Sensitivity of Reservoir Storage to Climate Change in a Water-limited River Basin

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Introduction

Motivation: During the past several decades, numerous reservoirs have been constructed for various water management purposes throughout the world. According to Chao et al. (2008), the global accumulative reservoir impounded water volume reached 11,000 km³ in 2007. With global environmental and anthropogenic change, great challenges have posed on the reservoir systems. However, our understanding of the intricate processes of water regulated flows is still critically limned by following reasons:

- For those few hydrological models which have a explicit reservoir component, the operation rules are typically optimized and rather simple;
- Water management models intend for use of historical inflows for decision making, while the potential alterations of future hydrological processes are often ignored;
- Commercial models are not suitable for public scientific research due to unavailability.

Objective: Develop a reservoir module using condition rules to integrate it with an open source physically based distributed hydrologic model, and use this powerful modeling tool to assist decision making related to reservoirs under changing environment.

Modeling Approach

Distributed Hydrology Soil Vegetation Model (DHSVM)

- Fully distributed hydrological model
- Open source
- Physically based with simulation of: Topography, Soil Vegetation, Sediment
- Full water-energy balance simulation
- High spatial-temporal resolution
- Detaled urban component
- Reservoir module (from this study)

Reservoir Module

A point reservoir module was developed and coupled to DHSVM. At each time step, the simulation involves three components:

- Reservoir Rating Curves

As the largest of all 28 reservoirs (by storage capacity) in the Brazos River Basin, Lake Whitney plays an essential role in the water resources management of Central Texas. After construction, it significantly reduced flood damage in the Brazos River Basin. Figure 1(left), (a) and (b) Temporally based basin discretization and water movement in DHSVM (Wigmosta et al., 1994); (c) the newly integrated multi reservoir module with each pool.

Figure 1. (left) a) Temporal based basin discretization and water movement in DHSVM (Wigmosta et al., 1994); (b) the newly integrated multi reservoir module with each pool.

Study Area

Lake Whitney watershed in the Brazos River Basin, Texas. Confluence of Brazos River with Bosque River was chosen as the outlet and USGS gauge 06091000 was chosen as the intial.

Figure 4. Lake Whitney watershed in the Brazos River Basin. Texas. Confluence of Brazos River with Bosque River was chosen as the outlet and USGS gauge 06091000 was chosen as the intial.

Table 1. Reservoir configuration of Lake Whitney and Aquilla Lake

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Lake Whitney</th>
<th>Aquilla Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main purpose</td>
<td>flood control, municipal</td>
<td>flood control</td>
</tr>
<tr>
<td>Date</td>
<td>December 10, 1951</td>
<td>April 28, 1983</td>
</tr>
<tr>
<td>Storage Elev. (m)</td>
<td>13.69</td>
<td>15.84</td>
</tr>
<tr>
<td>Storage Elev. (m)</td>
<td>31.70/10°</td>
<td>34.30/10°</td>
</tr>
<tr>
<td>Storage Elev. (m)</td>
<td>6.64/10°</td>
<td>7.25/10°</td>
</tr>
<tr>
<td>Inactive pool</td>
<td>136.79</td>
<td>162.46</td>
</tr>
<tr>
<td>Conservaion pool</td>
<td>155.45</td>
<td>163.80</td>
</tr>
<tr>
<td>Frustration pool</td>
<td>189.47</td>
<td>197.04</td>
</tr>
</tbody>
</table>

Results and Discussions

Calibration and validation

- Precipitation effects:
  - Precipitation has larger effect (Fig 6a) on reservoir storage and release than temperature (Fig 6c).
  - Elasticity values are higher with increase in precipitation for both reservoir storage and release. However, precipitation elasticity is not always linearly correlated with the percentage change of precipitation.

Temperature effects

- The trend in temperature sensitivity is similar to precipitation elasticity except that the values are all negative.
- Higher temperature will make the evapotranspiration larger, which leads less runoff from the same amount of precipitation.

Summary

- A new reservoir module is integrated into an open source distributed hydrologic model.
- The newly integrated model is able to capture the hydrologic characteristics of the reservoir systems at a sub-monthly time step.
- Precipitation has a larger effect on reservoir storage and release than temperature does.
- Positive trends are observed in precipitation elasticity and temperature sensitivity.
- Precipitation elasticity always positive and temperature sensitivity is always negative.

References


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