International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:8, No:6, 2014

Effect of Climate Change on Runoff in the Upper Mun River Basin, Thailand

Preeyaphorn Kosa, Thanutch Sukwimolseree

***Abstract*—**The climate change is a main parameter which affects the element of hydrological cycle especially runoff. Then, the purpose of this study is to determine the impact of the climate change on surface runoff using land use map on 2008 and daily weather data during January 1, 1979 to September 30, 2010 for SWAT model. SWAT continuously simulate time model and operates on a daily time step at basin scale. The results present that the effect of temperature change cannot be clearly presented on the change of runoff while the rainfall, relative humidity and evaporation are the parameters for the considering of runoff change. If there are the increasing of rainfall and relative humidity, there is also the increasing of runoff. On the other hand, if there is the increasing of evaporation, there is the decreasing of runoff.

***Keywords*—**Climate, Runoff, SWAT, Upper Mun River Basin.

I. INTRODUCTION

TO accurately estimate future supplies for water resources management plans, the effects of global climate change on runoff should be considered because the runoff is the main element of hydrology and water resources management. The runoffhave been addressed by the assessment of various global, region and nation [1], [2]. Normally, global runoff is computed using existing global climate models. However, the result from these model are based on quite inaccurate because of low spatial resolution, poor representation of soil water processes, and the lack of calibration against measured discharge [3]-[6]. Furthermore, there are many researches about the sensitivity of runoff to climate changes for many watersheds in the world. These researches are based on the watershed scale hydrologic models and the general circulation model (GCM) which can be uncertain and downscaling their estimation for local hydrologic use. Then, the sensitivity of runoff to climate change should be understood by analyzing the historical data [7]-[11]. Since runoff is affected by the climate change, the purpose of this study is to determine the effects of the climate change on surface runoff. To achieve this objective, land use map on 2008 and daily weather data during January 1, 1979 to September 30, 2010 were input data to SWAT.

II. MATERIALS AND METHODS

A. Description of Study Area

The upper Mun river basin is in northeast Thailand and it locates in the southwestern portion of the Khorat Plateau. It lies between latitude 14° 7'N and 15° 46'N, and longitudes 101° 11'E and 103° 00'E. The catchment area of the upper Mun river basin comprises 20.905 km^2 and consists of Lam Choengkrai, Lam Takhong, Lam Phraphloeng, upper part of Lam Nam Mun, Lam Sae, Lam Chakkarat, Lam Sa-Had, upper and lower part of Lam Paimash, and Lam Nam Mun part II subbasin. There are five large reservoirs included Lam Takhong, Lam Phraphloeng, Lam Sae, Lam Mun Bon, and Lam Paimash reservoirs and there is water storage from these five reservoirs about 939 million m^3. During 1979 to 2010, the average annual rainfall of the basin was 1080 mm while the maximum, minimum, and average of daily temperature were 32.41°C, 21.88°C, and 27.14°C, respectively.

B. Climate Change

The recorded daily data during January 1, 1979 to September 30, 2010 included temperature, rainfall, relative humidity, and evaporation in weather stations were analyzed to determine the tendency of these data. It can be presented that for the temperature there is the increasing of maximum, minimum, and mean temperature during 32 years equal to 0.015°C, 0.044°C, and 0.014°C, respectively. The different temperature from day to day was 5.92°C – 10.13°C in a year shown the high fluctuation. A number of a day in a year which the different temperature from day to day is more than 3°C was 28, 13, and 5 days for maximum, minimum, and mean temperature, respectively. The number of day in a year, which is less than 25°C, equals to 6, 318, and 72 days for maximum, minimum, and mean temperature, respectively and the number of day in a year included more than 35°C for maximum temperature is 74 days. Moreover, the mean monthly temperature for maximum and minimum temperature were 35.6°C in April and 17.17°C in December, respectively.

The recorded daily rainfall during 32 years was considered to be monthly rainfall and annual rainfall. The result presents that there is a high total rainfall from May to October while there is a low total rainfall from November to April. The highest total rainfall is in September (218.81 mm/month) but the lowest total rainfall is in December (3.52 mm/month). The mean annual rainfall is 1073.62 mm. The highest annual rainfall was 1386.33 mm in 2000 while the lowest annual rainfall was 693.13 mm in 1997.

The recorded of daily relative humidity included maximum,

K. Preeyaphorn is with the School of Civil Engineering, Suranaree University of Technology, Nakhon Ratchsima, Thailand (phone: 664-422-4421; fax: 664-422-4607;e-mail: kosa@sut.ac.th).

S. Thanutch is with the Department of Civil Engineering, Kasetsart University, Bangkok, Thailand (phone: 662-797-0999; fax: 662-579-7565; e-mail: fengtnsr@ku.ac.th).

minimum, and mean daily relative humidity was averaged using the data from all weather stations. They are consisted of 88.27%, 52.15%, and 72.03% for maximum, minimum, and mean daily relative humidity, respectively. The increasing tendency of mean daily relative humidity is 0.008% during 30 years.

The daily evaporation during 32 years was considered and the result shows that the mean monthly evaporation equals to 4.93 mm. The high mean monthly evaporation is from February to July which is more than 5 mm. The highest mean monthly evaporation is in April while the lowest mean monthly evaporation is in October. The increasing tendency of evaporation is 0.0008 mm during 32 years.

C. Soil and Water Assessment Tool (SWAT)

SWAT is hydrological model which continuously simulate time model and operates on a daily time step at basin scale. The main components of SWAT are consisted of weather, hydrology, sedimentation, crop growth, nutrients, pesticides, agricultural management, and stream routing [12]. However, this study focuses only on weather, hydrology, agricultural management, and stream routing to estimate surface runoff.

The surface runoff is calculated using the SCS runoff curve number and daily rainfall while the evapotranspiration is computed using [13], [14], or [15] depended on data available. The function of potential evapotranspiration and leaf area index are applied to estimate potential soil water evaporation while the exponential function of soil depth and water content is concerned to calculate actual soil evaporation. Plant water evaporation is simulated using the linear function of potential evapotranspiration, leaf area index, and root depth. Moreover, the simulation of hydrologic process in SWAT consist of infiltration, percolation losses, channel transmission losses, channel routing, and surface, lateral, shallow aquifer, and deep aquifer flow [12], [16]-[20].

The study area included the large scale spatial heterogeneity, considering information from the elevation map (DEM), the soil and land use map, is divided into subbasins and each subbasin is discriminated into a series of hydrologic response units or HRUs, which are unique soil and land use. SWAT model simulates soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices in each HRUs. Thereafter, the result of this simulation aggregated for the subbasin by a weighted average. Moreover, each subbasin is consisted of slope, reach dimensions and climate data. For climate data, the station nearest to the centroid of each subbasin is considered. The routing through the river system is concerned using the variable storage or Muskingum method [20].

In each HRU, water is stored in rainfall, soil profile (0-2 m), shallow aquifer (typically 2-20 m) and deep aquifer. The SCS curve method which estimates runoff based on land use, soil type, and antecedent moisture condition is applied in SWAT model to calculate surface runoff from daily rainfall [20].

The soil profile is subdivided into multilayer and it supports the process of infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation is concerned to estimate flow to soil layer in root zone using the method of water storage capacity. When field capacity of soil layer is exceeded and layer below is not saturated, the percolation to lower layers occurs. The simulation of daily average soil temperature is based on the function of maximum and minimum air temperature. There is not percolation to lower layer when temperature in soil layer is less than or equal 0^{o}C. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream [19], [20].

Weather data is the most fundamental input of hydrological model like SWAT. The daily data of rainfall and minimum/maximum temperature are required for SWAT. However, in many areas of the world including upper Mun river basin, the weather station network is not very dense and data duration is quite short. Moreover, there are many missing data and erroneous data. Then, to simulate missing data, the weather generator program WXGEN is applied in SWAT model. The WXGEN program fills data gap or extends time series of daily data based on monthly statistics. Then, if daily data is not available, this program is not useful [21].

Thereafter, water balance is applied in everything that occurs in the watershed. To accurately computation water balance, the hydrologic cycle must suitable for the simulation that is happening in the watershed. There are two major division of hydrologic cycle for the watershed. Firstly, the land phase of the hydrologic cycle is concerned to control the amount of water loading to the main channel in each sub-watershed. Secondary, the water phase of the hydrologic cycle is considered for the movement of water through the channel network of the watershed to the outlet. The water balance equation simulated in hydrologic cycle is presented as

$$S_f = S_i + \sum_{i=1}^{t} (P - Q_S - ET - w - Q_g) \tag{1}$$

where S_f is the final soil water content (mm H_2O), S_i is the initial soil water content (mm H_2O), t is the time (days), P is the precipitation on day i (mm H_2O), Q_S is the surface runoff on day i (mm H_2O), ET is evapotranspiration on day i (mm H_2O), w is the water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_g is the return flow on day i (mm H_2O).

D. Calibration

The calibration of SWAT model is based on measured data at the outlet of watershed and the simulated runoff was compared with observed field data for the period of 2005-2010. There are 2 steps of the calibration. Firstly, the R2 of the comparison between daily simulated runoff and observed field data equals to 0.43. These results agrees with the study of [22] (R^2 = 0.40), [23] (R^2 = 0.40) and [24] (R^2 = 0.45). The mean daily runoff of the observed field data and the simulated runoff are 5.90 $m^3.s^{-1}$ and 5.30 $m^3.s^{-1}$, respectively. Finally, the

R2 of the comparison between monthly simulated runoff and observed field data equals to 0.78. These results relate to the study of [25] (R^2 = 0.63), [23] (R^2 = 0.70), [26] (R^2 = 0.72), [27] (R^2 = 0.73), [28] (R^2 = 0.66), [29] (R^2 = 0.76), [30] (R^2 = 0.74) and [31] (R^2 = 0.77). The mean monthly runoff of the observed field data and the simulated runoff are 5.93 m^3/s and 5.28 m^3/s, respectively. These comparisons present that, in simulation, the mean monthly runoff is better than the daily runoff. Then, the mean monthly runoff is displayed in this study.

The estimation of runoff using SWAT is included erroneous result because of (1) limited and unevenly distributed gauge stations with varies time series length and (2) the lack of data on soil moisture and deep aquifer percolation which are considered for calibration and validation in SWAT model [21].

III. RESULTS AND DISCUSSION

The effect of climate change on runoff during 1979 to 2010 is described using the climate parameter contained temperature, rainfall, relative humidity and evaporation as following.

The relationship between mean temperature and mean monthly runoff is presented on Fig. 1. These results are the computed surface runoff from 1979 to 2010. It can be interpreted that there is the wide distributions of surface runoff. The tendency of relationship between mean temperature and mean monthly runoff is not clarity although among of linear equation, exponential equation and polynomial equation are considered this relationship. Then it's difficult to concern the change of runoff using only temperature.

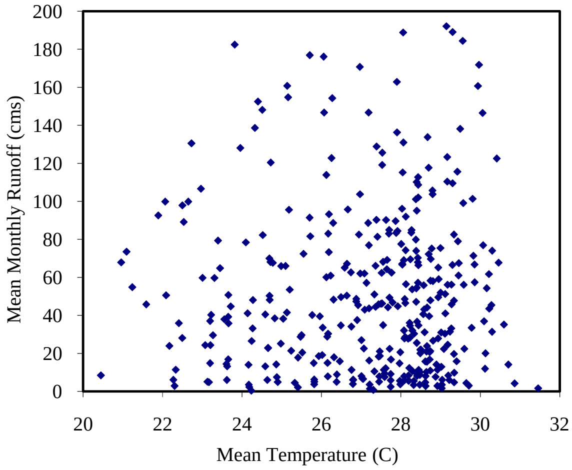

Fig. 1 The relation between mean monthly runoff and mean temperature

The relationship between total monthly rainfall and mean monthly runoff is presented on Fig. 2. If there is the increasing of rainfall, there is also the increasing of runoff. Thereafter, the monthly runoff is averaged shown in Fig. 3. It can be explained that if the mean rainfall is more than 170 mm, the mean monthly runoff is rapidly increase. If there is a heavy rainfall, the flooding can occur in the area. Then, rainfall is a parameter to consider the change of runoff.

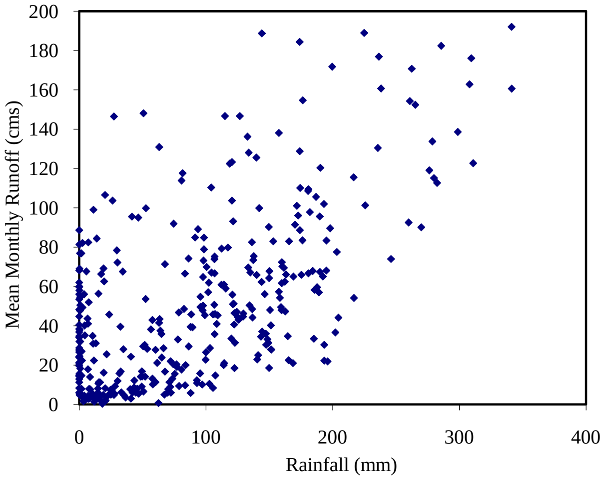

Fig. 2 The relationship between mean monthly runoff and total monthly rainfall

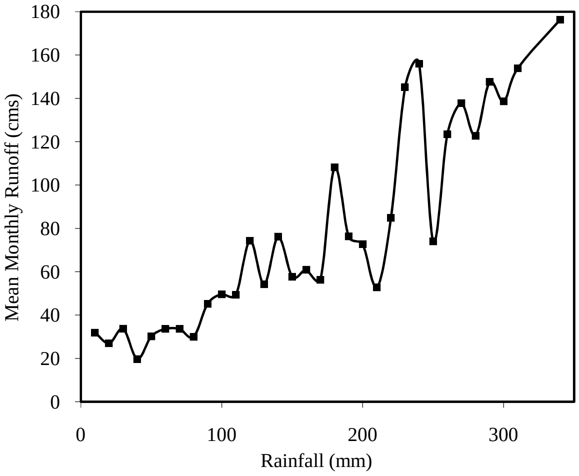

Fig. 3 The relationship between mean monthly runoff and total monthly rainfall

The relationship between mean monthly relative humidity and mean monthly runoff is shown on Fig. 4. The tendency of this relationship is explicated that the mean monthly runoff is increasing if the mean monthly relative humidity is also increasing. To concern the tendency of mean monthly relative humidity, the mean monthly runoff is averaged shown in Fig. 5. It can be explained that, the mean monthly runoff is gradually increasing from 53% to 73%. If the mean monthly relative humidity is more than 73%, the mean monthly runoff is rapidly increasing. Then, the mean monthly relative humidity is a parameter to concern the change of runoff.

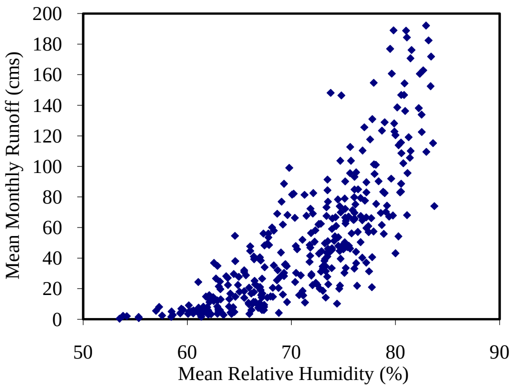

Fig. 4 The relationship between mean monthly runoff and mean monthly relative humidity

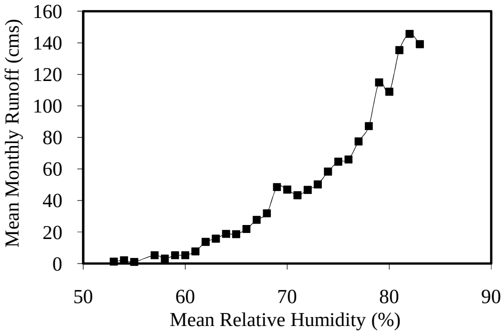

Fig. 5 The relationship between mean monthly runoff and mean monthly relative humidity

The relationships between mean monthly evaporation and mean monthly runoff are presented on Fig. 6. The mean monthly runoff is decreasing if there is the increasing of mean monthly evaporation. The tendency of mean monthly runoff presents in Fig. 7. The mean monthly runoff is rapidly decreasing if the mean monthly evaporation is increasing. Moreover, the decreasing of mean monthly evaporation from 3.25mm to 4.75mm is more than that from 4.75mm to 7.00 mm. Then the mean monthly evaporation is a parameter to consider the change of runoff.

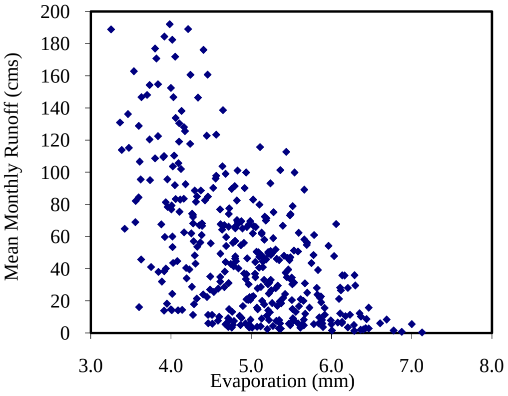

Fig. 6 The relationship between mean monthly runoff and mean monthly evaporation

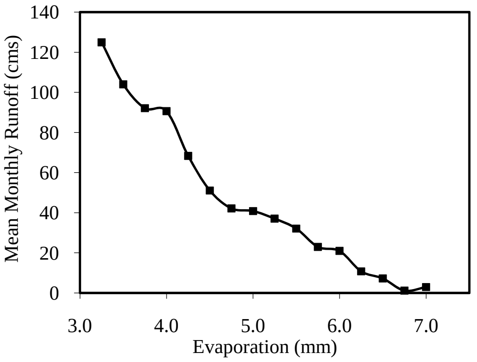

Fig.7 The relationship between mean monthly runoff and mean monthly evaporation

The results of the study can be concluded that the rainfall, relative humidity and evaporation are the parameters for the considering of runoff change. If there are the increasing of rainfall and relative humidity, there is also the increasing of runoff. On the other hand, if there is the increasing of evaporation, there is the decreasing of runoff. Moreover, the effect of temperature change cannot be clearly presented on the change of runoff.

ACKNOWLEDGMENT

This research supported financially by Suranaree University of Technology, Thailand is gratefully acknowledged. The authors would like to thank Royal Irrigation Department, Land Development Department and Thai Meteorology Department for providing rainfall, flow data, land use map and meteorological data.

REFERENCES

[1] D. P. Lettenmaier, A. W Wood, R. N. Palmer, E. F. Wood and E. Z. Stakhiv, “Water resources implications of global warming, pp. A U.S. regional perspective” Clim. Change., vol. 43, pp. 537–579, November 1999.

[2] V. K. Arora and G. J. Boer, “Effects of simulated climate change on the hydrology of major river basins” J. Geophys. Res., vol. 106, pp. 3335–3348, February 2001.

[3] B. Nijssen, G. M. O'Donnell, D. P. Lettenmaier, D. Lohmann and E. F. Wood, "Predicting the discharge of global river" J. Climate., vol. 14(15), pp. 3307–3323, August 2001.

[4] T. Oki, Y. Agata, S. Kanae, T. Saruhashi, D.W. Yang and K. Musiake, "Global assessment of current water resources using total runoff integrating pathways" J. SciHydrol., vol. 46, pp. 983–995, December 2001.

[5] P. Doll, F. Kaspar and B. Lehner, "A global hydrological model for derving water availability indicatorss, pp. model turning and validation" J. Hydrol., vol. 270(1-2), pp. 105–134, January 2003.

[6] S. Jurgen X, K. C. Abbaspour, R. Srinivasan and H. Yang, "Estimation of freashwater availability in the West African sub-continent using the SWAT hydrologic model" J. Hydrol., vol. 352, pp. 30–49, April 2008.

[7] J. S. Risbey and D. Entekhabi, "Observed Sacramento Basin streamflow response to precipitation and temperature changes and its relevance to climate impacts studies" J. Hydrol., vol. 184, pp. 209–223, October 1996.

[8] D. N. Yates and K. M. Strzepek, "Modeling the Nile basin under climatic change" J. Hydrol. Eng., vol. 3, pp. 98–108, March 1998.

[9] A. Sankarasubramanian, R. M. Vogel and J. F. Limbrunner, "Climate elasticity of streamflow in the United States" Water Resour.Res., vol. 37, pp. 1771–1781, June 2001.

[10] G. Fu, S. Chen, C. Liu and D. Shepard, "Hydro-climatic trends of the Yellow River Basin for the last 50 years" Clim. Change., vol. 65, pp. 149–178, July 2004.

[11] R. L. Wilby, L. E. Hay, W. J. Gutowski, R. W. Arritt, E. S. Takle, Z. Pan, G. H. Leavesley and M. P. Clark, "Hydrological responses to dynamically and statistically downscaled climate model output" Geophys. Res. Lett., vol. 27, pp. 1199–1202, April 2000.

[12] J. G. Arnold, R. Srinivasan, R. S. Muttiah and J. R. Williams, "Large area hydrologic modeling and assessment. Part I, pp. Model development" J. Am. Water Resour. Assoc., vol. 34, pp. 73–89, February 1998.

[13] C. H. B. Priestly and R. J. Taylor, "On the assessment of surface heat flux and evaporation using large-scale measurements" Mon. Weather Rev., vol. 100, pp. 81–92, February 1972.

[14] G. H. Hargreaves, "Moisture availability and crop production" Trans. ASAE., vol 18, pp. 980–984, August 1975.

[15] R. G. Allen, M. E.Jensen, J. L. Wright and R. D. Burman, "Operational estimates of reference evapotranspiration" Agron. J., vol 81, pp. 650–662, July 1989.

[16] J. R. Williams, C. A. Jones and P. T. Dyke, "A modeling approach to determining the relationship between erosion and soil productivity" Trans. ASAE., vol. 27(1), pp. 129–144, January 1984.

[17] J. R. Williams, A. D. Nicks and J. G. Arnold, "Simulator for water resources in rural basins" J. Hydraul. Eng., vol. 111, pp. 970–986, June 1985.

[18] R. A. Leonard, W. G. Knisel and D. A. Still, "Groundwater loading effects on agricultural management systems" Trans. ASAE., vol. 30, pp. 1403–1428, August 1987.

[19] J. G. Arnold and P. M. Allen, "Estimating hydrologic budgets for three Illinois watersheds" J. Hydrol., vol. 176, pp. 57–77, March 1996.

[20] K.C. Abbaspour, J. Yang, I. Maximov, R. Siber, K. Bogner, J. mieleitner, J. Zobrist, and R. Srinivasan, "Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT" J. Hydrol, vol 333, pp. 413–430, January 2007.

[21] J. Schuol, K.C. Abbaspour, R. Srinivasan and H. Yang, "Estimation of freshwater availability in the West African sub-continent using the SWAT hydrologic model" J. Hydrol., vol. 352, pp. 30–49, April 2008.

[22] M. E. Coffey, S. R. Workman, J. L. Taraba and A. W. Fogle, "Statistical procedures for evaluating daily and monthly hydrologic model predictions" Trans. ASAE, vol. 47(1), pp. 59–68, January 2004.

[23] B. L. Benham, C. Baffaut, R. W. Zeckoski, K. R. Mankin, Y. A. Pachepsky, A. M. Sadeghi, K. M. Brannan, M. L. Soupir, and M. J. Habersack, "Modeling Bacteria fate and transport in watershed model to support TMDLs" Trans. ASABE., vol. 49, pp. 987–1002, July 2006.

[24] A. El-Nasr, J. G. Arnold, J. Feyen and J. Berlamont, "Modelling the hydrology of a catchment using a distributed and a semi-distributed model" Hydrolog. Process., vol. 19, pp. 573–587, February 2005.

[25] J. G. Arnold, R. S. Muttiah, R. Srinivasan and P. M. Allen, "Regional estimation of base floe and groundwater recharge in the upper Mississippi basin" J. Hydrol., vol. 227, pp. 21–40, January 2000.

[26] M. Cerucci and J. M. Conrad, "The use of binary optimization and hydrologic models to form riparian buffers" J. Am. Water Resour. Assoc., vol. 39, pp. 1167–1180, October 2003.

[27] V. Chaplot, A. Saleh, D. B. Jaynes, and J. Arnold, "Predicting water, sediment, and NO_3-N loads under scenarios of land-use and management practices in a flat watershed" Water Air Soil Pollut., vol. 154, pp. 271–293, May 2004.

[28] T. W. Chu and A. Shirmohammadi, "Evaluation of the SWAT model's hydrology component in the Piedmont physiographic region of Maryland" Trans. ASAE., vol. 47, pp. 1057–1073, July 2004.

[29] M. W. Gitau, T. L. Veith and W. J. Gburek, "Farm-level optimization of BMP placement for cost-effective pollution reduction" Trans. ASAE., vol. 47(6), pp. 1923–1931, August 2004.

[30] M. Jha, J. G. Arnold, P. W. Gassman, F. Giorgi and R. Gu, "Climate change sensitivity assessment on upper Mississippi river basin steamflows using SWAT" J. Am. Water Resour. Assoc., vol. 42(4), pp. 997–1015, August 2006.

[31] L. Kalin and M. H. Hantush, "Hydrologic modeling of an eastern Pennsylvania watershed with NEXRAD and rain gauge data" J. Hydrol. Eng., vol. 11, pp. 555–569, November 2006.