Workshop report:
Tree-ring reconstructions of streamflow and climate and their application to Colorado River Basin water management - November 13, 2008, Boulder City, Nevada

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On November 13, 2008, nearly 50 individuals met for a technical workshop on tree-ring based reconstructions of streamflow in Boulder City, NV. Participants (listed in Table 1) included water managers from federal and state agencies, private consultants, and academic researchers. The workshop was convened by Jeff Lukas (University of Colorado) and Connie Woodhouse (University of Arizona; UA) to familiarize non-researchers with the methods and analyses used in developing tree-ring based reconstructions of streamflow in the Colorado River Basin (CRB). The Boulder City workshop was the 11th such workshop organized by Lukas and Woodhouse, although each workshop has been slightly different, tailored to the needs of each set of workshop participants. The format of this particular workshop was structured around a morning session covering the tree-ring methodologies, and an afternoon session with invited presentations on the development and application of tree-ring reconstructions of streamflow in the Colorado River Basin. Questions asked by participants during the workshop can be found in Table 2.

The morning began with the "Tree-Ring 101" presentation on the fundamentals of dendrochronology and the development of streamflow reconstructions (Figure 1). Lukas discussed the long history of dendrochronology in the CRB, dating back to earliest years of the formal study of tree-rings in the American West. He went on to explain the theoretical underpinnings for the dating method, and the use of tree growth as a proxy for precipitation and streamflow. Intimate detail was provided for the overarching principles and methods of tree-ring chronology development, including site selection, sample collection, cross-dating, ring-width measurement, standardization, robust-averaging to create the site ring-width indices, and autoregressive modeling. Woodhouse followed with a detailed discussion on the methodology of reconstructing streamflow from tree-ring chronologies. Her presentation covered screening the tree-ring chronology pool for potential predictors, analyzing instrumental hydroclimatic data, the various regression-based methods most commonly utilized for calibration, and finally, validation procedures. Woodhouse resumed her presentation after a break with a detailed discussion of the sources of uncertainty in these reconstructions. In addition to error associated with unexplained variance, choices made during the modeling process bear directly on the resulting reconstruction. Recently, there has been a trend towards generating ensembles of reconstructions to more faithfully represent uncertainty in the reconstructions.

Jeff Lukas takes a question during the presentation of "Tree-Ring 101"

After this introduction, the focus of the workshop shifted towards state-of-the-art research in tree-ring based streamflow reconstructions and their application in Colorado River Basin (CRB) water resource management. Woodhouse discussed the widespread availability of moisture-sensitive tree-ring chronologies in the CRB and the greater western United States, and she highlighted the TreeFlow webpage (http://wwa.colorado.edu/treeflow) as a resource for obtaining and interpreting existing tree-ring based streamflow reconstructions. She presented the latest reconstructions of Colorado River flow at Lees Ferry (Woodhouse et al. 2006; Meko et al. 2007), describing the virtues of the reconstructions and principal findings of both studies. She presented new work by Jain and Eischeid (2008), who used the Meko et al. (2007) reconstruction in a reservoir capacity/yield reliability model to highlight the importance of a characterizing a drought period not just in terms of mean flow, but also in terms of the variance and persistence structure. Tom Piechota (Civil Engineering, University of Nevada, Las Vegas) stressed his group's interest in employing streamflow reconstruction within the context of hydrologic engineering, and discussed their efforts to spatially and temporally characterize paleodrought using tree-ring-based reconstructions of streamflow and snowpack in the upper CRB. Glenn Tootle (University of Tennessee) followed with a discussion on his group's work in the Green River basin in the upper CRB, and their calculations of drought intensity-duration-frequency curves from tree-ring reconstructions of streamflow.

After a lunch break, Joe Leising of the Southern Nevada Water Authority discussed his agency's interest in the tree-ring record of pre-instrumental drought and their current contract with the University of Nevada-Reno (UNR) DendroLab to develop regionally-specific hydroclimatic reconstructions for eastern Nevada. Franco Biondi (Geography, UNR) followed with an overview of the DendroLab's most recent work in the Great Basin, including the development of over 43 single-leaf pinyon (*Pinus monophylla)* tree-ring chronologies and a growing number of hydroclimate reconstructions during recent years. Biondi went on to discuss the alternative methods of Saito et al. (2008), who use tree-ring reconstructed precipitation to drive a simple hydrologic model of Walker River streamflow in the western Great Basin.

David Meko, from the University of Arizona's Laboratory of Tree-Ring Research (UA LTRR) presented his new 600-year reconstruction of Little Colorado River flow at Cameron, AZ. This study was tailored to the Bureau of Reclamation's 24-month study model for planning. One significant challenge that the researchers face is disaggregating the annually resolved

streamflow estimates to the monthly values needed for the model. This disaggregation process was accomplished here using quantile mapping to identify analogous years in the reconstructed and instrumental records and the subsequent calculations of monthly cumulative distribution functions. Kiyomi Morino (UA LTRR) followed with a discussion of her work incorporating these data into a simplified 24-month model for the lower CRB. She noted the need for additional reconstructions of Colorado River tributary streamflow, reduction of uncertainty in the reconstructions, and improved disaggregation techniques.

Jim Prairie, from the Bureau of Reclamation and CADSWES, made the final technical presentation, providing an update on the Bureau's implementation of tree-ring based streamflow reconstructions into their Colorado River Simulation System (CRSS) modeling framework. Blending drought scenarios reconstructed from tree-rings with global climate model projections for future flow, they are generating impressive ensembles of potential drought scenarios for the CRB. This work was used to inform the interim shortage guidelines outlined in the recently released EIS, and to be used by the Bureau until 2026.

The workshop concluded with a brief question and answer session, which augmented the questions and discussions throughout the workshop. Group discussion entailed on climate-change and non-stationarity, long-term (low frequency) climate variability, and non-linear regression techniques.

References Cited*

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Saito, L., Biondi, F., Salas, J.D., Panorska, A.K. 2008. A watershed modeling approach to streamflow reconstruction from tree-ring records. *Environmental Research Letters* 3: doi:10.1088/1748-9326/3/2/024006

Woodhouse, C.A., S.T. Gray, and D.M. Meko. 2006. Updated streamflow reconstructions for the Upper Colorado River basin. *Water Resources Research* 42(5): W05415

*Additional references available at: http://wwa.colorado.edu/treeflow/resources.html

Table 1. Workshop participants and their professional affiliation.

Pam Adams	Reclamation	Janet Kirsch	Reclamation
Phil Aurit	Reclamation	Renee Kolvet	Reclamation
Ayoub Ayoub	SNWA	Joe Leising	SNWA
Leon Basdekas	Colorado Springs Utilities	Iris Lopez	Reclamation
Dana Belcher	Reclamation	Alexei Luganov	SNWA
Joseph Betzler	SNWA	Jeff Lukas	U. Colorado
Franco Biondi	U. Nevada-Reno	Leonard Martin	Reclamation
Becky Blasius	Reclamation	Dave Meko	U. Arizona
Dan Bunk	Reclamation	Paul Miller	Reclamation
Russ Callejo	Reclamation	Kiyomi Morino	U. Arizona
Hannah Campbell	NOAA	Tina Mullis	Reclamation
Randy Chandler	Reclamation	Hong Nguyen-DeCorse	Reclamation
David Donovan	SNWA	Don Ostler	Upper Colo. River Comm.
Carol Erwin	Reclamation	Tom Piechota	U. Nevada-Las Vegas
Nicole Everett	Colo. River Comm. of NV	Jim Prairie	Reclamation
Xavier Gonzalez	WAPA	Peggy Roefer	SNWA
Bill Green	Reclamation	Elsa Romero	Reclamation
Dan Griffin	U. Arizona	Mark Slaughter	Reclamation
Dave Gunderson	Reclamation	Scotty Strachan	U. Nevada-Reno
Norm Henderson	National Park Service	Colby Temple	SNWA
Pat Hicks	Reclamation	Jason Thiriot	Colo. River Comm. of NV
Cynthia Hoeft	Reclamation	Glenn Tootle	U. Tennessee
Steve Hvinden	Reclamation	Esther Valle	Colo. River Comm. of NV
Jeff Johnson	SNWA	Bruce Williams	Reclamation
Dave Kanzer	Colorado River WCD	Connie Woodhouse	U. Arizona

Table 2. Questions posed by attendees during the course of the workshop.

1. Are the trees used in these reconstructions native to the region?
2. How does competition from neighboring trees affect climate sensitivity?
3. Are the long bristlecone pine chronologies in the Great Basin relevant to the CRB?
4. Can trees outside the West be used for dendrohydrology?
5. Can the reconstructions account for sub-basin drought variability?
6. Are chronologies ever made up of tree-ring series “high-graded” for their climate sensitivity?
7. How and why does uncertainty in the reconstruction diminish back through time?
8. Is there any way to improve our (under) estimation of notably wet years?
9. What is the best way to evaluate a reconstruction’s uncertainty?
10. How objective are decisions made in selecting a reconstruction model?
11. Is there a consensus on which Lee’s Ferry reconstruction is the “best?”
12. Do trees have a better signal for precipitation or streamflow?
13. Were there multiple climate regimes over the CRB during the last 2,000 years?
14. Was the mean in Colorado River Flow stable through time?
15. Is it better to use 100 years or 1,000 years of climate record to look forward
16. Can we use records from multiple proxies to improve our perspective?
17. How are the reconstructions useful if climate is changing?
18. Is linear regression the best method for reconstruction?