to evaluate impacts of conservation management practices on non-point source pollution (NPSP), as *in situ* studies at the watershed scale have inherent problems such as high costs due to their large scale and complex nature, private ownership of land, and results not timely enough to avoid negative consequences of current practices (Korfmacher, 2001). The Agricultural Policy Environmental eXtender (APEX) model is a distributed, continuous, daily time-step, hydrologic/water quality model (Williams et al., 2008) and has been used to examine effectiveness of vegetative filter strips in controlling sediments and pollutants at a national scale (Arnold et al., 1998). The goal of this study was to evaluate the long-term effects of grass waterways in reducing NPSP from three adjacent small watersheds in Missouri with claypan soils under a corn/soybean rotation. Objectives were to determine the APEX sensitive parameters for crop yields, runoff, sediment, and nutrients; to calibrate and validate the APEX model for these outputs; and to use the calibrated model to quantify the reduction in NPSP from grass waterways.

Long-term data from a paired watershed study located at the University of Missouri Greenley Memorial Research Center in Knox County, Missouri, USA was used for the model simulations (40°01' N, 92°11' W; Udawatta et al., 2002). This study focused on three adjacent field-scale corn/soybean rotation watersheds (1.65 ha, 4.44 ha, and 3.16 ha) established with grass waterways from 1991 to 1993. The monitored data on runoff, sediments, nutrients, and crop yields of the watersheds were used in this study. ArcGIS 9.3, ArcAPEX, and APEX0604 software were used in the modeling process. Daily measured weather inputs of precipitation, maximum and minimum temperature, and solar radiation were obtained from the Novelty weather station. The modification of SCS curve number, the modified rational method, the Hargreaves and Samani method, and the MUSS, a modification of Modified Universal Soil Loss Equation (MUSLE) equation were used to simulate surface runoff, peak runoff rate, potential evaporation, and soil erosion estimation, respectively, in this study. The Center watershed was used for calibrating the APEX model for crop yields, daily runoff, and losses of sediment, total nitrogen (TN), and total phosphorous (TP) for the period, 1993 to 1997. Validation of the model was conducted using West and East watersheds over the same period. Model performance was evaluated using coefficients of determination (r^2) and Nash-Suttcliffe coefficients (NSC;Nash and Sutcliffe, 1970).

Simulated mean crop yields were within ±13% of the measured yields for calibration of the Center, West and East watersheds. Both corn and soybean yields were most sensitive to the root growth soil strength (P[2]), Hargreaves PET equation coefficient (P[23]), and Hargreaves PET equation exponent (P[34]) parameters. Corn yields were also sensitive to the SCS curve number index coefficient parameter (P[42]).

The model simulated the measured runoff for 42 storm events, and showed reasonably good agreement for calibration in the Center watershed and validation in the West and East watersheds (Figures. 1a, b, and c,). Model performance coefficients, r^2 and NSC values for calibration for the Center watershed were 0.88 and 0.87, respectively (Table 1). Model r^2 and NSC values were 0.86 and 0.71 for the West watershed and 0.86 and 0.78 for the East watershed, respectively for validation. Most sensitive model parameters for runoff were Hargreaves PET equation exponent (P[34]), SCS curve number index coefficient (P[42]), and Soil evaporation-plant cover factor (P[17]).

The sediments and total nitrogen were not well simulated by the model. The simulated and measured total phosphorus (TP) for the three watersheds are shown in Figures. 2a, b, and c. The APEX model was calibrated for TP losses using the Center watershed with, r^2 and NSC values of 0.39 and 0.18, respectively. The r^2 and NSC values improved to 0.61 and 0.57 respectively, with events 25 to 42 which consisted of higher rainfall (>50-mm; Table 1). The respective r^2 and NCS values during validation were 0.36 and 0.17 and 0.59 and 0.41 for the West and East watersheds, respectively, for all the events. The r^2 and NSC values improved to 0.60 and 0.58 and 0.62 and 0.50 for West and East watersheds, respectively, when calculated with events 25 to 42. This indicates that the APEX model simulates TP losses more accurately for larger rainfall events. The reason why TP was simulated better than sediments despite phosphorous being transported mainly in the sediment-bound form (Dillaha et al., 1989; Schmitt et al., 1999) may be that particulate P is bound to finer clay particles (Schmitt et al., 1999) which can remain suspended for longer time in the flow than larger particles of sediments which were better represented in the measured samples. The model's most sensitive parameters for TP were CHSO average upland slope (Control file), enrichment ratio method (IERT; control file), and sediment routing exponent P[18] (Table 1). Sensitive parameters for dissolved phosphorous were CHSO average upland slope and soluble phosphorous runoff coefficient (P[8]).

Two scenario analyses were conducted to evaluate the long-term effects of grass waterways using the calibrated and validated APEX models: one to replace grass waterways by crops and the other to expand the existing grass waterways by one meter from sides and front. The respective models were simulated for 20 years and the average annual runoff and TP at 10 and 20 years after the establishment of the three watersheds are shown in Figure 3. The reductions in long-term average annual runoff due to the presence of grass waterways were generally low. The greatest reduction was observed in the East watershed (2 to 3%) while reductions on West and Center watersheds ranged from 1 to 2% and 0 to 1%, respectively (Figures. 3a, b, and c). Hjelmfelt and Wang (1999) reported that grass waterways have great potential for reducing runoff peak discharges and sediment losses, but they are not as effective for reducing runoff volume. The presence of grass waterways has significantly ($p<0.05$) reduced average annual TP losses (Figures. 3d, e, and f) for 10 and 20 year simulations. The average annual TP reduction by grass waterways for East, Center, and West watersheds was 34 to 36%, 31 to 32%, and 23 to 25%, respectively, compared to the simulated watersheds without grass waterways. One meter expansion of grass waterways by sides and front only produced very slight reductions in runoff and TP.

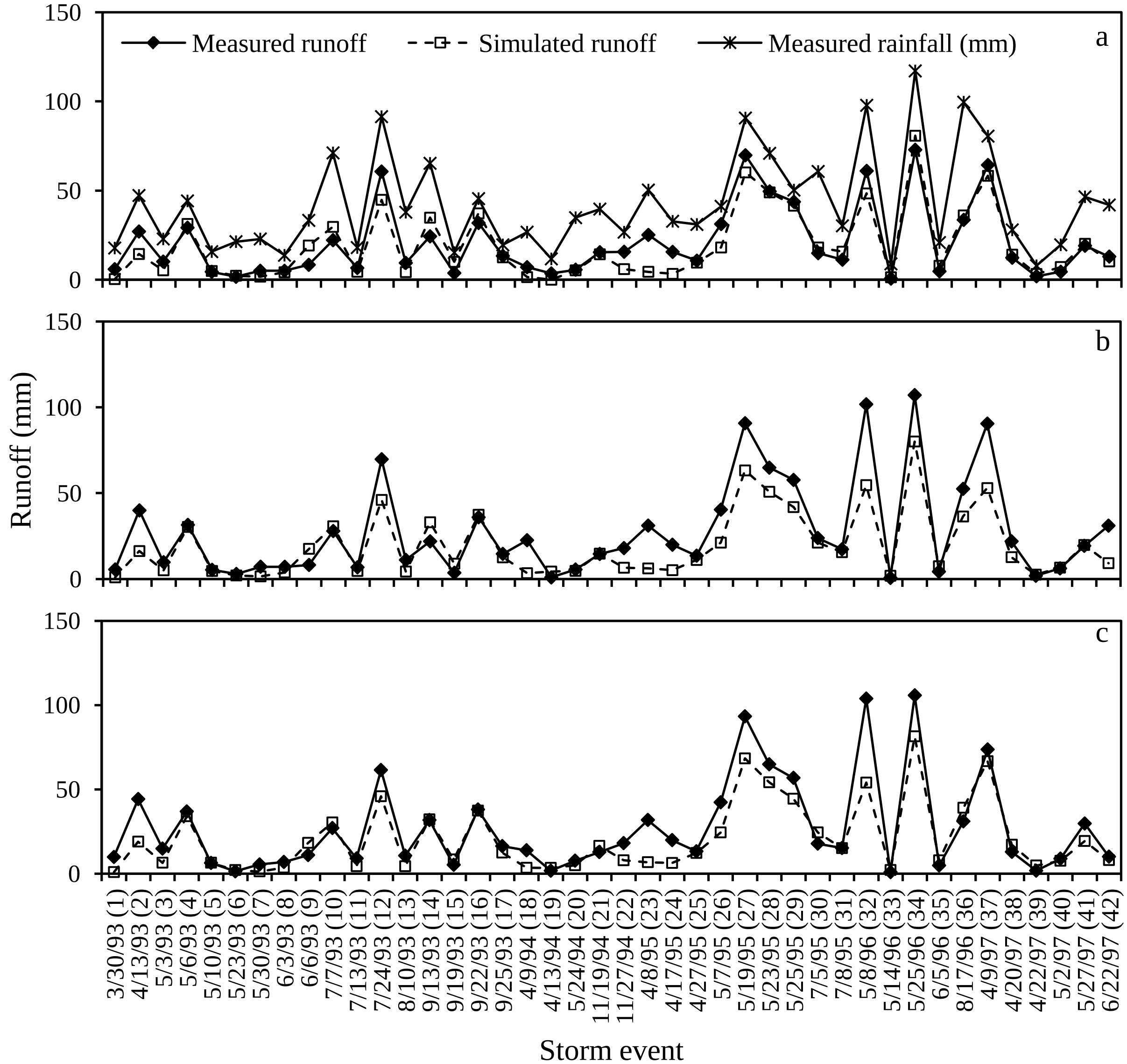

Figure 1. Measured and simulated runoff for Center (a), West (b), and East (c) watersheds during the study period at the paired watershed study, Greenley Research Center, Missouri, USA. The Center (a) watershed shows the results for calibration while West (b) and East (c) watersheds show the results for validation.

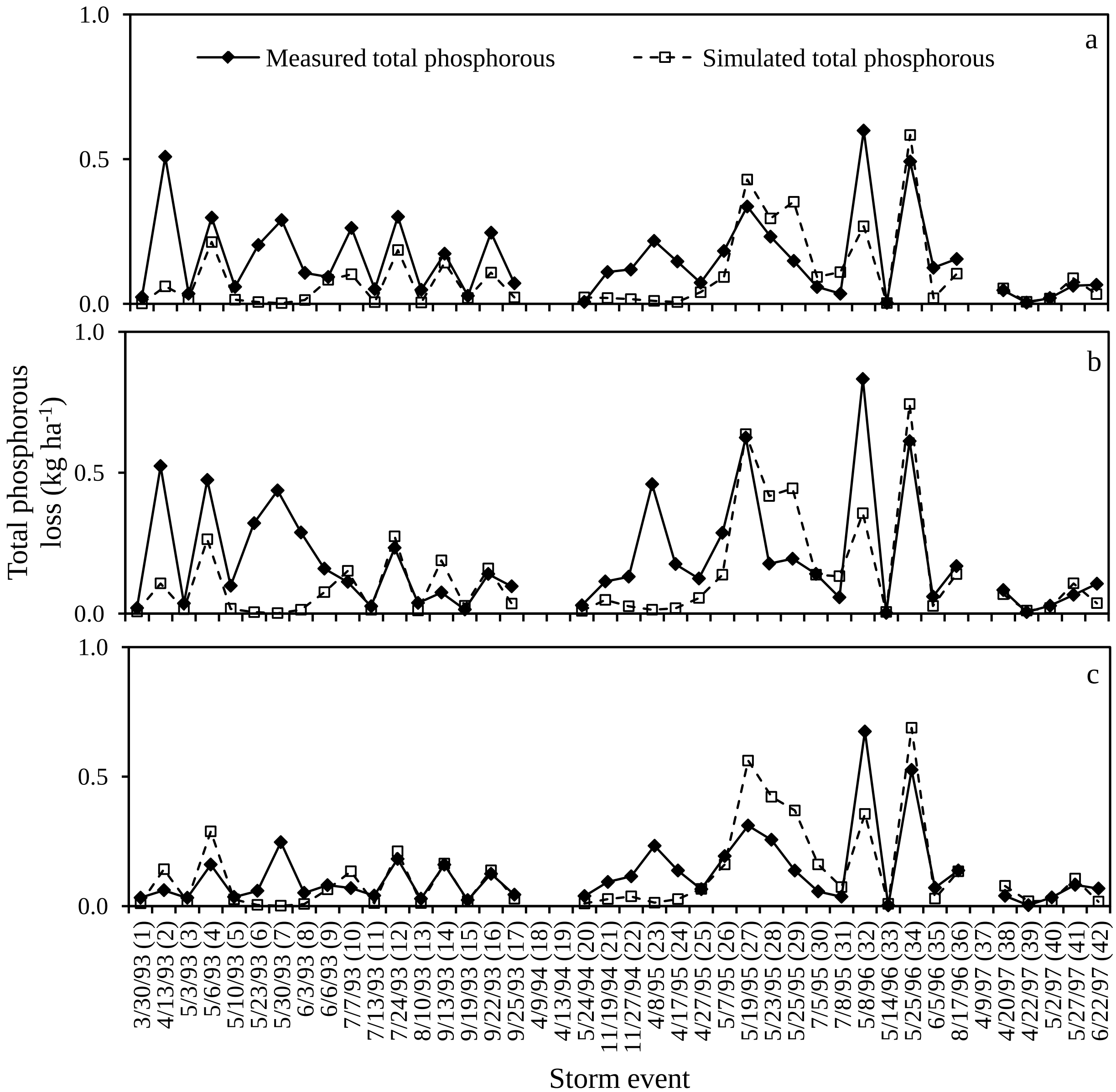

Figure 2. Measured and simulated total phosphorous losses for Center (a), West (b), and East (c) watersheds during the study period at the paired watershed study, Greenley Research Center, Missouri, USA. The Center (a) watershed shows the results for calibration while West (b) and East (c) watersheds show the results for validation. Measured total phosphorous for events 18, 19, and 37 were not available.

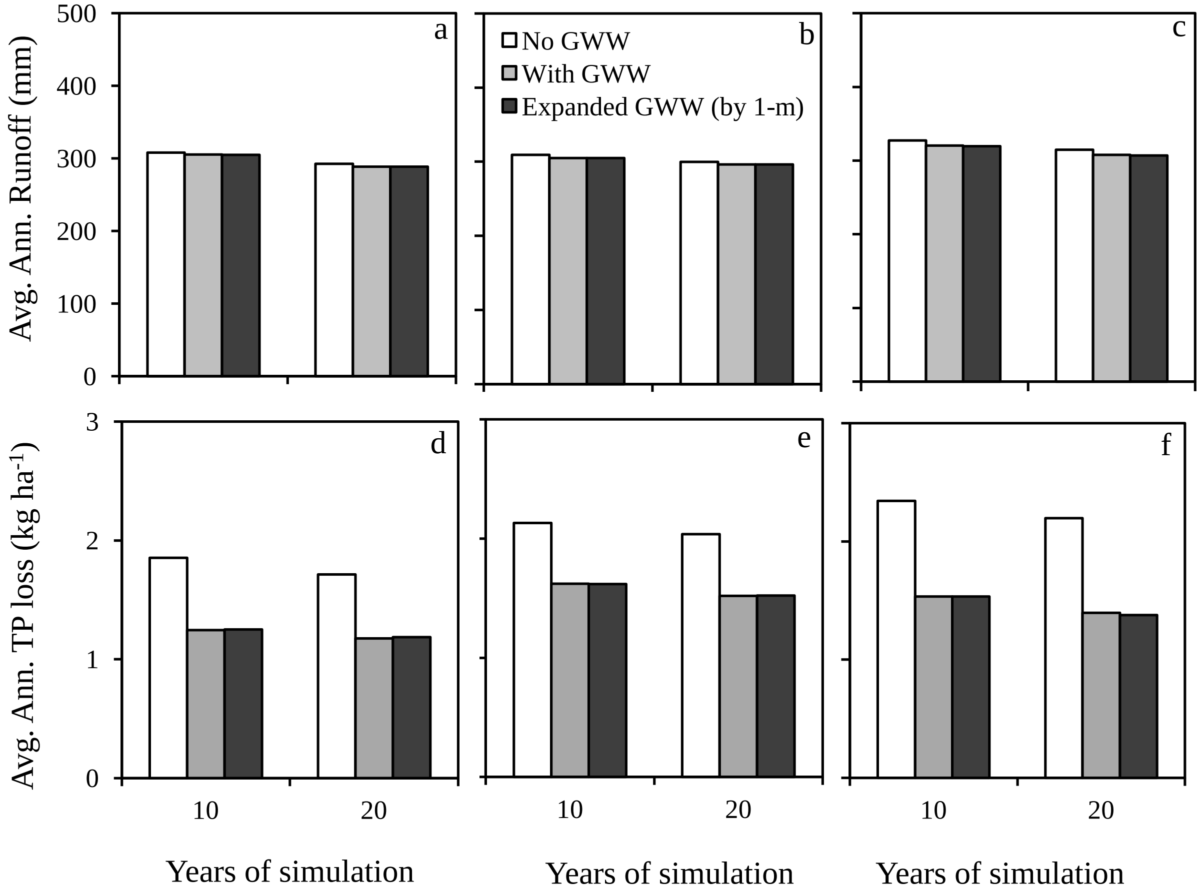

Figure 3. APEX model predictions for average annual runoff (a, b, and c) and average annual total phosphorous losses (d, e, and f) for Center, West, and East watersheds, respectively, at the paired watershed study, Greenley Research Center, Missouri, USA, for 10 and 20 years with and without grass waterways and with expanded grass waterway by one meter from all sides.

Table 1. Agricultural Policy Environmental Extender (APEX) model performance for coefficient of determination (r^2) and Nash-Sutcliffe Coefficient (NSC) values for event runoff, sediment, total nitrogen (TN), and total phosphorus (TP) for Center, West, and East watersheds at Greenley Research Center, Missouri, USA for calibration and validation.

Model output	Model performance	Calibration	Validation	
		Center	West	East
Runoff	r^2	0.88	0.86	0.86
	NSC	0.87	0.71	0.78
Sediments	r^2	0.21	0.14	0.17
	NSC	0.20	-0.01	0.01
TN	r^2	0.53*	0.27*	0.27*
	NSC	0.30*	0.18*	0.14*
TP	r^2	0.61*	0.60*	0.62*
	NSC	0.57*	0.58*	0.50*

* only for storm events 25 to 42.

References

Arnold, J.G., J.D. Atwood, V.W. Benson, R. Srinnivasan, and J.R. Williams. 1998. Potential environmental and economic impacts of implementing national conservation buffer initiative. Sedimentation Control Measures. USDA-NRCS. Staff paper. Washington, DC.

Dillaha, T.A., R.B. Renear, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. Trans. ASAE. 32:513-519.

Hjelmfelt, A., and M. Wang. 1999. Modeling hydrologic and water quality responses to grass waterways. J. Hydrol. Eng. 4:251–256.

Korfmacher, K.S. 2001. Forum: The Politics of Participation in Watershed Modeling. Environ. Manage. 27:161–176.

Nash, J.E., and J.V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part I. A discussion of principles. J. Hydrol. 10:282-290.

Schmitt, T.J., M.G. Dosskey, and K.D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. J. Environ. Qual. 28:1479-1489.

Udawatta, R.P., J.J. Krstansky, G.S. Henderson, and H.E. Garrett. 2002. Agroforestry practices, runoff, and nutrient loss: A paired watershed study. J. Environ. Qual. 31:1214-1225.

Williams, J.R., R.C. Izaurralde, and E.M. Steglich. 2008. Agricultural Policy/Environmental Extender model: Theoretical Documentation. Version 0604. BREC Report 2008-17. Temple, Tex.: Texas A&M University, Texas AgriLIFE Research, Blackland Research and Extension Center. Available at http://epicapex.brc.tamus.edu/downloads/user-manuals. (verified on 28 May 2012).