# APEX SIMULATION: ENVIROMENTAL BENEFITS OF AGROFORESTRY AND GRASS BUFFERS ON CORN-SOYBEAN WATERSHEDS

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Agricultural practices have often been scrutinized for degradation of water quality in rivers, lakes and estuaries in the U.S. (USEPA, 2013). Studies at various scales ranging from small plots, farms, fields, to watersheds are being conducted to evaluate conservation effects on non-point source pollution (NPSP; Mudgal et al., 2012; Udawatta et al., 2011a, 2011b). However, *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 any negative consequences of current practices.

Hydrological models provide a convenient, efficient, and economically feasible method to evaluate NPSP losses provided sufficient measured data are available at the small watershed scale (Sharpley et al., 2003). Among many hydrological models, the Agricultural Policy Environmental eXtender (APEX ) model has been widely tested and used to simulate complex combinations of farm level landscapes, cropping systems, and land management practices such as filter-strips at both field and watershed scales (Gassman et al., 2010; Mudgal et al., 2012; Senaviratne et al., 2013).

APEX model simulation was conducted to evaluate environmental benefits of buffer placement options and buffer dimensions. Sub-objectives of the study were to (1) calibrate and validate the APEX model for crop yields, runoff, and sediment for agroforestry, grass buffer and control watersheds, and (2) use the calibrated model to quantify NPSP reduction efficiencies for varying buffer widths and placement combinations.

## Materials and methods

Three adjacent north-facing no-till corn-soybean (*Zea mays* L.- *Glycine max* (L.)) watersheds (East-1.65 ha, Center-4.44 ha, and West-3.16 ha; Figure 1a) were established and instrumented in early 1991, at the University of Missouri Greenley Memorial Research Center in Knox County, Missouri, USA (40°01' N, 92°11' W; Udawatta et al., 2002). In 1997, buffer treatments were randomly assigned to two watersheds; grass buffers (CGS) on the west and agroforestry buffers (AGF; grass+oak trees) on the center watersheds.

The AGF, CGS and Control watersheds were custom delineated (Figure 1b) using ArcAPEX and ArcGIS 9.3 software. The APEX model was manually calibrated using the most sensitive parameters reported by Senaviratne et al. (2013) for the pre-buffer watersheds and the APEX user manual (Williams et al., 2008).

## Results and discussion

*Crop yields*

The APEX model was calibrated and validated for corn and soybean yields with $r^2$ over 0.80 and NSC over 0.72 for AGF, CGS and control watersheds except for the validation by the CGS watershed ($r^2$ 0.68 and NSC 0.42; Table 1). P bias values were within ±15% except for the validation. On the same watersheds, Senaviratne et al. (2013) reported crop yields within ±13% of the measured yields from the period 1991 to 1997. Hu et al. (2007) calibrated corn and soybean yields to be within -10 to 6% of measured yield for Soil and Water Assessment Tool model and Mudgal et al. (2012) calibrated the APEX model for crop yields to be within ±9% of the measured yields. Proper calibration and validation of the model for crop yield is a requirement for proper simulation of the nutrient balances of the watersheds (Hu et al., 2007; Nair et al., 2011; Mudgal et al., 2012 ) and proper evaluation of management scenarios (Arnold et al., 2012).

*Runoff*

APEX model was well calibrated and validated for event-based runoff of AGF, CGS and control watersheds with $r^2$ values ranging from 0.78 to 0.84 for calibration and 0.68 to 0.78 for validation (Table 1; Fig 2). NSC values ranged between 0.68 and 0.76 for calibration and 0.43 and 0.58 for validation for event-based runoff. Performance indicators for event-based runoff were better for the Control watershed model than for the other two. Pbias values were within ±25% for all calibrations and validations of the watersheds. Goodness of fit values of this study were highly satisfactory according to the specification given by Wang et al. (2012) for the APEX model.

*Sediment*

Figures 3a, b, and c illustrate the measured and simulated event-based sediment loadings from AGF, CGS buffer, and Control watersheds, respectively. The model was not well calibrated for event-based sediment; $r^2$ and NCS values were < 0.1 for all three watersheds. The model over predicted the largest event on the 10th of April, 1999. Annual average sediment loss was within ±10-14% of the measured value when this over predicted value was excluded. The APEX model study for the pre-buffer period reported that the model was calibrated for sediment only for events larger than 50 mm rainfall (Senaviratne et al., 2013). Mudgal et al. (2008) and Senaviratne et al. (2013) also reported sediment depositions at the flume bed prior to sampling point especially during low flow events which could have caused under representation of larger sediment particles in the samples.

The average measured event-based sediment loadings ranged from 0.0084 T $ha^{-1}$ for the AGF and CGS buffer watersheds to 0.0092 T $ha^{-1}$ for the Control watershed. The average measured sediment loadings for pre-buffer Center and West watersheds ranged between 0.099 and 0.1 T $ha^{-1}$ and that for the control ranged between 0.077 and 0.1 T $ha^{-1.}$ (Senaviratne, et al., 2013). Post buffer average sediment losses were 88-95% less than pre-buffer losses.

*Scenario analysis*

*Buffer width and placement of buffers*

The calibrated and validated APEX model for AGF and CGS watersheds were simulated with expanded buffer widths from 4.5 m to 5.5 and 7.5 m. The results indicate no significant reduction in average annual runoff (Figure 4). Studies have found diminishing return in pollutant filtration with the increase of buffer widths beyond four to seven meters (Dillaha et al., 1989; Robinson et al., 1996; Schmitt et al., 1999). A review on vegetative filter strips by Liu et al. (2008) revealed that the efficiency of a particular buffer width mainly depends on the slope of the land. The results of the current study also revealed that the increase of buffer width from 4.5 m to 5.5 and 7.5 m marginally reduced runoff, possibly because the average slopes of the AGF, CGS, and Control watersheds were 1.3%, 0.9%, and 2.1%, respectively (Udawatta et al., 2004).

The models were also simulated to test the effect of location of buffers on runoff by removing all buffers and buffers at summit, shoulder and back slope, and foot slope positions of the landscape at a time (Figure 5). The simulated AGF and CGS buffers did not significantly reduce average annual runoff but showed 4.3% and 5.2% respective reductions compared to non-buffer simulations. The buffers at the shoulder and back slope positions contributed to the highest reductions in runoff in AGF (1.7%) and CGS (2.4%) buffer watersheds (Figure 5).

## Conclusion

No study has calibrated and validated the APEX model for upland contour buffer strips in row-crop watersheds for event-based runoff with long-term data (10 years). The $r^2$ and NSC values were over 0.68 for runoff for calibration and they were over 0.43 for validation. Hence this study presents unique results obtained with the APEX model which has satisfactorily simulated the cropland, agroforestry and grass buffers, and grass waterways and their effects on event-based runoff with strong model performance coefficients for custom delineated watersheds, using long-term data for calibration and validation.

The model was not calibrated for event-based sediment probably due to low concentration as a result of buffers as well as low intensity rainfall events during the study periods. Underestimation of larger particles in the measured samples due to sedimentation on flume beds prior to the sampling point may also have affected sediments calibration results.

The long-term scenario analysis showed 4.3 to 5.2% reductions in average annual runoff by the buffers. The higher reductions in annual runoff were observed for the CGS buffer watershed. The results of this unique study demonstrated that APEX can be used to evaluate environmental benefits of upland filter strips, provided sufficient long-term data are available for calibration and validation.

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**Table 1.** Agricultural Policy Environmental Extender (APEX) model performance for coefficient of determination ($r^2$), Nash-Sutcliffe Coefficient (NSC), and Pbias values for crop yield and event runoff for agroforestry buffer, contour grass buffer, and control watersheds at Greenley Research Center, Missouri, USA for calibration (crop yields: 1998 to 2002; runoff events 1 to 14) and validation (crop yields: 2003 to 2008; runoff events 15 to 35).

| Model output | | Model performance | Agroforestry buffer | Contour grass buffer | Control |
|---|---|---|---|---|---|
| Crop yield | Calibration | $r^2$ | 0.96 | 0.97 | 0.99 |
| | | NSC | 0.88 | 0.89 | 0.98 |
| | | Pbias | 15.42 | -15.91 | 0.89 |
| | Validation | $r^2$ | 0.88 | 0.68 | 0.80 |
| | | NSC | 0.77 | 0.42 | 0.72 |
| | | Pbias | 15.48 | 22.45 | -4.38 |
| Runoff | Calibration | $r^2$ | 0.78 | 0.84 | 0.80 |
| | | NSC | 0.68 | 0.75 | 0.76 |
| | | Pbias | 10.98 | -22.58 | 22.63 |
| | Validation | $r^2$ | 0.68 | 0.73 | 0.78 |
| | | NSC | 0.58 | 0.51 | 0.43 |
| | | Pbias | 5.06 | -23.65 | 25.85 |

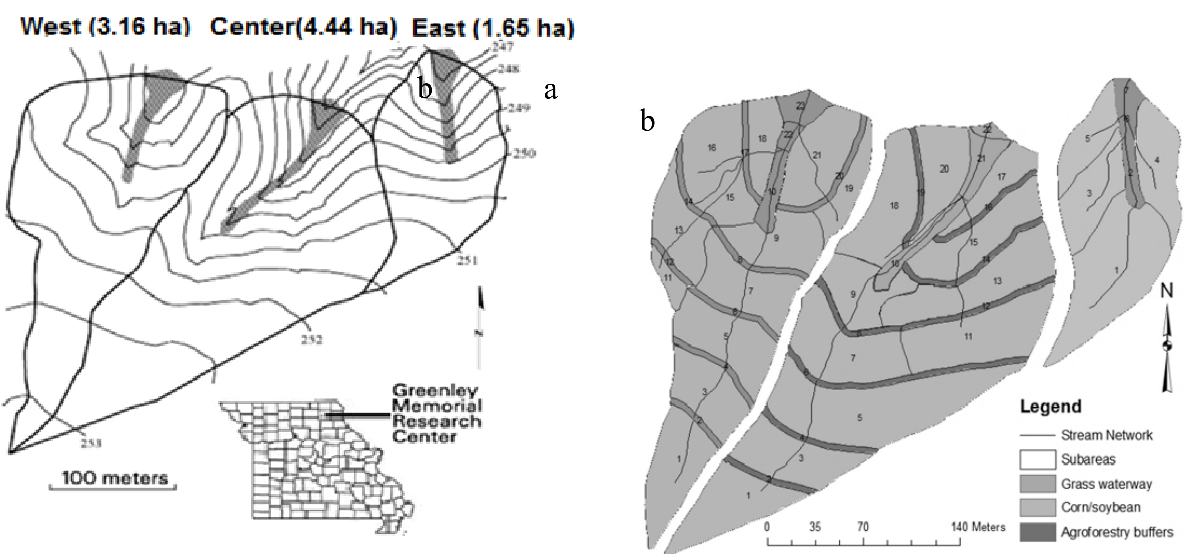


**Figure 1.** Topographic map (0.5-m interval) of West, Center and East watersheds (a; After Udawatta et al., 2004). Grey lines represent contour lines (thin) and grass waterways (wide). The inset map shows the approximate location of the study site in Knox County, Missouri. ArcAPEX model delineated subareas, and stream network of the three watersheds (b).

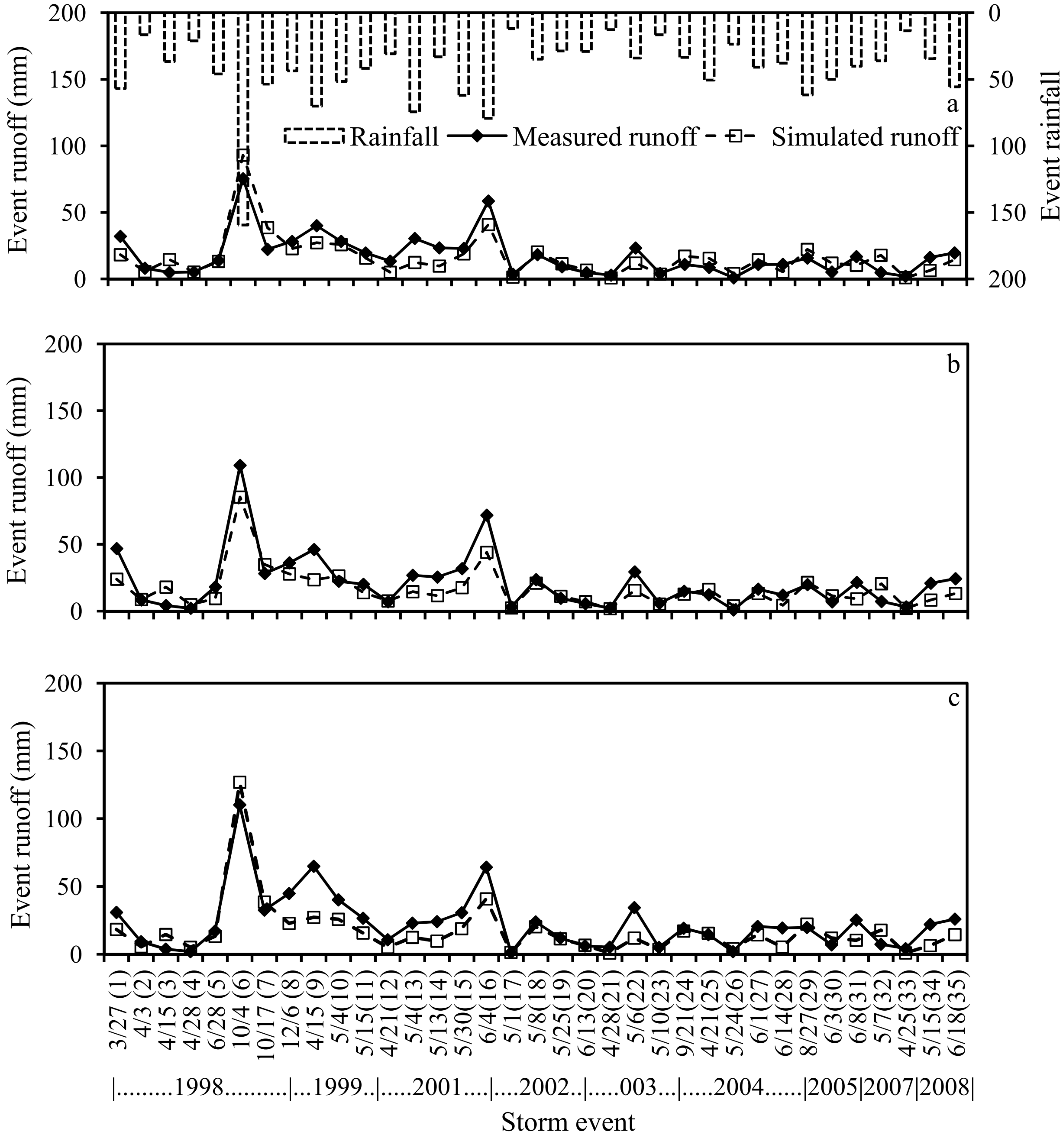


**Figure 2.** Measured and simulated event-based runoff for Agroforestry buffer (a), Grass buffer (b), and Control (c) watersheds during the study period at the paired watershed study, Greenley Research Center, Missouri, USA. The events 1 to 14 (1998-2001) represent results for calibration while events 15 to 35 (2002-2008) represent results for validation of all three watersheds.

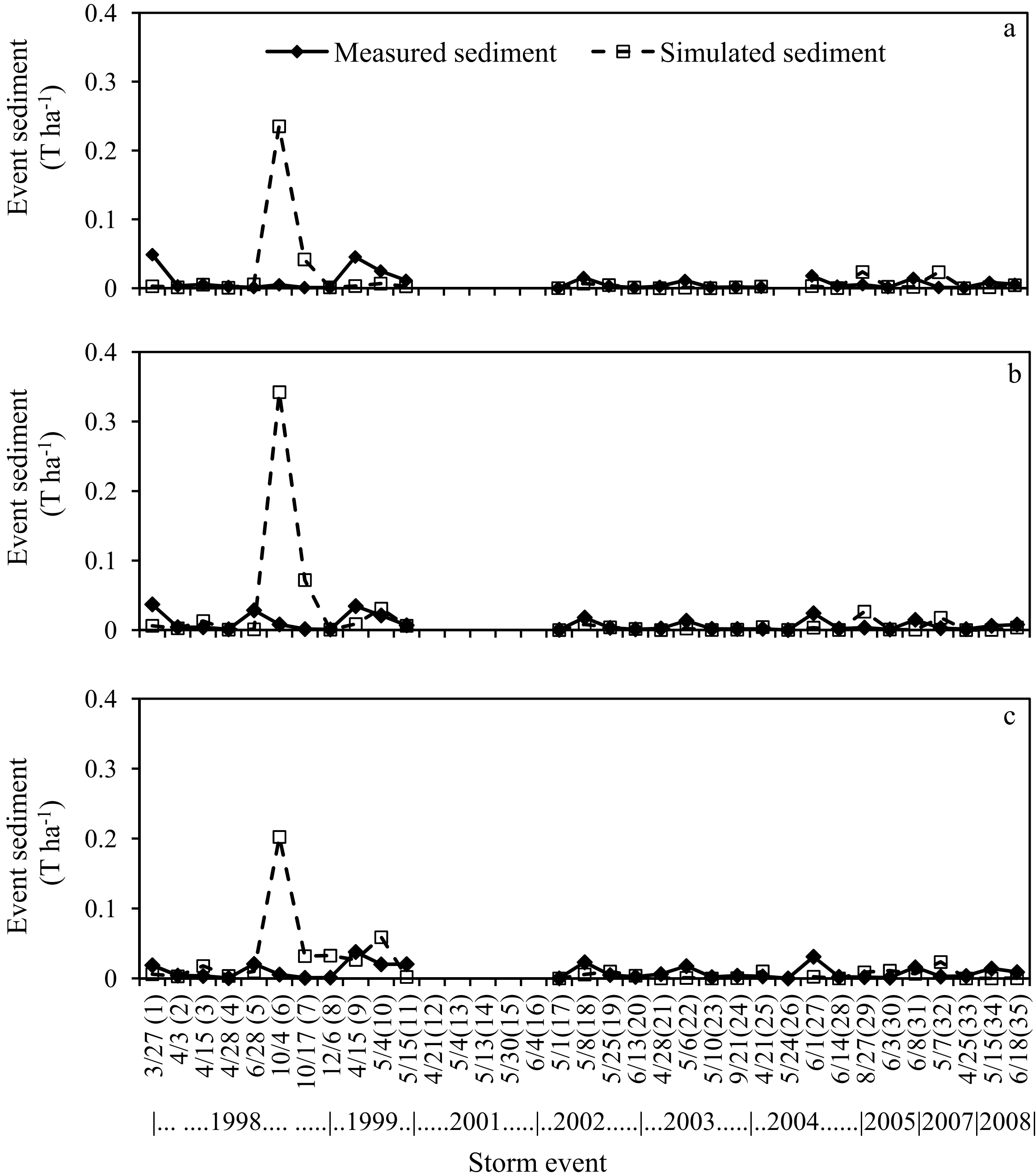


**Figure 3.** Measured and simulated event-based sediment for Agroforestry buffer (a), Grass buffer (b), and Control (c) watersheds during the study period at the paired watershed study, Greenley Research Center, Missouri, USA. The events 1 to 14 (1998-2001) represent results for calibration while events 15 to 35 (2002-2008) represent results for validation of all three watersheds.

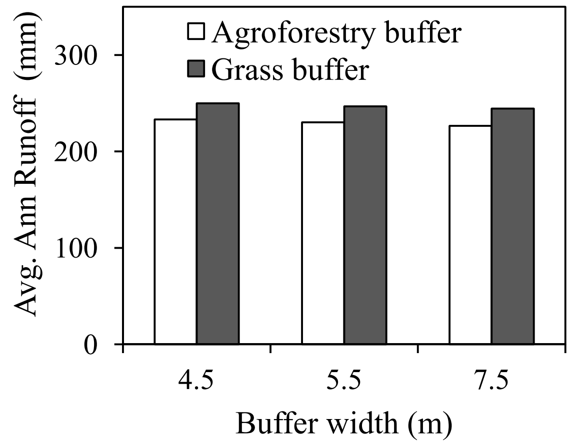


**Figure 4.** APEX model predictions for average annual runoff for agroforestry and grass buffer watersheds, at the paired watershed study, Greenley Research Center, Missouri, USA, with 4.5, 5.5, and 7.5 m buffer widths.

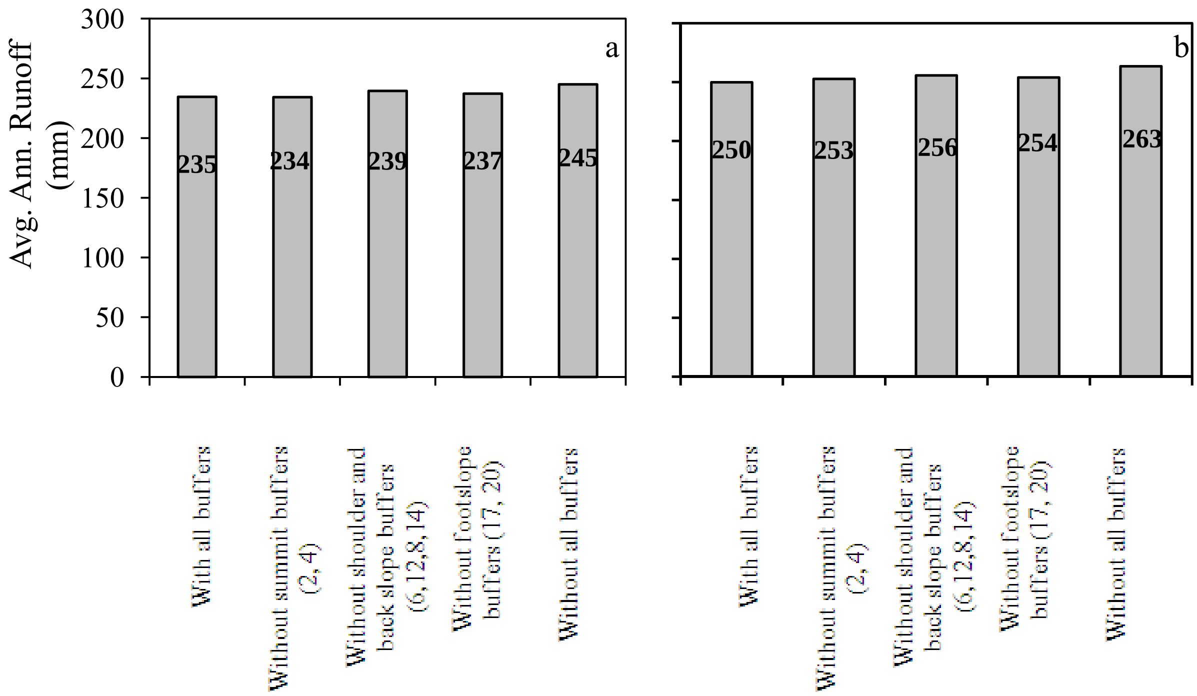


**Figure 5.** APEX model predictions for average annual runoff for agroforestry buffer (a) and grass buffer (b) watersheds, at the paired watershed study, Greenley Research Center, Missouri, USA, with varying buffers at summit, shoulder and back slope, and foot slope positions of the watershed landscape.