H23E-1619: Examination of different water balance models for use with tree-ring proxy records to extend hydroclimatic records

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Introduction
Tree-ring data can be used to provide longer views of past variability of streamflows, but when used as input to a mechanistic hydrologic approach, examination of factors that may affect streamflow independently of climate is possible. Selection of an appropriate model to use in this situation requires consideration of the number of coefficients, and the ability to provide reasonable estimates with just precipitation and air temperature inputs. In this study, we examined two seasonal water balance models for application with proxy inputs of precipitation and air temperature: a Thornthwaite model modified to operate on a seasonal timescale, and a simple water balance model with a snow component.

The models
Model A: The Thornthwaite seasonal model is a modification of the Thornthwaite monthly water balance model that allocates water among various components of the hydrologic system (Fig. 1; McCabe and Wolock 1999; McCabe and Markstrom 2007; Thornthwaite 1948).

Model B: The simple water balance model was modified from that used by Saito et al. (2008) to include a snow component from the Water and Snow Balance Modeling system (WASMOD; Fig. 2; Xu 2002).

Study area
The models were applied to the upper West Walker River watershed upstream of the Coleville USGS streamflow gage (Station 10296000; Fig. 3). The watershed has an area of 490 km² and is located in California and Nevada at elevations ranging from 2000 m to over 3700 m. Average annual precipitation is about 230 mm at the lower elevations, and annual snowfall is about 1100 mm at the higher elevations. According to Parameter Estimation: Regressions on Independent Slopes (PRISM; Daly et al. 1994) information for the cells over the watershed, average monthly temperatures range from −10°C in February to 23°C in July.

Approach
Snow equations (see Table 1 for parameter descriptions)

**MODEL A:**
1. \( P = P_{\text{rain}} + \frac{\text{G} \cdot \text{TMax}}{\text{PrayMax}} \)
2. \( P = P_{\text{snow}} + P_{\text{rain}} \)
3. \( DRO = P_{\text{snow}} - \text{DRO} \)
4. \( P_{\text{Marker}} = P_{\text{rain}} - \text{DRO} \)
5. \( \text{SMF} = \frac{\text{SM Max} \cdot \text{PrayMax}}{\text{SM Max} - \text{SM Min}} \)
6. \( \text{SN} = \frac{\text{SM} \cdot \text{PrayMax}}{\text{SM Max} - \text{SM Min}} \)

**MODEL B:**
1. \( R_i = \text{SN} \)
2. \( M_i = \text{SN} \cdot \text{PrayMax} \cdot \text{PrayMax} \)

Calibration/validation of models with PRISM inputs
- Divided daily streamflow record
  - Used WY 1940-1978 for calibration, WY 1979-2011 for validation
  - Used WY 1979-2011 for reverse calibration, WY 1940-1978 for reverse validation
  - Used shuffled complex evolution (SCE) with objective to minimize root mean squared error (RMSE)
  - Examined appropriate temperature (min, max, avg) to use as model input
  - Examined performance for cold-wet (Oct-Mar) and warm-dry (Apr-Sep) seasons

Seasonal proxy data preparation
- WY proxy precipitation: Regressed PRISM precipitation for WY 1986-2001 against precipitation standard deviation units from Biondi et al. (2008)
- Disaggregated to seasonal values using ratios of warm-dry season by precipitation quartiles based on PRISM 1940-2011 data
- WY proxy temperature: Regressed PRISM temperature for WY 1986-1990 against temperature anomalies from Wahl and Smerdon (2012) for grid cell nearest to West Walker River basin
- Disaggregated to seasonal values using linear regression coefficients between PRISM average WY temperatures and PRISM warm-dry or PRISM cold-wet seasonal temperatures for 1986-1990

Reconstruction
- Reconstructed WY streamflow, April 1 snow water equivalence, and actual evapotranspiration for 1500-1890 with best-performing model

Results and discussion
Both models performed well with PRISM inputs (Table 2; Fig. 4). Model performance was worse during the cold-wet season compared to the warm-dry season.

Model performance worsened with proxy inputs (Table 3), but remained better than a previous reconstruction by Gray and McCabe (2010) for the Upper Yellowstone drainage. Estimation of average annual actual evapotranspiration (AET) with Model A for the calibration period was 36.2 cm, which compared well with estimated mean AET of 31-40 cm for Mono County, CA (Sanford and Selnick 2013).

Overall, Model A performed slightly better and was used to reconstruct streamflow with proxy inputs from 1500 to 1890 (Fig. 5). Future work involves improving seasonal proxy inputs, and exploration of better approaches for simulating AET with only precipitation and air temperature inputs.

**Table 1. Parameters in Models A and B**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
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<tbody>
<tr>
<td>( P_{\text{rain}} )</td>
<td>total seasonal precipitation</td>
</tr>
<tr>
<td>( P_{\text{snow}} )</td>
<td>snow precipitation</td>
</tr>
<tr>
<td>( T )</td>
<td>seasonal temperature</td>
</tr>
<tr>
<td>( T_{\text{snow}} )</td>
<td>temperature threshold below which all precipitation is snow</td>
</tr>
<tr>
<td>( T_{\text{dry}} )</td>
<td>temperature threshold above which all precipitation is rain</td>
</tr>
<tr>
<td>( DRO )</td>
<td>direct runoff</td>
</tr>
<tr>
<td>( T_{\text{dry frac}} )</td>
<td>fraction of ( P_{\text{rain}} ) that becomes runoff</td>
</tr>
<tr>
<td>( P_{\text{Marker}} )</td>
<td>remaining precipitation after runoff removed</td>
</tr>
<tr>
<td>( \text{SMF} )</td>
<td>fraction of snow storage that melts</td>
</tr>
<tr>
<td>( \text{SN} )</td>
<td>snow water equivalence (SWE)</td>
</tr>
<tr>
<td>( \text{SM} )</td>
<td>accumulation of snow as a proxy for water stored as snow (SSW)</td>
</tr>
<tr>
<td>( R_i )</td>
<td>seasonality (rainfall)</td>
</tr>
<tr>
<td>( M_i )</td>
<td>seasonality (snow)</td>
</tr>
<tr>
<td>( \text{RMSE} )</td>
<td>overall error</td>
</tr>
<tr>
<td>( \text{NSE} )</td>
<td>Nash-Sutcliffe Efficiency</td>
</tr>
<tr>
<td>( \text{Bias} )</td>
<td>bias</td>
</tr>
</tbody>
</table>

**Table 2. Performance metrics of Models A and B with PRISM inputs for calibration period (X: WY 1940-1978); validation period (Y: WY 1979-2011).**

**Table 3. Performance metrics of Models A and B with proxy inputs calibrated for WY 1940-1996.**

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References


