Hydrologic evaluation and effect of climate change on the At Samat watershed, Northeastern Region, Thailand

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Abstract: The aim of this research is to apply the hydrological model Soil and Water Assessment Tool (SWAT) for evaluating the sustainability of water resources management in the 723 km^2 At Samat watershed, located in the Mae Nam Chi basin in Northeast Thailand. This was performed by assessing the impacts of future climate projections generated with the Providing Regional Climates for Impacts Studies (PRECIS) Regional Climate Model (RCM) on the hydrology of the watershed. In this study, the watershed was divided into three main subregions with a total of eleven subwatersheds using a Digital Elevation Model (DEM; scaled map 1:10,000). Land use, soil type, and watershed meteorological-hydrological data were used to create the Hydrological Response Units (HRUs). The SWAT model was found applicable to the At Samat watershed, and was further found to be able to analyze runoff characteristics in subwatersheds. This research found that during the years 2010 to 2050, once the region temperature has risen to the average of 0.8℃ and rainfall has increased for another 4%, average runoff yield will be increased by 3%-5% when compared with the overall runoff yield in the watershed area. However, the rising trend of the runoff yield is considered minimal when compared with the expected double demand of water supply in the At Samat watershed at that time.

Keywords: SWAT, hydrological model, climate change, hydrological evaluation

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1 Introduction

Ongoing environmental changes currently brought about by either natural or anthropogenic influences are significantly impacting on natural resources and societal living conditions worldwide. This is especially true of the latter, due to various forms of human activities ranging from forest encroachment, misuse of land, and exploitation of resources without proper conservation measures and good management plan causing land to become vulnerable owing to the lack of vegetation to cover the soil. This results in erosion and landslides in the rainy season and drought in dry seasons, depriving the land of water for consumption, agriculture, industry and other activities which adversely affects quality of life of people. At present, humans are living amid increasingly aggravating water crises affecting various aspects of people’s life such as health, sanitation, environment, urban community, food production, industry and energy.

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In addition, utilization of and accessibility to clean water has become the most critical issue in the aspect of natural resources the world is currently facing. According to the Global Environment Outlook Section of United Nations Environmental Program (UNEP, 2007), the water shortage that is threatening the world points to the urgency of the matter which corresponds with the concern raised by World Wide Fund for Nature (WWF) that fresh water, though necessary for human health, agriculture, industry and natural ecological system, is in severe shortage in various parts of the world (The National Water Resource Board, 2004).

The At Samat District in Roi-et Province of Thailand is faced with such problems and thus was chosen by the Thai cabinet in 2006 to be a role-model district to investigate social and poverty problems in an integrative manner. A plan was drafted to solve the problem, with basic infrastructure in water resources being one of those at the top of the list that needs to be urgently tackled. One option for investigating the water resource issues in the At Samat watershed is the use of water quality models, such as the Soil and Water Assessment Tool (Arnold and Forhrer, 2005; Gassman et al., 2007), which can be applied to investigate both baseline water balance characteristics as well as forecasted future climate change impacts on water resources. Applications of such models are particularly useful when interfaced with climate projections generated by Global Circulation Models (GCMS) and/or Regional Climate Models (RCMs).

Global temperature and other climatic indicators can be forecasted with GCMs, which are mathematical models based on physical laws that simulate heat exchange among the main components of the Earth’s climatic systems (Gregory et al., 2001). The models are complicated, work on a large spatial scale and require submodels of extensive information of the Earth’s climate. Downscaling the output to a smaller region may not capture enough information to perform impact studies. Thus, RCMs have been developed to construct climatic change scenarios for smaller regions, which are more appropriate for impact studies. Several well-accepted RCMs have been developed including those described by Fu et al., (2005) and Hadley Centre (2002).

Applications of SWAT have expanded worldwide over the past decade across a wide variety of watershed scales and conditions (Gassman et al., 2007). These include applications required by various government agencies, especially in the U.S. and the European Union, who require assessments of the impacts of different scenarios such as land use change and climate change. Gassman et al. (2007) describes several climate change impact studies that were performed for U.S. watershed and river basin systems, which focused on approaches that relied on downscaling of climate change projections generated by GCMs or GCMs coupled with RCMs such as reported by Jha et al. (2004). In this study, SWAT was interfaced with the Providing REgional Climates for Impacts Studies (PRECIS) RCM, which is based on the Hadley Centre's regional climate modeling system and was developed in order to help generate high-resolution climate change information for as many regions of the world as possible (Hadley Centre, 2002). The key objective of this research was to study and understand the climate change pattern effecting water yield in the watershed.

Results from this study will be applied as Integrated Quantity and Quality Model (IQQM) input data in order to further calculate water demand for each activity of water use in the At Samat Watershed, such as agricultural, consumption and water balance in the ecosystem with the purpose to plan for effective future water resources development and rehabilitation, especially those identified during drought season. The latter subject, however, is not addressed in this study.

2 Study area

The At Samat watershed is a small subwatershed of the Mae Nam Chi basin, which is located in the Northeast part of Thailand (Figure 1). The At Samat watershed partly covers three subwatersheds (subwatersheds 9, 12 and 50) of the larger Mae Nam Chi basin, which consists of 64 subwatersheds as divided for a SWAT analysis of the Lower Mekong River basin (MRC, 2004; Rossi et al., 2009). The At Samat watershed is in the southwest part of Roi-et Province. While the larger Mae Nam Chi basin covers 49,477 km^2, the At Samat watershed covers an area of 732 km^2 and consists of three major subregions: Huai Yang Cher, Huai Sai Kai and Namchi (Figure 2). However, drought and flood-related problems are generally not a problem in the Namchi subregion. Thus, the anlaysis of climate change impacts on water yields was performed only for the Huai Yang Cher and Huai Sai Kai subregions.

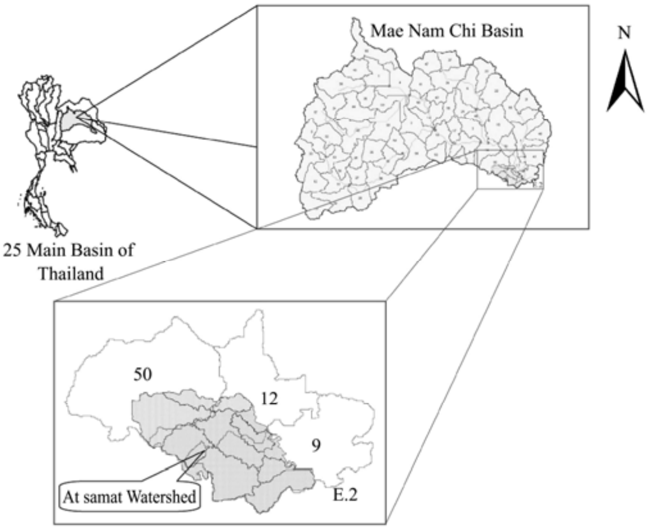

Figure 1 Locations of the Mae Nam Chi basin in Thailand and the At Samat watershed (study area) within the Mae Nam Chi basin

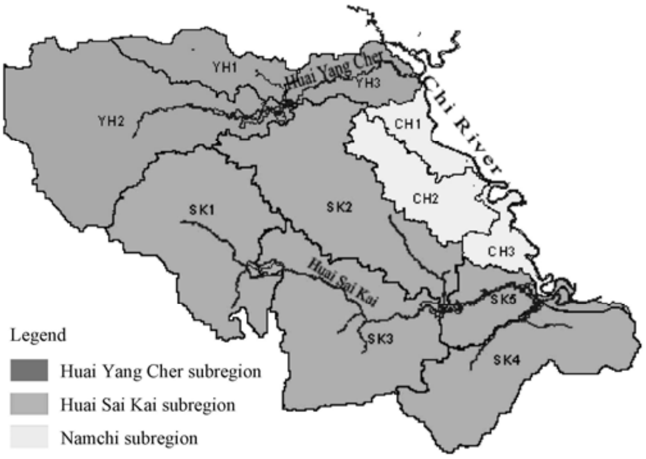

Figure 2 At Samat watershed study area and delineation into three main subregions and eleven subwatersheds

The At Samat watershed lies 115-150 m above mean sea level (MSL). The central portion of the watershed consists of rolling terrain which slopes downward to the Mae Nam Chi River. The northern part of the watershed is mainly characterized by a plain with scattered hills while the eastern part is an undulating plain. The southern part is alluvium suitable for rice and crop farming and also livestock. The weather data used in this study were accumulated from weather stations in the Roi-et Province. These data included temperature, relative humidity, wind speed, pan evaporation and rainfall; annual average values of these data are 27℃, 71%, 5 km/h, 1,659 mm and 1,356 mm, respectively. The major land use in At Samat watershed consists of agriculture (79.9%), forest (7.1%), urban (4.3%), water (1.2%), and other areas (6.3%). There are ten soil types in At Samat watershed based on Land Development Department (LDD). In this study, the soil types were classified into three classes, namely ACg (Clay and Silt), Ach (Clay) and ARa (Loamy) which covered 52.4%, 23.9% and 13.8%, respectively, of the watershed area.

3 Methodology

3.1 Description of SWAT

The SWAT model was developed by the U.S. Department of Agriculture (USDA) Agriculture Research Service (ARS) and represents a continuation of roughly 30 years of modeling efforts (Williams et al., 2008). SWAT is an operational or conceptual model that operates on a daily time step that can be used to predict the impact of management on water, sediment and agricultural chemical yields in large ungauged basins (Arnold and Fohrer, 2005; Gassman et al., 2007). SWAT is categorized as a Distributed Hydrologic Model (DHM). Following the DHM approach, a watershed is divided into subwatersheds in SWAT, which are then usually further subdivided into hydrological Response Units (HRUs) which represent a percentage of the watershed area. The HRUs are characterized by homogeneous soil, land use, and topographic data. Flow and pollutant output from each HRU are summed at the subwatershed level. Each subbasin is then related in the simulated hydrological process, based on the DHM approach which considers a watershed as non-uniform. In this way, the model realistically replicates the hydrological and pollutant transport processes in which flow and pollutants are routed between subwatersheds to the watershed outlet. A command structure is used for routing runoff and chemicals through a watershed similar to the structure included for routing flows through streams and reservoirs. Using the routing command language, the model can simulate a basin subdivided into grid cells or subwatersheds. Additional commands have been developed to allow measured and point source data to be input to the model and routed with simulated flows (Arnold and Fohrer, 2005).

SWAT version 2003 was used for this study, which is the same version that was for the larger Lower Mekong River basin study (MRC, 2004). Additional details about the different model components and required input data are given in Neitsch et al. (2005a, b).

3.2 Description of PRECIS RCM

The PRECIS Regional Climate Model is an atmospheric and land surface model of limited area and high resolution. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radiative processes, land surface and deep soil are all described in the model. Boundary conditions are required at the limits of the model's domain to provide the meteorological forcing for the RCM. The PRECIS modeling system is capable of simulating the entire globe on a relatively inexpensive, fast PC to provide regional climate information for impacts studies. It is a flexible, easy-to-use and computationally inexpensive RCM designed to provide detailed climate scenarios (Jones et al., 2004). The PRECIS modeling system is freely available to developing-countries research groups with the intention that climate change scenarios can be developed at national centres of expertise (Hadley Centre, 2002).

3.3 Data sources and data collection

The At Samat watershed partly overlaps some areas of subwatersheds 9, 12 and 50 of Mae Nam Chi basin. Thus some of the parameters derived from the existing SWAT modelling of the larger Mae Nam Chi basin, as described by Rossi et al. (2009) and MRC (2004), and was applied to the At Samat SWAT model. This was done by using the calibrated parameters from subwatershed 50 for Huai Yang Cher subregion and the calibrated parameters from subwatershed 9 for Huai Sai Kai subregion.

The At Samat SWAT watershed model was constructed using time series and spatial data. Time series data consisted of weather and stream flow data. Weather data were collected from the Thai Meteorological Department, Roi-et Province. These data consisted of relative humidity, sunshine duration (solar radiation), temperature, and wind speed for 1985 to 2004. Rainfall data were collected from Thai Meteorological Department. Nine rainfall stations (Figure 3) were selected for this study, which have average annual rainfall that ranges from 764.7 – 2,460.00 mm/y. Heavy rainfall generally occurs during June to October due to tropical depression storms that originate in the South Pacific or the South China Sea.

Measured stream flow data were not available at any sites within the At Samat watershed. However, measured stream flow data were used for the previously mentioned SWAT model calibration of the larger Mae Nam Chi River basin, which was obtained for 1985-1999 from the Royal Irrigation Department for station E.2 (Figure 1) that is located on Mae Nam Chi River in Muang District, Yasothon Province. Calibrated parameters previously determined for the Mae Nam Chi basin, as part of the overall Lower Mekong River basin SWAT study, were used in this study as discussed in more detail below.

Spatial data required for the At Samat watershed SWAT application were obtained from Thailand Land Development Department and included Digital Elevation Model (DEM), which is a digital representation of ground surface topography or terrain, land use data and soil data. The DEM data is characterized by a 30 m×30 m (1:10,000 scale) resolution, with minimum, maximum, and average elevations of 115 m, 167 m, and 136 m, respectively. The resolution of the soil classification map and land use data were both 1:50,000 scale.

3.4 SWAT model setup

The delineations of the At Samat watershed Huai Yang Cher and Huai Sai Kai subregions for the SWAT simulations was performed using the ArcView SWAT (AVSWAT) interface developed by Di Luzio et al. (2004). This resulted in the partitioning of the 204.6 km^2 Huai Yang Cher subregion into three subwatersheds (YH1, YH2 and YH3) and the 437.8 km^2 Huai Sai Kai subregion into five subwatersheds (SK1, SK2, SK3, SK4 and SK5) as shown in Figure 1. These configurations allowed for estimation of runoff yields for each subregion with SWAT for both the baseline and future climate change scenarios.

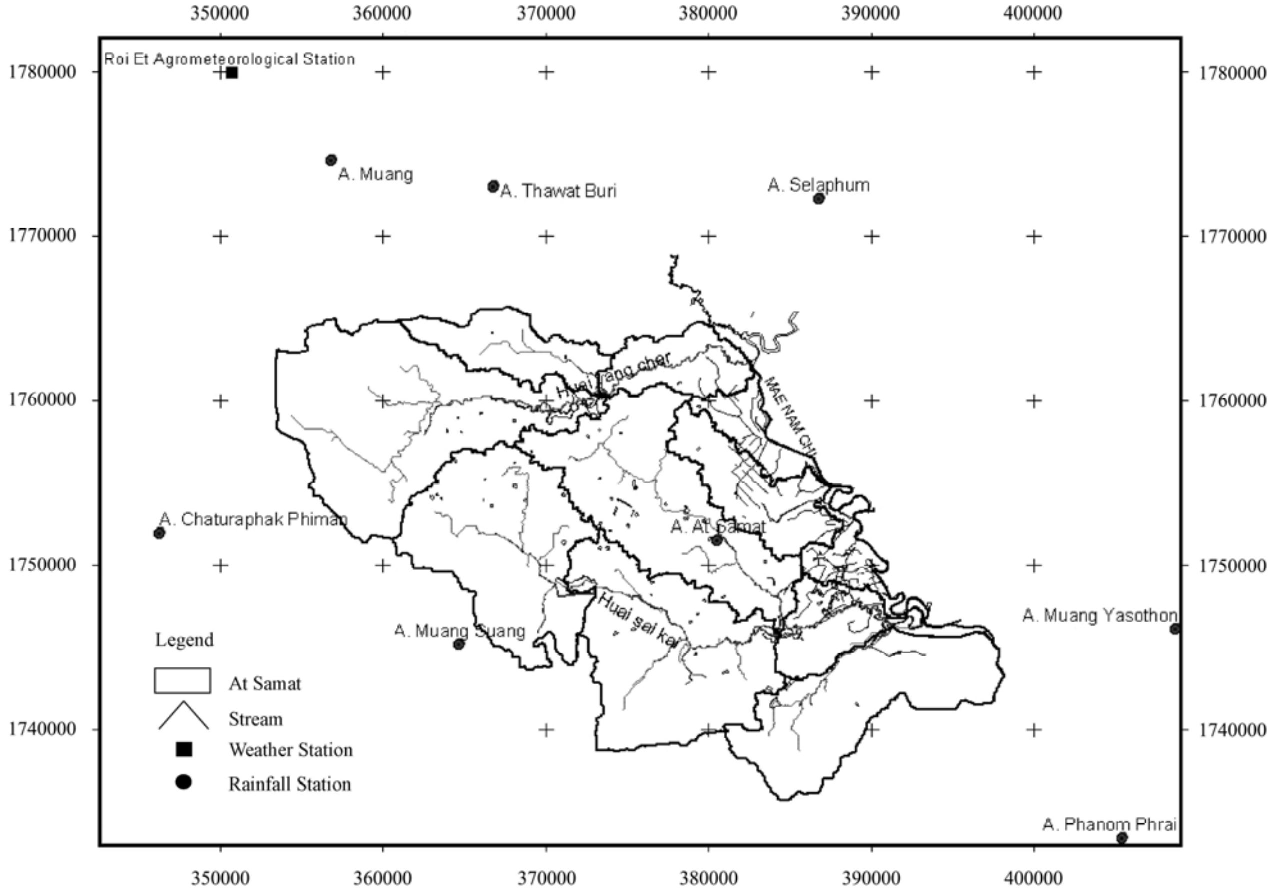

Figure 3 Locations of the nine rainfall stations used for the At Samat SWAT simulation study

3.5 Calibration from previous study

Hydrologic model calibrations are normally based on comparisons between simulated and measured flow rates. Since the study area is of small watershed without any measuring station, thus, calibrated parameters determined from the previous SWAT application for the Mae Nam chi basin were used to parameterize the model for the At Samat watershed application (Table 1), especially parameters used for subwatersheds 9, 12 and 50 which included the At Samat watershed (Figure 1).

Figure 4 shows a graphical comparison of the SWAT predicted stream flow versus the corresponding measured stream flow for station E.2 at the outlet of the Mae Nam Chi River for the previous SWAT study for the entire Lower Mekong River basin as reported by the MRC (2004). Additional calibration and validation results for the Lower Mekong River basin SWAT study are reported by Rossi et al. (2009), including statistical results at the outlet of the Mae Nam Chi River basin at Yasothon (Table 2) which is identified as gauge 709 in their study. The resultant Nash-Sutcliffe statistics for daily and monthly streamflow comparisons ranged from 0.70 to 0.89, which indicated strong model performance based on the suggested criteria by Moriasi et al. (2007).

Table 1 SWAT parameters used for the At Samat watershed study that were based on the previous study

Variable name	Definition	Range	Parameter used
CPNM	Swat Landuse Class	-	PDDY
HYDGRP	Hydrologic soil group	-	C
SNAM	Soil class	-	Ach
SOL_Z	Soil depth data	-	2,000
ESCO	Soil evaporation compensation factor	0.1 to 1.0	0.97
ALPHA_BF	Baseflow alpha factor (days)	0.1 to 1.0	0.1
GW_REVAP	Groundwater “revap” coefficient	0.02 to 0.20	0.1091
CN2	Initial SCS runoff curve number to moisture condition II	30 to 100	81
ICNUM	Plant Code	-	RICE

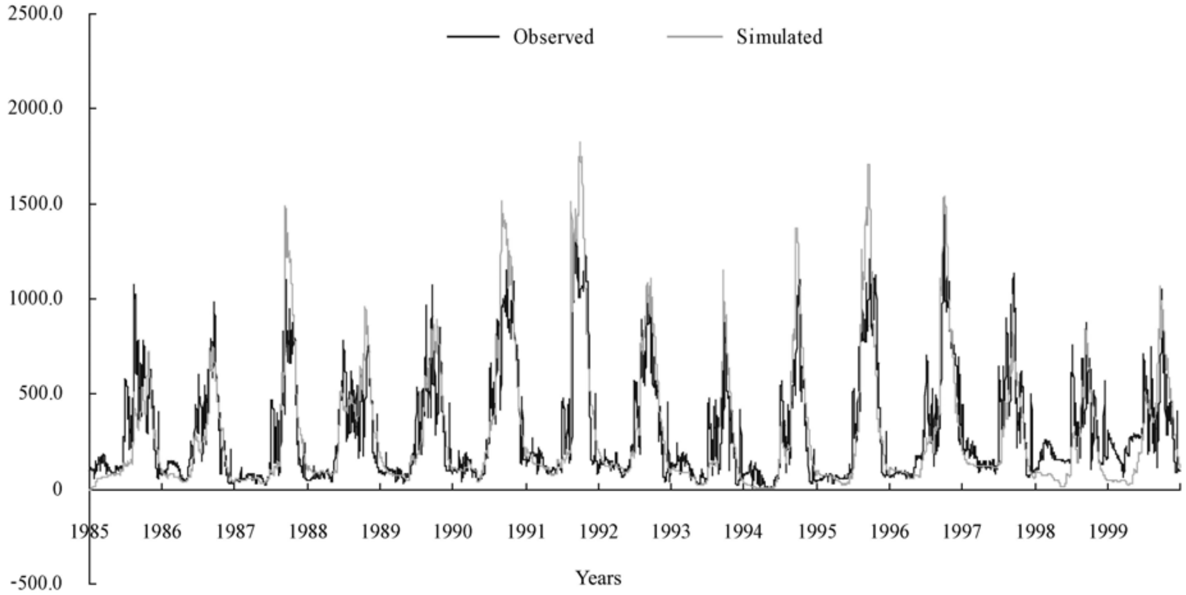

Figure 4 SWAT Calibration result for station E.2 located at Yasothon, at the outlet of the Mae Nam Chi River basin (Source: adapted from MRC, 2004)

Table 2 Calibration and validation result for Mae Nam Chi at Yasothon (709 Tributary Gauge)

Catchment area/km^2	Calibrated Period	Monthly N_{SE}	Daily N_{SE}	Validation Period	Monthly N_{SE}	Daily N_{SE}
43100	1985-1992	0.89	0.79	1993-1999	0.74	0.70

Source: Rossi et al., 2009.

4 Results

4.1 Baseline scenarios

The SWAT2003 baseline simulation was performed for 20 years (1985 to 2004) for both the Huai Yang Cher and Huai Sai Kai subregions within the At Samat watershed. The majority of the annual runoff yield for the Huai Yang Cher subregion was predicted to occur during May to November. The predicted average annual runoff yield was 115.8 million m^3 while the average annual runoff yield for the subwatersheds varied between 0.0167 to 0.0185 m^3 s^{-1} km^{-2} and the total average value was 0.0173 m^3 s^{-1} km^{-2} (Table 3). Most of the estimated runoff yield for the Huai Sai Kai subregion also resulted during May to November each year. The average annual runoff yield was predicted to be 214.6 million m^3, which was nearly twice the volume predicted for the Huai Yang Cher subregion. The average annual runoff yield for each subwatershed ranged between 0.0138 to 0.0166 m^3 s^{-1} km^{-2} and total average value of 0.0259 m^3 s^{-1} km^{-2}.

Table 3 Predicted average annual runoff of the At Samat watershed for the subregion baseline scenarios

Code	Subwatershed name	Area /km^2	Average annual runoff	
			million m^3	m^3 s^{-1} km^{-2}
YH1	Upper Huai Yang Cher	34.2	17.90	0.0167
YH2	Middle Huai Yang Cher	141.2	82.46	0.0185
YH3	Lower Huai Yang Cher	29.4	15.42	0.0167
	Total	204.8	115.78	-
	Total Average	-	-	0.0173
SK1	Upper Huai Sai Kai	81.4	35.54	0.0138
SK2	Huai Sang Khea	107.2	51.77	0.0153
SK3	Middle Huai Sai Kai	132.5	66.98	0.0160
SK4	Huai Keaw	84.5	44.10	0.0166
SK5	Lower Huai Sai Kai	32.3	16.19	0.0159
	Total	437.9	214.58	-
	Total Average	-	-	0.0259

4.2 Climate change scenarios

The baseline SWAT parameters were used in conjunction with projected climate data for 2000 to 2050 that consisted of rainfall, temperature, solar radiation, wind speed, relative humidity and evaporation for the climate change scenarios. The climate data were obtained from PRECIS scenarios performed for Thailand

(Southeast Asia START Regional Center, 2007) and downscaled to the case of At Samat watershed.

The trends in average temperature and precipitation, as projected by PRECIS for the At Samat watershed region, are shown for the period 1985 to 2050 in Figures 5 and 6, and in Table 4. Overall, the average temperature and precipitation were predicted to increase by 3% and 4%, respectively. The climate change scenarios resulted in overall water yield increase of 5% and 3.8% for the Huai Yang Cher and Huai Sai Kai subregions as shown in Figures 7 and 8, and in Table 5. In addition, the average monthly flow in Huai Yang Cher and Huai Sai Kai subregions increased 2.6% to 4.9% and 1.6% to 4.1%, respectively, as shown in Tables 6 and 7, and in Figures 9 and 10.

The forecasted climate change of increasing average temperature and precipitation resulted in a more even distribution of predicted runoff in both the Huai Yang Cher and Huai Sai Kai, due to a wider distribution of rainfall in the watershed. In addition, the peak flow periods of Huai Yang Cher and Huai Sai Kai were predicted to generally shift from August to September (Tables 6 and 7). The results also indicated that the predicted precipitation changes would lead to future positive water management developments because of reduced risks of water shortages for agricultural due to more rainfall during the historically

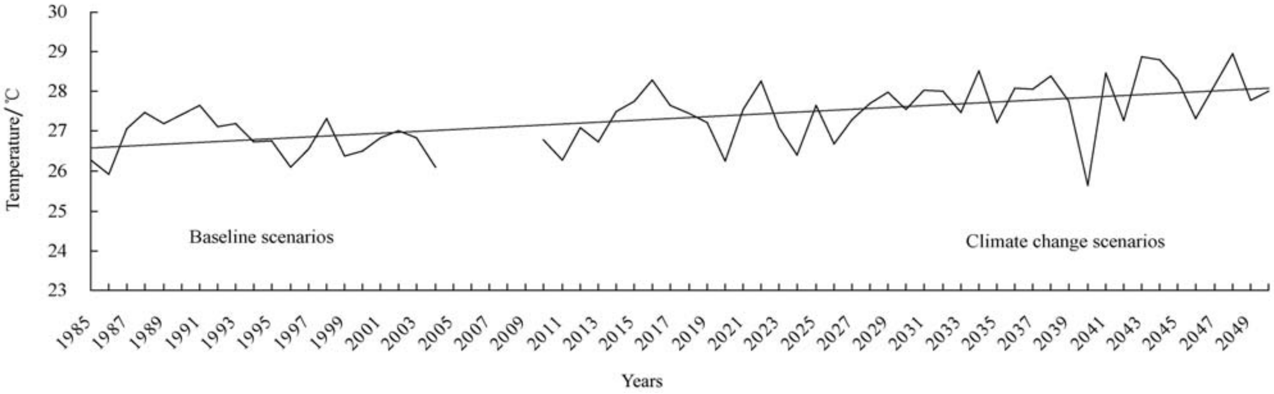

Figure 5 Long-term (1985 to 2050) average temperature trend predicted by the PRECIS model for the At Samat watershed

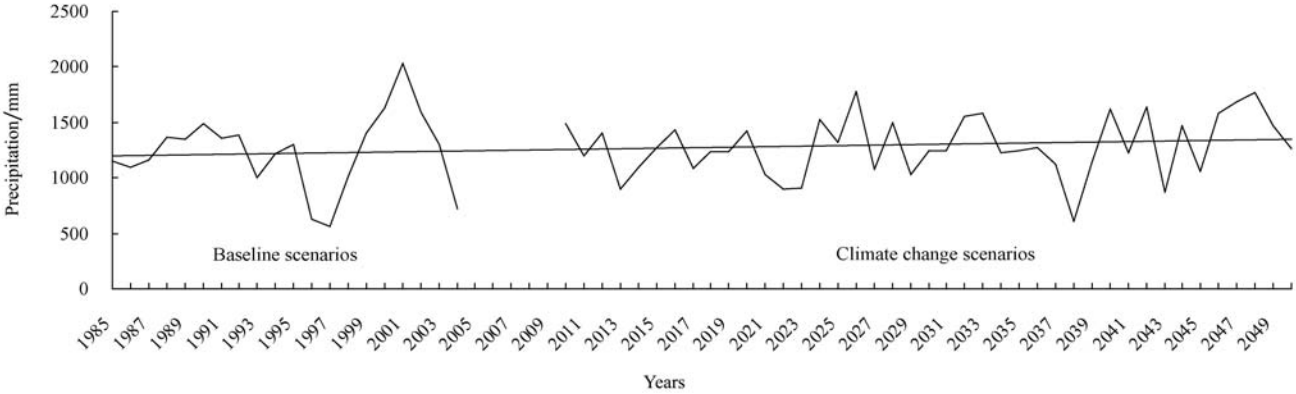

Figure 6 Long-term (1985-2050) average precipitation trend predicted by the PRECIS model for the At Samat watershed

Table 4 Summary of projected temperature and precipitation changes for At Samat watershed based on the PRECIS model projections

Avg. Period	Avg. Temp. /℃	Change /℃	Change rate/%	Avg. PCP/mm	Change/mm	Change rate/%
1885-2004	26.82			1,237.68		
2010-2025	27.24	0.43	1.59	1,217.08	-20.59	-1.66
2026-2041	27.68	0.86	3.21	1,279.98	42.31	3.42
2041-2050	28.16	1.34	4.99	1,424.28	186.60	15.08
2010-2050	27.61	0.80	2.97	1,287.11	49.43	3.99

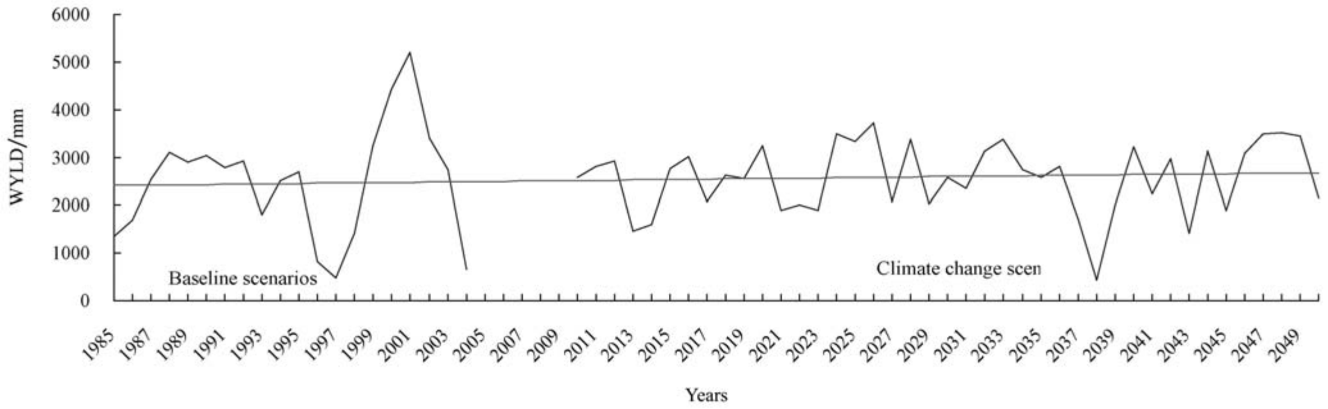

Figure 7 Average Runoff Yield Change during 1985 to 2050 for the Huai Sai Kai Subregion, in response to the climate change scenario

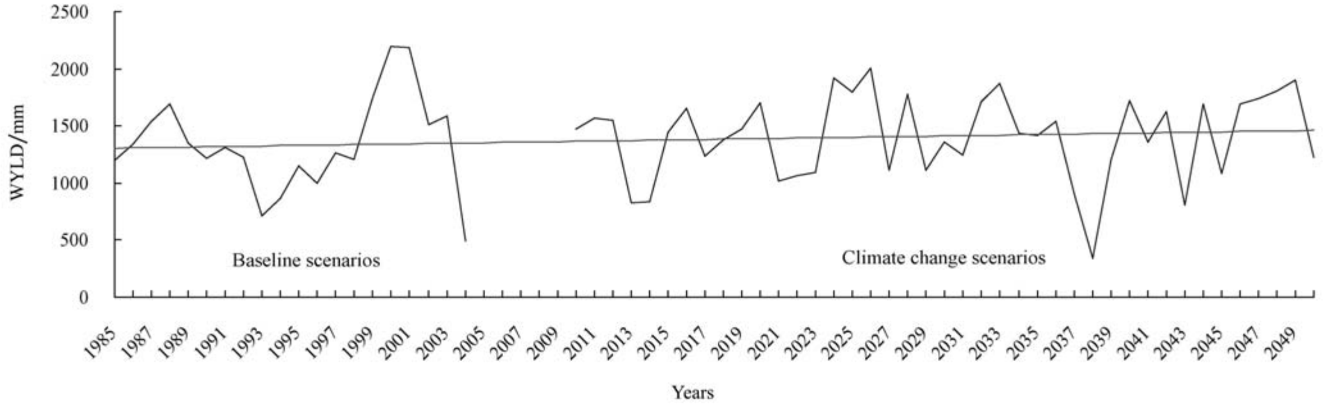

Figure 8 Average Runoff Yield Change during 1985 to 2050 for the Huai Yang Cher Subregion in response to the climate change scenario

Table 5 Predicted runoff yield changes for the two subregions for the climate change scenario

Avg. Period	Huai Yang Cher Subregion			Huai Sai Kai Subregion		
	Avg. Runoff Yield/mm	Change/mm	Change rate/%	Avg. Runoff Yield /mm	Change/mm	Change rate/%
1885-2004	1,339.76			2,483.29		
2010-2025	1,375.97	36.21	2.70	2,515.06	31.77	1.28
2026-2041	1,381.49	41.73	3.11	2,519.83	36.54	1.47
2041-2050	1,508.45	168.69	12.59	2,788.61	305.32	12.30
2010-2050	1,407.20	67.44	5.03	2,576.97	93.68	3.77

dry period in July (Figures 9 and 10). In addition to this, a forestation management could be introduced in order to increase the upstream forest area. The predicted future climate conditions could provide enhanced conditions for establishment of the trees, which would be planted in May, would receive more precipitation during the May to August period, and would have a reduced dry period to contend with in July, which in combination would lead to a higher survival rate. Potential future flooding could impact forest or other vegetation establishment, although the threat of flooding during the typical July to August flood season would be reduced based on the predicted climate patterns. Increased chances of flooding might occur during September due to the predicted shift in the precipitation peak from August to September (Figures 9 and 10), but such flood risks would likely be minor. However, flooding could still occur in the Huai Yang Cher and Huai Sai Kai subregions every year due to the much higher flow volumes carried by the Mae Nam Chi River, which typically overflow the banks of the main river channel and often result in backflows that overflow the Huai Yang Cher and Huai Sai Kai channels (and other tributary channels).

Table 6 Predicted average monthly flow (cms) changes for the Huai Yang Cher Subregion for the climate change scenario

Month	Year 1985-04	Year 2010-25	Year 2026-41	Year 2042-50	Year 2010-50	Month	Year 1985-04	Year 2010-25	Year 2026-41	Year 2042-50	Year 2010-50
JAN	1.4	1.7	1.8	2.0	1.8	SEP	7.0	7.4	7.0	7.8	7.3
FEB	1.9	1.9	1.8	1.8	1.8	OCT	4.2	4.9	4.5	5.3	4.9
MAR	1.9	1.6	1.6	1.7	1.6	NOV	1.9	3.0	2.9	3.2	3.0
APR	2.2	1.6	1.7	1.9	1.7	DEC	1.6	2.2	2.0	2.2	2.1
MAY	3.4	3.8	3.1	3.8	3.5	Average.	3.7	3.8	3.8	4.1	3.8
JUN	6.1	4.5	5.5	5.4	5.1	Change (+/-)	+/-	0.1	0.1	0.5	0.2
JUL	4.9	5.8	6.4	6.9	6.3	Change (%)	+/- (%)	2.59	3.03	12.46	4.93
AUG	7.6	6.9	6.9	7.5	7.1						

Table 7 Predicted average monthly flow (cms) change for the Huai Sai Kai Subregion for the climate change scenario

Month	Year 1985-04	Year 2010-25	Year 2026-41	Year 2042-50	Year 2010-50	Month	Year 1985-04	Year 2010-25	Year 2026-41	Year 2042-50	Year 2010-50
JAN	2.7	2.9	3.0	3.4	3.0	SEP	11.5	14.3	12.6	14.7	13.7
FEB	2.9	3.1	3.1	3.9	3.3	OCT	6.8	7.7	6.8	7.6	7.4
MAR	3.1	2.8	2.9	3.4	3.0	NOV	3.5	4.2	4.1	4.4	4.2
APR	3.6	2.8	3.4	3.5	3.2	DEC	2.8	3.3	3.2	3.2	3.3
MAY	6.7	7.9	6.7	7.7	7.4	Average.	6.8	6.9	6.9	7.6	7.0
JUN	10.7	9.0	11.2	10.9	10.3	Change (+/-)		0.1	0.1	0.9	0.3
JUL	8.7	10.7	12.1	14.3	12.0	Change (%)		1.59	1.83	12.69	4.12
AUG	18.2	13.7	13.3	14.4	13.7						

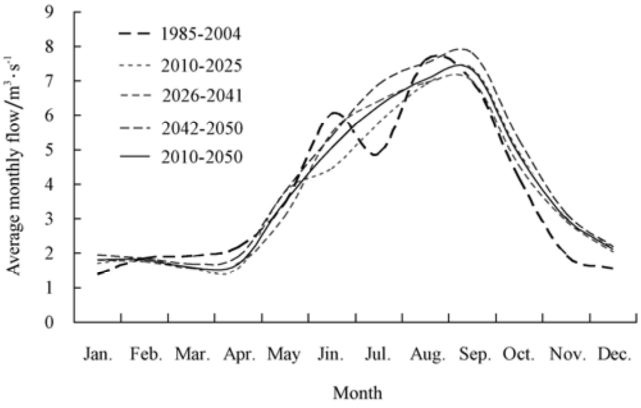

Figure 9 Average monthly flow change for Huai Yang Cher subregion

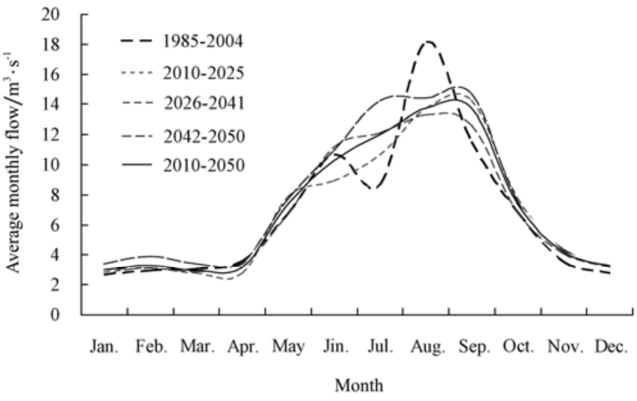

Figure 10 Average monthly flow change for Huai Sai Kai subregion

5 Discussion and conclusions

This study applied SWAT, which is a useful tool for determining the spatial and physical relationships between rainfall and runoff, within the context of future climate projections. The feasibility of using SWAT was first evaluated based on previous calibration work performed for the Mae Nam Chi basin within the larger Mekong River assessment (Rossi et al., 2009; MRC, 2004) before applying it for the climate change assessment. The research applied future climate projections for 2010-2050 generated with PRECIS to simulate climate change projection in the next 40 years, which is an innovative technique for applying SWAT in the Southeast Asia region. The climatic data used from the PRECIS projections for this study include the average of rainfall, wind speed, solar radiation, and maximum and minimum temperature, for the years 2010-2050, but did not include relative humidity. The climate projections resulted in a reasonable trend of increasing temperature and are consistent with the results reported by Chinvanno et al. (2009), who used the PRECIS and ECHAM4 models to forecast future climate change in the northeastern part of Thailand, particularly in the area near the Mae Kong River.

According to the estimation of runoff in the area of At Samat watershed, the average current runoff is about 368.46 million m^3/y or 0.0194 m^3 s^{-1} km^{-2}. The runoff in the At Samat watershed was estimated to increase about 3%-5% in the year 2050, when the regional temperature was estimated to rise at an average of 0.8℃ and rainfall to increase at a rate of 4%. This runoff impact is not expected to result in any measurable changes in land use or management practices and is also considered minimal when compared with the future water demand, which is expected to increase approximately twofold as compared to average current runoff for agricultural and consumptive water uses. Assessing the relationship between rainfall and runoff, it is important and must be conducted at an initial stage of water resource engineering assessments which can include analysis of water resource development feasibility, watershed and water balance, flood prevention, and dam or reservoir design. Such studies require accurate runoff yield estimates for both current and future conditions. The application of SWAT provided an efficient method to assess the impacts of alternative climate scenarios for the At Samat watershed and could be used in a similar way for other watersheds in the Southeast Asia region. However, direct measurement of future climate change and many other SWAT inputs is not possible, and thus users must be aware of the error that exists in such modeling assessments. This study also underscores the need for monitoring stations to be established in the At Samat watershed, especially at the outlet, to obtain streamflow and pollutant data for an in-depth calibration and validation assessment of SWAT. Such monitoring data would also be a valuable asset for many other watersheds in the Southeast Asia region.

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[References]

[1] Arnold J. G., and N. Fohrer. 2005. SWAT2000: Current capabilities and research opportunities in applied watershed modeling. Hydrol Process, 19(3): 563－572.

[2] Chinvanno S., V. Laung-Aram, C. Sangmanee, and J. Thanakitmetavut. 2009. Southeast Asia START Regional Center Technical Report No. 18: Future Climate Projection for Thailand and Mainland Southeast Asia Using PRECIS and ECHAM4 Climate Models. Southeast Asia START Regional Center. Bangkok.

[3] Fu C., S. Wang, Z. Xiong, W. J. Gutowski, D. K. Lee, J. L. McGregor, Y. Sato, H. Kato, J. W. Kim, and M. S. Suh. 2005. Regional Climate Model Intercomparison Project for Asia, 86(2): 257－266.

[4] Gassman P. W., M. Reyes, C. H. Green, and J. G. Arnold. 2007. The Soil and Water Assessment Tool: Historical development, applications, and future directions. Trans ASABE, 50(4): 1211－1250.

[5] Gregory J. M., J. A. Church, G. J. Boer, K. W. Dixon, G. M. Flato, D. R. Jacket, J. A. Lowe, S. P. O.¡¯Farrell, E. Roeckner, G. L. Russell, R. J. Stouffer, and M. Winton. Comparison of results from several AOGCMs for global and regional sea-level change 1900-2100. Climate Dynamics, 18: 225－240.

[6] Hadley Centre. 2002. The Hadley Centre regional climate modeling system: PRECIS ¨C Update 2002, providing regional climates for impact studies. Met Office, Hadley Centre, Bracknell, Berkshire, United Kingdom. Available at: http://precis.metoffice.com/new_user.html.

[7] Jha M., Z. Pan, E. S. Takle, and R. Gu. 2004. Impacts of climate change on streamflow in the Upper Mississippi River Basin: a regional climate model perspective. Journal of Geophysical Research, 109: D09105.

[8] Jones R. G., M. Noguer, D. C. Hassell, D. Hudson, S. S. Wilson, G. J. Jenkins, and J. F. B. Mitchell. 2004. Generating high resolution climate change scenarios using PRECIS, Met Office Hadley Centre, Exeter, UK, 40pp.

[9] Moriasi D. N., J. G. Arnold, M. W. Van Liew, R. L. Binger, R. D. Harmel, and T. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Trans ASABE, 50(3): 885－900.

[10] MRC. 2004. Water Utilisation Project Component A: Development of Basin Modelling Package and Knowledge

Base (WUP-A). Technical Reference Report DSF 620 SWAT and IQQM Models. Mekong River Commission, Bangkok, Thailand.

[11] Neitsch S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2005. Soil and Water Assessment Tool Theoretical Documentation, Version 2005. Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory. Available at: http://swatmodel. tamu.edu/documentation.

[12] Neitsch S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. 2005. Soil and Water Assessment Tool Input/Output File Documentation, Version 2005. Temple, Tex.: USDA-ARS Grassland, Soil and Water Research Laboratory. Available at: http://swatmodel.tamu.edu/ documentation.

[13] Rossi C. G., R. Srinivasan, K. Jirayoot, T. Le Due, P. Souvannabouth, N. Binh and P. W. Gassman. 2009. Hydrologic evaluation of the lower mekong river basin with the soil and water assessment tool model. IAEJ, 18(1-2): 1－13.

[14] Southeast Asia START Regional Center. 2007. PRECIS meeting, 31 Oct 2007 - 02 Nov 2007: Future Climate Changed in Thailand. Bangkok, Thailand.

[15] The National Water Resource Board. 2004. Guidelines of Watershed Management in Thailand. In: Seminar¡¯s supporting document of World Water Day. March 22, 2004.

[16] UNEP. 2007. The fourth Global Environment Outlook: environment for development (GEO-4). United Nations Environment Programme, United Kingdom. Available at: http://www.unep. org/geo/geo4/media.

[17] Williams J. R., J. G. Arnold, J. R. Kiniry, P. W. Gassman, and C. H. Green. 2008. History of model development at Temple, Texas. Hydrol Sci J, 53(5): 948－960.