# Technical Workshops for Water Managers on Tree-Ring Reconstructions of Streamflow

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*This article describes a series of workshops sponsored by WWA. Any one interested in participating in a future workshop is encouraged to contact the author Jeff Lukas at lukas@colorado.edu so that he can put you on their mailing list.*

The annual growth rings of many trees in the western U.S. capture regional hydroclimatic variability, and tree-ring records can be used to extend, or reconstruct, gaged streamflow records. These flow 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 thus have the potential to inform sustainable management of water resources.[1]

We have found that the successful application of 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, we have presented a series of workshops for water managers and stakeholders. An initial planning workshop was held in Tucson in May 2005.[2] In response to the feedback from participants in the planning workshop, we began developing and presenting one-day technical workshops in 2006.

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. We also tailor each workshop's content to meet the needs and interests of the participants, as indicated by a pre-workshop survey.

> ***"The workshop was very interesting and useful - hope to see more of them. My agency increasingly recognizes the growing public concern with climate change, and that paleodata is an important part of understanding that process."***
> ***- Chris Cutler, Hydrologist U.S. Bureau of Reclamation***

The first workshop was held in Alamosa, CO, in late April 2006, as a follow-up to presentations Connie had made to board meetings for the Rio Grande Water Conservation District (RGWCD) 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.

In early May 2006, we presented a second workshop in Boulder, CO, preceded by a half-day field trip in the foothills west of Boulder to demonstrate tree-ring field techniques. The fourteen participants represented a broad spectrum of water agencies and interests in Colorado and the Colorado River basin. We included more discussion of applications of the tree-ring data in this workshop, with each of the participants briefly describing their current and intended use of the data. Steve Schmitzer presented on Denver Water's use of tree-ring reconstructed streamflows to model water supply yield (Figure 1a).

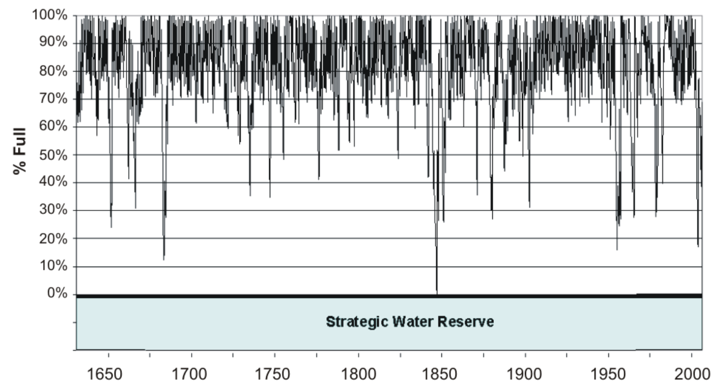


**Figure 1a.** Denver Water uses tree-ring reconstructed streamflows in a supplemental approach for water supply yield analyses, in addition to their standard approach based on the gaged flow record. The graph shows modeled reservoir contents for Denver Water's system from 1634 to 2005, with tree-ring reconstructed streamflows used as inputs to Denver Water's PACSM model, and progressive use restrictions implemented during droughts. While a particularly severe four-year drought in the mid-1840s nearly depletes reservoir contents to the strategic water reserve, demands are met throughout the 372-year period. *(Image courtesy of Denver Water)*

In late October 2006 we presented a workshop and field trip in Tucson, AZ, to water managers from across the Southwest, and one from Canada (Figure 1b). Workshop hosts included staff and graduate students from CLIMAS (Climate Assessment of the Southwest), the Institute for Study of Planet Earth (ISPE) and the Laboratory of Tree-Ring Research (LTRR) at the University of Arizona. The second half of the workshop featured short presentations by Chris Cutler (U.S. Bureau of Reclamation), Charlie Ester (Salt River Project), and Bill Girling (Manitoba Hydro) on

[1] See feature article in the June 2005 Intermountain West Climate Summary and http://www.ispe.arizona.edu/climas/conferences/CRBpaleo/index.html.

[2] See feature article in the June 2006 Intermountain West Climate Summary for information on new reconstructions for the upper Colorado River Basin.

**Figure 1b.** *(Top)* Participants in the Tucson tree-ring workshop listen as Ellis Margolis (University of Arizona) relates the history of a ponderosa pine stand during a field trip to the Catalina Mountains north of Tucson. *(Bottom)* Jeff Lukas (University of Colorado and WWA) describes the characteristics of old trees during the Tucson tree-ring workshop. *(Photos by Scott St. George)*

their respective uses of the reconstructions (the presentations are available online; see On the Web box).

Based on the positive feedback from participants, the workshops have fulfilled our 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 us to learn yet more about water management in the region. Since we began working with water managers several years ago, our role has been to provide data and technical assistance, with the managers and their consultants developing particular application methodologies (e.g., disaggregating annual tree-ring data into daily time steps for model input). The workshops have clearly enhanced the communication needed to bridge from data to applications.

Future workshops will follow the present format of a mix of instruction and discussion of applications, as dictated by the participants' needs and backgrounds. In 2007 we will be holding a follow-up workshop in Boulder, CO, focusing on applications of the data (May 14), a half-day workshop in Durango, CO (May 31), and possibly other workshops in Albuquerque, Las Vegas, and Southern California. We encourage anyone who is interested in participating in a workshop to contact us (lukas@colorado.edu) so that we can put you on our mailing list.

As a companion to the workshops, we have developed new web pages, hosted by WWA, which feature our instructional presentations as well as those given by water managers at the workshops (see On the Web box). The pages also list the water agencies that are currently using the tree-ring reconstructions, and describe several applications of the reconstructions to water resource planning. These pages also provide access to reconstruction data for the western US, which are archived at other websites.

**Top Seven Things Western Water Managers Should Know About Tree-ring Reconstructions of Streamflows**

We have condensed the workshop content into seven key points. For more detail on these points, please refer to the instructional presentations found on the WWA Tree Ring Reconstructions website (see On the Web box).

**1) The science behind streamflow reconstructions has a long history.** The first studies quantitatively relating tree-growth to streamflow in the western US were done in 1930s. The first modern tree-ring reconstructions of climate and streamflow (using computers and multiple linear regression techniques) were developed in the 1960s and 1970s. Techniques for calibrating and validating reconstruction models have been progressively refined since then.

**2) Tree growth in the western US is often closely associated with moisture variability, leading to high-quality streamflow reconstructions.** In semi-arid climates, the same climate factors, primarily precipitation and evapotranspiration, control both the growth of moisture-limited trees and the amount of runoff. Several widespread conifer species (ponderosa pine, pinyon pine, Douglas-fir) are particularly responsive

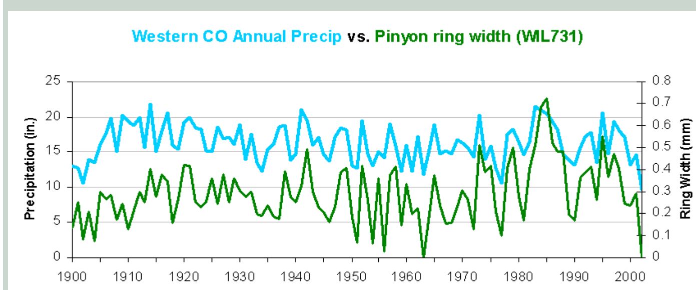


**Figure 1c.** The growth of a pinyon pine sampled in western Colorado near Delta very closely matches (r = 0.7) the annual precipitation for the Colorado Climate Division 2 (western Colorado). This strong moisture signal recorded in the trees is the basis for robust tree-ring reconstructions of streamflow in the region.

to the variability of moisture from year to year—a sensitivity that is even greater when they grow on dry, rocky sites (Figure 1c). Since the trees most sensitive to moisture are not those growing directly in river beds, but on steep slopes in the surrounding watersheds, 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) With extensive field collections, the already-strong moisture signal in the trees is enhanced through replication.** At each site, multiple trees are sampled (usually 20-30) to maximize the common climate signal. Each growth ring is cross-dated, assigning it to the exact year. Then measured ring-widths from multiple trees are averaged into one site "chronology." Multiple tree-ring chronologies from the region are used to reconstruct streamflows for a particular stream gage.

**4) The reconstruction process is based on the assumptions that the relationship between tree growth and streamflow over the gage period also existed in past centuries, and that the trees that perform the best in estimating the gaged flows will also do the best job of estimating earlier flows.** One of several statistical methods, based on multiple linear regression, is used to determine the subset of tree-ring chronologies that best estimates the gaged streamflow, resulting in a regression equation (the reconstruction model). The skill of the model is evaluated using independent data or on subsets of the calibration data. The model is then applied to the full tree-ring record, generating the streamflow reconstruction extending back hundreds of years.

**5) Trees generally do a very good job of estimating streamflow, but there is always uncertainty around the reconstructed flows.** Generally, streamflow reconstructions in the western US explain 50-80% of the variance ($R^2$) in the gaged record. They also capture the important features, particularly droughts, of the gaged record. But trees are imperfect recorders of streamflow. We can assess the statistical uncertainty in the model using the errors (reconstructed flows minus gaged flows) to generate confidence intervals (Figure 1d). This is helpful since it represents each year's reconstructed flow as a range of plausible flows, with the most probable value in the middle. There is also additional unquantified uncertainty related to the choices made in data treatment and modeling approaches, which affect the final result.

**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 rings clearly show that the hydrologic variability of the 20th century does not simply repeat itself. Reconstructions indicate longer and more severe droughts than those 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. Even as human activities exert a stronger influence on climate, this influence will still be superimposed on natural variability. Climate models project that the range of hydroclimatic variability will likely increase in the future relative to the recent past, and the variability seen in the multi-century tree-ring reconstructions of streamflow may be a useful analogue for enhanced future variability. Using the reconstructed flows, rather than just the gaged record, as the frame of reference for planning can lead to fewer "surprises" as we head into a climatically uncertain future.

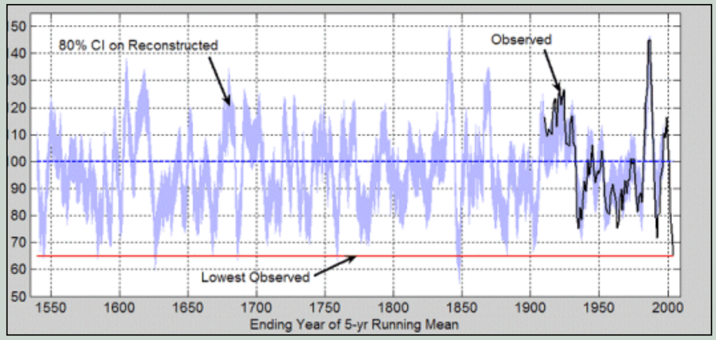


**Figure 1d.** A reconstruction of streamflow for the Colorado River at Lees Ferry (5-year running mean, with 80% confidence interval shown as purple band) is compared with the observed flow record (5-year running mean in black). The severity of the 2000-2004 drought (extended to the left by the red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

**7) The reconstructions can be applied to water management in different ways, depending on the needs and capabilities of the data user.** These applications fall into three general categories:

1. As informal, qualitative guidance for water managers, stakeholders and decision makers.
2. For quantitative assessments of long-term hydrologic variability. For example, assessing the frequency of reconstructed droughts of a given duration and/or severity.
3. As direct inputs into hydrologic models of a water system (Figure 1a). This allows water managers to model system performance under the tree-ring reconstructed hydrology, as they would do with the gaged hydrology. This typically requires additional processing of the reconstruction (annual values) to ingest it into the system model, which may have monthly, weekly, or daily time steps.

## On the Web

- New Web Resource at WWA: Tree-Ring Reconstructions of Streamflow
  - Technical workshop content, applications of tree-ring data, access to data: http://wwa.olorado.edu/resources/paleo/