Evaluation of Turbidity Water and Eutrophication in Chungju Lake by Future Climate Change Using CE-QUAL-W2 and SWAT

So R. Ahn
(Ahnsora@konkuk.ac.kr)
R. Ha, Sang H. Kim, Jong Y. Park and Seong J. Kim

Dept. of Civil & Environmental System Engineering
Konkuk University, SOUTH KOREA
Contents

- Introduction (Why this study?)
- Research Procedure
- Study Area
- Climate Change Scenarios Data
  - Climate scenarios (IPCC AR4 RCM)
  - Watershed runoff and stream water quality scenarios (SWAT)
- CE-QUAL-W2 lake model setup
  - Data for CE-QUAL-W2 model evaluation
  - Model calibration and validation
- Assessment of Climate Change Impact on Turbidity and Eutrophication
- Summary & Concluding Remarks
Introduction (Why this study?)

- Recently, long time turbidity water and algae proliferation in Korea water supply multi-purpose reservoir occurs with high frequency due to the rise in temperature and turbid flood by climate change.
  - It causes dangerous impacts on aqua-ecosystem itself and municipal water supply to downstream cities.
  - We need to estimate the impact how much from watershed and within lake for the turbidity and algae blooms, and also the future possible impact for proper mitigation planning from now on.

- Most lake studies are limited to just within waterbody not considering upstream watershed impact.

- The main objective of this study is to evaluate the future climate change impact on turbidity water and eutrophication of Chungju Lake in South Korea by applying reservoir water quality model (CE-QUAL-W2) with watershed model (SWAT).
20 Multi-purpose Dams of South Korea

- 5 river basins in our country (Han, Geum, Yeongsan, Seomjin and Nakdong)

- A total of 20 multipurpose dams in South Korea are being managed by Korea Water Resources Corporation (K-water).

- They have been successfully managed by K-water to fulfill water demands, flood control and hydropower generation.
**Climate Change Scenarios Data**

- Climate scenarios (RCM)
  - IPCC AR4 A1B scenario
    - Temperature
    - Precipitation
    - Relative humidity

- Runoff and water quality scenarios (SWAT)
  - Inflow
  - Stream water quality

**Future Lake Water Quality modeling**

- CE-QUAL-W2 boundary conditions
  - Inflow
  - Inflow temperature
  - Water quality

- **Multiple regression analysis**
  - Water temperature

- **Boundary Condition**
  - (Weather)
  - (Runoff and water quality)
  - (Water temperature)
**Chungju Dam Watershed (6,662 km²)**

- **Average precipitation 1359.5 mm**
- **Average temperature 9.4°C**
**IPCC AR4 RCM climate change scenario**

- **MM5 RCM (Regional Climate Model)**
  - Temperature (maximum, minimum)
  - Precipitation
  - Relative humidity

<table>
<thead>
<tr>
<th>Model</th>
<th>Country</th>
<th>Grid size</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONS: EHCO-G</td>
<td>Germany / Korea</td>
<td>96 × 48</td>
</tr>
</tbody>
</table>

**Dynamic Downscaling**

- 1860 – 2100
- A1B, B1, A2
- 400 km (~3.75°)
- Monthly

**MM5 (RCM)**

- 1871 – 2100
- A1B
- 27 km (~0.243°)
- Monthly, Daily

**Downscaling (Artificial Neural Networks method)**

**Typhoon Simulation, Quantile Mapping**

**SWAT model**
IPCC AR4 RCM climate change scenario

- Three time periods: 2030s (2011~2040), 2060s (2041~2070), 2090s (2071~2100)
  - Future precipitation showed the biggest change in summer period.
  - Future relative humidity has slightly increased.

<table>
<thead>
<tr>
<th>Period</th>
<th>Baseline (1991~2010)</th>
<th>2030s (2011~2040)</th>
<th>2060s (2041~2070)</th>
<th>2090s (2071~2100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. temp</td>
<td>15.6 (0.4°C)</td>
<td>15.9 (1.2°C)</td>
<td>16.8 (2.2°C)</td>
<td></td>
</tr>
<tr>
<td>Min. temp</td>
<td>4.3 (0.5°C)</td>
<td>4.8 (1.4°C)</td>
<td>5.7 (2.5°C)</td>
<td>6.8 (2.5°C)</td>
</tr>
<tr>
<td>Precip.</td>
<td>1449.7 (13.9%)</td>
<td>1651.1 (24.2%)</td>
<td>1800.3 (37.8%)</td>
<td>1998.3 (37.8%)</td>
</tr>
<tr>
<td>Rh. (%)</td>
<td>69.3 (0.1%)</td>
<td>69.6 (0.2%)</td>
<td>69.7 (0.3%)</td>
<td>69.8 (0.3%)</td>
</tr>
</tbody>
</table>

- Max. temperature: +0.4°C ~ +2.2°C
- Min. temperature: +0.5°C ~ +2.5°C
- Precipitation: +14% ~ +38%
- Relative humidity: +0.1% ~ +0.3%
# Data for SWAT Model Evaluation

## SWAT input data

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Source</th>
<th>Scale / Period</th>
<th>Data Description / Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Korea National Geography Institute</td>
<td>1/5,000</td>
<td>Digital Elevation Model (DEM), 30m X 30m</td>
</tr>
<tr>
<td>Soil</td>
<td>Korea Rural Development Administration</td>
<td>1/25,000</td>
<td>Soil classifications and physical properties viz. texture, porosity, field capacity, wilting point, saturated conductivity, and soil depth</td>
</tr>
<tr>
<td>Land use</td>
<td>Landsat TM satellite Image</td>
<td>30m</td>
<td>Landsat land use classification (9 classes)</td>
</tr>
<tr>
<td></td>
<td>NOAA/AVHRR satellite Image</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>Korea Meteorological Administration</td>
<td>1998~2010</td>
<td>Daily precipitation, minimum and maximum temperature, mean wind speed and relative humidity data</td>
</tr>
<tr>
<td>Streamflow</td>
<td>Water Management Information System</td>
<td>1998~2010</td>
<td>Daily streamflow data at watershed outlet</td>
</tr>
<tr>
<td>Dam inflow</td>
<td>K-water</td>
<td>1998~2010</td>
<td>Daily dam inflow data</td>
</tr>
<tr>
<td>Water quality</td>
<td>Water Information System</td>
<td>1998~2010</td>
<td>SS, TN, TP, DO, BOD, Chl-a</td>
</tr>
<tr>
<td>Climate change</td>
<td>Korea Meteorological Administration</td>
<td>1971~2100</td>
<td>Daily precipitation, minimum and maximum temperature and relative humidity data from RCM</td>
</tr>
</tbody>
</table>
GIS data

**Elevation**: 112 - 1562m (average: 607m)

**Soil**: clay loam (45%) and sandy loam (40%)

**Land cover (2000)**: forest (81%) and paddy rice (10%)
**SWAT Model**

- **SWAT (Soil and Water Assessment Tool) model**
  - Developed by USDA Agriculture Research Service (ARS)
  - Physically based continuous, long-term, distributed-parameter model
  - To predict the effects of land management practices on the hydrology, sediment, and contaminant transport in agricultural watersheds under varying soils, land use, and management conditions

---

**Nitrogen**

- Mineral N
  - Volatilization
  - Nitrification
  - Mineralization
  - NH₄
  - NO₂

- Organic N
  - Humic Substances
  - Organic N fertilizer
  - Plant uptake
  - Decay
  - Residue mineralization
  - Active
  - Stable
  - Fresh

---

**Phosphorus**

- Mineral P
  - Inorganic P fertilizer
  - Plant uptake
  - Stable
  - Active
  - Solution
  - Mineralization
  - Organic P
  - Humic Substances
  - Organic P fertilizer
  - Plant residue
  - Decay
  - Residue mineralization
  - Stable
  - Fresh
Watershed streamflow results

- **Calibration**: 6 years (2000-2005) / **Validation**: 5 years (2005-2010)
- **YW1, YW2** located upstream and **CJ** in the watershed outlet

![Calibration and Validation Results](image-url)
Stream water quality results

- **Calibration**: 6 years (2000-2005) / **Validation**: 5 years (2005-2010)
  - Sediment, T-N, T-P in four sites (PC, DR, DC, and JC)
Stream water quality results

- **Calibration**: 6 years (2000-2005) / **Validation**: 5 years (2005-2010)
  - Sediment, T-N, T-P in four sites (PC, DR, DC, and JC)
Future lake inflow and sediment from watershed

- **Dam inflow**: + 24.8% in 2030s, + 37.7% in 2060s, and + 56.8% in 2090s
- **Sediment load**: + 62.8% in 2030s, + 88.2% in 2060s, and + 126.5% in 2090s

---

**Future Watershed Runoff (SWAT)**

**Dam inflow**
+24.8% ~ +56.8%

**Sediment**
+62.8% ~ +126.5%
**Future Stream Water Quality (SWAT)**

**Future T-N and T-P to lake from watershed**

- **T-N**: +10.9% in 2030s, +36.0% in 2060s, and +52.4% in 2090s
- **T-P**: +9.1% in 2030s, +27.2% in 2060s, and +25.2% in 2090s
CE-QUAL-W2 model

- **CE-QUAL-W2 model**
  - A two-dimensional (longitudinal–vertical) hydrodynamic and water quality model
  - Developed by U.S. Army Corps of Engineers’ Waterways Experiment Station
  - In CE-QUAL-W2 model applications, the hydrodynamic runs provide real-time simulations of velocities, temperature, and a conservative tracer such as salinity prior to the water quality calculations.

**Water Quality**
- Conservative tracer
- SS, Coliform bacteria, TSD
- Labile-, Refractory-DOM
- Algae
- Labile-, Refractory-POM
- Phosphorous
- NH3, NOX- nitrogen
- DO, pH, CBOD
- CO2, HCO3, CO3
- Fe etc. (22 items)
Data for CE-QUAL-W2 Model Evaluation

CE-QUAL-W2 input data

- **Meteorological data**
  - Air temperature (°C), dew point temperature (°C), wind speed (m/s), wind direction (phi), and cloud cover (%)
- **Initial conditions**
  - Observed water temperature and turbidity data by depth on each starting date (January 1) in lake
- **boundary conditions**
  - Inflow, outflow, inflow temperature and water quality data (SS, NO3, NH4, PO4-P, DO, Chl-a)
Topographical profile and water balance

- Chungju Lake segmentation was configured as 7 branches, 261 segments and 83 layers according to their shape and tributary distribution.

Water level
Observed vs. Simulated

- 2010
  \[ R^2 : 0.999 \]

- 2008
  \[ R^2 : 0.949 \]
Lake water temperature results

- The water temperature began to increase in depth from April and the stratification occurred at about 10 m by early July heavy rain.

### Water temperature increase

**Calibration (2010)**
- 1/7(7): Observed: 7.09°C, RMSE: 0.709
- 3/4(63): Observed: 0.894°C, RMSE: 0.752
- 4/5(95): Observed: 0.335°C, RMSE: 0.362
- 5/7(127): Observed: 0.019°C, RMSE: 1.161
- 6/10(161): Observed: 1.127°C, RMSE: 1.572

**Validation (2008)**
- 2/4(35): Observed: 0.963°C, RMSE: 0.963
- 4/2(93): Observed: 0.888°C, RMSE: 0.755

### Stratification

- **Heavy rain (September)**
- **Temperature-inversion phenomenon**
- **Stabilization**

### Heavy rain (July)

- Thermocline descent

### Thermocline descent
Suspended solid (SS) results of model calibration and validation

- The high SS concentration of the interflow density currents entering from the watershed was well simulated especially for July 2008 heavy rainfall event.

Calibration (2010)

Validation (2008)
The simulated concentration range of T-N and T-P was acceptable.

The errors might occur from the poor reflection for sedimentation velocity of nitrogen component and adsorption-sediment of phosphorus by the model limitations.

The concentration of Chl-a was simulated well with the algal growth patterns in summer of 2010 and 2008.

The errors of under-estimation may come from the use of width-averaged velocity and concentration in the model, not considering the actual to one side inclination by wind effect.
The outputs of daily dam inflow and stream water quality data from SWAT model became inputs for boundary conditions for CE-QUAL-W2 model to evaluate the future water environment variation in lake.
Evaluation of future lake water temperature

- The future change in shallow-water temperature showed upward tendency by temperature rise.
- But deep-water temperature showed downward tendency.
- In the future, the period span of stratification increased by shallow-water temperature increase and the time of stratification advanced except wet year.

<table>
<thead>
<tr>
<th>Year</th>
<th>Shallow-water temperature (depth 5m) (°C)</th>
<th>Deep-water temperature (from the bottom 5m) (°C)</th>
<th>Stratification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet year</td>
<td>2027 (I)</td>
<td>2.9</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>2058 (II)</td>
<td>2.8</td>
<td>27.2</td>
</tr>
<tr>
<td></td>
<td>2095 (III)</td>
<td>4.0</td>
<td>27.7</td>
</tr>
<tr>
<td>Average year</td>
<td>2020 (I)</td>
<td>2.1</td>
<td>26.2</td>
</tr>
<tr>
<td></td>
<td>2047 (II)</td>
<td>2.7</td>
<td>26.6</td>
</tr>
<tr>
<td></td>
<td>2077 (III)</td>
<td>3.0</td>
<td>27.1</td>
</tr>
<tr>
<td>Dry year</td>
<td>2021 (I)</td>
<td>2.2</td>
<td>26.7</td>
</tr>
<tr>
<td></td>
<td>2048 (II)</td>
<td>2.6</td>
<td>27.4</td>
</tr>
<tr>
<td></td>
<td>2073 (III)</td>
<td>3.0</td>
<td>27.4</td>
</tr>
</tbody>
</table>
### Evaluation of future lake water turbidity

- **The future suspended solids concentration above 25 mg/L incoming to the lake from watershed showed the value from wet year (47.2 mg/L) to dry year (42.2 mg/L)**
- **The future predicted residence time above 10 mg/L suspended solids in the lake showed the value from wet year (166 days) to dry year (153 days)**
- **The occupying period of suspended solids above 10 mg/L showed about 7% increase in the future.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Inflow SS&gt;25mg/L</th>
<th>In lake SS&gt;10 mg/L</th>
<th>Outflow SS&gt;25mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of days</td>
<td>Min. (mg/L)</td>
<td>Max. (mg/L)</td>
</tr>
<tr>
<td>Wet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2027 (I)</td>
<td>146</td>
<td>0.6</td>
<td>419.3</td>
</tr>
<tr>
<td>2058 (II)</td>
<td>119</td>
<td>1.5</td>
<td>477.7</td>
</tr>
<tr>
<td>2095 (III)</td>
<td>140</td>
<td>0.8</td>
<td>412.1</td>
</tr>
<tr>
<td>Average</td>
<td>2020 (I)</td>
<td>122</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>2047 (II)</td>
<td>147</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>2077 (III)</td>
<td>169</td>
<td>0.9</td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021 (I)</td>
<td>137</td>
<td>1.5</td>
<td>353.4</td>
</tr>
<tr>
<td>2048 (II)</td>
<td>104</td>
<td>1.0</td>
<td>358.2</td>
</tr>
<tr>
<td>2073 (III)</td>
<td>145</td>
<td>1.4</td>
<td>373.0</td>
</tr>
</tbody>
</table>
Evaluation of future lake water turbidity

- The occupying period above 10 mg/L suspended solids in lake is expected to increase, and in the order of average, wet and dry year.
- The future reservoir releases of monthly concentration above 25 mg/L suspended solids are expected to increase, especially in wet year.
**Evaluation of future lake algal bloom**

- The future Chl-a growth increased in wet and dry years than average year.
- The peak concentration of Chl-a in dry year appeared one month advanced than wet year under the reduced lake inflow and storage condition.

<table>
<thead>
<tr>
<th>Year</th>
<th>Chl-a (μg/L)</th>
<th>Min.</th>
<th>Max.</th>
<th>Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wet year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2027 (I)</td>
<td></td>
<td>0.4</td>
<td>41.3</td>
<td>4.9</td>
</tr>
<tr>
<td>2058 (II)</td>
<td></td>
<td>0.5</td>
<td>33.6</td>
<td>4.0</td>
</tr>
<tr>
<td>2095 (III)</td>
<td></td>
<td>0.2</td>
<td>11.7</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Average year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020 (I)</td>
<td></td>
<td>0.6</td>
<td>14.1</td>
<td>3.3</td>
</tr>
<tr>
<td>2047 (II)</td>
<td></td>
<td>0.3</td>
<td>23.7</td>
<td>3.3</td>
</tr>
<tr>
<td>2077 (III)</td>
<td></td>
<td>0.6</td>
<td>16.2</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Dry year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2021 (I)</td>
<td></td>
<td>0.6</td>
<td>42.2</td>
<td>6.5</td>
</tr>
<tr>
<td>2048 (II)</td>
<td></td>
<td>0.2</td>
<td>12.9</td>
<td>2.7</td>
</tr>
<tr>
<td>2073 (III)</td>
<td></td>
<td>0.5</td>
<td>22.1</td>
<td>3.9</td>
</tr>
</tbody>
</table>
Summary & Concluding remarks

In this study, the reservoir water quality model (CE-QUAL-W2) and watershed model (SWAT) were applied to evaluate the future climate change impact on water turbidity and eutrophication in Chungju lake.

- For future climate change data, the MM5 RCM data of IPCC A1B scenario was adopted and downscaled by Artificial Neural Networks method. The future dam inflow and stream water quality (sediment, T-N, and T-P) by SWAT showed an increase tendency.

- The future watershed results by SWAT simulation were used to CE-QUAL-W2 lake water quality modeling.

- The future shallow-water temperature and period of stratification of lake increased directly affected by future temperature rise. The future concentration of suspended solids and algae seriously increased in both wet and dry years.

We hope the results of this study are incorporated into the MOE (Ministry of Environment) watershed TDML (Total Maximum Daily Load) management and K-water (Korea Water Resources Corporation) lake water quality management.
Thank you

Earth Information Engineering Lab.
Ahn, So Ra
Dept. of Rural Engineering
Konkuk University, Seoul, South Korea

Phone: +82-2-444-0186
Email: ahnsora@konkuk.ac.kr
Web: http://konkuk.ac.kr/~kimsj/