Calibration optimization of a stream temperature model applied to the Nooksack River

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1. Introduction
The River Basin Model (RBM) is used to assess how stream temperatures will change in the Nooksack River due to warming climates. Before modeling forecasted climate scenarios, I first calibrated the model to observed historical stream temperatures. The calibration of the RBM to a stream network involves the adjustment of many different variables until the simulated temperatures match the observed historical stream temperatures. Because the manual process of calibrating the model is extremely time consuming, I developed a Python script to converge on the optimal variables required for the RBM calibration.

I used my optimization script to calibrate the RBM in each of the three sub-basins in the Nooksack River basin: the South Fork, Middle Fork, and the North Fork. I used outputs from hydrology models produced by Murphy (2016) as inputs to the RBM and calibrated to observed temperatures from USGS gauges in each of the sub-basins (Figure 1).

2. Modeling Tools

Hydrology modeling using the DHSVM

The hydrology of the basin was simulated using the Distributed Hydrology Soil Vegetation Model (DHSVM, Wigmosta et al., 1994). The DHSVM is a physical based model that performs an energy and mass balance at the grid scale. Using digital spatial characteristics and meteorological inputs, the DHSVM simulates streamflow at thousands of stream segments (Figure 2).

Stream temperature modeling using the RBM

DHSVM stream discharge, energy, and riparian vegetation characteristics at each stream segment are used as inputs to the RBM (Figure 3).

The RBM is a semi-Lagrangian, one-dimension model that is scalable in space and time (Yearsley, 2009; Sun et al., 2014). The model requires initial headwater temperatures that are estimated using Mohseni parameters. Stream velocities and depths and required for each stream segment and are estimated from the DHSVM discharge values using Leopold parameters.

3. RBM Calibration

Calibration of the RBM requires the manipulation of eleven variables until the simulated stream temperatures match observed stream temperatures within statistical thresholds. Observed stream temperatures were collected at four USGS stream gauge sites (Figures 1 & 2).

The dominant calibration variables are those in the Mohseni relation used to estimate the initial headwater temperatures \(T_{0}(\tau)\), and the Leopold parameters used to estimate the stream velocity and depth from the DHSVM discharge values.

4. Optimization Script

The Python script changes each of the eleven variables based on initial values set by the user and pre-determined maxima and minima (Table 1). The script will adjust the variables until it hits either the imposed limits or until it detects that the summer NSE value begins to decrease. This script is run three times per basin, one with the variables set to their maximum and decreasing, one with the variables set to their minimum and increasing, and one with the variables set at the midpoint. This helps to correct for the possibility of a bimodal distribution in the summer NSE values.

The algorithm steps through the list of variables by first changing Tau until the summer NSE decreases. Then, the algorithm varies Alpha until the statistics begin to decrease, then it adjusts the Tau value to ensure that it is still the optimal value. It then changes Beta, then Alpha, Tau, etc., until it changes each variable and each is at the optimal point, the algorithm ends. The process takes about 12 hours per basin.

5. Calibration Results

Overall, the Python optimization script converged to values within the minima and maxima thresholds for all eleven RBM calibration variables at all four sites in the Nooksack River (Table 2). The comparative statistics in all cases are rated as good to very good according to the performance criteria outlined by Moriasi et al. (2007). Table 3. More importantly, the statistical accuracy improves during the critical summer months, when the temperatures increase. Note that the highest stream temperatures are in South Fork. Elevations in the South Fork Basin reach about 2000 meters where snowpack melts out relatively early in the spring. The headwaters of the Middle Fork and North Fork are in the high snow fields and glacier areas of Mt. Baker, producing cool meltwater late into the summer months, keeping the streams cooler.

6. Future Work

Following the methods of Truitt (2018), the calibrated models will be used with forecasted climate data to simulate the hydrology and stream-temperature response in the three forks of the Nooksack River into the 21st century. We will use forecasted meteorological data from 10 global climate models of the CMIP5 with RCP4.5 and RCP8.5 forcing scenarios. Outputs will be analyzed with R scripts to assess hydrology and stream temperature trends in 30-year intervals surrounding 1996 (hindcast) 2025, 2050 and 2075.

Acknowledgements

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Table 1: The starting values for each RBM calibration variable for a midpoint trial.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
<th>Starting/Current Value</th>
<th>Step Change</th>
<th>Increase/Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha</td>
<td>13.95</td>
<td>16.89</td>
<td>15.86</td>
<td>2</td>
<td>Increase</td>
</tr>
<tr>
<td>Beta</td>
<td>0.85</td>
<td>1.4</td>
<td>1.15</td>
<td>0.05</td>
<td>Increase</td>
</tr>
<tr>
<td>Gamma</td>
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<td>0.25</td>
<td>0.15</td>
<td>0.05</td>
<td>Increase</td>
</tr>
<tr>
<td>Tau</td>
<td>1.0</td>
<td>1.5</td>
<td>1.25</td>
<td>0.25</td>
<td>Increase</td>
</tr>
<tr>
<td>A</td>
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<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
<td>Increase</td>
</tr>
<tr>
<td>B</td>
<td>0.5</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
<td>Increase</td>
</tr>
<tr>
<td>C</td>
<td>0.5</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
<td>Increase</td>
</tr>
<tr>
<td>D</td>
<td>0.5</td>
<td>2.0</td>
<td>1.0</td>
<td>0.5</td>
<td>Increase</td>
</tr>
</tbody>
</table>

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References


Murphy, R., 2016, Modeling the Effects of Forecasted Climate Change and Glacier Recession on Late Summer Streamflow in the Upper Nooksack River Basin: WWU Graduate Student Collection. https://cedar.wwu.edu/wwuet/642.