Performance of Geno-Fuzzy Model on Rainfall-Runoff Predictions in Claypan Watersheds

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INTRODUCTION

- The claypan region of the Central U.S. experiences high rates of surface runoff from agricultural watersheds.
- Estimation of surface runoff is essential to determine management options for non-point source pollutants (NPSP) such as sediments and nutrients.
- Process-based physically distributed models are commonly used to predict runoff but require detailed physical data of watersheds in addition to significant time for setting-up the model.
- Fuzzy Logic Systems (FL; Zadeh, 1965) are data-driven, rule-based models developed based on fuzzy relationships of input/output variables.
- Fuzzy rainfall-runoff models are often used to forecast flood or water supply in large catchments and applications at small/field-scale agricultural watersheds are limited.

OBJECTIVES

1. Develop, calibrate, and validate a FL system to predict event-based runoff based on rainfall from three adjacent field-scale corn-soybean (*Zea mays* L.- *Glycine max* L.) watersheds before and after the establishment of upland contour agroforestry (tree+grass) and grass buffers on claypan soils of Northeast Missouri (Fig. 1a, Udawatta et al., 2002).
2. Compare the model performance with predictions by a physically-based Agricultural Environmental Policy eXtenter model (APEX) for the same watersheds in a previous study (Senaviratne et al., 2013).
3. Use the developed model to evaluate measured and predicted runoff from two large watersheds.

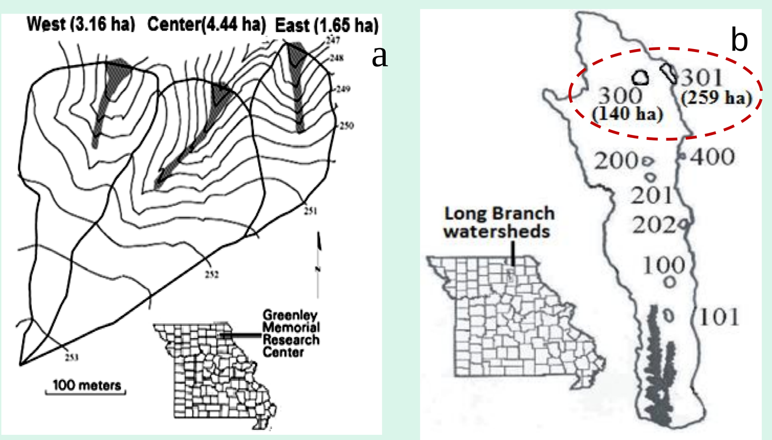

Fig. 1. Watersheds at Greenley Memorial Research Center in Knox County (a) and 300 and 301 watersheds in the Long Branch watershed in Macon and Adair Counties (b), Missouri, USA.

METHODOLOGY

- Three watersheds at Greenley were established with grass waterways in 1991. Center and West watersheds were established with agroforestry and grass contour upland buffers (4.5 m width, 22.5 to 36 m interval) in 1997.
- Mamdani type FL system for rainfall-runoff predictions was developed using MATLAB 7.10.0 fuzzy logic commands.
- Five fuzzy membership functions (MF) for rainfall and runoff and five rules were developed for the FL systems for pre- and post-buffer watershed conditions based on measured rainfall-runoff data of the watersheds used for calibration.
- Genetic algorithm (GA) was used to optimize the membership functions x-coordinate values (search space allowed was within 10% of the initial value).
- Robustness of the rainfall-runoff FL system was tested by changing number of membership functions (2, 3, and 4) and swapping data used for calibration and validation.
- The rainfall-runoff FL system for the pre-buffer period was validated with the data from East watershed which was the control during 1998 to 2008.
- The data from 1998 to 2001 of the post-buffer period was used for calibration and data from 2002 to 2008 was used for validation
- The developed rainfall-runoff FL system was used for simulation of runoff of 30 and 50 times larger watersheds (300 and 301) in the Long Branch watersheds (Fig.1 b).

RESULTS AND DISCUSSION

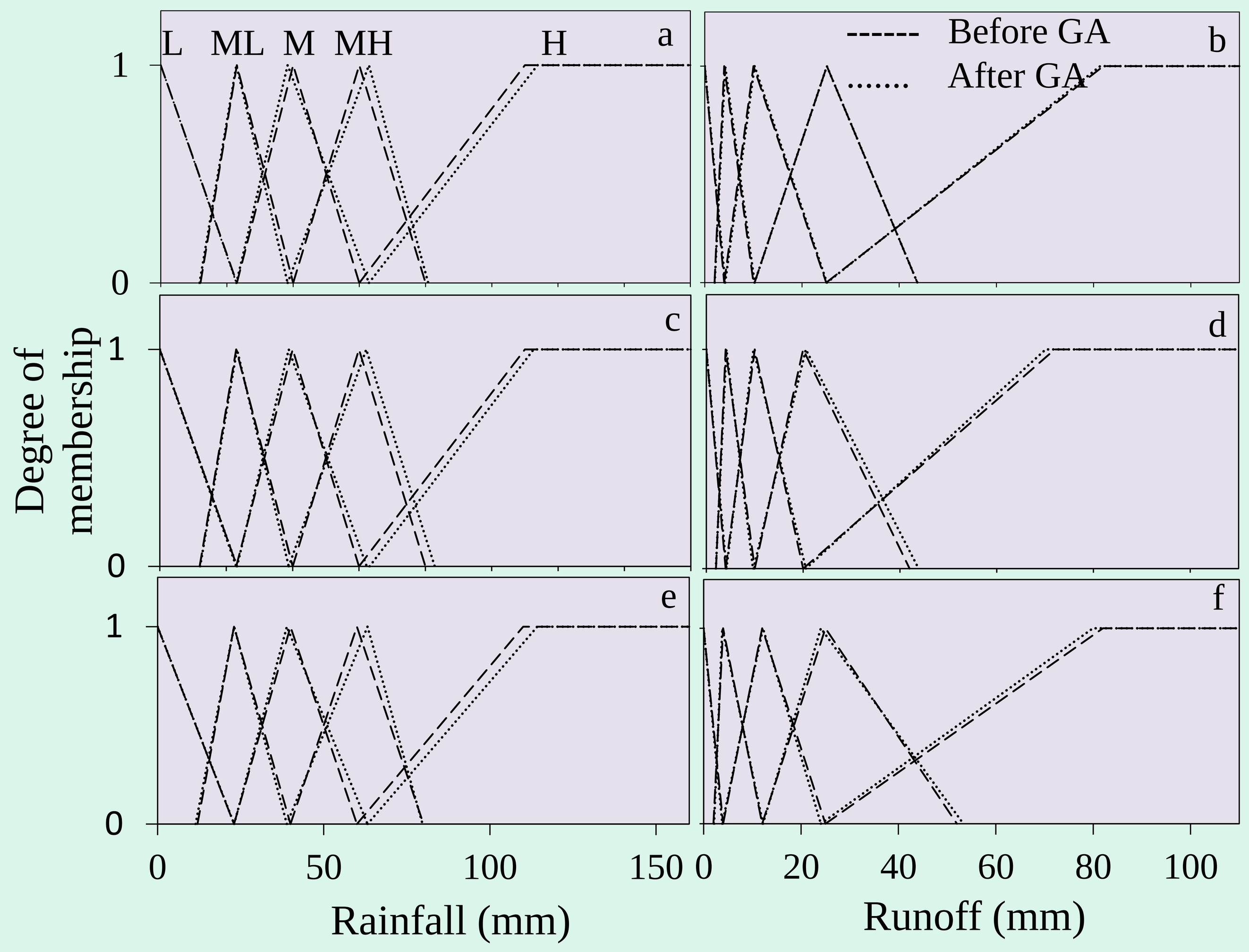

Fig. 2. Membership functions before and after genetic algorithm optimization of the rainfall and runoff output variables for fuzzy logic systems: pre-buffer (a and b), post-buffer agroforestry (c and d) and contour grass (e and f) watersheds at Greenley. Data labels represent membership functions: L- low, ML- medium low, M- medium, MH- medium high and H- High.

- The use of GA for the optimization of MFs improved model performance coefficients of r^2 and NSC values by 0.02 to 0.12.
- Figure 2 shows the membership functions used initially and after the GA optimization. Most of the changes by GA optimization were seen for rainfall MFs.
- The increase in number of MFs from 2 to 4 improved FL model performance coefficients [Nash Sutcliffe Coefficient (NSC), increased from -0.22 to 0.79; Percent Bias values (Pbias), decreased from -93.8 to -1.2].
- The FL system performance was minimally changed when calibration and validation data were swapped.
- The GA optimized FL system predictions on event-based runoff of pre-buffer watersheds were very similar to those of the APEX model for calibration (Fig. 3a; Center watershed during1993 to 1997 period) and for validation (Fig. 3b; East watershed during 1998 to 2008 period).
- The r^2 and NSC values ranged between 0.69 and 0.94 and Pbias values were less than ±20% for calibration and validation of the FL model for both pre- and post-buffer watersheds.
- The FL model predictions for event-based runoff showed 15% and 23% reductions due to the presence of agroforestry and grass buffers, respectively. The related measured reductions were 15% and 16%, respectively.
- The FL model satisfactorily predicted event-based runoff for two large watersheds in Long Branch watersheds (Table1).
- The results for watershed 300 were better than 301 because of similar land use on 300 (86% row-crop) and the watersheds (90% row-crop) used for calibration of the model.

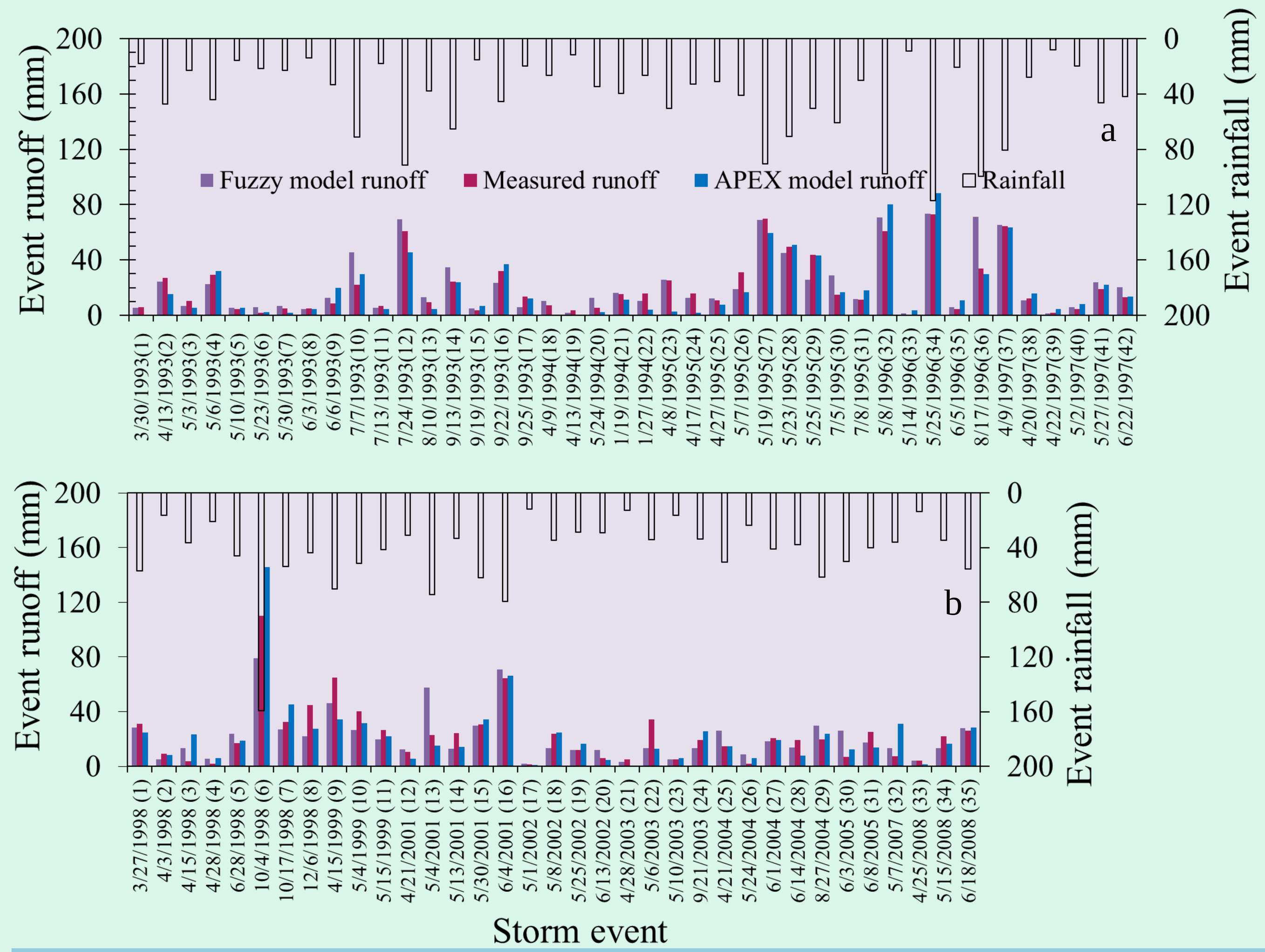

Fig. 3. Fuzzy logic (FL) and Agricultural Policy Environmental eXtender (APEX) model simulated event-based runoff for Center (a; 1993 to 1997, pre-buffer period) and East (b; 1998 to 2008, Control) watersheds with measured event rainfall and runoff.

Table 1. Model performance indicators of fuzzy logic (FL) system for prediction of event-runoff for 300 and 301 watersheds (1997-1999, 36 events), Long Branch watershed, MO.

Watershed	FL system performance		
	r^2	NSC	Pbias
300 (140 ha, 86% row-crop, 7% pasture, 7% forest)	0.82	0.77	26.52
301 (259 ha, 77% row-crop, 22% pasture, 4% forest)	0.68	0.53	41.02

CONCLUSIONS

- The FL model satisfactorily predicted event-runoff of field-scale watersheds using only rainfall as an input.
- The results closely agreed with the physically-based APEX model for the same watersheds.
- The FL model also predicted the effects of agroforestry and grass upland contour buffers on reductions of runoff comparable to the measured values.
- The FL model satisfactorily up-scaled the runoff predictions for 30 and 50 times larger watersheds.
- The study showed that FL model could be used as an efficient tool for runoff estimation for watersheds with limited details.

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