Building and Applying a Regional Streamflow Model to Assess Water Scarcity in the Western U.S.

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Introduction

Climate change is intensifying water scarcity in the Western U.S. and the Colorado River watershed, which supports 40 million people and 5.5 million acres of agricultural land. As part of a project to build new tools to evaluate the effects of climate change on water scarcity, we build a streamflow model as a function of the Palmer Modified Drought Severity Index (PMDI).

Research Questions

1. Can PMDI be used to project streamflow? What form of statistical model is the best?
2. How does projected streamflow impact the regional water supply reliability?

Case and Data Sources

Streamflow data is available from the U.S. Geological Survey (USGS), and PMDI data from the National Oceanic and Atmospheric Agency (NOAA). Both datasets range from water years 1905-2017.

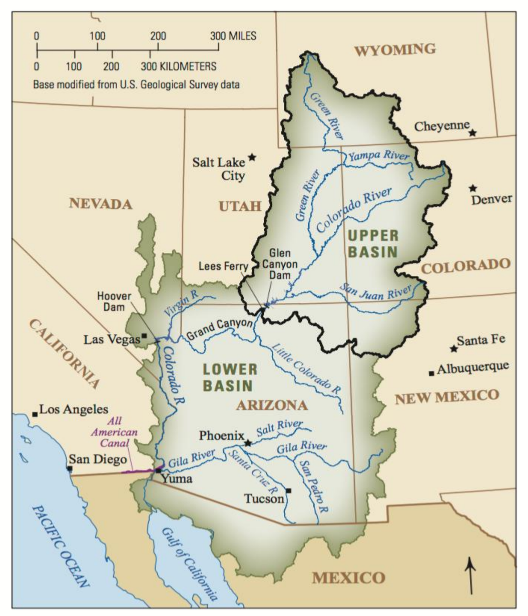

Fig. 1: Colorado River Basin

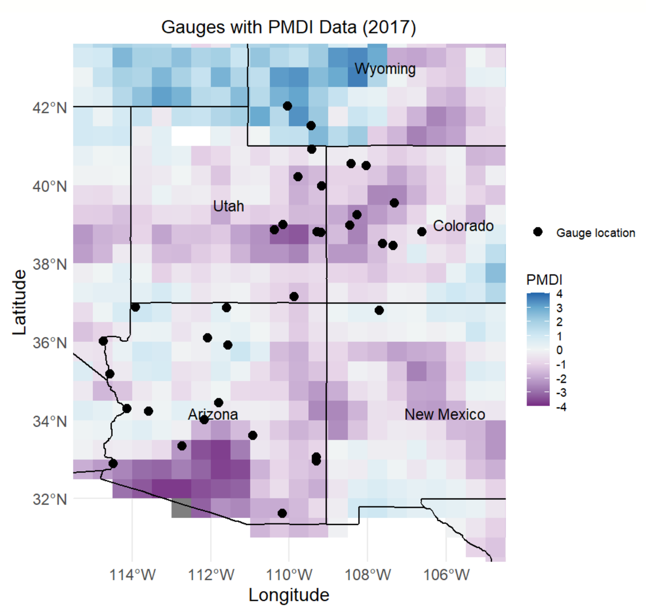

Fig. 2: Locations of Gauges studied

Methods and Results

- **Exploratory Data Analysis and QAQC:** Summary statistics were computed for all gauges in the R language. Data gaps in stream flows (ac-ft/month) were filled using interpolation (for shorter gaps) or nearby gauges with data available which correlated with linear $R^2 > 0.65$ (for longer gaps). Monthly and Annual summaries of streamflow data for gauge Colorado River near Grand Canyon given below.
- **PMDI:** 36/64 grid cells (GCs) containing PMDI data selected within 1.5°/2° from each gauge.

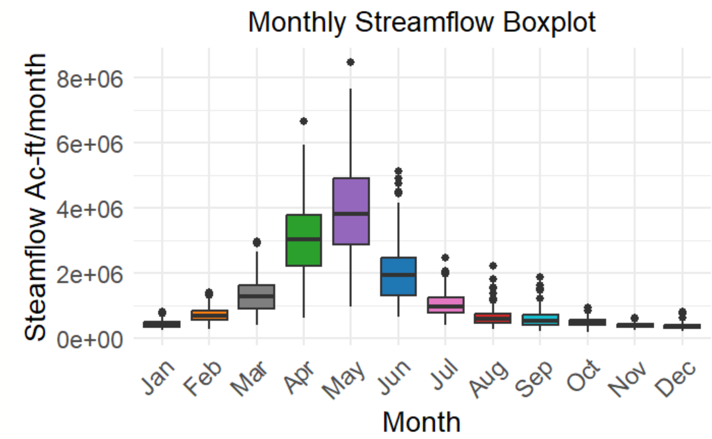

Fig. 3: Monthly Streamflow Boxplot

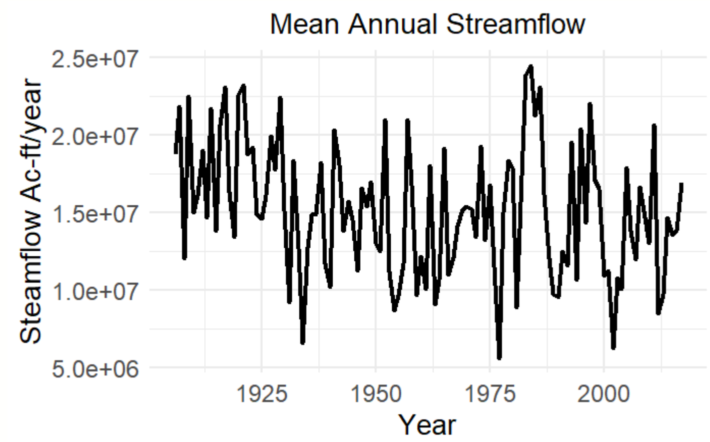

Fig. 4: Mean Annual Streamflow

Model Evaluation Metrics:

Adjusted $R^2 = 1 - \frac{(1-R^2)\,(1-N)}{N-K-1}$

Percent bias $= \frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})*100}{\sum_{i=1}^{n}(Y_i^{obs})}$

Nash-Sutcliffe Efficiency (NSE) =

$$1 - \frac{\sum_{i=1}^{n}(Y_i^{obs}-Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs}-Y_{mean}^{obs})^2}$$

- **Principal Component Analysis (PCA):** PCA was performed on PMDI data to extract the most information in a smaller number of uncorrelated variables. Then, the PCs were used to build alternate multiple linear regression (MLR) models of average annual stream flows. The model with the highest adjusted R^2 and NSE was selected.
- **Projections:** Annual projections of streamflow were generated using simulated PMDI from global circulation models, and the MLR model from this study. Using the method of fragments, these projections were downscaled to a monthly timestep.

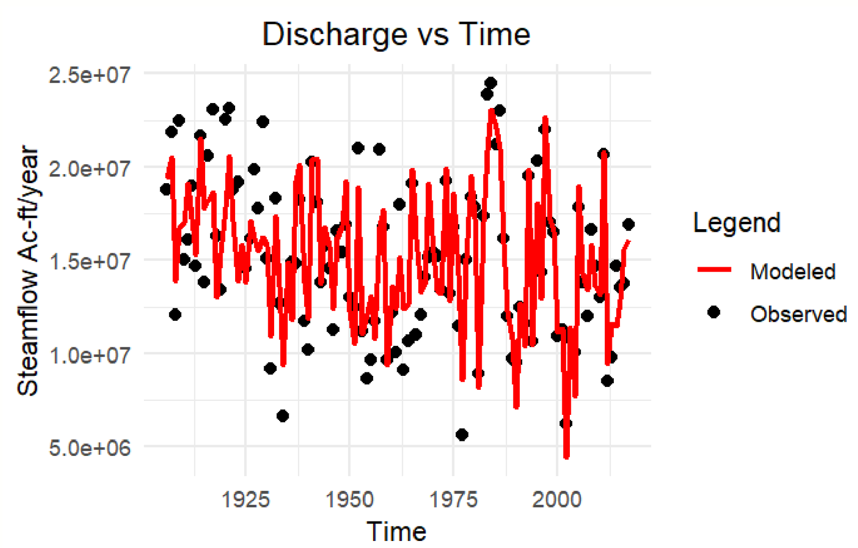

Fig. 5: PCA Model vs. Observed

Model for Streamflow for Selected Gauge:

$\mathit{Number\ of\ GCs\ used} = 64$

$\mathit{Adj.}\, R^2 = 0.80$

$\%\ \mathrm{Bias} = 2.89 * 10^{-16}$

$\mathrm{NSE} = 0.86$

NSE Criteria	Number of Gauges
NSE > 0.75	30
NSE > 0.7	32
NSE < 0.7	3

Table 1: Summary of MLR NSE Results

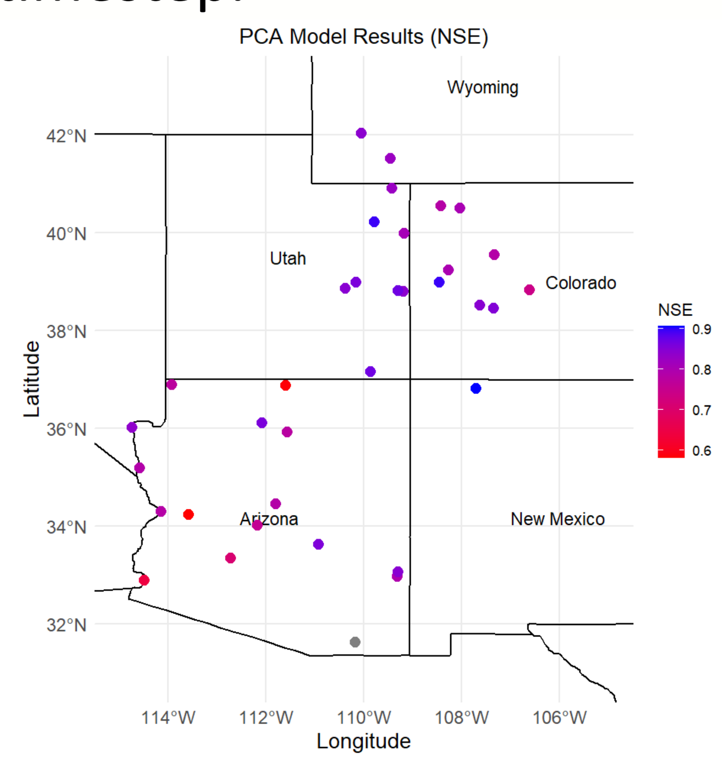

Fig. 6: MLR NSE Results for all Gauges

Results Contd.

- Results show that PMDI can be used to project streamflow in 32 out of 35 gauges.
- Low bias (3.55E-16%) across gauges shows no systematic under or overestimation.

Example of Projected Streamflow:

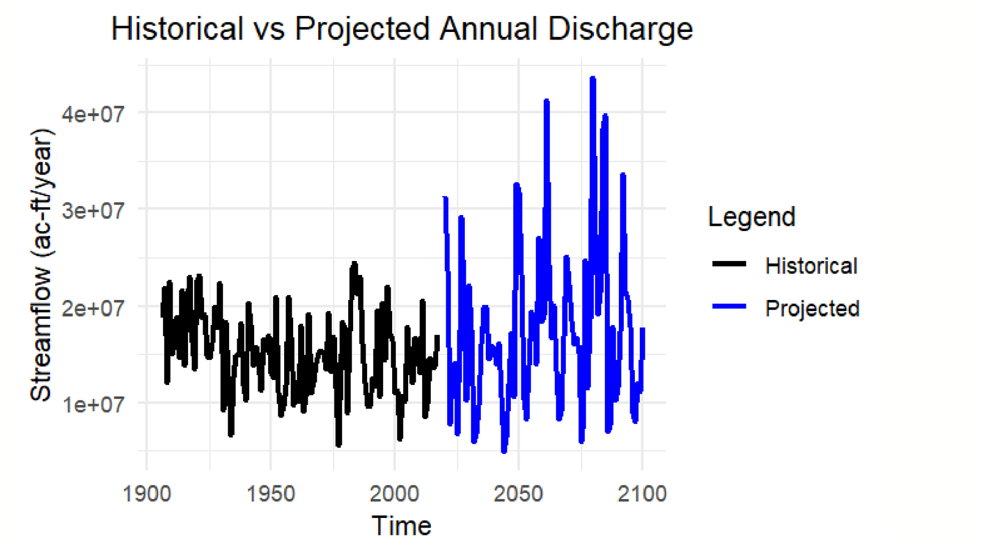

Fig. 7: Historical and Projected Annual Streamflow

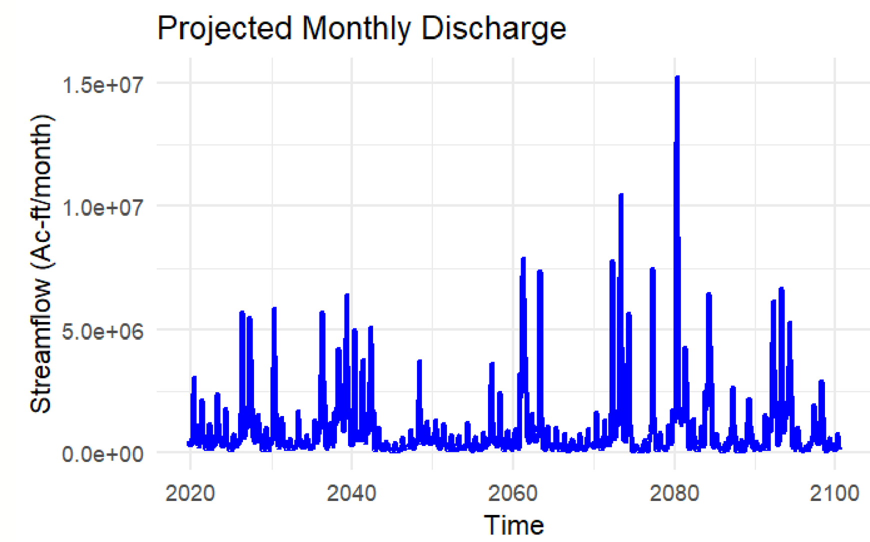

Fig. 8: Monthly Projections (Downscaled)

Next Steps

The research team will use Water Evaluation and Planning (WEAP) tool to test future climate scenarios simulated using the model and the impact of promising interventions in a few sectors, like agriculture, domestic use, etc., to manage water scarcity.

Grand Challenges Scholars Program

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