Water Resources Management: Hydrologic Evaluation and Effect of Climate Change on the Atsamart Watershed, Northeastern Region, Thailand

Prayuth Graiprab[1], Kobkiat Pongput[2] and Nipon Thangtham[3]

---

[1] Senior Civil Engineer, Department of Water Resources, Samsen Nai, Phayathai, Bangkok 10400, Thailand, pg895@hotmail.com & Corresponding author: pg895@hotmail.com

[2] Associate Professor, Department of Water Resources Engineering, Kasetsart University, Bangkhen, Bangkok 10900, Thailand, kobkiat.p@ku.ac.th

[3] Professor, Faculty of Environment and Resource Studies, Kasetsart University, Bangkhen, Bangkok 10900, Thailand, ffornpt@ku.ac.th

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 km2 Atsamart watershed, located in the Mae Nam Chi basin in Northeast Thailand. In this study, the watershed was divided into 3 main subregions with a total of 11 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 Atsamart 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°C and rainfall has increased for another 4%, average runoff yield will be increased 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 Atsamart watershed at that time.

Keywords: SWAT, Hydrological Model, Climate change, Hydrological Evaluation, WRM

Introduction

Ongoing environmental changes currently brought about by either natural or anthropogenic influences, have been significantly impact on natural resources and societal living conditions. 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. 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 Atsamart District in Roi-et Province of Thailand 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 Atsamart 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 reported in e.g., 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. 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 uses in Atsamart 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.

Study Area

The Atsamart watershed is a small subwatershed of Mae Nam Chi basin, which is located in the Northeast part of Thailand. Atsamart watershed partly covers three subwatersheds (subwatersheds 9, 12 and 50) of the larger Mae Nam Chi basin, which consists of 64 subwatersheds, divided by the modelling team of Mekong River Commission (Figure 1). Atsamart watershed is in the southwest of Roi-et Province on the highway Roi-et-Panom Prai, 34 kilometres from Roi-et, Thailand. While the larger Mae Nam Chi basin covers 49,477 km^2, the Atsamart watershed covers an area of 732 km^2 and consists of three major subregions: the Huai Yang Cher, Huai Sai Kai and Namchi subregion (Figure 2).

However, since the objective of the study is mainly focused on estimating the water yields of the two subregions, Huai Yang Cher and Huai Sai Kai by testing SWAT using parameters for larger Mae Nam Chi basin SWAT model as further described in the Methodology section in order to deal with the problem of drought and flood while water use in Namchi subregion, on the right side of Chi River does not have such problem, thus, SWAT was not applied with Namchi subregion.

The Atsamart watershed is 115-150 meter above mean sea level. Central of the watershed is a rolling terrain, slopes to Mae Nam Chi River. The northern part is 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 livestock.

The significant variable of weather statistics used in this study were accumulated from weather stations in Roi-et province. These variables namely temperature, relative humidity, wind speed, pan evaporation and rainfall, contained annual average at 27^0c, 71%, 5 km/h, 1,659 mm. and 1,356 mm., respectively. The major land use in Atsamart watershed consists of agriculture, forest, urban, water and other areas in the proportion of 79.85%, 7.14%, 4.33%, 1.22% and 6.31%, respectively.

There are 10 soil types in Atsamat 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) with the percents of coverage areas relative to the watershed area about 52.36%, 23.90% and 13.76% respectively.

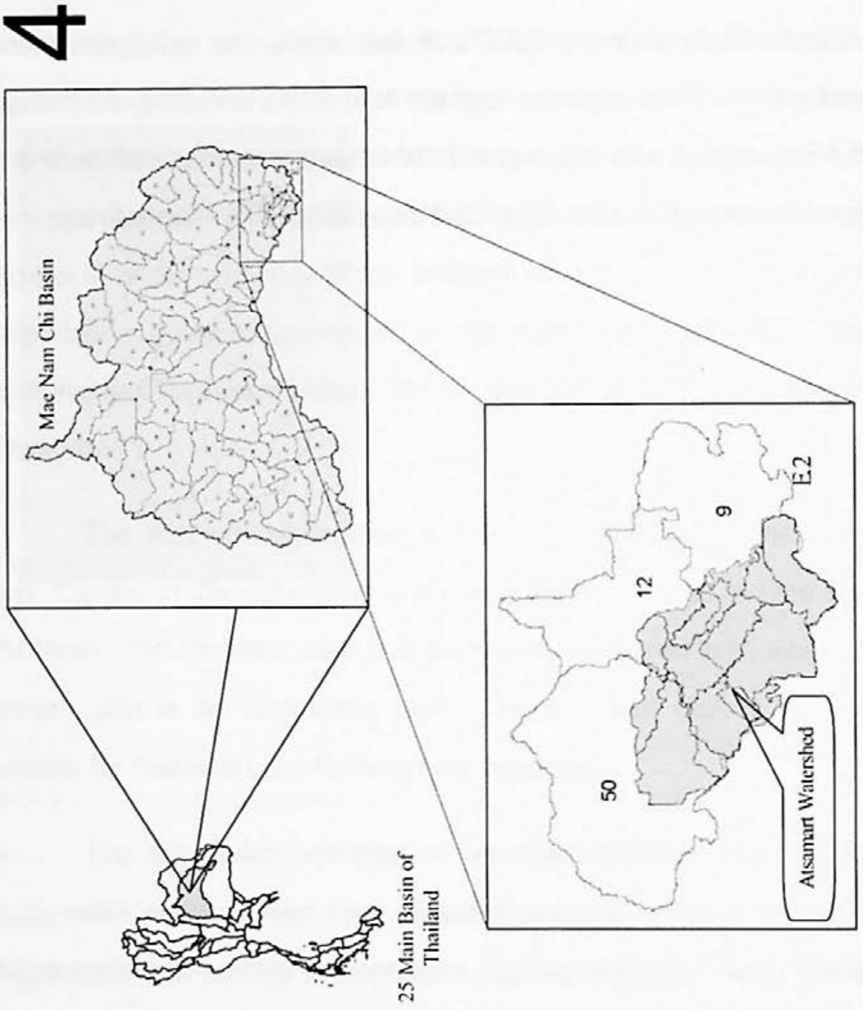


Figure 1. Location of study area

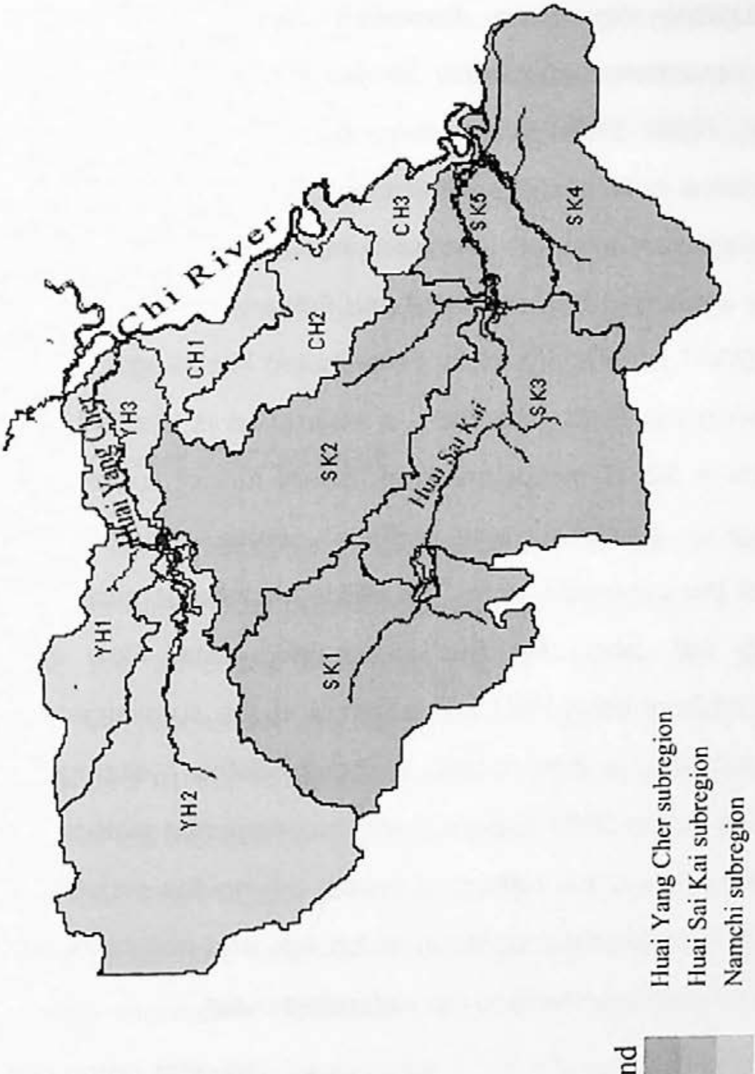


Figure 2. Study area and watershed delineation

Methodology

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 (Anold 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. This is the pattern of model having the simulation closest to real hydrological process in which flow and pollutants are routed between subwatersheds to the watershed outlet.

Weather data required for setting up SWAT includes climatic components of rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed (Neitsch et al., 2001). 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).

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, the land surface and the 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)

Data Sources and Data Collection

The Atsamart 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, conducted by the modelling team of Mekong River Commission, and applied to the Atsamart 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 Atsamart SWAT watershed model was constructed using time series and spatial data. Time series data consists of weather and stream flow data. Weather data were collected from Thai Meteorological Department, Roi-et Province. These data consists of relative humidity, sunshine duration (solar radiation), temperature, and wind speed, which were collected from year 1985 to 2004.

Rainfall data were collected from Thai Meteorological Department. Nine rainfall stations (Figure 3) were selected to use for this study. The daily rainfall data ranges from year 1985 to 2004. The average rainfall from nine stations varies from 764.70 – 2,460.00 mm/year. The average rainfall is 1,354.70 mm./year. Heavy rainfall generally occurs due to tropical depression storms originated in the South Pacific or the South China Sea during the period from June to October.

Stream flow data was previously used for SWAT model calibration for the larger Chi River Basin. It was collected from the E2 station of the Royal Irrigation Department. The Station is located on Chi River in Muang District, Yasothon Province. The period of daily data recorded at the station varied from 1952-2003. Maximum annual runoff was about 14,914.6 million cubic meters, while minimum annual runoff was about 3,057.4 million cubic meters. Moreover, average annual runoff was about 7,330.5 million cubic meters.

Spatial data consists of Digital Elevation Model (DEM), a 30x30 m (1:10,000 scale) which is a digital representation of ground surface topography or terrain. It was collected from the Land Development Department. The maximum of elevation was about 167 m.MSL., while the minimum of elevation was about 115 m.MSL. The mean of elevation was about 136 m.MSL. In addition, soil classification map and land use data, 1:50,000 scale were obtained from the Land Development Department.

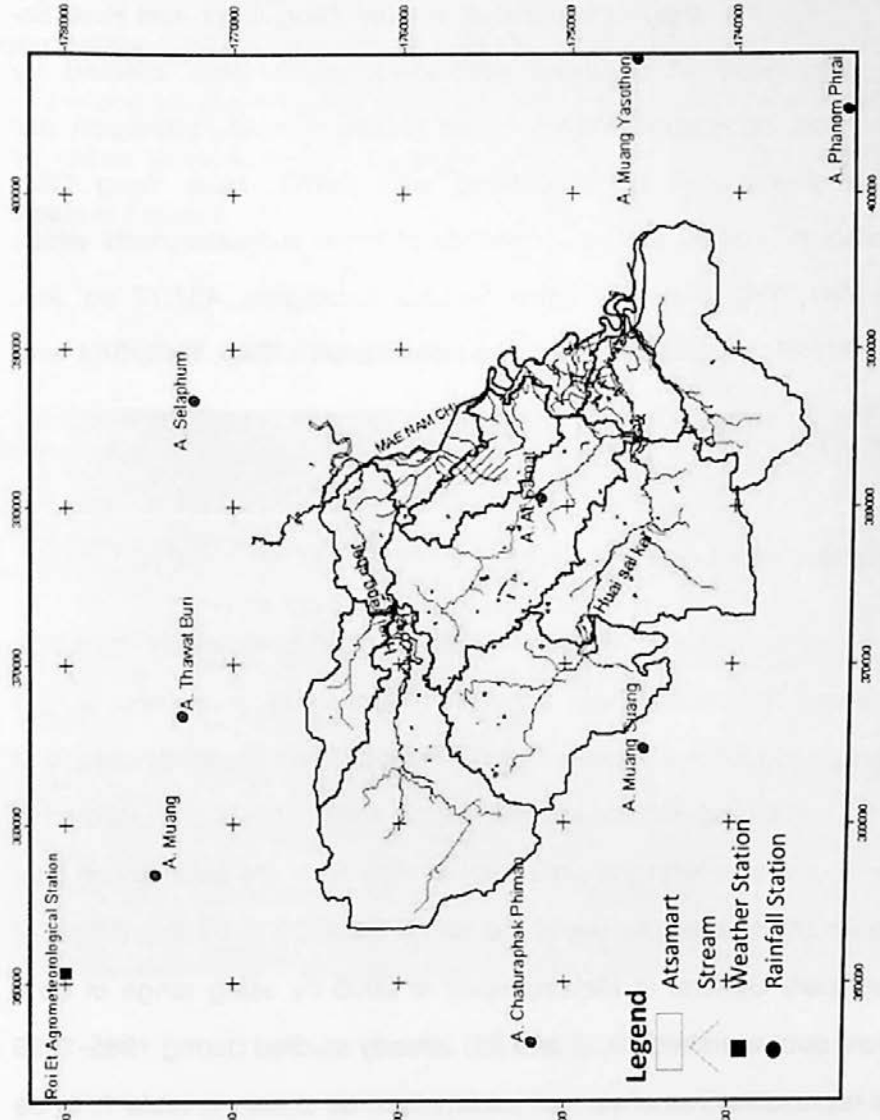


Figure 3. Location of nine rainfall stations

SWAT Model Setup

For the study of water use in Huai Yang Cher and Huai Sai Kai subregions of Atsamart watershed, which were created by automatic delineation SWAT, runoff yields of each subregion are required and can be calculated with SWAT. Huai Yang Cher subregion, 204.60 sq. km., consists of three subwatersheds which are YH1, YH2 and YH3. Huai Sai Kai subregion, 437.77 sq. km. consists of five subwatersheds, which are SK1, SK2, SK3, SK4 and SK5.

Calibration from previous study

For model calibration method, the comparison is made between flow rates from simulation and those measured at the measuring stations at the location of study. Since the study area is of small watershed without any measuring station, the model studied is thus compared with the simulation of Mae Nam chi basin which was previously studied by using the same SWAT2003 by the Office of Secretary General of Mekong River in 2005 by using range of data (from subwatersheds 9,12 and 50) already studied during 1985-1999 as representatives of various parameters, as shown in table 1, to be used for Atsamart watershed study. The Atsamart watershed was also be a part of the simulation model previously studied.

Model calibration at station E2 in Yasothon Province located close to the river mouth at the outlet of Atsamart watershed produces percentage volume ratio of 100.23 and coefficient of efficiency of 0.62 which are used to plot flow rates during each period to compare the values obtained from simulation and those from observation as shown in Figure 4.

Table 1. SWAT Parameters of Atsamart watershed

Variable name	Definition	Range	Parameter used
PDDY	Swat Landuse Class	-	PDDY
C	Hydrologic soil group	-	C
Ach	Soilclass	-	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

Variable name	Definition	Range	Parameter used
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
RICE	Plant Code	-	RICE

However, there was a study of Hydrologic Evaluation of the Lower Mekong River Basin with the Soil and Water Assessment Tool Model by Rossi et al., 2009, which mentioned the calculating of total water yield of Mae Nam Chi up to Yasothon at station E2, the same station of Atsamart Watershed by using parameters as shown in Table 2, 3 and Table 4.

Table 2 Calibrated values of adjusted parameter for discharge calibration of the SWAT2003 model for the Lower Mekong River Basin for all eight simulated areas

Parameter	Definition	Range	Calibrated Value
ESCO	Soil evaporation compensation factor	0.1 to 1.0	0.950-0.997
FFCB	Initial soil water storage expressed as a Fraction of field capacity water content	0 to 1.0	0.990-0.995
Surlag	Surface runoff lag coefficient(days)	0 to 4.0	0.263-4.00
CN2	Initial SCS runoff curve number to moisture condition II	30 to 100	44-83

Source : Rossi et al., 2009

Table 3 Chi up to Yasothon water balance (mm month^{-1})

Average Precipitation	Precipitation Range	Average Surface Runoff	Total Water Yield	PET	ET
91.0	8.0-266.3	10.6	16.5	117	76.2

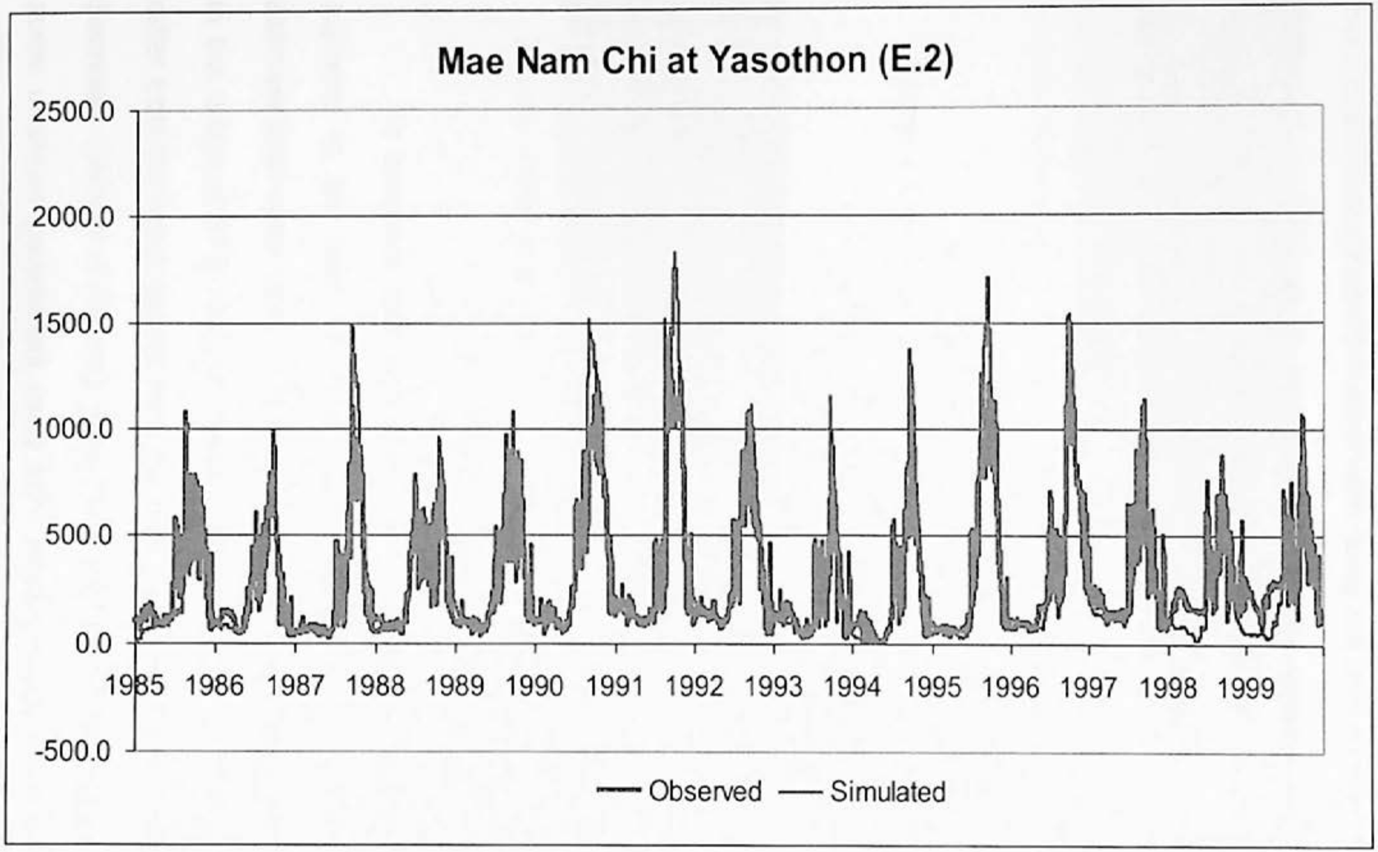
Source : Rossi et al., 2009

Table 4 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

To compare total water yield, the above parameters were adjusted to be used for Atsamart watershed study in order to estimate total water yield. The result shown the total water yield was in the range of 17.8-18.2 mm month^{-1} ,which was only 7.8%-9.34% differ from the result gained from the previous study by the Office of Secretary General of Mekong River that could be for the reason that some unshown parameters used from Rossi's study were not the same. Nevertheless, this small difference in percentage of water yield estimations studied by MRCs and Rossi et al. 2009, is regarded having slightly impact toward the overall water management in Atsamart watershed.



Source : Modified from MRC 2004

Figure 4. SWAT Calibration result modified from previous study

Results

Baseline Scenarios

The result of the study of runoff yield with SWAT2003 model in the area of Huai Yang Cher subregion and Huai Sai Kai subregion by using data from the statistics of 20 years during 1985-2004 can be summarized as follows:

Huai Yang Cher subregion is divided into three subwatersheds. Most of the runoff yield is produced during May to November every year. The average annual runoff yield is 115.78 million cu. m. with average annual runoff yield for each area having lowest variation at 0.0167-0.0185 cu.m/sec/sq. km. and total average value of 0.0173 cu.m/sec/sq. km.

Huai Sai Kai subregion is divided into five subwatersheds. Most runoff yield is produced during May to November every year. The average annual runoff yield is 214.58 million cu.m. with average annual runoff yield for each area having lowest variation at 0.0138-0.0166 cu.m/sec/sq. km. and total average value of 0.0259 cu.m/sec/sq. km.

Table 5. Average Annual Runoff of Atsamart watershed

Code	Subwatershed name	Area	Average Annual Runoff	
		(sq.km.)	(MCM)	(cu.m/sec/sq.km.)
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

Climate Change Scenarios

For data input of the case of climatic change, the baseline parameters are used, whereas weather data consists of data of rainfall, temperature, solar radiation, wind speed, relative humidity and evaporation during 2000-2050 obtained from PRECIS (Southeast Asia START Regional Center, 2007) program which is used to predict climatic change in Thailand and downscaled to the case of Atsamart watershed.

The SWAT result of Climate change scenarios impact using weather data during 2010-2050 from PRECIS Forecast model shown that average temperature and precipitation change for Atsamart watershed were increased 2.97% and 3.99% respectively. Details are shown in Figure 5, 6 and Table 6 This caused an increase of 5.03% and 3.77% of water yield in Huai Yang Cher and Huai Sai Kai Subregion. Details are shown in Figure 7, 8 and Table 7. In addition, average monthly flow in Huai Yang Cher and Huai Sai Kai Subregion were increased of 2.59% to 4.93% and 1.59% to 4.12% respectively. Details are shown in Table 8, 9 and Figure 9, 10.

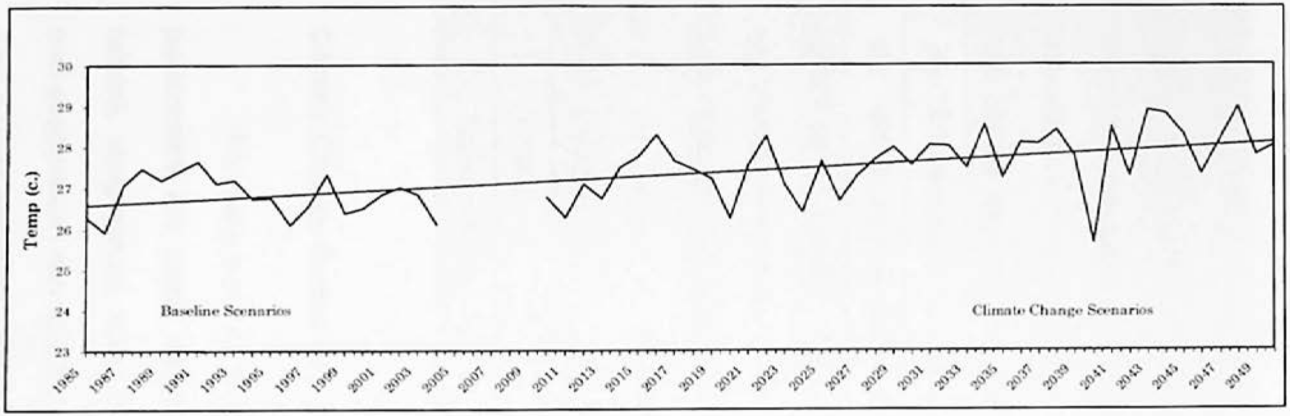


Figure 5. Tendency of Temperature Average for Atsamart Watershed by PRECIS Model

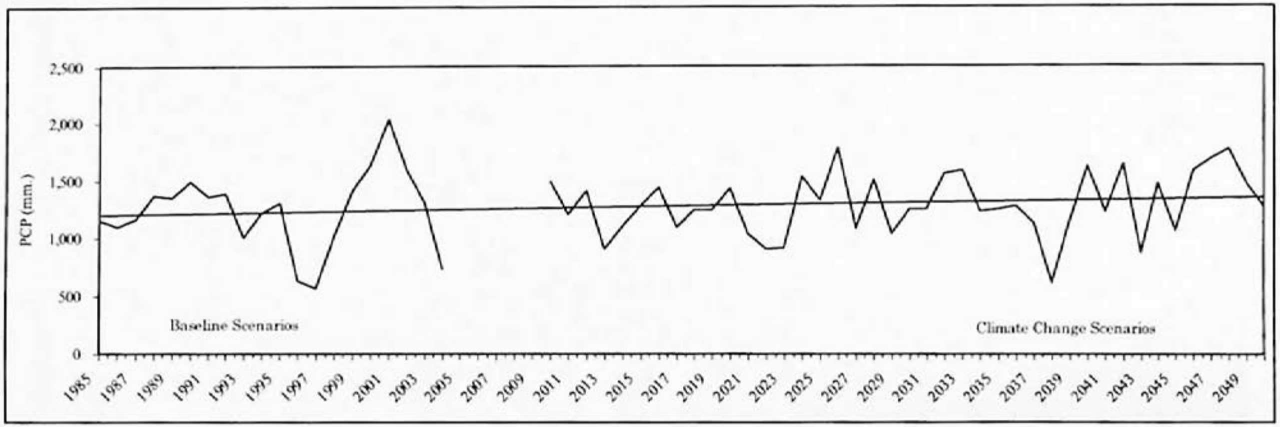


Figure 6 Tendency of Precipitation Average for Atsamart watershed PRECIS Model

Table 6. Summary of Temperature and Precipitation Change for Atsamart watershed

Avg. Period	Avg. Temp. (Celsius)	Change (Celsius)	% Change	Avg. PCP (mm.)	Change (mm.)	% Change
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

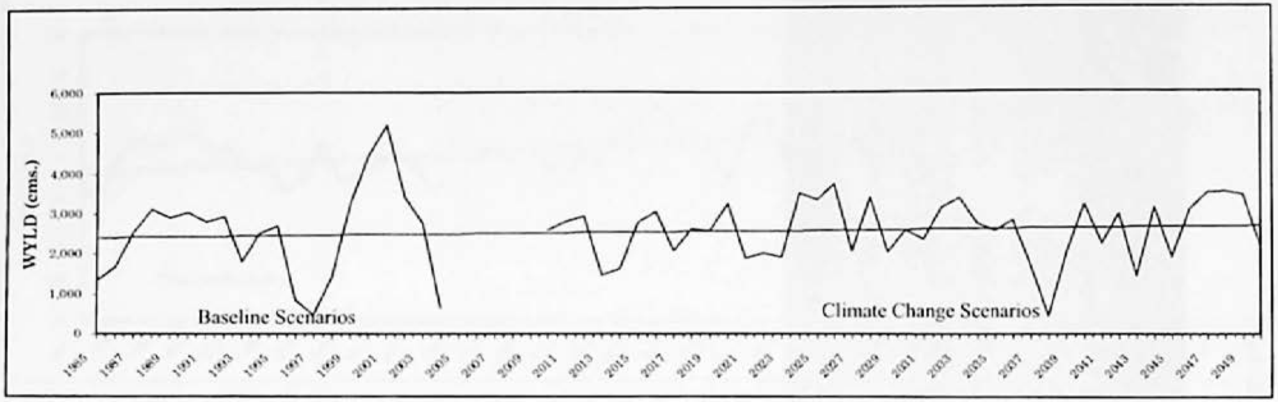


Figure 7. Average Runoff Yield Change for Huai Sai Kai Subregion

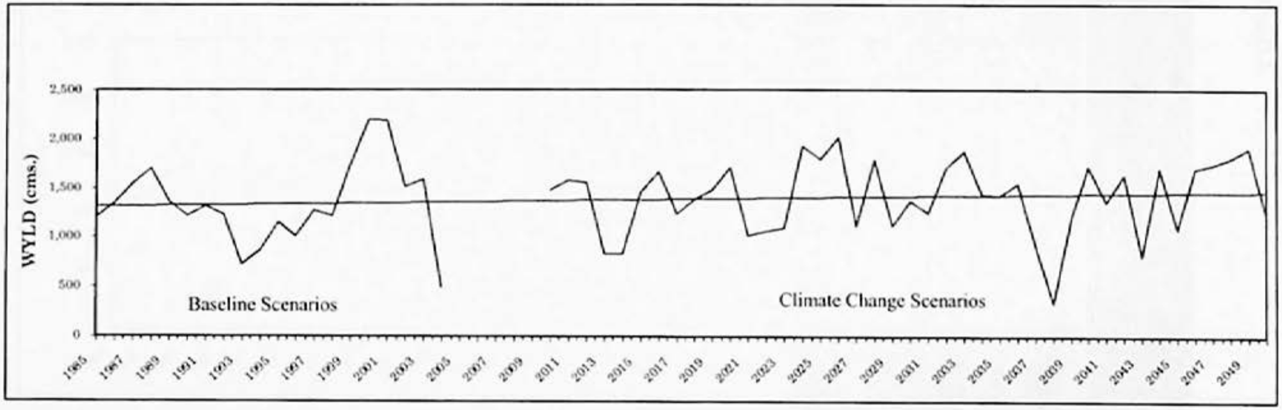


Figure 8. Average Runoff Yield Change for Huai Yang Cher Subregion

Table 7. Runoff Yield Change for Huai Yang Cher and Huai Sai Kai Subregion by SWAT

Avg. Period	Huai Yang Cher Subregion			Huai Sai Kai Subregion		
	Avg. Temp. (Celsius)	Change (Celsius)	% Change	Avg. PCP (mm.)	Change (mm.)	% Change
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

Table 8. Average Monthly Flow Change for Huai Yang Cher Subregion by SWAT

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

Table 9. Average Monthly Flow Change for Huai Sai Kai Subregion by SWAT

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

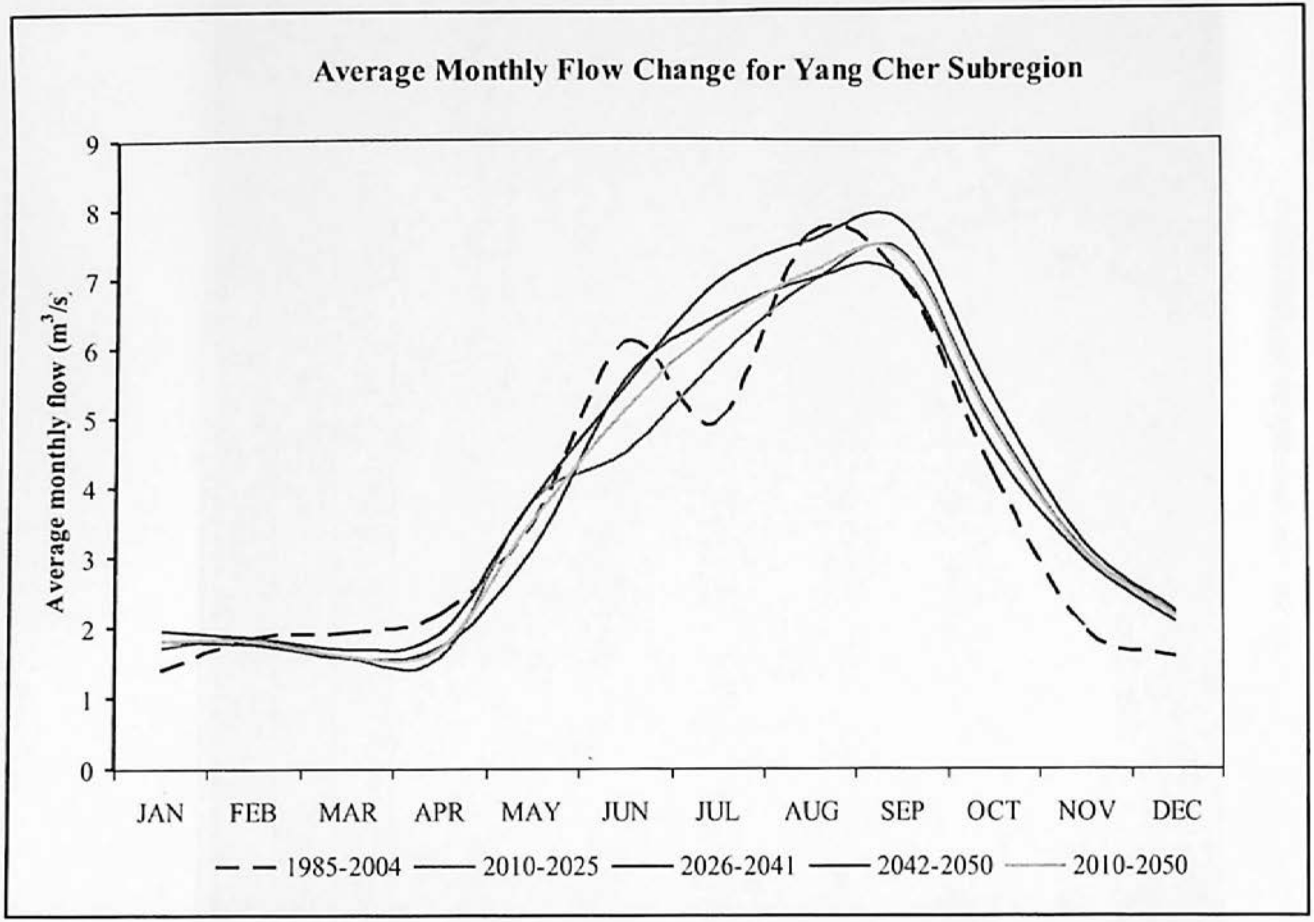


Figure 9. Average Monthly Flow Change for Huai Yang Cher Subregion

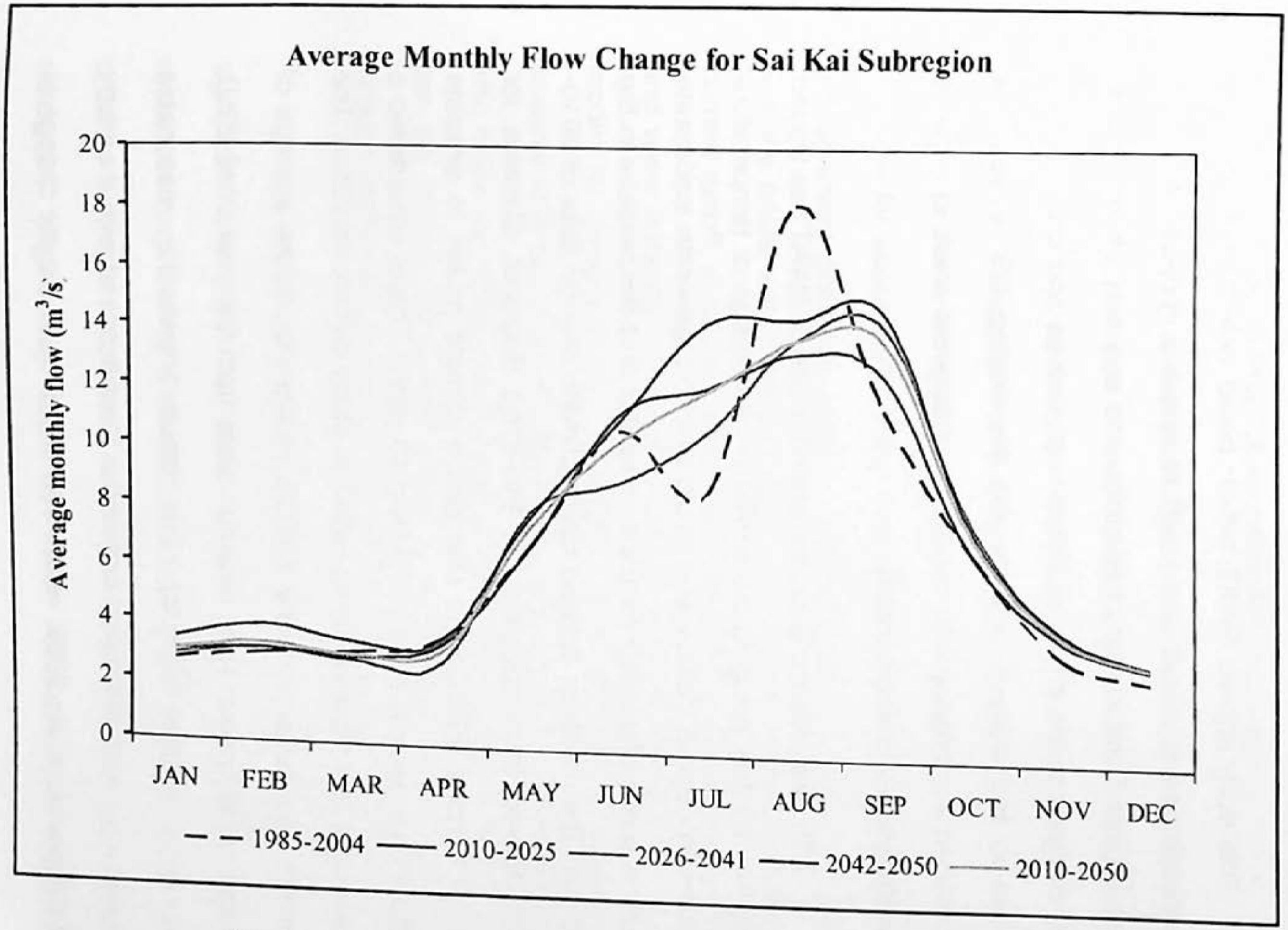


Figure 10. Average Monthly Flow Change for Huai Sai Kai Subregion

Discussion and Conclusions

This study applied SWAT, which could determine spatial and physical relations of rainfall and runoff to evaluate impacts of climate change on runoff and to study feasibilities and accuracy of such model before applying to the study as stated in objectives and criterion. The data set-up and analysis together with the existing DSF system are integrated in accordance with conditions of targeted areas in order to evaluate parameters appropriately.

With past climatic data, the previous use of SWAT has limited capacities by only gauging the rainfall in percentage or temperature changes in degree Celsius and could possibly generate inaccurate result on series of data for forecasting rainfall and temperature in the long run. The research applied future climate change data of 2010-2050 derived from applying the Providing Regional Climates for Impact Studies (PRECIS) to use with a climate model to simulate climate change projection in the next 40 years. This is considered a new model technique applying SWAT to study climate condition. The climatic data taken from the PRECIS model include the average of rainfall, wind speed, solar radiation were from the year 2010-2050, excluding relative humidity. The result shows the reasonable increasing trend of temperature and is in correspond with the study of Chinvanno et al., 2009, which forecasted future climate change in

Northeastern part of Thailand, particularly the area nearby the Mae Kong River by using PRECIS and ECHAM4 models.

According to the estimation of runoff in the area of Atsamart watershed, the average current runoff is about 368.46 MCM/year or 0.0194 cu.m/sec/sq.km. In the year 2050 when the region temperature is expected to rise at the average of 0.8 °C and rainfall to increase for another 4%, the runoff at Atsamart is estimated to increase for about 3-5%, which has no significance on land use and management practices and is considered minimal when compared with the future water demand, approximately twofold of the average current runoff, such as water uses for agriculture and consumption and water balance in ecosystem. Although the application of SWAT model to geographical information data, enables simulation to observe changes when variables are changed in the computer, those who make use of the model need to be aware that some input data can be directly measured, whereas others can only be obtained through mathematical method and thus might contain errors.

The study of relation, in terms of rainfall and runoff is significant and must be conducted at an initial stage of water resources engineering. The study includes hydrological analysis in order to generate runoff yield to analyze study feasibilities of water resources engineering such as water resources development feasibility, watershed and water balance, flood prevention, as well as dam or reservoir design. Those studies require to having most accurate runoff yield which could be appropriately applied to the real condition as project develops. The parameters used in Mae Nam Chi watershed SWAT model developed by the Mekong River Commission Secretariats (MRCs) together with the study of Rossi et al., 2009 could be applied with the DSF system of lower Kong River watershed, which covers Mae Nam Chi watershed positively to calculate runoff yield from precipitation and analyze physical relations of Atsamart watershed, the only 1.5 % area of Mae Nam Chi watershed. To calculate reasonable output, parameters and existing database are adjusted in order to import logical data which corresponds with actual runoff. However, water measuring stations need to be set up, especially at the river outlet of Atsamart watershed in the future to ensure the accuracy of the result of the runoff forecast or the monitoring of changes in water quality such as sediment deposition, oxygen content in the water or solvents that affect the watershed system. Upon daily observed data are obtained, the parameters should be re-calibrated in order to generate a more accurate and reliable data.

References

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

Chinvanno S., Laung-Aram V., Sangmanee C. and Thanakitmetavut J. (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.

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.

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.

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.

Hadley Centre. (2002) **The Hadley Centre regional climate modeling system: PRECIS – 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.

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

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.

Neitsch S.L., Arnold J.G., Kiniry J.R. and Williams J.R. (2001) **Soil and Water Assessment Tool User's manual Version 2000.** Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Texas. 86 p.

Rossi C.G., Srinivasan R., Jirayoot K., Le Due T., P. Souvannabouth, Binh N. and Gassman P.W. (2009) **Hydrologic Evaluation of the Lower Mekong River Basin with the Soil and Water Assessment Tool Model.** IAEJ, 18(1-2):1-13.

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

The National Water Resource Board. (2004) Guidelines of Watershed Management in Thailand. In: *Seminar's supporting document of World Water Day*. March 22, 2004.

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.

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.

Hadley Centre. (2002) **The Hadley Centre regional climate modeling system: PRECIS – 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.

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

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.

Neitsch S.L., Arnold J.G., Kiniry J.R. and Williams J.R. (2001) **Soil and Water Assessment Tool User's manual Version 2000.** Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Texas. 86 p.

Rossi C.G., Srinivasan R., Jirayoot K., Le Due T., P. Souvannabouth, Binh N. and Gassman P.W. (2009) **Hydrologic Evaluation of the Lower Mekong River Basin with the Soil and Water Assessment Tool Model.** IAEJ, 18(1-2):1-13.

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

The National Water Resource Board. (2004) Guidelines of Watershed Management in Thailand. In: *Seminar's supporting document of World Water Day*. March 22, 2004.

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.

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.