

Evaluation of Interdecadal Drought Variability Using Reconstructed Streamflow Data

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Abstract

The evaluation of long-term drought variability was investigated for the Colorado River basin using instrumental and reconstructed streamflow data. Streamflow data was reconstructed for the past 500 years in the Colorado River Basin using Partial Least Squares Regression (PLSR). The occurrence of past drought events is also presented for 17 streamflow stations in the basin. Results indicated that the 1500's through the 1800's had more droughts than the 1900's. In addition, the worst drought years were in the late 1500's.

Introduction

Hydrologic drought in the western U.S. has always been important and has been highlighted in recent years due to the drought that started in 2000 and continues. Hydrologic drought is typically measured with streamflow data and long term records are used based on reconstruction of streamflow using tree-ring data. There are a variety of methods available to reconstruct hydroclimatic variables from tree-ring data. Multiple linear regression and principal component regression have been used for developing reconstruction models (e.g., Hidalgo et al. 2000; Woodhouse et al. 2006). However, another method available for reconstruction of hydroclimate data is partial least square regression (PLSR) which combines the features from principal component regression and multiple linear regression (Ablitt et al., 2004). The objective of the research presented was to evaluate the long-term drought variability in the entire Colorado River basin. PLSR with the cross validation technique based on the absolute value of correlation was used for the reconstruction of streamflow.

Data

Unimpaired streamflow stations for the Upper and Lower Colorado River basin were obtained from the United States Geological Survey (USGS), Hydro-Climate Data Network (HCDN) website (http://pubs.usgs.gov/wri/wri934076/1st_page.html). Based on the HCDN website, there were 45 unimpaired streamflow stations in the

Upper Colorado River basin and 18 unimpaired streamflow stations in the Lower Colorado River basin (Figure 1). In the Upper basin, there were 16 stations which had at least 50 years of regular unimpaired streamflow record. Similarly in the Lower basin, 6 stations had at least a 50 year record of unimpaired regular streamflow. Out of the 22 stations (16+6), there were 17 stations that had sufficient overlapping data with the tree-ring data discussed below. These 17 stations are shown in Figure 1.

Tree-ring data was collected and compiled from the International Tree Data Bank website (http://www.ncdc.noaa.gov/paleo/treering.html) maintained by the National Oceanic and Atmospheric Administration (NOAA), World Data Center for Paleoclimatology. The standard normal widths of site chronologies (hereinafter referred to as standard tree-ring chronologies) represent the growth indices for each site, and this information was used for the unimpaired streamflow reconstructions. Altogether, the Upper Colorado River basin includes 57 standard tree-ring chronologies; and the Lower Colorado basin contains 54, of which 35 in the Upper and 7 in the Lower have at least the last 500 years of record. These 42 standard tree-ring chronologies are shown in Figure 1.

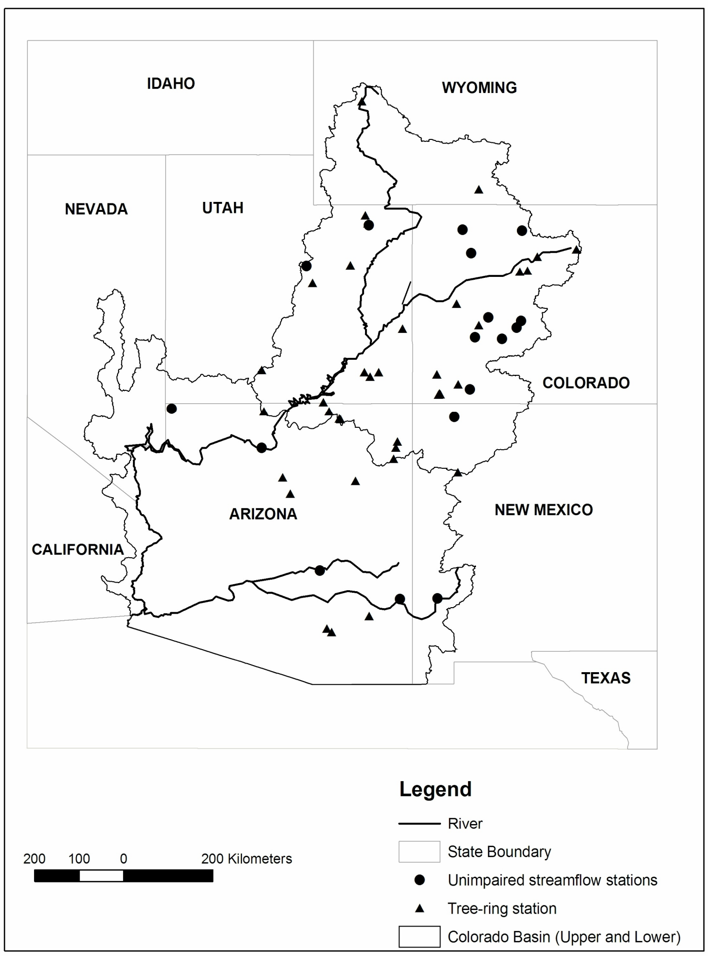

Figure 1: Location map displaying 17 unimpaired streamflow stations and 42 standard tree-ring chronologies.

Methodology

The first step in the analysis was to prescreen the standard tree-ring chronologies using correlation analysis for an overlapping period (initial 35 years for comparison) of instrumental water year streamflow and standard tree-ring chronologies. The correlation coefficients between water year streamflow and the selected standard tree-ring chronologies (lag -1, 0 and +1) within the basin were obtained. Chronologies that were positively and negatively correlated with station water year streamflow with less than 95% confidence were eliminated from the prescreening and were not used as predictors.

The next step was to apply PLSR in order to develop a streamflow reconstruction model for each station. PLSR is especially useful when there is a need to provide a prediction from a very large set of independent (predictors) variables (Abdi, 2003). In PLSR, the principal component scores of both (X) and (Y) are used in lieu of the original data to develop the regression model. PLSR identifies components from (Y) that are also relevant for (X) (Abdi, 2003). The generalization step results in PLSR searching for a set of components (latent vectors) that explains the maximum covariance between (X) and (Y) which is followed by a regression step where the decomposition of (X) is used to predict (Y) (Abdi, 2003). The prediction residual sum of squares (PRESS) statistic is a cross validation calculation that determines the minimum (optimum) number of components required (Geladi and Kowalski, 1986). The cross-validation consists of removing a row (or multiple rows) from the data matrix and then completing the eigen analysis on the reduced matrix. Target testing is then performed on the removed rows using the various levels of the abstract factor space and the difference between the target points and the predicted points is calculated (Malinowski, 2002). This process is repeated until every row has been deleted once and the errors in the target fit for each row are summed (Malinowski, 2002).

In order to find the best predictors in the case of PLSR, cross validation based on the correlation criterion was followed. First, significantly (95%) positively and significantly (95%) negatively correlated tree-ring chronologies with water year streamflow for the calibration period were ranked based on their absolute value of correlation. Then, PLSR was run for all the significantly correlated tree-ring chronologies. The procedure was followed by eliminating the least significantly correlated variables until the cross validation standard error (CVSE) was minimized (Michealson, 1987).

The spatial and temporal variability of drought was analyzed by dividing the streamflow data into epochal time periods. In this paper, drought years were defined as the years that have less than 10 percentile water year flow for the last 500 years. Once the drought years were identified for the last 500 years, the number of these drought years (<10 percentile water year flow) were separated for each 100 year period. In addition, the 5-yr moving average was found for each streamflow station in order to find the most severe drought year for the last 500 year based on the water year streamflow volume.

Results

Figure 2 summarizes spatial and temporal variability of the drought based on the 17 unimpaired streamflow stations in the Colorado River basin. The most number of droughts occurred during the 1500's, 1700's and 1800's. Compared to other 100 year periods, the 1900's had the least number of drought years in the region (Upper and Lower basin). These results are fairly consistent throughout the Upper and Lower basins.

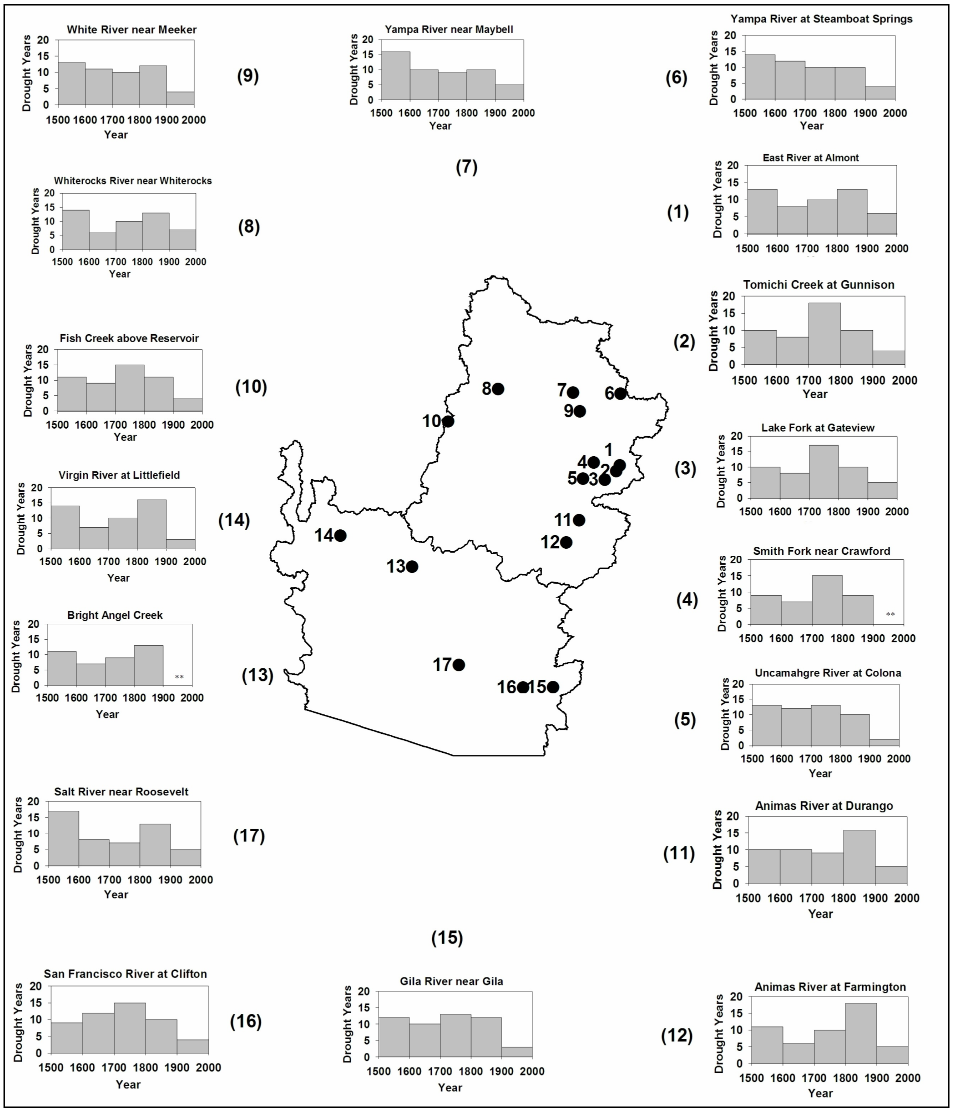

Figure 2: **Number of drought years for each 100 year period (1500-1599, 1600-1699, 1700-1799, 1800-1899 and 1900-1999) for all 17 unimpaired streamflow stations in the basin. The black dark circle indicates the unimpaired streamflow stations in the Colorado River basin. Shaded vertical bar indicates the number of drought years in each 100 year period.**

The 5-year moving average of each station water year streamflow volume (adjusted reconstructed plus observed water year streamflow) was also obtained, and the year that has the lowest streamflow volume was found and presented in the Table 1. Based on the 5-year moving average of water year streamflow volume, 10 stations indicated that the late 1500's had the lowest streamflow volume, but 5 other stations indicated that the late 1800's had the lowest streamflow volume. These results are consistent to the study by Hidalgo et al. (2000) and Timilsena et al. (2007).

Table 1: The most severe drought years based on 5-year moving average of last 500 years of water year streamflow for 17 reconstructed unimpaired streamflow stations in the Colorado River basin.

Sl. No.	STATION NAME	5-Year Moving
1	EAST RIVER AT ALMONT	1883
2	TOMICHI CREEK AT GUNNISON	1883
3	LAKE FORK AT GATEVIEW	1883
4	SMITH FORK NEAR CRAWFORD	1883
5	UNCOMPAHGRE RIVER AT COLONA	1883
6	YAMPA RIVER AT STEAMBOAT SPRINGS	1594
7	YAMPA RIVER NEAR MAYBELL	1585
8	WHITEROCKS RIVER NEAR WHITEROCKS	1587
9	WHITE RIVER NEAR MEEKER	1587
10	FISH CREEK ABOVE RESERVOIR NEAR SCOFIELD	1587
11	ANIMAS RIVER AT DURANGO	1585
12	ANIMAS RIVER AT FARMINGTON	1585
13	BRIGHT ANGEL CREEK NEAR GRAND CANYON	1585
14	VIRGIN RIVER AT LITTLEFIELD	1585
15	GILA RIVER NEAR GILA	1670
16	SAN FRANCISCO RIVER AT CLIFTON	1670
17	SALT RIVER NEAR ROOSEVELT	1588

Acknowledgments

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