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Invited Article

Application of SWAT Model in Simulating Stream Flow for the Chi River Subbasin II in Northeast Thailand

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Abstract

Hydrologic models have been used to assess water quality performance of complex watersheds and river basins for managing water resources systems. Hydrologic models can provide essential information to policy makers for making decisions on sustainable management system of water resources within watersheds. A study was conducted on the application of a watershed scale simulation model, Soil and Water Assessment Tool (SWAT), for the Chi River Subbasin II located in northeastern Thailand. Calibration and validation of the SWAT output were performed by comparing predicted stream flows with corresponding in-stream measurements from four gaging stations within the watershed for four years (2000-2003). Statistical comparisons between the simulated results and the observed data for the calibration year gave a reasonable agreement for both monthly coefficient of determination (r^2) and Nash-Sutcliffe Coefficient (E) within ranges of 0.77-0.88 and 0.55-0.79, whereas the validation results showed lower values of r^2 and E ranging from 0.23-0.77 and -7.98-0.66. Overall, the SWAT model has the capability to predict stream flows within the Chi River Subbasin II in northeast Thailand.

Key words: Calibration, Modeling, Simulation, SWAT, Validation.

Introduction

The northeast region of Thailand, an area of approximately 170,000 km2, supports about 22 million people. There are three main basins including Mekong, Chi, and Mun River Basin. The total water storage in the region is about 5,300 million m3. An analysis from the National Water Resources Development Project, Royal Irrigation Department in 1993 found that the water demand in this region was about 10,800 million m3 and will be 14,300 million m3 in 2006 [6]. Several surface water reservoirs and weirs have been constructed over the existing rivers. The use of some surface water systems was limited due to poor yield and quality [2]. Agriculture is the main occupation in northeast of Thailand. Common crops in this region are cassava, sugar cane, corn, kenaf, watermelon and tobacco. Within irrigated areas, farmers tend to grow rice, sweet corn, soybeans, peanuts and tomatoes [4]. Common problems related to water in this region are soil erosion, point and nonpoint source pollution, floods, insufficient water supply, and saline water. Improved assessment of both water quantity and quality is needed in order to provide possible future scenarios for water resource management and development in this region. In support of this goal, a watershed scale, continuous time, distributed hydrologic and water quality model, Soil and Water Assessment Tool (SWAT) model [1], was selected for testing its performance in predicting the hydrologic response of 7,000 km^2 of mixed land use in the Chi River Subbasin located in the northeast region of Thailand. The SWAT 2000 version of the model was validated in this study. Four years of hydrologic data (2000-2003) were used to calibrate and validate the capability of SWAT in predicting stream flow in this study.

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Description of study site

The Chi River Subbasin II constitutes approximately 7,000 km^2 located in the northeast region of Thailand. It is part of the Chi River Basin that drains a total of 49,480 km^2 and lies between latitudes 15° 24’ N and 16°39’ N, and longitudes 101°53’ E and 102°57’ E (Figure 1.).

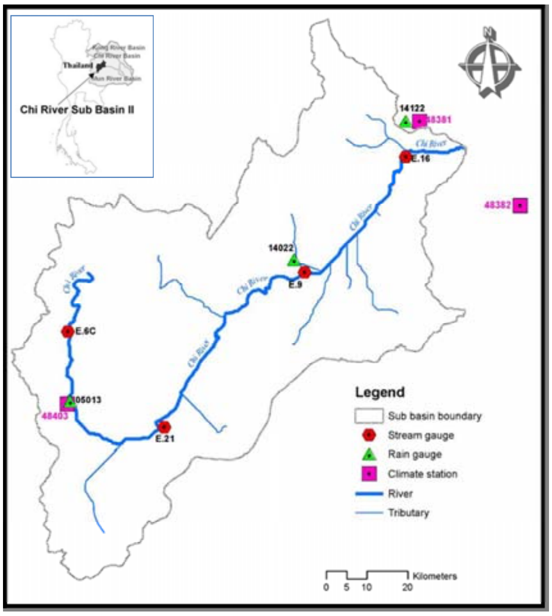

Figure 1. Location of the Chi River Subbasin II, monitoring stations, and climate stations Northeast Thailand.

The main river that passes through the subbasin is the Chi River, originating from the eastern slope of the Phetchabun Range. The main source of surface water is rainfall which brings most of the flow to the rivers within the basin. Based on data collected from three selected rain gauges by the Royal Irrigation Department (RID) for six years (2000-2005), the average annual precipitation for these three gaging stations were found to be 1,054, 1,321, and 1,204 mm at stations 05013, 14022, and 14122, respectively. Approximately 85 percent of the average annual precipitation occurred between May and October (raining season). Land use types included rice (56%), field crops (e.g. sugar cane, cassava, sweet corn, etc) (15%), forest (10%), pasture (6%), and the rest was composed of the urban, and rural resident activities. Most of the altitude of the subbasin is between 148 to 250 m. Soil types within the subbasin primarily consist of sandy clay, sandy loam, clay, and loam. Therefore, none of these soils are strongly favorable to agriculture and many are susceptible to erosion.

Input data acquisitions for the SWAT model

SWAT requires data inputs on topography, climate, land management, and soil. For this study, pertinent input parameter values for the model were compiled using several different databases. These databases included both GIS data and information extracted from both soils and land use maps. The topographic map was extracted from the contour map provided by the Royal Survey Thailand Department. The soil and land use databases were extracted from the provincial soil survey maps of the Land Development Department. Complete data sets for daily precipitation for years 2000 through 2003, derived from the three RID rain gauge stations were selected, including stations 05013, 14022, and 14122. Other climate data such as minimum and maximum temperatures, average relative humidity, solar radiation and wind speed were selected for the same period from three climate stations under the authority of Thai Meteorology Department. These included stations 48381, 48382, and 48403 at Khon kaen, Mahasarakham, and Chaiyaphum province, respectively.

Model evaluations

To test the ability of the model to predict system response, a graphical method (time series plot), and a statistical measurement were used to evaluate the model performance against the measured stream flow data for the period of years (2000-2003) at four stream gaging stations. Two statistical criteria were used including coefficient of determination (r2), and model efficiency (E) [7]. The r^2 represents the percentage of the variance in the measured data that is explained by the simulated data which varies between 0 and 1. The E statistic indicates how close the plot of the observed versus predicted values come to the 1:1 line. If r2 and E values are close to zero, the model prediction is considered unacceptable. In contrast, if these values approach one, the model predictions become highly accurate.

Model calibration and validation

For model calibration and validation, the predicted stream flows were compared to measured stream flows at four monitoring stations including stations E.6C, E.21, E9, and E16. The monthly measured stream flow data for 2002 were used for model calibration. The criterion used for calibrating the model was to minimize the difference between the measured and the predicted cumulative annual stream flows and to match the predicted cumulative monthly amounts with the measured values of stream flow. The calibration of the model for stream flow was done by adjusting the runoff curve number for condition II (CN2), soil available water capacity (SOL_AWC), and the soil evaporation compensation coefficient (ESCO). Hence, these three parameters were found to be very sensitive in SWAT studies performed by Spruill et al. (2000) [9], Santhi et al. (2001)[8], Jha et al. (2003)[5], and Chu and Shirmohammadi (2004)[3]. The procedure was continued until the shapes of the predicted and measured stream flows were in reasonable agreement.

To test the ability of the model to predict system response, the model was validated using monthly measured stream flow data for 2000, 2001, and 2003, without changing the calibrated CN2, SOL_AWC, and ESCO parameters.

Results and discussion

The SWAT simulations were conducted for a four year period (2000-2003). Calibration of SWAT was performed for year 2002 using data from the Chi River basin while the data from the years 2000, 2001, and 2003 were used for the model validation. Both graphic and statistical approaches were used to evaluate the SWAT model's performance. The statistical results of the model performance for both calibration and validation periods are summarized in Table 1. Figures 2 through 5 present a time series comparison of simulated and measured stream flows during the calibration and validation years at stations E.6C, E.21, E.9, and E.16, respectively. These figures clearly indicate that simulated stream flows reasonably match the measured stream flows most of the time except for the years 2000 and 2002, the model underestimated the stream flow. And in the year 2002 the model overestimated the flow for all four monitoring stations. These trends in the predictions of stream flows by SWAT might be due to the CN2 method used for simulations. The major weakness of the CN2 method is the absence of inclusion of spatial and temporal variability in precipitation. More specific, for stream flow calibration, the time series plots for all four monitoring stations showed that the simulated flows matched well with the measured flows except that some of the model generated peak flows did not occur on the same days of the measured flows from April to July in 2002. The r^2 values of 0.88, 0.85, 0.86, and 0.82 for stations E.6C, E.21, E.9, and E.16, respectively, indicated a strong linear relationship between the measured and simulated flows. The E values of 0.8, 0.58, 0.83, and 0.81 for the calibration period also suggested a very strong relationship between the measured and simulated stream flows. For stream flow validation, the time series plots for all four monitoring stations showed that the simulated flows reasonably matched the measured flows with r^2 values in a range from 0.23 to 0.77. The lowest r2 value of 0.23 was found at station E.6C for year 2001, while the highest r^2 value of 0.77 was found at station E.6C for year 2003. However, the monthly E values between -7.89 and 0.67 were found during the validation periods. The negative E values indicated a poor model performance in predicting stream flows.

Table 1. Statistical results comparing monthly measured and simulated stream flow data at monitoring station E.6C, E.21, E.9, and E.16

Year	Station	r^2	E	Station	r^2	E	Station	r^2	E	Station	r^2	E
2000	E.6C	0.70	0.67	E.21	0.49	-0.06	E.9	0.45	0.17	E.16	0.44	0.19
2001		0.23	-7.89		0.58	0.04		0.56	0.05		0.54	-0.25
*2002		0.88	0.80		0.85	0.58		0.86	0.83		0.82	0.81
2003		0.77	0.25		0.63	0.59		0.76	0.62		N/A	N/A

* = Calibration year
N/A = No record of measured stream flow

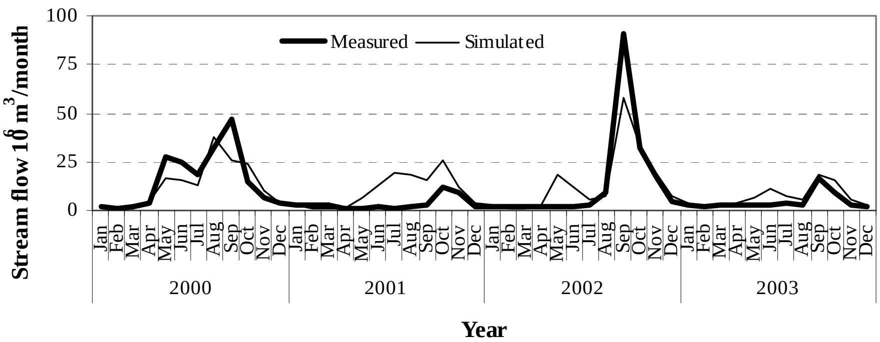

Figure 2. Time series of measured and simulated stream flow at station E.6C for 2000-2003.

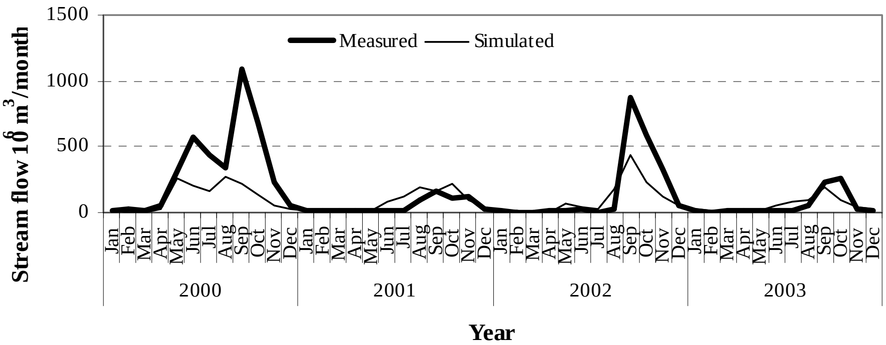

Figure 3. Time series of measured and simulated stream flow at station E.21 for 2000-2003.

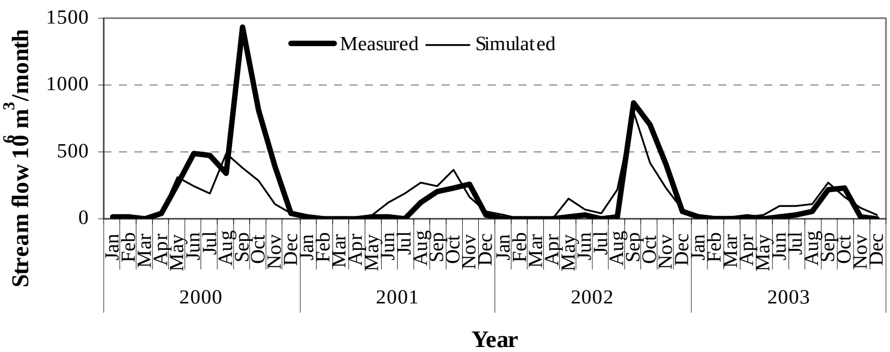

Figure 4. Time series of measured and simulated stream flow at station E.9 for 2000-2003.

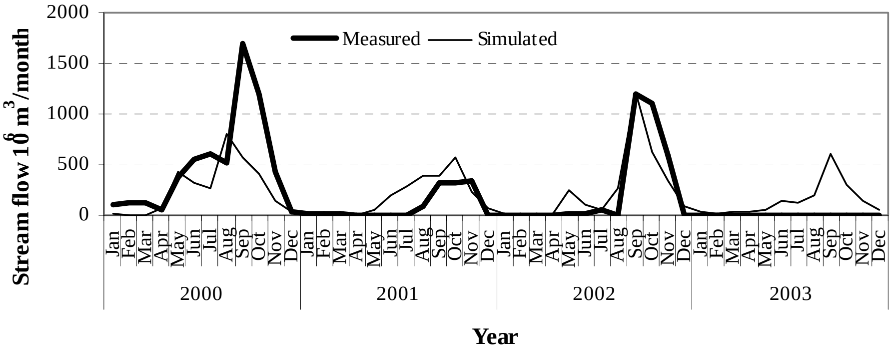

Figure 5. Time series of measured and simulated stream flow at station E.16 for 2000-2003.

Summary and conclusion

Calibration and validation of the SWAT's hydrologic component were performed by comparing predicted stream flows with corresponding in-stream measurements for four years (2000-2003) at four gaging stations within the Chi River Subbasin II in Northeast Thailand. Statistical comparisons of calibration results with observed data indicated a reasonable agreement for both monthly coefficient of determination (r^2) and Nash-Sutcliffe Coefficient (E) with the ranges of 0.77-0.88 and 0.55-0.79, respectively. The model validation results showed lower values of r^2 and E values ranging from 0.23 to 0.77 and -7.98 to 0.66. In summary, the overall evaluation of the SWAT demonstrated that the model has the capability to predict stream flows within the Chi River Subbasin II in northeast Thailand. Therefore, to improve on this model performance, detailed and long-term data will be needed for further analyses.

Acknowledgements

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