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Scaling up the SWAT model from Goodwater Creek Experimental Watershed to the Long Branch Watershed

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***Abstract*.** The primary model selected for use in the Conservation Effects Assessment Project-Watershed Assessment Study (CEAP-WAS) was the Soil and Water Assessment Tool (SWAT) model. In this study, the scaling of the SWAT model from a small watershed to a larger watershed was evaluated. The model was first calibrated and evaluated for Goodwater Creek Experimental Watershed (GCEW), a 70 km^2 watershed located in north-central Missouri, using SSURGO and STATSGO soil data sets. Then, the performance of the calibrated model in simulating stream flow from Long Branch watershed, a 462 km^2 watershed that contains GCEW, was evaluated. Both GCEW and Long Branch watersheds had similar soil, land use, and cropping and management systems. The performance of the model in simulating stream flow from the Long Branch watershed was as good as that from GCEW. For Long Branch watershed, the 9-yr (1995-2003) average simulated annual stream flow was less than 4 % higher than that measured, and the E_{NS} and r^2 values were 0.97 and 0.94 for annual stream flow and 0.79 and 0.77 for monthly stream flow, respectively. The model, however, did not perform well in simulating daily stream flow. Overall, the model performed quite well in simulating annual and monthly stream flows. Future plans include (1) improving stream flow simulation on a daily basis, (2) improving sediment yield simulation, and (3) calibrating the pesticide component of the model.

Keywords. Watershed modeling, stream flow, surface runoff, sediment yield.

Introduction

The National Resources Conservation Service (NRCS) and Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) developed the Conservation Effects Assessment Project (CEAP) to quantify the environmental benefits of conservation practices implemented under the 2002 Farm Bill (Mausbach and Dedrick, 2004). The two major components of CEAP are the national assessment study and the watershed assessment study (CEAP-WAS). The primary objective of the CEAP-WAS is to quantify the benefits of conservation programs and their many practices on water quality at the watershed scale. Twelve USDA-ARS watersheds were selected for the CEAP-WAS, including the Salt River Basin (~6500 km^2) in Missouri.

The Salt River Basin lies within the claypan soil (MLRA 113), which occupies about 4 million ha in Missouri and Illinois. Claypan soils contain a naturally occurring argillic horizon 15 to 45 cm below the surface that consists of more than 50% clay. Because of the low permeability of these soils, surface runoff accounts for ~85% of the mean annual stream flow (Hjelmfelt et al., 1999). The impact of agricultural practices on nutrient, sediment, and pesticide fluxes need to be better assessed to improve general water quality and reduce water treatment cost. Stream and reservoir water quality data alone are not sufficient to determine these impacts because of the presence of confounding factors such as land use changes and weather trends. A comprehensive water quantity and quality model capable of simulating the impact of weather, land use, land management, and Best Management Practices (BMPs) on water quality can enhance our ability to understand how these factors interact. The Soil and Water Assessment Tool (SWAT) model (Neitsch et al., 2005) was selected to evaluate the watershed-scale benefits of conservation practices.

One of the more intractable challenges in watershed-scale analyses is scaling up from controlled area research results (i.e, plot and field) to mixed-use watersheds, and then to increasingly larger watersheds. The Goodwater Creek Experimental Watershed (GCEW) is substantially richer in hydrologic, weather, land use, and water quality data than are the larger scales between the GCEW and the Salt River Basin. Thus, challenges in obtaining input parameters increase when we scale up from GCEW. Preliminary studies have been conducted to evaluate the performance of the SWAT model for GCEW (Sadler et al., 2006; Ghidey et al., 2005; Sadler et al., 2005). Bockhold et al. (2005) also evaluated the water quality benefits from conservation practices from GCEW. In this study, further calibration and evaluation of the SWAT model for GCEW will be conducted using both the STATSGO and the SSURGO soil data sets and detailed cropping and management systems (Table1 and Table 2). Then, the performance of the SWAT model will be evaluated for its ability to simulate flow within the Long Branch watershed, the 462 km^2 watershed containing the GCEW and draining into Mark Twain Lake within the Salt River Basin. The objectives were (1) to calibrate the SWAT model to simulating stream flow and sediment yield for GCEW using the STATSGO and the SSURGO soil data sets, and (2) to evaluate the performance of the calibrated model in simulating stream flow for Long Branch watershed.

Study Watershed

The Long Branch watershed drains 462 km^2 within the Central Claypan Major Land use Resource Areas (MLRA 113; NRCS, 2002) and is a direct tributary to Mark Twain Lake. The GCEW is a 70 km^2 area watershed in the headwaters of the Long Branch watershed (Fig. 1). The soil mapping units in this specific study mostly belong to the Mexico and Putnam soil series, and are considered poorly drained because of a naturally occurring argillic claypan horizon. Long Branch is mainly an agricultural watershed and approximately 70% of the area is cropland.

The land use classification of the watershed is discussed in detail in the next section. The Goodwater Creek Experimental Watershed (GCEW), which was established as a research catchment by the USDA-ARS in 1971 to study the hydrology of these claypan soils, is primarily agricultural. From 1992 until present, sediment and chemical concentrations were also measured at the outlet of GCEW.

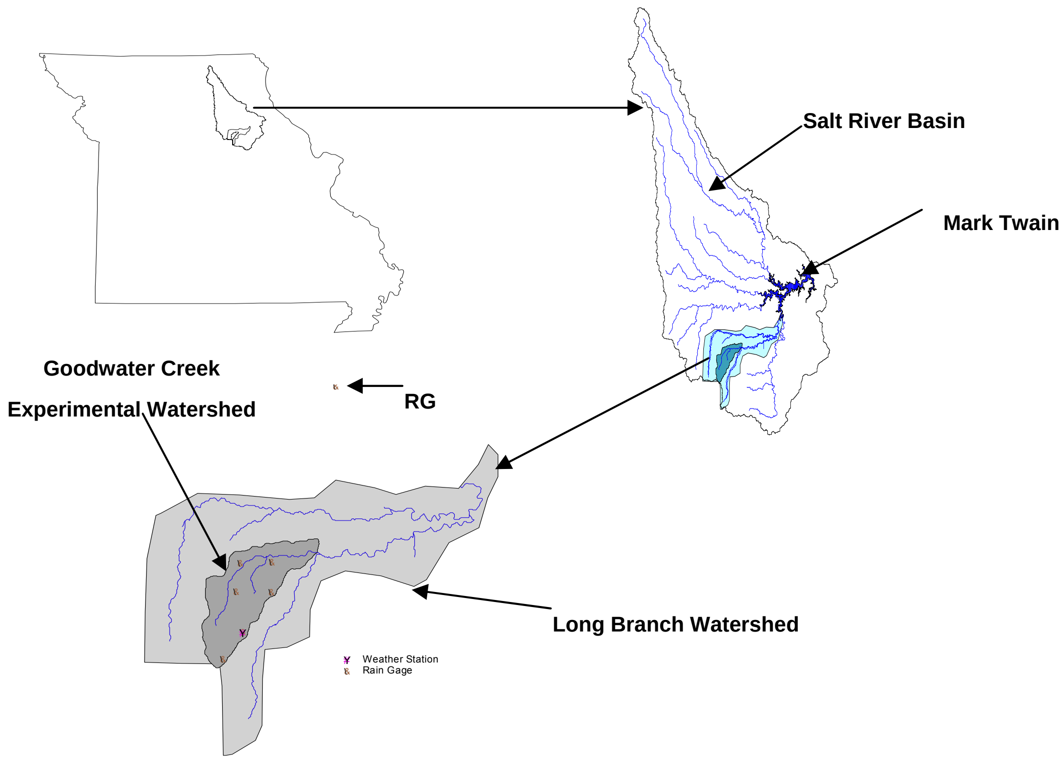

Figure 1. The location of the study watershed. RG is the rain gauge located outside Long Branch watershed

Model Input Parameters

Model input parameters for GCEW were discussed in detail by Ghidey et al. (2005). The Digital Elevation Model (DEM) for the Long Branch Creek watershed was obtained from 10-m buffered ESRI grid of the10-digit watershed 0711000604.The Soil Survey Geographic database (SSURGO) and State Soil Geographic (STATSGO) soil data sets were used in this study. The land use/cover data for 2005 was obtained from the Missouri Spatial Data Information Service (MSDIS) website (www.msdis.missouri.edu). The land use/cover was classified into cropland (70.1%), pasture (17.6%), forest (10.3%), and urban (2.0%). To classify the cropland into corn, soybean, grain sorghum, and wheat, crop data from the National Agricultural Statistics Service (NASS) (http://www.nass.usda.gov) was used. The average (1995-2005) cropland consisted of 26.6% corn, 59.0% soybean, 7.9% grain sorghum, and 6.5% wheat. Tillage type for each crop was also determined using data from Conservation Technology Information Center (CTIC, www.ctic.purdue.edu). Based on the data from 1995 -2005, the percentage of each crop under conventional, conservation, and no-till tillage system was 46.9, 33.3, and 19.8% for corn; 20.1, 31.5, and 48.4% for soybean; 9.9, 18.9, and 79.2% for wheat; and 59.1, 30.0, and 10.1% for grain sorghum, respectively. The cropping and management information for conventional and no-till tillage systems are presented in Table1 and Table 2. Conservation tillage had similar management system as conventional tillage system, except that a chisel plow was used instead of a moldboard plow. Tillage and chemical practices used for grain sorghum were assumed similar to corn. Both Long Branch and GCEW had similar soil, land use, and cropping and management information systems.

The Long Branch watershed was divided into 14 sub basins. Daily precipitation measured from six rain gauges distributed within Goodwater Creek watershed, and one rain gauge outside the Long Branch watershed boundary was used in the analysis (Figure1). Other available weather stations were located farther from the centroid of the 14 sub basins and were not retained for this analysis. Minimum and maximum temperature, solar radiation, wind speed, and relative humidity data measured from a weather station in GCEW were used to run the model.

Stream flow and sediment yield measured at the outlet of GCEW (1993-2003) and stream flow measured in the Long Branch watershed (1995-2003) was used in the analysis. Stream flow data for Long Branch watershed was obtained form USGS website (http://waterdata.usgs.gov/ Station Number 05506100). No measured sediment yield data were available from Long Branch watershed.

Table 1. Crop and tillage management for conventional tillage system.

Crop type	**Management**	**Date**
Corn	General Fall Plowing	Nov 11
	Anhydrous Ammonia @168 kg ha^{-1} (injected)	March 25
	Elemental Nitrogen @ 33.6 kg ha^{-1}	April 11
	Elemental Phosphorous at 39.4 kg ha^{-1}	April 11
	Disking (Disc Plow Ge23ft)	April 11
	Planting	May 5
	Atrazine (2.25 kg ha^{-1})	May 18
	Cultivation (Row cultivator ge 15 ft)	June 6
	Harvest/kill	Oct 11
Soybean	General Fall Plowing	Nov 1
	Elemental Nitrogen @ 22.4 kg ha^{-1}	May 10
	Elemental Phosphorous at 20 kg ha^{-1}	May 10
	Disking (Disc Plow Ge23ft)	May 10
	Planting	May 12
	Cultivation (Row cultivator ge 15 ft)	June 15
	Harvest/kill	Oct 1
Wheat	General Fall Plowing	Oct 1
	Elemental Nitrogen @ 44.8 kg ha^{-1}	Oct 3
	Elemental Phosphorous@ 30 kg ha^{-1}	Oct 3
	Disking (Disc Plow Ge23ft)	Oct 3
	Planting	Oct 5
	Elemental Nitrogen@ 67.2 kg ha^{-1}	March 15
	Harvest/kill	June 25

Table 2. Crop and tillage management for no-till tillage system.

Crop type	Management	Date
Corn	Anhydrous Ammonia @168 kg ha^{-1} (knifed)	March 23
	Elemental Nitrogen @ 33.6 kg ha^{-1}	April 8
	Elemental Phosphorous @ 39.4 kg ha^{-1}	April 8
	Atrazine @ 1.25 kg ha^{-1}	April 8
	No-till mixing	April 8
	Planting	May 5
	Atrazine@ 1.25 kg ha^{-1}	May 16
	Harvest/kill	Oct 18
Soybean	Elemental Nitrogen @ 22.4 kg ha^{-1}	May 10
	Elemental Phosphorous @ 20 kg ha^{-1}	May 10
	Roundup @ 1 quart/acre	May 10
	No-till tillage	May 10
	Planting	May 12
	Roundup @ 1 quart/acre	June 12
	Harvest/kill	Oct 1
Wheat	Elemental Nitrogen @ 44.8 kg ha^{-1}	Oct 3
	Elemental Phosphorous @ 30 kg ha^{-1}	Oct 3
	No-till tillage	Oct 3
	Planting	Oct 5
	Elemental Nitrogen@ 67.2 kg ha^{-1}	March 15
	Harvest/kill	June 25

Data Analysis

Model predictions were evaluated using two methods: (1) a linear regression (r^2) method, and (2) the model efficiency using the Nash and Sutcliffe (1970) equation:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{mi} - Q_{ci})^2}{\sum_{i=1}^{n}(Q_{mi} - Q_{av})^2}$$

where: E_{NS} is the efficiency of the model, Q_{mi} are measured values, Q_{ci} are predicted values, and Q_{av} is the average measured value.

The r^2 value represents the degree of correlation between simulated and observed values. The Nash-Suttcliffe efficiency value (E_{NS}) indicates how well the plot of observed versus simulated values fits the 1:1 line. An E_{NS} value of 1 indicates a perfect 1:1 relationship between measured and simulated values. A negative E_{NS} value means that the prediction is worse than the observed mean.

Results and Discussion

Default Run for GCEW

To evaluate the performance of the model in simulating stream flow and sediment yield using the default parameters, the model was run for 11 years (1993-2003). The model overestimated average annual stream flows (surface runoff + base flow) and surface runoff by 14 and 27%, respectively, when run using the STATSGO data set, Surface runoff contributed 95% of the simulated total stream flow, which was higher than that from GCEW and higher than that reported by Hjelmfelt et al. (1999). The model also greatly underestimated (by 88%) sediment yield. Measured and simulated average annual sediment yields were 1618 and 204 kg ha^{-1}, respectively. When the model was run using the SSURGO data set, it overestimated stream flow and surface runoff by 32 and 37%, respectively, and underestimated sediment yield by 23%. For both soil data sets, the model significantly overestimated stream flow and underestimated sediment yield. Thus, calibration of the model focused on reducing surface runoff, increasing base flow, and increasing sediment yield.

Calibration and Validation for GCEW

The model was calibrated using 5 yr (1993-1997) of stream flow and sediment yield data. The adjustments made to the model parameters to calibrate flow were similar with the STATSGO and SSURGO soil data sets. To decrease surface flow, adjustments were made to curve number (CN2), operation curve number (CNOP), available soil water content (AWC), soil hydraulic conductivity, and soil evaporation compensation factor (ESCO). Both CN2 and CNOP for each crop type were reduced by 3. ESCO was increased from 0.75 to 0.85. Adjustments were also made to soil available water content (AWC) and soil hydraulic conductivity based on the data available from USDA-Natural Resources Conservation Service soil physical properties for each soil series (http://soildatamart.nrcs.usda.gov). To calibrate base flow, ground water re-evaporation coefficient (GW_REVAP) was adjusted from 0.01 to 0.05. The model was calibrated to closely match measured and simulated values. Santhi et al. (2002) suggested that if the simulated runoff is within 15% of that measured and $E_{NS} \geq 0.5$ and $r^2 \geq 0.6$, then model simulation of runoff is expected to be satisfactory. After calibration, the difference between measured and simulated annual stream flow was ~ 10 % for both soil data sets. Simulated surface runoff accounted for 85 % and 87 % of the total stream flow for the models with the STATSGO and the SSURGO data sets, respectively. Calibrated results (r^2 and E_{NS} values) obtained for the model run using the STASGO data set on an annual, monthly and daily basis were similar to those results for the calibrated model using the SSURGO data set (Table 3). For both soil types, the model performed quite well, particularly in simulating annual and monthly stream flows.

To improve sediment yield prediction of the model, adjustments were made to the parameters used to calculate sediment routing including the linear (SPCON) and exponential (SPEXP) parameters. SPCON was increased from 0.0001 to 0.001, and SPEXP was increased from 0.10 to 0.14. The model underestimated average annual sediment yield by 36% for the model using the STATSGO data set and 32% for the model run using the SSURGO data set. Simulated annual sediment yield compared well with those measured except in 1993 where the measured sediment yield was approximately twice higher than that simulated. Excluding the data for this year that was exceptionally wet in late spring and early summer, the model underestimated average annual sediment yield by only 9% for the model with the STATSGO data set and 7 % for the model with the SSURGO data set. The model performed quite well in simulating annual and monthly sediment yields (Table 3).

The calibrated model was validated using 6 years (1998 through 2003) of data measured at the outlet of GCEW. The difference between measured and simulated average annual stream flow was 1% for the model with the STATSGO data set and 4% for the model with the SSURGO data set. For both soil types, r^2 and E_{NS} for annual, monthly, and daily stream flow values indicate that the model is satisfactory (Table 3). The model overestimated average annual sediment yield by 22% for the model with the STATSGO data set and 47% for the model with the SSURGO data set. Low values for the model efficiency for sediment yield indicate that the processes may not be well represented (Table 3). However, the method used to calculate sediment loads from the measured sediment yield from concentrations and flows is being re-evaluated. Once new data are available, the sediment component of the SWAT model will be re-calibrated.

Overall, our study showed that stream flow simulation of the SWAT model using the STATSGO soil data set was as good as the results obtained running the model using the SSURGO soil data set. This indicates that, for our soil condition, using the SSURGO soil data set, which has higher resolution than the STATSGO soil data set, did not improve stream flow simulation of the model.

Model Results for Long Branch Watershed

The performance of the SWAT model calibrated for GCEW (using the STATSGO soil data set) was evaluated in simulating stream flow from Long Branch watershed. The model was run for 8 yrs (1995-2003). Measured and simulated annual and monthly stream flows are shown in Figure 2. The difference between measured and simulated average annual stream flow was 4%. There was a good relationship between measured and simulated annual stream flows (Fig. 2 and Table 3). The r^2 and E_{NS} values for monthly stream flow were 0.79 and 0.77, respectively. The r^2 and E_{NS} values for daily stream flow were 0.45 and 0.45, respectively. Simulated surface runoff accounted for 85% of the total stream flow. Overall, the performance of the SWAT model calibrated for a small watershed (GCEW) was satisfactory in simulating stream flow from a watershed approximately 7 times larger in area.

Table 3. The r^2 and E_{NS} values for GCEW and Long Branch watersheds.

	GCEW Calibration				GCEW Validation				Long Branch	
	SSURGO		STATSGO		SSURGO		STATSGO		STASTGO	
Parameter	r^2	E_{NS}	r^2	E_{NS}	r^2	E_{NS}	r^2	E_{NS}	r^2	E_{NS}
Daily stream flow	0.50	0.50	0.49	0.49	0.54	0.52	0.53	0.50	0.45	0.45
Daily sediment yield	0.46	0.45	0.47	0.48	0.16	-0.20	0.14	-0.01	NA	NA
Monthly stream flow	0.76	0.72	0.77	0.73	0.67	0.66	0.66	0.64	0.79	0.77
Monthly sediment yield	0.58	0.47	0.58	0.50	0.49	0.33	0.53	0.49	NA	NA
Annual stream flow	0.92	0.87	0.91	0.80	0.93	0.92	0.92	0.91	0.97	0.94
Annual sediment yield	0.95	0.51	0.93	0.56	0.65	0.11	0.66	0.51	NA	NA

NA – Sediment yield data were not measured from Long Branch watershed.

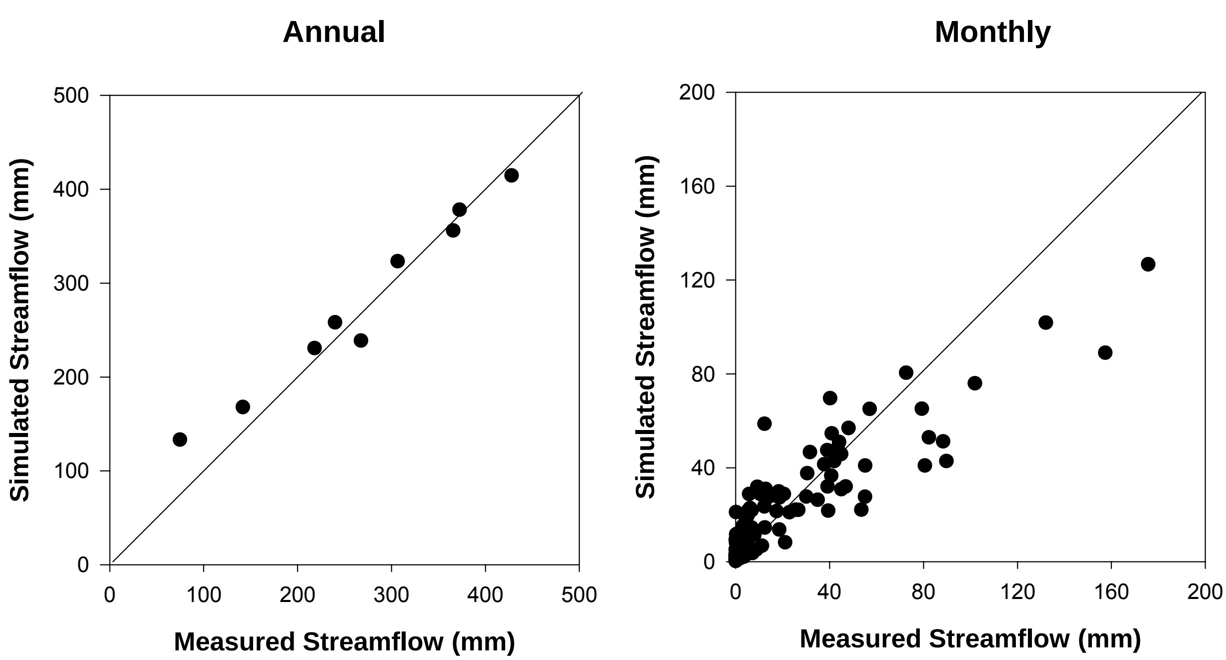

Figure 2. Measured and simulated annual and monthly stream flow for Long Branch watershed.

Conclusion

The performance of the SWAT model in simulating stream flow from the Long Branch watershed (462 km^2) located in the north-Central Missouri, was evaluated. The model was first calibrated and validated for Goodwater Creek Experimental Watershed (GCEW), a 70 km^2 watershed located within Long Branch watershed using the STATSGO and the SSURGO soil data sets. The model performed well in simulating stream flow, particularly on an annual and monthly basis. The study showed that the performance of the model in simulating stream flow using the STATSGO soil data was as good as that using the SSURGO soil data. The model calibrated for GCEW was used to simulate stream flow from Long Branch watershed. The model performed quite well on an annual and monthly basis. The r^2 and E_{NS} values were 0.97 and 0.94 for annual stream flow, 0.79 and 0.77 for monthly stream flow, and 0.45 and 0.45 for daily stream flow. The model did not perform as well in simulating stream flow on a daily basis but its performance was similar in the GCEW and Long Branch watersheds. In the future, calibration will be performed to improve daily stream flow. Also, further calibration of the sediment yield component of the model will be performed, once the sediment load computation process from GCEW is completed.

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