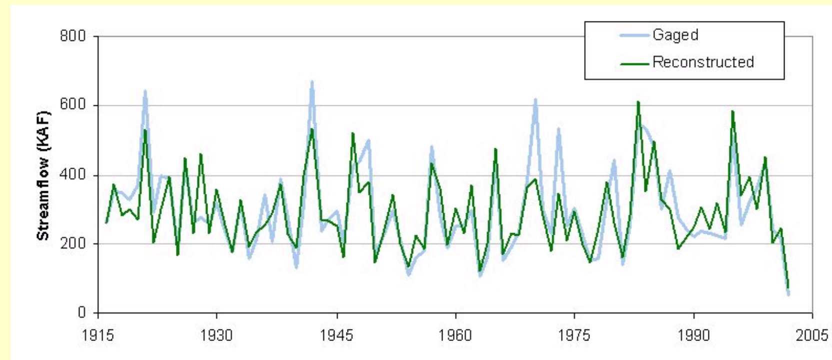
The long view of drought in Colorado

What tree rings tell us about hydrologic variability



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Denver, CO – October 8, 2008

Jeff Lukas

University of Colorado-INSTAAR and Western Water Assessment

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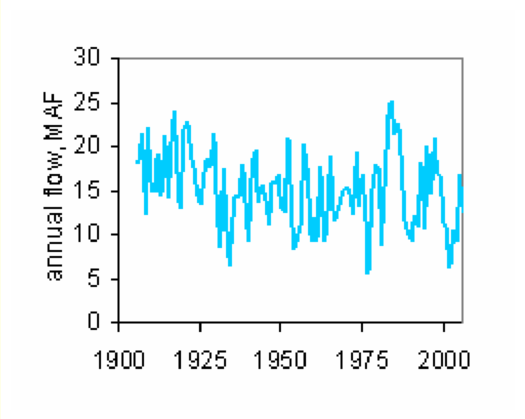
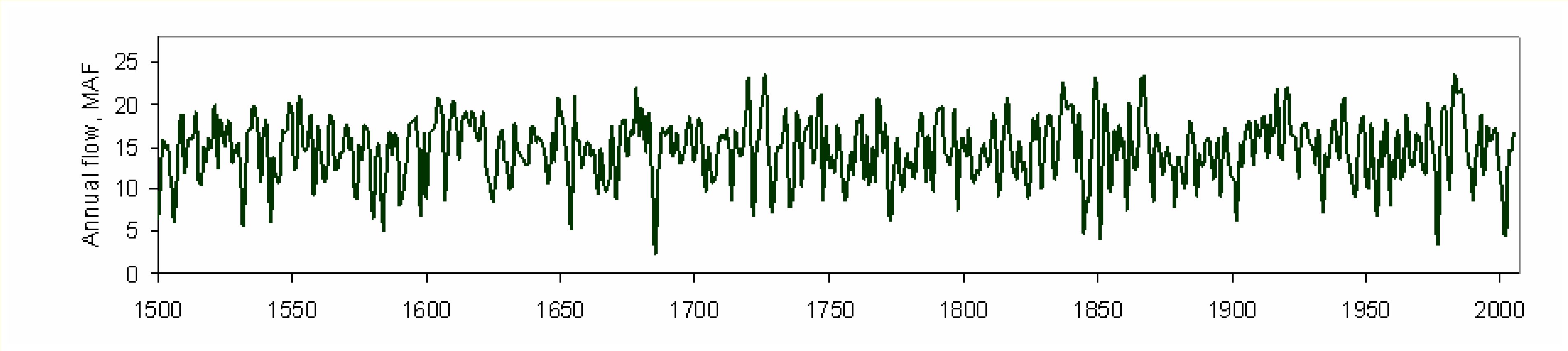
Tree-ring records provide a more complete picture of past variability, thus a better-informed assessment of risk

Observed hydrology: <100 years



Tree-ring record: 400-1000+ years

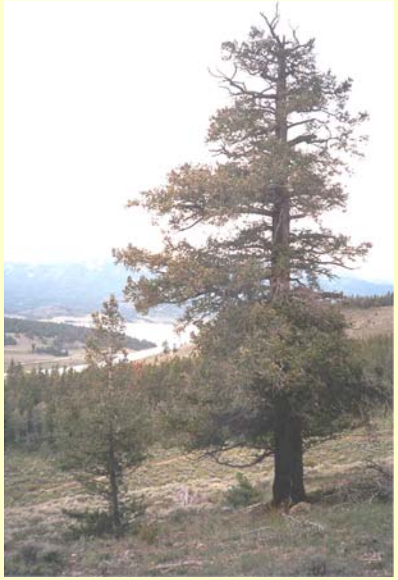


In semi-arid climates like Colorado, tree growth is generally limited by moisture availability

So:
– a dry year leads to a *narrow* growth ring
– a wet year leads to a *wide* growth ring

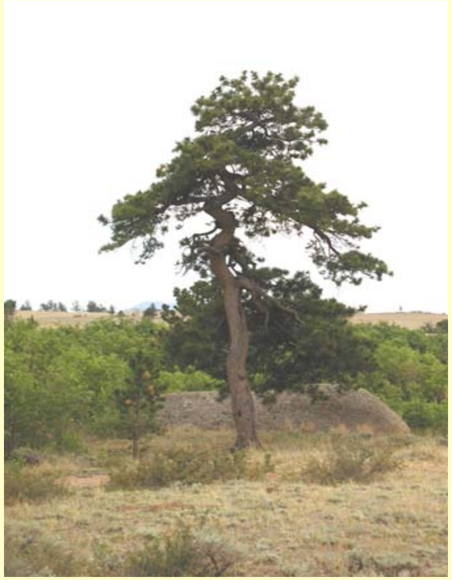
- Ring width mainly reflects precip from previous fall-winter- spring = soil moisture at start of growing season

Principal moisture-sensitive species of Colorado



Douglas-fir
500-800 years

Pinyon Pine
500-800 years



Ponderosa Pine
300-600 years

Also, dead wood from all three species can be used to extend records back 1500 years or more

Moisture sensitivity = consistent ring-width patterns among trees = cross-dating

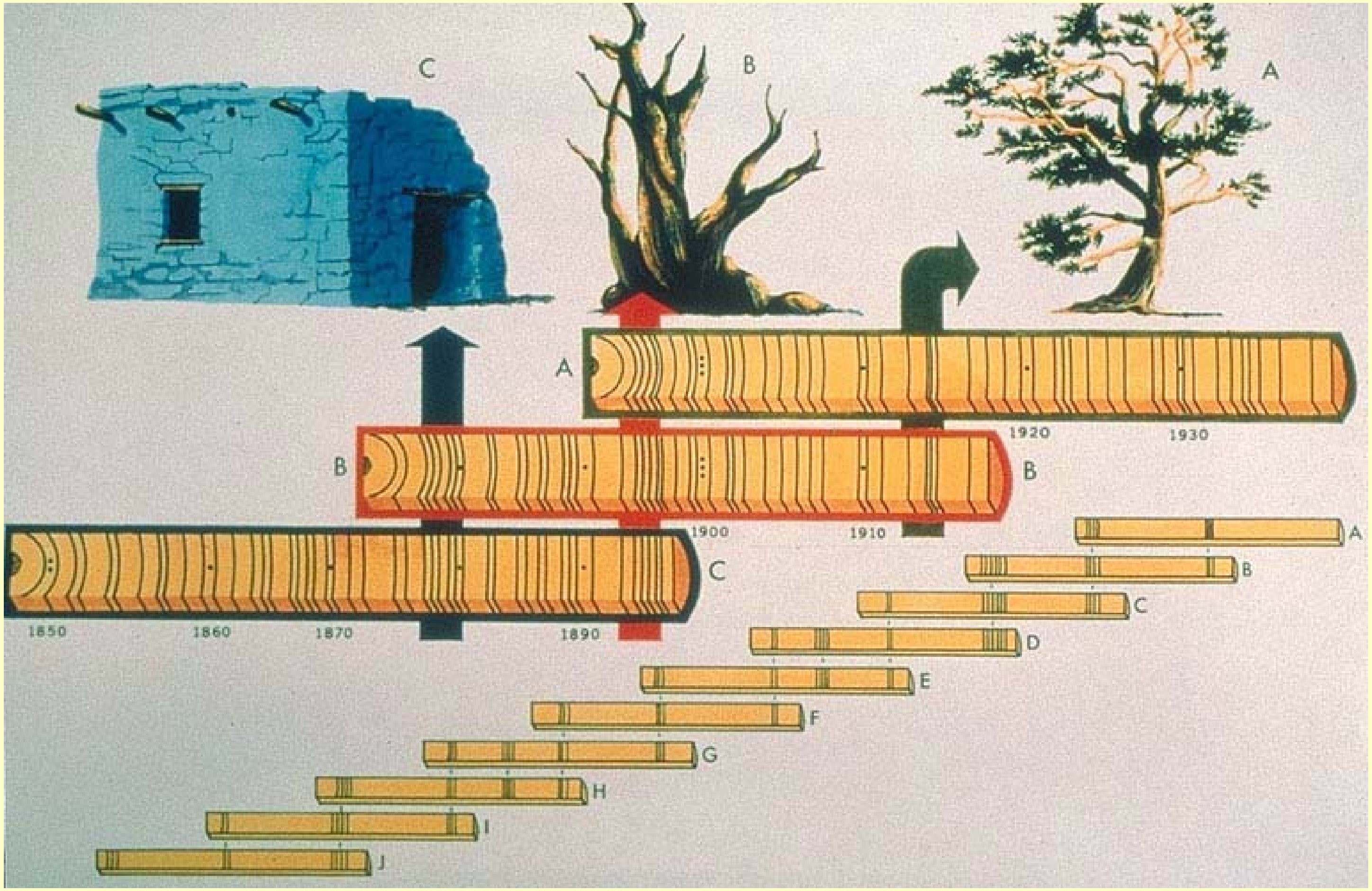
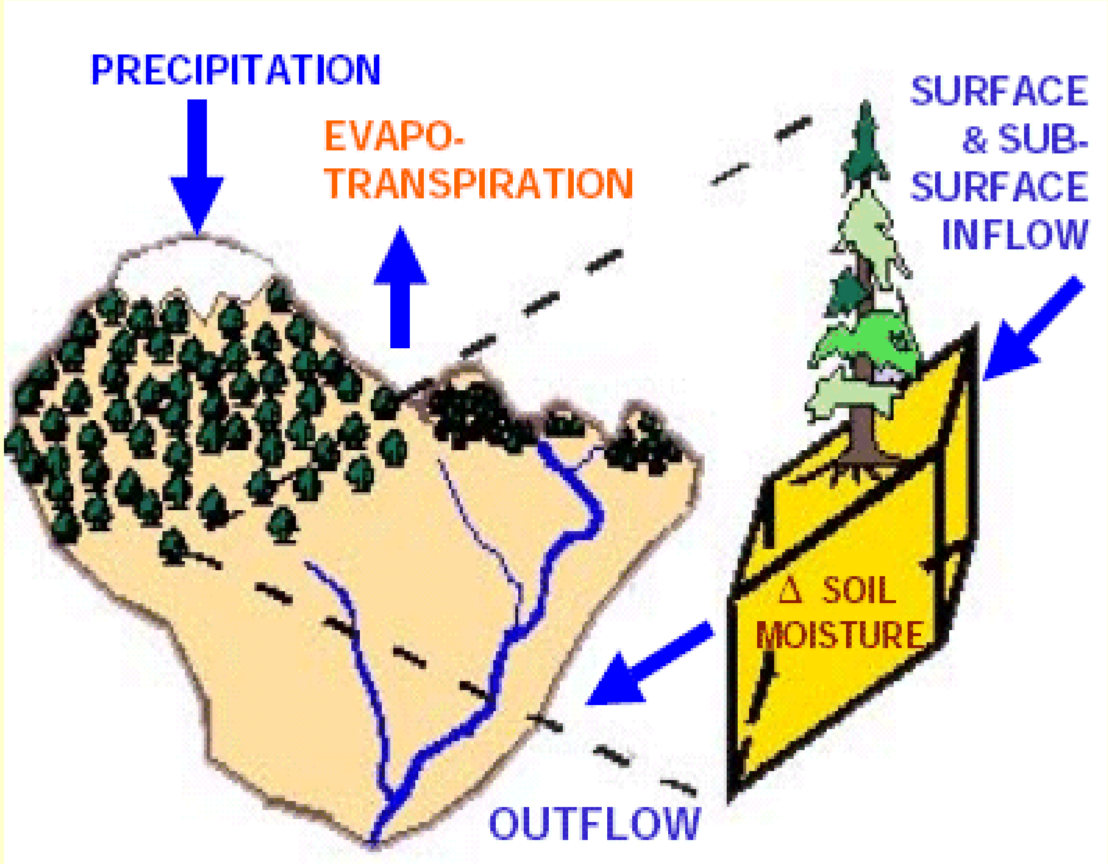


Image courtesy of LTRR (U. AZ)

Ring-width and annual streamflow - an indirect but robust relationship

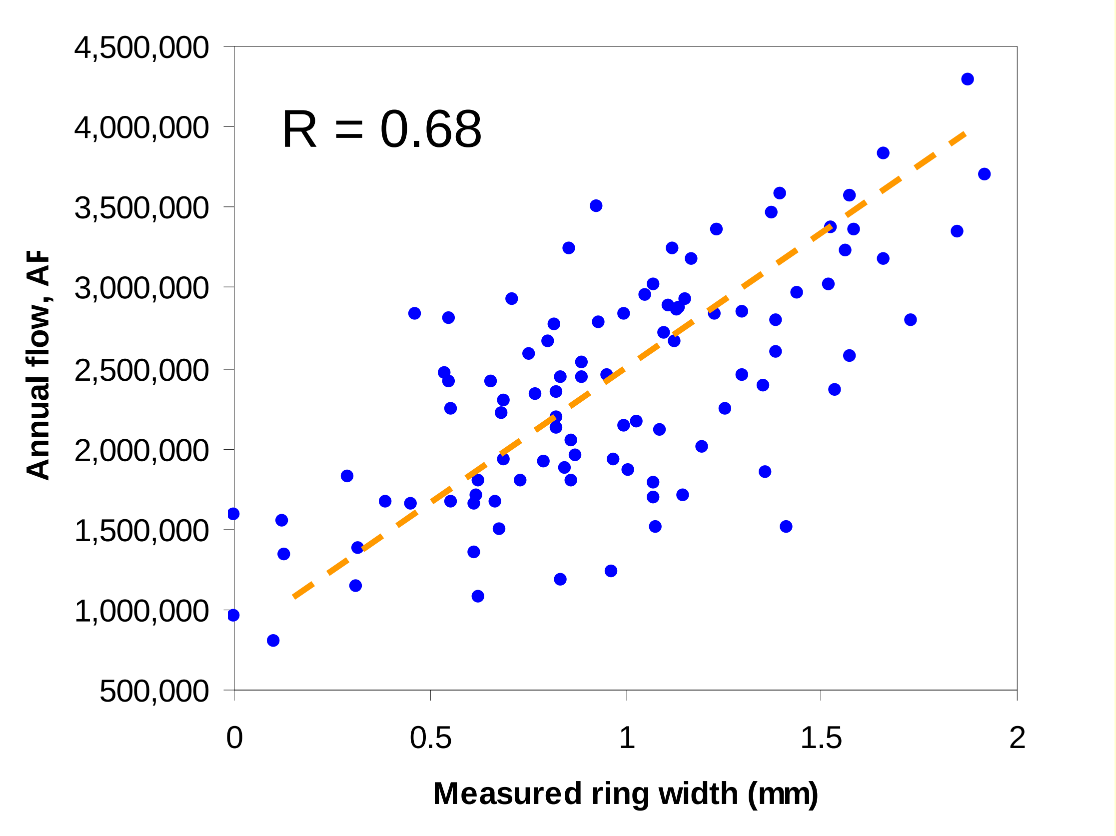


- The growth of moisture-sensitive trees responds to the same set of climatic factors that influence streamflow

Image courtesy of Dave Meko, LTRR

The tree growth – streamflow relationship in Colorado is particularly strong

Scatterplot of ring widths from a pinyon pine on Grand Mesa, and annual flow of Gunnison River above Grand Junction, 1906-2002

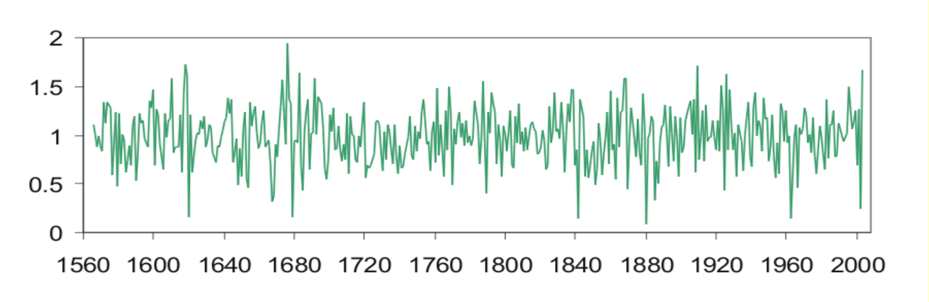


- Our job is to *capture* and *enhance* the hydrologic signal, and reduce noise, through careful sampling, replication, and data processing

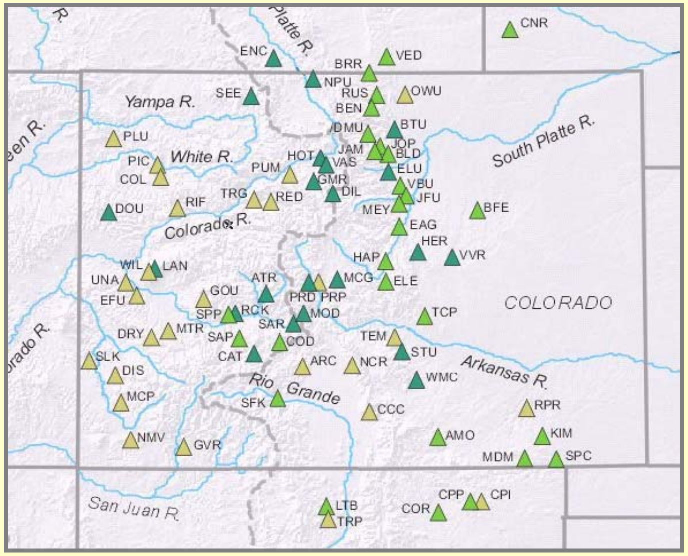
Generating tree-ring reconstructions – Part I

1) Collect samples from 20-40 old, moisture-sensitive trees at one site

2) Cross-date and measure their rings, and compile into a site *chronology*

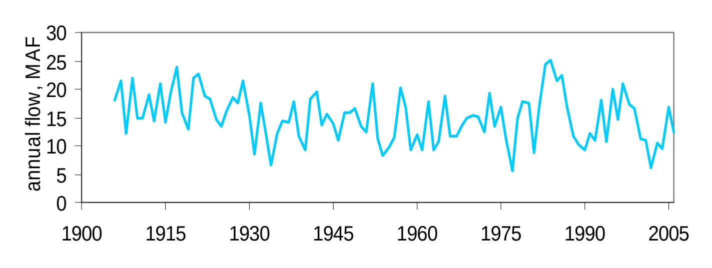


3) Repeat until you have network of chronologies across the basin(s) you want to reconstruct

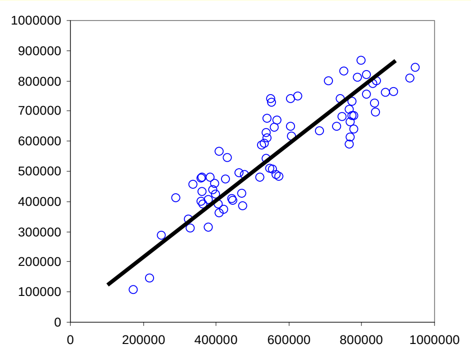


Generating tree-ring reconstructions – Part II

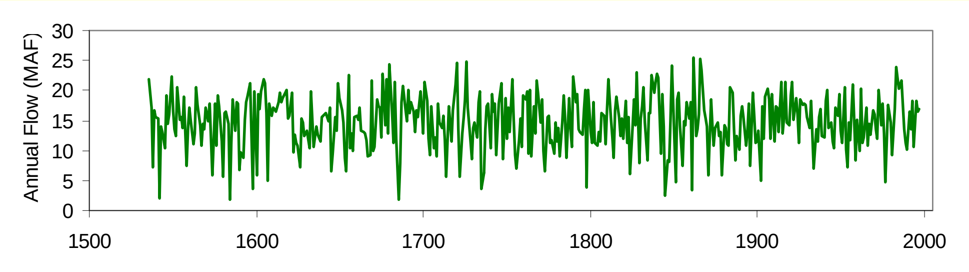
1) Obtain gaged annual flow record at least 40 years long, corrected for depletions



2) Use regression or other procedure to select the subset of chronologies that best-fit the flow record, generating a numerical model

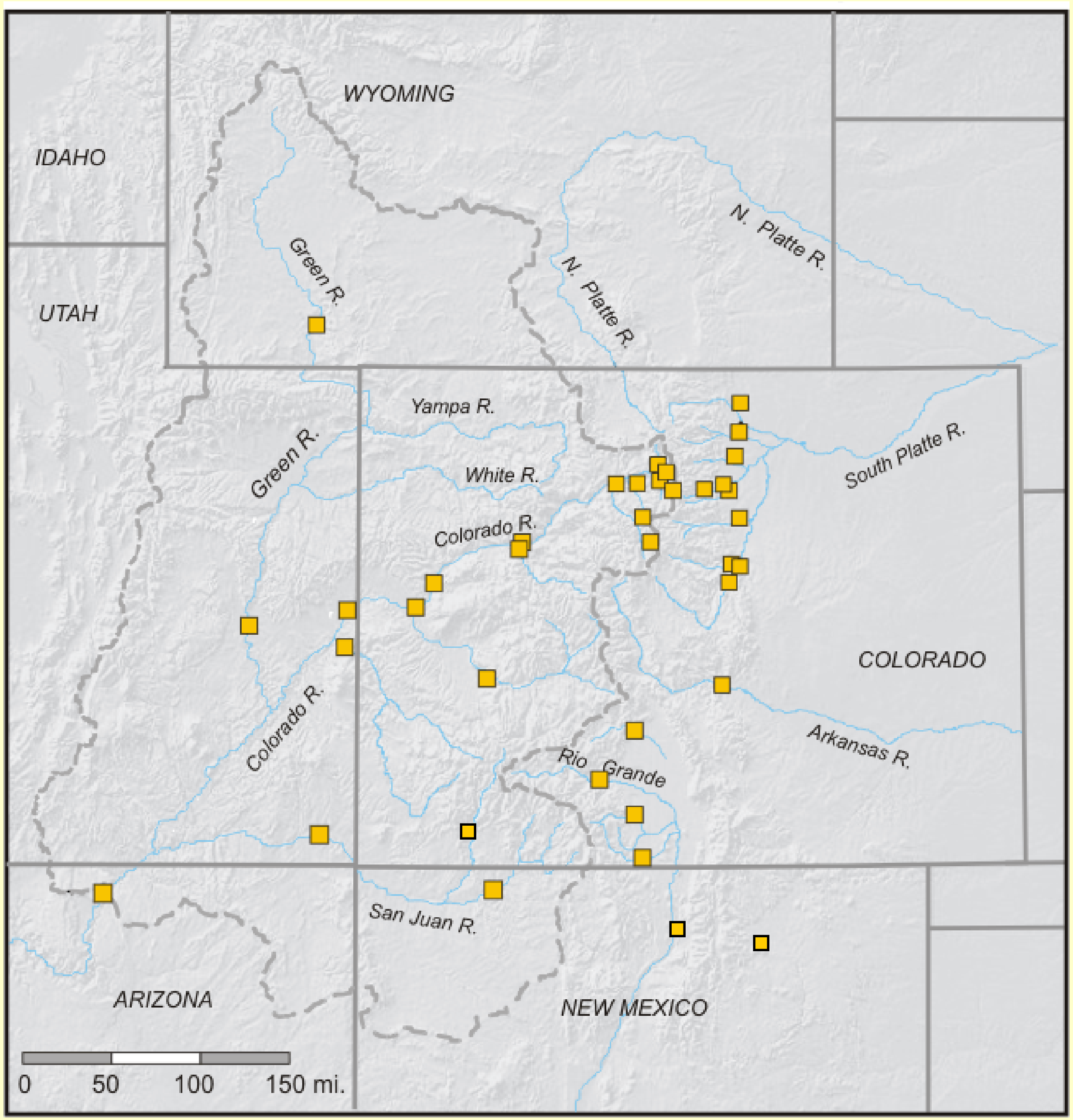


3) Plug the full chronologies (>300 years) into the model to make the reconstruction

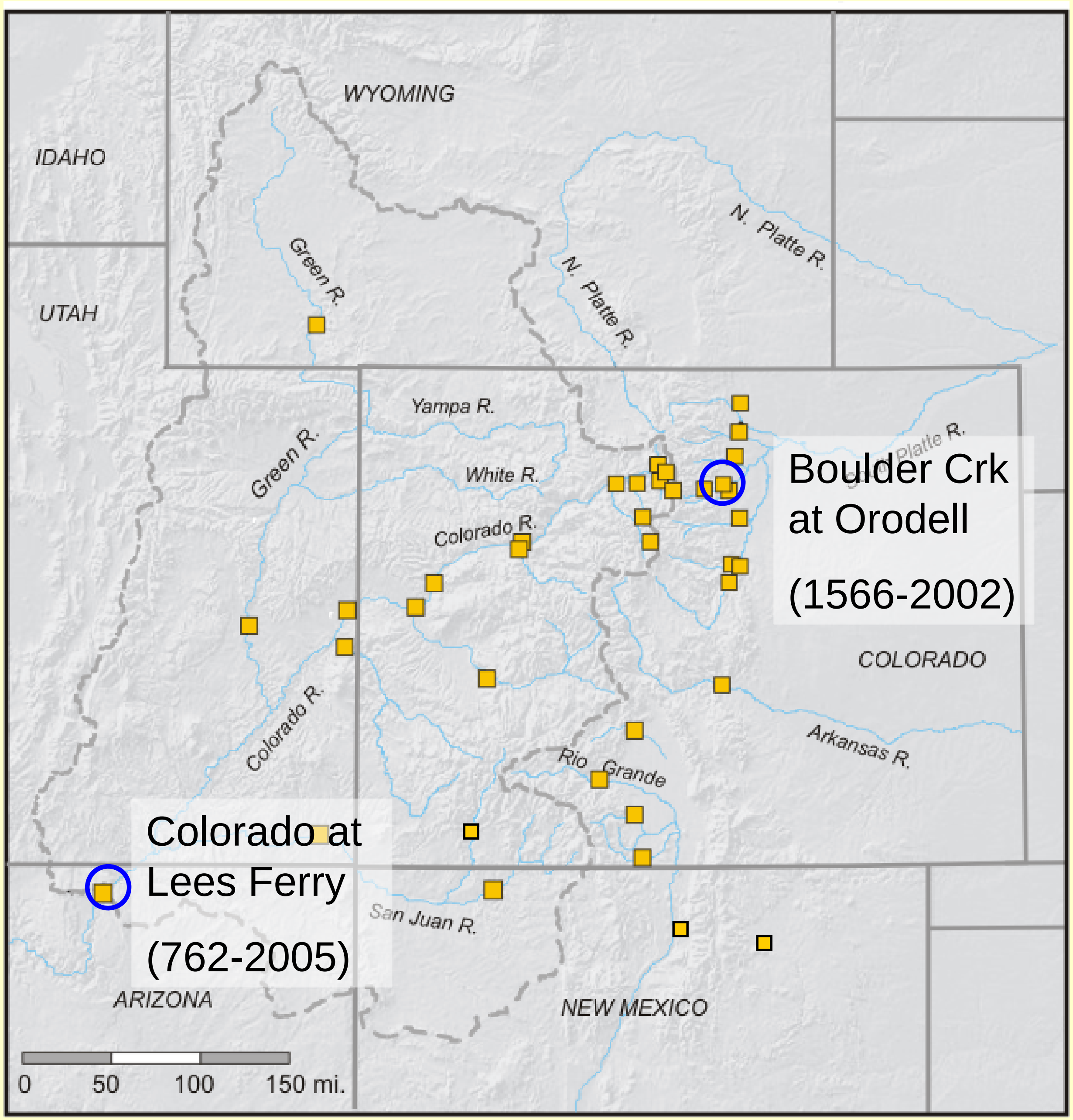


Streamflow records reconstructed using our tree-ring chronologies

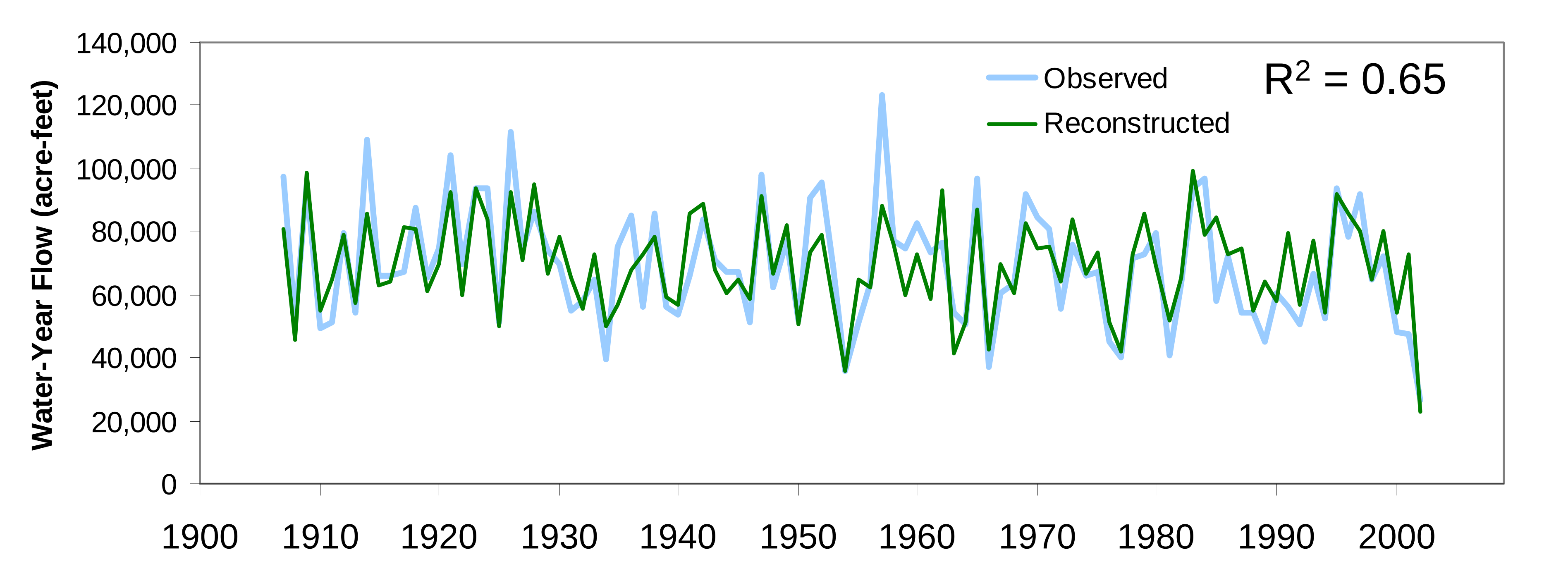
- Developed in collaboration with several water providers
- 350-700 years long, except new Lees Ferry (1240 years)
- Reconstructions explain 60-80% of variance in the flow records



Streamflow records reconstructed using our tree-ring chronologies

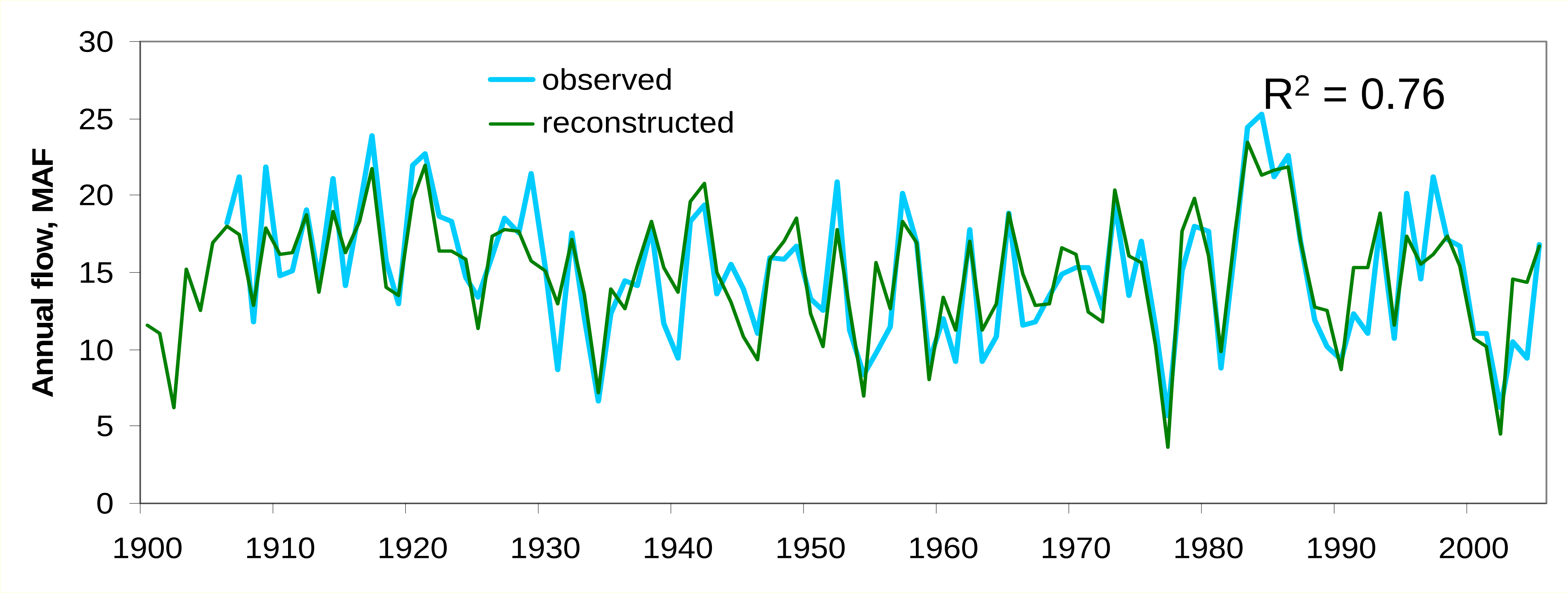


Boulder Creek observed vs. reconstructed flows, 1907-2002



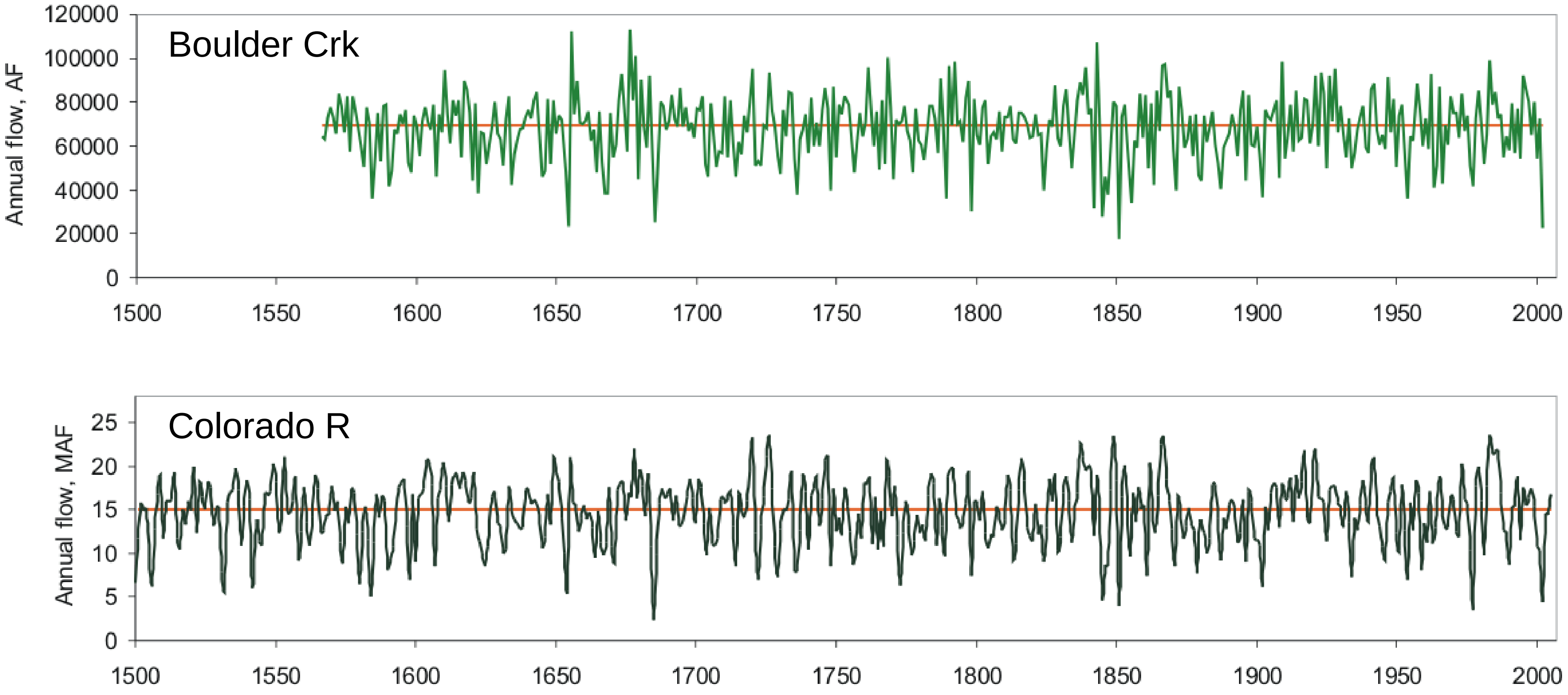
- Because not all variance is explained, the reconstructed flows have uncertainty around them
- 2002 is lowest observed flow

Colorado R. at Lees Ferry, observed and reconstructed flow, 1906-2005



- 1977 is lowest observed flow since 1906; 2002 is second lowest

Boulder Creek and Colorado R. reconstructed annual flows, 1500-2005 (orange line = observed mean)

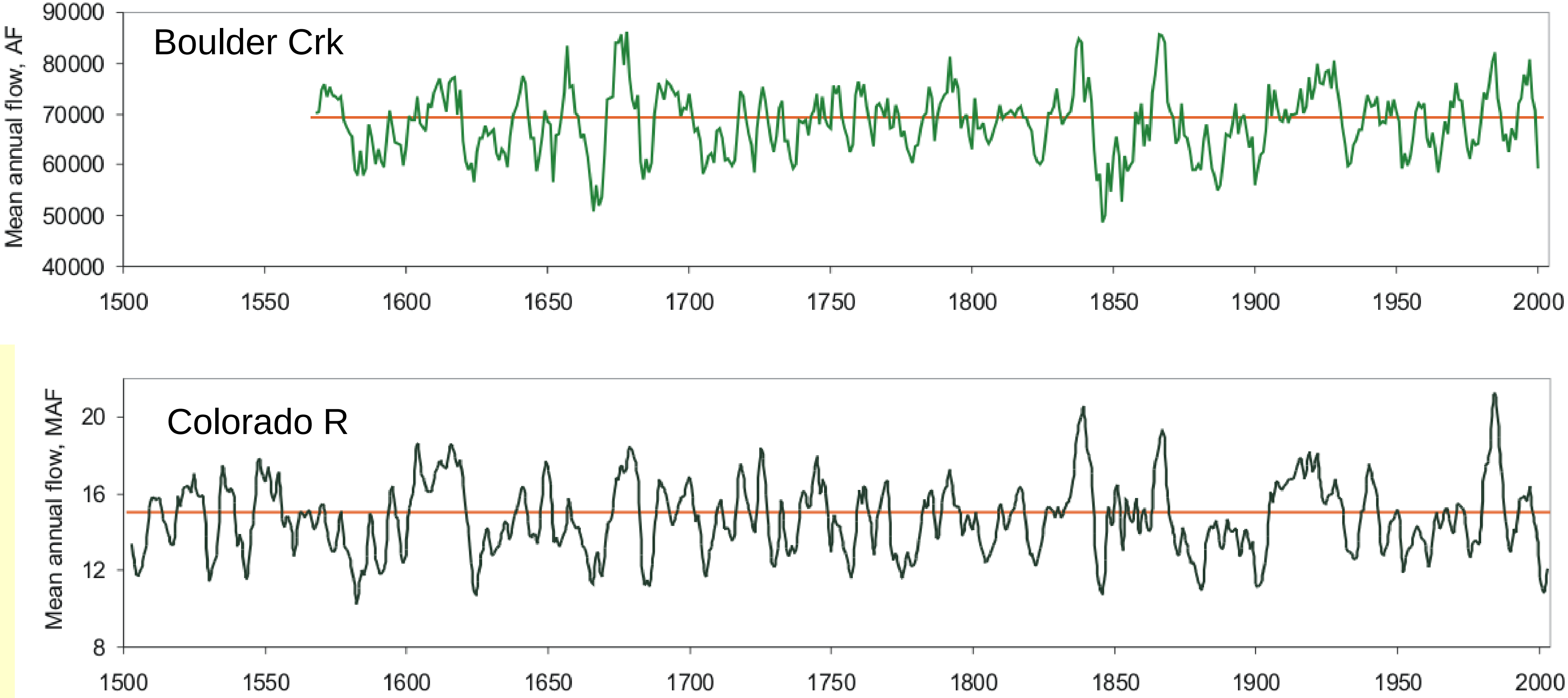


5 Lowest annual reconstructed flows since 1500

Boulder Crk: 1851, **2002**, 1654, 1685, 1845

Colorado R: 1685, 1977, 1851, **2002**, 1845

Boulder Creek and Colorado River reconstructed flows, 5-year running mean, 1500-2005

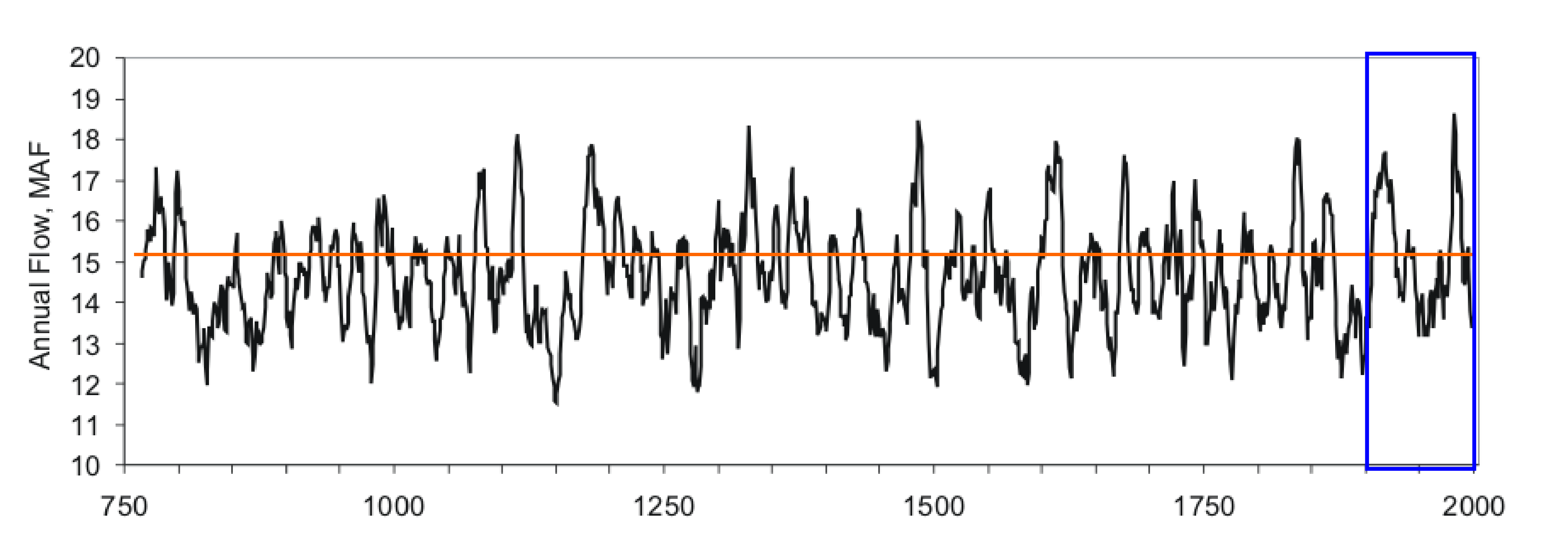


Lowest 5-year flows since 1500

Boulder Crk: 1844-1848 (none since 1907 in lowest 10)

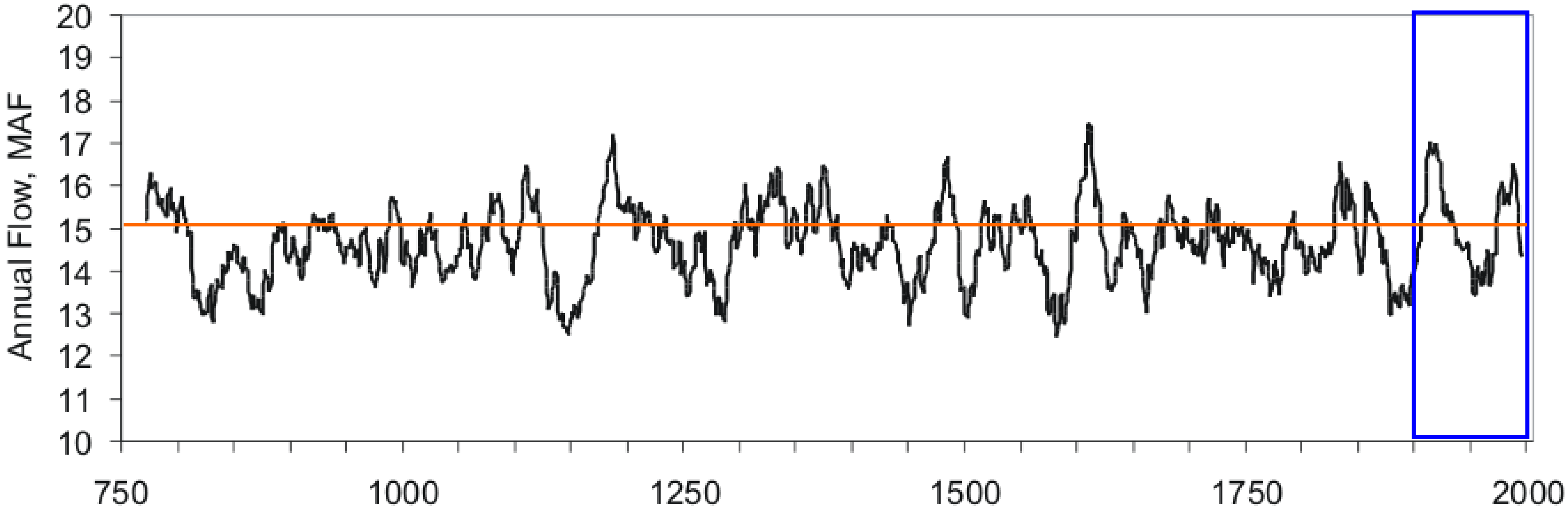
Colorado R: 1580-1584 (2000-2004 – 4th lowest)

Reconstruction of Lees Ferry streamflow, 762-2005, with 10-year running mean



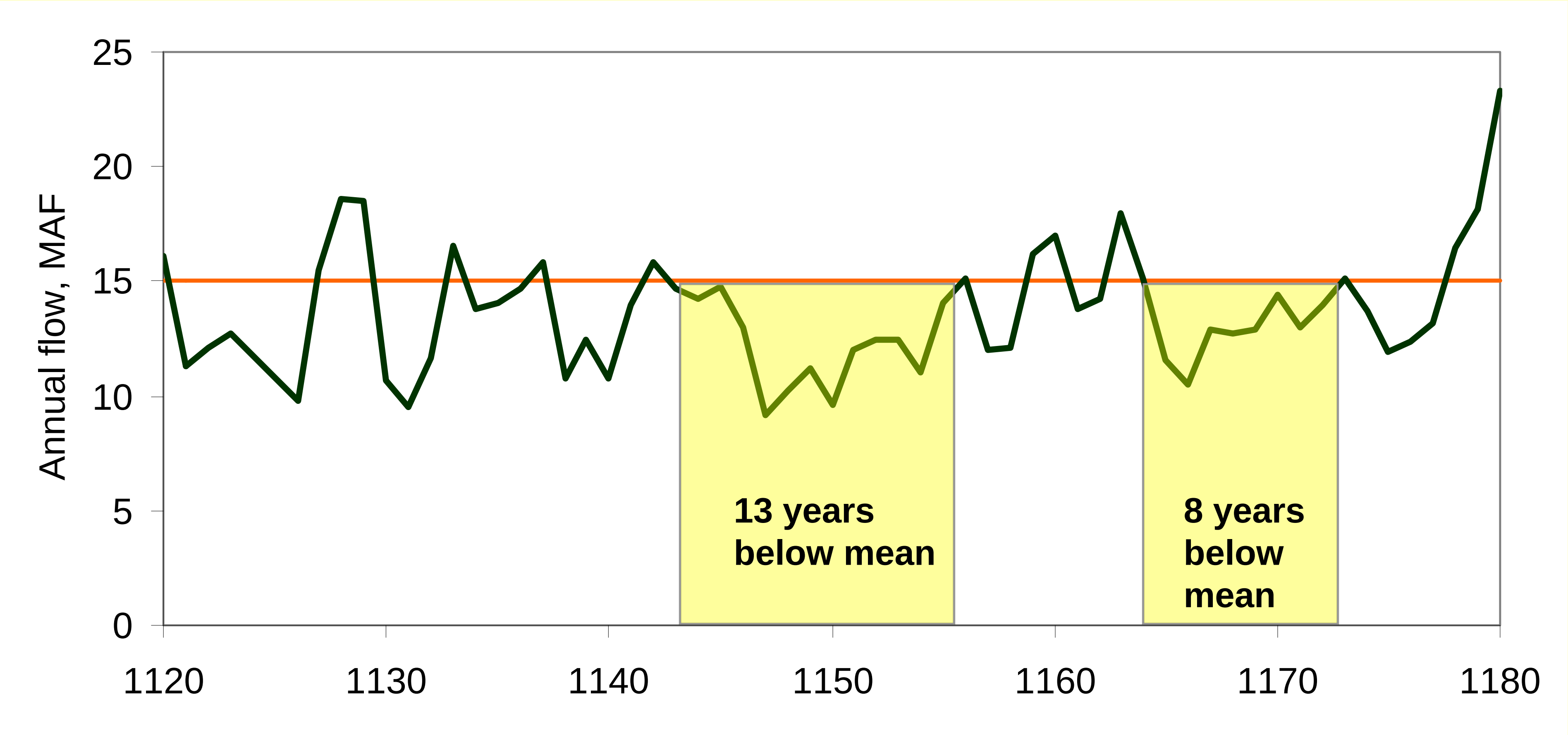
- 5 dry periods before 1900 when reconstructed 10-year mean flow was below 12 MAF (lowest: 1146-1155, 11.5 MAF)
- Assuming average flow in 2009, mean observed flow for 2000-09 will be ~12.1 MAF
- Note wet periods in 1900s

Reconstruction of Lees Ferry streamflow, 762-2005, with 20-year running mean



- 7 dry periods before 1900 when reconstructed 20-year mean flow dropped below 13 MAF (lowest: 1573-1592, 12.5 MAF)
- Lowest post-1900: 1945-1964, 13.4 MAF (reconstructed), 13.3 MAF (observed)
- Again, note wet periods in 1900, and century-scale non-stationarity

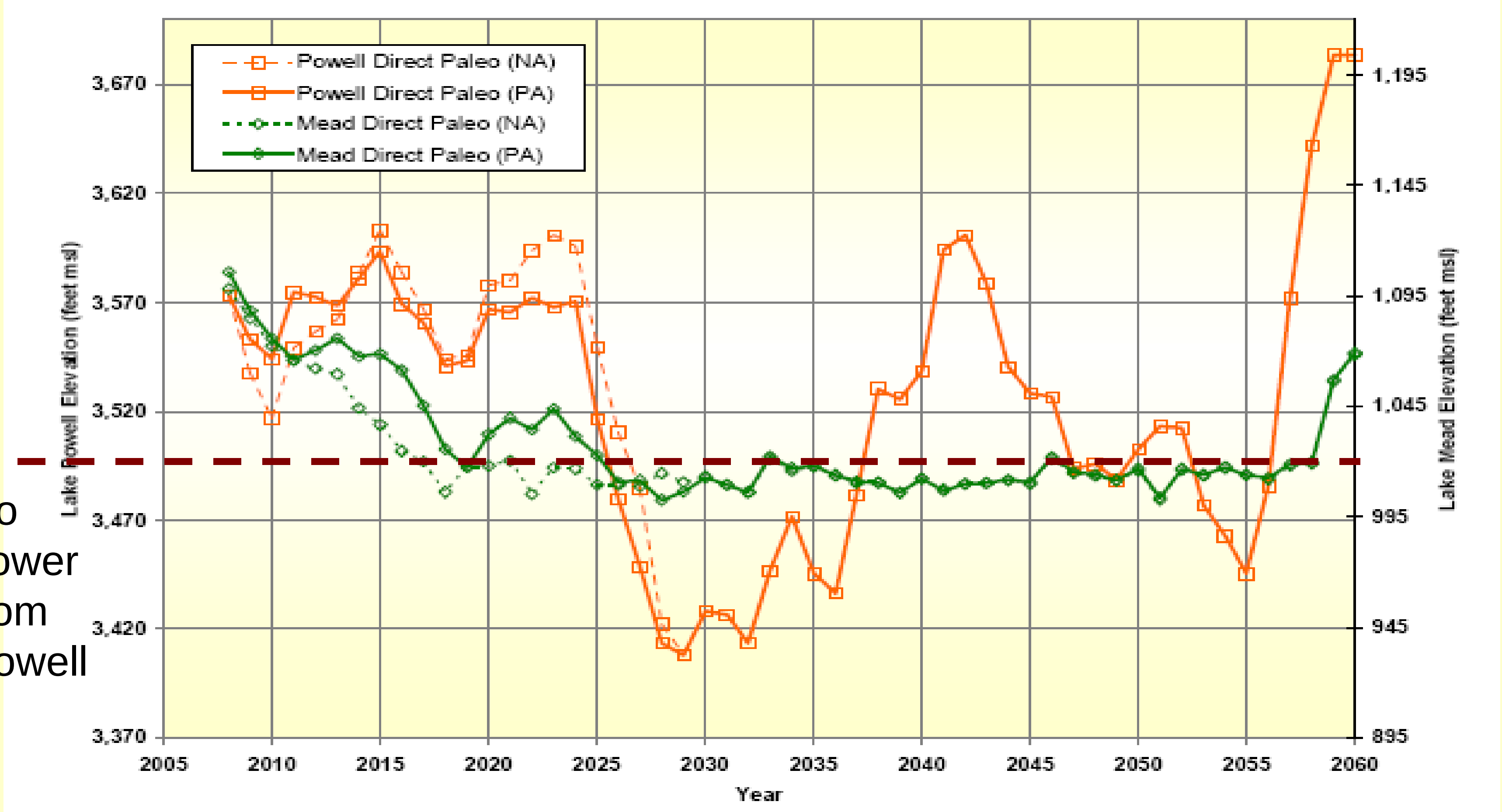
Reconstructed Lees Ferry streamflow, 1120-1180



- From 1121-1177 (57 years), reconstructed flow averages 13.2 MAF, and 4/5 of years are below observed mean

US Bureau of Reclamation - analyses for "Shortage EIS"

Hydrology from Lees Ferry reconstruction, yrs 1130-1182
Modeled Powell (orange) and Mead (green) year-end elevations



No power from Powell

Recap

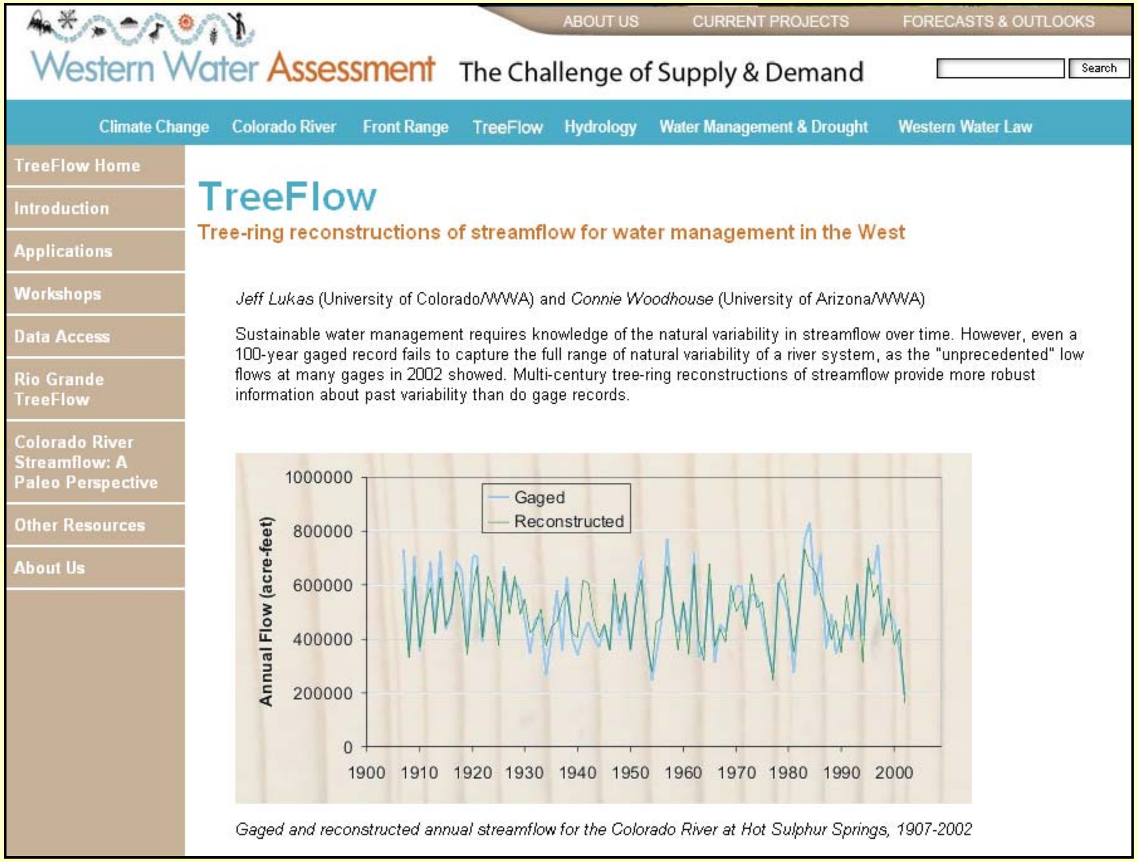
- Tree-ring reconstructions of streamflow exploit a robust relationship between tree growth and moisture

- Reconstructions in Colorado capture droughts not seen in the observed hydrology and indicate the 20th century is not representative of previous centuries

- The early 21st-century drought (inc. 2002) is extreme but still within the bounds of past natural variability

- Reconstructions are being used by many water providers to assess the risk of variability beyond the observed hydrology

TreeFlow webpages at WWA



- Reconstruction data access
- Descriptions of applications
- Technical workshop presentations
- Other resources

http://wwa.colorado.edu/treeflow/

The long view of drought in Colorado:
What tree rings tell us about hydrologic variability

Jeff Lukas
University of Colorado-INSTAAR and Western Water Assessment
lukas@colorado.edu

Water resource management requires robust information about hydrologic variability to assess the risk of drought. There is growing appreciation in Colorado and the West that the relatively short (~100 years or less) observed records of streamflow do not capture the full range of potential hydrologic variability, particularly with respect to severe and sustained drought events. This became especially evident during 2002, which saw the lowest flow on record at many gages in Colorado.

The annual rings of moisture-sensitive trees can be used to extend, or reconstruct, observed streamflow records back in time 300-1000+ years, providing a much longer window onto past hydrologic variability and drought occurrence. Because annual growth of these trees and annual (water year) runoff both integrate the effects of precipitation and evapotranspiration over the course of a year, ring-width is a robust proxy for annual streamflow. Since 2000, Connie Woodhouse (University of Arizona) and I have developed a network of over 80 ring-width chronologies across Colorado and adjacent states. To reconstruct streamflow, we generate a numerical model that best-fits a subset of these chronologies to an observed streamflow record, and then use the model to estimate past flows. In collaboration with water providers through the TreeFlow project, we have now generated over 30 multi-century streamflow reconstructions for gages critical to water management in the Colorado, Rio Grande, San Juan, South Platte, and Arkansas river basins.

Examination of two of these flow reconstructions provides a window into the long-term hydrologic variability over much of Colorado. The reconstruction of Boulder Creek at Orodell (1566-2002) is representative of variability across the northern Front Range, and the reconstruction of the Colorado River at Lees Ferry (762-2005) reflects variability in runoff from Colorado's entire western slope. Looking first at the individual flow years, while 2002 ranks among the ten most extreme low flows at both gages, its severity is not unprecedented. Two other years (1685 and 1851) have similarly low reconstructed flows at both gages. Examining 3-year and 5-year running means for the two gages, to assess the occurrence of multi-year drought, shows that there have been multiple droughts prior to 1900 in one or both basins (1580s, 1660s, 1680s, 1770s, 1840s) that were more severe than any that have occurred since then. Both reconstructions indicate that overall, the 20th century was less drought-prone than the previous four centuries.

The Lees Ferry reconstruction also allows an assessment of droughts prior to the 1500s, and the occurrence of sustained droughts over a 1200-year span. The 10-year and 20-year running means show several decadal-scale dry periods more severe and sustained than the worst such periods of the 20th century. The most dramatic feature of the Lees Ferry reconstruction is the multidecadal dry period in the mid-1100s. From 1130 to 1177, 39 of 48 years had reconstructed flows below the observed mean, with the longest runs of below-mean flows lasting 13 years and 8 years. In summary, the long view of drought in Colorado provided by the tree-rings shows us that while 2002 was indeed an extreme event, the observed flow record contains an incomplete sample of the droughts of the past millennium, and thus is an inadequate basis for planning for the future.

Beyond expanding our appreciation of past hydrologic variability in Colorado, these streamflow reconstructions can be used as numerical input into models to formally assess the risk to water systems posed by past hydrology. For example, the Bureau of Reclamation, in analyses to support their recent Colorado River EIS, ran the Lees Ferry reconstruction through their CRSS policy model to assess the impacts of a recurrence of past hydrology, including the 1100s drought. Other water entities in Colorado and adjacent states are applying the streamflow reconstructions in model-based analyses. The TreeFlow project webpages (http://wwa.colorado.edu/treeflow) describes several of these applications and provides access to the streamflow reconstruction data.

Jeff Lukas:

Jeff Lukas is a Professional Scientist at the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado, Boulder, where he manages the INSTAAR Dendrochronology Lab and conducts tree-ring research. He is also affiliated with Western Water Assessment. Since 2002 his work, with Connie Woodhouse (University of Arizona), has centered on developing reconstructions of streamflow from tree-ring data, and facilitating their application to water resource planning and management (the Treeflow project: http://wwa.colorado.edu/treeflow). As part of this work, Jeff has collaborated with many water providers and consultants in Colorado.