



*The Society for engineering  
in agricultural, food, and  
biological systems*

*An ASAE Meeting Presentation*

*Paper Number: 052167*

## **Evaluation of SWAT Input Parameter Sensitivity for the Little River Watershed**

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**Written for presentation at the  
2005 ASAE Annual International Meeting  
Sponsored by ASAE  
ampa Convention Center  
Tampa, Florida  
17 - 20 July 2005**

**Abstract.** *Water quantity and quality issues continue to be a concern on the Southeast Coastal Plain. Changes to land management practices can conserve soil moisture and reduce sediment, nutrient, and pesticide loadings at the field scale. The Soil Water Assessment Tool (SWAT) watershed scale model was used to simulate the hydrologic response of a 1692-ha subwatershed of the Little River in south-central Georgia over the 1995-2004 period. When calibrated to annual average water yield for a ten-year period that included substantially wet and dry years, the model overpredicted total water yields in 7 of 10 years, primarily due to overestimation of base flow by 20%, and underprediction of evapotranspiration by 7%. Predicted annual average surface runoff was estimated to within 3% of calculated values for the ten-year period. Analysis of model input parameter sensitivity on annual total water yield and surface runoff was conducted for key hydrologic parameters within the LRW. Additional work planned includes analyzing input parameter sensitivity*

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*for daily peak flows, calibrating the model for hydrology and chemical loading, and estimating the uncertainty in the model outputs.*

**Keywords.** Hydrologic modeling, Uncertainty, Parameters.

## Introduction

The objective of the USDA-ARS Conservation Effects Assessment Project (CEAP) is to assess on a nation-wide basis the benefits of soil and water conservation programs in support of policy decision and implementation (USDA-ARS, 2005). The approach adopted by the USDA to carry out the assessment is to use 12 benchmark watersheds with historic hydrologic and land management records to calibrate and validate the watershed-scale hydrologic simulation model Soil Water Assessment Tool (SWAT) (Arnold et al., 1998). Subsequently, SWAT simulations will be relied upon to assess the effects of various conservation practices. Since model input parameters are uncertain to some degree, outputs from simulation models will also have an associated uncertainty. One of the supporting objectives of CEAP is to provide estimates of the model output uncertainty. Estimates of output uncertainty necessarily include analysis of input parameter uncertainty. Sensitivity analysis of the influence that input parameters have on model outputs helps determine which input parameters need increased attention in order to improve model accuracy. The focus of this paper is to evaluate SWAT input parameter sensitivity on annual water yield and surface runoff for the Subwatershed K of the Little River Watershed (LRW), which is one of the 12 benchmark watersheds identified in CEAP.

Several authors have previously addressed input sensitivity and output uncertainty for SWAT modeling efforts. Lenhart et al. (2002) used two approaches to develop sensitivity indices for 44 SWAT input parameters. The authors developed a simple artificial catchment, utilizing soil and climate information from a low mountain range area in Central Germany. The most sensitive parameters were found to be the soil physical properties, two plant specific parameters, and slope length, slope steepness and curve number. In another study based upon the same artificial catchment representation, Huisman et al. (2004) concluded that plant parameter uncertainty had a much larger effect on SWAT-G (Eckhardt et al., 2002) model output uncertainty than did soil property changes due to land use change from cropland to pasture. Huisman et al. (2004) cited Eckhardt et al. (2003), who identified that a relatively large range of values was possible for the plant input parameters.

Sensitivity analysis results in better understanding of which particular input parameters have greater effect on model output. Monte Carlo Simulation (MCS) is a technique that quantifies the input parameters' influence on the model output. Sohrabi et al. (2002) used MCS to estimate uncertainty in SWAT flow, sediment and nutrient loading outputs, given a mean, range, and distribution for 33 input parameters, for the Piedmont physiographic region of Maryland. The authors concluded that the modeled flow estimate was decreased by 64%, sediment load estimate was increased by 8%, and nutrient load estimates remained unchanged when input parameter uncertainty was included in the modeling process, as compared to using a fixed, mean value for each input parameter.

In order to reduce the SWAT output uncertainty for a specific study area in upstate New York, Benaman and Showmaker (2004) developed a methodology for reducing input parameter ranges prior to employing MCS analysis. They performed a sensitivity analysis for input parameters throughout the entire range of values at regular intervals. When the difference in model output of the sensitivity analysis and model output of the base case exceeded a threshold value considered to be the limit for a reasonable outcome, the end of the range for the input parameter was established. They reported a reduction in output uncertainty of an order of magnitude after applying the methodology.

Although SWAT evaluations within the LRW have been performed (Bosch et al., 2004; Van Liew et al., 2005a; Van Liew et al., 2005b), a sensitivity analysis of the SWAT input parameters for the LRW has not been published. The purpose of this paper is to: (i) analyze the sensitivity in

key SWAT hydrologic inputs for K subwatershed of the Little River experimental watershed and (ii) calibrate and validate SWAT model stream flow predictions against measured values for K subwatershed. Additional investigation of stream nutrient and pesticide loadings with the calibrated and validated model is planned.

## **Methods**

### ***Watershed Description***

The LRW is a 334 km<sup>2</sup> area at the head of the Little River in Turner, Worth and Tift counties in southwestern Georgia. The watershed outlet, station “B,” is approximately five km west of the Coastal Plains Research Station near Tifton, GA. Eight stream gages are placed within the watershed to create nested subwatersheds. Precipitation, flow, and water quality records have been collected on the LRW since the late 1960’s. Stream gage measurements quantify the portion of the hydrologic budget identified as the water yield (WYLD) in SWAT. Observed stormflow, or surface runoff, was calculated to be 35% of the stream gage measurements, based upon prior work in the watershed (Shirmohammadi et al., 1984). Groundwater recharge into the deep aquifer was estimated to be 1% of precipitation (Sheridan, 1997). Observed evapotranspiration was calculated as the difference between: precipitation minus deep groundwater recharge; and total water yield.

The sensitivity analysis was performed on subwatershed “K” (SW-K), which is located at the upper end of the LRW. Mixed forest and pines cover approximately 65% of SW-K; land use in the remainder of the 1692 ha subwatershed is primarily row crops including cotton, peanuts, corn, and an increasing proportion of fruit and vegetable crops. The agricultural fields are generally small and nested among the forested areas. Riparian zones along the dendritic system of stream channels buffer the stream water from sediment and chemical runoff from the fields, and from nitrate-nitrogen leaching from lateral groundwater flow.

The soils in SW-K are typically loamy sands with a layer of low hydraulic conductivity soil underneath the plow layer. Once the soil profile fills, surface runoff occurs commonly from the intense convective storms that characterize the region.

### ***Model Description***

The version of SWAT used for the investigation was AVSWATX-2003, which has been developed with a GIS interface. SWAT is a hydrologic and geochemical process model developed to estimate hydrologic balance, and nutrient and pesticide loadings at the watershed scale.

### ***Sensitivity Analysis***

The method followed for analysis of input parameter sensitivity was proposed by C.T. Haan et al. (1995) and restated by P.K. Haan and Skaggs (2003).

1. Determine objective functions of interest.
2. Identify the most influential parameters.
3. Perform a sensitivity analysis; select the most sensitive parameters for further study.

## Objective Functions

The annual mean water yield and surface runoff were the output variables studied for the sensitivity analysis. The Nash-Sutcliffe Efficiency (NSE) was used as a measure of model goodness of fit:

$$NSE = 1 - \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \quad (1)$$

where  $O_i$  is the observed water yield or surface runoff for year  $i$ ,  $S_i$  is the simulated value for the same period, and  $\bar{O}$  is the mean annual value over the simulation period.

## Input Parameter Selection

Bosch et al. (2004) evaluated SWAT on subwatershed J (SW-J) in the LRW, which is adjacent to SW-K. They used three parameters to reflect initial simulation conditions and to improve streamflow predictions: the initial depth of water in the shallow aquifer (SHALLST), the time required for water leaving the bottom of the root zone to reach the shallow aquifer (GW\_DELAY), and the initial water storage in the vadose zone (FFCB).

Van Liew et al. (2005b) found that these parameters influenced the calibration of the SWAT model for five USDA ARS experimental watersheds including the Little River watershed:

Surface response: runoff curve number (CN2), soil evaporation compensation factor (ESCO), and available soil water capacity (SOL\_AWC).

Subsurface response: groundwater “revap” coefficient (GW\_REVAP), depth of water in the shallow aquifer for “revap” to occur (REVAPMN), depth of water in the shallow aquifer required for return flow to occur to the stream (GWQMN), baseflow recession constant (ALPHA\_BF), time for water leaving the bottom of the root zone to reach the shallow aquifer (GW\_DELAY), and deep aquifer percolation fraction (RCHRG\_DP).

Basin response: channel hydraulic conductivity (CH\_K2), and surface runoff lag time (SURLAG).

Table 1 provides a description of the fourteen parameters included in the sensitivity analysis: CN2 (forest land use), CN2 (crop land use), ESCO, SOL\_AWC, SHALLST, GW\_DELAY, FFBC, GW\_REVAP, REVAPMN, GWQMN, ALPHA\_BF, RCHRG\_DP, CH\_K2, and SURLAG. Table 1 also shows the AVSWATX default values and the base values used in the analysis. The parameter base values were selected in view of the previous modeling work done by Bosch et al. (2004) on SW-J and Van Liew et al. (2005a) on subwatershed F (which includes SW-K) and the entire experimental LRW. Base parameter values were selected at or near the values calibrated by one of the authors, or between the values used by the authors.

The sensitivity coefficient,  $S$ , represents the ratio of the rate of change of the output function versus the rate of change of the input parameter under study:

$$S = \frac{\delta O}{\delta P} \quad (2)$$

where  $O$  is the model output and  $P$  represents an input parameter. The absolute sensitivity is approximated as follows (Haan, C.T., 2002):

$$S \approx \frac{(O_{P+\Delta P} - O_{P-\Delta P})}{2\Delta P} \quad (3)$$

where  $S$  is absolute sensitivity,  $O_{P+\Delta P}$  and  $O_{P-\Delta P}$  are model outputs with the input parameter being studied set at a value equal to the base value plus or minus a specified percentage (often taken to be in the range of 10-25%), and  $\Delta P$  represents the prescribed absolute change in the value of the input parameter.

The relative sensitivity,  $S_r$ , is defined as the ratio of the ratio of the difference in the model output to the value of the output when the input parameters are set to their base values, and the ratio of the change in the input parameter to the initial value of the parameter. The relative sensitivity is approximated as follows:

$$S_r \approx \frac{\frac{(O_{P+\Delta P} - O_{P-\Delta P})}{O}}{\frac{\Delta P}{P}} \quad (4)$$

where  $S_r$  is relative sensitivity,  $O$  is model output with input parameters set at base values,  $P$  is the value of the input parameter,  $\Delta P$ ,  $O_{P+\Delta P}$ , and  $O_{P-\Delta P}$  are as previously described.

The SWAT model results shown in table 2 and figures 2 and 3 were obtained by using the base values of the input parameters.

Table 1. AVSWATX input parameters chosen for sensitivity analysis.

Parameter	Description	Units	AVSWATX Default Value	P, Parameter Base Value
<i>Surface water response</i>				
CN2 (Forest)	SCS curve number, antecedent moisture condition II, for forested land use	n/a	55.0	55.0
CN2 (Crop)	SCS curve number, antecedent moisture condition II, for crop land use	n/a	77.0	77.0
ESCO	Soil evaporation compensation factor	(fraction)	0.95	0.80
SOL_AWC	Available soil water capacity	(mm/mm)	0.09 – 0.19 <sup>[a]</sup>	0.09 – 0.19 <sup>[a]</sup>
<i>Subsurface water response</i>				
SHALLST	Initial depth of water in the shallow aquifer	(mm)	0.5	800
GW_DELAY	Time required for water leaving the bottom of the root zone to reach the shallow aquifer	(d)	31	1
FFBC	Initial water storage in the vadose	(fraction)	0.0	0.5

	zone			
GW_REVAP	Rate of transfer from shallow aquifer to root zone	n/a	0.02	0.1
REVAPMN	Threshold water depth in shallow aquifer for perc to deep aquifer to occur	(mm)	1.0	200
GWQMN	Threshold water depth in shallow aquifer for return to reach to occur	(mm)	0.0	10
ALPHA_BF	Baseflow apha factor, lower number means a slower response	(d)	0.048	0.5
RCHRG_DP	Deep aquifer percolation fraction	(fraction)	0.05	0.05
<i>Basin Response</i>				
SURLAG	Surface lag coefficient; controls fraction of water entering reach in one day	n/a	4.0	1.0
CH_K2	Effective hydraulic conductivity in main channel alluvium	(mm/hr)	0.0	50

<sup>[a]</sup> values for layer 1 of the four soil groups covering 96% of the HRU's

## Results and Discussion

The departure of annual precipitation for each of the ten years of the study from the 37-year mean for the LRW is shown in figure 1. The average annual precipitation over the ten-year period was 8% below the 37-year mean annual precipitation. In five of the ten years, the annual precipitation was less than the long-term mean by a difference of more than 15%.

The method used by SWAT to calculate evapotranspiration has a significant impact on the hydrologic outputs of a model run (table 3). Van Liew et al. (2005a) indicated they used the Hargreaves method to determine PET, as did Bosch et al. (2004). For the ten-year simulation, the Hargreaves method yielded higher actual ET than did either of the other two methods examined (table 3). Since SWAT results with the Hargreaves ET method for surface runoff, water yield, and ET were closest to measured results for water yield, and calculated values for surface runoff and ET based upon past studies in the LRW, the Hargreaves method was used for the remainder of the analysis.

Table 2. Sensitivity analysis results for sensitive parameters; input parameters (P) were perturbed +/-25%.

Parameter	Units	P, Parameter Base Value	Water Yield, $S_r$	Surface Runoff, $S_r$
CN2 (Forest)	n/a	55.0	0.05	1.69
CN2 (Crop)	n/a	77.0	0.45	3.27
ESCO	(fraction)	0.80	0.54	0.31
SOL_AWC	(mm/mm)	0.09 – 0.19 <sup>[a]</sup>	-0.48	-0.46

The relative sensitivities of the four most sensitive input parameters on annual total water yield and annual surface runoff are shown in table 2. The absolute values of the relative sensitivities of CN2 on the cropped land, ESCO, and SOL\_AWC on total water yield were greater than 0.45. The relative sensitivities of CN2 for forested and cropped land use on surface runoff were 1.69 and 3.27, respectively. The parameters ESCO and SOL\_AWC were somewhat sensitive on surface runoff with  $S_s$  of 0.31 and -0.46 respectively. The annual total water yield and surface runoff were insensitive to changes in the ten parameters associated with subsurface and basin response. The relative sensitivities for these parameters were less than 0.05. Annual total water yield was also relatively insensitive to CN2 for forested land; the  $S_r$  for CN2 (Forest) was 0.05.

It is interesting to note the difference in sensitivities for CN2 (Forest) and CN2 (Crop) on total annual water yield. For forested acreage, changing the curve number +/-25% only affected the fraction of surface runoff and not total flow. Increase or decrease in surface runoff due to increase or decrease in CN2 resulted in a corresponding decrease or increase in base flow of roughly the same volume, and thus total flow remained unchanged. For crop land, changing CN2 also changed surface runoff, but since more of the infiltrated water went to ET for this land use, increase in CN2 also influenced water yield. This exercise stresses the importance of looking at the components of the flow in addition to total flow.

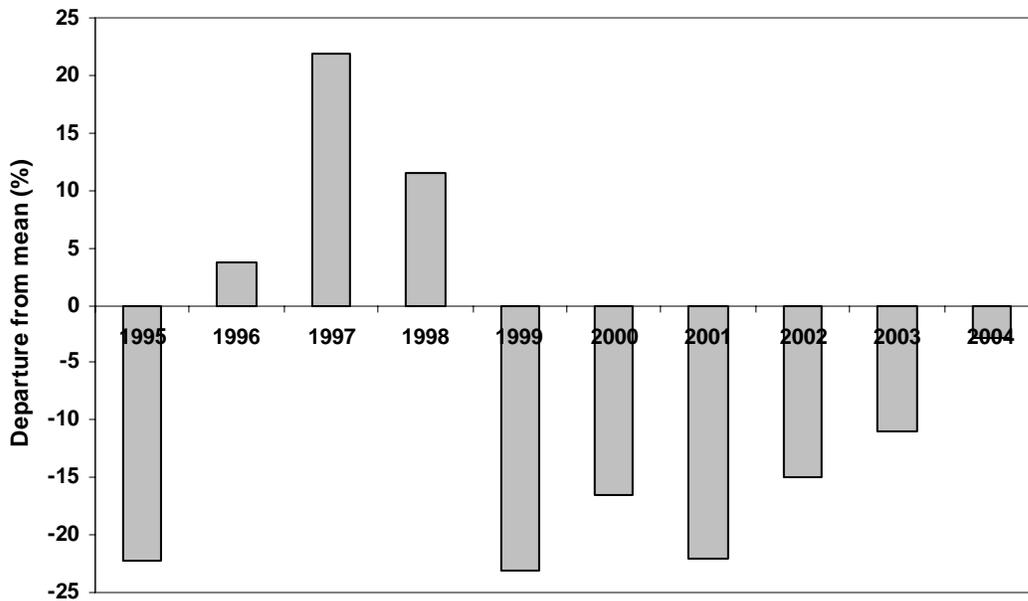


Figure 1. Annual precipitation departure from 37-year mean of 1228 mm.

Table 3. Ten-year annual average results using various ET methods.

	Observed	SWAT Model Output		
		ET Method		
		Priestley-Taylor	Penman-Monteith	Hargreaves
Precipitation (mm)	1135	1138	1138	1138
Stormflow (SURQ) (mm)	113	119	120	110
Baseflow (LATQ + GWQ) (mm)	210	291	333	219
Water Yield (WYLD) (mm)	324	423	466	340
ET (mm)	805	688	643	775
PET (mm)	-	1165	1475	1353
Sediment Yield (SED) (t/ha)	-	2.21	1.97	2.00

The results of simulated versus observed total water yield by year for the ten year study period are shown in figure 2. The NSE for total water yield was 0.67. Figure 2 indicates that the model more nearly simulates observed total water yield for the years with above average precipitation (1996-1998) than for years with below average precipitation. The NSE for above-average precipitation years was 0.78, and the NSE for the remaining years was -0.28, indicating a bias in the base parameter set toward years with above average precipitation. AVSWATX overpredicted total water yield during five of the seven drier-than-average years and overpredicted surface runoff in four of seven of the dry years. Previous research on the LRW (Sheridan and Shirmohammadi, 1986) indicated that more accurate predictions of streamflow were made when CN2 for low-lying, poorly-drained areas was adjusted to represent seasonal variation in available soil water storage. They reported that although 37% of annual precipitation occurred the first four months of the year, 73% of the annual streamflow was measured in the same period. Specifically, Sheridan and Shirmohammadi (1986) used a lower CN2 during the dry season of the year that typically occurs in the late summer and fall.

The disparity in model efficiency for wet and dry years indicates that additional analysis of model output is needed. For example, investigating seasonal variation of water yield may provide insight into total water yield overprediction in dry years and the underprediction of water yield in 2003, when annual precipitation was 11% below the 37-year mean. Also, separate calibrations of SWAT for either dry years or years with below average precipitation during the first four months of the year may improve model efficiencies. The approach of handling wet and dry years separately may lead to unique calibration settings for the two conditions.

The simulation trend for surface runoff (fig. 3) is similar to that for total water yield. Overall NSE for surface runoff was 0.67. For the above-average precipitation years NSE was 0.77, and for the below-average precipitation years NSE was -0.25.

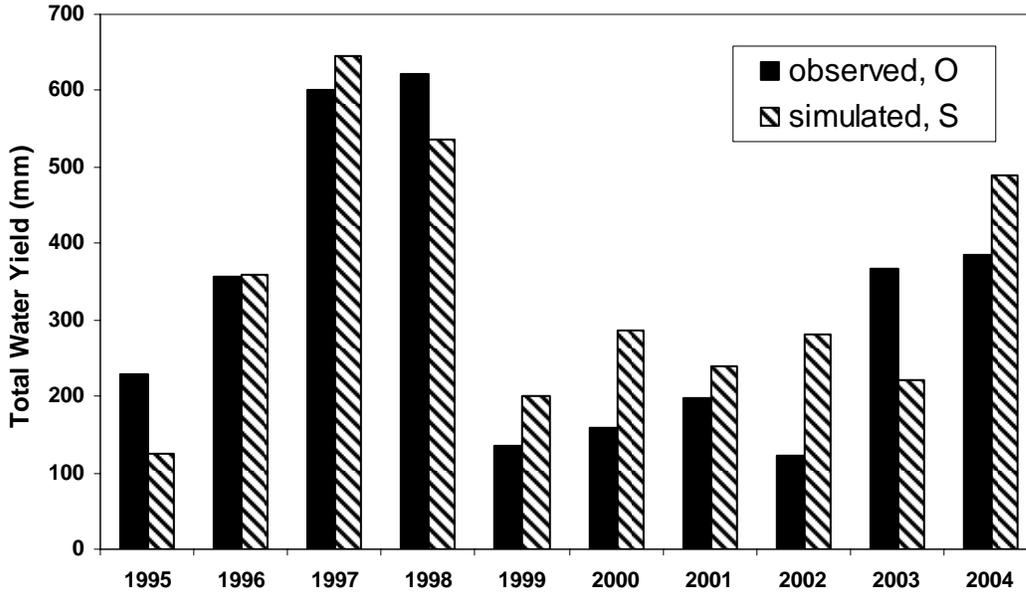


Figure 2. Ten-year average total water yield.

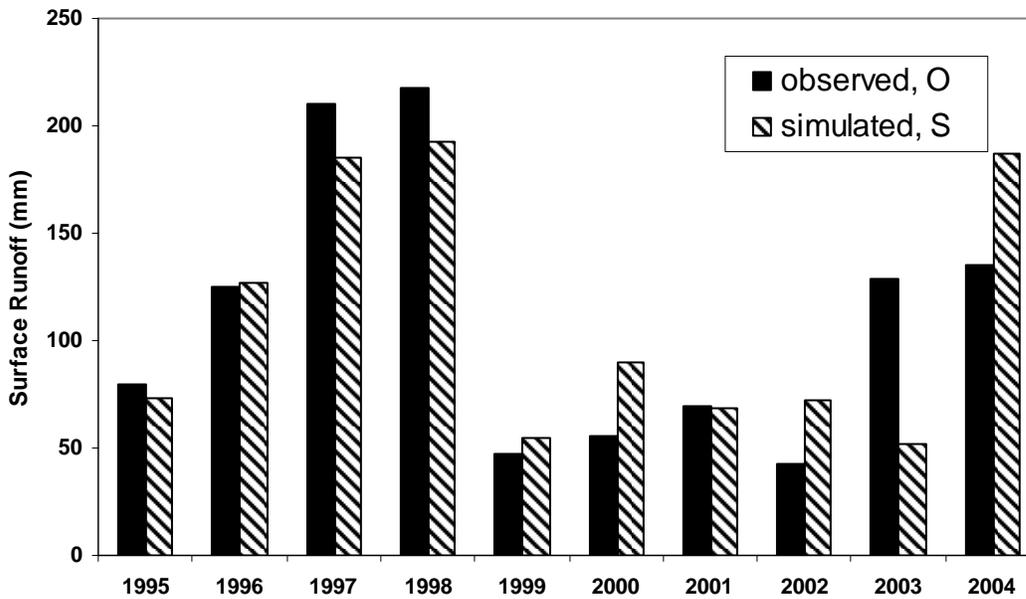


Figure 3. Ten-year average surface runoff.

### ***Future Work Planned***

Additional modeling work planned includes analyzing input parameter sensitivity for daily peak flows, calibrating the model for hydrologic and chemical loading, and estimating the uncertainty

in the model outputs. One year's land use coverage was used in this analysis. Additional years of detailed land use information are available and will be used to determine the effect of land use change over time on SWAT model predictions.

## Conclusion

The most sensitive input parameters on SWAT model simulation outputs for annual total water yield in LRW subwatershed K are CN2 on cropped land, ESCO, and SOL\_AWC. The most sensitive parameters for annual surface runoff are CN2 for forested and cropped land use, ESCO, and SOL\_AWC. Additional calibration may improve model efficiency. Further analysis is needed to find the reasons that the model results for drier-than-average years are significantly worse than for wetter-than-average years.

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