How tree rings can help reconstruct streamflow

A series of technical workshops for water manager and stakeholders

By Jeff Lukas & Connie Woodhouse

Records from the annual growth rings of many trees in the U.S. West can be used to extend, or reconstruct, streamflow records based on gaged measurements. These streamflow reconstructions can provide water managers and stakeholders with a much longer window—300 years and more—into the past hydrologic variability of a river system, and have the potential to inform sustainable management of water resources.

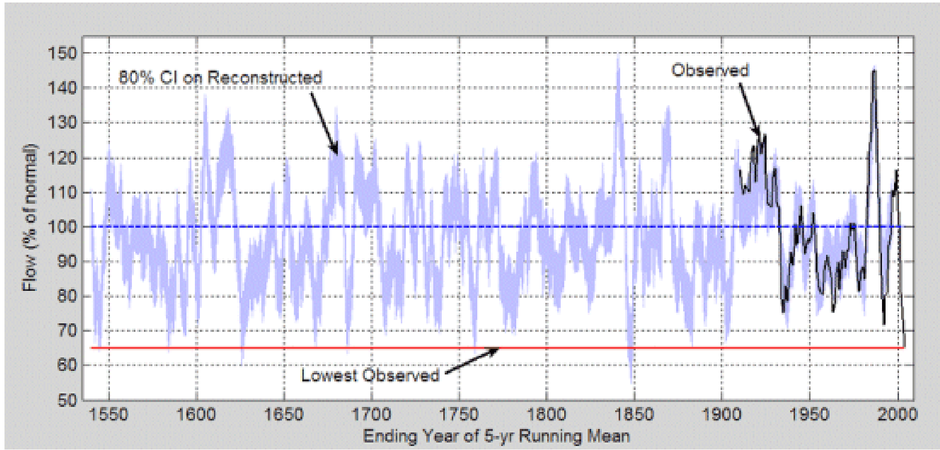

Figure 1: A reconstruction of streamflow for the Colorado River at Lees Ferry (5-year running mean, with the 80 percent confidence interval shown as a purple band) is compared with the observed streamflow record (5-year running mean in black). The severity of the 2000–2004 drought (red line) is likely to have been exceeded at least once in the previous 500 years. Image courtesy of David Meko.

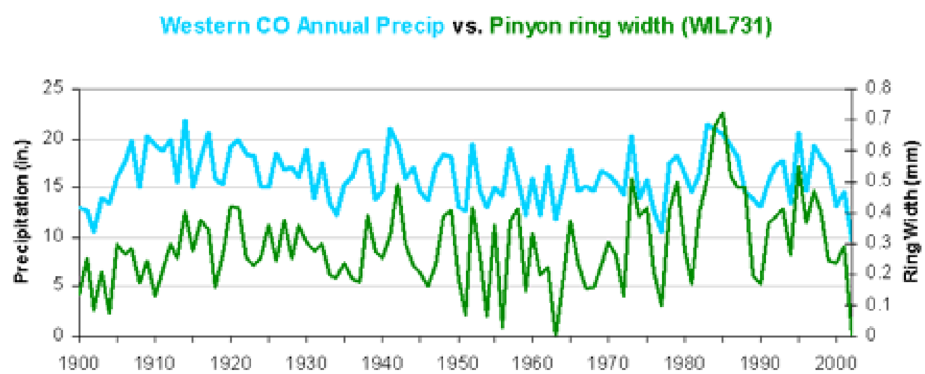

Figure 2: The growth of a pinyon pine sampled in western Colorado near the Delta explains about 70 percent of the variability in annual precipitation for western Colorado. The strong moisture signal recorded in the trees is the basis for robust tree-ring reconstructions of streamflow in the region.

Successfully applying these paleohydrologic data to water management depends on sustained interaction between the scientists who develop the data and the managers who have interest in using them, with each group coming to better understand the operational environment and methodologies of the other. To this end, the Western Water Association (WWA) began presenting a series of workshops for water managers and stakeholders in 2006, with some contributions from the Climate Assessment for the Southwest (CLIMAS). The initial planning workshop was held in Tucson in May 2005.

The goal of these technical workshops is to comprehensively cover the methods of generating reconstructed streamflow from tree rings, so that water managers interested in applying these data have a better basis of understanding from which to work. The core of the all-day workshop is a multi-section instructional presentation, interspersed with hands-on activities, lab tours, and group discussions. Participants respond to a pre-workshop survey so that each workshop's content can be tailored to meet the needs and interests of the specific group. Some points from the workshops are described on page 4.

The first workshop was held in Alamosa, Colorado, in late April 2006, following interest expressed by the Rio Grande Water Conservation District the previous year. The participants—San Luis Valley water managers and natural resource managers—grasped the tree-ring data as an important means to convey to water users and stakeholders in the San Luis Valley the need to constrain demand, particularly groundwater pumping, to accommodate the inevitable sustained dry periods.

A half-day field trip to the foothills west of Boulder to demonstrate field techniques for extracting tree-ring cores from living trees was part of the second workshop in Colorado, held in May 2006. The 14 participants represented a broad spectrum of water agencies and interests in Colorado and the Colorado River basin. The workshop included discussion of applications of the tree-ring data, with each of the participants briefly describing their current and intended use of the data. Some examples are given in Figures 1 and 2.

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Streamflow reconstruction, continued

An October 2006 workshop and field trip in Tucson attracted water managers from across the Southwest and even one from Canada to The University of Arizona's Institute for Study of Planet Earth. Researchers from CLIMAS and the UA Laboratory of Tree-Ring Research also helped out. The workshop featured presentations by Chris Cutler of the U.S. Bureau of Reclamation, Charlie Ester of the Salt River Project, and Bill Girling of Manitoba Hydro on their respective uses of the streamflow reconstructions for management purposes.

Participants' feedback indicates the workshops have fulfilled their objective of conveying relevant information about the tree-ring data. They have also been a venue for water managers to share information with each other about applications of the data, and for researchers to learn more about water management in the region.

Researchers have filled the role of providing data and technical assistance, while the managers and their consultants are developing particular application methodologies (e.g., disaggregating annual tree-ring data into daily time steps for model input). The workshops clearly have enhanced the communication needed to bridge research data and management applications.

Future workshops will continue to mix instruction with discussion of applications as dictated by the participants' needs and backgrounds. A half-day workshop in Durango, Colorado, will be held on May 31, and other 2007 workshops could include Albuquerque, Las Vegas, and southern California.

As a companion to the workshops, web pages hosted by WWA feature the instructional presentations as well as the applications presentations given by water managers. The pages also describe several applications of the streamflow reconstructions to water resource planning, list the water agencies currently using tree-ring reconstructions for management purposes, and provide links to archived reconstruction data for the western United States. The web pages are available at: http://wwa.colorado.edu/resources/paleo/.

Jeff Lukas of the University of Colorado and Connie Woodhouse of The University of Arizona both are affiliated with the Western Water Assessment (WWA). Anyone interested in participating in a future workshop can email lukas@colorado.edu. This article was originally published in the April issue of the Intermountain West Climate Summary, available at http://wwa.colorado.edu/products/forecasts_and_outlooks/intermountain_west_climate_summary/

7 things western water managers should know about tree-ring reconstructions of streamflow

Adapted from an article by Jeff Lukas & Connie Woodhouse

1) The science behind streamflow reconstructions has a long history. In the 1930s, researchers first began to quantify the close relationship between tree-ring growth and the amount of water flowing in rivers and streams (streamflow) in the western United States. In the 1960s, researchers began to employ computers and modern multiple linear regression techniques to develop tree-ring reconstructions of streamflow. Techniques have been progressively refined since then.

2) Tree growth in the West is closely associated with moisture variability, leading to high-quality streamflow reconstructions. In semi-arid climates, the same two climate factors generally control both the growth of moisture-limited trees and the amount of runoff trickling into streams. Precipitation is obviously important. The other important climate factor is evapotranspiration, which refers to water evaporated from the landscape and transpired through plants. Several widespread conifer species such as ponderosa pine, pinyon pine, and Douglas-fir are particularly responsive to the variability of moisture from one year to the next. This sensitivity is even greater when they grow on dry, rocky sites like those found on many western mountainsides (Figure 4). Thus, the trees that are most likely to show annual changes in tree-ring size from annual changes in moisture levels are not the ones growing closest to rivers, but the ones eking out a living on steep slopes in the surrounding watersheds. Because of this, the relationship between tree growth and streamflow is not direct. Instead, tree growth and streamflow are robustly linked by the regional climate that influences both.

3) Combining samples from many trees into one "chronology" improves the moisture signal from a site. At each site, researchers collect pencil-sized core samples from living trees (usually 20 to 30) to maximize the common climate signal. After preparing and sanding the cores so every ring is visible under a microscope, researchers use sophisticated equipment to measure each annual growth ring. Next, they compare the growth patterns among the trees

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7 things about streamflow reconstruction, continued

for a given site, crossdating them to account for any missing or false rings and assigning an exact year to each annual ring. Then, measured ring widths from multiple trees for each site are averaged into a timeline showing the ups and downs of annual growth, which serves as the site chronology. Finally, multiple tree-ring chronologies from the region are combined to reconstruct streamflows for a particular stream gage.

4) The reconstruction assumes the documented relationships between specific trees' growth and streamflow extends back in time. Researchers use several statistical methods to find the chronologies that best reflect streamflow measurements of a specific gage on the river in question. The chronologies that perform the best in estimating the gaged flows are selected to reconstruct earlier flows. The multiple linear regression equation derived from the relationship between tree growth and streamflow serves as the reconstruction model. After creating the model, researchers evaluate its skill by testing it on independent data or on data that had been left out of the model specifically so it could be used for these calibration purposes. Scientists then apply the model to the full tree-ring record, using the reconstruction to extend the streamflow record back hundreds of years.

5) Trees generally do well at estimating streamflow, but there is always uncertainty around the reconstructed flow. Streamflow reconstructions in the West generally explain about 50 to 80 percent of the variance observed in the gaged record. They also capture the important features, particularly droughts, of the gaged record. But trees are imperfect recorders of streamflow. About 20 to 50 percent of streamflow typically relates to factors that are not reflected by the growth of trees in the sampled areas. Researchers can assess the statistical uncertainty in the model by comparing the differences between the reconstructed flows and the gaged flows. They use this information to generate "confidence intervals." For example, an 80 percent confidence interval suggests there is an 80 percent chance the values fall within the illustrated range (Figure 1). In effect, this represents each year's reconstructed flow as a range of plausible flows, with the most probable value in the middle. In addition to the uncertainty shown by the confidence intervals, there is an undefined amount of uncertainty relating to the choices made in data treatment and modeling approaches.

6) By providing a longer window into the past, the tree-ring reconstructions describe the natural variability of climate more completely than gaged records. The tree-ring record clearly shows that the streamflow variability of the 20th century does not simply repeat itself moving back in time. Reconstructions indicate the existence of longer and more severe droughts than those measured in the gaged record—and longer and more pronounced wet periods, too. They also demonstrate that the mean annual streamflow has changed over past centuries. While human activities exert a stronger influence on climate, the influence is superimposed on natural variability. Climate models project that the range of hydroclimatic variability will likely increase in the future relative to the recent past as seen in the instrumental record. Thus the greater variability seen in the multi-century tree-ring reconstructions of streamflow may be a useful analogue for increased future variability. Using the reconstructed flows rather than just the gaged record as the frame of reference for water management planning can help reduce the number of "surprises" that will arise as we head into a climatically uncertain future.

7) Water managers can apply the streamflow reconstructions in different ways, depending on their needs and capabilities. The uses of tree-ring reconstruction of streamflow fall into three general categories:

1. An informal guide for water managers, stakeholders and decision makers.

2. A quantitative assessment of long-term hydrologic variability. For example, assessing the reconstructed frequency of droughts of a given duration and/or severity.

3. A direct input into hydrologic models of a water system. This allows water managers to model system performance using the reconstructed streamflow as they would the gaged measurements. This typically requires additional processing of the reconstruction, which provides annual values, into the monthly, weekly, or daily time steps required by the system model.

A similar article by Jeff Lukas and Connie Woodhouse was published in the April issue of the Intermountain West Climate Summary. Jeff Lukas of the University of Colorado and Connie Woodhouse of the University of Arizona are affiliated with the Western Water Assessment (WWA).

The article published here was adapted by Melanie Lenart, Climate Assessment for the Southwest Research Associate.