Developing a water balance model approach with tree-ring records to reconstruct past streamflow in the upper Walker River basin

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Abstract:
Understanding historic streamflows can be useful for determining regional patterns of climate and streamflow trends, yet measured streamflow data in the western U.S. is typically either unavailable or cover less than 100 years. Regressions of observed streamflows against tree-ring data, which serve as proxies for streamflow, can be used to extend the measured record. This empirical approach cannot, however, test or account for factors that do not directly affect streamflow, but which may influence streamflow. To reconstruct past streamflows in a more mechanistic way, a seasonal water balance model has been developed for the Upper West Walker River basin that can use proxy precipitation and air temperature data derived from tree-ring records. The model incorporates simplistic relationships between temperature, precipitation, and other components of the hydrologic cycle, and operates at a seasonal time scale. An advantage of this approach is the ability to investigate sources of uncertainty in streamflow reconstructions by manipulating various hydrologic processes and land-use characteristics. The model also allows investigation of how climate-independent factors such as changes in land-use could influence estimates of past flows, something regression-based models are not able to do. In addition, use of a mechanistic water balance model with proxy climate reconstructions can provide useful information on changes in various components of the water cycle, including the interaction between runoff, snowmelt, and evapotranspiration under warmer climatic regimes.

Methods:
Modeling began with an initial model investigation for appropriate water balance models. Models were deemed appropriate based on:
• Seasonal temperature calculations
• Snow component inclusion
• Minimal parameters
Models were then narrowed down to simple models with:
• Water and Snow Model (WASMOD) snow calculations
• Thornthwaite snow calculations

Results:
Comparison between models using both WASMOD and Thornthwaite snow components, with three temperature schemes representing average minimum, average maximum, and average seasonal temperature for wet (Oct-Mar) and dry (Apr-Sept) seasons was done over 500 model runs. Model results (Table 1) were then averaged, showing the simple water balance model incorporating the WASMOD snow component with minimum seasonal temperature performing the best. When compared to regression (tree-ring) reconstructions, the WASMOD with minimum temperature had an R² of 0.46, compared to R² of 0.42. This model showed over and under prediction (±% bias) of seasonal streamflow less than 17% and had the lowest root mean squared error of 0.173.2. Modeled streamflow plotted against observed streamflow between 1939 and 2007 shows the wet and dry season trends (Figure 4).

Conclusions:
Model investigation indicated that use of a mechanistic modeling approach is appropriate for reconstructing past streamflow, and this approach performed better (R² = 0.49) than current regression (tree-ring) reconstructions (R² = 0.42). An approach such as this shows promise for enabling water resource managers to predict high or low streamflow using annually or seasonally resolved proxy records of climate as model input, and can be utilized to evaluate influences from physical factors influencing streamflow such as wildfire or changes in land-use. Future work includes further evaluation of influence by historic wildfire in the Upper Walker River basin on streamflow, improvement of proxy (tree-ring) data, and analysis of seasonal temperature correlations to improve modeled streamflow reconstructions.

Study Site:
The Walker River watershed originates in the eastern Sierra Nevada mountain range west of Bridgeport, CA, crossing over the California border into Nevada, and terminating at Walker Lake, NV (Figure 1). The majority of the streamflow originates as snowmelt from the Sierra Nevada, which provides water storage for surrounding and downstream irrigated agriculture as well as water for recreation and fisheries, among other uses. Precipitation in this basin is primarily in the form of snow. Climate plays a huge role in watershed function and streamflow, and climate change effects are predicted to greatly influence water resource scarcity in the western U.S. (Seager et al. 2007)

Research Questions:
1) Can a mechanistic watershed model reproduce streamflows as well as traditional regression approaches?
2) Can the mechanistic watershed model be used to evaluate effects of natural disturbances such as wildfire or vegetation dynamics, on streamflows?

Preliminary Wildfire Model Results:
GIS analysis of available records did not identify any major wildfires within the Upper Walker Watershed for the period between 1961 to 2005. Locations of wildfire are distributed throughout the watershed across 44 years. The concentration of fires are located in the northern part of the watershed. downstream.

References:

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Acknowledgements:
Research support provided by:
Dr. Franco Biondi, DendroLab, University of Nevada, Reno
Scotty Strachan
Kurt Solomonsen

This material is based upon work supported by the National Science Foundation under Grant No. ATM-0823480

Figures:
1. Water balance model schematic
2. Collecting living samples, Walker River basin.
3. Observed streamflow using total seasonal discharge at U.S.GS, Carlin, NV 1033600, plotted with streamflow from the simple model and WASMOD snow component and minimum seasonal temperature between 1939 to 2007. Modelled streamflow was obtained using parameter table averages from 500 runs using Excel Solver generating random initial parameter values, in concert with 1939 to 2007 seasonal precipitation and air temperature data generated from PRISM.
4. Observed streamflow using total seasonal discharge at U.S. GS, Carlin, NV 1033600, plotted with streamflow from the simple model and WASMOD snow component and minimum seasonal temperature between 1939 to 2007. Modelled streamflow was obtained using parameter table averages from 500 runs using Excel Solver generating random initial parameter values, in concert with 1939 to 2007 seasonal precipitation and air temperature data generated from PRISM.
5. Modeled streamflow compared to the Upper Walker River watershed. GIS analysis of available records did not identify any major wildfires within the Upper Walker Watershed for the period between 1961 to 2005. Locations of wildfire are distributed throughout the watershed across 44 years. The concentration of fires are located in the northern part of the watershed, downstream.
7. Modeled wildfires located in the Upper Walker River Watershed.