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The Relationship between Land Use Change and Runoff

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***Abstract*—**Many problems are occurred in watershed due to human activity and economic development. The purpose is to determine the effects of the land use change on surface runoff using land use map on 1980, 2001 and 2008 and daily weather data during January 1, 1979 to September 30, 2010 applied to SWAT. The results can be presented that the polynomial equation is suitable to display that relationship. These equations for land use in 1980, 2001 and 2008 are consisted of $y = -0.0076x^5 + 0.1914x^4 – 1.6386x^3 + 6.6324x^2 – 8.736x + 7.8023 (R^2 = 0.9255)$, $y = -0.0298x^5 + 0.8794x^4 - 9.8056x^3 + 51.99x^2 - 117.04x + 96.797$; ($R^2 = 0.9186$) and $y = -0.0277x^5 + 0.8132x^4 8.9598 - x^3 + 46.498x^2 – 101.83x + 81.108 (R^2 = 0.9006)$, respectively. Moreover, if the agricultural area is the largest area, it is a sensitive parameter to concern surface runoff.

***Keywords*—**Land use, Runoff, SWAT, Upper Mun River Basin.

I. Introduction

THERE are many problems in watershed due to human activity and economic development and these problems have attracted increasing attention. Subsequently, many researchers concerns on the effect of land use change on runoff [1]. The effect of land use change on runoff depends on the size, average slope, and baseline land cover characteristics of the watershed [2]. The magnitude of the effect of land use change on simulated runoff also depends on the hydrological model used and the processes that are considered [3]. The peak runoff can be raised by increased urbanization while it can be decreased by reforestation [4]. Also, the increasing of peak runoff could be attributed to intensive urbanization and increasing incidences of heavy rainfall [5]. Furthermore, runoff coefficient is high for a high forest area during severe flooding and it is low for a high forest area during small flooding [6].

In Southeast Asia, Thailand, which is one of the most flood countries, is faced with severe flood during rainy season in the north, northeast and central parts of country [2]. On the other hand, there is drought during dry season. For example the upper Mun river basin, located in the northeast Thailand, is typically flooded during rainy season such as a severe flood in October 2010. Additionally, there is a large arid area during dry season. The Royal Irrigation Department (RID) has tried to address these problems. Then, it is important to quantitatively computation runoff responses of water over various temporal scales in whole the upper Mun river basin. This river basin is consisted 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 total water storages 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.

Since runoff is affected by land use change, the purpose of this study is to determine the effects of the land use change on surface runoff. To achieve the objective, land use map on 1980, 2001 and 2008 and daily weather data during January 1, 1979 to September 30, 2010 were input data to SWAT.

II. Materials and Methods

A. Land Use Change

In 1980, the upperMun river basin was a forest landscape about 28.01%, but in 2001 and 2008 it was covered by forest only 16.98% and 17.94%, respectively. Over the last 30 years, this deforestation in the upperMun river basin has occurred due to the expansion of agricultural areas and urban communities. This deforestation has been driven by economic development in and around Nakhon Ratchasima province, located in the upperMun river basin, especially the increasing of hotel and resort in forest and the increasing of industrial area. The agricultural area was 63.92%, 77.22% and 69.72% in 1980, 2001 and 2008, respectively. The urban area is 7.47%, 4.84% and 10.14% in 1980, 2001 and 2008, respectively. Moreover, water resources were 0.61% 0.97% and 2.19% in 1980, 2001 and 2008, respectively.

B. Soil and Water Assessment Tool (SWAT)

To understand the hydrological cycle change and associated potential of runoff, this study applied SWAT model to evaluate the surface runoff in the upper Mun river basin. SWAT is hydrological model which continuously simulate time model and operates on a daily time step at basin scale. In watershed scale, all of a range in climatic, soils, topographic, and land use condition are input data. Normally, SWAT is applied to determine hydrology element, sedimentation, nutrients, pesticides, agricultural management, and stream routing [7]. However, this study focuses only on hydrology element that is surface runoff.

Since the study area is included the large scale spatial

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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. 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 [8].

To compute surface runoff, the concept of water balance is concerned using the elements of hydrology cycle. Evapotranspiration is computed using Penman-Monteith equation [9]. 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 [7]-[8], [10]-[13]. The SCS curve method based on land use, soil type, and antecedent moisture condition is applied in SWAT model to calculate surface runoff from daily rainfall [8]. Moreover, soil profile, subdivided into multilayer, is considered to support the process of infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. To estimate flow to soil layer in root zone, the soil percolation is concerned using the method of water storage capacity. The percolation to lower layers occurs when field capacity of soil layer is exceeded and layer below is not saturated. 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^oC. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream [7], [8].

Since the weather station network in the upper Mun river basin is not very dense and data duration is quite short, 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 [14]. Thereafter, water balance is applied in everything that occurs in the watershed. To accurately computation water balance, 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.

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

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).

To simulate surface runoff and peak runoff rates, the runoff coefficient, C, is computed as the ratio of the inflow rate to the peak discharge rate:

$$C = \frac{Q_S}{P}$$

where P is the rainfall on the day (mm H_2O), and Q_S is the accumulated runoff or rainfall excess (mm H_2O) [15].

$$Q_S = \frac{(P - I_a)^2}{(P - I_a + S)}$$

where I_a is the initial abstractions included surface storage, interception and infiltration prior to runoff (mm H_2O), and S is the retention parameter (mm H_2O) that depends on the change of soil, land use, management and slope.

The modified version of the rational equation is applied to compute the peak runoff rate.

$$q_{peak} = \frac{C \cdot i \cdot A}{3.6}$$

where q_{peak} is the peak runoff rate ($m^3.s^{-1}$), i is the rainfall intensity ($mm.h^{-1}$), A is the subbasin area (km^2), and 3.6 is a unit conversion factor.

The time of concentration for overland flow, t_c, is defined as the time for water needed to flow from the most remote point in a river basin to the river basin outlet[16].

$$t_c = \frac{L_S}{3600 v_c}$$

where L_S is the subbasin slope length (m), 3600 is a unit conversion factor, and v_c is the overland flow velocity (m/s). It can be estimated using Manning's equation based on a strip 1 m wide down the sloping surface.

$$v_c = \frac{q_c^{0.4} \times Slp^{0.3}}{n^{0.6}}$$

where q_c is the average overland flow rate (m^3/s), Slp is the average slope in the subbasin (m/m), and n is Manning's coefficient for the subbasin.

C. Calibration

To calibrate the watershed model, observed monthly runoff at the outlet of watershed was compared with simulated monthly runoff during 1979-1984 (R^2 = 0.65), 1998-2002 (R^2 = 0.73), and 2005-2010 (R^2 = 0.78) for the land use map in 1980, 2001 and 2008, respectively. These results relate to the study of [17] (R^2 = 0.63), [18] (R^2 = 0.70), [19] (R^2 = 0.72), [20] (R^2 = 0.73), [21] (R^2 = 0.66), [22] (R^2 = 0.76), [23] (R^2 = 0.74) and [24] (R^2 = 0.77).

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 [25].

III. Results and Discussion

Since the simulated monthly runoff is contained from January 1979 to September 2010, the mean monthly runoff during January 1979 to September 2010 is displayed in each land use. In 1980, the mean monthly runoff is presented by Table I. The maximum mean monthly runoff is in October and equal to 131.36 m^3/s while the minimum mean monthly runoff is in March and equal to 5.79 m^3/s. The mean annual runoff is 51.60 m^3/s. The relation of calculated mean monthly runoff shown in Fig. 1 is based on the polynomial equation ($y = -0.0076x^5 + 0.1914x^4 – 1.6386x^3 + 6.6324x^2 – 8.736x + 7.8023$; R^2 = 0.9255). For these equations, y is mean monthly runoff in m^3/s and x is number of month (1-12).

TABLE I
Mean Monthly Runoff Using Land Use Map on 1980

Month	Mean monthly runoff (m^3/s)
January	18.79
February	6.22
March	5.79
April	15.44
May	42.78
June	50.62
July	51.27
August	57.26
September	105.08
October	131.36
November	86.67
December	47.94

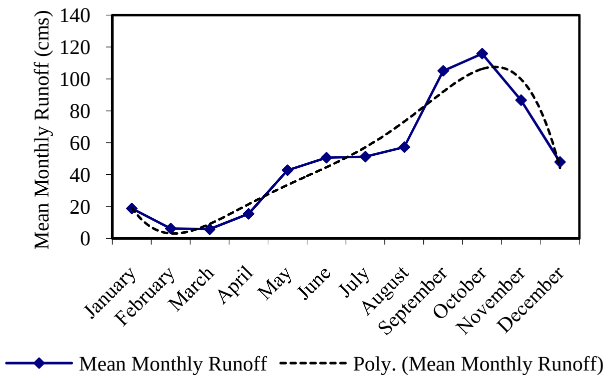

Fig. 1 Mean monthly runoff on 1980

In 2001, the simulated runoff is presented as Table II. This table presents that the mean monthly runoff in every month is higher than that on 1980 and 2008 because of the highest agricultural area. Although urban area on 2008 is higher than that on 2001, the mean monthly runoff on 2008 is lower than that on 2001. The maximum mean monthly runoff is in October and equal to 151.66 m^3/s while the minimum mean monthly runoff is in February and equal to 8.04 m^3/s. The mean annual runoff is 62.13 m^3/s. The relation of calculated mean monthly runoff shown in Fig. 2 is based on the polynomial equation ($y = -0.0298x^5 + 0.8794x^4 - 9.8056x^3 + 51.99x^2 - 117.04x + 96.797$; R^2 = 0.9186).

TABLE II
Mean Monthly Runoff Using Land Use Map on 2001

Month	Mean monthly runoff (m^3/s)
January	22.67
February	8.04
March	8.20
April	21.72
May	54.37
June	62.56
July	63.53
August	72.65
September	127.94
October	151.66
November	97.64
December	54.53

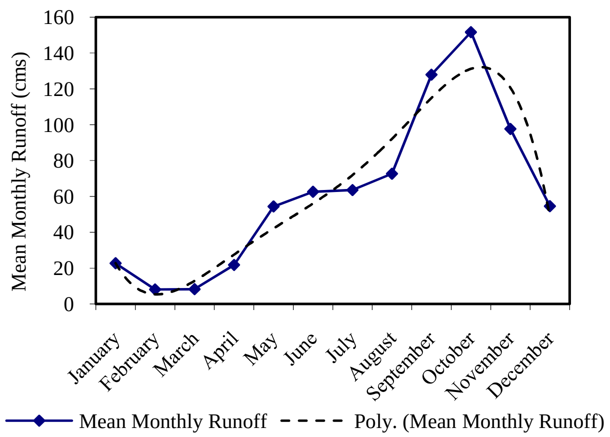

Fig. 2 Mean monthly runoff on 2001

In 2008, the mean monthly runoff during 1979 to 2010 is shown in Table III. The maximum mean monthly runoff is in October and equal to 133.14 m^3/s while the minimum mean monthly runoff is in February and equal to 6.46 m^3/s. The mean annual runoff is 52.48 m^3/s. The polynomial equation is $y = -0.0277x^5 0.8132 + x^4 8.9598 - x^3 46.498 + x^2 101.83 - x + 81. 108$; R^2 = 0900.6) as presented in Fig. 3.

TABLE III
MEAN MONTHLY RUNOFF USING LAND USE MAP ON 2008

Month	Mean monthly runoff (m^3/s)
January	17.50
February	6.46
March	6.85
April	18.58
May	47.98
June	53.15
July	52.12
August	59.11
September	109.80
October	133.14
November	81.36
December	43.78

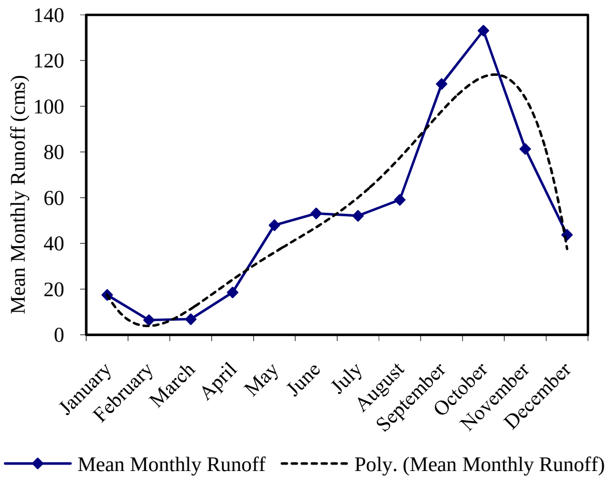

Fig. 3 Mean monthly runoff on 2008

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