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Original Article

Effects of climate and land use changes on water balance in upstream in the Chao Phraya River basin, Thailand

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ABSTRACT

A monthly water balance model was used to investigate the effects of climatic and land use changes on water resources upstream in the Chao Phraya River basin. The objective was to simulate and predict the hydrological processes under different climate change and land use change scenarios. The results showed that the climatic conditions and land development had an impact on changing the rainfall, evapotranspiration and streamflow. The simulated water balance for future climatic conditions and land use change scenarios showed increases during 2010–2099 in rainfall, temperature, evapotranspiration and streamflow. Under all land use conditions, the estimated evapotranspiration trends increased, especially for the worst case (12% forest area) which showed the highest evapotranspiration values in the A2 and B2 climate change scenarios. When discharge was calculated in the future, there was 27–40% of both A2 and B2 climate change scenarios under all land use conditions (12%, 20% and 40% forest area) when compared between 1970 and 1989 (calibration period) and 2090–2099 (prediction period). Increasing streamflow will be useful for human activities but it raises water resources issues such as the frequency of flood and drought events in the future.

Introduction

The hydrology of a watershed is affected by climate and land use among other factors and there is now essential consensus that all of these factors and interactions are influenced by human activities, including fluvial geomorphology and climate (Tomer and Schilling, 2009). The results of studies in many regions have found that streamflow variability is closely associated with climate and land use changes which are both key drivers of water balance change (Tu, 2009). Interactions between these drivers are complex and currently not well understood (Chazal and Rounsevell, 2009). Climate change could be expected to affect many sectors, including water resources, agriculture and food security, ecosystems and biodiversity, human health and coastal zones. Under climate change, predicted rainfall increases over most of Asia, particularly during the summer monsoon, could increase flood-prone areas in East Asia, South Asia and Southeast Asia (United Nations Framework Convention on Climate Change, 2007). Consequently, land use change may have inadvertent, negative effects on the hydrological regime, such as increasing the occurrence of floods and decreasing dry season flow (Lorup et al., 1998). Very few researchers have documented the major role of land use/cover change and variability in the climate system (Rai, 2009).

To research the impact of climate change on future water resources, a hydrological model can be driven by the output (precipitation and temperature) from a general circulation model, or GCM (Watson et al., 1996). However, many studies have used a regional climate model (RCM) which has a high horizontal resolution (25–50 km) and is more appropriate for resolving the small-scale features of topography and land use that have a major influence on climatological variables (Akhtar et al., 2008). RCM-PRECIS was developed to help generate high-resolution climate change information for as many regions of the world as possible (Jones et al., 2003). The Southeast Asia START Regional Center (http://cc.start.or.th) downscaled climate change data from GCMs which used PRECIS and covered Thailand and neighboring countries. It has output data which consists of A2 and B2 scenarios (described later).

For the purpose of water resources assessment and the study of climate and land use impacts, a monthly water balance model has

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been proposed and developed in this paper to simulate and predict hydrological processes such as rainfall, evapotranspiration and streamflow upstream in the Chao Phraya River basin, Thailand. Moreover, this study estimated the impact of climate and land use changes on different water balance scenarios under future meteorological conditions.

Site description and dataset

The upstream area of the Chao Phraya River basin is located in northern Thailand, with a drainage area of 105,056 km^2 (Fig. 1) and consists of four watersheds (Ping, Wang, Yum and Nan) covering 15 provinces. The Chao Phraya River basin is the principal water resource in Thailand for agricultural irrigation, hydropower and water supply (United Nations Educational, Scientific and Cultural Organization, 2009). However, the temporal distribution of rainfall throughout the year is strongly heterogeneous and on average, 85% of the total annual rainfall occurs between May and October in the high-flow period (wet season), while from November to April is the low-flow period (dry period) (Techamahasaranont, 2001). The C2 station in Nakhon Sawan province is a streamflow gauge station in this basin.

Table 1 lists the locations of the gauged stations used in the current study; the streamflow stations were used to calibrate the water balance model, while the meteorological stations, which have maintained long-term records of daily mean temperature and rainfall from 1970 to 1989 were used to detect trends in temperature and rainfall. Fig. 2 shows the monthly rainfall, evaporation, mean temperature and streamflow using the Theisen method in the study area.

Data sources and methods

Simulation model

A monthly water balance model provides a framework to conceptualize and investigate the relationships between climate, land use and water resources (Jothityangkoon et al., 2001; Legesse et al., 2003). Thus, there are two models which relate climatic and land use parameters including rainfall, temperature and evapotranspiration.

Monthly evapotranspiration (ET_c) was estimated using the Blaney–Criddle equation which is a simpler alternative for estimating ET_c and is calculated from the effective temperature, based on the mean temperature and day length (Fooladmand, 2011). The Blaney–Criddle method always refers to mean monthly values, both for the temperature and the ET_c. Moreover, this equation can be calibrated with a crop coefficient (K_c) that depends on the type of crop, the growth stage of the crop and the crop calendar (Food and Agricultural Organization, 1986). Eq. (1) was adapted from Polsan (2005):

$$Et_c = 0.4568Kc \times DL \times (Tc + 18) \tag{1}$$

where Et_c is the reference crop evapotranspiration (measured in millimeters per day) as an average for a period of one month, Kc is the crop coefficient for water consumption, which depends on crop types and growth stages and is taken from Royal Irrigation Department (1994), DL is the average annual day length percentage and Tc is the mean annual temperature (°C).

One set of monthly water balance equations for estimating discharge (V_Q) involving the use of soil water storage and evapotranspiration is that of Van Der Beken and Byloos (1977) that was cited by Singh (1989) as shown in Eqs. (2)–(4):

$$V_Q = a_2S + a_1\left[V_P - ET_P\left(1 - e^{-a_1S_i}\right)\right] \tag{2}$$

$$S_{i+1} - S_i = (V_p - ET_c) - \left[a_2S_i + a_3(V_p - ET_p)\right] \tag{3}$$

$$ET_c = Kc \cdot ET_p \tag{4}$$

where V_Q is the monthly water discharge, S_i is the monthly water storage, V_p the monthly rainfall, ET_c is monthly actual evapotranspiration or crop evapotranspiration and ET_p is the monthly potential evapotranspiration (all measured in millimeters) and a_1, a_2, a_3 are constants related to soil texture (0.005–0.02), storage in soil and streamflow (0.07–0.55) and the hard pan in the soil (0.05–0.30), respectively, and are used to adjust the results related to soil properties.

This study determined land use change using a Markov chain model as did Boochabun (2001) to predict the future of land use and land use changes impacts on the water balance in the Chi River basin. The crop coefficient (Kc) values were taken from Pukngam (2001) and Thongdeenok (2001), where they were calculated based on the type of plant and crop calendars.

Data sources

Climatic data (rainfall, maximum and minimum temperature) from 1970 to 1989 were obtained from the Thai Meteorological Department and were downloaded from the Southeast Asia START Regional Center web (START web; http://cc.start.or.th) which used downscaled output data from GCM-ECHAM4 using the PRECIS model (SEA START RC, 1996). Streamflow data between 1970 and 1989 were obtained from the C2 gauge station in Nakhon Sawan province from the Royal Irrigation Department (RID). The data from the calibration period were used for model calibration and validation. The comparisons of downscaled output of GCM-ECHAM4 from START versus the observed monthly rainfall and mean temperature for upstream in the Chao Phraya River basin are illustrated in Fig. 3. The correlation coefficient (r^2) between observed and downscaled (PRECIS) data were 0.71 and 0.84 for rainfall and mean temperature, respectively.

Land use data in GIS format for three time periods (1980, 1989, and 1996) were obtained from the Land Development Department (LDD) and the Environmental Systems Research Institute, Thailand (Environmental Systems Research Institute, 2000) and are shown in Table 2. The data for developed land use for all three time periods were used to analyze the historical land use change rates, which were then used to set up future land use scenarios.

Climate change data

The outputs of the GCM-ECHAM4 model were downscaled using the PRCIS model. The rainfall and temperature data from 2010 to 2099 were used for two climate scenarios with 437 points covering the study area (Fig. 4). The A2 and B2 scenarios are part of a set of scenarios used to model future climate change (Intergovernmental Panel on Climate Change, 2000). The A2 storyline describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in a continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines. The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing

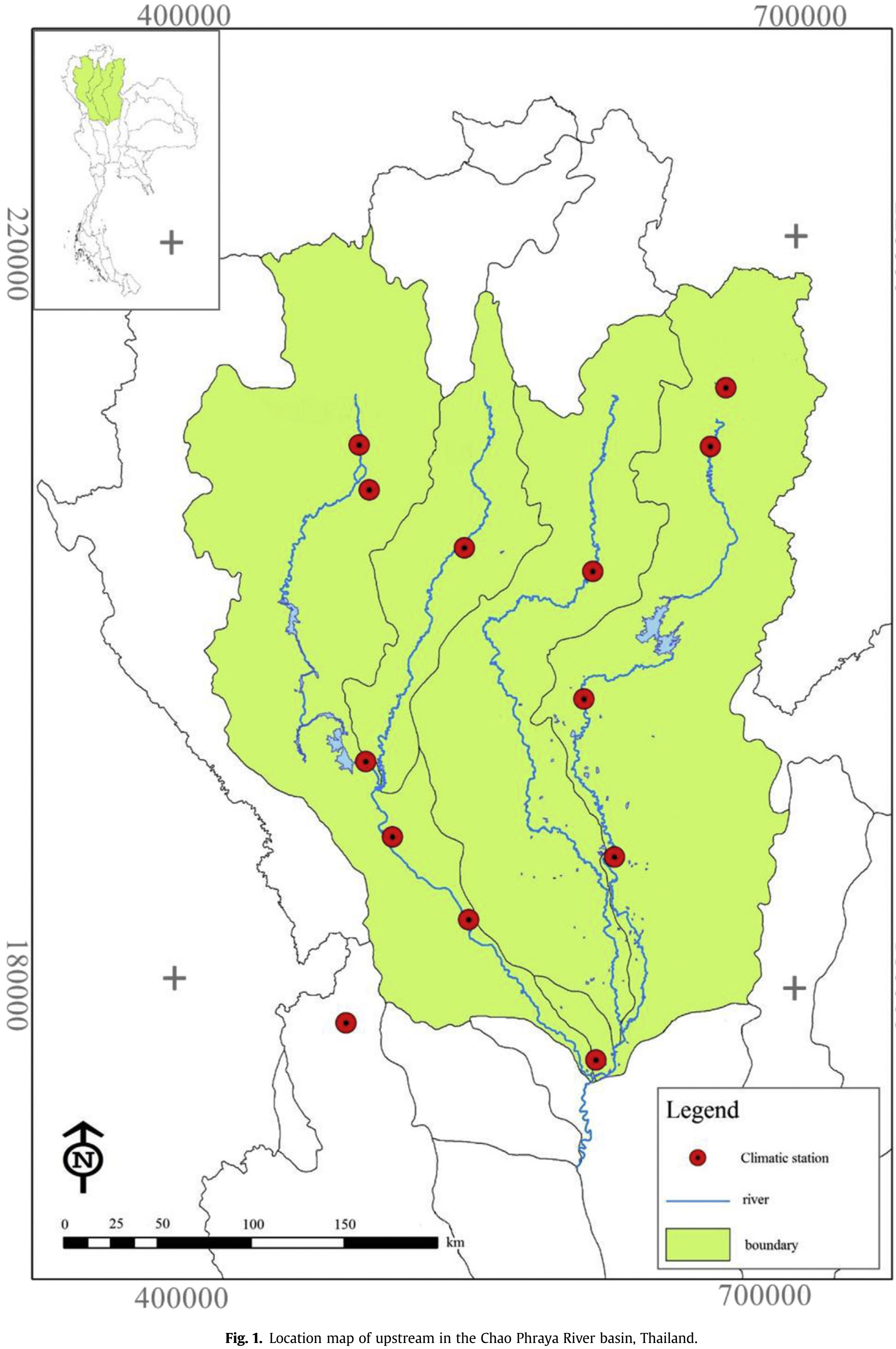

Fig. 1. Location map of upstream in the Chao Phraya River basin, Thailand.

Table 1
Gauge stations used in the study and their record lengths.

Name	Station[a]	Observation type	Record length
Chiang Mai	Climatic station from the Thai Meteorological Department (TMD)	Monthly rainfall	1970–1989
Lampang		Mean temperature	
Lampaun		Monthly evaporation	
Phrae			
Nan			
Tha Wang Pha			
Uttradit			
Tak			
Bhumibol Dam			
Umphang			
Phetsanulok			
Kamphaeng Phet			
Nakhon Sawan			
C2 Nakhon Sawan	Streamflow station from the Royal Irrigation Department (RID)	Discharge	1970–1989

[a] 13 meteorological stations and 1 streamflow station.

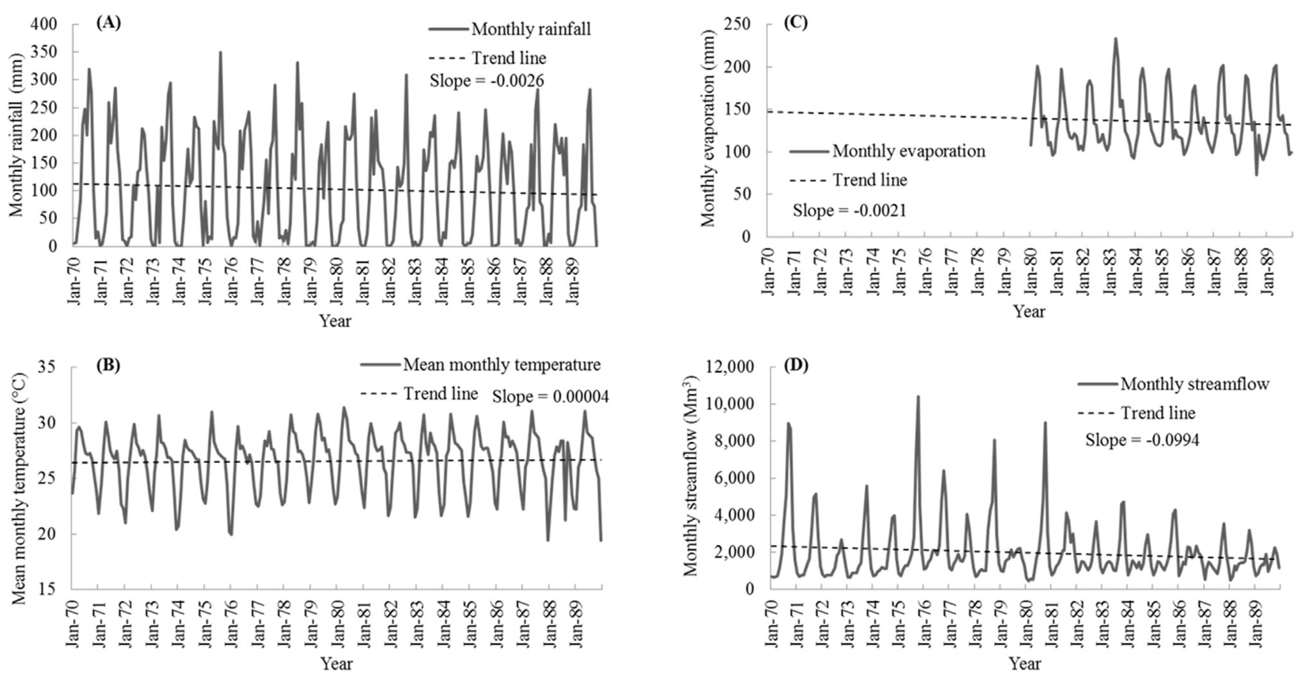

Fig. 2. Climatic data for upstream in the Chao Phraya River basin in calibration period: (A) monthly rainfall; (B) mean monthly temperature; (C) monthly evaporation; (D) monthly streamflow.

global population at a rate lower than A2, intermediate levels of economic development and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Land use change scenarios

In the study area, land use changes mainly involve the conversion of forest to developed land (Tu, 2009) especially agricultural land. This trend is considered to continue in the future. Thus, future land use change scenarios were set up based on the historical data (1980, 1989 and 1996). First, the current land use change rate was obtained using the difference between each land use type. Secondly, three future land use scenarios were set up: 1) a continuous deforestation scenario (CnDS), in which the forest area will reduce to about 12% in the future known as the worst case; 2) a condition deforestation scenario (CdDS) defined as the forest area decreasing to 20% known as the normal case; and 3) a fixed deforestation scenario (FDS) with a fixed forest area of 40%, known as the best case.

The Markov chain model was used to predict the land use change for the future conditions as shown in Eq. (5):

$$M_{LC} * M_t = M_{t+1} \quad (5)$$

$$\begin{pmatrix} LC_{FF} & LC_{FT} & LC_{FC} & LC_{FP} & LC_{FW} \\ LC_{TF} & LC_{TT} & LC_{TC} & LC_{TP} & LC_{TW} \\ LC_{CF} & LC_{CT} & LC_{CC} & LC_{CP} & LC_{CW} \\ LC_{PF} & LC_{PT} & LC_{PC} & LC_{PP} & LC_{PW} \\ LC_{WF} & LC_{WT} & LC_{WC} & LC_{WP} & LC_{WW} \end{pmatrix} \begin{pmatrix} F_t \\ T_t \\ C_t \\ P_t \\ W_t \end{pmatrix} = \begin{pmatrix} F_{t+1} \\ T_{t+1} \\ C_{t+1} \\ P_{t+1} \\ W_{t+1} \end{pmatrix}$$

where the Markov chain equation was constructed using the land use distributions at the beginning (M_t) and the end (M_{t+1}) of a discrete time period as well as a transition matrix (M_{LC}) representing the land use changes that occurred during that period (Muller and Middleton, 1994).

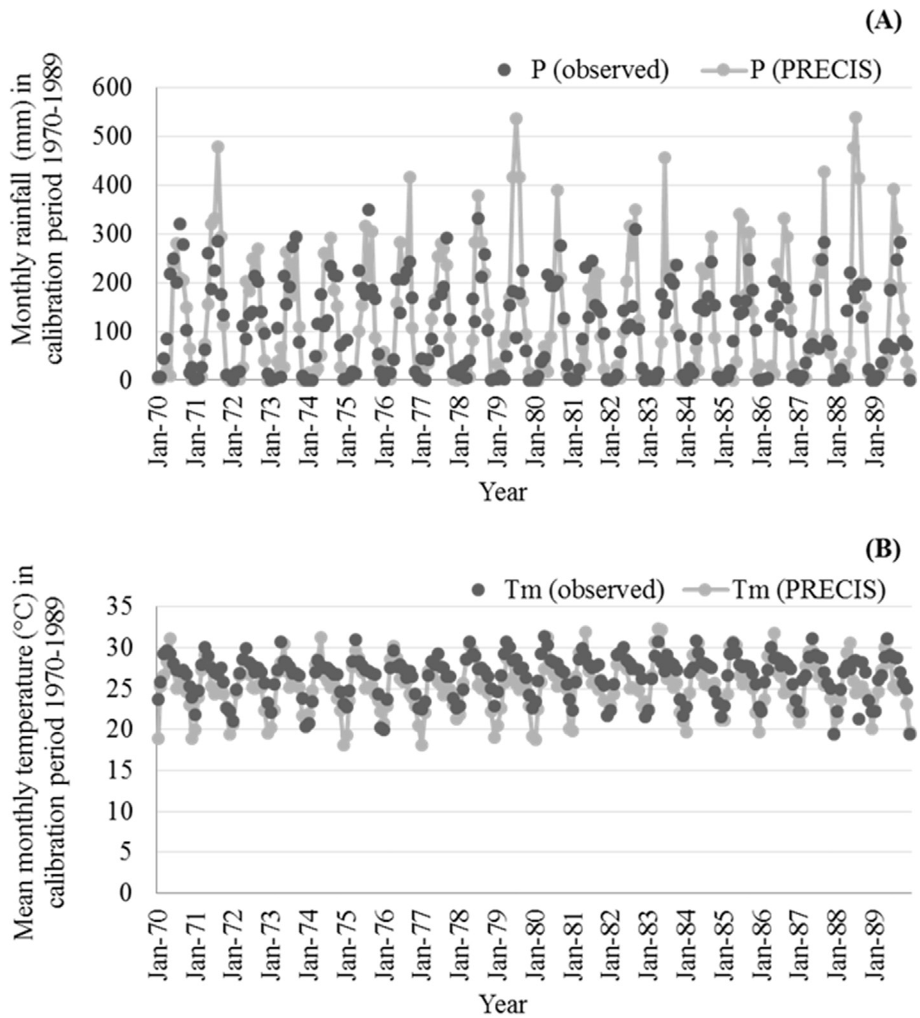

Fig. 3. Comparisons of downscaled output of GCM-ECHAM4 from START (PRECIS), PRECIS versus observed upstream in the Chao Phraya River basin in the calibration period (1970–1989): (A) monthly rainfall; (B) mean monthly temperature.

Table 2
Land use/cover data for three time periods upstream in Chao Phraya River basin.

Year	Land use type (%)				
	Forest[a]	Tree/Plantation[b]	Crop field and urban[c]	Paddy field[d]	Water body[e]
1980	59.82	0.98	25.50	12.72	0.98
1989	49.87	1.93	28.93	18.29	0.98
1996	50.05	0.68	30.83	17.47	0.97

[a] Evergreen forest, deciduous forest, evergreen disturbed forest, and deciduous disturbed forest.
[b] Mixed perennial crops, mixed orchard, and forest plantation.
[c] Mixed field crops, corn, sugar cane, cassava, pineapple, soybean, shifting cultivation, bush and shrub, mine operating, city town and commercial land, village, and institutional land.
[d] Paddy field.
[e] Marsh and water body.

Simulation

The water balance and land use model was run for 100 yrs, with an initial period (1970–1989), in which calibration and validation were achieved. The streamflow obtained from the evapotranspiration and water balance models resulted in data with close agreement between the observed and simulated data. Then, there was a change in the observed climatic data to the downscaled GCM-ECHAM4 data from START and the water balance was calculated for the calibration period. This was followed by the future period (2010–2099), during which the land use data were projected based on the model. The land use and climate data were modified for each of the two climate scenarios and each of the three land use scenarios for future periods. Therefore, there were six model runs simulating future changes in streamflow.

Methodology

The overall methodology used in this study is based on the effects of climate change and land use change in water balance which

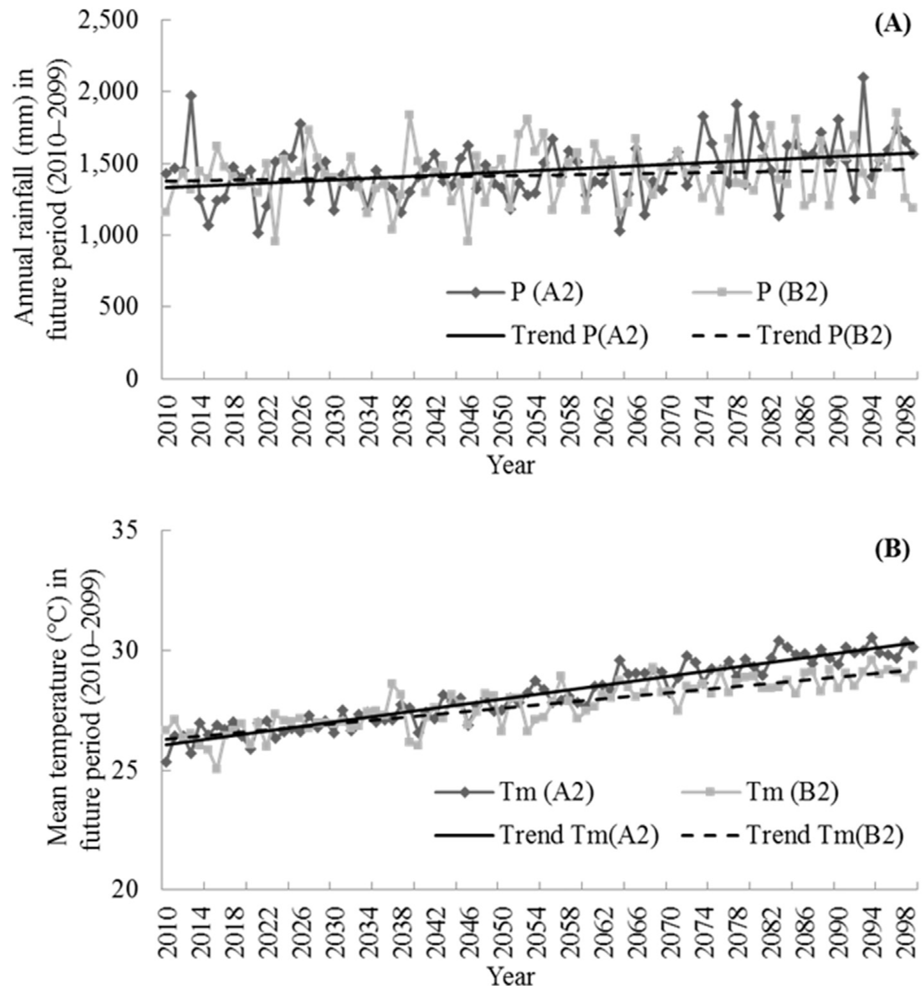

Fig. 4. Comparison between A2 and B2 climate change scenarios from 2010 to 2099 for upstream in the Chao Phraya River basin: (A) annual rainfall; (B) mean temperature. Note: P is annual rainfall (mm), Tm is mean temperature in yearly, A2 and B2 mean climate change scenarios with downscaled output of GCM-ECHAM4 from START (PRECIS).

was computed as a monthly watershed response. Simulations were undertaken for the calibration and future periods. Fig. 5 shows schematic diagrams of the various components of the water balance model in the calibration period (1970–1989) and future period (2010–2099), respectively.

Results and discussion

Calibration and verification results

The calibration period involved estimating the evapotranspiration of a basin and validating the evapotranspiration model (Blaney–Criddle equation). This model ran with parameters and input data corresponding to the land use change conditions. Fig. 6 shows the monthly estimated potential evapotranspiration (ET_p) and observed evaporation upstream in the Chao Phraya River basin. The r^2 value in the calibration and validation period for evapotranspiration was 0.89 indicating a good agreement between the estimated and observed monthly values for evapotranspiration in the calibration period (1970–1989) and suggesting that the model, when calibrated, can provide good estimates of monthly evapotranspiration in the future.

Furthermore, the water balance model was run based on the Van Der Beken and Byloos model. A comparison of the simulated versus observed monthly streamflow is illustrated in Fig. 7. The calibration of the monthly streamflow resulted in an r^2 value of 0.70. The agreement between the observed and simulated monthly streamflow values over the period 1970–1989 was quite good.

Effect of climate change and land use change on water balance in the future period

Climate (rainfall and temperature)

The trend of annual rainfall upstream in the Chao Phraya River basin is shown in Fig. 4; in both the A2 and B2 scenarios it gradually increased in the future. The trend in rainfall in the A2 scenario showed a greater increase than in B2. The average annual rainfall in the calibration period (1970–1989) was 1393 mm compared to 1616 mm and 1479 mm in 2090–2099 for the A2 and B2 scenarios, respectively. In addition, the comparison between average annual rainfall in the calibration period (1970–1989) and the A2 and B2 scenarios in the future (2090–2099) indicated that there were differences of +223 mm and +86 mm in the A2 and B2 scenarios, respectively. Intergovernmental Panel on Climate Change (2000) cited by Hydro and Agro Informatics Institute (2012) reported an increasing rainfall trend especially for the Thailand region during 2090–2099.

Upstream in the Chao Phraya River basin has a tropical monsoon climate (Peterson et al., 2012) with a mean annual temperature varying from 25.3 °C to 30.0 °C and 29.0 °C for the A2 and B2

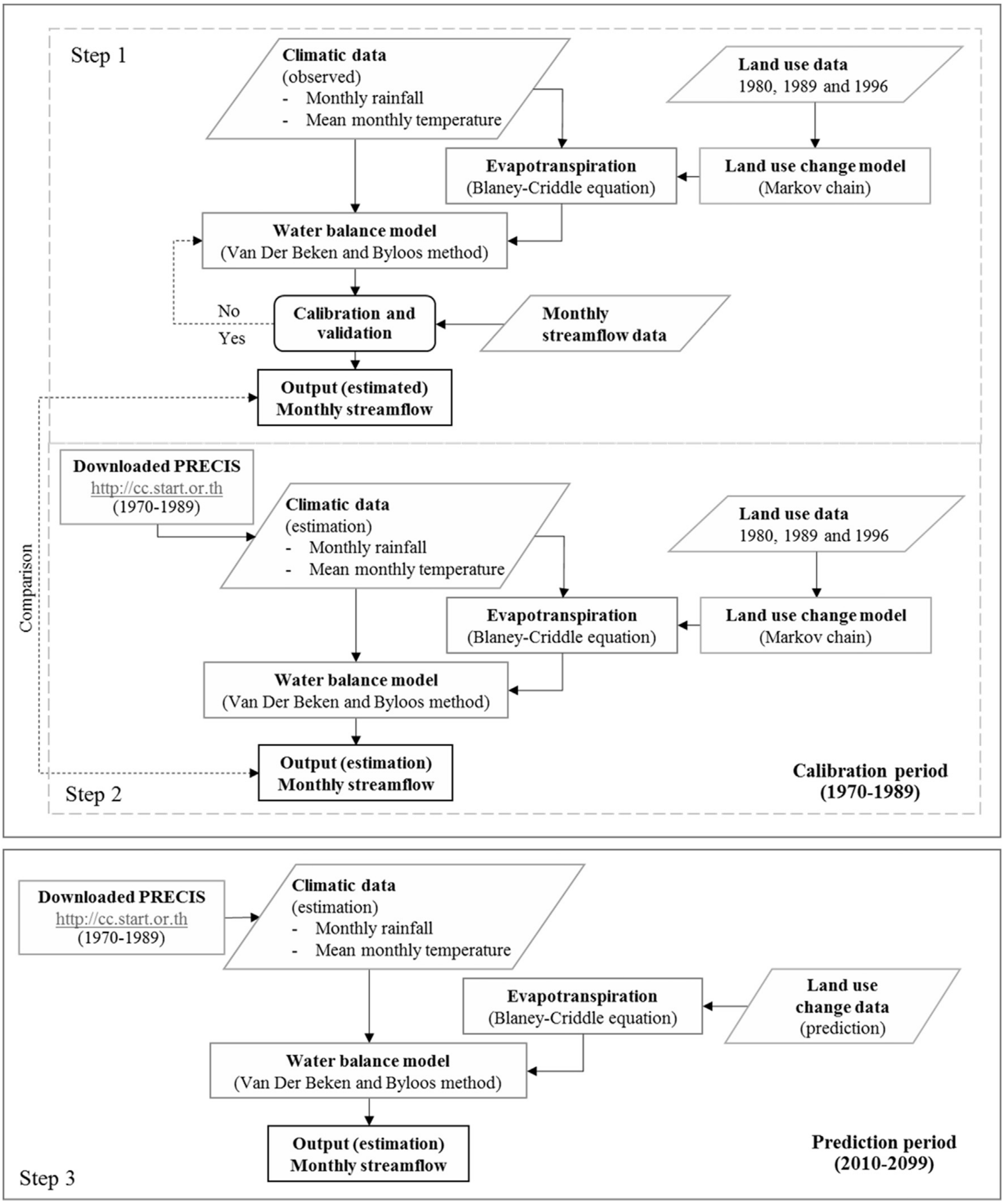

Fig. 5. Flow chart of methodology used in calibration (1970–1989) and prediction (2010–2099) periods.

scenarios, respectively, in the future. Fig. 4 compares the trend in mean temperature between the calibration period and the A2 and B2 scenarios in the future (2090–2099) suggesting changes of +4.7 °C and +3.7 °C, respectively. The average temperature in Thailand will increase slightly, according to both the A2 and B2 scenarios, and this trend will continue further in the future (2040–2059). A more detailed analysis showed that the maximum temperature will increase under both scenarios in both the near and distant future. The minimum temperature under the A2 scenario tended to be slightly warmer than under the B2 scenario, but nevertheless, the B2 scenario showed a trend of increasing minimum temperature in the near future. The long-term, minimum temperature tended to increase under both the A2 and B2 scenarios (SEA START RC, 1996).

Land use changes on evapotranspiration

The projected evapotranspiration levels under different land use scenarios, but under the same climate change scenarios, were compared to assess the impact of land use changes between 2010 and 2099 (Fig. 8). The changes in the percentage of land use for the worst case (forest area = 12%), normal case (forest area = 20%) and best case (forest area = 40%) land use change scenarios are shown in Table 3. The impact can also be examined by comparing the evapotranspiration between climate change scenarios (A2 and B2)

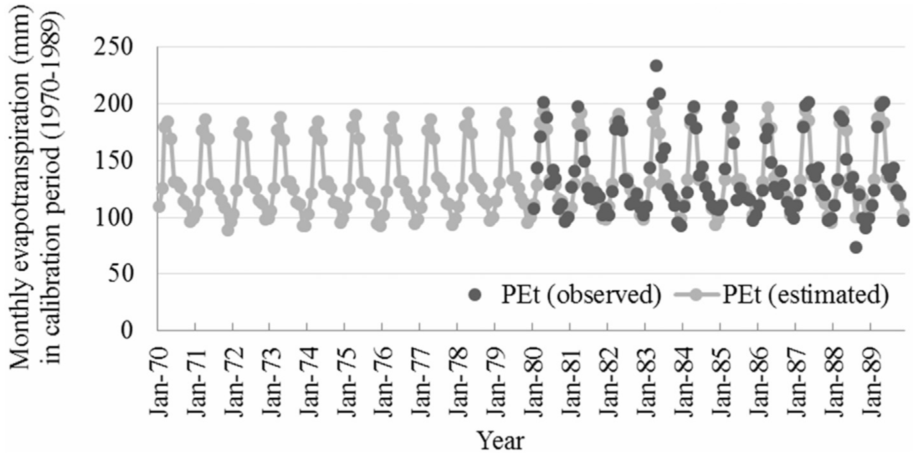

Fig. 6. Monthly estimated potential evapotranspiration (PEt) and observed evaporation in the calibration period (1970–1989) in the upstream of the Chao Phraya River basin (coefficient of determination is 0.89).

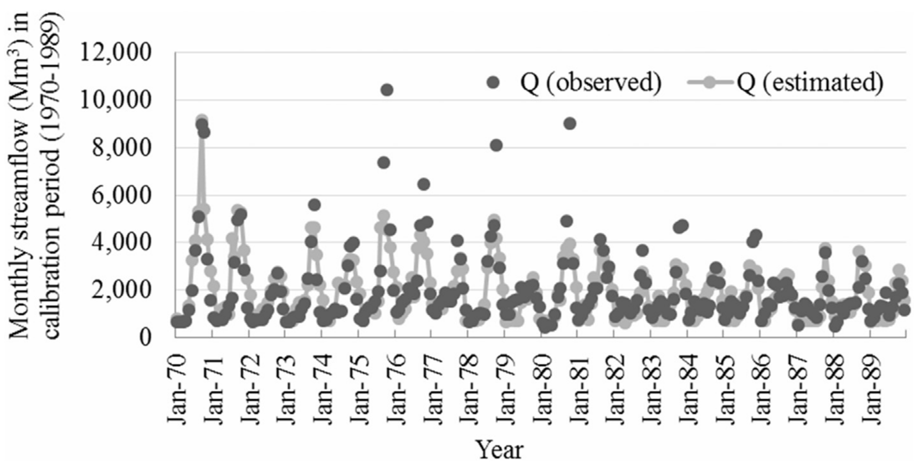

Fig. 7. Estimated and observed of monthly streamflow (Q) in calibration period (1970–1989) in the upstream of the Chao Phraya River basin, calculated using the Van Der Beken and Byloos method (coefficient of determination = 0.70).

and land use change scenarios (worst, normal, and best case scenarios).

As shown in Fig. 8, the land use changes have a substantial impact on evapotranspiration. For all land use change scenarios, the trends of evapotranspiration in the future showed increases. Under both the A2 and B2 scenarios, the evapotranspiration values in CnDs (worst case) were higher than in FDS (Best case) and CdDs (normal case). There was more forest area and deforestation of agricultural land which resulted in a high Kc value. Moreover, the temperatures in the future rose. Differences in evapotranspiration for the three land use scenarios were also evident between the A2 and B2 scenarios. The evapotranspiration rates in A2 were higher than in B2 for all land use scenarios. A study of river discharge projections under climate change in the Chao Phraya River basin using the MRI-GCM3.1S dataset found that the potential evapotranspiration tends increased (Hunukumbura and Tachikawa, 2012).

Impact of climate changes and land use changes on streamflow

The simulated streamflow levels under different climate scenarios were compared to assess the impact of land use changes (Fig. 9). Under the A2 and B2 climate change scenarios, the trends of simulated streamflow for three land use scenarios tended to increase and fluctuate in the future when compared with the calibration period. Most streamflows under the worst case (CnDS) scenario were higher than in the under normal case (CdDS) and best case (FDS) scenarios. The streamflow data in A2 were lower than in the B2 scenario. The differences in streamflow for the A2 scenario between the calibration period and 2090–2099 resulted in land use change under the worst, normal and best cases of 40.17%, 36.55% and 36.17%, respectively, while in the B2 scenario, the steamflows changes were 35.24%, 27.79% and 29.85%, respectively (Table 4).

In order to analyze the combined effect of climate and land use changes, the precipitation, evapotranspiration and streamflow under the CnDS (worst case), CdDS (normal case), and FDS (best case) land use scenarios and under the A2 and B2 climate change scenarios for the future period (2010–2099) were compared to the corresponding conditions in the calibration period (1970–1989). The current study described the response to climate change projection datasets under scenario A1B of the Special Report on Emissions Scenarios which used the Meteorological Research Institute, Japan atmospheric general circulation model 3.1 and 3.2 output data as input to a watershed hydrology model to assess the impact of climate change for the basin. As a result, the mean annual river discharge in the future was predicted as likely to increase in the Chao Phraya River basin due to increased rainfall. Furthermore, increases in the annual maximum daily flows were expected toward

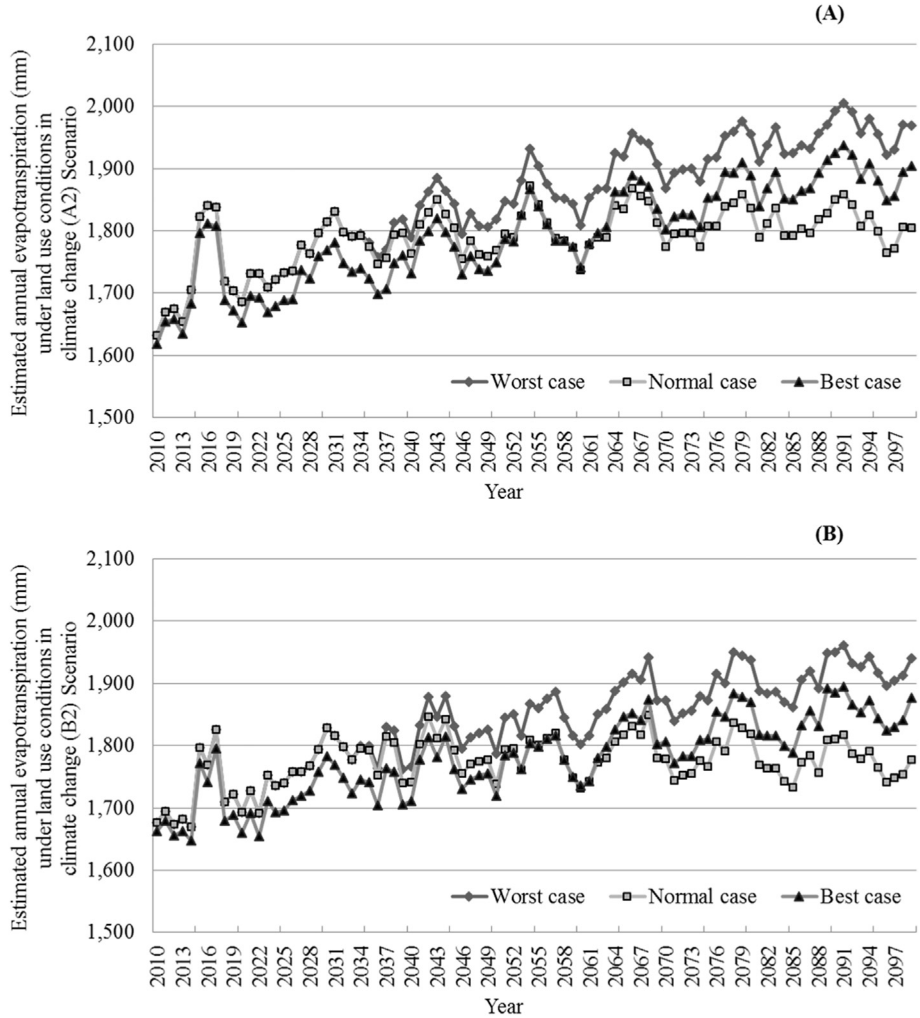

Fig. 8. Estimated annual evapotranspiration values under three land use change scenarios and two climate change scenarios (A2 and B2) for upstream in the Chao Phraya River basin. (worst case, forest area = 12%; normal case, forest area = 20%; best case, forest area = 40%) for: (A) A2 climate change scenario; (B) B2 climate change scenario.

Table 3
Land use change in the future under three scenario conditions upstream in the Chao Phraya River basin (change in percentage area).

Scenario[a]	Land use type	Calibration period	Future period (year)								
		Area (%)	Area (%)								
		1970–89	2010–19	2020–29	2030–39	2040–49	2050–59	2060–69	2070–79	2080–89	2090–99
CnDS (Worst case)	Forest	59.5	34.1	26.6	19.4	13.4	11.9	11.9	11.9	11.9	11.9
	Tree	1.0	2.7	3.7	4.4	5.1	5.8	6.5	7.1	7.8	8.5
	Crop	25.7	37.3	40.5	44.2	47.4	47.7	47.0	46.4	45.7	45.0
	Paddy	12.8	25.0	28.2	31.9	33.5	33.5	33.5	33.5	33.5	33.5
	Water	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
CdDS (Normal case)	Forest	59.5	34.1	26.6	20.4	20.4	20.4	20.4	20.4	20.4	20.4
	Tree	1.0	2.7	3.7	4.6	5.3	6.0	6.6	7.3	8.0	8.7
	Crop	25.7	37.3	40.5	45.0	48.3	51.5	54.8	58.0	61.2	64.4
	Paddy	12.8	25.0	28.2	28.7	24.8	20.8	16.9	13.0	9.1	5.2
	Water	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
FDS (Best case)	Forest	59.5	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1	40.1
	Tree	1.0	2.7	3.7	4.8	5.4	6.1	6.8	7.5	8.2	8.8
	Crop	25.7	35.0	34.0	32.9	32.2	31.5	30.8	30.1	29.4	28.9
	Paddy	12.8	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2
	Water	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1

[a] CnDS = continuous deforestation scenario (Worst case) forest area about 12% in future period (2090–2099); CdDS = condition deforestation scenario (Normal case) forest area about 20% in future period (2090–2099); FDS = fixed deforestation scenario (Best case) forest area about 40% in future period (2090–2099).

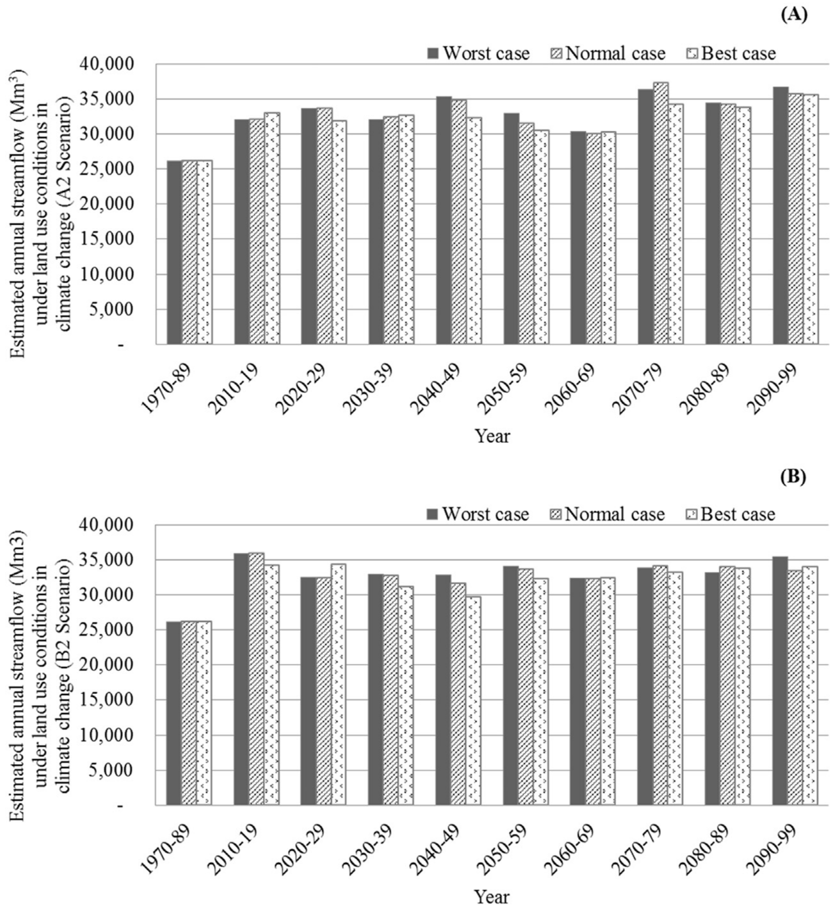

Fig. 9. Estimated annual streamflow under three land use change scenarios and two climate change scenarios (A2 and B2) at the outlet of the upstream of the Chao Phraya River basin (C2 streamflow station) and (A) A2 climate change scenario; (B) B2 climate change scenario. Note: land use change scenarios had the worst case (forest area = 12%), the normal case (forest area = 20%) and the best case (forest area = 40%).

Table 4
Estimated average annual rainfall, evapotranspiration and streamflow data under land use change and climate change scenarios (2010–2099).

A2 scenario	Average annual rainfall (mm)	Average annual evapotranspiration (mm)			Average annual streamflow (Mm^3)		
		Worst case[a]	Normal case[b]	Best case[c]	Worst case	Normal case	Best case
1970–89	1237	1543	1543	1543	26,168	26,168	26,168
2010–19	1400	1726	1726	1703	32,092	32,092	33,001
2020–29	1427	1739	1739	1700	33,677	33,677	31,841
2030–39	1309	1797	1789	1741	32,087	32,424	32,639
2040–49	1450	1832	1795	1767	35,337	34,774	32,326
2050–59	1412	1865	1805	1800	32,982	31,525	30,545
2060–69	1325	1899	1815	1825	30,396	30,071	30,312
2070–79	1547	1916	1810	1851	36,346	37,291	34,210
2080–89	1564	1942	1811	1881	34,452	34,268	33,837
2090–99	1616	1968	1813	1898	36,680	35,733	35,633
B2 scenario	Average annual rainfall (mm)	Average annual evapotranspiration (mm)			Average annual streamflow (Mm^3)		
		Worst case	Normal case	Best case	Worst case	Normal case	Best case
1970–89	1237	1543	1543	1543	26,168	26,168	26,168
2010–19	1393	1722	1722	1699	35,926	35,926	34,243
2020–29	1418	1742	1742	1702	32,479	32,479	34,419
2030–39	1362	1800	1792	1744	32,990	32,756	31,186
2040–49	1351	1829	1792	1764	32,888	31,631	29,761
2050–59	1511	1845	1786	1781	34,032	33,645	32,361
2060–69	1403	1875	1793	1810	32,437	32,289	32,400
2070–79	1412	1888	1783	1823	33,878	34,147	33,189
2080–89	1445	1899	1771	1832	33,196	34,013	33,827
2090–99	1479	1928	1777	1859	35,389	33,440	33,978

[a] Worst case (CnDS = Continuous deforestation scenario) forest area about 12% in future period (2090–2099).
[b] Normal case (CdDS = Condition deforestation scenario) forest area about 20% in future period (2090–2099).
[c] Best case (FDS = Fixed deforestation scenario) forest area about 40% in future period (2090–2099).

the end of the 21st century. In addition (Ogata et al., 2012), found that the mean annual discharge in each decade did not show a high variance. On the other hand, the highest annual discharge seemed to increase for future decades, especially from 2021 to 2030. Moreover, the streamflow obtained from the monthly water budget simulation with the three different land use scenarios showed an increase of about 4–7% in the double CO_2 scenario (greenhouse effect condition; 2060–2099) compared to the calibration period (1961–1990) according to Techamahasaranont (2001).

In both the A2 and B2 climate change scenarios, the annual streamflow showed similar increasing trends in all land use conditions because of increasing rainfall. The best case for land use change in the future (40% forest cover) resulted in lower discharges and evapotranspiration than in the other cases. Therefore, it was possible that the watershed could be storing water in the soil and thus allowing less water to be released from the system than in other landscape cases.

Conclusions

This study investigated the effects of climate change and land change on water balance upstream in the Chao Phraya River basin. A water balance model was developed which related climate parameters (rainfall and temperature) and land use conditions to the estimated evapotranspiration and streamflow in the calibration period (1970–1989). The simulated results were calibrated and validated with observed data. They were highly correlated (r^2 = 0.89 and 0.70) for evapotranspiration and streamflow, respectively, and the correlations of rainfall and mean temperature between observed and downloaded (PRECIS) data were $r^2 = 0.71$ and $r^2 = 0.84$, respectively.

In addition, the simulated water balance for future climatic conditions and land use change scenarios showed an increasing tendency during 2010–2099 for rainfall, temperature, evapotranspiration and streamflow. Furthermore, the increase of streamflow for the three land use conditions would be 36–40% and 27–35% for the A2 and B2 climate change scenarios, respectively, when comparing the calibration period (1970–1989) with 2090–2099.

Water balance prediction in the future may become increasingly challenging due to the increasing variability in rainfall, evapotranspiration and streamflow. The management and control of water resources will become an essential future issue for the Chao Phraya River basin.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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