The Western U.S. Drought:
How Bad Is It?

Thomas C. Piechota – University of Nevada
Janak Timilsena – University of Nevada
Glenn Tootle – University of Nevada
Hugo Hidalgo – Scripps Institution of Oceanography, California

Citation of published version:
Piechota, T., Timilsena, J., Tootle, G., Hidalgo, H. (2004): The Western U.S. Drought: How Bad Is It? *EOS,* 85(32). DOI: https://doi.org/10.1029/2004EO320001

EOS
EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 85 NUMBER 32
10 AUGUST 2004
PAGES 301–308

The Western U.S. Drought: How Bad Is It?

PAGES 301, 304

Historical stream flow records and the forecast for 2004 make the current (1999–2004) drought in the southwestern United States the worst one in the past 80 years for portions of the Upper Colorado River Basin (UCRB).

For the Colorado River (near Cisco, Utah), the cumulative stream flow deficit (departure from long-term mean) for the current drought is almost 11 km^3, or approximately 2 years of average stream flow. Although the current drought is the most significant, based on historical stream flow records, is it the worst ever?

Tree-ring data from the UCRB indicate that even more severe droughts have occurred in the past, and that the current drought is the seventh worst in an approximately 500-year proxy record. The largest drought in the tree ring data occurred at the end of the sixteenth century and lasted for at least 20 years [*Stahle et al.*, 2000]. The research presented in this article examines the current drought in the southwestern United States using stream flow data from the Colorado River and a drought index for the UCRB.

The Colorado River provides a vital water supply to the southwestern United States including major population centers such as Las Vegas, Nevada; Phoenix and Tucson, Arizona; and San Diego and Los Angeles, California. In addition, agricultural areas such as the Imperial Valley of southern California rely on the Colorado River for irrigation of crops.

The UCRB is the primary surface water producer for the Colorado River due to spring-summer runoff from snowmelt (Figure 1). The UCRB has a total area of approximately 286,000 km^2 and is comprised of mountains, forests, agriculture, and low-density development. The basin extends through five states and terminates at Lee's Ferry, just downstream from Glen Canyon Dam in northern Arizona. The main tributaries include the Green River, Yampa River, White River, and Little Snake River. The amount of water supplied to each state in the Colorado River Basin is governed by a set of water rights documents known collectively as the "Law of the River." However, many states, including California, depend on water surpluses (water amounts that exceed their legal allocations) to keep up with the demand of a growing population and agricultural industry.

The current drought, combined with increased water demands, has severely stressed the storage at the major reservoirs of the Colorado River: Lake Mead (Hoover Dam) and Lake Powell (Glen Canyon Dam). Since January 2000, the elevation of Lake Mead has declined by over 23 m, or over 17 km^3 of volume. This volume equates to approximately three water years of allocation for the state of California.

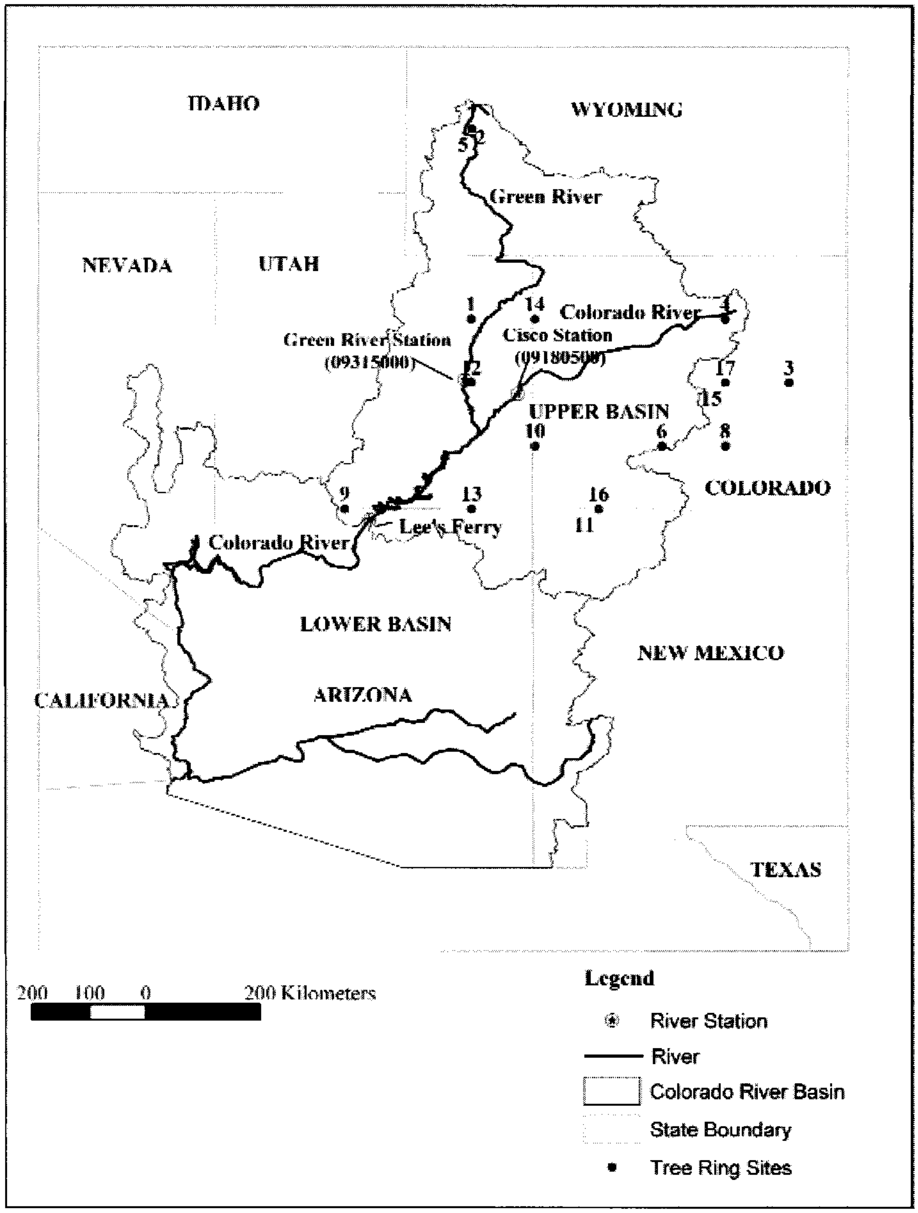

Fig. 1. Location map of Upper Colorado River Basin with selected tree ring (1 thru 17) and stream flow (Cisco and Green) station locations.

By Thomas Piechota, Janak Timilsena, Glenn Tootle, and Hugo Hidalgo

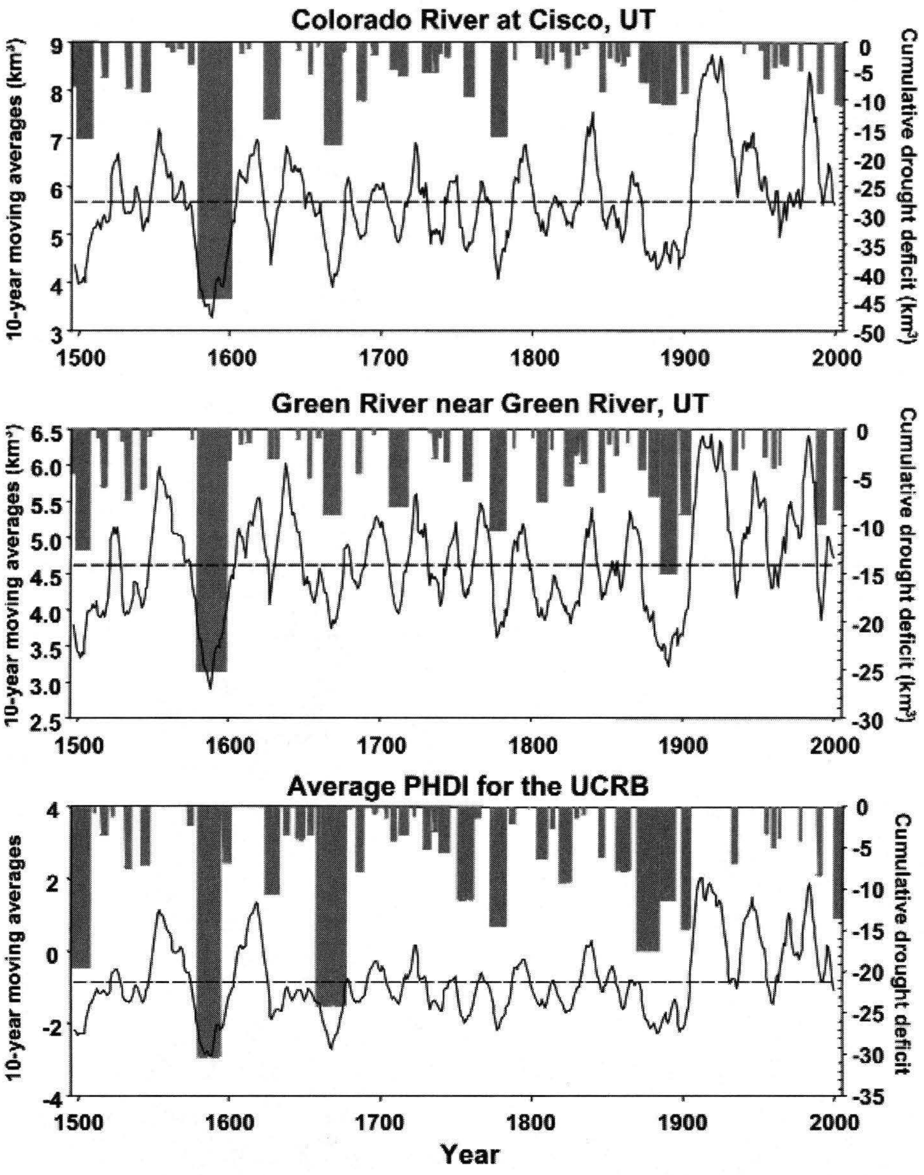

Fig. 2. Drought frequency, duration, and magnitude (vertical bars), and critical periods for water supply shown as 10-year moving averages of stream flow at Cisco, Green, and PHDI (solid line). The long-term mean is shown with a dashed line.

Lake Powell is also at historic low levels—approximately 40% of total live storage available. Other smaller reservoirs in the UCRB are currently at 50–70% of the available storage.

Hydrologic drought in the Colorado River Basin has been extensively studied by researchers using recorded stream flow, and stream flow reconstructions from tree-ring data [e.g., *Meko et al.*, 1995; *Tarboton*, 1995; *Hidalgo et al.*, 2000]. Tree-ring data (dendrohydrology) can be used to extract various hydrological and climatic signals for periods in which little or no data exist. Typically, the data in trees are represented by the ring width or wood density. These tree-ring data allow researchers to formulate yearly time series relationships with stream flow and drought indices such as the Palmer Drought Severity Index (PDSI) and the Palmer Hydrological Drought Index (PHDI).

These relationships are typically developed through the use of principal component analysis (PCA) regression model procedures. A study by *Hidalgo et al.* [2000] evaluated various PCA regression model procedures when using tree-ring data, applying the model to reconstruct warm-season stream flow in the UCRB. Basically, it is a procedure for selecting between many subsets of predictors to obtain a quasi-optimal model. The approach used by *Hidalgo et al.* [2000] to reconstruct stream flow at Lee's Ferry along the Colorado River is utilized here to reconstruct water-year (October - September) stream flow volume at two stations within the UCRB that have minimal impairment, and the average PHDI for the UCRB's climate divisions. The results will identify the magnitude and timing of the worst droughts in the UCRB, and place the relative magnitude of the current drought in the context of long-term hydrologic variability.

Data

Average monthly stream flow data from 1923 to 2003 (81 years) were obtained from the U.S. Geological Survey National Water Information System (NWISWeb) for two stations located in the UCRB: Colorado River, near Cisco, Utah (Station No. 09180500) and Green River, near Green River, Utah (Station No. 09315000) (Figure 1). The U.S. Department of Agriculture's National Water and Climate Center April 2004 forecast of 55% of average annual flow was used for the 2004 water year for the two stream flow stations. Based on the historical record, the average water year (October through September) stream flow volume for the Colorado River station (referred to as Cisco) was 6.3 km^3 and for the Green River station (referred to as Green) was 5.1 km^3.

For the purposes of this study, a drought is defined as two or more consecutive years of below-average stream flow. For the time period 1923–2004, eleven droughts have occurred at both the Cisco and Green stations (Figure 2). The magnitudes of the drought were calculated by evaluating the cumulative negative departure from the long-term mean over the drought period. For the historical stream flow and PHDI record, it is noteworthy that the two largest droughts are the most recent: one occurred during the late 1980s to early 1990s, and the current drought began in 1999–2000 [*Tootle and Piechota*, 2003] (Figure 2).

Palmer [1965] described drought as a "....prolonged and abnormal moisture deficiency." The PDSI was originally developed for semi-arid regions and is based on a weekly (or monthly) water balance for a generic, two-layer soil strata. PDSI values are dimensionless and typically vary between -4 (indicating a severe shortage of water) and +4 (indicating a large surplus of water). The PHDI is similar to the PDSI, utilizing a water balance on a two-layer soil model. However, the criteria for the elimination of a dry spell (or wet spell) are more stringent with the PHDI. The difference is that the PHDI considers a drought to have ended when the moisture deficit actually vanishes, while the PDSI considers a drought finished when moisture conditions begin an uninterrupted rise that ultimately erases the water deficit. The PHDI data for the climate divisions of the UCRB were obtained from the National Climatic Data Center (NCDC) and are used in this study.

In accordance with *Hidalgo et al.* [2000], tree ring data were obtained for 17 representative chronologies in the UCRB from the National Oceanic and Atmospheric Administration's International Tree Ring Data Bank, and are composed of a set of standardized chronologies representing tree growth [*Hidalgo et al.*, 2000]. The 17 chronologies are spatially located throughout the UCRB (Figure 1) in the states of Colorado (8 chronologies), Utah (6 chronologies) and Wyoming (3 chronologies).

Procedures and Results

As noted earlier, the procedures outlined by *Hidalgo et al.* [2000] were utilized in this research. For each reconstruction, more than 16,000 possible models were evaluated and ranked according to their cross-validation standard error. Along with the requirements met by potentially good models mentioned by *Hidalgo et al.* [2000], the time stability of the models was checked.

When utilizing the model, several key verification statistics are determined to validate the

Table 1. Rankings of Drought Periods for Cisco, Green, and PHDI.

	Drought Ranking					
Station/ Indices	#1	#2	#3	#4	#5	Current Drought (1999-2004)
Cisco	1579-1601	1663-1673	1499-1508	1773-1783	1623-1632	#7
Green	1579-1598	1886-1896	1499-1507	1773-1783	1988-1994	#7
PHDI	1579-1594	1658-1677	1495-1507	1870-1884	1900-1905	#7

results. One of these verification statistics is the reduction-of-error (RE) statistic. This statistic provides a sensitive measure of reliability and contains three components: RISK, BIAS, and COVAR [*Fritts*, 1991]. For the Cisco and Green stations, the RE values were high (0.97 and 0.98) and the coefficients of determination (R2) were 0.72 and 0.74, respectively. The calibration of tree-ring data and the PHDI had an RE value of 0.69 and an R2 value of 0.69. All of these values indicate a good relationship between the hydrologic variables and the tree-ring data.

Using the calibrated models, the reconstructed hydrologic variables are shown in Figure 2. The 10-year moving average of the hydrologic variable is also shown so the major periods of drought can be identified. The vertical bars in Figure 2 represent the length and magnitude of the drought as noted by the height of the bar and the width of the bar, respectively.

The current drought (1999–2004) ranks as the seventh worse drought for the Cisco and Green stations and the PHDI in the past 500-plus years of record (Figure 2 and Table 1). The largest drought occurred during the late 1500s, and this is consistent for both stream flow stations and the PHDI. The magnitude of this drought is significantly greater than the current drought (2.5 – 4 times greater, depending upon the station or PHDI selected). The 10-year moving average shows that the late 1500s and the late 1800s were the most significantly affected time frames in terms of water supply (Figure 2). Although the current drought is significant, it follows a fairly high stream flow period, which is why the 10-year moving average is not significantly negative. The current drought is amplified by increased water demand due to population growth in the southwest. This highlights the importance of evaluating all the possible causes of a decreased water supply. A mild hydrologic drought combined with the overuse of water supply can cause extreme drought conditions in a basin.

Figure 2 also highlights the impact of establishing the "Law of the River" in the early 1900s, which was the highest period of stream flow, and resulted in overestimates of the water availability of the Colorado River. The causes of long-term drought are important to establish. Recent studies suggest that the low-frequency component of the large-scale climate system may be playing a role in sustaining the dry conditions in the western United States [*McCabe et al.*, 2004; *Hidalgo*, 2004], while the influence of other factors such as climate change are unknown.

As many communities in the southwestern United States consider enacting a "drought emergency," in which severe water restrictions are implemented, the tree-ring data and reconstruction of hydrologic variables show that the current drought is bad, but it could be worse.

Acknowledgments

The research of the University of Nevada, Las Vegas authors is supported by the USGS Water Resources Research Program, the U.S. National Science Foundation award CMS-0239334, and the NSF Nevada Experimental Program to Stimulate Competitive Research (Advanced Computing in Environmental Sciences) program. Hugo Hidalgo is supported by the California Energy Commission through the California Climate Change Center at Scripps Institution of Oceanography and the U.S. Department of Energy.

References

Fritts, H. C. (1991), *Reconstructing Large-Scale Climatic Patterns from Tree-Ring Data*, University of Arizona Press, Tucson.

Hidalgo, H. G, T. C. Piechota, and J. A. Dracup (2000), Stream flow reconstruction using alternative PCA-based regression procedures, *Water Resour. Res., 36(11)*, 3241–3249.

Hidalgo, H. G. (2004), Climate precursors of multidecadal drought variability in the western United States, *Water Resources Res.*, in press.

McCabe, G. J., M. A. Palecki, and J. L. Betancourt (2004), Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States, *Proc. Nat. Acad. Sciences U.S.A., 101*, 4136–4141.

Meko, D., C. W. Stockton, and W. R. Boggess (1995), The tree-ring record of severe sustained drought, *Water Resour. Bull., 31(5)*, 789–801.

Palmer, W. C. (1965), *Meteorological drought, Weather Bur. Res. Pap. 45*, U.S. Dep. of Commer., Washington, D.C.

Stahle, D. W., E. R. Cook, M. K. Cleaveland, M. D. Therrell, D. M. Meko, and H. D. Grissino-Mayer (2000), Tree-ring data document 16th century megadrought over North America, *Eos, Trans. AGU, 81*, 121–125.

Tarboton, D. G. (1995), Hydrologic scenarios for severe sustained drought in the southwestern United States, *Water Resour. Bull., 31(5)*, 803–813.

Tootle, G. A. and T. C. Piechota (2003), Drought and the 2002–2003 El Niño in the southwest U.S., *Proceedings of the World Water and Environmental Resources Congress 2003*, Am. Soc. Civil Eng., Philadelphia, Pa., 22–26 June.

Author Information

Thomas Piechota, Janak Timilsena, and Glenn Tootle, University of Nevada, Las Vegas; and Hugo Hidalgo, Scripps Institution of Oceanography, La Jolla, Calif.