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Effects on runoff under climate change and reforestation in Lam Dom Yai river basin, Thailand

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Abstract

Presently, nearly all global regions including northeastern Thailand are expected to experience more frequent severe flood and drought hazards which are basically caused by human's accelerated activities as well as inappropriate land use change (LUC) consequently resulting, green house gas (GHG) effects, global warming, and climate change (CC) respectively. Therefore, it is essential to study the effects of CC and LUC on runoff of Lom Dom Yai (LDY) river in Thailand and to suggest an appropriate adaptive measure to alleviate the effects. This study aims to (1) study effects of CC and LUC on future river flows of LDY basin covering 5,000 km2 which is located in the northeast of Thailand, by developing a climate-hydrologic model, and (2) apply and recommend land use management as an adaptive measure for alleviating CC effects on flows. The GIS-based ARC –SWAT model was developed and applied using 78 years of future climatic data from MRI-GCM which were statistically downscaled with observed data. Additionally taking into account LUC, CA-Markov technique was adopted to simulate temporal and spatial pattern of land use in periodically periods as the model input. Results of the model development indicated model reliability. For the case study of the future with the selected CC scenario RCP 4.5, the 78-years mean annual flow of LDY would be increased approximately 6 percent more than the past mean annual flow. Furthermore, the future mean monthly flows and extreme daily flows would be significantly increased in September and October (wet season), and decreased in February and March (dry season) respectively. In addition, high flows would be deferred from September to October. Application of reforestation could be applied as one of adaptive measures to alleviate CC effects on flow regime in better balancing seasonal flow fluctuation by decreasing wet season high monthly flows and mean daily flood peak, whereas increasing most of dry season mean monthly flows.

Keywords

climate change; land use change; climate hydrologic model; land use transition probability matrix; reforestation measure.

Introduction

Global warming and climate change (CC) becomes the world's critical phenomenon that challenge all nations' co-operation in greenhouse gas (GHG) reduction to decelerate global warming and essential adaptive measures preparation to alleviate CC impacts respectively. According to the IPCC, 2021 during 1950-2020 higher global temperature was increased up to 1.09°C on average. Increasing of temperature significantly causes global warming and CC consequently affects hydrologic system comprising surface runoff, groundwater, and evapotranspiration.

Numerous international studies have researched quantitatively hydrologic response due to long term future CC by applying different global climate models (GCM) with downscale technique and various hydrologic model. Results indicated that effects from CC would be uncertain in either increasing or decreasing trends of river flows. Increasing trends of river flows and floods were determined in Mekong River from Lao PDR, Thailand, Cambodia to Vietnam [12], Elbow River in Canada [1], Bago River in Myanmar [17], Ping River in Thailand [20], and Geum River in Korea [16]. On the other hand, decreasing trend of runoff was examined in Srepok River in Vietnam [14].

Additionally, some researches considering CC and land use change (LUC) affecting hydrologic response have been employed. A study of rapid urbanization only or both of urbanization and CC in Elbow River in Canada would affect increasing mean annual flow and flood flows [1]. On the other hand, LUC due to reforestation in Tahe River in China [22] and Nam Phong River in Thailand [18] would result in contrarily decreasing mean annual flows and extreme flood volumes.

Nevertheless, little research on both CC and LUC affecting hydrologic response in Thailand especially in the northeast has been conducted. Therefore development of GIS-based meteo-hydrologic model was applied to research on effects of both changes on river flows in the northeast of Thailand as well as to study on application of land use management as one of strategic adaptive measures to sustain flow regime that affected by both changes.

Material and Methods

1. Study area

Lam Dom Yai (LDY) river basin is one of four main sub basins of the Lower Mun river basin located in the northeast of Thailand. The basin is located in Ubon Ratchathani province covering 5,000 sq.km or one-third of the catchment area of the Lower Mun river basin. At present approximately 54% of the catchment area is rainfed paddy, whereas only 15% of the area is forest. According to past land use maps, changing of forest area was vastly decreasing from 34% in year 1985 to 25% in year 2000 and down to 16% in the year 2019, together with global CC effects, consequently more severe droughts and floods have been frequently occurred. Such events have caused severe losses on environments, social and mainly on economic of agriculture sector in Ubon Ratchathani province which is the fifth largest province of Thailand and producing the third highest GPP of the northeast region. It is essential to develop a tool to forecast future change of hydrologic response due to CC and LUC and to apply for considering appropriate adaptive measures against the adverse effects.

2. Objectives

The objectives of the study aim to firstly developing a GIS-based hydrologic rainfall-runoff model of Lam Dom Yai River Basin, considering static basin parameters. Secondly studying how CC affecting river runoff i.e. average annual flow, monthly flows, and extreme daily flows in near future period (2022-2047), mid future period (2048-2073), and far future period (2074-2099). Lastly, applying LUC effect as a measure of land use management to mitigate the CC effects on hydrologic response.

3. Methodology

A mathematical hydrologic (Rainfall – Runoff) model named Arc SWAT was developed for the studied basin on the principle of soil water balance equation as follow;

$$SW_t = SW_0 + \sum_{i=0}^{n} \left(P_{day} - Q_{surf} - E_a - W_{seep} - Q_{qw} \right) \quad (1)$$

where □□□ is the soil moisture (mm), □□□□ is the precipitation (mm), Q_{surf} is the streamflow (mm), □□ is evapotranspiration (mm), W_{seep} is the water flow to the unsaturated zone (mm), and is Q_{qw} the ground water flow (mm).

The study approach is depicted in Figure 1 comprising three main procedures i.e. (1) SWAT Model development consisting of input data, calibration and verification, (2) simulation of future river runoff, (3) application of land use management as an adaptive measure for CC mitigation plan.

3.1 Model Development

3.1.1 Model Input Data

Three key physical data are basically required by the Arc SWAT model, i.e. 1) topographic map or digital elevation model (DEM) of 1:50,000scale, 2) soil series map of 1:250,000 scale, and 3) land use map of 1:50,000 scale of four different years, i.e., year 2000, year 2008, year 2017, and year 2019 as shown in Figures 2 to 4, respectively. The other type of data is meteo-hydrologic data comprising (1) daily maximum and minimum temperatures of the meteorologic station at Amphoe Muang Ubon Ratchathani and data set of six rain gauge stations were selected basing on well - spreaded locations and valid observed data availability, (2) daily streamflow data set of six selected discharge stations were used for model calibration namely M152, M153 and M154 in the upstream reach, M170 in the middle reach, and TS7 and Lam Dom Yai Regulator in the downstream reach, respectively, (Figure 2).

3.1.2 Model Calibration

Calibration of the SWAT model's groups of parameters mainly comprising surface runoff, groundwater, river channel, soil type, and land cover, were accomplished by upstream, middle, and downstream reaches with the past recorded data of climate, hydrology and land use maps during the period of 2001-2017.

To consider land use effects, three more land use maps of the year 2005, 2012 and 2015, which were simulated by CA Markov's model using following equation of transition probabilities matrix, were added.

$$S(t+1) = P_{ij} \times S(t) \quad (2)$$

Where $S(t)$, $S(t+1)$ are the system status at the time of t or $t+1$; P_{ij} is the transition probability matrix in a state which is calculated as follows;

$$P_{ij} = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1n} \\ P_{21} & P_{22} & \cdots & P_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ P_{n1} & P_{n2} & \ldots & P_{nn} \end{bmatrix} \quad (3)$$

Where $\left(0 \le P_{ij} < 1 \ and \sum_{j=1}^{N} P_{ij} = 1.(i.j = 1,2,\ldots,n) \right)$

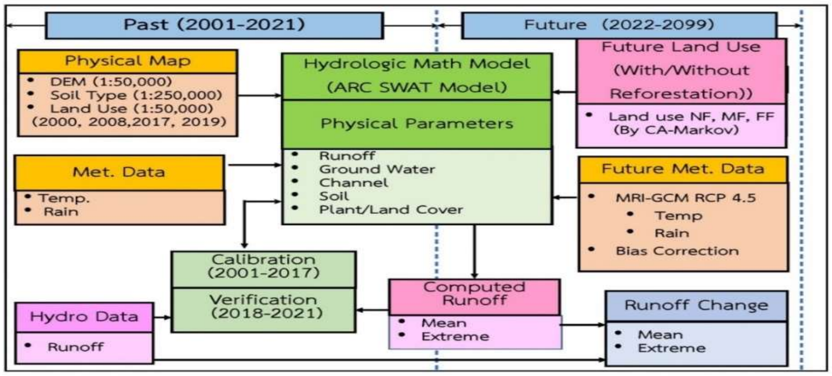

Figure 1 Conceptual approach of study

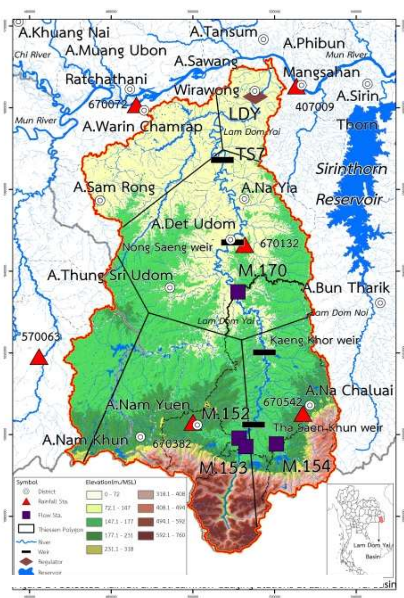

Figure 2 DEM and gauging stations.

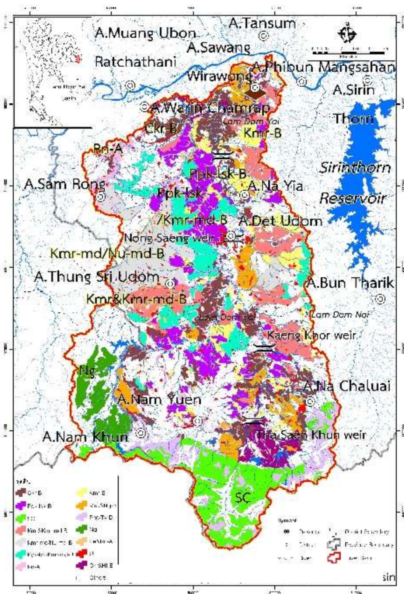

Figure 3 Soil type map of Lam Dom Yai river basin.

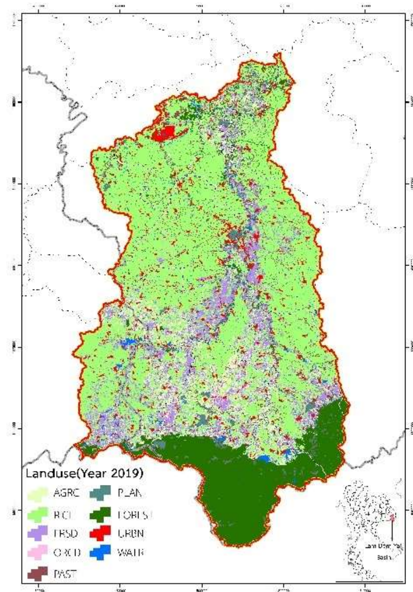

Figure 4 Land use map of Lam Dom Yai river basin (year 2019.)

3.1.3 Model Verification

According to no available observed data in the upper basin since 2010, verification with the observed stations at middle basin (M170) and downstream basin (TS7 and LDY) during 2018 to 2021 were applied excluding the upper basin.

3.1.4 Model Performance Tests

Reliability of the model was determined by three indicators at good performance rating requirement i.e. 1) Correlation coefficient (R^2) ranging 0.75-0.85, 2) Nash–Sutcliffe coefficient of effective (NSCOE) ranging 0.7-0.8, and 3) Bias factor (BIAS) ranging ±5-10% [13]

3.2 Simulation of Future River Runoff.

The calibrated model was then adopted as the tool for simulation of the river runoff under future CC condition from 2022 to 2099. Three future time periods were defined as near future (NF) for years 2022-2047, mid future (MF) for years 2048-2073, and far future (FF) for years 2074-2099, respectively. Following data were prepared.

3.2.1 Future Climate Data

Future daily climate data set of temperature and rainfall during 2001-2099 were obtained from the GCM model. The Hydro – Informatics Institute (HII) of Thailand has manipulated various GCM data for Thailand by using statistical downscaling technique. Rainfall data of MRI –GCM model were selected since the MRI-GCM model utilized finer grid resolution and the resulted R^2 and S.D. of the downscaled data compared to observed data were more preferable both temporal and space to those of other six GCM models [2].

The downscaled MRI-GCM rainfall data of RCP 4.5 were manipulated bias correction using the Standard Deviation Ratio (SDR) method [4]. The SDR method presented good results of R^2 and SD in term of temporal and space in wet season and especially in dry period comparable to the other methods [2].

3.2.2 Future Land Use Maps

Future land use maps were periodically generated for three future periods interval from 2022 to 2099 by CA-Markov method based on past land use changing rate during 2008 – 2019. The forest area at 2021 would be decreased from 736 km^2 (14.6% of the whole basin) down to 652 km^2 or 12.9% in 2099. (Figure 5)

3.2.3 Future Parameters

Model parameters were applied using the resulted parameters obtained from the calibration.

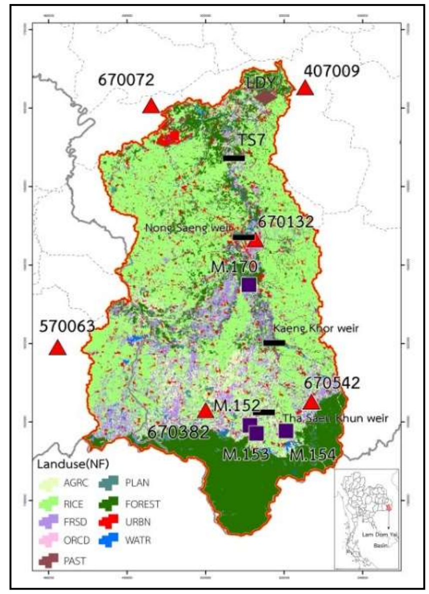

Figure 5 Land use map during far future period 2074-2099 (base case)

3.3 Model Application for Reforestation Measure

Land use management by reforestation was proposed as one of adaptive measures to alleviate hydrologic response effects due to CC. Future target reforestation area of approximately 1200 km^2 was aimed to increase the present forest area from 14.6% up to 40% or 2,000 Km^2 in 2099 as it ever existed in the year 1985. The projected reforestation plan was consecutively stepwise increased at totally 25% within three future periods of NF, MF, and FF. Figure 6 shows the represented far future land use map with reforestation.

3.4 Sensitivity of Reforestation Area to Runoff

Three targets of reforestation area were delineated to determine sensitivity of reforestation size affecting the mean annual flows at LDY station. Various total reforestation areas of LDY beyond 78 years were targeted at 12%, 19%, and 25% of the catchment area or equivalent to approximately 600 km^2, 900 km^2 and 1,200 km^2, respectively. In addition, another case study of no deforestation beyond the future period was also applied.

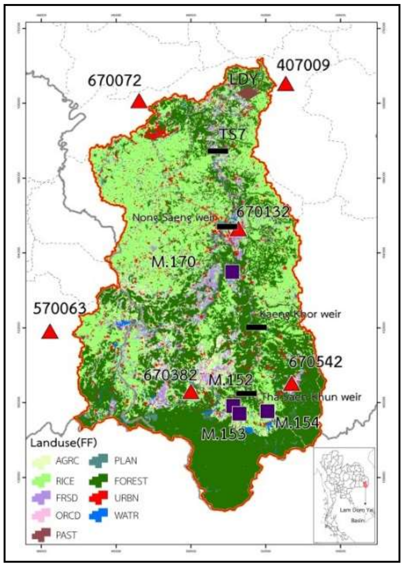

Figure 6 Land use map during far future period 2074 - 2099 (with reforestation case)

Results

4.1 Model Calibration and Verification Results

Figures 7 to 9 show results of daily simulated flows compared to observed flows and correlation coefficients of upper to downstream basins. The calibrated results showed significant reliability ranges of R2 (0.79-0.80), NSCOE (0.75-0.77), and BIAS (4.84%-10.92%). The verified results also showed moderate to good compatibility with observed data both in hydrograph pattern and magnitude. The resulted ranges of R2 was 0.73-0.78, NSCOE was 0.70-0.77 and BIAS was 3.6%-7.9% respectively.

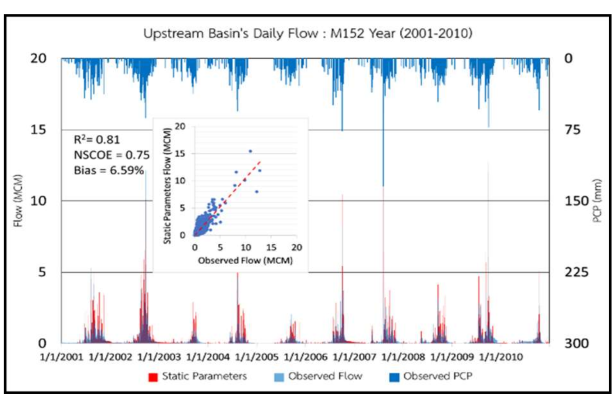

Figure 7 Calibrated results of daily flows at upstream reach (M152).

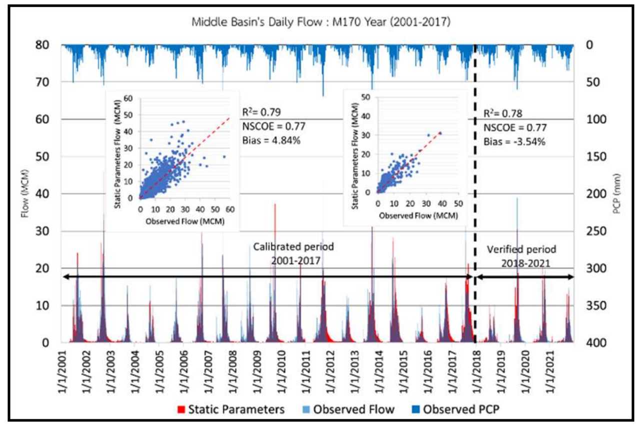

Figure 8 Calibrated and verified results of daily flows at middle reach (M170).

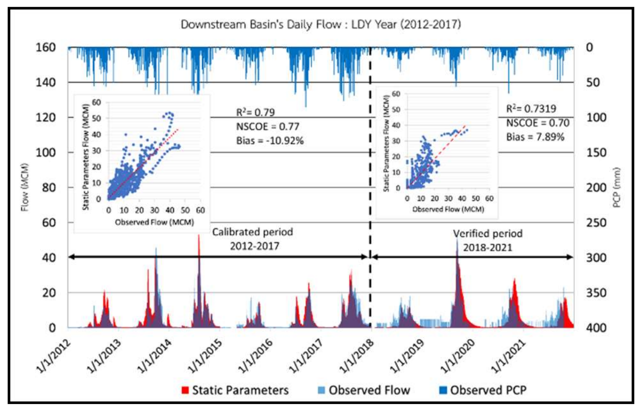

Figure 9 Calibrated and verified results of daily flows at downstream reach (LDY).

4.2 Results of Model parameters

Following parameters were calibrated;

1) Groundwater : AIPHA-BF (Baseflow alpha factor) and GWQMN (Threshold depth of water in the shallow aquifer required for return flow). GW_DELAY (Groundwater delay), and REVAPMN (Threshold depth of water in shallow aquifer for revaporation).

2) Surface– runoff: CN2.Mgt (Initial SCS CNII Value), and OV_N (Overland N Value).

3) Channel: CH-K2 (Effective hydraulic conductivity), and CH-N2 (Manning N value for main channel).

4) Land cover: EPCO (Plant uptake compensation factor).

5) Soil: ESCO (Soil evaporation compensation factor), SOL_AWC (Available water capacity of the soil layer), and SOL_K (Saturated hydraulic conductivity).

Referring to previous studies on main parameters significantly affecting runoff calculation (i.e. Base flow factor, GWQMN, CN, SOL-AWC ESCO GW-DELAY) [9] and [10], the key parameters determination were precedently emphasized of which results together with other parameters are presented in Table 1.

Table 1 Calibrated key basin parameters

Parameters	Value Type	UpStream M152	MiddleStream M170	DownStream LDY
1.ALPHA_BF	Value	0.75	0.52	0.49
2.GW_DELAY	Value	86.92	80.35	67.50
3.GW_REVAP	Value	0.24	0.21	0.18
4.GWQMN	Value	642.92	1137.11	1168.53
5.REVAPMN	Value	101.31	138.12	69.64
6.RCHRG_DP	Value	0.14	0.14	0.18
7.CH_K2	Value	84.41	76.38	54.27
8.CH_N2	Value	0.15	0.18	0.18
9.CN2	Relative	0.12	0.10	0.08
10.ESCO	Value	0.74	0.91	0.60
11.EPCO	Value	0.85	0.77	0.91
12.SOL_AWC	Relative	0.13	0.16	0.05
13.SOL_K	Relative	0.12	0.10	0.10
14.SOL_Z	Relative	0.03	0.04	0.05
15.HRU_SLP	Relative	0.02	0.08	0.06
16.OV_N	Relative	-0.05	0.05	0.07
17.SLSUBBSN	Relative	0.02	0.01	0.01

4.3 Future Conditions

4.3.1 Future Climates

Future rainfall data from the MRI–GCM scenario RCP 4.5 at six stations were bias corrected with observed rainfall data during past period as summarized in Table 2. All stations' data indicated increasing of future rainfall approximately 6-10 percent more than those of past period whereas mean basin rainfall at downstream reach (LDY) would be increased by 7.2%. The average maximum and minimum daily temperature would be increased by approximately 2.0°C and 3.0 °C respectively in the far future period.

Table 2 MRI- GCM future rainfall and temperature at selected stations under CC scenario RCP 4.5

Stations	Average RCM Annual Rainfall (After Bias Correction), mm								
	2001-2021	2022-2047	Diff (%)	2048-2073	Diff (%)	2074-2099	Diff (%)	2022-2099	Diff (%)
Rainfall	PAST	RCM NF	fr. Past	RCM MF	fr. Past	RCM FF	fr. Past	Av. NF-FF	fr. Past
1.1) A. Na Chaluai STA. 670542	1431	1562	9.20	1569	9.63	1573	9.93	1568	9.58
1.2) A. Nam Yuen STA. 670382	1151	1202	4.49	1221	6.10	1252	8.81	1225	6.47
1.3) A. Det Udom STA. 670132	1371	1431	4.37	1465	6.91	1480	7.99	1459	6.42
1.4) A. Phibun Mangsahan STA. 670022	1432	1481	3.42	1594	11.34	1591	11.11	1555	8.62
1.5) A. Warin Chamrap STA. 670072	1292	1296	0.34	1409	9.10	1390	7.62	1365	5.68
1.6) A. Kantharalak STA. 570063	1333	1357	1.80	1490	11.76	1488	11.62	1445	8.39
Climate	Average Max and Min Daily Temperature, °C								
2.1) A. Meung Ubon	33.4	33.8	1.1	33.9	1.5	34.5	3.2	34.1	1.9
Ratchathani	22.7	24.2	7.7	25.2	12.4	25.7	14.6	25.0	11.6

4.3.2 Simulated Future River Runoff of RCP 4.5

Figure 10 shows the results of the simulated daily runoff of future 78-years (2022-2099). Table 3 presents the mean annual flows would be higher than observed data in the past period i.e., 9.8% at upstream reach (M152), 23% at middle reach (M170), and 4.9% at downstream reach (LDY), respectively.

In term of monthly basis, the model indicated that future wet season flows would be greater than those of the past especially in October approximately 16.7% at M152, 24.8% at M170, and 5.6% at LDY. Whereas mean daily peak flows would also be greater than those of the past at 13%, 39%, and 9% respectively (Figure 11). In addition, the future higher flow hydrographs would be shifted later from September to October.

Future dry season flow volume would overall be greater than the past due to future higher rainfall but some months be drier than those of the past especially in February and March with the range of 5-18%. The mean daily minimum discharges would be increased by 6% at M152, 60% at M170, and 12% at LDY respectively.

In summary, future CC would affect LDY mean annual runoff and wet season runoff on more volume, higher extreme flood flows, drier minimum flows, and deferred high flow occurrence period.

4.3.3 Reforestation Measure

With the target reforestation area over the whole basin within 78 years, the results indicated that on annual basis, the mean annual flows would be decreased from 108 mcm in case of without reforestation down to 104 mcm for with reforestation or 3.7% decrease at M152, 1,161 mcm down to 1,107 mcm or 4.7% decrease at M170, and 1,875 mcm down to 1,784 mcm or 4.9% at LDY, respectively. At 1,200 km2 of reforestation area, the future mean annual flow at LDY would be closed to the historical mean annual flows. (Table 3)

On seasonal basis, mean wet season flows of with reforestation would be lesser than those of without reforestation by decreasing 6.5%, 5%, and 6.9% at M152, M170, and LDY, respectively. Whereas mean dry season flows of with reforestation would be more by 10% at M152, but be less by 3% at M170, and be more by 4.5% at LDY, respectively.

On monthly basis, the reforestation would benefit by decreasing most of monthly flow volume in flood period during August to October by 3% - 6% at M152, 2% - 3% at M170, and 6% - 8% at LDY, whereas increasing more volume in dry season during November to December by 6% -16% at M152, 1% - 27% at M170, and 3% -4% at LDY, respectively. (Figure 11, Table 4)

On daily basis, mean daily maximum flow (with reforestation) in October would be decreased at all stations from 4.75 to 4.70 mcm/day or 1% at M152, from 19.9 to 15.4 mcm/day or 23% at M170, and from 22.6 to 20.7 mcm/day or 8% at LDY, respectively. Whereas mean daily minimum flow in March would be insignificantly different at M152, decreased at M170 (from 0.18 to 0.12 mcm/day or 33%), but increased at LDY (from 0.29 to 0.37 mcm/day or 28%), respectively. Accordingly, the reforestation measure would result in better future flow regime by decreasing high flood flows and increasing low flows.

4.3.4 Results of Reforestation Sensitivity to Runoff

Figure 12 presents relationship between mean annual flows and various reforestation areas under forecasted future 78-years CC situation. Results indicated that in order to maintain the affected future mean annual flow due to CC to be equal to the latest 20-years mean annual flow, the past occupied forest area that changed into cropping approximately 1,200 km^2 (25% of the LDY catchment) should be replaced by reforestation

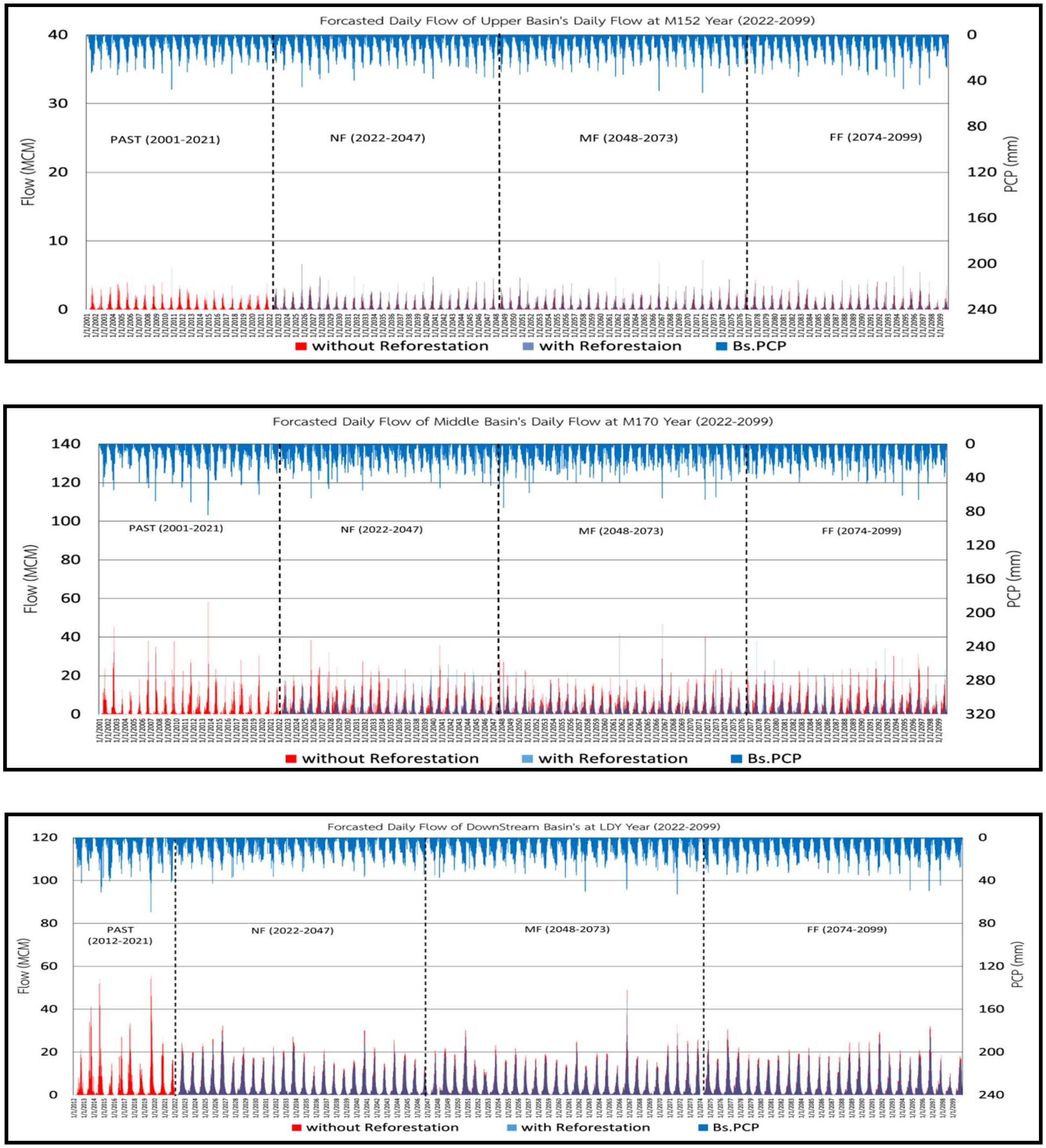

Figure 10 Forecasted future daily flow at M152, M170 , and LDY year (2022-2099) in case with and without reforestation.

Table 3 Summary of simulated future mean annual flows.

Stations	PAST (2001-2021)		NF (2022-2047)						MF (2048-2073)						FF (2074-2099)						Total (2022-2099)					
	Bs.PCP	$\bar{Q}$	Bs.PCP		$\bar{Q}$ (MCM)		$\bar{Q}$Diff (%)		Bs.PCP		$\bar{Q}$ (MCM)		$\bar{Q}$Diff (%)		Bs.PCP		$\bar{Q}$ (MCM)		$\bar{Q}$Diff (%)		Bs.PCP		$\bar{Q}$ (MCM)		$\bar{Q}$Diff (%)	
	mm/yr	MCM	mm/yr	Diif %	w/o	with	w/o	with	mm/yr	Diif %	w/o	with	w/o	with	mm/yr	Diif %	w/o	with	w/o	with	mm/yr	Diif %	w/o	with	w/o	with
M152 Upstream Reach	1151	98	1202	4.5%	100	99	2.1%	0.5%	1221	6.1%	108	102	10.3%	3.5%	1252	8.8%	115	111	16.9%	12.8%	1225	6.5%	108	104	9.8%	5.6%
M170 Midstream Reach	1368	944	1468	7.4%	1088	1062	15.3%	12.5%	1483	8.5%	1196	1098	26.7%	16.4%	1495	9.3%	1198	1161	26.9%	23%	1482	8.4%	1161	1107	23%	17.3%
Lamdomyai Downstream Reach	1309	1787	1368	4.5%	1818	1751	1.7%	2.1%	1415	8.1%	1879	1793	5.2%	0.3%	1427	9%	1928	1809	7.9%	1.2%	1403	7.2%	1875	1784	4.9%	0.2%

Table 4 Summary of mean monthly flows in cases of with and without reforestation.

Seasons	Month	Mean Monthly Flow, MCM														
		M152					M170					LDY				
		Past	Future (2022-2099)				Past	Future (2022-2099)				Past	Future (2022-2099)			
			w/o	Diff (%)	with	Diff (%)		w/o	Diff (%)	with	Diff (%)		w/o	Diff (%)	with	Diff (%)
Dry	Jan	1.2	1.3	6.2	1.4	9.6	6.9	23.8	71.3	18.8	63.5	21.3	21.6	1.5	24.4	12.5
	Feb	0.7	0.6	-17.8	0.6	-15.4	4.8	11.6	58.4	8.9	45.8	11.0	10.4	-5.2	11.7	6.5
	Mar	0.6	0.6	-8.1	0.6	-6.6	4.4	10.9	59.3	6.6	32.4	9.2	9.5	2.9	10.4	11.5
	Apr	0.7	1.4	50.2	1.4	50.5	5.8	20.2	71.4	10.8	46.4	9.9	9.4	-4.6	10.3	4.8
Wet	May	2.8	2.9	3.0	2.9	3.3	15.9	19.2	17.0	27.9	42.9	24.8	30.0	17.1	29.3	15.3
	Jun	4.2	4.5	5.8	3.5	-20.5	29.1	32.4	10.1	33.9	14.4	81.5	49.9	-63.3	43.9	-85.6
	Jul	12.6	12.5	-0.2	11.6	-8.0	89.2	103.9	14.2	67.4	-32.3	237.0	238.6	0.6	226.7	-4.6
	Aug	19.6	19.4	-1.3	18.5	-6.1	171.6	185.7	7.6	179.7	4.5	298.7	315.5	5.3	290.5	-2.8
	Sep	24.7	25.4	2.7	24.6	-0.7	259.9	284.8	8.8	275.4	5.6	438.3	453.2	3.3	415.1	-5.6
	Oct	22.6	27.1	16.7	25.5	11.4	221.4	294.3	24.8	289.7	23.6	430.7	456.0	5.6	431.1	0.1
Dry	Nov	5.7	8.7	33.7	10.1	43.0	121.1	130.5	7.2	132.2	8.4	161.6	164.8	2.0	169.6	4.7
	Dec	2.7	3.4	21.0	3.6	24.5	13.7	43.3	68.4	55.5	75.4	63.4	116.5	45.6	120.5	47.4
Wet		86.5	91.8	5.8	86.5	0.1	787.1	920.2	14.5	874.1	9.9	1511.0	1543.1	2.1	1436.6	-5.2
Dry		11.7	16.0	26.8	17.7	33.6	156.7	240.3	34.8	232.7	32.7	276.3	332.3	16.8	346.9	20.3
Annuual		98.2	107.8	8.9	104.2	5.7	943.8	1160.5	18.7	1106.8	14.7	1787.3	1875.4	4.7	1783.5	-0.2

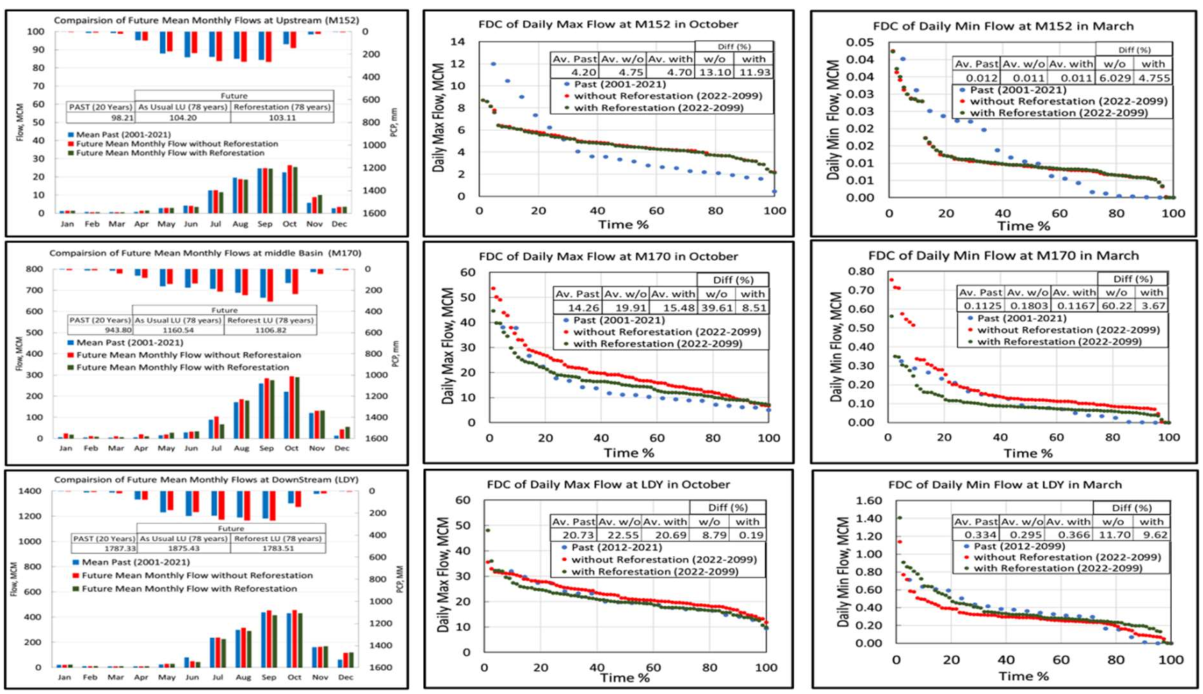

Figure 11 Future mean monthly flows, FDC of daily maximum flows in October, FDC of daily minimum flows in March in cases of with and without reforestation.

Conclusions and Recommendations

5. Conclusions

The developed SWAT model showed good correlation between computed flows and the observed flows in daily, monthly and annual basis. The results indicated that calibrated parameters gave good correlation between computed flows and the observed data.

The future mean annual flows of the basin over 78 years would be increasing trend for upstream, middle, and downstream reaches, respectively. Mean monthly flow volumes and extreme floods would be mostly increasing in wet season whereas volumes decreasing in some dry months in dry season. Consequently, future deforestation at as usual rate would result more serious problems to flow regime.

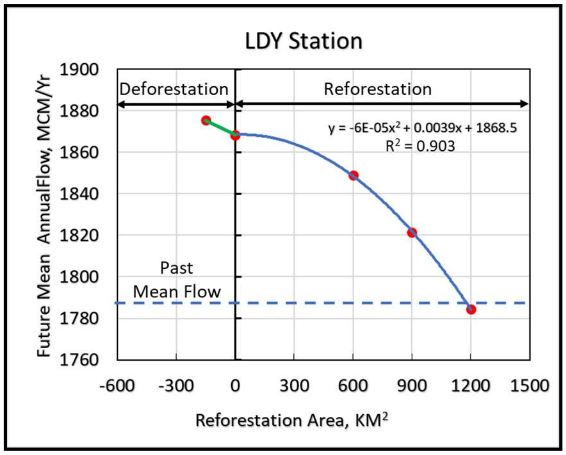

Figure 12 Relationship between reforestation areas and mean annual flows at LDY station.

With the reforestation measure the results concluded that the river runoff volumes and extreme flows that affected by the CC could be partially recovered into better flows conditions by decreasing CC high flood volumes and flood peak discharges, and increasing dry season flow volumes. The relationship between forest areas and mean annual flows in corporated with forecasted land use maps and the LDY SWAT model could be applied to prepare reforestation implementation plans in order to cope with the CC effects on LDY river runoff. However, even the study revealed that reforestation measure could alleviate the CC effects on flow regime, but only some portion of the CC effects, therefore to recover the whole CC effects on flows, large area of reforestation be required. Consequently the effective measure to minimize the CC effects is reduction of the GHG from global rapid expansion of human activities.

6. Recommendations

1. The study was not taken into account irrigation water usage along the river and tributaries. The existing irrigation area of 30,000 rai utilized water from the river approximately average flow volume of 40-50 mcm per year. Consequently, the simulated flows especially in dry reason were calculated more volume than observed flows. Further studies on irrigation water demand would result in better model performance.

2. Since the past overbank flood flows could not actually be measured, instead, responsible agencies applied rating curve extrapolation technique of which results might be deviated from the actual flows. A further study of hydrodynamic model calibrated with measured floodplain flow velocity should be additionally developed in parallel to rectify overbank flows and improving parameters of LDY's SWAT model.

3. Monitoring and review of model's parameters of LDY should be manipulated in the future to improve parameters, additionally, other adjacent river basin models are suggested to be developed. Sufficient results of model parameters could be analyzed and summarized as regional basin parameters that could be applied for modeling other ungauged river basins.

4. Further future researches on quantitative effects of LUC on the river flow regime comparable to effects of climate change and feasible application of land use management measure, of other river basins should be carried out and compared.

5. The developed LDY model could be applied as an essential tool to forecast future hydrologic situation under CC and applied in further studies to prepare CC adaptive measures i.e. other alternatives of land use management, redesign or enhance capacities of existing and future hydraulic structures, review of water management operating rule curves of present and future water resources, and study effects of potential reservoir development projects on hydrologic response and appropriate mitigation plans.

6. Continuously recording of rainfall and discharge data that corresponding to reforestation area should be monitored and model's basin parameters should also be updated.

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