Assessment on Hydrologic Response by Climate Change in the Chao Phraya River basin, Thailand

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Outline

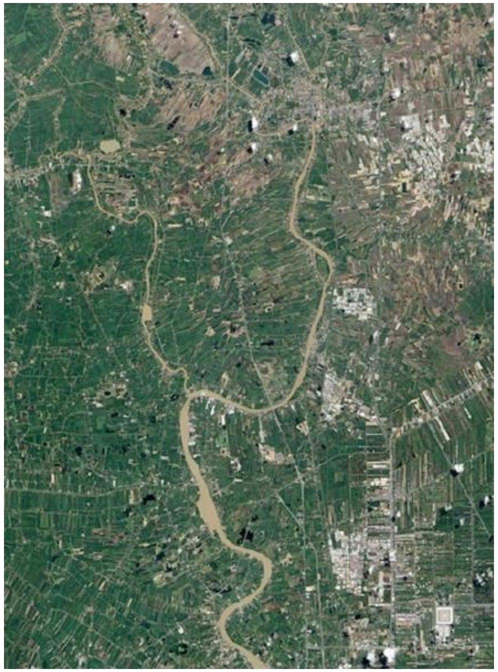
I. Introduction
II. Methodology
III. Results and Discussion
IV. Conclusions

Introduction

Introduction

❖ Chao Phraya River basin in July and October in 2011

Exhibit 43: Chao Phraya River in Ayutthaya Province
July 11, 2011



Before flood

Source : NASA

Exhibit 44: Chao Phraya River in Ayutthaya Province
October 23, 2011

After flood

Breakdown of Economic Losses

Sector	Economic Losses, $ (Billions THB)	Comments
Manufacturing	32.19 (1,007)	Most losses sustained at industrial factories
Tourism	3.04 (95)	Loss of tourism revenues over a 6-month span
Households /Personal Property	2.96 (84)	Includes structural and indoor content Losses
Agriculture	1.28 (40)	Loss of agricultural production

Introduction

Land resources and use

1. Agriculture

Source : Thani PBS

2. Urban

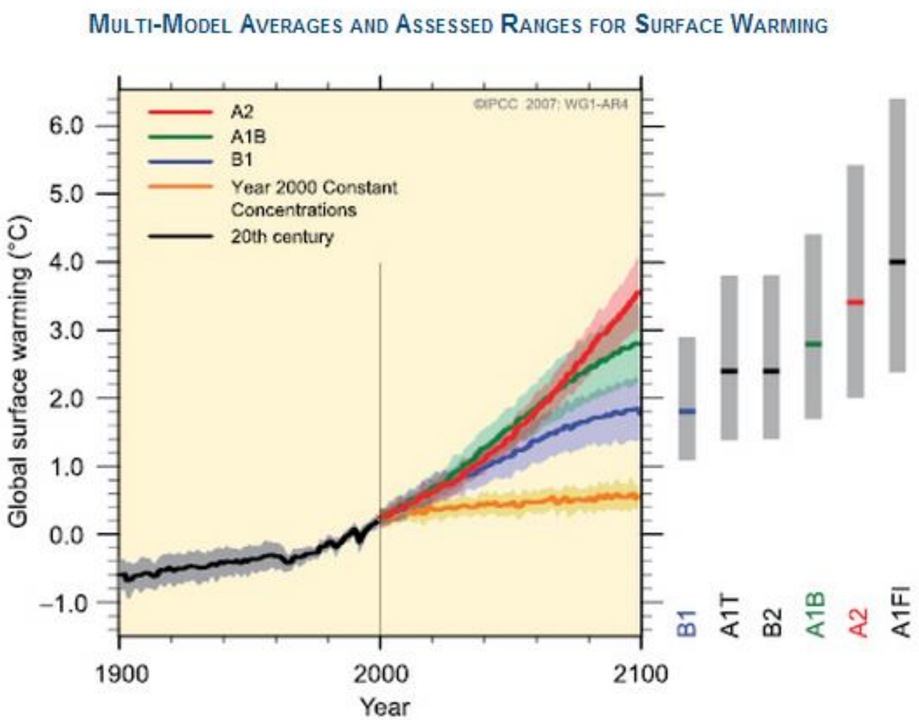
Water resources

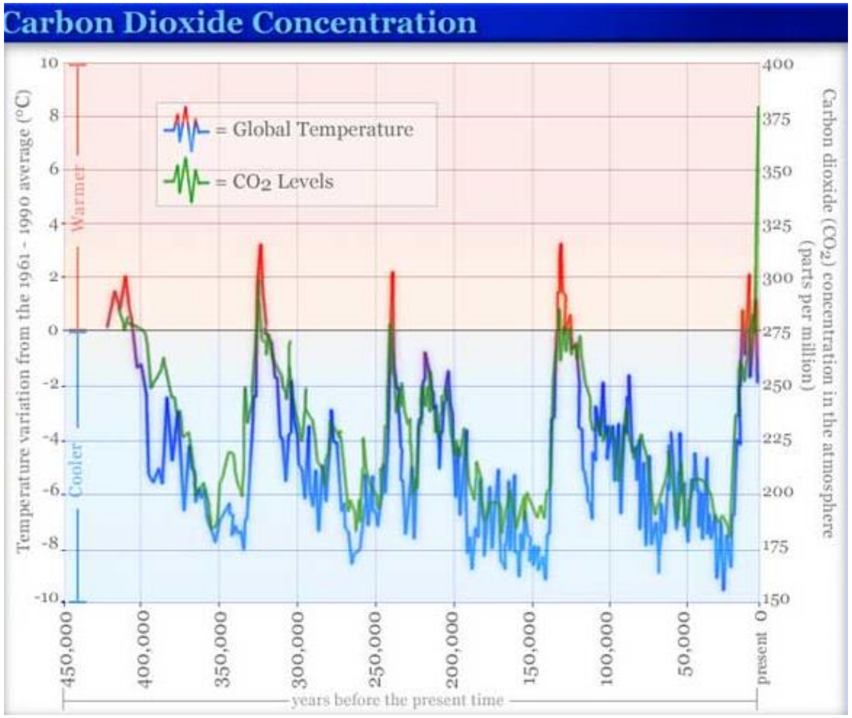
1. Surface water
   a) Riverine resources
   b) Runoff
      Total Volume: 37,120 m^3
   c) Dams
   d) Barrages

2. Groundwater

Groundwater Basin	Groundwater Storage (million m^3)	Safe Yield per year (million m^3)	Safe Yield per day (m^3)
Chiangmai-Lampoon	485	97	265,000
Lampang	295	59	161,000
Chiangrai-Payao	212	42	115,000
Prae	160	32	87,000
Nan	200	40	110,000
Upper Chao Phraya	6,400	1,280	3,500,000
Lower Chao Phraya	6,470	1,294	3,500,000
Total	14,222	2,844	7,738,000

Introduction





- ❖ Future temperatures are expected to increase gradually.
- ❖ The increased amounts of carbon dioxide (CO_2) and the other greenhouse gases from industrial and daily activities are seen as the reason for the global warming.

Reference : https://www.ipcc.ch/, Temp. Changes caused by global Warming & CO2, Eric Turner

Introduction

- Objective
  1. Calibrate and validate the water quantity in the Chao Phraya River basin using the SWAT model.

  2. Assess hydrological responses under hypothetical climate sensitivity scenarios and greenhouse gas emission scenarios.

Methodology

Study Area: Chao Phraya River Basin

Area

- 119,663 km^2

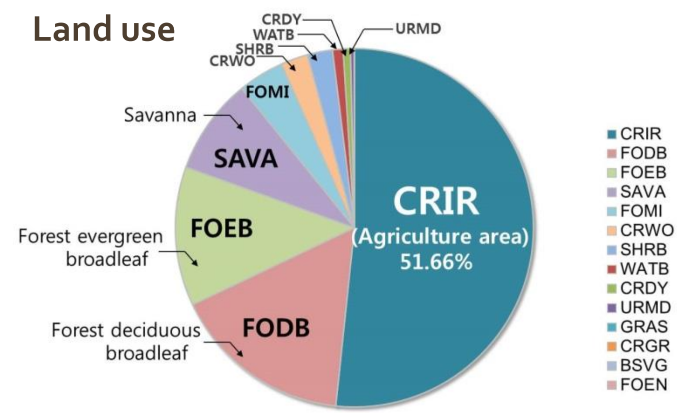
Hydrological characteristics

- Annual precipitation : 1,179 mm/year
- Annual discharge : 196 m^3/s

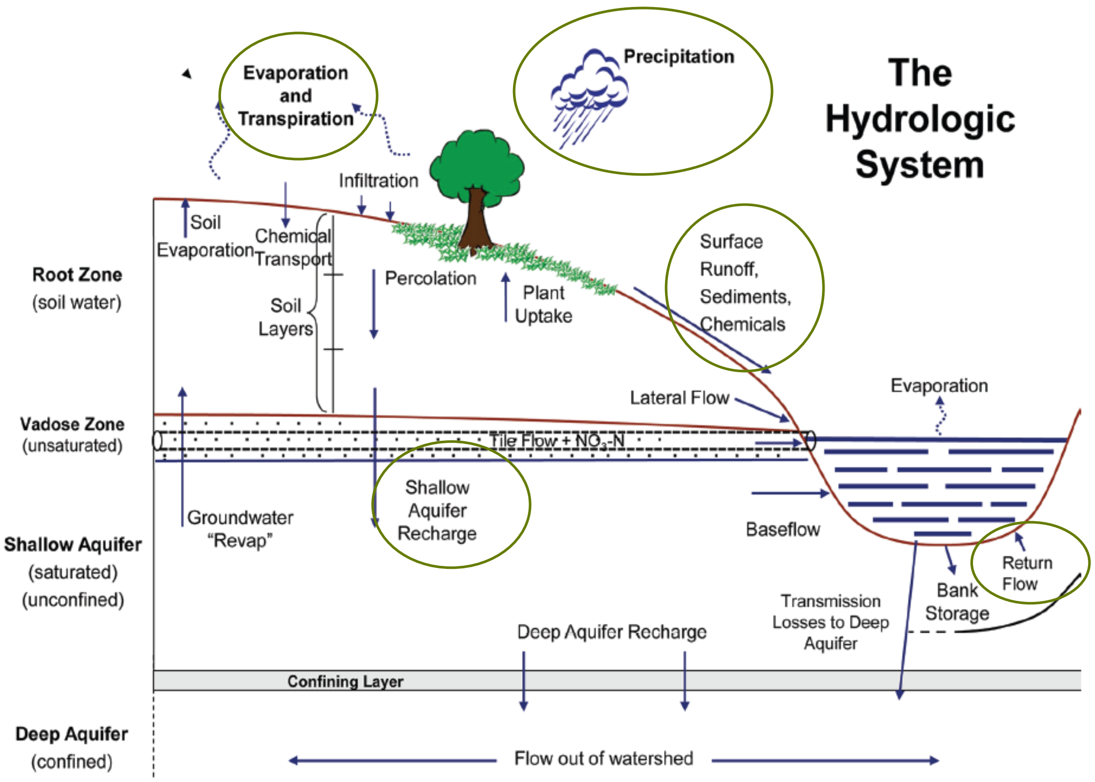
Legend

- Weather station (12sta.)
- Outlets station
- Watershed
- Subbasin (132sub)
- Streamline

Land use



SWAT Model



$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

SW_t = Final soil water content (mmH_2O)
SW_0 = Initial soil water content on day
R_{day} = Amount of precipitation on day

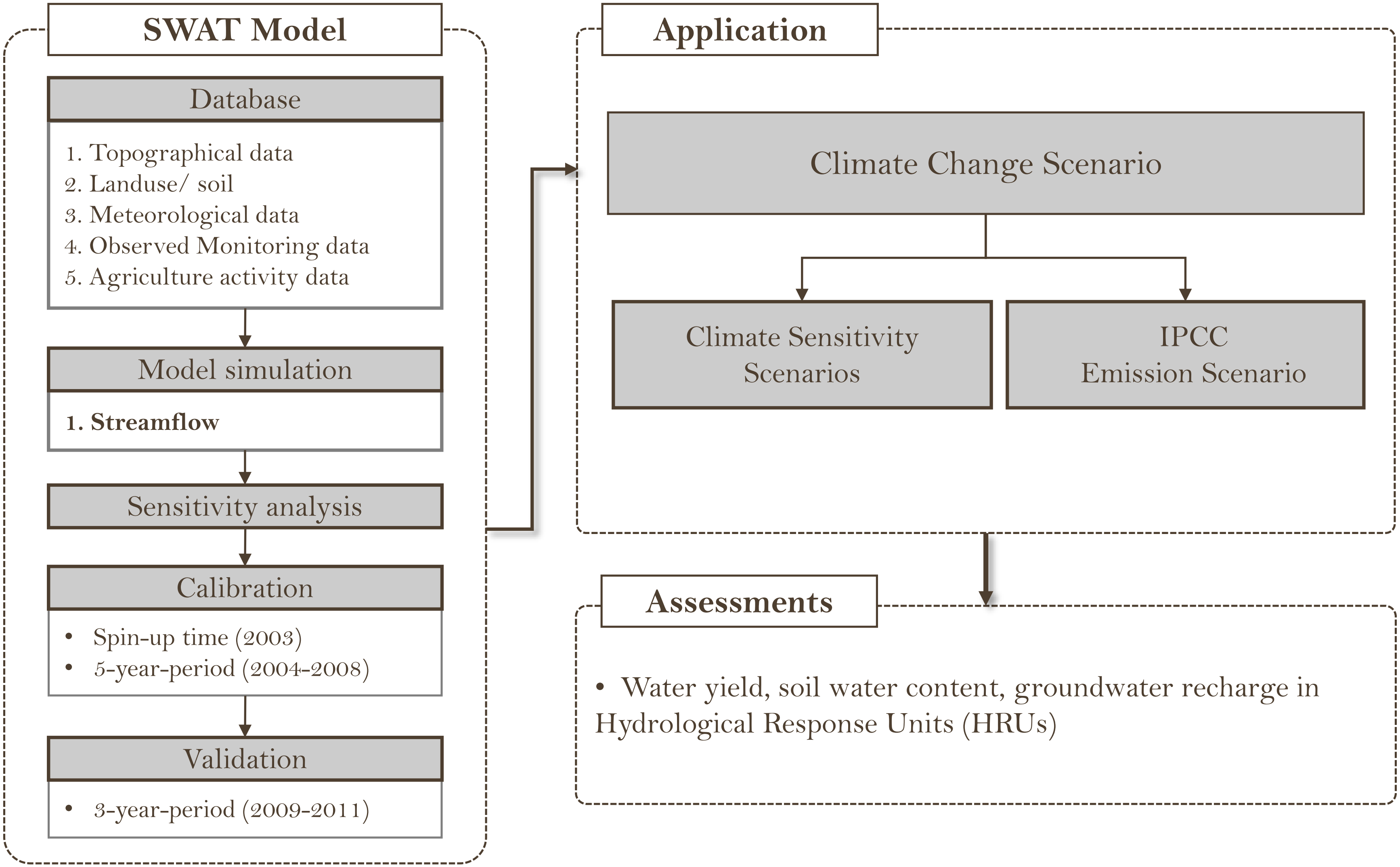
Q_{surf} = Amount of surface runoff on day
E_a = Amount of evapotranspiration on day
W_{seep} = Amount of water entering the vadose zone from the soil profile on day
Q_{gw} = the amount of return flow on day

MWSWAT

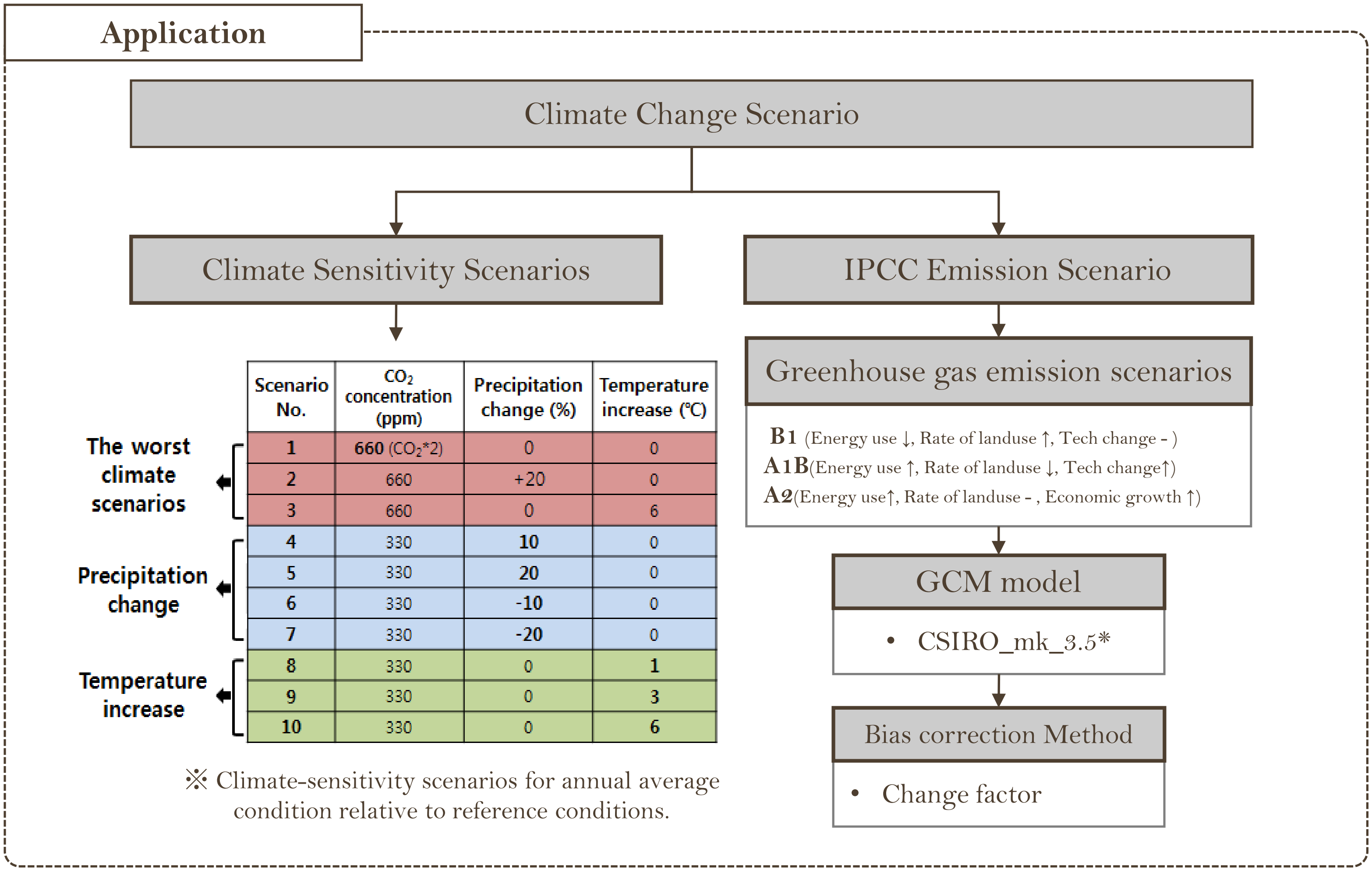
- MWSWAT (version 4.8.6)
- MapWindowGIS system
- WaterBase website
  - global data for model

Reference : Evaluation of the Hooghoudt and Kirkham Tile Drain Equations in the Soil and Water Assessment Tool to simulate Tile Flow and Nitrate-Nitrogen, Journal of Environmental Quality (2013)

Flow of the Methods



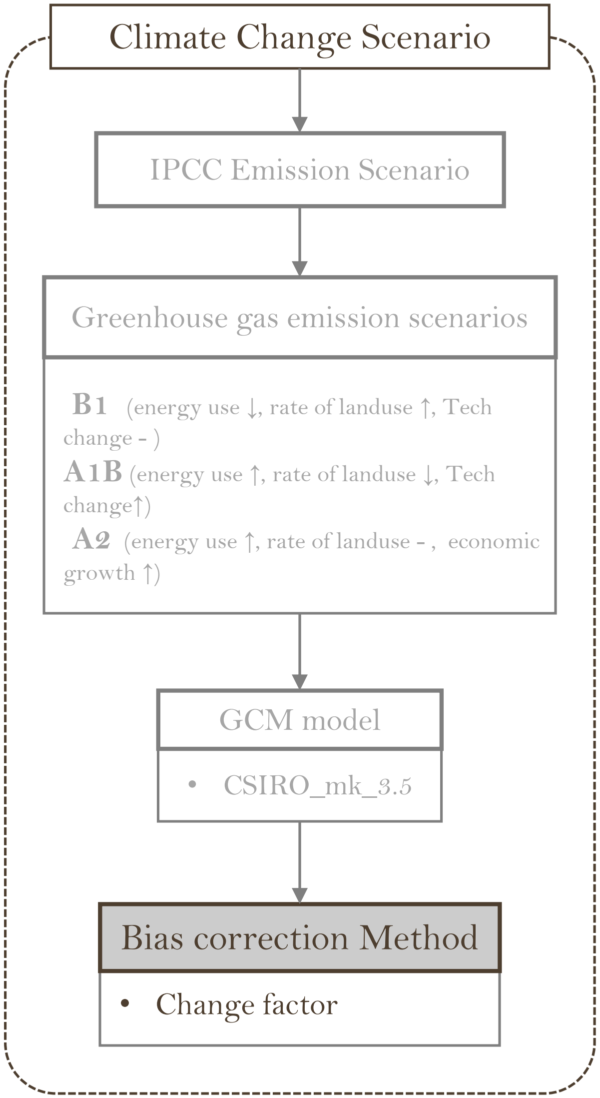
Flow of the Methods



Scenario No.	CO_2 concentration (ppm)	Precipitation change (%)	Temperature increase (℃)
1	660 (CO_2*2)	0	0
2	660	+20	0
3	660	0	6
4	330	10	0
5	330	20	0
6	330	-10	0
7	330	-20	0
8	330	0	1
9	330	0	3
10	330	0	6

※ Climate-sensitivity scenarios for annual average condition relative to reference conditions.

Change factor



- The advantage of the Change Factor method is simple and it makes changing boundary to be similar both general circulation model (GCM) or the regional climate model (RCM).
- The limitation of CF method is that it assumes sometimes rainfall events and droughts as long period or extremely little rainfall during summer and fall seasons.

$$T_{adj,2059,d} = T_{obs,d} + (\overline{T}_{GCM,2059,m} - \overline{T}_{GCM,ref,m})$$

$$P_{adj,2059,d} = P_{obs,d} \times (\overline{P}_{GCM,2059,m} / \overline{P}_{GCM,ref,m})$$

$T_{adj,2059,d}$: Future 2059 daily temperature
$T_{obs,d}$: Observed temperature
$\overline{T}_{GCM,2059,m}$: Mean of future daily temperature (2051 -2059)
$\overline{T}_{GCM,ref,m}$: Mean of reference daily temperature (2003-2011)

$P_{adj,2059,d}$: Future 2059 daily precipitation
$P_{obs,d}$: Observed precipitation (2003-2011)
$\overline{P}_{GCM,2059,m}$: Mean of future daily precipitation (2051-2059)
$\overline{P}_{GCM,ref,m}$: Mean of reference daily precipitation (2003 -2011)

Change factor		B1	A1B	A2
Precipitation		1.0054	1.0644	1.0338
Temp	Max	0.7926	2.0621	1.8729
	Min	0.6106	2.4954	2.2905

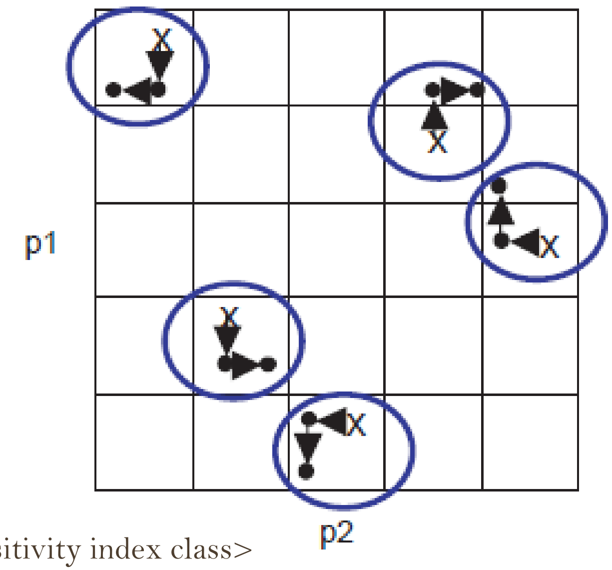
Reference : Chen, Jie, Brissette, François P., & Leconte, Robert. (2011). Uncertainty of downscaling method in quantifying the impact of climate change on hydrology. Journal of Hydrology, 401(3–4), 190-202

Data Sources of Model Inputs

Data	Scale, type	Source	Data description
Topography (DEM)	90m Digital Elevation Data	USGS (strm.csi.cgiar.org)	Shuttle Radar Topographic Mission
Landuse map	Satellite raster (1km resolution)	Global Land Cover Classification (glcf.umiacs.umd.edu)	24 classifications of landuse
Soil map	1:5,000,000 (raster 5×5 arc-minute, spatial resolution of 10 kilometers)	Digital Soil Map of the World (www.fao.org)	Almost 5000 soil types
Weather	12 stations	Thailand weather	Daily precipitation, maximum/minimum temperature
Flow Discharge	2 stations (Cubic Meter per Second)	Royal Irrigation Department computer center	Daily discharge
Water quality	Monthly monitoring data	Pollution Control Dept. & Irrigation Dept.	Monthly water quality monitoring data
Agriculture activity	Scheduled Management operation	Reference	Rice, corn, sugarcane

Sensitivity Analysis and Evaluation Criteria

- ❖ Sensitivity Analysis: LH-OAT
  - ➢ Latin-Hypercube (LH) sampling
  - ➢ One-factor At a Time (OAT)



< Sensitivity index class>

Class	Index	Sensitivity
I	$0.00 \le \mid I \mid < 0.05$	Small to negligible
II	$0.05 \le \mid I \mid < 0.20$	Medium
III	$0.20 \le \mid I \mid < 1.00$	High
IV	$\mid I \mid \ge 1.00$	Very high

(T.Lenhart et al., 2002)

- ❖ Evaluation Criteria
  - ➢ Coefficient of determination (R^2)

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (O_i - O_{avg}) \times (P_i - P_{avg})}{\left[\sum_{i=1}^{n} (O_i - O_{avg})^2\right]^{0.5} \times \left[\sum_{i=1}^{n} (P_i - P_{avg})^2\right]^{0.5}} \right\}^2$$

  - ➢ Nash-Sutcliffe Efficiency (NSE)

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O_{avg})^2}$$

< NSE Evaluation Index>

Performance rating	NSE
Very good	$0.75 < \text{NSE} \le 1.00$
Good	$0.65 < \text{NSE} \le 0.75$
Satisfactory	$0.50 < \text{NSE} \le 0.65$
Unsatisfactory	$\text{NSE} \le 0.50$

(Moriasi et al., 2007)

Results and Discussion

- Results (1) Streamflow

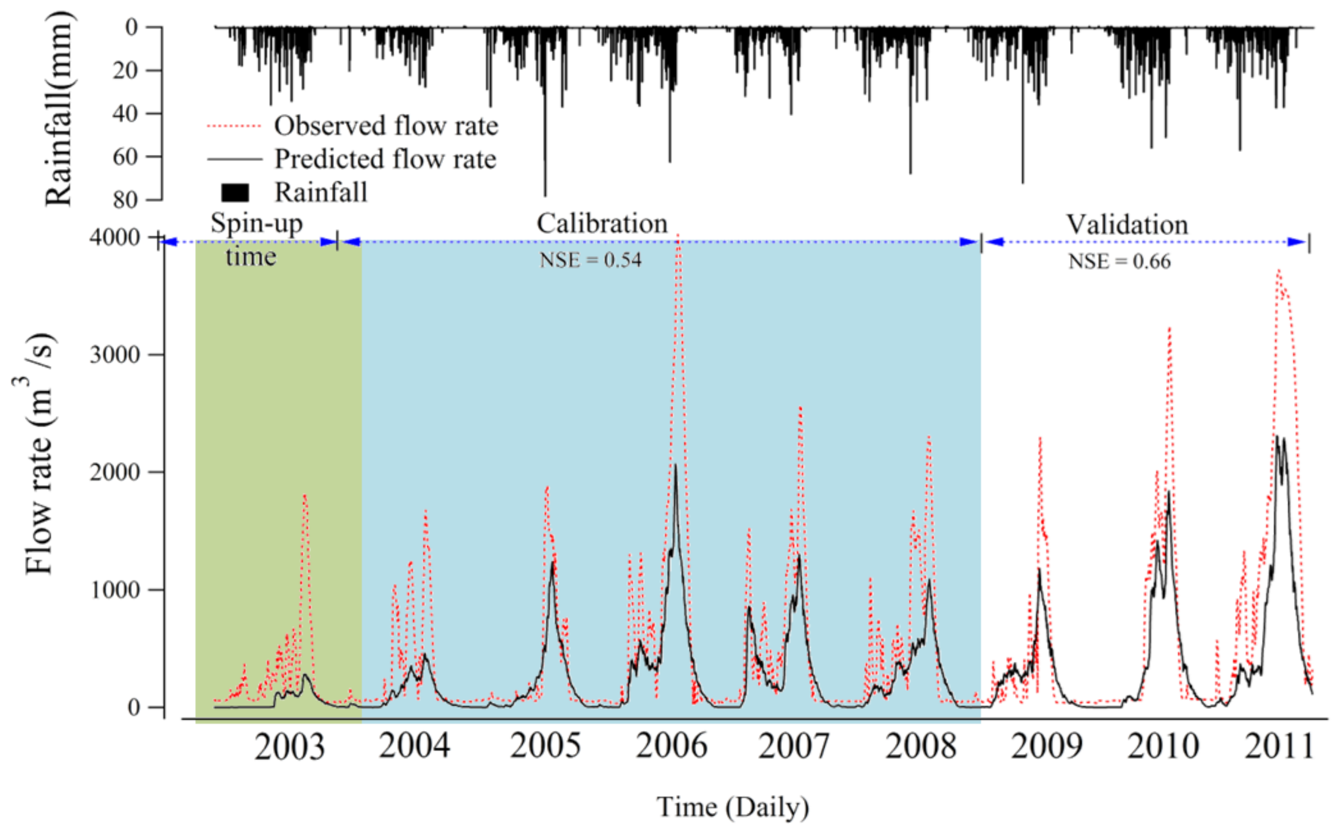
- Stream flow Sensitivity analysis result with definition, bound, and sensitivity rank

RANK	NAME	DEFINITION	BOUNDS Min-Max	Process	Sensitivity
1	Cn2	SCS runoff curve number for moisture condition 2	35-98	Runoff	1.49
2	Alpha_Bf	Baseflow alpha factor (days)	0.00-1.00	Groundwater	1.42
3	Rchrg_Dp	Deep aquifer percolation fraction	0.00-1.00	Groundwater	0.66
4	Esco	Soil evaporation compensation factor	0.00-1.00	Evaporation	0.48
5	Revapmn	Threshold depth of water in the shallow aquifer for percolation to the deep aquifer (mmH_2O)	0-500	Groundwater	0.22
6	Ch_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	-0.01-150	Channel	0.20
7	Gwqmn	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0-5000	Soil	0.18
8	Sol_Awc	Available water capacity of the soil layer (mm/mm soil)	0-100	Soil	0.14
9	Sol_Z	Maximum canopy index Soil depth	0-3000	Soil	0.07
10	Gw_Revap	Groundwater "revap" coefficient	0.02-0.2	Groundwater	0.06
11	Surlag	Surface runoff lag coefficient	0.00-10.00	Runoff	0.05
12	Blai	Leaf area index for crop	0.00-1.00	Crop	0.02
13	Slope	Average slope steepness (m/m)	0.0001-0.6	Geomorphology	0.02
14	Canmx	Maximum canopy index	0.00-10.00	Runoff	0.01
15	Epco	Threshold depth of water in the shallow aquifer to percolation to the deep aquifer (mmH_2O)	0.00-1.00	Evaporation	0.01

• Results (1) Streamflow

- Observed and simulated daily flow rate for model

(calibration : 2004-2008, validation : 2009-2011)



Performance rating	NSE
Very good	0.75 < NSE ≤1.00
Good	0.65 < NSE ≤ 0.75
Satisfactory	0.50 < NSE ≤ 0.65
Unsatisfactory	NSE ≤ 0.50

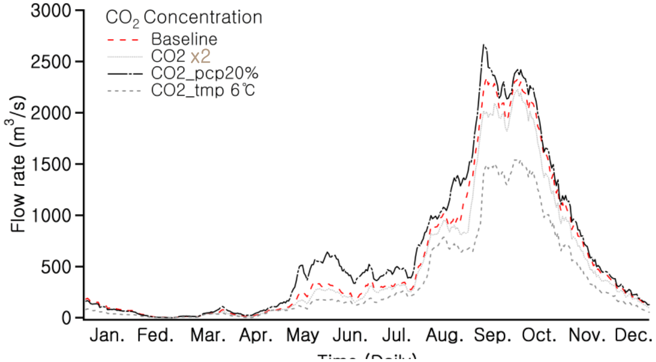
(Moriasi et al., 2007)

- Calibration:
  - NSE: 0.54; R^2: 0.81
- Validation:
  - NSE: 0.66; R^2: 0.89

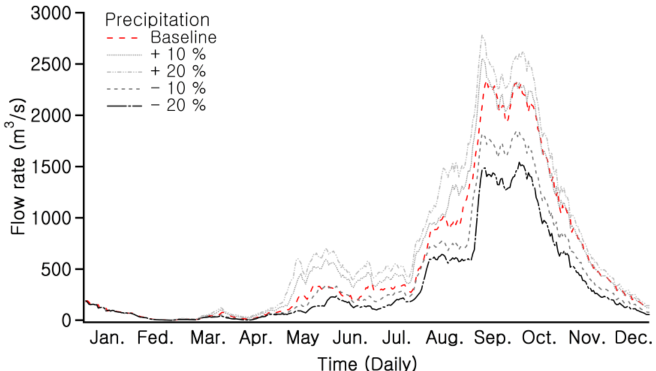
• Results (2) Streamflow under climate change scenarios

Climate Sensitivity Scenarios

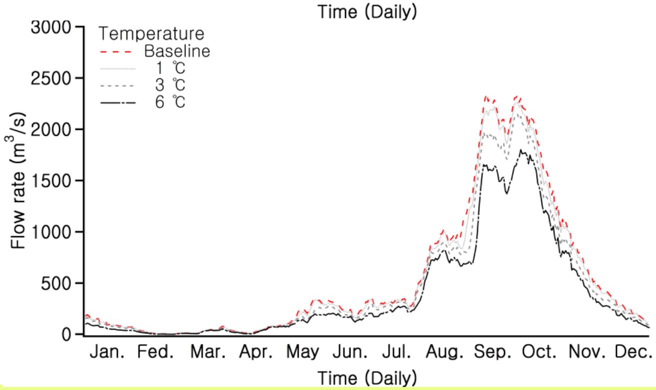
The worst condition
(S1 – S3)
(based on $CO_2 \times 2$)



Precipitation change
(S4 - S7)
(±10, ±20)

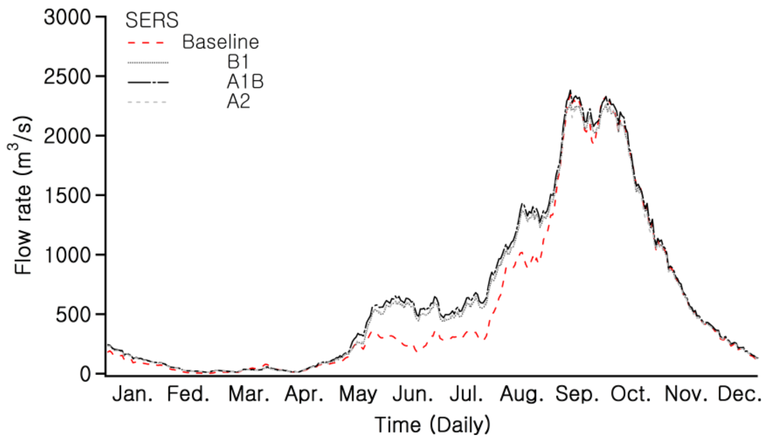


Temperature Increase
(S8 - S10)
(+1,3,6℃)



IPCC Emission Scenario

B1 (Energy use ↓, Rate of landuse ↑, Tech change -)
A1B (Energy use ↑, Rate of landuse ↓, Tech change↑)
A2 (Energy use↑, Rate of landuse - , Economic growth ↑)



p-value							
S1	0.142	S4	0.42	S8	0.47	B1	0.041
S2	0.022	S5	0.001	S9	0.053	A1B	0.011
S3	0.00	S6	0.027	S10	0.00	A2	0.037
		S7	0.00				

- The climate change scenarios for streamflow were significantly different baseline under emission scenario.

- Results (2) Climate change scenario

HRU 128
CORN

Climate Sensitivity Scenarios

IPCC Emission Scenario

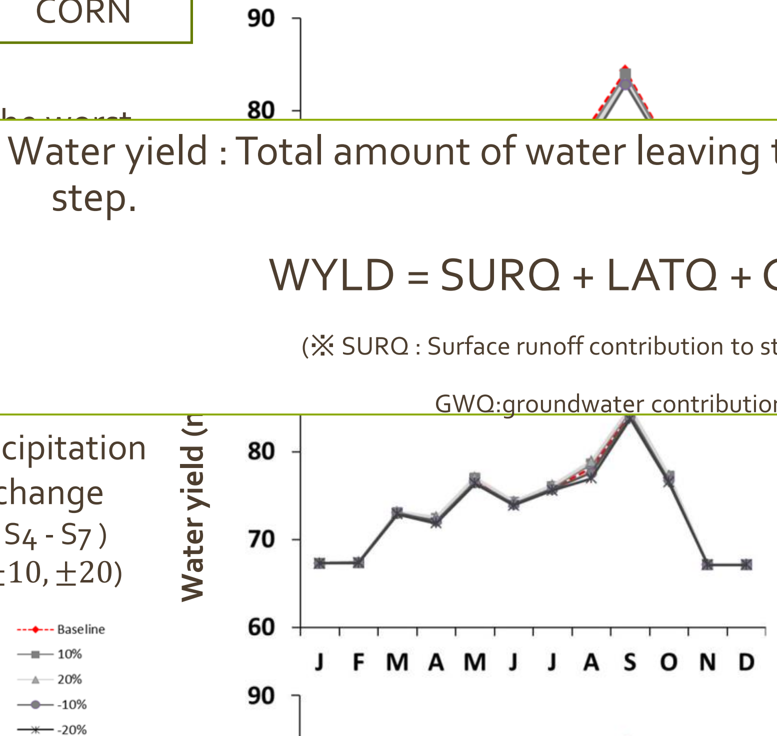
B1 (Energy use ↓, Rate of landuse ↑, Tech change -)
A1B (Energy use ↑, Rate of landuse ↓, Tech change↑)

Water yield : Total amount of water leaving the HRU and entering main channel during the time step.

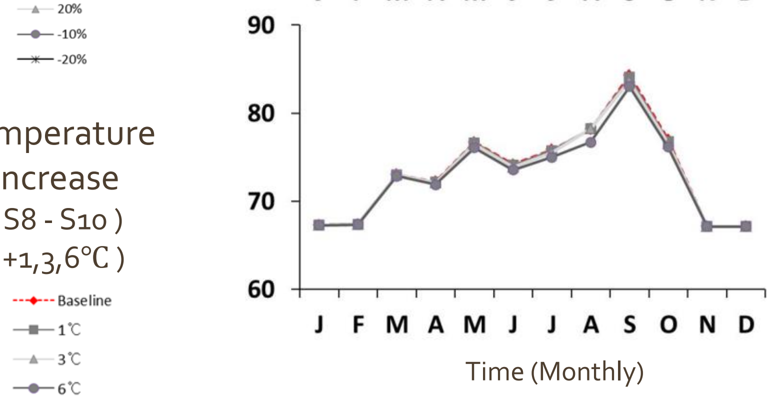
$$WYLD = SURQ + LATQ + GWQ - TLOSS - \text{pond abstractions}$$

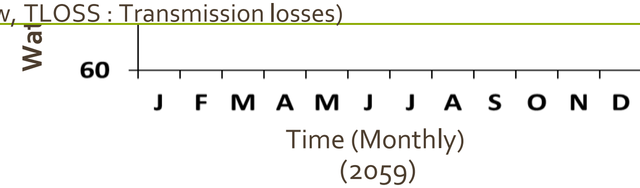
(※ SURQ : Surface runoff contribution to streamflow, LATQ : lateral flow contribution to streamflow, GWQ:groundwater contribution to streamflow, TLOSS : Transmission losses)

Precipitation change
(S4 - S7)
(±10, ±20)



Temperature Increase
(S8 - S10)
(+1,3,6℃)





p-value ($p < 0.05$)							
S1	0.72	S4	0.81	S8	0.81	B1	0.86
S2	0.68	S5	0.75	S9	0.77	A1B	0.95
S3	0.64	S6	0.81	S10	0.64	A2	0.95
		S7	0.70				

- The climate change scenarios for water yield were not significantly different baseline.

• Results (2) Climate change scenario

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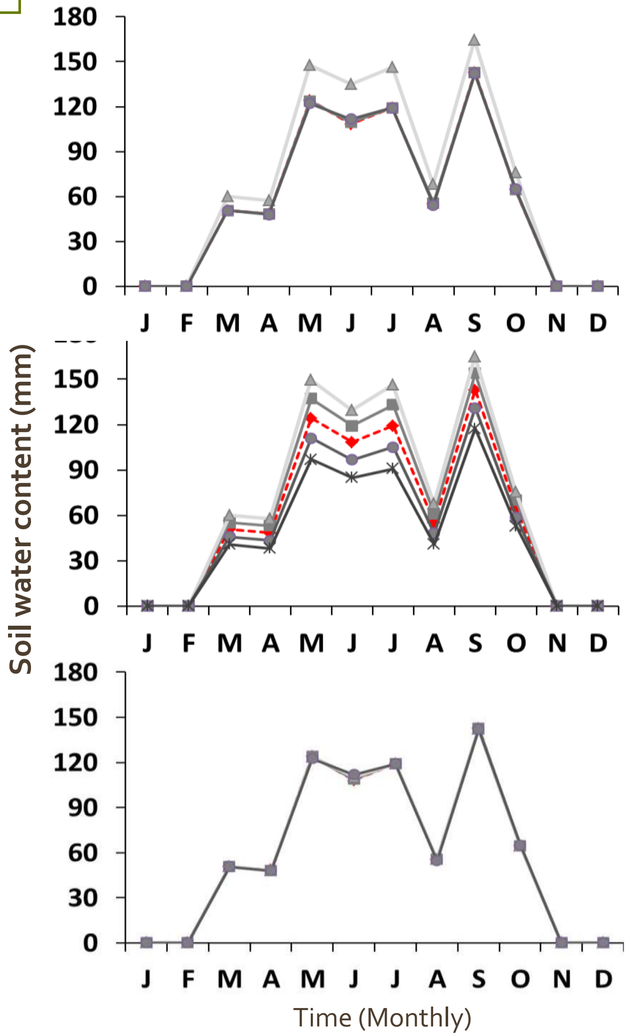
Climate Sensitivity Scenarios

The worst condition
(S1 – S3)
(based on $CO_2 \times 2$)

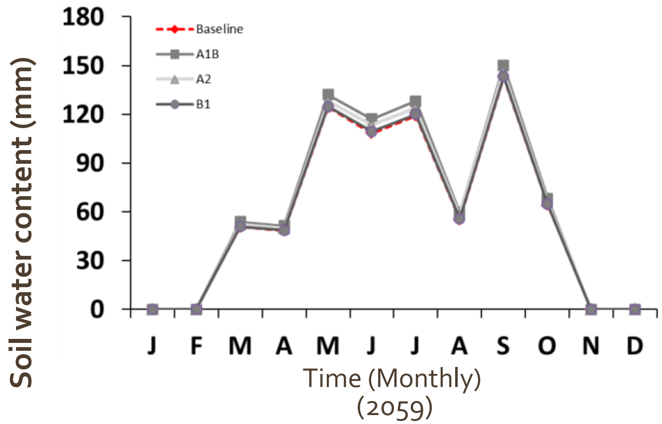
Precipitation change
(S4 - S7)
(±10, ±20)

Temperature Increase
(S8 - S10)
(+1,3,6℃)



IPCC Emission Scenario

B1 (Energy use ↓, Rate of landuse ↑, Tech change -)
A1B (Energy use ↑, Rate of landuse ↓, Tech change↑)
A2 (Energy use↑, Rate of landuse - , Economic growth ↑)



Soil water content				*p*-value ($p < 0.05$)			
S1	0.95	S4	0.63	S8	0.95	B1	0.57
S2	0.44	S5	0.44	S9	0.95	A1B	0.48
S3	0.90	S6	0.59	S10	0.90	A2	0.55
		S7	0.44				

- The climate change scenarios for soil water content were not significantly different baseline.

• Results (2) Climate change scenario

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Climate Sensitivity Scenarios

The worst condition
(S1 – S3)
(based on $CO_2 \times 2$)

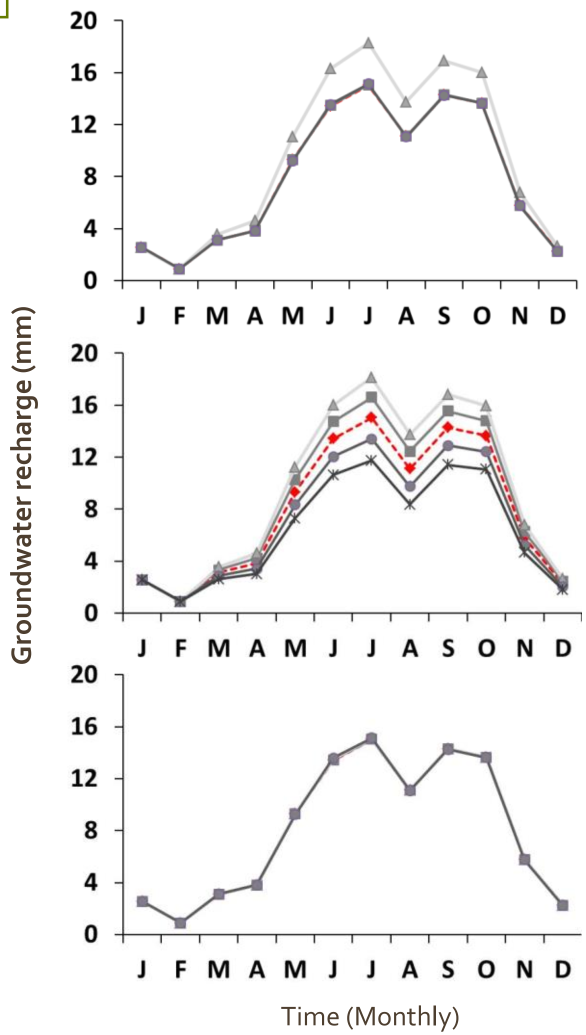
Baseline
CO2*2
CO2*2+pcp20%
CO2*2+tmp6℃

Precipitation change
(S4 - S7)
(±10, ±20)

Baseline
10%
20%
-10%
-20%

Temperature Increase
(S8 - S10)
(+1,3,6℃)

Baseline
1℃
3℃
6℃



IPCC Emission Scenario

B1 (Energy use ↓, Rate of landuse ↑, Tech change -)
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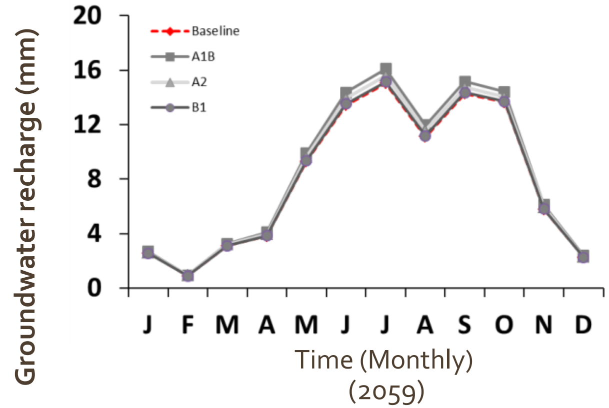
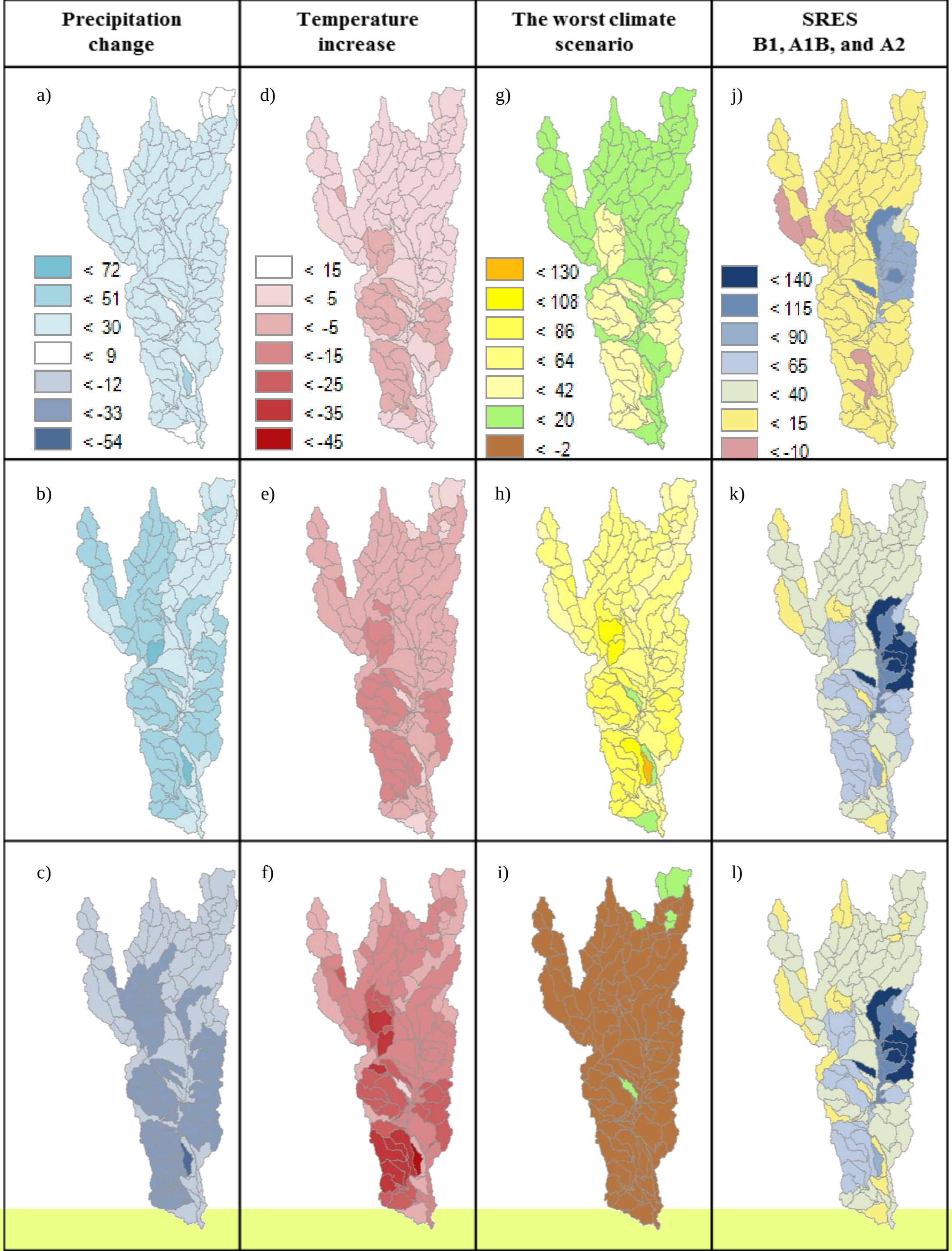


p-value ($p < 0.05$)							
S1	0.95	S4	0.60	S8	0.93	B1	0.52
S2	0.43	S5	0.38	S9	0.97	A1B	0.45
S3	0.90	S6	0.52	S10	0.90	A2	0.48
		S7	0.38				

- The climate change scenarios for groundwater recharge were not significantly different baseline.



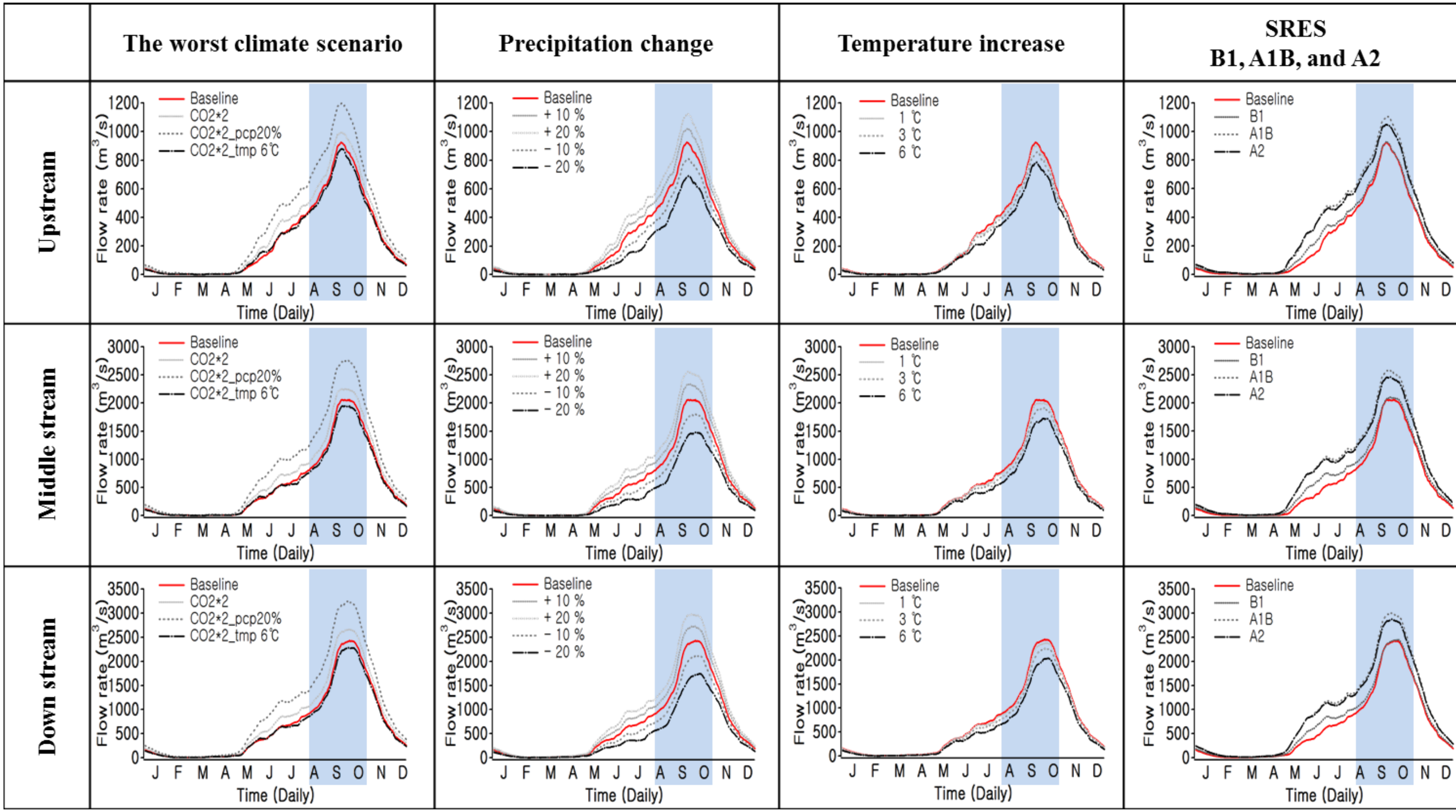
Spatial distributions of flow rate ratio

(a–c) precipitation change scenarios

(d–f) temperature increase scenarios

(g–i) worst climate scenarios

(j-l) SRES.



Seasonal variations of stream flow under different climate scenarios.

Conclusion

Conclusion

- ❖ **Precipitation scenarios:** streamflow variations corresponded to the change of rainfall intensity and amount of rainfall.
- ❖ **Air temperature scenarios:** decrease in water level leading to a water shortage.
- ❖ **IPCC gas emission scenarios:** streamflow variations increased from the baseline (2003–2011).
- ❖ **Worst climate scenarios:** increase in streamflow levels; negative change in streamflow when the air temperature was increased.
- ❖ **Spatial and seasonal variations:** Variations under three SRES in northern Chao Phraya Watershed indicate low streamflow values compared to those of the southern part. Hence, flood measures should be performed in the main streamline of Chao Phraya River and the southern area of the basin. As such, further water resource management will be needed in the northeastern area of the Chao Phraya river basin in the future.

WRQM

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Thank you for listening.