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SWAT Revisions for Simulating Landscape Components and Buffer Systems

David D. Bosch, Research Hydrologist

USDA-ARS SEWRL, PO Box 748, Tifton, GA 31794 david.bosch@ars.usda.gov

Jeffrey G. Arnold, Agricultural Engineer

USDA-ARS, GSWRL, 808 E. Blackland Rd., Temple, TX 76502 jgarnold@spa.ars.usda.gov

Martin Volk, Geographer

UFZ-Helmholtz Centre for Env. Res., Dept. of Landscape Ecology, Permoserstr.15, D-04318, Leipzig, Germany Martin.volk@ufz.de

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Abstract. *Methods for simulating different landscape positions within the SWAT model are being examined. A three component system, consisting of the watershed divide, the hillslope, and the floodplain landscape positions, has been developed to address flow and transport across hydrologic response units prior to concentration in streams. The modified SWAT model is capable of simulating flow and transport from higher landscape positions to lower positions within a single river basin. The revision was developed to address variable source areas within watersheds and stream-side buffer systems which exist alongside many streams. The enhanced model will allow for more accurate simulation of natural transport processes within a hillslope. The revision was tested using data collected from a low-gradient watershed near Tifton, Georgia, USA which contains heavily vegetated riparian buffers. The modified model provided reasonable simulations of surface and subsurface flow across the landscape positions without calibration. The application demonstrates the applicability of the model to simulate filtering of surface runoff, enhanced infiltration, and water quality buffering typically associated with riparian buffer systems.*

Keywords. Watershed modeling, natural resource modeling, surface hydrology

Introduction

Watershed models are valuable tools for examining the impact of land-use on hydrology and water quality. While extensive research has been done to describe the impact of management practices on field and farm runoff, less is known about how these changes are reflected at the watershed scale. The success of the Total Maximum Daily Load (TMDL) program will be based on water quality improvements that result at the watershed scale. Additionally, a national assessment of the effects of conservation practices on watershed scale water quality is underway which relies heavily upon the reliability of watershed flow and transport models (Mausbach and Dedrick, 2004).

The SWAT model has been applied to watersheds throughout the world (Arnold and Fohrer, 2005). The model has received extensive testing in Texas (Saleh et al., 2000; Santhi et al., 2001; Srinivasan et al., 1997), Kentucky (Spruill et al., 2000), Wisconsin (Kirsch et al., 2002), Mississippi (Bingner, 1996), Indiana (Smithers and Engel, 1996), Pennsylvania (Peterson and Hamlett, 1998), and Georgia (Bosch et al, 2004; Van Liew et al., 2006). In most cases, the prediction accuracy was satisfactory to obtain working knowledge of the hydrologic system and the processes occurring in the watersheds. One of the shortcomings of SWAT has been an inability to model flow and transport from one position in the landscape to a lower position prior to entry into the stream. The model utilizes a Hydrologic Unit Area (HUA) concept which combines a unique combination of land-use and soil type within a defined subbasin. Transported water, sediment, and chemicals from the HUA are routed directly into the stream channel. As currently configured, SWAT does not allow transport from upslope HUAs to flow through lower landscape position HUAs prior to entry into the stream.

Arnold et al. (2007) have developed a modification to the model which facilitates such a process (SWAT-L). The modification divides the catchment into three units, the upland divide, the hillslope, and the floodplain (Fig. 1). The modified model routes surface runoff, lateral subsurface flow, and shallow ground water flow from the divide, through the hillslope, through the floodplain, and eventually to the stream. Additional details are provided by Arnold et al. (2007).

The objectives of this manuscript were to test SWAT-L for a small watershed in South-central Georgia. Simulations were conducted which incorporated the landscape routing and a comparison made to observed data.

Methods

Site Description

A site located near Tifton, GA was selected for this research (Fig. 2). The study site consists of two paired watersheds, 57 and 47 ha (Table 1), which join to form a larger watershed (123 ha). Soils in the watershed consist of loamy sands, with Tifton loamy sand (Plinthic Kandiudults; fine loamy, siliceous, thermic) being the dominant soil type in the upland (Calhoun, 1983). The Tifton soil contains subsurface horizons with reduced infiltration rates which perch water and initiate lateral flow during wet conditions (Hubbard, 1983). The Tifton soil contains 7-14 % plinthite from 0.8 to 1.4 m. Over the year, the shallow aquifer water-table varies from 0 to 7 m below the ground surface, depending upon landscape position. The watershed contains dense riparian buffers in the flood plain. The dominant soil type in the flood plain is an Alapaha loamy sand. The uplands consist of tilled fields and some forest (Fig. 2).

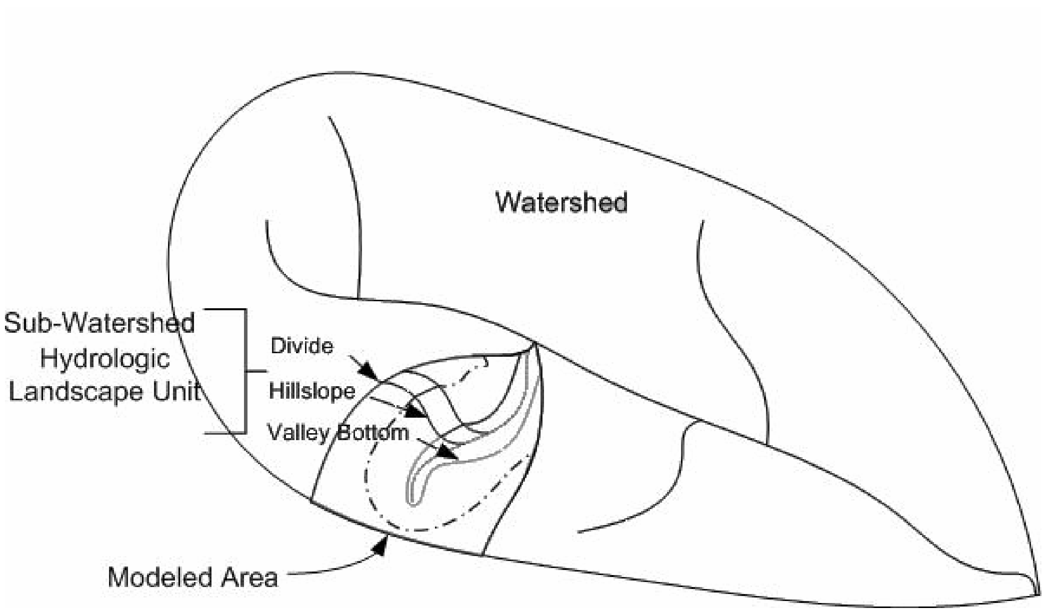

Figure 1. SWAT-L subwatershed landscape delineation within a watershed.

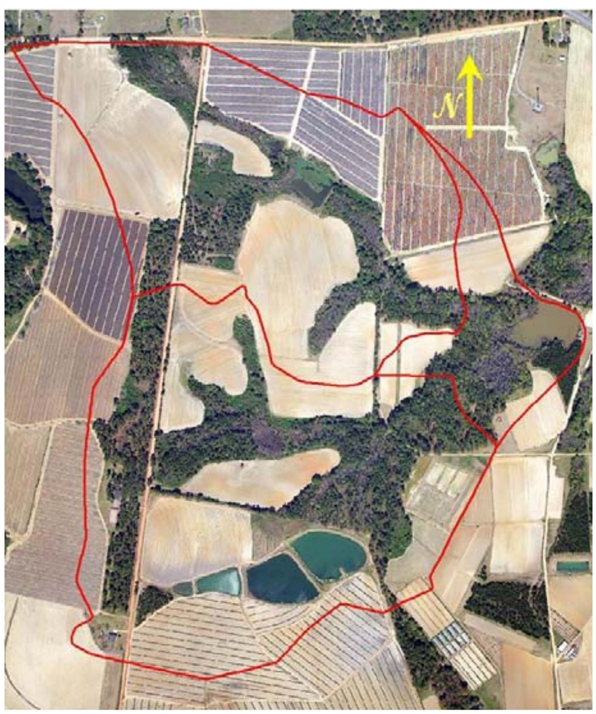

Figure 2. Gibbs Farm Watershed, Tifton, Georgia, illustrating north and south branch watersheds.

Table 1. Land-use for the studied watersheds.

Land-Use	Gibbs South ha (%)	Gibbs North ha (%)
Ponds	3.2 (5.5%)	0.8 (1.7%)
Fields	28.9 (50.6%)	32.0 (68.4%)
Forest	24.2 (42.4%)	13.5 (28.9%)
Roads	0.8 (1.5%)	0.5 (1.0%)
Total	57.1 (100%)	46.8 (100%)

The North and the South basins join and eventually flow into the outlet pond (Fig. 2). Both watersheds are instrumented with weirs within the streams for streamflow measurement. Hydrologic and water quality data were collected in the watershed from October 1996 through November 2004 (Lowrance et al., 2007).

Both basins include stream reaches bordered by mature riparian forests (Fig. 2). Upland areas within the watersheds are tilled. Row crops grown include corn, peanuts, cotton, and vegetables. Most of the field borders between the upland fields and the riparian forests are grassed and used as turn-around areas for farm implements. The grassed areas vary from 5 to 20 m in width. The riparian buffers vary in width from 20 to 100 m.

SWAT-L simulations

The Gibbs Farm Catchment was manually configured for SWAT-L as shown in Figure 3. The simulation was established for one subbasin and three landscape units (divide, hillslope, and flood plain). One HRU was simulated for each landscape unit. A transect through the Fox Den Field at the University of Georgia Gibbs Farm was simulated (Fig. 4). This site has been extensively studied, particularly the riparian buffer (Bosch et al., 1996; Lowrance et al., 1997). The field drains into the lower part of the Southern basin (Fig. 2). Corn, peanuts, and cotton have been grown in the field. There is a grass edge downslope from the field and a woody riparian buffer between the grass buffer and the stream.

SWAT-L input datasets were developed for the watershed and landscape units using the landscape unit configuration shown in Figure 3. Three landscape positions and vegetation types were simulated. A peanut / cotton rotation was assumed in the upland divide, a bermuda grass in the hillslope, and a pine forest in the floodplain. A catchment area of 10 ha was simulated. The divide corresponded to 70% of the area or 7 ha with a slope of 3.0%. The hillslope made up 10% of the area or 1 ha with a slope of 2.4%. The floodplain made up 20% of the area with a slope of 2.0%. The upland and the grass buffer were simulated with the soil type of a Tifton loamy sand while the riparian buffer was simulated with a soil type of a Alapaha loamy sand. Rainfall data were obtained from an on-site recording rain gage while climate data were obtained from a nearby weather station (University of Georgia, 2007). A 5 year simulation was conducted using observed rainfall.

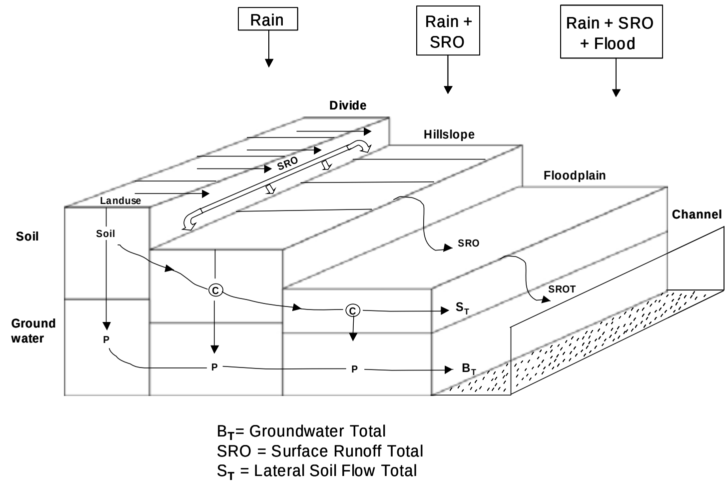

Figure 3. Processes considered in landscape routing units.

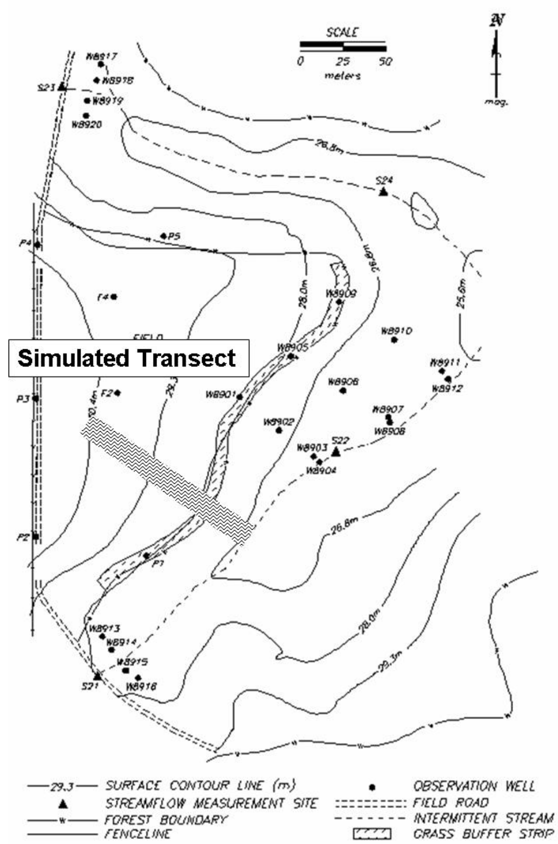

Figure 4. Simulated SWAT-L transect through the Fox Den field.

Results

The summary results for the five year simulation are shown in Table 2. The average annual simulated precipitation for the five year period was 1298 mm. The total water yield on a per area basis for the simulated catchment was 355 mm or 27% of the annual precipitation. Evapotranspiration for the catchment was 702 mm, or 54% of the annual precipitation, while transmission losses from the plants accounted for 16 mm.

The water balance for each of the individual landscape units was also calculated (Table 2). Each component is on a per area basis using the area of that individual landscape unit. The largest contributor to flow from the upland divide was the surface runoff, while the largest contributor from the floodplain was the groundwater (Table 2). On a per area basis, surface runoff within the upland and the hillslope were roughly equivalent although the volume was significantly greater from the upland due to the larger upland area. Surface runoff within the floodplain was only 61% of that in the upland despite the contributions of overland flow from the hillslope to the floodplain. Evapotranspiration within the three units was fairly constant (Table 2). There was a large increase in the groundwater component of the flow within the hillslope landscape component, increasing from 33 mm from the divide to 745 mm in the hillslope. Groundwater within the hillslope includes contributions from both the upland and the hillslope units and is also impacted by the smaller area of this unit.

Table 2. Average annual results for the five year simulation of the Gibbs Farm landscape using the SWAT-L model.

Landscape Unit	Precipitation (mm)	Surface Runoff (mm)	Lateral Flow Contribution (mm)	Groundwater Contribution (mm)	Evapotranspiration (mm)
Divide / Peanut-Cotton	1298	260	99	33	716
Hillslope / Bermuda	1298	304	312	745	642
Floodplain / Pine	1298	159	133	335	683
Watershed Outlet	1298	244	127	164	702

Simulated evapotranspiration (ET) within each landscape unit makes up the largest component of the water balance. In the divide where the row crops are grown ET is simulated to take up 55% of the precipitation. In the hillslope, Bermuda, unit it is 49% and it is 53% in the floodplain pine unit. Simulated surface runoff remains fairly constant across the first two landscape units, 20% in the divide and 23% in the hillslope, but it decreases to 12% in the floodplain landscape unit.

The water balance within each landscape was investigated by calculating the fraction of each water component as a percentage of catchment yield of that water component (Fig. 5). Precipitation is evenly distributed with area, with 70% in the upland, 10% in the hillslope, and 20% in the floodplain. Evapotranspiration is similarly distributed. Surface runoff is disproportionally distributed with respect to the area, with greater surface runoff generated in the upland and the hillslope and less generated in the floodplain. Lateral runoff and groundwater flow are also disproportionally distributed with larger contributions than the fraction of the area in the hillslope and the floodplain. The hillslope generates four times the groundwater flow than its fraction of the area.

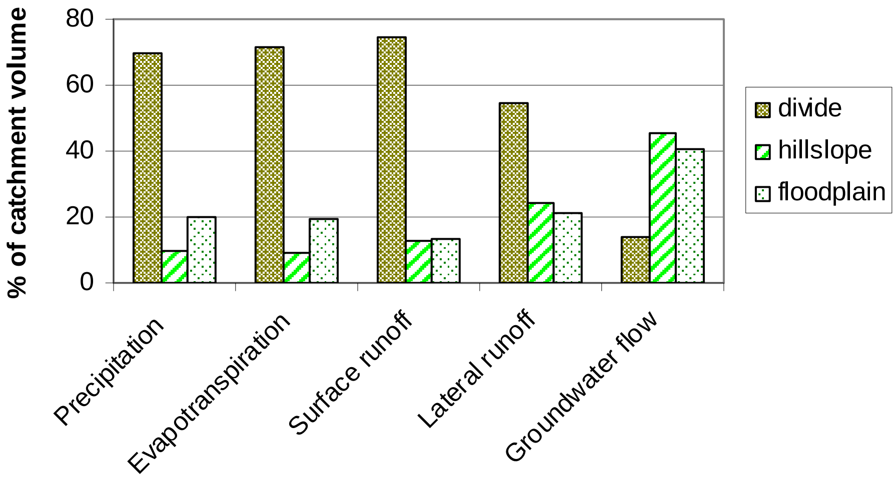

Figure 5. Average annual water balance for each landscape unit expressed as a percentage of the catchment yield of each hydrologic component.

Summary and Conclusions

Lowrance et al. (2007) reported the streamflow for the entire South watershed (Fig. 2) was approximately 15% of the precipitation that fell from 1996 through 2004. The yield from the North watershed was 27% of the precipitation during the same period. While the observed yield from the South watershed was less than the 27% simulated by the SWAT-L model, the measurements of Lowrance et al. (2007) included the area of the watershed which contained several irrigation ponds (Fig. 2) which could increase losses considerably.

Bosch et al (2005) observed that for similar soils 29% of precipitation in conventionally tilled upland fields is lost as surface runoff while other measurements of surface runoff in regional soils have been as low as 7% (Shirmohammadi et al., 1984). Simulated average annual runoff values for the divide (20%) and the hillslope (23%) for this study fall within this range. Prior research within this watershed indicates a 56 to 72% decrease in surface runoff as the flow moves from the upland fields into the grassed buffers (Sheridan et al., 1999). Surface runoff was fairly consistent moving from the grassed buffers into the riparian forest (Sheridan et al., 1999). The average annual volume of surface runoff simulated from the upland was 18172 m^3 while the average annual volume of surface runoff simulated from the hillslope was 3037 m^3. The large decrease indicates a large infiltration component in the hillslope, supporting prior research findings. Simulated surface runoff volume for the hillslope and the floodplain was fairly consistent (Fig. 5), also in agreement with prior field observations (Sheridan et al., 1999).

Estimates for ET in watersheds dominated by pine forests range from 60 to 80% of precipitation per year (Riekerk, 1985). Knisel et al. (1991) reported ET from an upland field in this region as 69% of precipitation for a corn/soybean rotation with an oats winter cover. Bosch et al. (1996) reported ET for the riparian forests in this watershed at 67%. Estimates for ET losses for the corn and fallow upland fields obtained using the GLEAMS model ranged from 700 to 1000 mm per year for the observation period (Bosch et al., 1996). Simulated estimates of ET from this study ranged from 55% for the divide to 53% for the hillslope, slightly below the reported ranges.

While additional calibration and testing of the SWAT-L model is necessary, the results are encouraging. The modifications will allow the model to more realistically represent actual landscape flow and transport processes. The relocation of water flow between surface, lateral, and groundwater flow appears to be represented with the model. As testing of the model is expanded to examine water quality effects the full utility of the model will be utilized.

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