Assessment of Future Climate Change Impacts on Snowmelt and the Stream Water Quality in a Mountainous Watershed using SWAT

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Professor
Contents

I. Introduction

II. Material and Methods
   ▪ Study watershed
   ▪ Terra MODIS data for snow cover detection
   ▪ SWAT model and the snowmelt theory
   ▪ Climate change scenarios

III. Results and Discussion
   ▪ SWAT snow depletion parameter
   ▪ SWAT calibration and validation
   ▪ Climate change impact on snowmelt and stream water quality

IV. Summary and Conclusion
Study procedure

**Input Data**

**Meteorological Data**
- Temperature (°C)
- Precipitation (mm)
- Relative humidity (%)
- Wind speed (m/s)
- Sunshine hour (MJ/m²/day)

**Hydrological Data**
- Dam Inflow (mm)
- Total Nitrogen (kg/day)
- Total phosphorus (kg/day)
- Sediment (ton/day)

**GIS/RS Data**
- Land use
- Soil
- DEM

**Snow Cover Area Data**
- Ground snowfall data (KMA)
- Terra MODIS (mod10, snow cover, NASA)

**Future Climate Data (2040s, 2080s)**
- HadGEM3-RA
  - Scenarios: RCP4.5, RCP8.5
- Bias-correction

**SWAT model**
- Calibration & Validation (2000-2010)

**Model Parameters**
- Snow areal depletion curve
- Snowfall temperature
- Max/Min melt rate
- Snowmelt temperature
- Initial snow water content

**SWAT Application**

Assessment of Future Climate Change Impacts on Snowmelt and Stream Water Quality in a Mountainous Watershed
Korea seasons

Winter (December - February)
Temperature -2.9 °C
Precipitation 76.6 mm

Spring (March - May)
Temperature 9.5 °C
Precipitation 210.0 mm

Summer (June - August)
Temperature 21.7 °C
Precipitation 752.6 mm

Autumn (October - November)
Temperature 11.2 °C
Precipitation 253.7 mm
Korea Seasons

- **Winter (December – February)**
  - Winter lasts from December to mid-March. It can be bitterly cold and dry during this time due to the influx of cold Siberian air. Heavy snow in the northern and eastern parts of Korea. Winters can be extremely cold with the minimum temperature dropping below \(-20 \, ^\circ\text{C}\) in the inland region of the country: in Seoul, the average January temperature range is \(-7 \, ^\circ\text{C}\) to \(1 \, ^\circ\text{C}\) (19 \(^\circ\text{F}\) to 33 \(^\circ\text{F}\)). January is the coldest month. Snow piled up and the snow is starting to melt in January especially in the mountain. It is a perfect time to have fun in the snow. One of the most popular winter activities is skiing.
Study Watershed

Chungju Dam watershed

- Watershed area: 6,642.0 km² (heavy snowfall area: about 40%)
- Annual average snow depth: **80.9 cm**
- Annual average precipitation: 1,359.5 mm
- Annual average temperature: 9.4 °C
- Forest area: 88.5 % (5573.1 km²)
- Latitude range: 36.8 °N ~ 37.8 °N
- Longitude range: 127.9 °E ~ 129.0 °E
SWAT Model Description

- The hydrology cycle as simulated by SWAT is based on the water balance equation:

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

- \(SW_t\) = Final soil water content (mm)
- \(SW_0\) = Initial soil water content on day \(i\) (mm)
- \(R_{day}\) = Amount of precipitation on day \(i\) (mm)
- \(Q_{surf}\) = Amount of surface runoff on day \(i\) (mm)
- \(E_a\) = Amount of evapotranspiration on day \(i\) (mm)
- \(W_{seep}\) = Amount of water entering the vadose zone from the soil profile on day \(i\) (mm)
- \(Q_{gw}\) = Amount of return flow on day \(i\) (mm)
SWAT Model Description

- Mass balance equation
  - In SWAT, snowmelt hydrology is realized on an HRU (Hydrologic Response Unit) basis.
  - The mass balance for the snowpack is computed as:

\[
SNO = SNO + R_{day} - E_{sub} - SNO_{mlt}
\]

- \( SNO \) = The water content of the snow pack on a given day (mm \( H_2O \))
- \( R_{day} \) = The amount of precipitation on a given day (mm \( H_2O \))
- \( E_{sub} \) = The amount of sublimation on a given day (mm \( H_2O \))
- \( SNO_{mlt} \) = The amount of snowmelt on a given day (mm \( H_2O \))
SWAT Model Description

- Snow depletion curve
  - The areal depletion curve is based on a natural logarithm

\[ sno_{cov} = \frac{SNO_i}{SNOCOVMX} \left[ \frac{SNO_i}{SNOCOVMX} + \exp(\text{cov}_1 - \text{cov}_2) \frac{SNO_i}{SNOCOVMX} \right] \]

- \( sno_{cov} \): the fraction of the HRU area covered by snow on the current day
- \( SNOCOVMX \): the minimum snow water content that corresponds to 100% snow cover (mm H\text{\textsubscript{2}}O)
- \( \text{cov}_1 \) and \( \text{cov}_2 \): the coefficients that define the shape of the curve

10\% SNO\textsubscript{100} = 50\% coverage
30\% SNO\textsubscript{100} = 50\% coverage
50\% SNO\textsubscript{100} = 50\% coverage
70\% SNO\textsubscript{100} = 50\% coverage
90\% SNO\textsubscript{100} = 50\% coverage
Terra MODIS Snow Cover Area

- MODIS (Moderate Resolution Imaging Spectroradiometer)
  - MODIS data is to permit the regional to global study of the land, atmosphere, and ocean on a daily or near-daily basis (Salomonson et al., 1992)

- NDSI (Normalized Difference Snow Index)
  - The automated MODIS snow-mapping algorithm uses satellite reflectance in MODIS band 4 (0.545-0.565 μm) and band 6 (1.628-1.652 μm) to calculate the normalized difference snow index

\[
NDSI = \frac{\text{MODIS}_6 - \text{MODIS}_4}{\text{MODIS}_6}
\]

2004. 3. 7
MODIS image

MODIS image
The generated snow depth distribution using the MODIS snow cover extent and the ground-measured snowfall data (2000-2010)
Snow Depletion Curve

The snow depletion curves from the fraction of snow cover area and snow volume of each data set.

TOTAL

10% $SNO_{100} = 50\%$ coverage
30% $SNO_{100} = 50\%$ coverage
50% $SNO_{100} = 50\%$ coverage
70% $SNO_{100} = 50\%$ coverage
90% $SNO_{100} = 50\%$ coverage

2000-2001
2001-2002
2002-2003
2003-2004
2004-2005
2005-2006

0.7
0.7
0.4
0.7
0.48
0.7
## Preparation of SWAT input data

### Elevation: 115 – 1,559m (average: 609.1 m)

### Land cover (2000)

### Soil: sandy loam (40%), clay loam (45%)

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Source</th>
<th>Scale</th>
<th>Data Description / Properties</th>
</tr>
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<td>Soil classifications and physical properties such as bulk density, texture, and saturated conductivity.</td>
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<tr>
<td>Land use</td>
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<td>Land use classifications such as paddy, grass, and forest.</td>
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<td>Korea Meteorological Administration</td>
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<td>precipitation, minimum and maximum temperature, mean wind speed and relative humidity data from 1998 to 2010</td>
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<td>Streamflow</td>
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<td>streamflow data from 1998 to 2010</td>
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<td>Water Quality</td>
<td>Ministry of Environment</td>
<td>Monthly</td>
<td>Water quality (SS, T-N and T-P) data from 1998 to 2010</td>
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</tbody>
</table>
## Snow Parameters

### The calibrated model parameters

- The 7 snowmelt parameters of **SFTMP**, **SMTMP**, **SMFMX**, **SMFMN**, **TIMP**, **SNOCOVMX** and **SNO50COV**

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<thead>
<tr>
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<td>5</td>
<td>-2</td>
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</table>

- **SFTMP**: Snowfall temperature (°C)
- **SMTMP**: Snow melt base temperature (°C)
- **SNOCOVMX**: Threshold depth of snow, above which there is 100% cover [mm]
- **SNO50COV**: Fraction of SNOCOVMX that provides 50% cover
- **TIMP**: Snow pack temperature lag factor
- **SMFMX**: Maximum snow melt factor (mm H₂O/°C-day)
- **SMFMN**: Minimum snow melt factor (mm H₂O/°C-day)
Calibration and Validation

- **Streamflow**
  - Calibration period: 2000-2010

```
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<th>R²</th>
<th>ME</th>
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<td>YW #1 / PR #3</td>
<td>0.74</td>
<td>0.71</td>
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<tr>
<td>YW #2 / DR</td>
<td>0.72</td>
<td>0.61</td>
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<tr>
<td>Chungju dam</td>
<td>0.88</td>
<td>0.80</td>
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</table>
```
Calibration and Validation

Stream Water Quality (SS, T-N and T-P)

(PR #3)

- **Total Phosphorus (mg)**
  - \( R^2: 0.87 / ME: 0.72 \)

- **Total Nitrogen (kg)**
  - \( R^2: 0.74 / ME: 0.54 \)

(DR)

- **Total Phosphorus (mg)**
  - \( R^2: 0.61 / ME: 0.75 \)

- **Total Nitrogen (kg)**
  - \( R^2: 0.85 / ME: 0.70 \)

- **Total Phosphorus (kg)**
  - \( R^2: 0.88 / ME: 0.85 \)

- **Total Nitrogen (kg)**
  - \( R^2: 0.62 / ME: 0.70 \)
Calibration (November-April)

- Snowmelt period: November to April

- Graphs showing discharge and precipitation for the years 2000-2001 to 2009-2010.
## Calibration and Validation

<table>
<thead>
<tr>
<th>Year</th>
<th>Period</th>
<th>Snow depth (cm)</th>
<th>PCP (mm)</th>
<th>Q (mm)</th>
<th>QR (%)</th>
<th>RMSE (mm/day)</th>
<th>NSE</th>
<th>QRA/QRS</th>
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<td>Obs.</td>
<td>Sim.</td>
<td>Obs.</td>
<td>Sim.</td>
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<td>2000-2001</td>
<td>Annual</td>
<td>128.6</td>
<td>831.2</td>
<td>309.4</td>
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<td></td>
<td>Snowmelt</td>
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<td>177.2</td>
<td>90.7</td>
<td>62.6</td>
<td>51.2</td>
<td>35.3</td>
<td>0.49</td>
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<tr>
<td>2001-2002</td>
<td>Annual</td>
<td>56.5</td>
<td>1238.0</td>
<td>836.7</td>
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<td>242.0</td>
<td>83.5</td>
<td>56.8</td>
<td>34.5</td>
<td>23.5</td>
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<td>2002-2003</td>
<td>Annual</td>
<td>129.7</td>
<td>1590.5</td>
<td>1032.2</td>
<td>1167.6</td>
<td>64.9</td>
<td>73.4</td>
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<td></td>
<td>Snowmelt</td>
<td></td>
<td>270.0</td>
<td>191.6</td>
<td>151.8</td>
<td>71.0</td>
<td>56.2</td>
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<td>59.6</td>
<td>1375.9</td>
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<td>187.9</td>
<td>103.5</td>
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<td>55.1</td>
<td>47.3</td>
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<td>2004-2005</td>
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<td>86.9</td>
<td>1260.0</td>
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<td>59.6</td>
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<td>175.0</td>
<td>101.3</td>
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<td>52.2</td>
<td>1870.0</td>
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<td></td>
<td>Snowmelt</td>
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<td>218.0</td>
<td>105.0</td>
<td>57.2</td>
<td>48.2</td>
<td>26.3</td>
<td>0.69</td>
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<td>2006-2007</td>
<td>Annual</td>
<td>49.7</td>
<td>1538.0</td>
<td>1019.5</td>
<td>963.5</td>
<td>66.3</td>
<td>62.6</td>
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<td>265.0</td>
<td>131.3</td>
<td>103.6</td>
<td>49.6</td>
<td>39.1</td>
<td>0.54</td>
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<tr>
<td>2007-2008</td>
<td>Annual</td>
<td>80.5</td>
<td>1083.0</td>
<td>472.9</td>
<td>458.3</td>
<td>43.7</td>
<td>42.3</td>
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<td>162.0</td>
<td>83.0</td>
<td>46.4</td>
<td>51.3</td>
<td>28.6</td>
<td>0.44</td>
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<td>2008-2009</td>
<td>Annual</td>
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<td>1263.0</td>
<td>596.7</td>
<td>539.4</td>
<td>47.2</td>
<td>42.7</td>
<td>3.32</td>
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<tr>
<td></td>
<td>Snowmelt</td>
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<td>202.0</td>
<td>55.3</td>
<td>29.4</td>
<td>27.4</td>
<td>14.5</td>
<td>0.29</td>
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<tr>
<td>2009-2010</td>
<td>Annual</td>
<td>92.5</td>
<td>1250.3</td>
<td>819.7</td>
<td>684.5</td>
<td>65.6</td>
<td>54.7</td>
<td>3.16</td>
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<td></td>
<td>Snowmelt</td>
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<td>260.3</td>
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<td>0.80</td>
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<td>Mean</td>
<td>Annual</td>
<td>76.9</td>
<td>1330.0</td>
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<td>57.3</td>
<td>57.0</td>
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<td></td>
<td>Snowmelt</td>
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<td>215.9</td>
<td>112.7</td>
<td>75.7</td>
<td>51.6</td>
<td>34.1</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Q : Streamflow, QR : Runoff ratio, QRA : Runoff ratio for annual period (Nov-Oct), QRS : Runoff ratio for snowmelt period (Nov-Apr), and RMSE : Root mean square error.
General Circulation Model (GCM)

IPCC AR5 model

<table>
<thead>
<tr>
<th>Model</th>
<th>Center</th>
<th>Country</th>
<th>Scenario</th>
<th>Grid size</th>
</tr>
</thead>
<tbody>
<tr>
<td>HadGEM3-RA</td>
<td>UKMO (UK Met. Office)</td>
<td>UK</td>
<td>RCP 4.5 (540 ppm)</td>
<td>$12.5\text{km} \times 12.5\text{km}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RCP 8.5 (940 ppm)</td>
<td>$(0.125^\circ \times 0.125^\circ)$</td>
</tr>
</tbody>
</table>

- **HadGEM3-RA**
  - Model Center: UKMO (UK Met. Office)
  - Country: UK
  - Scenarios: RCP 4.5 (540 ppm), RCP 8.5 (940 ppm)
  - Grid size: $12.5\text{km} \times 12.5\text{km}$

- **Weather station**
  - Locations: Various

- **Rainfall station**
  - Locations: Various
Bias correction

Before correction

![Before correction graphs for temperature and precipitation](image)

After correction

![After correction graphs for temperature and precipitation](image)
Climate Scenarios

Temperature (°C)

Precipitation (mm)

Humidity (%)

Wind speed (m/s)
## Climate Scenarios

<table>
<thead>
<tr>
<th>Period</th>
<th>Scenario</th>
<th>TMN (℃)</th>
<th>TMN difference (℃)</th>
<th>TMP (℃)</th>
<th>TMP difference (℃)</th>
<th>TMX (℃)</th>
<th>TMX difference (℃)</th>
<th>PCP (mm)</th>
<th>PCP variation (%)</th>
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<td>Baseline (1987~2010)</td>
<td>5.33</td>
<td>-</td>
<td>10.58</td>
<td>-</td>
<td>15.83</td>
<td>-</td>
<td>1292.9</td>
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<td>RCP 4.5 2040s</td>
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<td>16.94</td>
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<td><strong>Spring</strong></td>
<td>Baseline (1987~2010)</td>
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Climate Change Impact on Snowmelt (Nov- Apr)

- Change of future monthly snowmelt and streamflow

**Snowmelt**

- Big change in 2040 March
- Advanced by the future temperature increase

**Streamflow**

- Increased up to 55.4 mm in 2040s RCP8.5 and 55.9 mm in 2080s RCP8.5 scenario
Climate Change Impact on Water Quality

Runoff Characteristics of Nonpoint Source Pollution Loads

- The future sediment load showed general tendency of increase during snowmelt period.
- The future T-N & T-P loads showed clear increase in November, March, and April.
- Especially, the reason of future T-P decrease in Jan. and Feb. can be interpreted as follows:
  - By the water temperature increase in the future, the soluble phosphorus concentration (solP) in the stream may be decreased by the uptake of inorganic P by algae. In addition, the organic phosphorus mineralization rate and the organic phosphorus settling rate can be adjusted to the water temperature in the direction of decreasing solP.
Summary and Conclusion

- This study tried to determine the **SWAT snow depletion characteristics** and assess **future climate change impacts on snowmelt and the stream water quality** for a mountainous watershed using SWAT.

- The average value of SWAT SNO50COV was **0.47** in Chungju Dam watershed.

- The average runoff during snowmelt period (November-April) was **12.6 %** for the full period (November to October).

- The future snowmelt and streamflow increased up to **141.0%, 154.7%** respectively, and the **future melt was advanced compared to present**.

- The future SS, **T-N**, and **T-P loads also increased except January and February of some scenarios.**
“Thank You”

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