Evaluation of snowmelt contribution to streamflow in a heavy snowfall watershed of South Korea using SWAT model

17 June 2011

Hyung Jin SHIN
Post-doctoral researcher, Konkuk Univ., South Korea

Min Ji Park / Rim Ha / Jae Eung Yi / Gwang Seob Kim
Post-doctoral researcher / Researcher / Professor / Professor
Univ. of Massachusetts / KICT / Ajou Univ. / Kyungbook National Univ.

Seong-Joon KIM
Professor, Dept. of Civil & Environmental System Eng., Konkuk Univ., South Korea
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Introduction

- We have snowfall from the beginning of November to the first period of April.

- Three areas (Southwest-plain area, Northeast-mountainous area, and far East island) of South Korea usually have big snowfall up to 50 cm, 100 cm, 200 cm respectively. Recently since 2000, we suffer some unexpected heavy snowfall events in other areas except the above three areas.

- In our case, the heavy snowfall is treated as a natural disaster not for use as water resources. Thus, we have few studies for the snowmelt impact on streamflow (contribute about less than 5%) as a part of hydrology.

- SWAT has algorithms and parameters related with the snowmelt.

- We need our own snowmelt parameters. So, here by using the ground measured snowfall data and satellite snow cover area information, we can determine our parameters to simulate the snowmelt driven streamflow.

The objective of this study

- Is to determine the SWAT snowmelt related parameters using 9 years snowfall and Terra MODIS data and calibrate the streamflow during the snowmelt periods (March to April) for a mountainous watershed located in the northeastern part of South Korea.
Flowchart of Study

Observation data

- DEM, Landuse, Soil Map
- Weather and dam inflow
- Terra MODIS satellite images, Ground snowfall data

SAWT Hydrological Model
Calibration and Validation

Impact Assessment of Snowmelt on Streamflow

Snow depletion characteristics
Algorithm of snowmelt simulation in SWAT model (Degree-day Method)

\[ M = R_1(T_a - T_c) \]

- \( M \) is depth of melt water (mm)
- \( R_1 \) is melt rate (mm/day/°C)
- \( T_a \) is mean air temperature (°C)
- \( T_c \) is critical temperature (usually, 0 °C)
Study Watershed

- Study area: 2,694.4 km² forest-dominant (93 %) watershed
- The annual average precipitation is 1,359.5 mm, and the mean temperature is 9.4 °C over the last 30 years (1977 - 2006).
Elevation, Soil, Land Cover Data

**Elevation**
- range: 155 - 1,639 m
- average: 643.9 m

**Land use**
- The 9 categories
- prepared by 2000 Landsat TM (Thematic Mapper) supervised classification with NOAA NDVI

**Soil**
- loam (52.4 %), and loamy sand (42.4 %)
Material and Method

- **Input Datasets for Calibration and Validation of the SWAT Model**

  **Meteorological data**
  - Daily weather data (temperature, relative humidity, wind speed, sunshine hour) were collected from five stations (1998-2008)
  - Daily precipitation data were collected from eighteen stations (1998-2008)

  **Streamflow data**
  - Daily streamflow data at the three water level stations were obtained (1998-2008) from the Ministry of Construction and Transportation.
MODIS (Moderate Resolution Imaging Spectroradiometer)

- MODIS is one of four sensors carried on-board NASA's first Earth Observing System (EOS) satellite 'Terra'.
- The automated MODIS snow-mapping algorithm uses at-satellite reflectances in MODIS bands 4 (0.545-0.565 μm) and band 6 (1.628-1.652 μm) to calculate the normalized difference snow index (Hall, Riggs, & Salamonson, 1995)

SNOW COVER (Normalized Difference Snow Index)

- 1 day interval & 500 m resolution

\[
NDSI = \frac{\text{MODIS4} - \text{MODIS6}}{\text{MODIS4} + \text{MODIS6}}
\]
The generated snow depth distribution within the MODIS snow cover extent
Spatial distribution map of snow depth using GIS interpolation and MODIS SCA

- **IDW (Inverse Distance Weighting)**

  76 point data of snowfall
  - IDW Interpolation
  - DEM

  Snow cover area by MODIS

Spatial distribution of snow depth
**Spatial distribution of snow depth considering elevation effect**

IDW Interpolation

2001.12.25

2001.12.29

2001.01.02

2002.01.10

Considering elevation effect

2001.12.25

2001.12.29

2001.01.02

2002.01.10
2001-2002 Spatial distribution of snow depth

- The generated snow depth distribution within the MODIS snow cover extent using the ground-measured snowfall data
The watershed snow depth summary (1998-2008)

Average snow depth and temperature

Maximum (old-gray) and average (new-black) snow depth
Derivation of snow depletion curve

- **Maximum, minimum and mean snow depletion curve** (I chose the most left curve after calibration)
  - As the curve goes to the left, the snow is melt slowly.
Model Calibration and Validation for the Streamflow

- SWAT model setup process
  - No. of Subbasin: 20
  - No. of HRU: 348

- The calibrated model parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Calibration Range</th>
<th>Soyanggang Dam Default</th>
<th>Soyanggang Dam Optimal value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFTMP</td>
<td>Snowfall temperature (°C)</td>
<td>-5 ~ +5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>SMTMP</td>
<td>Snow melt base temperature (°C)</td>
<td>-5 ~ +5</td>
<td>0.5</td>
<td>0</td>
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<tr>
<td>SMFMX</td>
<td>Maximum snow melt factor (mm H2O/°C-day)</td>
<td>0 - 10</td>
<td>4.5</td>
<td>2</td>
</tr>
<tr>
<td>SMFMN</td>
<td>Minimum snow melt factor (mm H2O/°C-day)</td>
<td>0 - 10</td>
<td>4.5</td>
<td>1</td>
</tr>
<tr>
<td>TIMP</td>
<td>Snow pack temperature lag factor</td>
<td>0 - 1</td>
<td>1</td>
<td>0.05</td>
</tr>
<tr>
<td>SNOCOVM</td>
<td>Threshold depth of snow, above which there is 100% cover [mm]</td>
<td>0 ~ 500</td>
<td>50</td>
<td>500</td>
</tr>
<tr>
<td>SNO50COV</td>
<td>Fraction of SNOCOVM that provides 50% cover</td>
<td>0-1</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>PLAPS</td>
<td>Precipitation lapse rate (mm H2O/km)</td>
<td>0</td>
<td>5.33</td>
<td></td>
</tr>
<tr>
<td>TLAPS</td>
<td>Temperature lapse rate (°C/km)</td>
<td>0</td>
<td>-5.10</td>
<td></td>
</tr>
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</table>
Model Calibration and Validation for the Study Watershed

Calibration period (1999-2003: Full period)

Validation period (2004-2008: Full period)

<table>
<thead>
<tr>
<th>Year</th>
<th>$R^2$</th>
<th>RMSE (mm/day)</th>
<th>NSE</th>
</tr>
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<tbody>
<tr>
<td>2000-01</td>
<td>0.75</td>
<td>2.9</td>
<td>0.74</td>
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<tr>
<td>2001-02</td>
<td>0.86</td>
<td>1.9</td>
<td>0.97</td>
</tr>
<tr>
<td>2002-03</td>
<td>0.66</td>
<td>5.5</td>
<td>0.66</td>
</tr>
<tr>
<td>2003-04</td>
<td>0.64</td>
<td>5.3</td>
<td>0.64</td>
</tr>
<tr>
<td>2005-06</td>
<td>0.55</td>
<td>3.0</td>
<td>0.21</td>
</tr>
<tr>
<td>2006-07</td>
<td>0.82</td>
<td>5.6</td>
<td>0.80</td>
</tr>
<tr>
<td>2007-08</td>
<td>0.69</td>
<td>4.3</td>
<td>0.67</td>
</tr>
<tr>
<td>2008-09</td>
<td>0.69</td>
<td>3.9</td>
<td>0.68</td>
</tr>
<tr>
<td>Average</td>
<td>0.71</td>
<td>4.1</td>
<td>0.67</td>
</tr>
</tbody>
</table>
- The 2001 calibrated streamflow considering the snowmelt parameters
The 2001 calibrated streamflow considering the snowmelt parameters
Summary and Conclusions

- This study tried to identify the SWAT snow depletion characteristics for a mountainous watershed (2,694.4 km\(^2\)) located in the northeastern part of South Korea using the 8 years (2000-2008) sets of snow depth distribution information.

- Through understanding the characteristics of our snow depletion using Terra MODIS data, we could simulate the snowmelt driven streamflow better than before.
Thank you
For your attention