SIMULATION OF DAILY AND MONTHLY STREAM DISCHARGE FROM SMALL WATERSHEDS USING THE SWAT MODEL

C. A. Spruill, S. R.Workman, J. L. Taraba

ABSTRACT. *The Soil and Water Assessment Tool (SWAT) was evaluated and parameter sensitivities were determined while modeling daily streamflows in a small central Kentucky watershed over a two-year period. Streamflow data from 1996 were used to calibrate the model and streamflow data from 1995 were used for evaluation. The model adequately predicted the trends in daily streamflow during this period although Nash-Sutcliffe* R^2 *values were –0.04 and 0.19 for 1995 and 1996, respectively. The model poorly predicted the timing of some peak flow values and recession rates during the last half of 1995. Excluding daily peak flow values from August to December improved the daily* R^2 *to 0.15, which was similar to the 1996 daily* R^2 *value. The Nash-Sutcliffe* R^2 *for monthly total flows were 0.58 for 1995 and 0.89 for 1996 which were similar to values found in the literature. Since very little information was available on the sensitivity of the SWAT model to various inputs, a sensitivity analysis/calibration procedure was designed to evaluate parameters that were thought to influence stream discharge predictions. These parameters included, drainage area, slope length, channel length, saturated hydraulic conductivity, and available water capacity. Minimization of the average absolute deviation between observed and simulated streamflows identified optimum values/ranges for each parameter. Saturated hydraulic conductivity, alpha baseflow factor, drainage area, channel length, and channel width were the most sensitive parameters in modeling the karst influenced watershed. The sensitivity analysis process confirmed die trace studies in the karst watershed that a much larger area contributes to streamflow than can be described by the topographic boundaries. Overall, the results indicate that the SWAT model can be an effective tool for describing monthly runoff from small watersheds in central Kentucky that have developed on karst hydrology however calibration data are necessary to account for solution channels draining into or out of the topographic watershed.*

Keywords. *Watershed models, SWAT, Hydrology, Runoff, Water quality, KARST.*

Watershed models serve as a means of organizing and interpreting research data while also providing continuous water quality predictions that are economically feasible and time efficient. A long history of legislation has made water quality assessments of river systems a critical issue throughout the country. Examples of national legislation include the creation of the United States Environmental Protection Agency (USEPA, 1979), the passage of the Clean Water Act in 1972, and the 1985 and 1990 Farm Bills. Efforts of Kentucky to protect statewide water resources through watershed management have been demonstrated by the establishment of the Kentucky River Authority and the passage of the Agriculture Water Quality Act (1996).

The goal of the Agriculture Water Quality Act was to protect surface and groundwater resources from pollution resulting from agriculture and silviculture activities in Kentucky. This will be done by requiring all landowners with at least 10 contiguous acres of agriculture or silviculture production to develop and implement a water quality plan based upon guidance from the Statewide Agriculture Water Quality Plan.

Many agencies, universities, and scientists have responded to legislation by developing models to simulate water and chemical transport. Models are important tools because they can be used to understand hydrologic processes, develop management practices, and evaluate the risks and benefits of land use over various periods of time. Models such as the Hydrological Simulation Program—FORTRAN (HSPF) developed under EPA sponsorship by Johansen et al. (1984) is an example of a model used to simulate hydrologic and water quality processes in natural and man-made water systems. Since its initial development, the HSPF model has been applied throughout North America and numerous countries with various climatic regimes around the world; it enjoys the joint sponsorship of both the EPA and the U.S. Geological Survey. However, the required calibration of the empirical equations to the target watershed is a drawback to the HSPF.

Other models that have been developed for short-term runoff simulations include HEC-1 (US Army Corps of Engineers, 1981) and TR-20 (USDA-SCS, 1965). The USDA-Agricultural Research Service (ARS) developed the

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CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980) model to simulate the long-term impact of land management on water leaving the edge of a field. Several other models with origins from CREAMS include GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leonard et al., 1987), EPIC (Erosion-Productivity Impact Calculator) (Williams et al., 1985), OPUS (Smith, 1992), AGNPS (Agricultural Non-point Source) (Young et al., 1989), and SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985; Arnold et al., 1990). These models were all developed for their specific reasons but have limitations for modeling watersheds with hundreds or thousands of sub-watersheds. The SWAT (Soil and Water Assessment Tool) (Arnold et al., 1998) model was developed to overcome these problems and was selected for this study for the following reasons:

- The model is physically based; and simulates actual processes such as streamflow, runoff, tillage, and crop growth.
- The model originated from agricultural models.
- The degree of support available.

Srinivasan and Arnold (1994) used the SWAT model to simulate water transport in the upper portion of the Seco Creek basin (114 km^2) in Texas. The watershed was subdivided into 37 subbasins and the predominate land use was rangeland. Monthly simulated streamflow data from SWAT were compared to monthly measured streamflow data for a 20-month period. The authors reported that there were no general tendencies to over or underpredict surface runoff during certain seasons of the year. Simulated values compared well with measured values, with the average monthly predicted flows 12% lower than measured flows, and a Nash-Sutcliffe R^2 of 0.86.

Rosenthal et al. (1995) tested SWAT predictions of streamflow volume for the Lower Colorado River basin (8927 km^2) in Texas. A geographic information system (GIS)-hydrologic model link was used to aid in forming input files. Streamflow was simulated for nine years for four stream gage locations with 60 sub-watersheds. With no calibration, the model closely simulated monthly streamflow with a regression coefficient of 0.75. The model underestimated streamflow volume during extreme events, where precipitation was scattered with high intensity. Without the two extreme events the regression relationship decreased to 0.66, but the slope increased to 0.87 and was not significantly different from 1.0. The authors confirmed that the added groundwater flow component as described by Arnold et al. (1993) did an adequate job in simulating low flow volume.

Bingner (1996) evaluated the SWAT model using the Goodwin Creek Watershed (21.31 km^2) located in northern Mississippi over a 10-year period. The watershed contained 14 in-stream measuring stations, each representing an outlet of one or more subbasins. The land use of the watershed was primarily pasture and cultivated field. The Nash-Sutcliffe coefficients, R^2, values computed with observed monthly flow were all around 0.80 except one station, which was predominately in forest.

Smithers and Engel (1996) used the SWAT model to monitor the Animal Science (3.28 km^2) and Greenhill (113.37 km^2) watersheds in west-central Indiana. The SWAT model underestimated totals for both while simulating none or very little baseflow. Possible reasons identified for the poor simulation were inappropriate soil input parameters or water budgeting procedures, which resulted in little drainage. The effect of varying the minimum hydrologic response unit (HRU) or "virtual sub-basin" size on the simulated runoff was investigated in the Greenhill watershed. The scale of HRU delineation up to 10% did not affect model performance but higher percentage levels decreased simulated runoff volume.

Srinivasan et al. (1997) used the SWAT model to simulate hydrology from 1960 to 1989 in the Rio Grande/Rio Bravo river basin (598,538 km^2) located in parts of the United States and Mexico. The simulated average annual flow rates were compared against USGS stream gage records. Visual time-series plots and statistical techniques were used to evaluate the model performance. Stream flow comparisons at Otowi Bridge and Cochiti have regression coefficients of 0.96 and 0.71, respectively.

In one of the few applications to study daily streamflow, Peterson and Hamlett (1997) used the SWAT model to simulate discharge in the Ariel Creek watershed (39.5 km^2) of northeastern Pennsylvania. Model evaluation of daily flow prior to calibration revealed a deviation of runoff volume (D_v) of 68.3% and a R^2 of –0.03. Unusually large observed snowmelts and the inability of the model to accurately simulate interflow affected model performance. Neglecting snowmelt events, a D_v of 4.1% and R^2 of 0.20 were calculated on a daily comparison and a R^2 of 0.55 was calculated for monthly flows.

Previous flow comparisons have been made using AGNPS (Fogle, 1998) to study the impacts of topographic data resolution on computer model input and output in Kentucky. The experiment focused on two karst catchments at the Animal Research Center located in central Kentucky. Conclusions from the study noted that in karst terrains, an increase in contour resolution from 3.06 m to 0.61 m improved the estimate of sink drainage area by 97%. Increased resolution resulted in changes of input parameters. Some of these parameters included catchment boundary, drainage area contributing to flow, slope shape, slope length, and time of concentration. Overall, increasing topographic data resolution was useful to determine whether a management practice was impacting surface or groundwater.

There are significant karst areas in the continental United States not covered by glacial drift located in Florida, Missouri, Texas, Pennsylvania, Indiana, Kentucky, Tennessee, and Alabama (Fogle, 1998). The interactions as noted between groundwater and surface water associated with the karst topography can be difficult to determine and model. With this in mind, SWAT was evaluated with data collected from the University of Kentucky Animal Research Center (ARC) in central Kentucky. The primary objective of the study was to evaluate the performance of the Soil and Water Assessment Tool (SWAT) for simulating daily discharge in small watersheds that are susceptible to lateral subsurface flow and deep groundwater flow, typical of karst topography. While completing the project a void in the research literature was noted regarding the significance of the parameters within SWAT. As a result, it became necessary to complete a sensitivity analysis to determine the key parameters within SWAT that caused the greatest change in streamflow prediction and to illustrate how these parameters can best be estimated.

MATERIALS AND METHODS

RESEARCH SITE

Flow records from the University of Kentucky Animal Research Center (ARC) in northcentral Kentucky were used to evaluate the SWAT model. Land uses for the 5.5 km^2 watershed include tobacco, row crops, small grains, and animal research plots. Information concerning soil properties was documented by Moore (1994) and the Soil Survey of Jessamine and Woodford Counties, Kentucky (USDA, 1983). The dominant soil series at the site was a Maury soil derived from the residuum of limestones and shales of the Lexington Limestone Formation.

The Maury series consists of deep, well-drained soils that are moderately rapidly permeable. These soils primarily occur along broad ridges, with slopes ranging from 0 to 12%. The depth of bedrock ranges from 1.5 to 5 m. The ARC is characterized by gently rolling uplands, numerous sinkholes and springs created by the karst terrain. The climate is temperate with a mean annual temperature of 18.3°C. Winters are mild, having an average temperature of 4.4°C. The average summer daily temperature is 25°C. The average annual precipitation determined by the National Weather Service is 1260 mm. The monthly average precipitation during August to February is 89 mm and from March to July 127 mm.

THE SWAT MODEL

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1993), is a long-term, continuous simulation watershed model. SWAT is a modification of the SWRRB model (Simulator for Water Resources in Rural Basin) (Williams et al., 1985; Arnold et al., 1990) and includes a new routing structure, flexibility in watershed configuration, irrigation water transfer, a lateral flow component, and a groundwater component (Arnold et al., 1993). SWAT also incorporates shallow groundwater flow, reach routing transmissions losses, sediment transport, chemical transport, and transformations through streams, ponds, and reservoirs.

There are three major components of SWAT (1) Subbasin, (2) Reservoir Routing, and (3) Channel Routing. The subbasin component consists of eight major divisions. These are hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, agricultural management, and pesticides. The SWAT computer interface uses a table format for entering parameter information. Since no large reservoirs exist on the watershed, only the inputs to the subbasin and channel routing components will be discussed.

SUBBASIN INPUTS

The hydrology component is comprised of surface runoff, percolation, lateral subsurface flow, groundwater flow, snow melt, evapotranspiration, transmission losses, and ponds. Surface runoff from daily rainfall is predicted using a procedure similar to the CREAMS runoff model, (Knisel, 1980; Williams and Nick, 1982). The runoff volume is estimated with a modification of the SCS curve number method (USDA-SCS, 1972). Peak runoff rate predictions are based on a modification of the Rational Formula. The rainfall intensity during the watershed time-of-concentration is estimated for each storm as a function of total rainfall using a stochastic technique. Watershed time-of-concentration is estimated using Manning's Formula considering both overland and channel flow. The percolation component uses a storage routing technique to predict flow through each soil layer in the root zone. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation. Groundwater flow contribution to total streamflow is simulated by routing a shallow aquifer storage component to the stream (Arnold et al., 1993). Percolate from the bottom of the root zone recharges to the shallow aquifer.

The model offers three options for estimating potential ET: Hargreaves (Hargreaves and Samani, 1985), Priestley-Taylor (Priestley and Taylor, 1972), and Penman-Monteith (Monteith, 1965). If snow is present, it is melted on days when the maximum temperature exceeds 0°C. Melted snow is treated the same as rainfall for estimating runoff and percolation. Pond storage is simulated as a function of pond capacity, daily inflows and outflows, seepage, and evaporation. Required inputs are capacity and surface area.

CHANNEL INPUTS

Channel inputs include reach length, slope, depth, top width, side slope, flood plain slope, channel roughness factor, and flood plain roughness factor. Channel losses are a function of channel width and length and flow duration. Both runoff volume and peak rate are adjusted when losses occur. Flow rate and average velocity are calculated using Manning's equation. Travel time is computed by dividing channel length by velocity. Outflow from a channel is also adjusted for transmission losses, evaporation, diversions, and return flow. Output from other continuous water balance models or measured reservoir outlet data can also be input into SWAT.

MODEL PARAMETERIZATION

Site specific data for the ARC were used where available for model input. Other parameters were estimated using suggested values in the SWAT user manual. Soil properties were estimated by the SWAT/GRASS link based on soil maps and data from the Soils-5 database. An assumption within SWAT is that each watershed or sub-basin simulated responds as a homogeneous unit. With this in mind, parameters were estimated based on the average characteristic of the parameter across the watershed. Groundwater input parameters were estimated from observed baseflow recession curves.

Inputs including basin area and main channel length were determined from a 0.61-m contour map using a digital planimeter. SCS curve number and overland Manning's n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics. The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and support practice factors (P-factors) were chosen for grazing practices and crop land areas. Crop land areas were assigned a P-factor value of 0.5.

Measured daily rainfall and temperature for Lexington (approximately 20 km from the Animal Research Center) were used in the model. There was one weather station specified for the entire basin. Wind speed and solar radiation were simulated for the nearest climate station using the weather generator in SWAT. Evapotranspiration was calculated within the model using the Penman-Monteith method (Monteith, 1965).

SENSITIVITY ANALYSIS

Many of the parameters used to describe the watershed are difficult to measure directly. Since parameter estimation and the sensitivity of the model to the estimated values are important to the successful application to unmonitored watersheds, a sensitivity analysis was developed to provide insight to parameterization. Fifteen parameters (table 1) were selected and varied to determine model sensitivity in daily streamflow simulation. Each parameter was varied separately. Optimum parameter values were determined by minimizing the average absolute deviation (α):

$$\alpha = \frac{\left(\sum_{i=1}^{n} \left| Q_m - Q_p \right|\right)}{n} \qquad (1)$$

where

Q_m = measured average daily streamflow (cm)
Q_p = predicted average daily streamflow (cm)
n = number of observations

The Nash-Sutcliffe coefficient, R^2, (Nash and Sutcliffe, 1970) was also used to measure the goodness-of-fit between observed and simulated daily stream discharge:

$$R^2 = 1 - \frac{\sum_{i=1}^{n} \left(Q_m - Q_p\right)^2}{\sum_{i=1}^{n} \left(Q_m - Q_{avg}\right)^2} \qquad (2)$$

where

Q_m = measured daily discharge (cm)
Q_p = predicted daily discharge (cm)
Q_{avg} = average daily discharge (cm)
n = number of daily discharge values

Table 1. Parameters used in the sensitivity analysis significant affect range optimum value

1.	Alpha Baseflow Factor (ABF)	Yes	0.05-0.80	0.1
2.	Available water capacity combinations	Yes	Com. 1-9 *	Com. 7 *
3.	Baseflow Factor (BFF)	No	0.0-1.0	---
4.	Hydraulic Conductivity of Channel (CHK) (mm/h)	Yes	50-500	200
5.	Channel Length (CL) (km)	Yes	0.05-100	20
6.	Channel Width (CW) (m)	Yes	1-50	4
7.	Drainage Area (DA) (km^2)	Yes	4-16	13
8.	Groundwater Delay (GWD) (day)	Yes	0-100	5
9.	Groundwater Delay (GWD) (day)	Yes	0-5	2
10.	Initial Groundwater Height (GWHT) (m)	No	0-100	---
11.	Recharge (RC)	Yes	0.0-1.0	0.1
12.	Return Flow Travel Time (RT) (day)	No	0-50	---
13.	Saturated Conductivity (SC) (mm/h)	Yes	0-1000	150
14.	Slope Length (SL) (m)	Yes	10-500	200
15.	Specific Yield (SY)	No	0.0-1.0	---
16.	Maximum Rooting Depth (ZMX) (mm)	Yes	5-1000	100

* *Com. 1*: 0.08, 0.114, 0.148 *Com. 2*: 0.250, 0.216, 0.182 *Com. 3*: 0.08, 0.250, 0.148 *Com. 4*: 0.182, 0.08, 0.114 *Com. 5*: 0.182, 0.148, 0.114 *Com. 6*: 0.114, 0.08, 0.148 *Com. 7*: 0.114, 0.08, 0.08 *Com. 8*: 0.114, 0.08, 0.114 *Com. 9*: 0.114, 0.114, 0.08.

RESULTS AND DISCUSSION

SWAT SIMULATION

One of the main objectives of the project was to determine the ability of SWAT to closely simulate daily streamflow from excess precipitation. Streamflow was monitored on 5-min intervals and averaged over each day. Observed and simulated daily streamflows were compared. An emphasis was placed on daily simulations rather than the customary monthly comparisons because of the rapid response of the streams to rainfall in the relatively small watershed. Data from 1996 were used for the calibration and sensitivity analysis and data from 1995 were used for evaluation.

SENSITIVITY ANALYSIS

Fifteen parameters were varied individually within the SWAT model (table 1). Of those 15, variations in four parameters showed no significant effect on daily streamflow simulations for this central Kentucky watershed. These parameters included baseflow factor, initial groundwater height, return flow travel time, and specific yield. Errors in the remaining eleven parameters were found to affect the stream flow within the SWAT model.

Alpha factor for groundwater is defined within SWAT as the groundwater recession or the rate at which groundwater is returned to the stream. Baseflow recession is a function of the overall topography, drainage pattern, soils, and geology of the watershed. The alpha factor is a direct index of the intensity with which the groundwater outflow responds to changes in recharge (Smedema and Rycroft, 1983) and is calculated as follows:

$$\text{ALPHA} = \frac{1}{t} \ln \frac{Q}{Q_0} \qquad (3)$$

where

ALPHA = alpha factor (day^{-1})
Q = streamflow (cm)
Q_o = streamflow at time t = t_o (cm)
t = days after Q_0 was observed (day)

An alpha factor of 0.21 d^{-1} was determined from baseflow recession data. In the sensitivity analysis, the alpha factor was varied from 0.05 to 0.80 day^{-1} and an optimum value was found to be 0.1 day^{-1} (fig. 1). As the

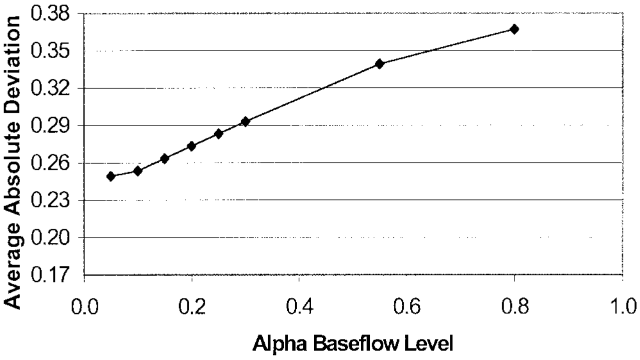

Figure 1–Average absolute deviation between observed and simulated streamflow for deviations in alpha baseflow factor levels, 1996 ARC.

alpha level was increased the deviation between observed and simulated discharge increased with an alpha factor of 0.80 having the largest average absolute deviation of 0.367. Increases in the alpha factor caused the simulated recession curve to be much faster than the observed recession.

Available water capacity is a measure of the ability of the soil to hold water. Available water capacity combinations were varied among three soil layers to determine the best combination for the average soil in the watershed (fig. 2). The default available water capacity of 0.2 cm^3/cm^3 for the Maury soil was used for the initial simulation. Nine combinations of available water capacity were simulated in the sensitivity analysis (table 1). Although there were only marginal differences, combination seven, 0.114, 0.08, 0.08, yielded the smallest deviation and was determined to be the best combination for available water capacity. Decreasing the available water capacity (combinations 7-9) helped to decrease the affects of evaporation and increased the amount of throughflow within the soil profile. One of the characteristics of the soils at the ARC is rapid infiltration caused by macropores (Fogle, 1998).

Hydraulic conductivity of the channel alluvium was varied from 50 to 500 mm/h (fig. 3). The optimum value was determined to be 200 mm/h. Reference effective hydraulic conductivity values were given in the SWAT interface for various channel bed materials. Extreme low and high values of conductivity were simulated and resulted in the largest deviations. Conductivity values between 150 and 350 mm/h had similar values of deviation between observed and simulated discharge.

Optimum values for channel length and width were determined to be 15 to 20 km and 4 m, respectively (figs. 4 and 5). Average channel length is defined as the distance along the channel from the subbasin outlet to the most distant point in the subbasin. Although the maximum distance from the watershed outlet to the furthest point in the watershed was less than 5 km, the modeled watershed contained many smaller channels and numerous solution channels associated with the karst hydrology. The average channel width was first estimated at 2 m while other widths between 1 and 50 m were simulated. Results from calculating the average absolute deviation concluded 4 m

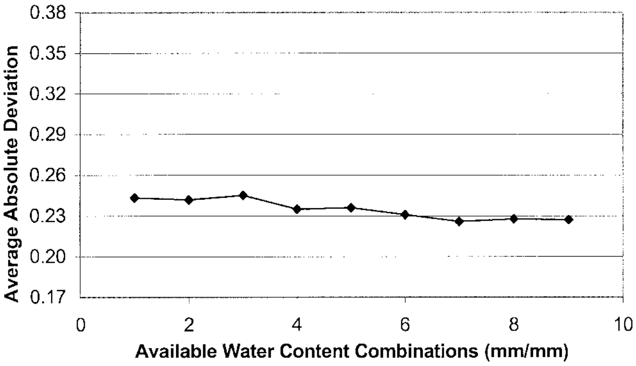

Figure 2–Average absolute deviation between observed and simulated streamflow for deviations in available water capacity combinations levels, 1996 ARC. (See table 1 for combinations.)

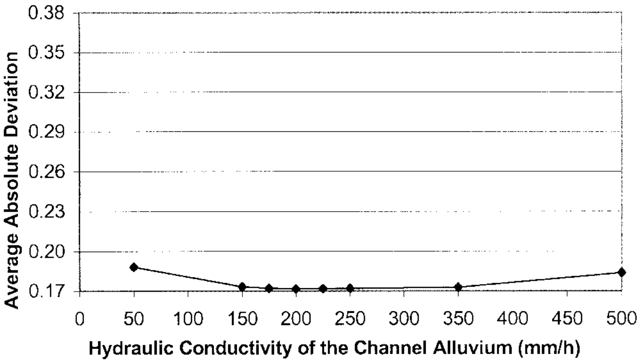

Figure 3–Average absolute deviation between observed and simulated streamflow for deviations in hydraulic conductivity of the channel alluvium levels, 1996 ARC.

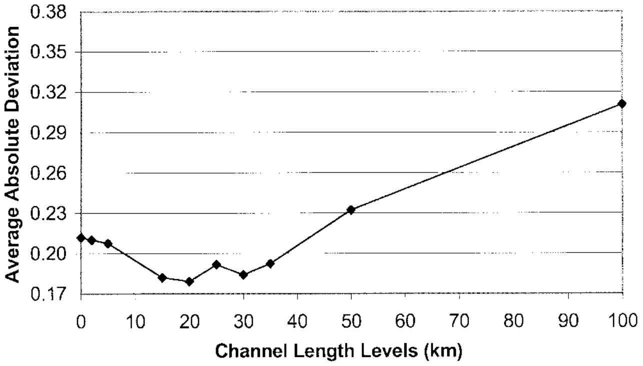

Figure 4–Average absolute deviation between observed and simulated streamflow for deviations in channel length levels, 1996 ARC.

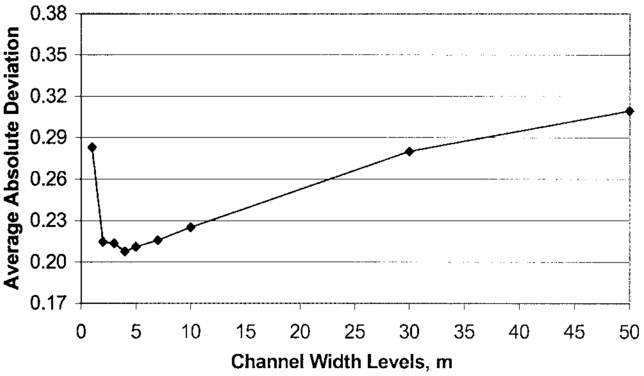

Figure 5–Average absolute deviation between observed and simulated streamflow for deviations in channel width levels, 1996 ARC.

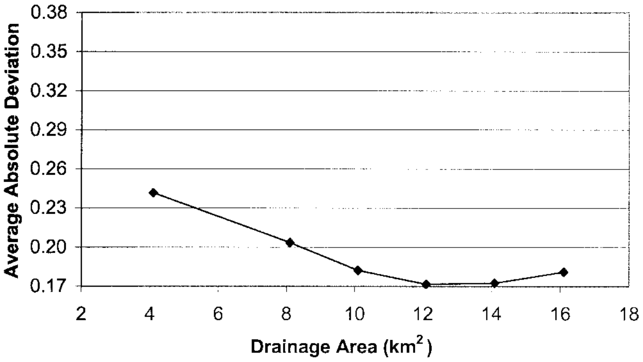

Figure 6–Average absolute deviation between observed and simulated streamflow for deviations in drainage area levels, 1996 ARC.

as the optimum value although a value of 2 m had a similar average absolute deviation (fig. 5).

The average absolute deviation between the observed and SWAT simulated streamflow was lowest when the drainage area was set at 12 to 14 km^2 (fig. 6). The measured drainage area as determined from the topographic data was 8.2 km^2. The 12 to 14 km^2 area is more representative of the farm drainage area determined from die traces of the surrounding sink holes. Gremos (1994) documented the occurrence of sinkholes on and around the Animal Research Center from areal photographs of the study site. Several swallets were also identified through field reconnaissance. Swallets at the study site were generally large holes or soil collapse features, which could rapidly transmit surface drainage to the subsurface. Fogle (1998) identified 71 sinks or depressions within the Animal Research Center on a 2 ft contour map using both visual inspection and GIS surface analysis techniques. The karst features at the ARC include numerous springs associated with the sinkholes. The results of the sensitivity analysis indicate that the watershed gains water from sinkholes that discharge water within the watershed boundary and that little water is transmitted beyond the watershed boundary in the solution channels.

Groundwater delay is defined as the time it takes for water leaving the bottom of the root zone to reach the shallow aquifer where it can become lateral groundwater flow. Arnold et al. (1993) credited Johnson (1977) and Sangrey et al. (1984) with establishing a more efficient way to estimate the delay factor. Groundwater delay was varied from zero to five days (fig. 7). From this analysis groundwater delay was determined to be closer to two days for the Animal Research Center watershed. A quick response time is reasonable when considering both the karst topography and the small watershed area.

Recharge is the replenishment of deep and shallow groundwater storage from infiltration. The deep groundwater storage is defined as a portion of water from the shallow aquifer that percolates into the deep aquifer. Within SWAT, the deep groundwater storage is assumed to be lost from the hydrologic system. From Arnold et al. (1993) the deep aquifer percolation coefficient is calculated using equation 4:

$$perc_{gw} = \beta_p Rc \tag{4}$$

where

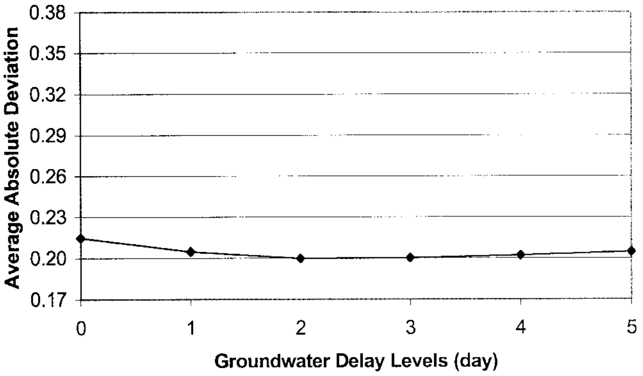

Figure 7–Average absolute deviation between observed and simulated streamflow for deviations in groundwater delay levels, 1996 ARC.

$perc_{gw}$ = is the percolate to the deep aquifer
β_p = is the percolation coefficient
Rc = is the recharge

The percolation coefficient was varied from 0 to 1.0 within the model. Calculated average absolute deviations indicated there was no difference in 0 and 0.10 coefficients. From 0.10 to 1.0 deviations increased with 1.0 having the greatest deviation (fig. 8). These data indicate that little of the percolation is reaching deep aquifer supplies. The importance of the near surface sinkhole-spring combinations associated with the karst hydrology at the ARC is consistent with the low value for the percolation coefficient.

Saturated hydraulic conductivity in soils of stable structure is characteristically constant although chemical, physical, biological and land management processes may affect the value. The default saturated conductivity values for Maury soil within the SWAT interface for the first three layers were 101.6, 101.6, 83.82 mm/h. The saturated conductivity was varied between 0 and 1000 mm/h. The smallest average absolute deviation for conductivity was either 50 or 100 mm/h, which was very similar to the default value of 101.6 mm/h (fig. 9).

Average slope length is estimated within the SWAT model for each subbasin with the Contour-Extreme Point Method (Williams and Berndt, 1977). Fogle (1998) defined slope length as the slope distance from the point of origin of overland flow to the point of concentrated flow or until deposition occurs. Average slope length was determined from a topographic map as 37 m. The average slope length

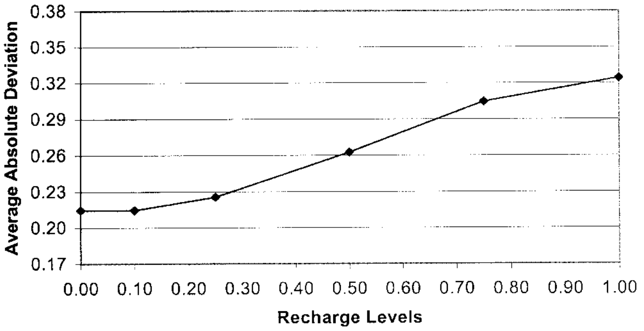

Figure 8–Average absolute deviation between observed and simulated streamflow for deviations in recharge levels, 1996 ARC.

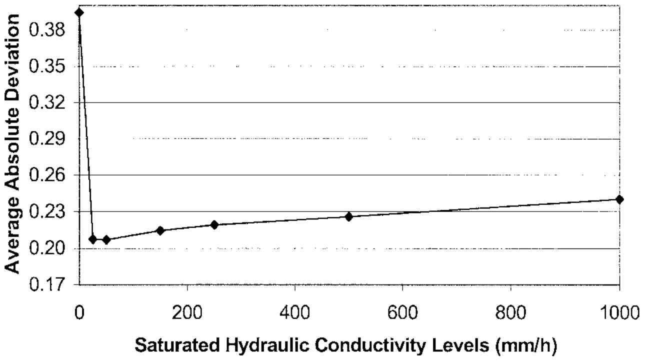

Figure 9–Average absolute deviation between observed and simulated streamflow for deviations in saturated hydraulic conductivity levels, 1996 ARC.

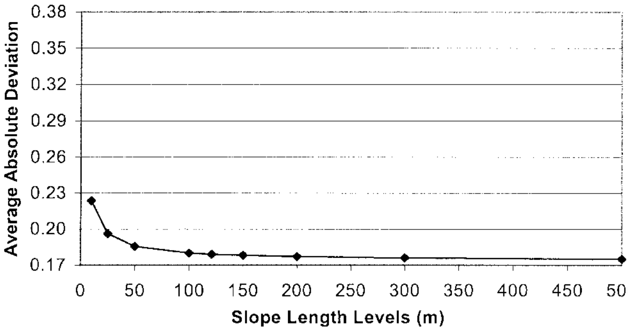

Figure 10–Average absolute deviation between observed and simulated streamflow for deviations in slope length levels, 1996 ARC.

was varied from 10 to 500 m, with 500 being the maximum slope length possible (fig. 10). From this analysis, as the length was increased the deviation decreased. The largest rate of decrease was between 10 and 25 m while only moderate reduction in average absolute deviations was observed for slope lengths in excess of 100 m.

The maximum rooting depth default for Maury soil was zero, which sets the rooting depth to the soil profile depth. The maximum rooting depth was varied from 5 to 1000 mm (fig. 11). Rooting depths less than 100 mm caused no difference in the deviation between observed and simulated streamflow, but values of 250, 500, and 1000 mm increased the deviation. The optimum value for maximum rooting depth was determined to be 100 mm.

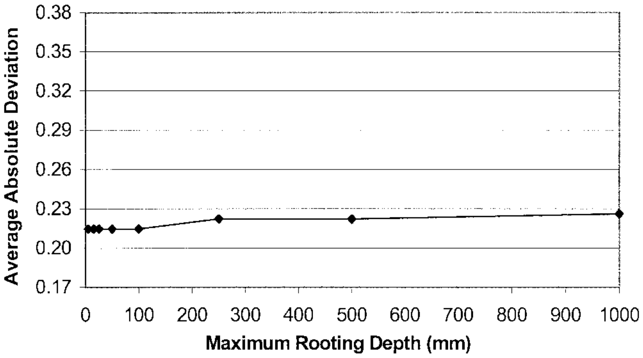

Figure 11–Average absolute deviation between observed and simulated streamflow for deviations in maximum rooting depth levels, 1996 ARC.

SIMULATED RESULTS

Streamflow data from 1996 were used for the sensitivity analysis and calibration of the SWAT model. The Nash-Sutcliffe R^2 value for the daily data was 0.19 and R^2 was 0.89 for monthly totals. The monthly totals tend to smooth the data, which in turn increases the R^2 value. Figure 12 shows average daily measured and simulated streamflow after calibration was completed. Overall, visual inspection indicates simulated peak flow within the magnitude of the measured peak flows. However, simulated peak flows sometimes occurred a day earlier than observed, which may be a result of the model's inability to predict the surface and sub-surface interaction associated with the karst topography and the effect of rainfall timing associated with a weather gage located offsite. The simulated recession curves were adequate but often faster than the observed recession. The model simulated less water in the watershed during the spring season than what was observed. The reason for this may be due to the sink drainage area not being represented in the model but contributing to the streamflow.

The model was evaluated with the streamflow data from 1995 shown in figure 13 (no measured data between 10 July and 3 August 1995). Model parameter values determined from the sensitivity analysis were held constant during this evaluation. Observed and predicted daily streamflow for the year yielded a Nash-Sutcliffe, R^2, of -0.04, which indicates a very poor correlation. An R^2 of 0.58 was computed for the monthly totals. Closer inspection of the data indicated that the SWAT model estimated peak flows and recession curves well in 1995 except during the summer season where four separate peak discharge events were simulated but not observed. The R^2

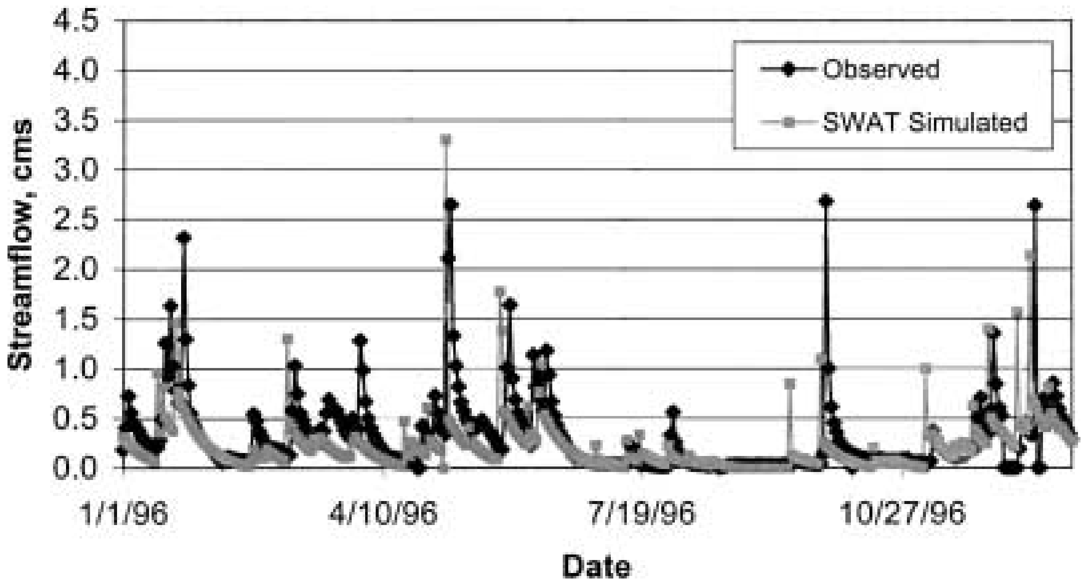

Figure 12–Animal Research Center Daily Streamflow Comparison, 1996.

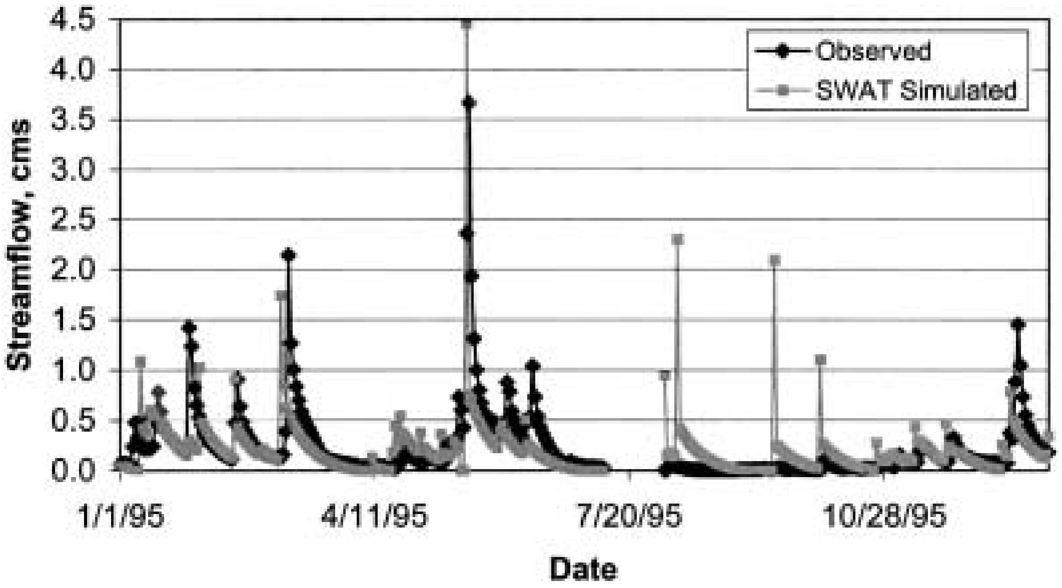

Figure 13–Animal Research Center Daily Streamflow Comparison, 1995.

for the January to July period in 1995 was 0.15 for daily data, which was similar to the 1996 calibrated values and was of the same magnitude as the Peterson and Hamlet (1997) study in Pennsylvania.

CONCLUSIONS

The most sensitive parameters for the SWAT model for use in central Kentucky included saturated hydraulic conductivity, alpha baseflow factor, recharge, drainage area, channel length, and channel width. Daily assessments of measured and simulated streamflow data from 1995 and 1996 were evaluated to determine model performance and yielded low R^2 values (–0.04 and 0.19 respectively). An R^2 of 0.15 was computed for the first half of 1995. Monthly totals of the data indicated a much better correlation with Nash-Sutcliffe R^2 values of 0.58 for 1995 and 0.89 for 1996. Results indicate that the SWAT model can be an effective tool for describing monthly runoff from small watersheds in Central Kentucky that have developed on karst geology. Determination of accurate parameters when modeling watersheds in karst areas is vital for producing simulated streamflow data that are in close agreement to measured streamflow values.

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