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

Mayzonee Ligaray\textsuperscript{1†}, Hanna Kim\textsuperscript{2†}, Suthipong Sthiannopkao\textsuperscript{3}, Kyung Hwa Cho\textsuperscript{1}, Joon Ha Kim\textsuperscript{4*}

\textsuperscript{1} School of Urban and Environmental Engineering, Ulsan National Institute of Science and Technology, Ulsan, 689-798, Republic of Korea
\textsuperscript{2} K-water Institute, 1689beon-gil 125, Yuseong-daero, Yuseong-gu, Daejeon, 305-730, Republic of Korea
\textsuperscript{3} Department of Environmental Engineering, Dong-A University, Busan, 604-714, Republic of Korea
\textsuperscript{4} Department of Environmental Science and Engineering, Gwangju Institute of Science and Technology, Gwangju, 500-712, Republic of Korea
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

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

Breakdown of Economic Losses

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

Source: NASA

Introduction

Land resources and use

1. Agriculture

2. Urban

Water resources

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

2. Groundwater

<table>
<thead>
<tr>
<th>Groundwater Basin</th>
<th>Groundwater Storage (million m$^3$)</th>
<th>Safe Yield per year (million m$^3$)</th>
<th>Safe Yield per day (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiangmai-Lamphun</td>
<td>485</td>
<td>97</td>
<td>265,000</td>
</tr>
<tr>
<td>Lampang</td>
<td>295</td>
<td>59</td>
<td>161,000</td>
</tr>
<tr>
<td>Chiangrai-Payao</td>
<td>212</td>
<td>42</td>
<td>115,000</td>
</tr>
<tr>
<td>Prak</td>
<td>160</td>
<td>32</td>
<td>87,000</td>
</tr>
<tr>
<td>Non</td>
<td>200</td>
<td>40</td>
<td>110,000</td>
</tr>
<tr>
<td>Upper Chao Phraya</td>
<td>6,400</td>
<td>1,280</td>
<td>3,500,000</td>
</tr>
<tr>
<td>Lower Chao Phraya</td>
<td>6,470</td>
<td>1,294</td>
<td>3,500,000</td>
</tr>
<tr>
<td>Total</td>
<td>14,222</td>
<td>2,844</td>
<td>7,738,000</td>
</tr>
</tbody>
</table>
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.

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 km²

Hydrological characteristics

- Annual precipitation: 1,179 mm/year
- Annual discharge: 196 m³/s

Legend

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

Land use

- CRIR (Agriculture area) 51.66%
- SAVA
- FOEB
- FODB
- Savanna
- Forest evergreen broadleaf
- Forest deciduous broadleaf

Thailand
**SWAT Model**

The Hydrologic System

- **Root Zone** (soil water)
- **Vadose Zone** (unsaturated)
- **Shallow Aquifer** (saturated) (unconfined)
- **Deep Aquifer** (confined)

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

- \(SW_t\) = Final soil water content (mmH\(_2\)O)
- \(SW_0\) = 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
Flow of the Methods

**SWAT Model**
- Database
  1. Topographical data
  2. Landuse/soil
  3. Meteorological data
  4. Observed Monitoring data
  5. Agriculture activity data
- Model simulation
  1. Streamflow
- Sensitivity analysis
- Calibration
  - Spin-up time (2003)
  - 5-year-period (2004-2008)
- Validation
  - 3-year-period (2009-2011)

**Application**
- Climate Change Scenario
- Climate Sensitivity Scenarios
- IPCC Emission Scenario

**Assessments**
- Water yield, soil water content, groundwater recharge in Hydrological Response Units (HRUs)
Flow of the Methods

Application

Climate Change Scenario

Climate Sensitivity Scenarios

IPCC Emission Scenario

Greenhouse gas emission scenarios

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

GCM model
- CSIRO_mk_3.5*

Bias correction Method
- Change factor

※ 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.

\[
T_{adj,2059,d} = T_{obs,d} + (\bar{T}_{GCM,2059,m} - \bar{T}_{GCM,ref,m})
\]

\[
P_{adj,2059,d} = P_{obs,d} \times (\bar{P}_{GCM,2059,m} / \bar{P}_{GCM,ref,m})
\]

- Change factor
  - Future 2059 daily temperature
  - Observed temperature
  - Mean of future daily temperature (2051-2059)
  - Mean of reference daily temperature (2003-2011)
  - Future 2059 daily precipitation
  - Observed precipitation (2003-2011)
  - Mean of future daily precipitation (2051-2059)
  - Mean of reference daily precipitation (2003-2011)

<table>
<thead>
<tr>
<th>Change factor</th>
<th>B1</th>
<th>A1B</th>
<th>A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>1.0054</td>
<td>1.0644</td>
<td>1.0338</td>
</tr>
<tr>
<td>Temp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max</td>
<td>0.7926</td>
<td>2.0621</td>
<td>1.8729</td>
</tr>
<tr>
<td>Min</td>
<td>0.6106</td>
<td>2.4954</td>
<td>2.2905</td>
</tr>
</tbody>
</table>

## Data Sources of Model Inputs

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

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

- **Evaluation Criteria**
  - Coefficient of determination ($R^2$)
  - Nash-Sutcliffe Efficiency (NSE)

**Coefficient of determination ($R^2$)**

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

**Nash-Sutcliffe Efficiency (NSE)**

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

**Performance rating**

- **Very good**
  - $0.75 < NSE \leq 1.00$

- **Good**
  - $0.65 < NSE \leq 0.75$

- **Satisfactory**
  - $0.50 < NSE \leq 0.65$

- **Unsatisfactory**
  - $NSE \leq 0.50$

(The performance rating thresholds are based on Moriasi et al., 2007.)

**Sensitivity index class**

- **Class I**
  - $0.00 \leq |I| < 0.05$
  - Small to negligible

- **Class II**
  - $0.05 \leq |I| < 0.20$
  - Medium

- **Class III**
  - $0.20 \leq |I| < 1.00$
  - High

- **Class IV**
  - $|I| \geq 1.00$
  - Very high

(The sensitivity index class thresholds are based on T.Lenhart et al., 2002.)
Results and Discussion
• Results (1) Streamflow

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

<table>
<thead>
<tr>
<th>RANK</th>
<th>NAME</th>
<th>DEFINITION</th>
<th>BOUNDS Min-Max</th>
<th>Process</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cn2</td>
<td>SCS runoff curve number for moisture condition 2</td>
<td>35-98</td>
<td>Runoff</td>
<td>1.49</td>
</tr>
<tr>
<td>2</td>
<td>Alpha_Bf</td>
<td>Baseflow alpha factor (days)</td>
<td>0.00-1.00</td>
<td>Groundwater</td>
<td>1.42</td>
</tr>
<tr>
<td>3</td>
<td>Rchrg_Dp</td>
<td>Deep aquifer percolation fraction</td>
<td>0.00-1.00</td>
<td>Groundwater</td>
<td>0.66</td>
</tr>
<tr>
<td>4</td>
<td>Esco</td>
<td>Soil evaporation compensation factor</td>
<td>0.00-1.00</td>
<td>Evaporation</td>
<td>0.48</td>
</tr>
<tr>
<td>5</td>
<td>Revapmn</td>
<td>Threshold depth of water in the shallow aquifer for percolation to the deep aquifer (mmH₂O)</td>
<td>0-500</td>
<td>Groundwater</td>
<td>0.22</td>
</tr>
<tr>
<td>6</td>
<td>Ch_K2</td>
<td>Effective hydraulic conductivity in main channel alluvium (mm/hr)</td>
<td>-0.01-150</td>
<td>Channel</td>
<td>0.20</td>
</tr>
<tr>
<td>7</td>
<td>Gwqmn</td>
<td>Threshold depth of water in the shallow aquifer required for return flow to occur (mm)</td>
<td>0-5000</td>
<td>Soil</td>
<td>0.18</td>
</tr>
<tr>
<td>8</td>
<td>Sol_Awc</td>
<td>Available water capacity of the soil layer (mm/mm soil)</td>
<td>0-100</td>
<td>Soil</td>
<td>0.14</td>
</tr>
<tr>
<td>9</td>
<td>Sol_Z</td>
<td>Maximum canopy index Soil depth</td>
<td>0-3000</td>
<td>Soil</td>
<td>0.07</td>
</tr>
<tr>
<td>10</td>
<td>Gw_Revap</td>
<td>Groundwater “revap” coefficient</td>
<td>0.02-0.2</td>
<td>Groundwater</td>
<td>0.06</td>
</tr>
<tr>
<td>11</td>
<td>Surlag</td>
<td>Surface runoff lag coefficient</td>
<td>0.00-10.00</td>
<td>Runoff</td>
<td>0.05</td>
</tr>
<tr>
<td>12</td>
<td>Blai</td>
<td>Leaf area index for crop</td>
<td>0.00-1.00</td>
<td>Crop</td>
<td>0.02</td>
</tr>
<tr>
<td>13</td>
<td>Slope</td>
<td>Average slope steepness (m/m)</td>
<td>0.0001-0.6</td>
<td>Geomorphology</td>
<td>0.02</td>
</tr>
<tr>
<td>14</td>
<td>Canmx</td>
<td>Maximum canopy index</td>
<td>0.00-10.00</td>
<td>Runoff</td>
<td>0.01</td>
</tr>
<tr>
<td>15</td>
<td>Epco</td>
<td>Threshold depth of water in the shallow aquifer to percolation to the deep aquifer (mmH₂O)</td>
<td>0.00-1.00</td>
<td>Evaporation</td>
<td>0.01</td>
</tr>
</tbody>
</table>
• Results (1) Streamflow

• Observed and simulated daily flow rate for model


• Calibration:
  • NSE: 0.54; R²: 0.81

• Validation:
  • NSE: 0.66; R²: 0.89
• Results (2) Streamflow under climate change scenarios

The worst condition (S1 – S3) (based on CO₂×2)

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

Temperature Increase (S8 – S10) (+1,3,6°C)

**Climate Sensitivity Scenarios**

**IPCC Emission Scenario**

The climate change scenarios for streamflow were significantly different baseline under emission scenario.
Results (2) Climate change scenario

**Climate Sensitivity Scenarios**

**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↑)

**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 \( (S_4 - S_7) \) (±10, ±20)
- Temperature Increase \( (S_8 - S_{10}) \) (+1, 3, 6°C)

**The climate change scenarios for water yield were not significantly different baseline.**
• Results (2) Climate change scenario

The worst condition (S1–S3) (based on CO₂ × 2)

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

Temperature Increase (S8 – S10) (+1, 3, 6°C)

Climate Sensitivity Scenarios

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 (mm)

Soil water content (mm)

Soil water content (mm)

Soil water content (mm)

Soil water content (mm)

Soil water content (mm)

Soil water content (mm)

HRU 128
CORN

The climate change scenarios for soil water content were not significantly different baseline.
• Results (2) Climate change scenario

The worst condition (S1 – S3) (based on CO₂×2)

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

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

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

<table>
<thead>
<tr>
<th>Climate Sensitivity Scenarios</th>
<th>IPCC Emission Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>CO₂×2</td>
<td>A1B</td>
</tr>
<tr>
<td>CO₂×2+pcp20%</td>
<td>A1B</td>
</tr>
<tr>
<td>CO₂×2+tmp6°C</td>
<td>A1B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groundwater recharge (mm)</th>
<th>Groundwater recharge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 4 8 12 16 20</td>
<td>0 4 8 12 16 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groundwater recharge (mm)</th>
<th>Groundwater recharge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 4 8 12 16 20</td>
<td>0 4 8 12 16 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groundwater recharge (mm)</th>
<th>Groundwater recharge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 4 8 12 16 20</td>
<td>0 4 8 12 16 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (Monthly)</th>
<th>Time (Monthly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2059)</td>
<td>(2059)</td>
</tr>
<tr>
<td>0 4 8 12 16 20</td>
<td>0 4 8 12 16 20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>p-value (p &lt; 0.05)</th>
<th>p-value (p &lt; 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 0.95</td>
<td>S1 0.95</td>
</tr>
<tr>
<td>S4 0.60</td>
<td>S4 0.60</td>
</tr>
<tr>
<td>S8 0.93</td>
<td>S8 0.93</td>
</tr>
<tr>
<td>B1 0.52</td>
<td>B1 0.52</td>
</tr>
<tr>
<td>S2 0.43</td>
<td>S2 0.43</td>
</tr>
<tr>
<td>S5 0.38</td>
<td>S5 0.38</td>
</tr>
<tr>
<td>S9 0.97</td>
<td>S9 0.97</td>
</tr>
<tr>
<td>A1B 0.45</td>
<td>A1B 0.45</td>
</tr>
<tr>
<td>S3 0.90</td>
<td>S3 0.90</td>
</tr>
<tr>
<td>S6 0.52</td>
<td>S6 0.52</td>
</tr>
<tr>
<td>S10 0.90</td>
<td>S10 0.90</td>
</tr>
<tr>
<td>A2 0.48</td>
<td>A2 0.48</td>
</tr>
<tr>
<td>S7 0.38</td>
<td>S7 0.38</td>
</tr>
</tbody>
</table>
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

- **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.
Thank you for listening.