The Tree-Ring Record of Drought in the Southwest

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Non-destructive increment core sampling
Historically, compacts, water policy and management have been based on the available gage records.

Severe 21st century drought has prompted many managers to reconsider long-term drought variability.
Trees form one ring per year

Ring width reflects environmental conditions

Climate is often the primary limitation on tree growth (wide = good; narrow = bad)

Ring width can be used as a proxy for past climate
Moisture-stressed trees closely track variations in precipitation.

Ring widths from a single tree near Grand Junction, CO are plotted with annual precipitation in western Colorado. The correlation between the two is 78% ($r = 0.78$).
How can tree rings reflect variations in streamflow?

Ring widths and streamflow both integrate the effects of precipitation and evapotranspiration, as mediated by the soil, over the course of the water year.
North American Tree-Ring Chronologies > 200 years long

Species
- JUOC
- JUSC
- JUVI
- PIAZ
- PIED
- PIMO
- PIPO
- PSMA
- PSME
- QUDG
- TADI
- TAMU
- other

Colored Triangles = Moisture Sensitive Chronologies
North American Tree-Ring Chronologies > 1000 years long

Species
- JUOC
- JUSC
- JUVI
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- TADI
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- other

Colored Triangles = Moisture Sensitive Chronologies
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

Locations of chronologies used in the extended Lees reconstruction

Medieval drought in the upper Colorado River Basin

David M. Meko,1 Connie A. Woodhouse,2 Christopher A. Baisan,1 Troy Knight,1 Jeffrey J. Lukas,3 Malcolm K. Hughes,1 and Matthew W. Salzer1

1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

Colorado River at Lees Ferry, AZ

- Observed
- Reconstructed

Annual Flow, MAF

Water Year

Observed Flow (MAF)

Reconstructed Flow (MAF)

R² = 0.75
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

- 80% Confidence Interval
- Reconstructed
- Observed

Lowest Observed = 87% of 1906–2004 mean

Flow (% of mean)

Ending Year of 25-yr Running Mean
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry (Meko et al. 2007)

Graph showing the flow of the Colorado River from 800 to 2000 AD. The graph includes an 80% confidence interval and a reconstructed flow line. The lowest observed flow is 87% of the 1906-2004 mean.
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

Graph showing flow data over time, with annotations indicating an 80% confidence interval, lowest observed flow at 87% of 1906–2004 mean, and periods of early 20th century pluvial and late 19th century drought.
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

- Early 20th Century Pluvial
- 16th Century “Megadrought”
- Late 19th Century Drought

Flow (% of mean)

Ending Year of 25-yr Running Mean

80% Confidence Interval
Reconstructed
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

- 80% Confidence Interval
- Reconstructed
- 1100’s Drought
- 16th Century “Megadrought”
- Early 20th Century Pluvial
- Late 19th Century Drought

Flow (% of mean)

Ending Year of 25-yr Running Mean
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

“Medieval Era”

80% Confidence Interval
Reconstructed

16th Century
“Megadrought”

Early 20th Century
Pluvial

Observed

Ending Year of 25-yr Running Mean

Flow (% of mean)

9th Century
Drought

1100’s Drought

Late 19th Century Drought
1,244 Year Tree-Ring Reconstruction of Colorado River Flow at Lee’s Ferry

(Meko et al. 2007)

1100’s Drought

**Figure 3.** Runs properties of 1100s drought. (a) Time series of reconstructed flow in units of billion cubic meters (BCM) for segment A.D. 1098–1202. Horizontal line at 18.53 BCM is observed mean for 1906–2004. (b) Time series of runs below the observed mean flow. Bars mark runs of two-or-more years. Run-length annotated below bar. Run-sum (cumulative departure from mean) given by length of bar.
TreeFlow
streamflow reconstructions from tree rings

http://treeflow.info/

Data access
Background info
Examples of application

Tree-Ring Background Information
A tree-ring reconstruction is a best-estimate of past streamflows, based on the relationship between tree-ring data and observed streamflow over the modern period. To learn more about how streamflow reconstructions are developed, click here.

Applications to Water Management
Tree-ring reconstructions are being used in water management and planning in a number of ways, to provide context for the observed flow record, for establishing more realistic worst-case drought scenarios, and as numerical input into water system models to test policies. For more information on applications of tree-ring reconstructions to water management, click here.

Technical Workshops
Our one-day workshops for water managers and stakeholders in Colorado, Utah, Wyoming, Arizona, New Mexico, and Nevada, have comprehensively covered the methods for developing streamflow reconstructions from tree rings. Each workshop has a page with a summary and links to the presentations. Click here for more information about these technical workshops.

Colorado River Streamflow: A Paleo Perspective
The Colorado River is the lifeline of the southwestern US. Over the years, much work has been done to assess the long-term variability in its streamflow, using tree rings and other environmental proxies. Click here for a multi-page feature providing a "paleo perspective" on Colorado River streamflow.
New Tree Ring/Monsoon Project

- Develop the first network of monsoon-sensitive chronologies in the SW U.S.
- Investigate long-term monsoon variability across region
- Compare paleo records of summer and winter precipitation
- Evaluate tree-growth response to large-scale circulation (i.e. ENSO)
- Partner with regional stakeholders
Earlywood & Latewood

1874
1873
1872
1871

LW
EW
LW
EW
LW
EW

Correlation

(Giffin et al. 2011 Tree-Ring Research)
Earlywood & Latewood

[Image of cross-sectional view of tree showing ring patterns with labels LW, EW, and LW subscripts]

Correlation

<table>
<thead>
<tr>
<th>Chronology Type</th>
<th>Oct-Apr</th>
<th>Jul-Aug</th>
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<td>EW</td>
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(Griffin et al. 2011 Tree-Ring Research)
Earlywood & Latewood

(Griffin et al. 2011 Tree-Ring Research)
Earlywood & Latewood

(Griffin et al. 2011 Tree-Ring Research)
New Reconstructions

Summer Monsoon
June-August Precip

- 15 Chronologies
- 662 Trees
New Reconstructions

Summer Monsoon
June-August Precip

- 15 Chronologies
- 662 Trees

Winter Spring
October-April Precip

- 37 Chronologies
- 1,605 Trees
NAME Region 2 SPI Reconstructions

June-August Standardized Precipitation

- Instrumental Data
- Tree-Ring Data

R^2 adj. = 0.54
RE = 0.53

Griffin et al. (in prep.)
NAME Region 2 SPI Reconstructions: 1539-2008
Seasonality of Drought

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Griffin et al. (in prep.)
NAME Region 2 SPI Reconstructions: 1539-2008
Seasonality of Drought

Griffin et al. (in prep.)

A

B

17th Century Puebloan Drought
NAME Region 2 SPI Reconstructions: 1539-2008
Seasonality of Drought

Griffin et al. (in prep.)
NAME Region 2 SPI Reconstructions: 1539-2008
Seasonality of Drought

Griffin et al. (in prep.)
Concluding thoughts

- Tree-ring records are offer invaluable perspective on past drought variability
- Extensive tree-ring research on the CO River
- Paleo droughts seem more severe and sustained than any witnessed during the instrumental era.
- New monsoon records indicates persistent drought often occurs during both seasons
- Results underscore importance of drought seasonality in the Southwest
Advisors / Collaborators

Connie Woodhouse
David Meko
Katie Hirschboeck
Christopher Castro
Carlos Carillo
Holly Faulstich

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U.S. Bureau of Reclamation
CA DWR
U.S. Geological Survey
Tree-Ring Collection and Measurement

20-50 living trees are non-destructively sampled

Old wood is collected when possible

Samples are prepared and dated. Ring widths are measured to the 0.001 mm. Measurements are averaged into site tree-ring chronologies.
Generating the climate reconstruction

Tree Ring Chronologies (predictors) → Statistical Calibration: regression → Reconstruction Model → Climate reconstruction

Observed Climate (predictand) → Statistical Calibration: regression → Reconstruction Model → Climate reconstruction

Model validation

based on Meko (2005)
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- Longest reconstruction to date
- “Low Frequency” chronology development
  - discard series less than 250 years
  - uber conservative spline detrending
  - 0.85 minimum subsample signal strength
  - Variance stabilization
- 11 “single site reconstructions” reduced with PCA to yield:
- 4 Nested regression models

Table 1. Summary Statistics of Sub-Period Reconstruction Models

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Start</th>
<th>Years</th>
<th>n-p-q</th>
<th>Calibration $^c$</th>
<th>$R^2_{adj}$</th>
<th>Validation $^d$</th>
<th>m</th>
<th>RE</th>
<th>RMSE</th>
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<td>9</td>
<td>0.54</td>
<td>2.63</td>
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</tbody>
</table>
Chronology Network Status and PCA

Maximum Loading
- PC1
- PC2
- PC3
- PC4
- PC5

(in preparation)

PCA w/ Varimax Rotation
36 Chronologies (1895-2008)
Latewood Climate Response

PC1 vs Jul-Aug SPI

PC4 vs Jun-July SPI
North American monsoon

- Summer season climate regime
- Synoptic-scale changes in pressure
- Shift in upper level wind direction
- Local-scale convective thunderstorms
- Emanates northward from Mexico
- Large fraction of annual precip in SW
- U.S. largely on fringe of influence
- Interannual variability dramatic over U.S.

US: PRISM
MX: Vose and Heim