Assessment of Agricultural Water Supply Capacity Using SWAT and MODSIM models

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Introduction (Why this study?)

- The acute agricultural water shortage from drought is becoming a serious problem in South Korea where the water is of the essence from agriculture of mainly rice farming.
  - The agricultural water shortage of irrigation per area in our country is considerably vulnerable to drought.
  - It required a lot of efforts for securing agricultural water of irrigation facilities to flow from the water rich region into the water shortage region or store water in a reservoir to solve perennial problem of water shortage.

- The assessment of the water shortage that is due to short supply according to water demand is obtained from water balance analysis.

- The purpose of this study is to assess the agricultural water supply capacity for Geum River basin, where includes 2 multipurpose dams of South Korea using SWAT and MODSIM models.
5 River Basins of South Korea

- 5 River basins in our country (Han, Geum, Yeongsan, Seomjin and Nakdong)
- The global warming is now warning the management of streamflow (intensify drought and flood)
- Need to evaluate the water supply capacity by water balance analysis
- From the evaluation, find out some insight and prepare proper direction of water management system
A total of 67,582 irrigation facilities (reservoirs, pumping stations, diversion weirs, culverts, groundwater wells) in South Korea are being managed by both Korea Rural Community Corporation and local governments.
Research Procedure

Meteorological Data
- Weather data (2001-2011)
- Streamflow data (2001-2011)

GIS Data
- DEM, Soil, Land use

Multipurpose Dam Data
- 2 Multipurpose dams (2001-2011)
  - Water level, storage, release
  - Area-level and storage-level

Model Setup
SWAT Model
- Calibration (2005-2007) and validation (2008-2010)
- Dam operation (2005-2010)

Agricultural Irrigation Facilities
- Agricultural reservoir
- Pumping station, weir, culvert, well

Water Supply
- Inflow (2004-2011)

Water Demand
- Municipal, industrial and agricultural water

Water Supply Network
- Water balance analysis (2004-2011)
- Assessment of agricultural water supply capacity

Dam Operation Data
- 2 Multipurpose dams
  - Target storage
Third largest river of five rivers (Han, Nakdong, Geum, Yeongsan, Seomjin) in South Korea

Geum River basin (9645.5 km²)

- Average precipitation 1323.1 mm
- Average temperature 12.2 °C
**Water balance**

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

- \( SW_t \) = 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)

**Reservoir**

\[ V = V_{stored} + V_{flowin} - V_{flowout} + V_{pcp} - V_{evap} - V_{seep} \]

- \( V \) = volume of water in the impoundment at the end of the day (m3H2O)
- \( V_{stored} \) = volume of water stored in the water body at the beginning of the day (m3 H2O)
- \( V_{flowin} \) = volume of water entering the water body during the day (m3 H2O)
- \( V_{flowout} \) = volume of water flowing out of the water body during the day (m3 H2O)
- \( V_{pcp} \) = volume of precipitation falling on the water body during the day (m3 H2O)
- \( V_{evap} \) = volume of water removed from the water body by evaporation during the day (m3 H2O)
- \( V_{seep} \) = volume of water lost from the water body by seepage (m3 H2O).
Data for SWAT Model evaluation

GIS data

Elevation: 8 - 1609m (average: 224.3m)

Soil: Loam (24%) and sandy loam (58%)

Land cover (2008): Forest (62%) and Paddy rice (15%)
Data for SWAT Model evaluation

2 Multipurpose dam data (area-level and storage-level relationship curve)

- **Daecheong dam (DC)**
  - Total storage: 1,490 m³
  - Area: 3,204 m³

- **Yongdam dam (YD)**
  - Total storage: 815 m³
  - Area: 930 m³
Data for SWAT Model evaluation

2 Multipurpose dam data (release and storage: 2001-2011)

Yongdam dam (YD)

Daecheong dam (DC)
Model calibration and validation

Fitted results of 2 dams storage and input parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Definition</th>
<th>Multipurpose Dams</th>
</tr>
</thead>
<tbody>
<tr>
<td>IYRES</td>
<td>Year the reservoir became operational</td>
<td>YD</td>
</tr>
<tr>
<td>RES_ESA</td>
<td>Reservoir surface area when the reservoir is filled to the emergency spillway (km²)</td>
<td>37.0</td>
</tr>
<tr>
<td>RES_EVOL</td>
<td>Volume of water needed to fill the reservoir to the emergency spillway (10⁶m³)</td>
<td>815.0</td>
</tr>
<tr>
<td>RES_PSA</td>
<td>Reservoir surface area when the reservoir is filled to the principal spillway (km²)</td>
<td>33.9</td>
</tr>
<tr>
<td>RES_PVOL</td>
<td>Volume of water needed to fill the reservoir to the principal spillway (10⁶m³)</td>
<td>742.5</td>
</tr>
<tr>
<td>RES_VOL</td>
<td>Initial reservoir volume (10⁶m³)</td>
<td>479.5</td>
</tr>
<tr>
<td>RES_K</td>
<td>Hydraulic conductivity of the reservoir bottom (mm/hr)</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Model calibration and validation

Observed vs. simulated streamflow results of model calibration and validation


### Calibration and Validation Periods

- **Calibration period**
  - $R^2$: 0.58 / ME: 0.53

- **Validation period**
  - $R^2$: 0.66 / ME: 0.63

- **Calibration period**
  - $R^2$: 0.88 / ME: 0.87

- **Validation period**
  - $R^2$: 0.58 / ME: 0.53
MODSIM Model

- **MODSIM - DSS**: a generalized river basin Decision Support System and network flow model developed at Colorado State University designed specifically to meet the growing demands and pressures on river basin management.

- Reservoir operation, watershed management, and drought management planning.
MODSIM Model

MODSIM network structure with artificial nodes and links

<table>
<thead>
<tr>
<th>Icon</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Reservoir" /></td>
<td>▪ Main-stream reservoir operation</td>
</tr>
<tr>
<td><img src="image" alt="NonStorage" /></td>
<td>▪ Watershed runoff</td>
</tr>
<tr>
<td><img src="image" alt="Demand" /></td>
<td>▪ Tributary inflow</td>
</tr>
<tr>
<td><img src="image" alt="Flowthru" /></td>
<td>▪ Consumptive demand</td>
</tr>
<tr>
<td><img src="image" alt="NetworkSink" /></td>
<td>▪ Nonconsumptive demand</td>
</tr>
<tr>
<td><img src="image" alt="NetworkSink" /></td>
<td>▪ River basin outlet</td>
</tr>
<tr>
<td><img src="image" alt="Link" /></td>
<td>▪ Channel losses</td>
</tr>
</tbody>
</table>
Agricultural irrigation facilities

- Agricultural reservoirs
- Pumping stations
- Diversion weirs
- Culverts
- Groundwater wells

Agricultural water supply network

Agricultural water supply (SWAT output)

Municipal & industrial water supply (SWAT output)

Agricultural water demand
Data for MODSIM Model evaluation

Water supply (Inflow) and water demand (Municipal, industrial and agricultural water)

Water supply (SWAT output)

- Inflow of watershed (80%)
- Inflow of agricultural reservoir (20%)

Water demand

- Agricultural (64%)
- Municipal & Industrial (36%)

Map showing Daecheong Dam and Yongdam Dam.
Agricultural irrigation facilities

- Agricultural reservoirs, Pumping stations, Weirs, Culverts, Wells

![Map showing locations of Daecheong Dam and Yongdam Dam with charts illustrating reservoir and water storage data.](image-url)
## Water balance analysis

<table>
<thead>
<tr>
<th>Year</th>
<th>Municipal and industrial water</th>
<th>Agricultural water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand (10^6 m³)</td>
<td>Supply (10^6 m³)</td>
</tr>
<tr>
<td>2004</td>
<td>872.0</td>
<td>870.4</td>
</tr>
<tr>
<td>2005</td>
<td>872.0</td>
<td>865.7</td>
</tr>
<tr>
<td>2006</td>
<td>872.0</td>
<td>865.7</td>
</tr>
<tr>
<td>2007</td>
<td>872.0</td>
<td>870.7</td>
</tr>
<tr>
<td>2008</td>
<td>872.0</td>
<td>863.9</td>
</tr>
<tr>
<td>2009</td>
<td>872.0</td>
<td>856.2</td>
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<tr>
<td>2010</td>
<td>872.0</td>
<td>871.8</td>
</tr>
<tr>
<td>2011</td>
<td>872.0</td>
<td>871.3</td>
</tr>
</tbody>
</table>

- **Shortage above 282 10^6 m³**
## Water balance analysis

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Municipal and industrial water</th>
<th>Agricultural water</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand ($10^6$ m$^3$)</td>
<td>Supply ($10^6$ m$^3$)</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>3001</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>3002</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>3003</td>
<td>4.1</td>
<td>3.6</td>
</tr>
<tr>
<td>3004</td>
<td>25.2</td>
<td>25.2</td>
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<tr>
<td>3005</td>
<td>7.0</td>
<td>6.4</td>
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<tr>
<td>3006</td>
<td>5.0</td>
<td>5.0</td>
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<tr>
<td>3007</td>
<td>10.3</td>
<td>10.2</td>
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<tr>
<td>3008</td>
<td>40.3</td>
<td>40.3</td>
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<tr>
<td>3009</td>
<td>262.6</td>
<td>262.6</td>
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<tr>
<td>3010</td>
<td>11.2</td>
<td>11.2</td>
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<tr>
<td>3011</td>
<td>293.3</td>
<td>289.8</td>
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<tr>
<td>3012</td>
<td>79.8</td>
<td>79.8</td>
</tr>
<tr>
<td>3013</td>
<td>39.1</td>
<td>39.0</td>
</tr>
<tr>
<td>3014</td>
<td>20.4</td>
<td>20.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>813.9</strong></td>
<td><strong>809.2</strong></td>
</tr>
</tbody>
</table>
Assessment of impact on agricultural water supply capacity


2006:
- June: 6.4, 25.6, 7.3, 1.9, 5.8, 8.7
- July: 2.1, 3.2, 1.4, 4.1
- August: 27.7, 8.6, 8.8, 3.7, 3.6, 5.7
- September: 5.1

2008:
- June: 49.4, 6.8, 6.6, 7.5, 0.6
- July: 0.8, 0.2, 0.9
- August: 25.2, 11.6, 1.5, 4
- September: 29.8, 4.1, 6.1

2009:
- June: 60.5, 26.2, 7.5, 0.9, 7.9
- July: 3.5, 13.8, 10.3
- August: 15.2, 4.1
- September: 28.9, 6.6, 16.7

Legend:
- No shortage
- 1 – 10
- 10 – 20
- 20 – 30
- 30 – 40
- 40 – 50
- 50 – 60
- Above 60

Agricultural Shortage (10^6 m³)

Daecheong Dam
Yongdam Dam
Assessment of impact on agricultural water supply capacity


- **Water supply capacity (2004~2011)**
  - Municipal and industrial water 98.5%, Agricultural water 86.4%
- **Water supply capacity (drought period)**
  - 2006: Agricultural water 81.6%
  - 2008: Agricultural water 81.5%
  - 2009: Agricultural water 78.5%
Summary & Concluding remarks

- The agricultural water demand and supply capacity were evaluated by SWAT streamflow routing and MODSIM water balance networks
  - The SWAT was calibrated using the observed dam inflow data
  - The simulated streamflow using SWAT model is used to inflow for each watershed as an input data of MODSIM model.
  - Using MODSIM model, water balance networks that consider agricultural irrigation facilities were designed for the Geum River basin.

- By MODSIM run for 8 years from 2004 to 2011, the agricultural water shortage had occurred during the drought years of 2006, 2008, and 2009.

- The agricultural water shortage could be calculated as $282 \times 10^6 \text{m}^3$, $286 \times 10^6 \text{m}^3$, and $329 \times 10^6 \text{m}^3$ respectively.

- The results of this research should be identified and incorporated into water resources planning and management in order to promote more sustainable water demand and water availability for a stream watershed of our country.
Thank you

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