Increasing Influence of Air Temperature on Upper Colorado River Streamflow

Upper Colorado River flow is largely influenced by winter precipitation with wet years leading to higher streamflow and dry years leading to lower streamflow. However in some years, such as 2002, winters are dry, but flows are even lower than anticipated, given precipitation amounts. What causes these reduced flows? Do warmer temperatures play role in reducing flows? Are prior autumn moisture conditions important? What role do these factors play during droughts?

Although it's been a few decades, wet winters with flows higher than anticipated given the precipitation amounts have also occurred (e.g., 1984). Are temperatures and antecedent moisture conditions also important in these years?

This study has addressed these questions by examining naturalized annual streamflow at Lees Ferry and monthly precipitation, temperature, and soil moisture data for the upper Colorado River basin, 1906-2012.

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Goal of the study:

To determine how spring/summer temperatures and soil moisture in the autumn prior to the water year influence water year flow in the upper Colorado River basin. The importance of cool season precipitation is well-known, but how have these other factors influenced flow?

Major Study Findings:

1. Cool season precipitation accounts for most of the variability in UCRB flow, explaining 66% of the variability in water year streamflow between 1906 and 2012 and 70% since 1960 (*Figure 1, top*). March-July average temperature explains about 6-8% of the variability in flow, and prior November soil moisture explains an additional 2-3%.

In years with flows less or greater than expected given cool season precipitation (such as 2002 and 1984), temperature is a much greater influence (*Figure 1, bottom left*), explaining about 40% of the variability. Spring moisture can be an important contributor to flow as well (*Figure 2, bottom right*). An example of this is 1957, a high flow year with an extremely wet May and June, cool spring, and moderately wet cool season.

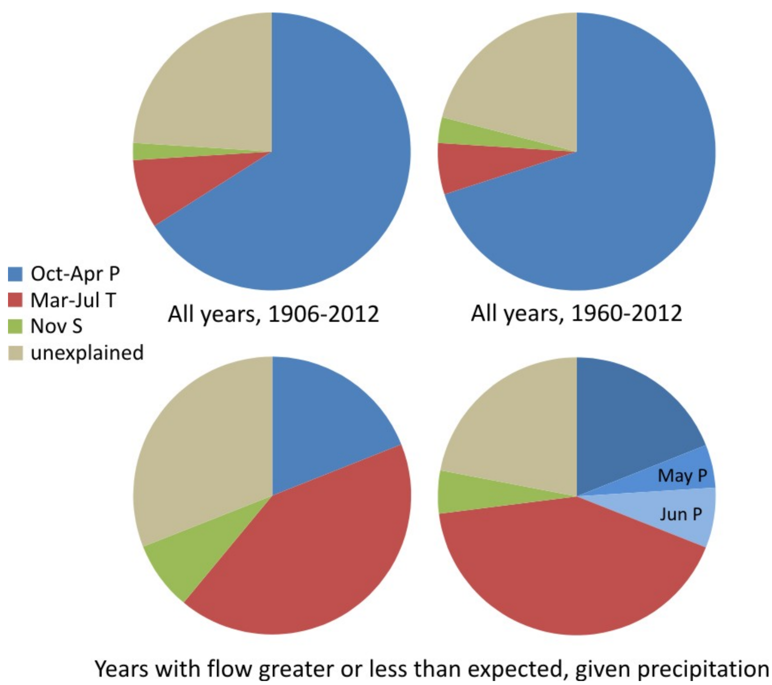

Figure 1. Relative importance of temperature (T), precipitation (P), and soil moisture (S) in explaining water year flow variability.

2. Major upper Colorado River droughts of the 20th and 21st centuries have occurred under various combinations of precipitation, temperature, and prior fall soil moisture.

- Water year flows were generally similar between the six drought periods, but precipitation, temperature, and soil moisture were more variable from drought to drought
- The **1950s drought (1950-56) was the driest**, in terms of precipitation (30th percentile), **but the coolest** (43rd percentile).
- The **2000s drought (2000-12) was the least dry (precipitation at the 48th percentile), but the warmest (79th percentile)**. The 1980-90 drought (1988-96) was also only moderately dry but quite warm.
- The 1930s drought (1931-40) was dry (36th percentile for precipitation, 30th percentile for soil moisture, the driest soil of all drought periods) and warm (61st percentile), but not as warm as the most recent droughts.

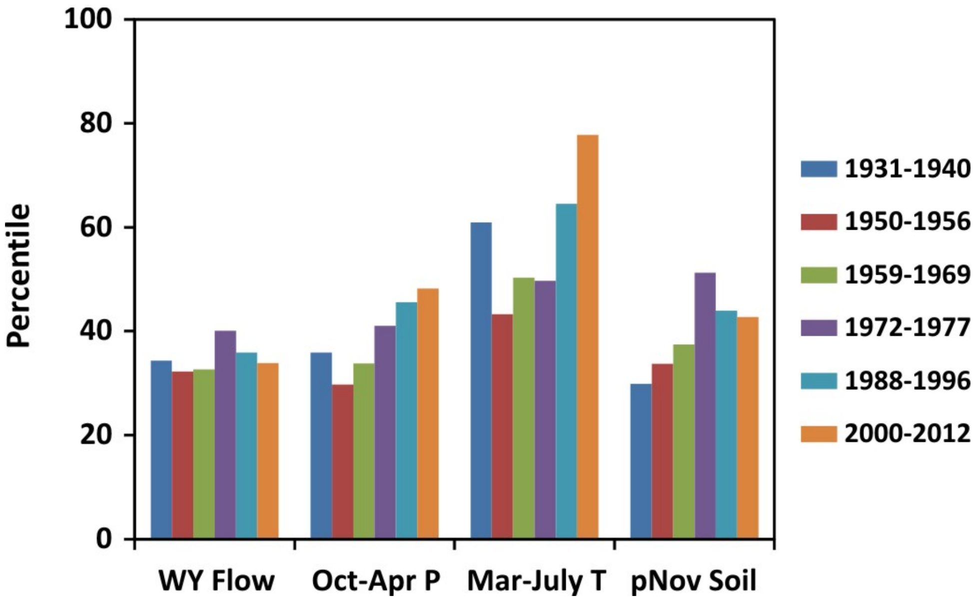

Figure 2. Major UCRB droughts, with water year flow (WY flow), cool season precipitation (Oct-Apr P), runoff temperature (Mar-July T) and November soil moisture (p Nov Soil) averaged across all years in each drought period, in percentile values.

Droughts are defined as consecutive years of below average flow at Lees Ferry, broken by no more than one year.

3. While cool season precipitation explains most of the variability in annual flows, temperature appears to be highly influential under certain conditions, with the role of antecedent fall soil moisture less clear.

Specifically, in years when flow is substantially different* than expected given cool season precipitation (*Figure 3a*), temperature or soil moisture can modulate the influence of precipitation on flow.

- In years with **higher flows than expected** given cool season precipitation – in both above and below median flow years – March-July average **temperatures are cool**, at the 40th percentile or less (*Figures 3b and c*).
- In **dry years with less flow than expected** given cool season precipitation, March-July average **temperatures are quite warm**, above the 80th percentile (*Figure 3d*).
- In **wet years with less flow than expected** given cool season precipitation (*Figure 3d*), **timing and distribution of precipitation across the basin play a role**. In these years, lower early season snow in the highest-elevation regions and warmer average March temperatures in the northern half of the basin are key features.

- **Years with flows greater than expected given precipitation are mostly clustered in the early part of the 20th century**, with the most recent year occurring in 1984 (*Figure 3a*).
- **Since 1988, a marked increase in the frequency of warm years with lower flows than expected given precipitation has occurred** (*Figure 3a*), suggests continued warming temperatures will be an increasingly important influence in reducing future UCRB water supplies.

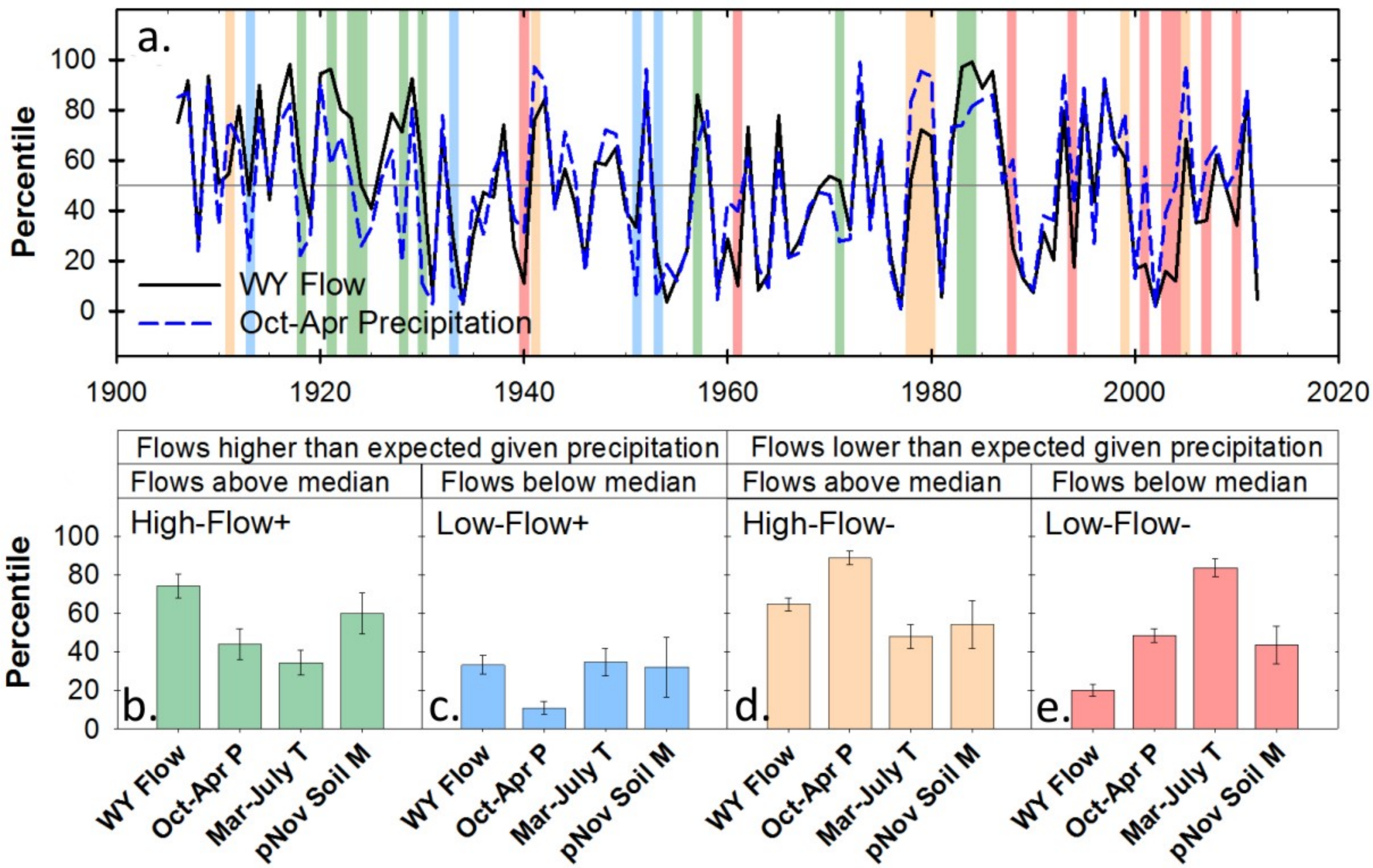

Figure 3 a. Water year flow (black line) and cool season precipitation (blue dashed line). Colored vertical bars indicate years with flows higher than expected given precipitation in green (high-flow years), and blue (low-flow years). Years with flows lower than expected given precipitation are in orange (high-flow years) and pink (low-flow years). 3b-e. Percentile hydroclimatic values averaged for water year flow anomalies in each of the four categories, with standard error bars. Categories are the same as in the top graph and described above the bar graphs.

*Substantially different is defined as years when water year flow, in percentile values, is more than one standard deviation different from cool season precipitation, in percentile values. Percentiles range from 0 (driest, coldest) to 1.0 or 100th percentile (wettest, warmest), with the 50th percentile (0.50) equivalent to the median value.

For more information on this study:

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Data available from http://www.nrmsc.usgs.gov/ColoradoRiverWater

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Additional study details:

Data and Methods

This study uses observed or observation-based data to examine the influence of precipitation, temperature, and antecedent soil moisture on upper Colorado River basin (UCRB) water year streamflow over the past century (1906-2012). Data used for this study include: estimated natural water year flow for Lees Ferry from the Bureau of Reclamation; total cool season (October-April) precipitation and March-July average temperature gridded data from PRISM (Parameter-elevation Relationships on Independent Slopes Model, http://www.prism.oregonstate.edu/); and modeled soil moisture based on a simple water balance model for November, using PRISM data as input. All values were averaged across the UCRB.

The variance in water year streamflow explained by these three factors, cool season precipitation, March-July temperature, and prior November soil moisture, was estimated using multiple linear regression. Characteristics of major droughts in the UCRB, defined as consecutive runs of below average Lees Ferry flow broken by no more than one year of above average flow, were assessed by averaged values for each variable over the years of each drought. Values were converted to percentiles to allow comparison between different climatic and hydrologic variables. The difference between percentile values of water year streamflow and total cool season precipitation was used to identify years when flow is less than or greater than expected given cool season precipitation. The years analyzed in Figure 3 were those with a difference greater than one standard deviation from the mean difference.