Tropentag 2007
University of Kassel-Witzenhausen and
University of Göttingen, October 9-11, 2007
Conference on International Agricultural Research for Development

Calibration and Validation of SWAT Hydrologic Model for Meki Watershed, Ethiopia

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Abstract

SWAT (Soil and Analysis Tool) is a continuous time, physically based, and spatially distributed public domain hydrologic model. SWAT is used in different tropical watersheds and reported to be able to well explain watershed hydrologic processes. To benefit from its free accessibility and good modelling capability, testing this model for the Ethiopian condition is necessary. The Meki Watershed, covering an area of 2233 km^2, is located in central Ethiopia and has an average elevation of 2143 m.a.s.l. It is estimated that 62% of the flow is contributed by baseflow. The sensitivity analysis showed that from 28 parameters, only 14 revealed meaningful effects on the flow simulation. The curve number (CN2), the soil available water capacity (SOL_AWC) and the soil evaporation compensation factor (ESCO) are the most sensitive of all controlling the surface flow. For the baseflow, threshold water depth in the shallow aquifer for flow (GWQMN), saturated hydraulic conductivity (sol_k), deep aquifer percolation fraction (rchrg_dp), and groundwater revap coefficient (GW_REVAP) have the highest influence. The flow was manually calibrated using monthly gauged and simulated flows from 1985 to 1989. Validation was carried out for flows from 1990 to 1992. The calibration result showed that there is a good agreement (R^2=0.84, E_{NS}=0.69) between the simulated and gauged monthly flows. For validation, the R^2 was found to be 0.81. The estimated E_{NS} value of 0.54, though relatively lower, is acceptable as this value is more than 0.5. The results showed that SWAT is able to simulate the hydrologic characteristics of the watershed very well.

Keywords: Baseflow, Baseflow separation, Correlation coefficient, Modeling, Nash-Sutcliffe simulation efficiency, Sensitivity analysis, Soil and Water Analysis Tool, Surface flow

Introduction

SWAT is a physically based, continuous time (Lenhart *et al.* 2002) and a public domain hydrologic model. It was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time (Neitsch (a) *et al.* 2002). The model has been tested in different tropical watersheds and reported to be able to well explain watershed hydrologic processes. To benefit from its free accessibility and good modelling capability, testing this model for the Ethiopian condition is quite necessary. Hence, the objective of this study was *to test the suitability of the SWAT hydrologic model in simulating the hydrologic processes of the Meki Watershed.* Meki River is one of the rivers discharging flow into Ziway Lake. Its Watershed, covering an area of 2233 km^2, is found in central Ethiopia and has a mean elevation of 2143 m.a.s.l.

Methodology

For this study, the ArcView integrated SWAT version called *AVSWAT-X* was used. The ArcView environment provides the tools for delineation, HRU definition, data base editing, weather stations definition, inputs parameterization and editing, model running, and calibratiion of simulation results.

Baseflow Separation and Sensitivity Analysis

For baseflow separation, the automated baseflow separation and recession analysis technique (Arnold *et al.* 1999) was applied. This is followed by sensitivity analysis, which is a technique to identify the responsiveness of parameters. For that, a built-in tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) design method of Morris (1991) was used.

Flow Simulation and Simulated Flow Evaluation

To account for differences in soils, land use, crops, topography, weather, etc; the watershed was first subdivided into subbasins and further into hydrologic response units (HRUs). Missing weather data were filled using the built-in weather generator. The surface runoff volume was computed using the SCS curve number method. Flow was routed using a variable storage method. The potential evapotranspiration was estimated using the Hargreaves Method.

Calibration and Validation

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated. For this study, the manual calibration was applied. The calibration procedure followed in this study is presented in figure 1. The steps followed were based on the recommendations given in the SWAT user manual (Neitsch *et al.* (b) 2002): first calibration of the water balance followed by that of temporal flow. Water balance calibration takes care of the overall flow volume and its distribution among hydrologic components; whereas temporal flow calibration takes care of the flow time lag and the hydrograph shape. Calibration was commenced by the yearly average of surface runoff volume.

Parameters identified from the sensitivity analysis were varied in sequence of their relative sensitivity within their ranges (table 1) till the volume is adjusted to the required quantity. This process continued till the volume simulated is within ±15% of the gauged volume. The surface runoff adjustment was then followed by that of the baseflow. Here, the same approach was followed being the adjustment made to the most sensitive parameters affecting the baseflow. Each time the baseflow calibration is finalized, the surface runoff volume was also checked as adjustment of the baseflow parameters can also affect the surface runoff volume. The same procedure was also followed to calibrate the water balance of the monthly flows. After each calibration, R^2 and E_{NS} values were checked ($R^2 > 0.6$ and $E_{NS} > 0.5$, Santhi *et al.* 2001). After the water balance calibration, temporal trend calibration was continued to take care of the inconsistency occurred in the patterns of the simulated and gauged flows.

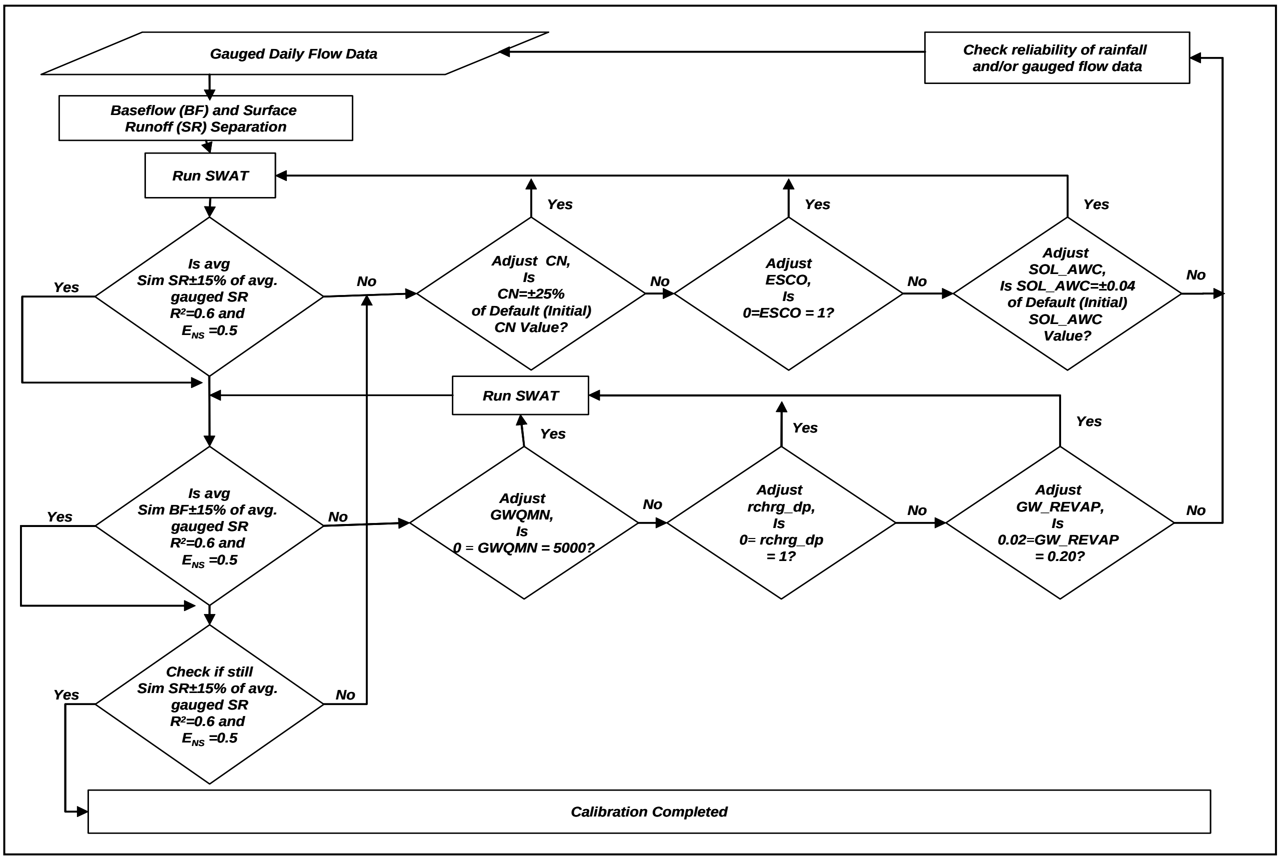
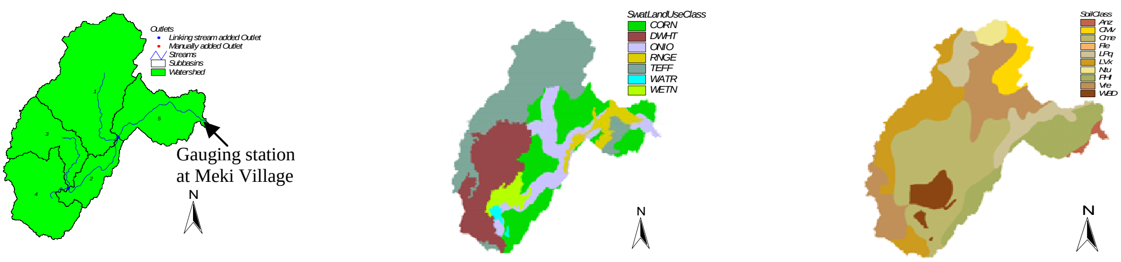


Figure 1: The manual flow calibration procedure used in this study (diagram extended from that developed by Santhi et al. 2001)

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The process continued till simulation of validation-period stream flows confirmed that the model performs satisfactorily. The statistical criteria were also checked.

Results and Discussion



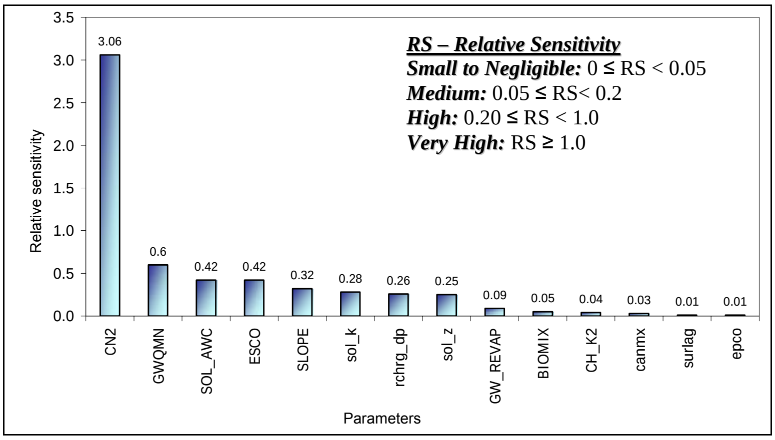
a) Delineated Subbasins b) Landuse Map c) Soil Map

Figure 2: Delineated subbasins, landuse, and soil map of Meki Watershed

The watershed is divided into five subbasins (threshold area 20,000 ha) and 41 hydrologic response units (HRUs). The watershed's landuse is largely dominated by agricultural crops. Out of nine soil types identified in the watershed, Eutric Cambisols (CMe) and Eutric Vertisols (VRe) jointly cover about half of the whole watershed area.

Baseflow Separation and Sensitivity Analysis

The baseflow separation showed that 62% of the flow is contributed by baseflow. The sensitivity analysis was carried out for a period of six years, which included both the calibration period and one year of *warm-up*[1] period. Out of 28 parameters, only 14 of them revealed meaningful effect on the flow simulation. The sensitivity analysis results are shown in figure 3.



Parameters	*Description*
CN2	Initial SCS CN II value
GWQMN	Threshold water depth in shallow aquifer for flow
SOL_AWC	Soil available water capacity
ESCO	Soil evaporation compensation factor
SLOPE	Average slope steepness
sol_k	Saturated hydraulic conductivity
rchrg_dp	Deep aquifer percolation fraction
sol_z	Soil depth
GW_REVAP	Groundwater "revap" coefficient
BIOMIX	Biological mixing efficiency
CH_K2	Channel effective hydraulic conductivity
canmx	Maximum canopy storage
surlag	Surface runoff lag time
epco	Plant uptake compensation factor

Figure 3: Sensitive parameters and their relative sensitivity.

Flow Calibration and Validation

Flow calibration was performed for five years from January 1985 to December 1989. However, flow was simulated for six years including one year of *warm up* period. Manipulation of the sensitive parameter values were carried out within the allowable ranges (table 1). The calibration results in table 2 show that there is a good agreement between simulated and gauged flows.

Table 1: Initial and finally adjusted parameter values of flow calibration

No.	*Parameters*	*Effect on simulation when parameter values increase*	*Range*	*Intitial Value*	*Adjusted value*
1	CN2	increase surface runoff	-25%-25%	Default*	-25%
2	GWQMN	decrease baseflow	0-5000	0.00	10.00
3	ESCO	decrease evaporation	0-1	0.95	0.10
4	SLOPE	increases the lateral flow	0-0.60	Default*	0.10
5	rchrg_dp	increase deep aquifer recharge	0-1	0.05	0.275
6	GW_REVAP	decrease baseflow by increasing water transfer from shallow aquifer to root zone	0.02-0.20	0.02	0.15
7	GW_DELAY	increases the time between water exits the soil profile and enters the shallow aquifer	0-500	31	20

The results fulfilled the requirements for $R^2 > 0.6$ and $E_{NS} > 0.5$. Validation was performed for three years period from January 1990 to December 1992. However, the flow was simulated for

[1] "*Warming-up*" is the very essential part of the simulation process that ensures the establishment of the basic flow conditions for the simulations to follow by bringing the hydrologic processes to an equilibrium condition.

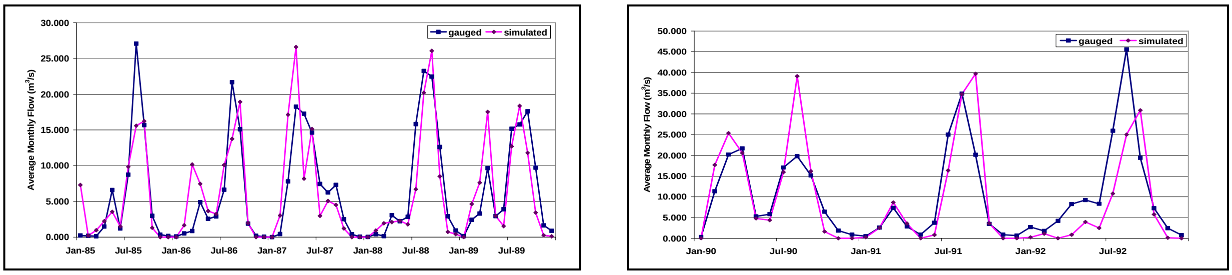
[*] Variable default values in the subbasins according to the landuse and soil types

four years considering one year of *warm-up* period. The validation statistics in table 2 shows that the simulated flow has a very good correlation with the gauged flow. The E_{NS} was; however, found to be 0.54, which is relatively small but still acceptable as this value is more than 0.5.

Table 2: Calibration and validation statistics of average monthly simulated and gauged flows

	Period (Monthly)	*Standard Error* (m^3/s)		*% Error*	R^2	E_{NS}
		Observed	*Simulated*			
Calibration	1985-1989	7.28	7.03	+2.2	0.84	0.69
Validation	1990-1992	10.85	12.22	-7.6	0.81	0.54

As shown in figure 4 - calibration, peak values are slightly underestimated during 1985 and 1986, and overestimated during 1987. However, the overall flow trend is well simulated by the model. As shown in figure 4 - validation, even though the model overestimated the flow in 1990 and 1991, and underestimated in 1992; the overall trend of the flow is again well described by the model. The percentage error of -7.6% is also quite acceptable as this is also well within the tolerable range of ±15%. These results showed that the model is able to describe the hydrologic processes of the watershed.



Calibration Validation

Figure 4: Calibration and validation results of average monthly simulated and gauged flows

Conclusion

The SWAT model performed well in simulating flows of the Meki Watershed. Therefore, the calibrated parameter values can be considered for further hydrologic simulation of the watershed.

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