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Use of Swat Model for Hydrological Simulation in Lam Takhong Watershed in Thailand

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Abstract:

The flow stream in Lam Takhong river has been gradually decreasing in recent years, which is one of the causes affecting the water quality in the river. Therefore, it is necessary to simulate and forecast the flow in the river and this helps environmental agencies to control and make appropriate decisions on water resources management. In Thailand, the application of models in environmental and hydrological simulation is widely applied and appreciated. However, previous studies have not auto-calibrated parameters by SWAT-CUP in Lam Takhong watershed. The environmental parameters estimation impacting streamflow in Lam Takhong watershed uses the calibrated results of the SWAT model. The calibration used the traditional weather data in Nakhon Ratchasima from 1990 to 2014 and from 2015 to 2017 for validation. The study has applied 11 the parameters for the streamflow calibration and the sensitive analysis gave the main initial SCS CN II value and groundwater delay parameters affecting the flow simulation process. In general, the weather data is one of good additions to the dataset for hydrological modeling in the Lam Takhong watershed and the modified values for SWAT give the R2 value 0.85 in upstream and 0.70 in downstream for monthly total flows is good. The flow from the simulation shows that the SWAT model is suitable for stream flow in Lam Takhong river in Thailand. In addition, these results can be integrated water quality model to forecast water quality and allocate the Nitrogen loading in Lam Takhong river.

Keywords:*Soil and Water Assessment Tool (SWAT); SWAT-CUP; Lam Takhong watershed; calibration; hydrological modeling*

INTRODUCTION

Lam Takhong watershed had a high economic value but Lam Takhong watershed was on the brink of a water shortage that this made watershed couldn't develop the agricultural economic by government plan in future [1]. Besides, water qualiy was also degraded that overall water quality was in class 3, expect NH_3-N, P and BOD_5 in class 4 of surface water standard in Thailand in 2008 and 2009 [2]. Water pollution in the region is often caused by agricultural, urban, and industrial activities in Thailand, and most pollutants are sediments and nutrients[3]. The state of water quality across 65 significant surface water sources nationwide measured in 2016 showed that percentage of water quality in the proportion as 34% good quality, 46% fair quality and 20% of poor quality. Compared to 2015, it is found that the overall water quality in 2016 had improved, with the percentage of surface water sources as fair quality increasing from 41% to 46%, and poor quality decreasing from 25% to 20%[4]. The Northeastern Region of Thailand has surface watersources that are seven sources of good quality, four sources offair quality and one of the poor quality[4]. The poorest source is the lower Lam Takhong river, which is among the critical watersheds of Thailand.

An incident occurred in 2012 in Lam Takhong river in Muang Nakhon Ratchasima, an ice factory released ammonia into Lam Takhong river that dead the hundreds of thousands of fishes in the river. The total value of pollution damage was 5 million Baht in that time. Therefore, if there is an overall view of flow in the area, it is better to be able to predict future flows. This will be useful for water resource managers to make timely and effective decisions.

To water resources is sustainably used, it is important to understand the hydrological processes in the watershed and the causes affect it. Hydrological and water quality models are being used in studies to evaluate the impacts of land use, soil, climate [5], and the watershed size [6]. Several hydrological and nutrient loading modeling researches have been conducted in the Lam Takhong watershed. Some of these studies[7][8] have simulated and estimated the flow in upper Lam Takhong, whilePongpetch[9] evaluated environmental factors affecting on sediment and nutrient loads in Lam Takhong River basin.Pongpetch[9] applied the Soil and Water Assessment Tool (SWAT) model for evaluation of streamflow, sediment, nitrate-nitrogen and total phosphorus simulations in Lam Takhongwatershed. From the simulation, SWAT identified 9 sub-basins and classified into a high phosphorus loading rate. However, the accuracy of SWAT application for flow and nutrient simulation depends largely on the model calibration.

Along with choosing the appropriate model, the selection of data sources is also very important. The studies usually use the local climatedatasets from national mornitoringstaions and the Climate Forecast System Reanalysis (CFSR) of the National Centers for Environmental Prediction (NCEP), or called global climate datasets. However, the simulations with the conventional data gave results better than CFSR data for the flowstream[10]. On the other hands, CFSR global climate data sets can be an optimal alternative for data scarcity areas [11].

This study used ArcGIS integrated into the SWAT model with the conventional climate data from Thai meteorological department, this combination can represent the spatial variability of watershed characteristics to study in Lam Takhong river area. SWAT-CUP model was selected to conduct the calibration of flow for this study because it is freeware and widely used around the world. The results of these studies could be used to validate flow in Lam Takhong river and integrate a quality water model to calculate nutrient loading and Lam Takhong basin management.

MATERIALS AND METHODS

Study area

Lam Takhong River is a part of the Mun basin in the Northeastern of Thailand, is also a river branch of the great Mekong river network. The length of the river is 220 km, originated from Khao Yai National Park with an area of 3,518 km2 covering six districts in Nakhon Ratchasima province and which more than 880,000 people reside [1] (Fig. 1.).

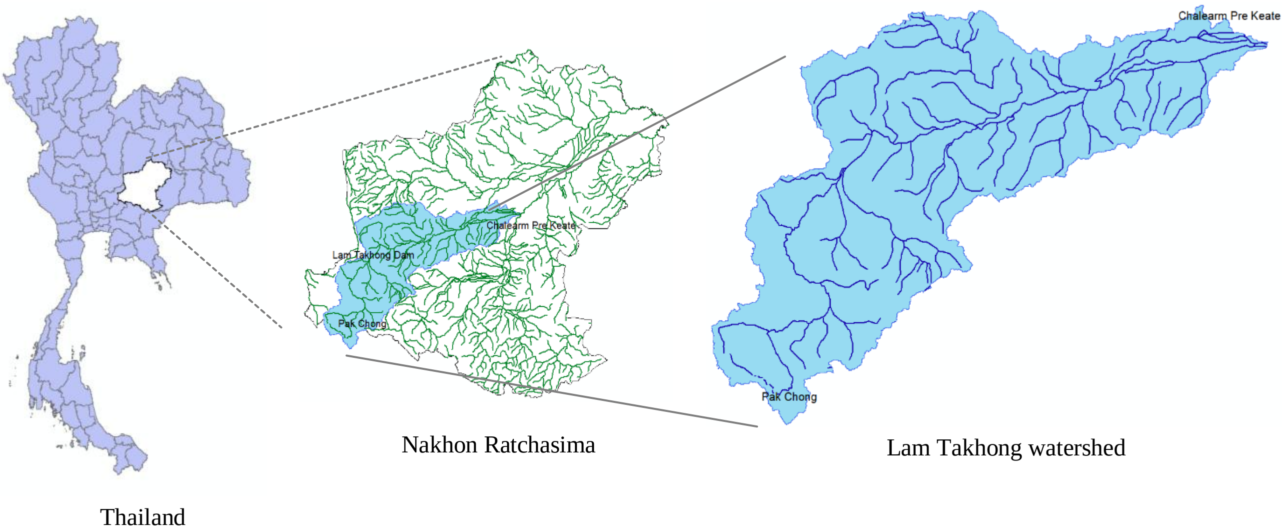

Fig. 1. Location ofLam Takhong watershed

Lam Takhong River watershed in the past was covered majority with large forests. At the present, most areas are invaded to keep up with local progress and it can be divided into nine parts including agriculture (46.073%), deciduous forest (15.073%), urbanization (11.808%), orchard

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(9.655%), evergreen forest (6.205), wetland (0.369), water (1.446), miscellaneous (5.083), factory (4.288)[4]. Nonpoint source area occupied 89.183% of the total area, therefore water pollution comes from nonpoint sources that should be considered.

SWAT Model Description

SWAT model can be used to determine the polluted loading from nonpointsources[12], especially nutrient loads [13] and to predict satisfactory river flow in poorly monitored watersheds [14]. This study integrated ArcGIS 10.1 with the SWAT2012 model to calculate the flow in Lam Takhong watershed. The SWAT model was selected for this study due to a wide variety and with proper testing[15].

The ArcSWAT2012 interface is used to delineate the Lam Takhong watershed by an automatic procedure function based on the Digital Elevation Model (DEM) database that a DEM grid map has a 5m spatial resolution. The subwatershed discretization of SWAT divides the watershed into 75 subbasins. Then, subbasins continue to be partitioned into multiple hydrologic response units (HRUs) based on soil and land use distribution of the watershed. For each HRU, the land phase of the hydrological cycle is modeled, and flow from each HRU are calculated. Then flow from HRUs within a subbasin are summed to get flow from this subbasin.

The necessary data was collected for simulation of flow in the Lam Takhong river. The main input data for simulating the hydrological processes in ArcSWAT are the base map data, meteorological data and observed flow data.

Calibration was used autocalibration tools by SWAT-CUP. Automatic calibration and uncertainty analysis capability were directly incorporated in SWAT2012 via the SWAT-CUP software developed by the Swiss Federal Institute of Aquatic Science and Technology [16]and R^2values [17]were selected as the efficiency criterion. SWAT-CUP includes automated as well as the semi-automated program SUFI2 for model calibration.The sensitive parameters will be considered in the calibration after conducting the sensitivity analysis. These parameters will be included in the calibration CN2, GW_DELAY, ALPHA_BF, GWQMN, SURLAG, CH_N2, CH_K2, GW_REVAP, REVAPMN, ESCO, EPCO.

Input data

The input data for the hydrological simulationinArcSWAT are the base map data, meteorological data and observed data. The necessary data is showned in Table 1.

Table 1. Model input data sources for the Lam Takhong watershed

Data type	Detail	Note
Topography	5m x 5m	DEM
Soil	1:4000	Soil types and properties
Landuse	1:4000	Land cover classification
Weather	• Precipitation • Temperature • Solar radiation, relative humidity, wind speed, 431003, 431004, 431201, 431301, 431401	Daily, 2002-2017
Flow (m^3/s)	M89, M164	Monthly, 2002-2017

The base map data is overlayed by land use and soil data.Climate data input consists of rainfall, temperature, relative humidity, wind speed, solar radiation; and observed flow data.

Nine land use types were used for this study are rice farm, cassava farm, urban and built-up land, corn farm, sugarcane farm, other agriculture, forest land, water body, and miscellaneous land which be described in proportion in Table 2.

Table 2. Landuse data in Nakhon Ratchasima province

Land use types		% of total area
Urban and Built-up land	(UBL)	6.62
Rice farm	(RF)	32.92
Corn farm	(CF)	3.55
Sugarcane farm	(SF)	7.33
Cassava farm	(CF)	19.09
Other agriculture	(OF)	6.44
Forest land	(FL)	17.70
Water Body	(WB)	2.27
Miscellaneous land	(ML)	4.07

Landuse along the Lam Takhong river is mainly agricultural land for rice, cassava and residential areas, which accounts for about 60% of the total area. In addition, the soil typesaremainlysoiltexture,structure, permeability, and porosity. Fourteen soil series with soil texture class and particle size distribution from LDD were converted into hydrologic soil groups(Fig. 2). The study uses five monthly flow monitoring stations in the area and is located as shown in Fig. 3.

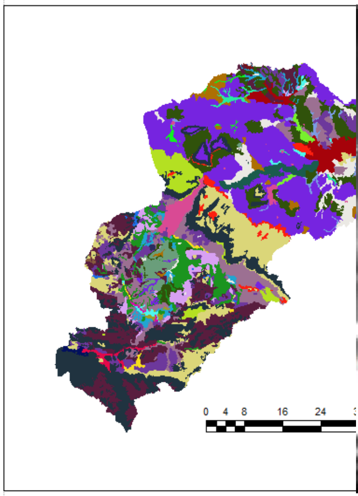

Fig. 2. Soil classification of Lam Takong River

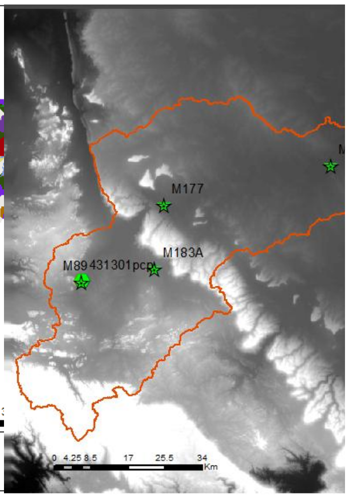

Fig. 3. Locations of hydro-gauging and weather Stations in Lam Takhong watershed

Model Setup

DEM, soil, and landuse were converted to a grid raster data and projected to the projection coordinate system of the Universal Transverse Mercator (WGS_1984_UTM_Zone_48N) before building up SWAT model. SWAT divided the watershed into subbasins thatsubbasins continue to be partitioned into HRUs based on land use andsoil distribution of the basin. The land use, soil, and slope were defined in SWAT proportionate, land use (10%), soil (10%), and slope (10%) [18] to calculate each response unit. The simulated period of the study was from 1 January 2005 to 31 December 2017 and the process of study for Lam Takhong basin is shown in Fig. 4.

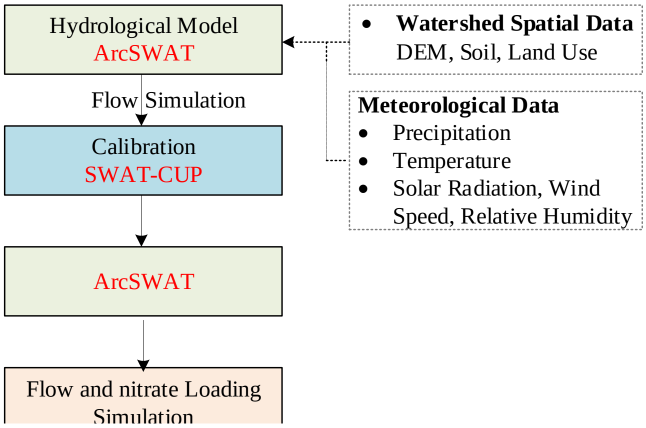

Fig. 4. Diagram of study framework.

The SWAT model wasset up with a monthly time-step in the 16-year period from 2002 to 2017. A warming-up period was selected in the first 3 years and the calibration wasconducted for the period from 2005 to 2014 while from 2015 to 2017 as the validation period. There are two gauging stations including M89 and M164that data for flow is available and correspond to outlets at M164 gauge. The downstream gauging station M164 was chosen as calibrated station for flow.

The methods to compare observed data to prediction use statistical methods by the coefficient of determination (R^2)[19] that the R^2 value can range from 0 to 1 value (where 0 indicates no correlation, values greater than 0.50 are considered acceptable and 1 represents perfect correlation). This is one of methods to indentify the compatibilitybetween observed and simulated data [20].

Pearson's coefficient of determination (R2) was calculated using Equations (1):

$$\boldsymbol{R^2} = \frac{\left(\sum_{i=1}^{n}(y_i - \bar{y})(y_i^{'} - \bar{y}^{'})\right)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2 \sum_{i=1}^{n}(y_i^{'} - \bar{y}^{'})^2} \qquad \text{Eq. (1)}$$

where y_i is the observed data, $\bar{y}$ is the average of the observed data, $y_i^{'}$ is the simulated data, $\bar{y}^{'}$ is the average of the simulated data, and n is the sample number.

RESULTS AND DISCUSSION

Water delineator result

Lam Takhong watershed is delineated by ArcSWAT based on an automatic procedure using

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Digital Elevation Model (DEM) data. The Lam Takhong watershed is divided into75 subbasins outlet of Lam Takhong River.

Landuse data w considered for pollution assessment since the activities on land create the pollutants from the Land Development Department in the year 2015. The main properties of soil data and the number of existing nutrients in the soil are related to water pollution. The sub-basin, land use, and soil map were overlaid and SWAT simulates different types of land use in each sub-basin.

Lam Takhong River watershed's DEM, land use and soil data are integrated to accumulate flow direction and stream network in Lam Takhong River. The Lam Takhong river network is shown Fig. 5.

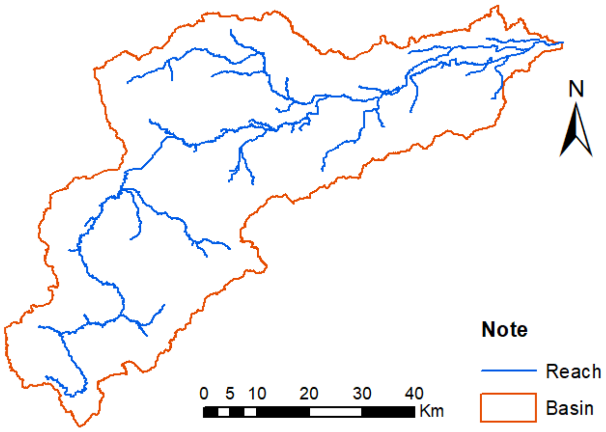

Fig.5. Stream network of Lam Takhong watershed.

Calibration of modelling

Modeling is calibrated by adjusting the input value of eleven parameters from initial default conditions by SWAT-CUP software version 2012. Input data to calibrate modeling is mentioned in Table 3.

Table 3. Input data of the SWAT-CUP calibration in Lam Takhong river

Input File		Data
Calibaration Inputs	Par_inf.txt	Number of parameters: 11 Number of simulations: 500
	SUFI2_swEdit.def	Starting simulation number: 1 Ending simulation number: 500
	File.Cio	Number of years simulated: 13 Beginning year of simulation: 2005
	Absolute_SWAT_Values.txt Absolute_SWAT_Values.txt	All parameters to be fitted should be in this file plus their absolute min and max ranges. CN2, GW_DELAY, ALPHA_BF, GWQMN, SURLAG, CH_N2, CH_K2, GW_REVAP, ESCO, EPCO
Observation	Observed_rch.txt	Number of observed variables (1): Flow
	Var_file_rch.txt	Flow.txt;
Extraction	SUFI2_extract_rch.def	Number of variables to get: 1 Total number of reaches (subbasins) in the project: 75 Time step: monthly
Objective function	Observed.txt	Number of observed variables: 2 Objective function type: 3= R^2
	Var_file_name.txt	Flow.txt

The calibration is conducted in lower Lam Takhong (outlet subbasin) on 11 parameters and

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eleven input parameters were calibrated for the flow process (Table 4).

Table 4. List of calibrated parameters and their default

No.	Parameters	Description	Calibrated value
1	CN2	Initial SCS CN II value	-0.148
2	ALPHA_BF	Baseflow alpha factor [days]	1.064
3	GW_DELAY	Groundwater delay [days]	91.872
4	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur [mm]	2.374
5	SURLAG	Surface runoff lag time [days]	4.000
6	ESCO	soil evaporation compensation factor	0.246
7	EPCO	plant water uptake compensation factor	0.957
8	CH_N2	Manning's value for main channel	0.101
9	CH_K2	Effective hydraulic conductivity [mm/hr]	312
10	GW_REVAP	Groundwater "revap" coefficient	0.157
11	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur [mm]	513

The flow stream simulation

The calibration was conducted in six periods including three periods of daily calibration and three periods of monthly calibration. The calibrated and validated values are shown in Table 5. The study has selected the value of parameters by monthly calibration in 10 years.

Table 5. The value of calibration of the SWAT model in Lam Takhong river

Period	Daily Calibration		Monthly Calibration	
	R^2_upstream	R^2_downstream	R^2_upstream	R^2_downstream
1 year (2013)	0.57	0.29	0.97	0.89
3 years (2012 - 2014)	0.48	0.23	0.86	0.74
10 years (2005 - 2014)	-	-	0.85	0.7

The calibration of the monthly flow stream is improved significantly from 0.69 value of R^2[21]increase to 0.85 for 10 years (2005-2014). This high calibrated value has continued to validate the model and the validated value is obtained 0.7 value of R^2. The streamflow simulation in Lam Takhong river is shown in Fig. 6.

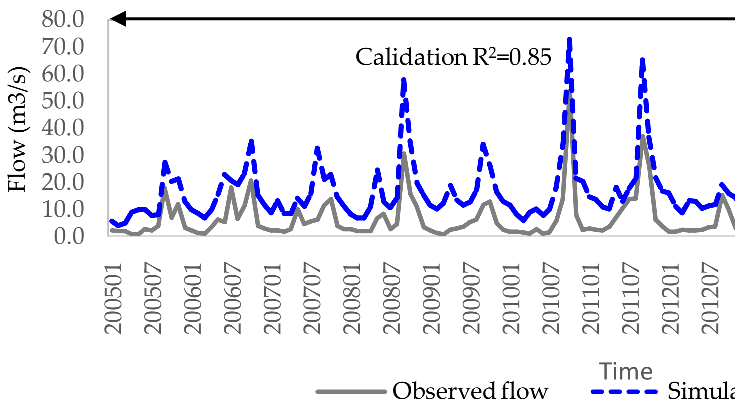

Fig.6. Calibration and validation of upstream flow from 2005 to 2017.

Parameters are identified during calibration because of the aim of matching the model as closely

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as possible. The flow simulation was calibrated for the period from 2005 to 2014 at the lower of Lam Takhong river and validated from 2015 to 2017. The peak flow values are around 58.9m^3/s observed flow and 76.1m^3/s simulated flow, respectively and the minimum values are similarly 0.7m^3/s and 3.3m^3/s. The average flow values are approximately 6.4 and 16.0 m^3/s in the calibration; 3.1 and 6.9 m^3/s in the validation.

The 3 months average value of streamflow in 30 years was the minimum value from January to March and the peak values from August to October in upstream of the river, however, the minimum value was from February to April and had the peak values from September to November in downstream. This result is compatible with the simulated streamflow value.

CONCLUSIONS

The study used the conventional climate data from the Thai meteorological department as input data of the SWAT model to calculate flow in Lam Takhong watershed. The calibration was carried out at M89 station in the upper watershed and M164 station in the lower watershed by SWAT-CUP from 2005 to 2014 and the validation from 2015 to 2017. The observed streamflow date was collected in M89 and M164 stations from 2005 to 2017 in the lower northeastern region hydrological irrigation center. The minimum flow value is usually from January to April and the high flow value from August to November.

The calibration process was conducted with eleven parameters CN2, GW_DELAY, ALPHA_BF, GWQMN, SURLAG, CH_N2, CH_K2, GW_REVAP, REVAPMN, ESCO, EPCO. The R^2 value 0.85 in upstream and 0.70 in downstream is comparable to the results fromZhao[Zhao et al. 2013] that the regression coefficient of observed value and simulation value was 0.63 and it shows that the correlation between observed and simulated monthly runoff is good[Tolera, Chung, and Chang 2018]. This means that the SWAT model is suitable for stream flow in Lam Takhong river. Determination of accurate parameters in calibration when modeling watersheds are vital for simulating streamflow data corresponding to measured values.

The simulatedresults from the SWAT model can be used to integrate Qual2k software to simulate water quality in Lam Takhong river and allocate the nutrient loading in Lam Takhong watershed.

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