Journal of
Thai Interdisciplinary Research

Volume 12, Number 3, Pages 7 - 14

Application of the Precipitation-Runoff Modeling System (PRMS) to the investigation of the effects of land use changes on the runoff coefficient in the Thap Lan National Park, Prachinburi river basin, Thailand

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Abstract

Thap Lan National Park (TLNP) and it's vicinities are located in the northern part of the Prajin River basin and are a famous tourist spot, as they are not too far from Bangkok, not to the least due to the beautiful mountainous scenery and the cool weather in the winter time. Unfortunately, as a caveat to this increased tourist attraction, the tourism service sector in TLNP has been steadily expanded in recent years, with partly illegal deforestation, intrusion and build-up of resorts and/or hotels. Thus, land use in that area has changed to a certain degree. Moreover, as this part of the TLNP, because of its hill-slope topography, acts as a recharge area for the Prajin River basin, the hydrology of the latter may have been affected as well. One parameter to quantify the hydrological consequences of these land-use changes in the TLNP is the runoff- coefficient (C). For its computation the PRMS-model was set up for the whole Prachinburi River basin and calibrated with meteorological and discharge data for the time period 1993–2012 and the recent land-use. The results show that PRMS has an acceptable performance in simulating the monthly runoff in the study area and, consequently, also the runoff-coefficient in the TLNP area, which on annual average, turns out to be C = 0.21 for the time period considered. Starting from this base scenario, and extrapolating the above-mentioned land-use change in the TLNP to some extreme deforestation, PRMS was applied again to simulate the ensuing hydrological effects. A change of C from C = 0.21 to C = 0.28 is obtained, i.e. an increase of the average annual runoff by 33%. For some months of the year, namely, at the end of the dry season in late spring, the runoff for this adverse scenario is augmented by an even higher rate of more than 100%. All these run-off increases go, obviously, hand in hand with corresponding decreases of the groundwater recharge of the basin which indicates that its hydrological water budget would be significantly altered by such extreme land-use changes in the TLNP area.

Keywords: Prachinburi river basin, Thailand, land use changes, PRMS model, runoff

Article history: Received 22 February 2017, Accepted 5 June 2017

1. Introduction

The Thap Lan National Park (TLNP) with a total area of 2,236 km^2 is located at the northern boundary of the Prajin river basin (PRB). TLNP and its neighboring areas are famous tourist spots [1], as the region is not too far from Bangkok, and the cool weather in the winter time lures many tourists not to the least due to the beautiful mountainous scenery, - called for that reason also “Little Switzerland” - including the Lan wild tree and recreational garden, where wonderful yellow blossoms can be admired in the months April to June. Two famous waterfalls, Namtok Thap Lan and Namtok Bo Thong, serve as peaceful relaxation spots during the rainy season, when high water flow occurs. The Thap Lan reservoir is also a pretty picnic place as is Hat Chom Tawan - a 300 meters long shoreline along the Lam Plai Mat Dam reservoir.

Unfortunately, as a caveat to this great tourist attraction of the TLNP, the tourism industrial sector there has been continuously increased in recent years [2] and with it came significant land-use changes, partly from illegal deforestation [3], invasion and construction of resorts and/or hotels – with more than 100 resorts nowadays- or setup of new farms in the TLNP. Moreover, as the southern part of the TLNP (STLNP), with an area of about 106 km^2, forms also the northern flank of the PRB and acts there also, due to its hill-slope topography, as a major natural recharge area for PRB as a whole, the aforementioned land-use changes will adversely affect the PRB's hydrology.

DOI 10.14456/jtir.2017.15

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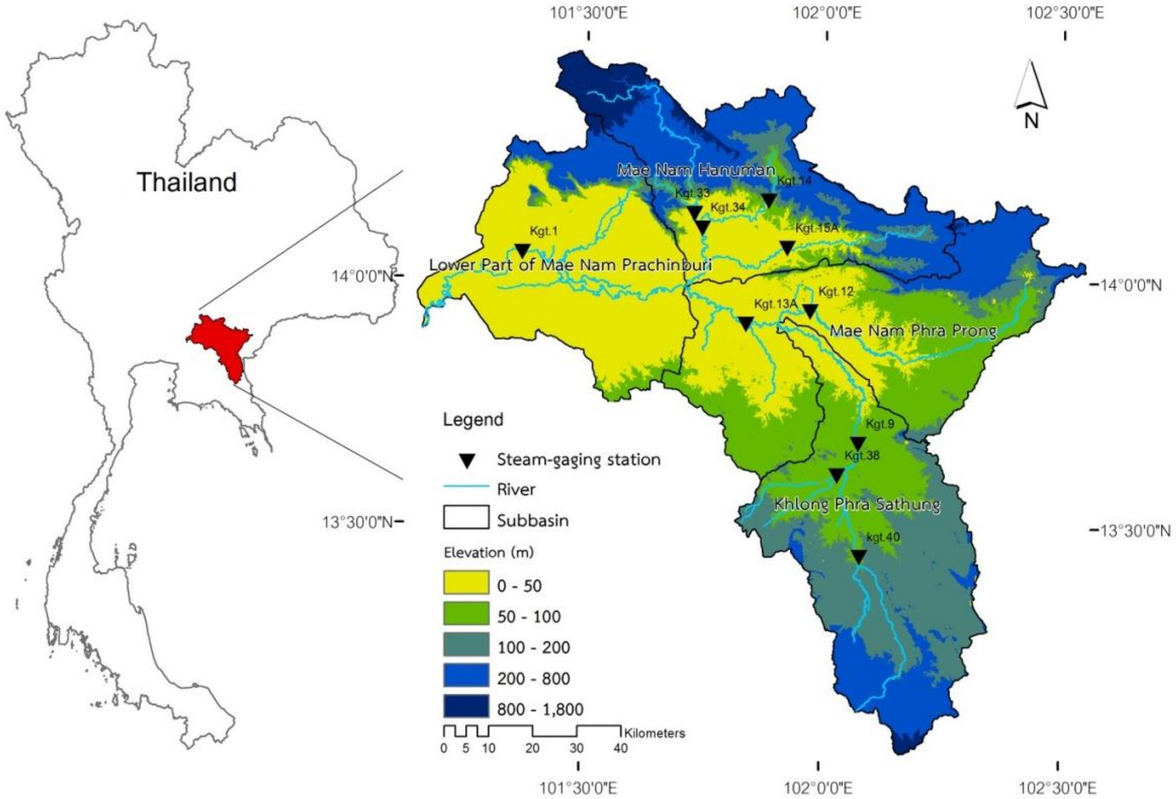


Figure 1 Location and topography of the Prachinburi river basin in eastern Thailand

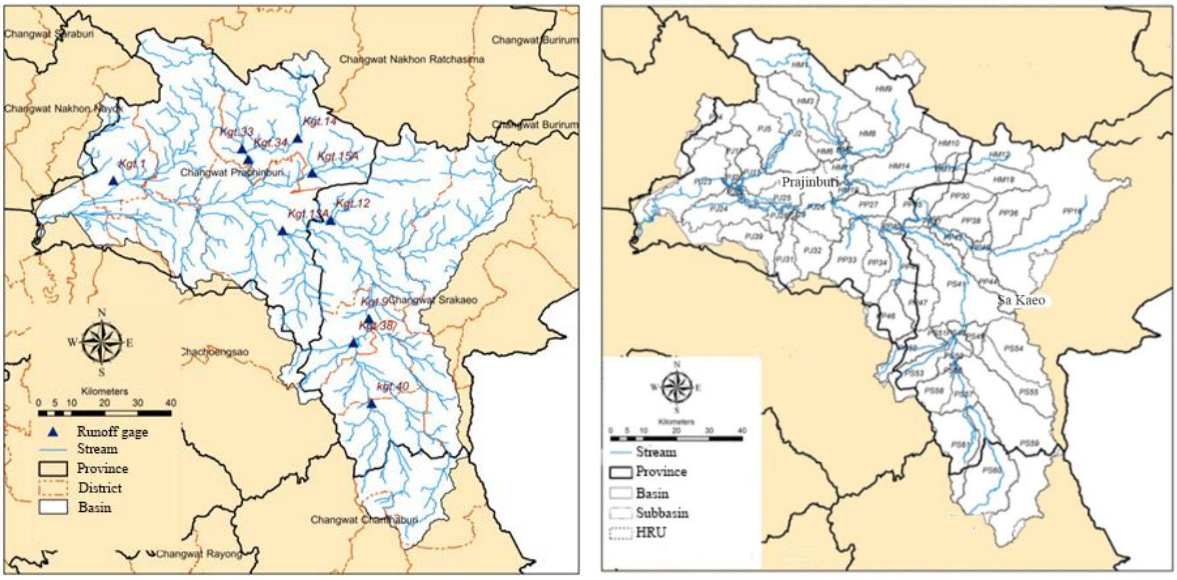


Figure 2 Prachinburi river basin map with streams and locations of the 10 river gauge stations (left panel) and division in to four sub basins and 60 HRUs (right panel)

The objective of the present study is to quantify these land-use change effects in the STLNP by computing the runoff- coefficient (C) for the PRB by means of the Precipitation-Runoff Modeling System (PRMS). More specifically, C-values and PRB-aquifer recharge simulated for scenarios of ongoing extreme deforestation in the STLNP will be compared with those of the present-day situation, to gauge the detrimental effects of deforestation.

Table 1 Geo-spatial data with source and specifications used in PRMS model

Data	Source	Resolution
DEM	ASTER GLOBAL DEM (http://earthexplorer.usgs.gov/)	30 m x30 m
Land use data	Land use data , 2003, Land Development Department of Thailand MODIS and Landsat 8	1:25,000
Soil data	Soil Series data, Land Development Department of Thailand	1:25,000

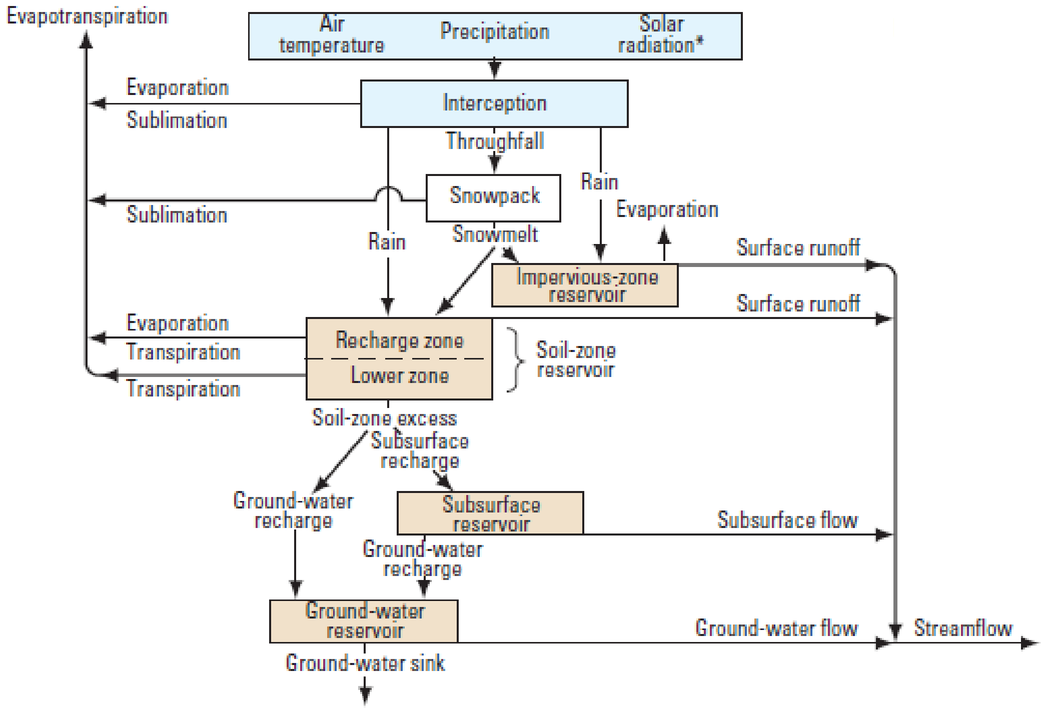


Figure 3 Schematics of the water processing used in PRMS [4]

Study Area

Prachinburi river basin (PRB) (Figure 1), is situated in the eastern region of Thailand, located between longitude 101° 8' – 102° 32' E and latitude 13° 2' – 14° 27' N. The basin encompasses Nakhon Nayok, Nakhon Ratchasrima, Prachinburi, Chachensao, Srakeaw and Chantaburi provinces. The total river basin area is 9,677 km^2. The basin is composed of 4 sub-basins, so-called "Phra Pong- (2,688 km^2), Phra Satung- (2,650 km^2), Lower Prachinburi- (2,189 km^2) and Hanuman sub-basin (2,158 km^2). Likewise to the overall climate of the country, that of the PRB is also a monsoon climate, with more than 80% of the precipitation occurring between the months of May and October. The basin's altitude ranges between 0 and 1800 m, with an average altitude of 170 m. The southern part of the Thap Lan National Park Area (STLNP) with an area of 106.4 km^2 belonging to the Prachinburi river basin is located in the Hanuman basin, while the rest area (2,236 km^2) of the TLNP is located in the Mun river basin.

The main land-use of the PRB is composed of 4 types, namely, (a) forest area, (b) agricultural and other areas, (c) water bodies and (d) urban area. The major land-use category of the STLNP itself is forest area which has been deforested up-to-now by about 3% [3], at the benefit of agricultural-, water body and urban areas.

2. Materials and methods

2.1 Data

Available daily runoff data of 10 river gauge stations in the Prachinburi river basin (Figure 2) were collected during the time period 1993 to 2012 from the Royal Irrigation Department (RID). Daily precipitation, daily maximum and minimum temperatures during the same time period were gathered at 10 climate stations, distributed across the basin and administered by the Thai Meteorological Department (TMD).

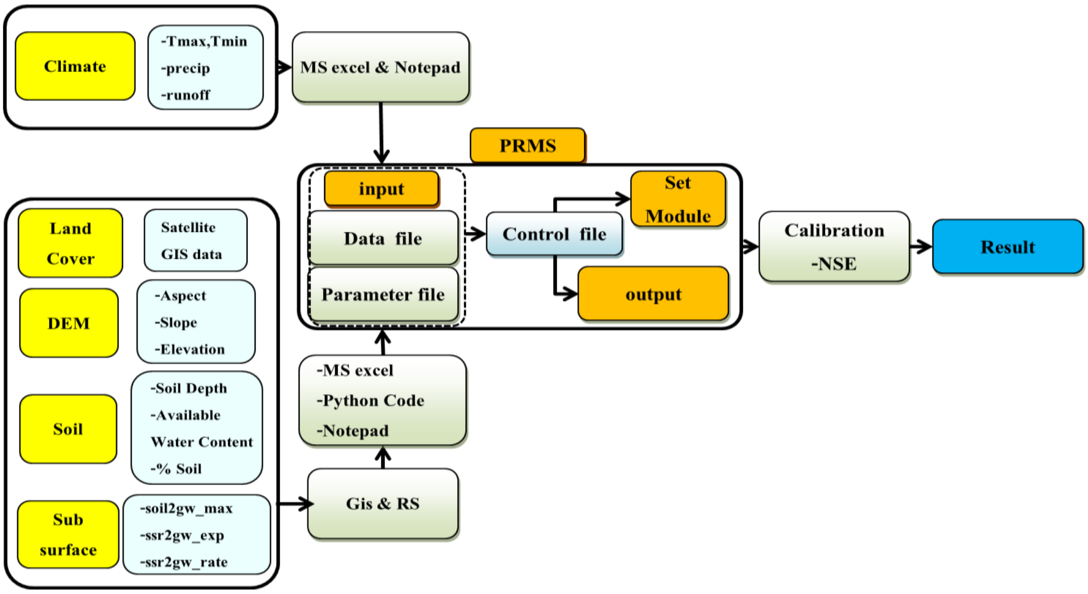


Figure 4 Schematics of input and procedures for the set-up of the PRMS model

Potential evapotranspiration (PET) for PRMS-model input was calculated by the modified Jensen-Haise formulation [4, 5], using daily maximum and minimum temperatures from TMD.

Furthermore, DEM (digital elevation model), soil and land use information for the PRB as required for input in PRMS were gathered from various sources, with the specifications indicated in Table 1.

2.2 The Precipitation-Runoff Modeling System (PRMS)

1) PRMS-overview

The Precipitation-Runoff Modeling System (PRMS) [6] is “a deterministic, distributed-parameter, physical process based modeling system developed to evaluate the response of various combinations of climate and land use on streamflow and general watershed hydrology”. Despite these vast and versatile properties, for whatever reasons, PRMS has not yet received the widespread acceptance and application as, for example, the infamous SWAT-model [7]. Nevertheless, there have been a few PRMS-applications for basins in the US [8, 9, 10, 11] and China [12] to simulate the hydrologic cycle at a watershed scale under variability in climate, biota, geology, and human activities.

2) PRMS- model specification

Likewise to other distributed hydrological models, PRMS conceptualizes a basin as an interconnected series of sub-basins and, furthermore, so-called Hydrologic Response Units (HRU). Each HRU includes interception storage in the vegetation canopy and storages in the impervious zone, soil zone, subsurface reservoir, and the ground-water reservoir (Figure 3). A HRU is supposed to be homogeneous spatial unit with respect to these hydrological and physical conditions. In PRMS, a water - and an energy balance are computed at each calculation time step for each HRU. Inflow and outflow of the PRMS-reservoirs represent various processes of the hydrologic cycle. The entire water system response is the balance of surface, subsurface, and groundwater flow. The computation of the water processing system in PRMS is based on the classical water balance equation [6, 13]:

$$I - Q = \frac{dS}{dt} \tag{1}$$

where I = inflow (L^3/T), Q = outflow (L^3/T), S = storage (L^3) and t = time.

Eq. (1) is evaluated for each time step and HRU and the computed output Q for each HRU is routed through the entire basin and accumulated accordingly to get the final streamflow at a sub-basin- or, eventually, the basin outlet. Further details of this PRMS- methodology can be found in the PRMS-documentations [6, 12].

3) PRMS model set-up for the PRB

For the set- up of the PRMS- model for the study region, i.e. the Prajin river basin (PRB), the ArcGIS tool was used to define the Hydrologic Response Units (HRUs) with respect to the DEM, land use and soil data in the basin. Herewith, the

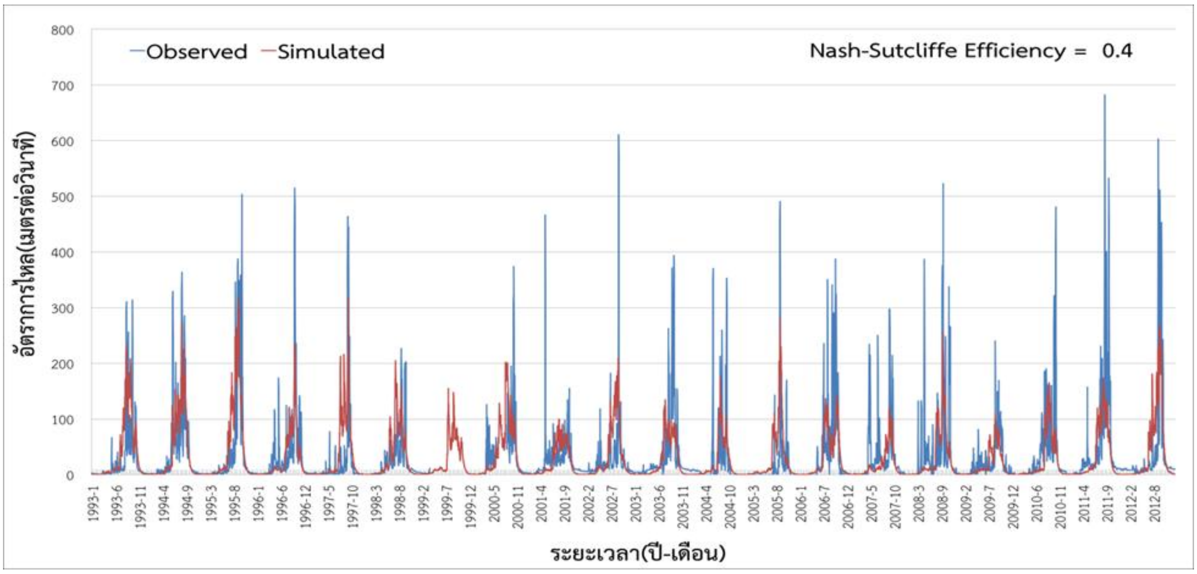


Figure 5 Observed and simulated daily flow at KGT.9 stream gauge station for the 1993-2012 calibration period

entire basin was discretized into four sub-basin with a total of 60 HRUs (Figure 2, left panel).

In the subsequent step the set of time-independent spatial data of Table 1 were imported into each HRU, including the physical based data (impervious zones, soil zone, subsurface reservoir, and ground-water reservoir), as well as the climatic data and hydrological data (see Figure 4). To make the data compatible with the input form of PRMS, Python coding and/or Notepad and Microsoft Excel was used. With the PRMS-data file complete, a control-file specifying the simulation period (1993 to 2012) as well as the needed modules to compute the hydrological processes and the desired output files had to be set up. Figure 4 summarizes again the various procedures involved in the general set-up the PRMS-model and the particular step for the present application to the PRB.

3. Results

3.1 Calibration of the PRMS-model under existing conditions

Observed daily flows from 10 stream gauge stations (see Figure 1) were used to calibrate the PRMS model for the time period 1993–2012. The calibration performance of PRMS model was estimated by using the well-known Nash Sutcliffe Efficiency (NSE) coefficient [14] which has been recommended in [15] as one of the most powerful criteria for the evaluation of hydrological models, although other measures, like R^2, have also been proposed. The expression for *NSE* reads as follows:

$$\text{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right] \qquad (2)$$

where Y_i^{obs} = observed daily flow (m^3/s), Y_i^{sim} = simulated daily flow (m^3/s) and Y^{mean} = mean of observed daily flow. An acceptable calibration is usually characterized by an *NSE*, ranging between 0 to 1 [15]. However, it should be noted that, whereas in some of the previously mentioned PRMS- studies [8, 9, 10] the *NSE* was computed on monthly averaged data, here the NSE are calculated with the daily data, which usually results in somewhat (less appealing) lower *NSE*- values [15].

Under these reservations, the daily *NSE*-values obtained here for the 10 stream gauge stations vary between 0.2 and 0.5, which discloses a rather satisfactory calibration [16]. For the basin outlet station, in particular, the highest value of *NSE* = 0.5 is obtained.

Figure 5 shows an example of the observed and calibrated hydrograph time-series for the KGT.9 stream gauge station, wherefore one can notice a reasonable conformity between observed and simulated daily flow. However, as is typical for these kinds of watershed models, the peaks of the observed flow discharges are usually under-predicted.

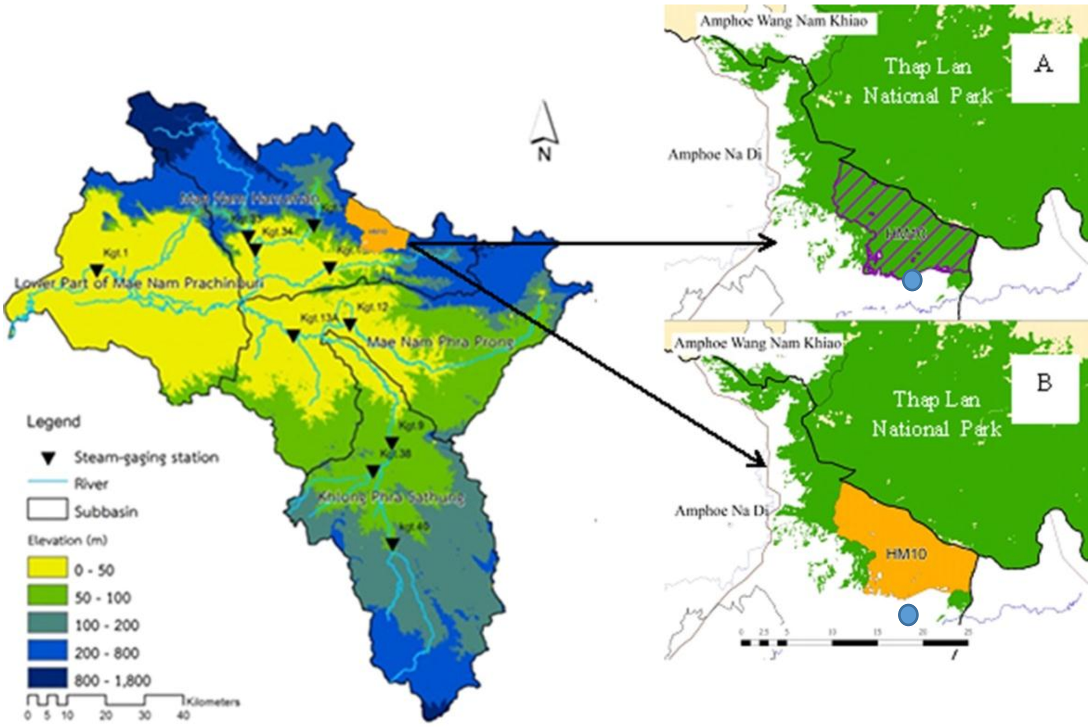
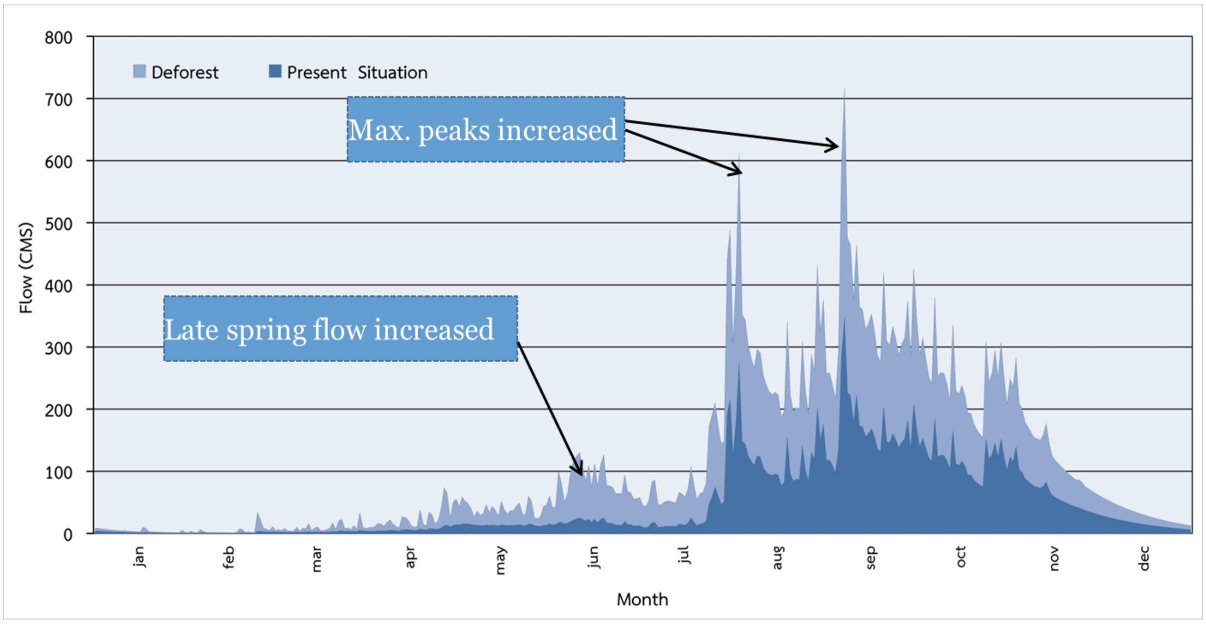


Figure 6 Left: location of the STLNP in the PRB. Right: zoomed-in map of the TLNP with present land-use (A) and 100% deforestation (B) in the STLNP: ● Control Point (CCP)



Max. peaks increased

Late spring flow increased

Figure 7 The dark blue hydrograph (present situation, 2012) versus pale blue hydrograph (deforest) at CCP

Table 2 Runoff- coefficients C and annual hydrograph volumes for the two land-use situations

	Present day land-use	**Land-use due to deforestation**
Runoff coefficient C	0.21	0.28
Annual hydrograph volume	41 MCM	54 MCM

3.2 Investigation of the effects of land use changes in the STLNP on the runoff and recharge in the PRB

The calibrated PRMS-model was then applied to investigate the effects of the mentioned ongoing land-use changes in the southern part of the Thap Lan National Park (STLNP) on the runoff and, more specifically, the runoff- coefficient *C*. To that avail a control point (CCP) was specified at the outlet of HRU #10 which, based on the previously HRU-discretized PRMS-model, covers most of the area of the STLNP (see Figure 6).

For the definition of the present-day reference situation, a calibrated PRMS-simulation (1) of the rainfall-runoff process with the present land-use (forest) in HRU #10 was run to quantify the hydrograph at the CCP. Then, in a second simulation (2), the land-use in HRU #10 was completely converted to be 100% deforestation and the CCP-hydrograph re-evaluated and compared with that of the present-day reference land use scenario (1).

The hydrographs of two simulation cases are plotted in Figure 7. One can notice from that figure that, whereas the streamflow for the present-day, reference land use scenario stays rather low and constant throughout the dry spring season, that when the land-use in the STLNP changes to deforestation, the CCP-streamflow increases already strongly in the late spring, reaching maximum peak of about 100 m^3/s in June. The differences become even more dramatic over the course of the summer wet season, when the peak-flow of the deforestation scenario go up to values of ~700 m^3/s, i.e. more than twice as much as the present-day peak flow value. These results indicate clearly that if such a tremendous deforestation occurs in the STLNP, the overall flood volume and the peak streamflow, in particular, will be significantly enlarged with adverse impacts on the downstream areas.

Integrating the streamflow underneath the two hydrograph provides the annual hydrograph volume for the two cases. These are then used further to finally compute the runoff coefficient (C) which is defined as the ratio of the named surface runoff to the incoming precipitation [17]. The results of this analysis are listed in Table 2 which unveils that, whereas the runoff coefficient for the present-day land use situation is C = 0.21, it will change for the case of complete deforestation to C = 0.28, owing to the fact that the annual hydrograph volume of 41 million m^3/a in the former case increases to 54 million m^3/a in the latter. As this this increased runoff is no more available for the recharge of this northern section of the PRB-aquifer, the long term groundwater yield of the latter is also affected.

4. Conclusions and suggestions

Based on the results of the hydrological simulations in the study, the following conclusions can be drawn:

4.1 A land-use change in the Southern Tap Lan National Park (STLNP) from the present day land-use with still more or less intact forest to the extreme case of complete deforestation will increase the present day annual runoff from the outlet of the park by about 33% which, in turn, means that the natural recharge of the Prachinburi basin (PRB) aquifer in its northern section will also be reduced by that amount.

4.2 The increase of the runoff when deforesting will go hand in hand with a corresponding increase of the runoff coefficient C from 0.21 to 0.28.

4.3 Department of National Park should restore and/ or conserve the forest area of the Tap Lan National Park, in general, in order to reduce the flood volumes in the downstream areas of the basin.

4.4 Doing so, will also increase the natural recharge from the STLNP into the PRB- aquifer system.

Acknowledgements

We appreciate the financial as well as valuable support of the Department of Groundwater Resources and the RID and Thai Meteorological Department for their data support and Groundwater Fund for the financial support.

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