A Tree-Ring Based Assessment of Synchronous Extreme Streamflow Episodes in the Upper Colorado & Salt-Verde-Tonto River Basins

Press Information

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A Collaborative Project between The University of Arizona's Laboratory of Tree-Ring Research & The Salt River Project

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PROJECT ABSTRACT

Tree-ring reconstructions of total annual (water year) streamflow for gages in the Upper Colorado River Basin and Salt-Verde River Basin were computed and analyzed for the period 1521-1964. These reconstructed flow series were used to identify years of extreme low flow (**L**) and high flow (**H**) discharge in each basin, based on 0.25 and 0.75 quantile thresholds, respectively. Synchronous extreme events in the same direction in both basins (**LL** and **HH** events) were much more frequent than **LH** or **HL** events, which turned out to be extremely rare occurrences. Extreme synchronous low flow (**LL**) and high flow (**HH**) events tended to cluster in time. The longest period of consecutive **LL** years in the record was 3 years. In terms of multi-year extremes, a scenario of 2 extreme years occurring anywhere within a 3-yr or 4-yr moving window was the most common. **The overall conclusion based on the long-term record is that severe droughts and low flow conditions in one basin are unlikely to be offset by abundant streamflow in the other basin.**

For more details, see the project website at:
http://www.ltrr.arizona.edu/srp

KEY FINDINGS & IMPLICATIONS

(1) Gaged vs. Reconstructed Records: Upper Colorado River Basin (UCRB)
& Salt-Verde-Tonto River Basin (SVT)

Findings:

- Mean flow of observed records **higher** than longterm reconstructed means

Implications:

- 20th century has been **wetter in both basins** than in previous centuries.
  (NOTE: recent drought years not included; should lower the observed mean.)

(2) Synchronous Extreme Streamflow Sceanrios:

HH = High flow (**H**) in the UCRB at the same time as high flow (**H**) in the SVT
LL = Low flow (**L**) in the UCRB at the same time as low flow (**L**) in the SVT
HL = High flow (**H**) in the UCRB at the same time as low flow (**L**) in the SVT
LH = Low flow (**L**) in the UCRB at the same time as high flow (**H**) in the SVT

Findings:

- **HH** and **LL** events were much more frequent than **HL** and **LH** events, especially in the long, 444-year reconstructed time series.
- In the reconstructed record: no **HL** events & only 2 **LH** events occurred.
- In the observed record, only 3 **HL** events and no **LH** events occurred.
  *(In order to examine some **LH**-like scenarios in the observed record, the UCRB **L** threshold was relaxed to < 0.50 quantile, yielding **LH** events.)*
- Due in part to the quantile method, the number of **LL** events tends to be counterbalanced by the number of **HH** events, but overall – in both the observed and reconstructed records – **LL events are more frequent occurrences than HH events.**

Implications:

- **Working hypothesis that UCRB can serve as a buffer to compensate for extreme low flow in the SVT during drought periods needs to be re-evaluated.**
- Assumption that streamflows in the two river systems are relatively independent of each other due to a difference in the climatic regimes needs to be reevaluated.
- Our analysis indicated that:
  -- Flow values in two basins = significantly correlated (444 year record)
  -- **HH** and **LL** events dominated, not **HL** or **LH** scenarios.
- Hence annual streamflow variability in the SVT – especially extreme streamflow – is not independent of annual streamflow variability in the UCRB.
- **Severe drought in one basin will tend to be accompanied by severe drought in the other basin, even though the two areas are widely separated geographically.**
- **High volume water supply of the large UCRB may allow continued buffering during climate stress; but demand on this supply also increasing due to non-climatic factors**

(3) Persistence of Extreme Streamflow Episodes

Findings:

- strong tendency for **extreme years to occur in sequences or clusters**
- strong evidence of a linkage in **multi-year drought occurrence in the two basins**

Implications:

- If # of wet extreme years = # of dry extreme years, could “cancel each other” on a year-to-year basis ➔ little long-term stress on water supply operations.
- **Because of clustering tendency, it's more probable that episodes of sustained drought or sustained high flow will persist ➔ *more* of a burden on water systems management**
- **Reservoir storage <u>can</u> buffer water supplies during these persistent episodes, but supplies will be increasingly strained as droughts extend over multi-year periods**

(4) Longterm (multi-century) Variability

Findings:

- Some past periods / centuries have experienced more variability in extremes (**HH** and **LL**) than others
- 20th and 21st century have fairly good representation of extremes when compared to longterm record; **but higher magnitude flows and higher #'s of extremes do occur in reconstructed record**
- Low-frequency variation apparent in longterm record

Implications:

- **Observed record a fairly good indicator of past extremes, but does not reflect highest or lowest flows possible, nor the longest persistence of extremes -- for this we need tree-rings**
- **Understanding climatic drivers for low-frequency variations key to better longterm management of supply; but at present ultimate causes are unknown**

(5) Circulation Patterns Leading to LL, HH, LH and HL Scenarios

Findings:

- Characteristic circulation pattern for **LL** events is higher-than-normal upper level pressure over the west in early winter (Oct -Dec) & over the North Pacific ocean storm track region in mid- to late winter (Jan - Mar).
- Inverse of this pattern leads to **HH** events.
- **LH** and **HL** scenarios arise when the Pacific storm track appears to shift to an anomalous poleward (**HL**) or equatorward (**LH**) location

Implications:

- Persistent circulation anomalies are important for development of extreme episodes
- Development of circulation patterns may help in assessment of impending scenarios

(6) Driving Mechanisms of Longterm Variability

Findings:

- **Preliminary examination of El Niño, La Niña influences and ocean indices such as the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO) suggest linkage to some – but not all LL years in the observed record**

Implications:

- +AMO / **-**PDO sea-surface temperature anomaly "driver" a possible influence on synchronous episodes, but more analysis needed
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(7) Severity of Recent Drought on Salt River in a Multicentury Context

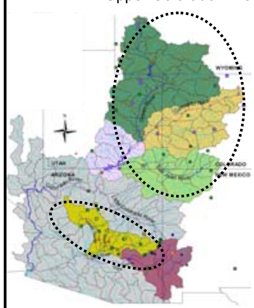
Findings:

- **1-year** Salt R flows of the basin decreased beginning in water-year 1994 and culminated in single-year flows for 2000 & 2002 lower than any previously experienced in the observed record
- As a **5-year** running mean, the recent drought is about as severe as the lowest-flow period in the 1950s.
- **As 11-year running mean, also about as severe as the 1950s --suggests that the period commencing with the decline in water year 1994 and continuing through water year 2004 ranks with the driest conditions in the entire gaged record.**
- As 15-year running mean, recent drought no longer ranks among the most severe (due to wet sequence of years in the early 1990s)
- **Up to an averaging period of 11 years, the recent drought is at least comparable in severity to any earlier drought in the gaged record.**
- Tree-ring reconstruction for SVT ends in 1988, and so does not cover the recent drought, but because the 1950s drought was characterized by flow departure of roughly the same magnitude as the recent drought, we can use the lowest reconstructed flows of the 1950s to indirectly evaluate the relative severity of the recent drought in the context of the reconstruction to A.D. 1199.
- A plot of 11-year running means of the SVT reconstruction with the baseline marked as the low point in the 1950s **suggests that the current drought was exceeded in severity several times in the past 800 years**
- **Eight distinct periods before the start of the gaged record show lower 11-year mean flow than the lowest reconstructed value of the 1950s.** The **most severe of the tree-ring droughts** was in the **late 1500s**, during the well-documented “mega-drought” of North America, when 11-year average flow is reconstructed about 100 cfs below the lowest flows of the 1950s.

Implications:

- **BOTTOM LINE: The recent drought, while severe, does not appear to be unprecedented when viewed in a multi-century context.**

Upper Colorado River Basin



Salt-Verde-Tonto River Basin

PURPOSE: use long-term records from tree rings . . .

• to reconstruct annual streamflow in the two basins

&

• analyze variations of extreme low flow & high flow over the past several hundred years

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The central question guiding the research was:

How frequently have extreme droughts or high flows occurred in <u>both</u> basins simultaneously in the past?

What's at stake: Reliability of the Colorado River system as a water-supply buffer for the Salt River system during times of extreme drought

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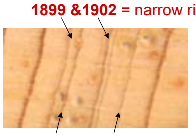
A TREE-RING CORE FROM THE SALT RIVER BASIN showing ring-width variations in the 1900s

1899-1904 dry "signature" pattern

1950's DROUGHT

1905 -1908 **1914 – 1920** **two wet episodes**

1899 &1902 = narrow rings



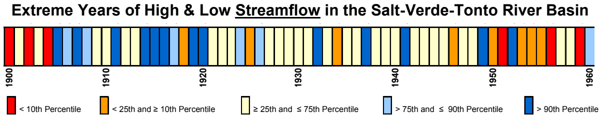
1900 & 1904 = missing rings

Even in a single tree, the record of ***extreme wet and dry streamflow episodes*** *is evident.*

1952 (one wet year)

1950 &1951 **1953 -1956** series of narrow rings

Extreme Years of High & Low <u>Streamflow</u> in the Salt-Verde-Tonto River Basin

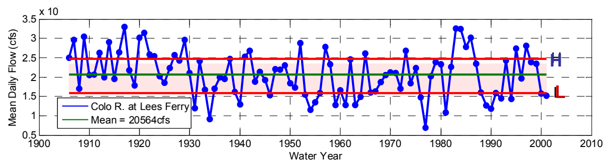


OVERVIEW OF PROJECT STEPS:

1. Develop threshold procedure to identify extreme streamflow episodes: Low Flow, L (drought) and High Flow, H in each basin   < 25th   > 75th
2. Use existing tree-ring data to refine previous tree-ring reconstructions of streamflow and produce new reconstructions
3. Define extreme synchronous streamflow scenarios: LL, HH, LH, HL in <u>observed</u> & <u>reconstructed</u> records
4. Investigate possible climatic causes of scenarios
5. Develop <u>assessment tool</u> to transfer information into useful operational decision-making format

Determination of Extreme L & H Years by Thresholds:

(based on 25th (L) & 75th (H) percentile thresholds)



Example of Colorado River Thresholds for Gaged Streamflow Record

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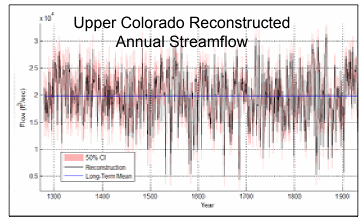
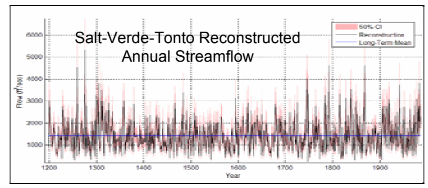
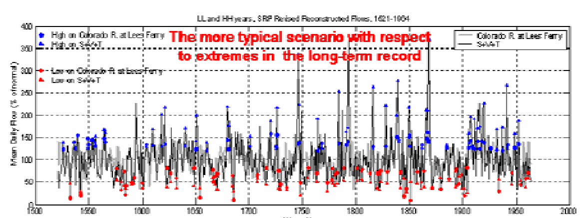
WHAT THE RECONSTRUTIONS TELL US:

The observed (gaged) record is a fairly good indicator of past extremes, but does not reflect highest or lowest flows possible, nor the longest persistence of extremes -- for this we need tree-rings





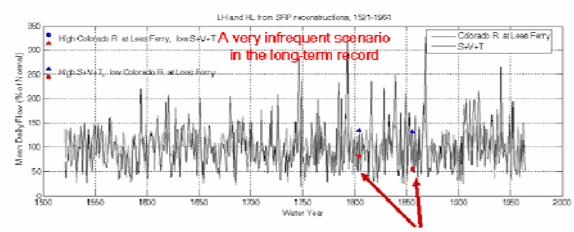
Reconstructed flows: LL & HH events



HH = HIGH on Colo & HIGH on SVT (blue symbols)
Probability (HH) = 57 / 444 = 0.1284

LL = LOW on Colo & LOW on SVT (red symbols)
Probability (LL) = 66 / 444 = 0.1486

Reconstructed flows: HL & LH events



HL = HIGH on Colo & LOW on SVT
(None)

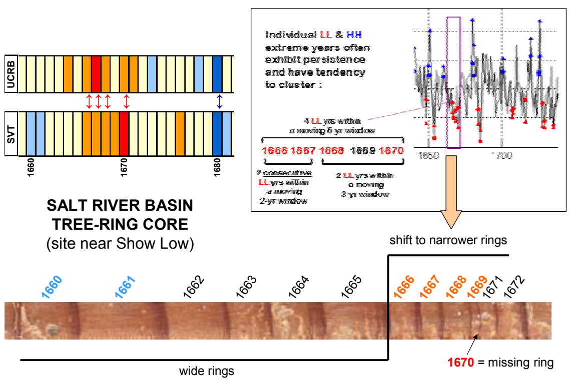
Probability (HL) = 0 / 444 = 0

LH = LOW on Colo & HIGH on SVT
(Year: 1804 & 1855)

Probability (LH) = 2 / 444 = 0.0045

Extreme High & Low Flow Years in BOTH Basins Together

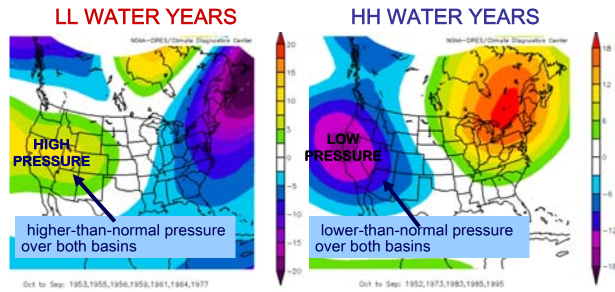
Salt-Verde-Tonto (SVT) & Upper Colorado River Basins (UCRB)



RESULTS: Atmospheric circulation patterns are unique for each type of extreme-year scenario

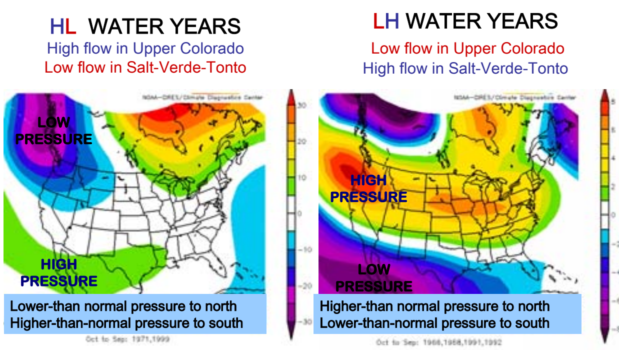
Atmospheric Circulation Anomalies

(based on observed record)



500 mb Geopotential Height (m) Composite Anomaly, Oct-Sep water year

Atmospheric Circulation Anomalies for Observed Years with Streamflow in Opposite Direction

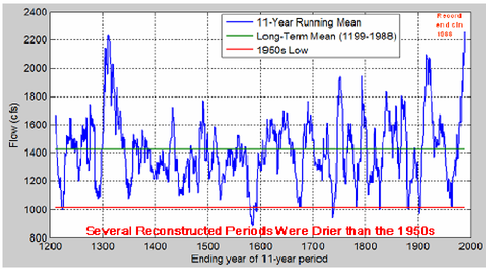


500 mb Geopotential Height (m) Composite Anomaly, Oct-Sep

Key Project Conclusions

- **Synchronous extreme events in the same direction (LL and HH events) were much more frequent than LH or HL events**
- **Extreme synchronous low flow (LL) and high flow (HH) events tended to cluster in time**
- **The longest period of consecutive LL years in the record was 3 years**
- **In terms of multi-year extremes, a scenario of 2 extreme yrs within a 4-yr moving window was the most common**
- **BOTTOM LINE: Severe droughts and low flow conditions in one basin are unlikely to be offset by abundant streamflow in the other basin**

Severity of Current Drought in Context of Reconstructed Record:
Salt + Verde + Tonto Reconstruction



- Current drought was about as severe as 1950s in terms of flows averaged over 11 years
- 8 other droughts were as severe, according the tree-ring record
- Late 1500s megadrought was much more severe

Long-Term Context of Salt-Verde-Tonto's Current Drought

- Severity of current drought in terms of single years is worst in observed record
- Current drought is about as severe as 1950s in terms of flows averaged over 11 years
- Even during 1950s drought, occasional 1-year "breaks" of above normal flow were not unusual
- 8 other droughts in the long-term tree-ring record were as severe as the current drought
- Late 1500s mega-drought was much more severe than the current drought

SOME IMPLICATIONS OF THE RESULTS:

• Working hypothesis that UCRB can serve as a buffer to compensate for extreme low flow in the SVT during drought periods needs to be re-evaluated.

• High volume water supply of the large UCRB may allow continued buffering during climate stress; but demand on this supply is also increasing due to non-climatic factors

• Because of clustering tendency, it's more probable that episodes of sustained drought or sustained high flow will persist
➔ more of a burden on water systems management

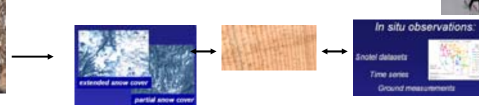
• Reservoir storage can buffer water supplies during these persistent episodes, but supplies will be increasingly strained as droughts extend over multi-year periods

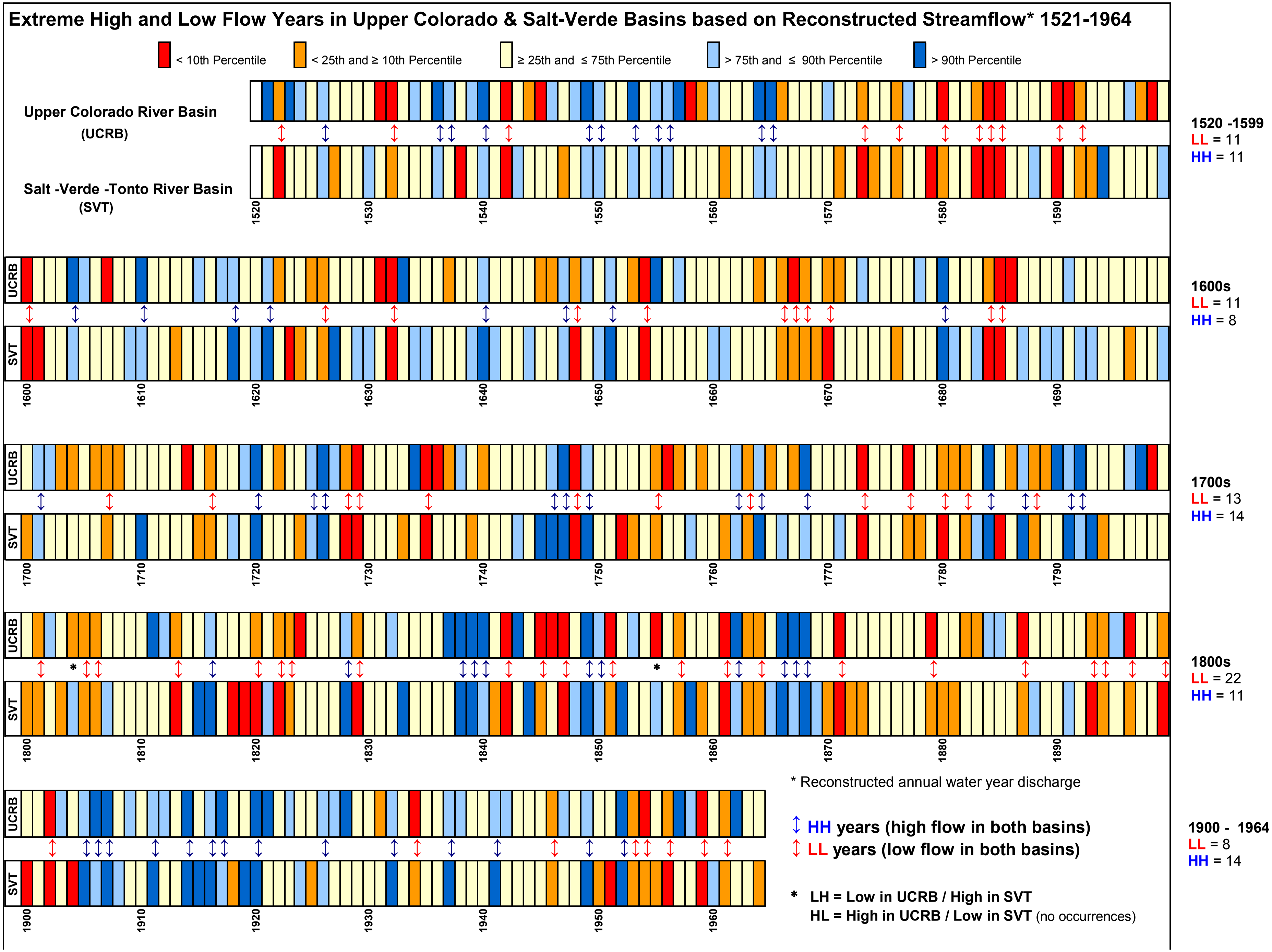
Next Phase:


- Updated collection of tree-ring sites in Salt-Verde-Tonto Basin to cover period of recent drought
  - Improved perspective on current drought
  - Ability to explore seasonal signal of moisture variation (summer vs. winter precipitation)

- Tree-ring / snow cover / remote sensing study
  - Improved linkage of tree-ring information to remotely sensed snow variables (e.g., snow cover)
  - Potential for long-term reconstruction of spatial variation of snow cover as it relates to streamflow






Extreme High and Low Flow Years in Upper Colorado & Salt-Verde Basins based on Reconstructed Streamflow* 1521-1964
< 10th Percentile
< 25th and ≥ 10th Percentile
≥ 25th and ≤ 75th Percentile
> 75th and ≤ 90th Percentile
> 90th Percentile
Upper Colorado River Basin
(UCRB)
Salt -Verde -Tonto River Basin
(SVT)
1520 -1599
LL = 11
HH = 11
1600s
LL = 11
HH = 8
1700s
LL = 13
HH = 14
1800s
LL = 22
HH = 11
1900 - 1964
LL = 8
HH = 14
UCRB
SVT
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1940
1950
1960
* Reconstructed annual water year discharge
HH years (high flow in both basins)
LL years (low flow in both basins)
* LH = Low in UCRB / High in SVT
HL = High in UCRB / Low in SVT (no occurrences)