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PROBLEM AND RESEARCH OBJECTIVES:

The research problem addressed during this study focused on assessing and improving the accuracy of climate reconstructions from tree-ring width records in the Upper Colorado River Basin. The impact of severe sustained droughts (SSD) is a major concern for water availability in the face of increasing population growth in the southwestern United States. This concern is acute in the case of the Colorado River Basin, which includes Wyoming, Colorado, Nevada, Utah, Arizona, New Mexico and California. These states withdraw significant proportions of water for drinking and irrigation from the Colorado River. Since long-term records of hydrologic variability may influence the allocation of water resources, this research has focused on the following question: **Are Paleoclimate Reconstructions of Past Severe Drought in the Colorado Basin Accurate Enough to Warrant Changing the Current "Law of the River"?**

The worth of tree-ring width records for hydrologic reconstruction has been validated in a substantial literature and body of knowledge (Loaiciga et al. 1993). However, in order to provide reliable estimates of past hydrologic variability, tree-ring based models must be calibrated and verified using an instrumental data set that incorporates as large a range of magnitudes and variability in flow as possible. Previous reconstructions of Colorado River flow have used an existing 1896 to 1963 instrumental record of flow at Lee's Ferry, Arizona (Stockton and Jacoby 1976). There are now over 30 years of additional streamflow data that can be added to the original instrumental record period to better calibrate and validate tree-ring models of the Colorado River flow.

The reconstruction of severe sustained drought from these records, in particular the reconstruction of a drought from 1579 to 1598 AD, has been identified as a baseline from which Colorado River water allocations should be governed. However, the sample collection, laboratory processing and primary statistical analysis of these tree-ring records was completed some 30 years ago. Major improvements in tree-ring analysis have been made in the intervening decades, and are continuing. In addition, 1963 was the last year of instrumental hydrological data that was incorporated in the models developed to reconstruct hydrology from these tree-ring records. The magnitude of extreme drought events and natural climatic variability over the period 1963 to present is significantly different than the prior period. Thus, the full range of variability present in the Colorado system over the past 100 years is not incorporated in these earlier studies.

In addition, climatological analysis shows that there are significant differences in the precipitation regime of the Upper Colorado River Basin (UCRB) for the period 1976 to the present, compared with the prior period. In order to use the additional instrumental data from 1976 to present and create reconstruction models based on the full range of climatic and hydrologic conditions over the 20th Century, a new set of tree-ring records extending to the present is needed.

This research addressed the critical needs of developing new tree-ring records and analytic techniques to reconstruct precipitation and drought in the Colorado River Basin, and provided a more accurate model of severe and sustained drought occurrence in the Colorado Basin and adjacent regions over the past 500 years. The research focused on identifying the magnitude, duration, geographic extent, and causes of the late 1500s SSD and the impact of such a drought on current storage capacity and water allocations today.

The main research objectives were:

- To identify the most climatically sensitive tree species and site locations in order to develop chronologies that maximize the accuracy of the extended tree-ring record in a hydrologic reconstruction.
- To collect new tree-ring samples of living and dead drought sensitive tree species to create a ring width and densitometric data set for the UCRB, extending from the mid 1400s to the present.
- To use recently developed procedures for detrending and standardizing raw tree ring data and to develop width and density chronologies.
- To use climate and streamflow data from the entire 1896 to 1998 instrumental record, coupled with new analytic techniques based on independent testing or cross validation procedures in order to refine and improve the reconstructed streamflow and precipitation estimation from our new data set.
- To compare earlier drought magnitude, duration and periodicity with 20th Century drought occurrence. Using time-series analysis, particularly wavelet analysis, to examine differences in temporal patterns in drought occurrence.
- To use the resulting reconstruction to investigate the spatial extent, regional variability, and possible causes of the 1579-1598 drought.

METHODOLOGY:

Douglas (1914) was the first researcher to identify a relationship between tree growth rings and a climatic variable (precipitation), originating the fields of dendrochronology and dendroclimatology. Since then, dendrochronology has become a valuable tool in reconstructing high-resolution records of past climatic variability (Fritts, 1976; Stockton and Jacoby, 1976; Cook and Kairiukstis, 1989; Fritts, 1991). In the last 20 to 30 years, there have been several important advances in dendrochronology. New methods exist to determine if the sample size is adequate to reflect the real variability in common tree-ring signals (Cook and Kairiukstis, 1989). The sample size of trees for the period 1579-1598 was relatively small in the original data set (often less than 5 radii per-site for this period) and larger sample sizes (approximately 30 radii) were needed to improve sample representation. Cross-dating of preserved dead-wood enhanced the sample size for stands with few very old living trees. Adding cross-dated dead trees that are very old (trees established 800-700) helped provide a more reliable estimate of conditions during the 1579-1598 drought. Our analysis showed that the ring records of some species of trees in the UCRB capture extreme drought events better than others. A sampling of these drought sensitive species improved reconstructions of past droughts.

New procedures for detrending ring measurements have been developed for correcting ring width series in trees with special growth characteristics (Cook and Peters, 1981; 1997). In particular, it has been shown that some previously used approaches caused significant bias when comparisons were made of 20th Century conditions and events that occurred earlier in the record (Cook and Peters, 1997). Other recent improvements have been made to adjustments and filters for signal processing (Mann, 1996; Garg, 1998) to stabilize the variance and reduce the influence of non-climatic information, as well as new chronology construction procedures (Cook and Peters, 1997; Cook and Briffa, 1989). Another important breakthrough in dendrochronology has been the introduction of the analysis of the maximum density of late wood as an additional proxy indicator. Late wood maximum density is known to be sensitive to climatic variations (Schweingruber et al., 1978; 1979; 1996) and can be measured using X-rays.

The accuracy of the reconstructed streamflows was improved by selecting models with better predictive (reconstructive) skill and using parameters obtained from independent testing techniques (Jackson and Chan, 1980; Garen, 1992). Recent techniques allow us to measure this predictive skill and the accuracy of both the resulting flow estimation and drought parameters derived from the reconstructed flow (Brockway and Bradley 1995).

PRINCIPAL FINDINGS AND SIGNIFICANCE:

Identification of the sites and tree species that are most sensitive to climate variations, and that would best reconstruct streamflow in the UCRB, was an important objective of this study. In order to identify these regions we used available ring width data from NOAA's International Tree Ring Data Bank (1997) and a natural streamflow record for Lee's Ferry (Arizona) obtained from the U.S. Bureau of Reclamation. Using this information we developed statistical techniques that were improved over those of earlier studies and generated a new Lee's Ferry streamflow reconstruction. This reconstruction showed significant differences when compared with the original Stockton and Jacoby (1976) study, especially for periods of drought.

This research included a more refined study assessing the sensitivity of different species to high and low flows, which expanded our preliminary findings. We were able to identify the most climatically sensitive species, Colorado Pinyon; the species most sensitive to high flows, Douglas Fir; and evaluate the usefulness of Limber Pine in reconstructions of streamflow.

Other results of our study indicated that parts of the upper Green River watershed in Wyoming needed to be resampled using a more sensitive tree species than the existing chronologies derived from Limber Pine (*Pinus flexilis*). The future use of Colorado Pinyon (*P. edulis*) in the Green River watershed in Utah may also improve reconstructions of the UCRB flow (Hidalgo, King et al. 1999e). The use of new chronologies from a more sensitive species will afford a better estimation of the Lee's ferry streamflow and drought history in the basin.

M.S. THESIS: None

Ph.D. DISSERTATION: Hidalgo, Hugo: "The Identification of Severe Sustained Droughts Using New Dendrochronological Procedures" (in progress).
Civil & Environmental Engineering Department, University of California, Los Angeles.

PUBLICATIONS AND PROFESSIONAL PRESENTATIONS:

Publications:

Manuscript under preparation, submitted to *Water Resources Research*:
Hidalgo, H.G., Piechota, T.C. and Dracup, J.A. "Alternative Principal Components Regression Procedures for Dendrohydrologic Reconstructions".

Conference Proceedings and presentations:

Hidalgo H.G., Dracup J.A. "Regional Effects on the Pacific Decadal Oscillation in the Upper Colorado River Basin Hydroclimate." *EOS Transactions*, American Geophysical Union (AGU), 1999 Fall meeting. December, 1999.

King, J.A., Hidalgo H.G., Dracup J.A., MacDonald G.M. "Identification of Hydrologically Sensitive Tree Species in the Upper Colorado River Basin." *EOS Transactions*, American Geophysical Union (AGU), 1999 Fall meeting. December, 1999.

Hidalgo-Leon H.G., King J.A., Dracup J.A. MacDonald G.M. "Species Suitability in Dendrohydrological Reconstructions in the Colorado River Basin". Presented at the Ninth National Conference, Society of Environmental Journalists. September, 1999.

Hidalgo H., Dracup J., Piechota T. "Alternative PCA-Based regression techniques in dendroclimatic reconstructions." Proceedings of the 16th Annual Pacific Climate (PACLIM) Workshop, May 1999. California Department of Water Resources. Interagency Ecological Study Program Technical Report.

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