Colorado River Basin Climate

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Southern California & the "Perfect Drought"

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Introduction

The book 'Perfect Storm' by Sebastian Junger recounts meteorological factors that came together in October 1991 to create a devastatingly lethal storm that swept up the eastern coast of the United States. In terms of Southern California water management one might ask if there could be a similar analogy in terms of a devastating 'perfect drought' that would critically strain drought mitigation capacities in the region. One might also consider what the probabilities are of such a perfect drought occurring in the future. In this article we suggest that a perfect Southern California drought occurs when a local drought increases water demand and decreases water supplies and storage at the same time that the Northern California and Colorado River Basin imported water sources are impacted by droughts, and that such conditions persist for several years or longer. We then explore historical climate records for the past century and tree-ring records for the past 500 years to look for evidence of such droughts.

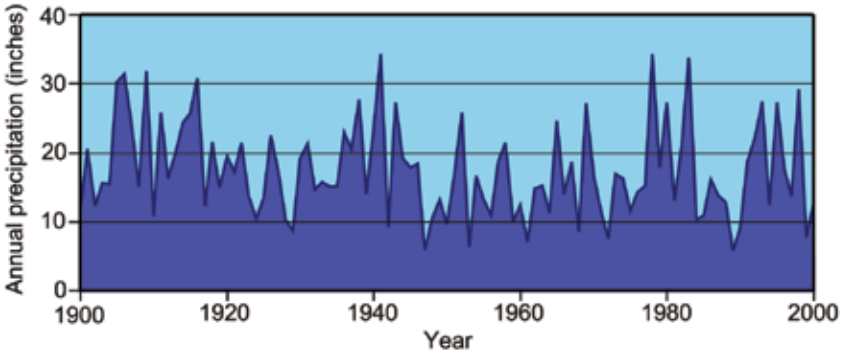

FIGURE 1 *Measured annual precipitation in Southern California*

FIGURE 2 *Sources of imported water for Southern California and MWD.*

Southern California Water Demand and Sources

Two factors dictate the sensitivity of Southern California to drought. First, Southern California has exhibited wide variability in annual precipitation over the period of historical records (Figure 1). The average annual precipitation for coastal Southern California from 1895 to today is about 17 inches. However, during that time there have been 14 years (about 13% of the time) with precipitation below 10 inches. In some years precipitation has been less than 6 inches. Second, local water supplies are insufficient to meet demands even in normal precipitation years, and the region relies heavily on imported water. The Metropolitan Water District (MWD) is the largest distributor of imported water in southern California. MWD typically wholesales some 1.8 million acre-feet (MAF) of water annually to Southern California's larger urban water suppliers, which serve a

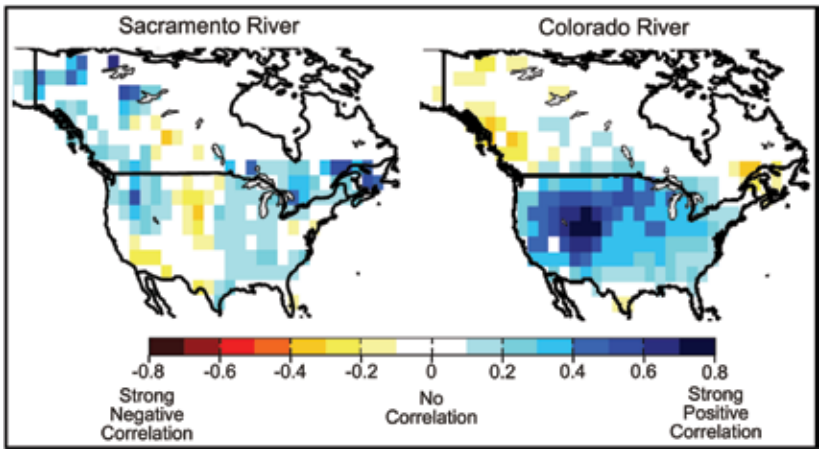

FIGURE 3 *Correlations between river flow and regional geographic patterns of Palmer Drought Severity for the Sacramento and Colorado rivers. High flows on the rivers are most highly correlated with wet years in the blue areas of the maps.*

population totaling about 18 million people. In recent years sources for imported water (Figure 2) include the Colorado River (~1.2 - 0.5 MAF) , the California State Water Project (~ 0.4 - 1 MAF) and the Los Angeles Aqueduct (0.2-0.4 MAF).

Imported Water as a Buffer Against Local Drought

Supplementation of Southern California water supplies with imported water can provide a buffer against the impacts of local drought if the sources of the imported water are unaffected by local drought conditions. Water flowing in the lower Colorado River comes largely from mountain snowpack in the states of Wyoming, Colorado and Utah. Water provided by the California State Water Project and the Los Angeles Aqueduct come largely from Sierra Nevada snowpack that feeds the Sacramento River drainage basin on the western slope of the Sierra and the Owens River drainage on the eastern slope. Analysis of the relationship between Colorado and Sacramento river flow shows that over the past century flows in these rivers are typically most strongly correlated with local conditions in their headwaters areas (Figure 3). High or low flows in either river system are not particularly highly correlated with each other or with precipitation in Southern California, allowing MWD and other state and local authorities to manage resources to take advantage of supply availability. However, a multi-year perfect drought presents greater water management challenges.

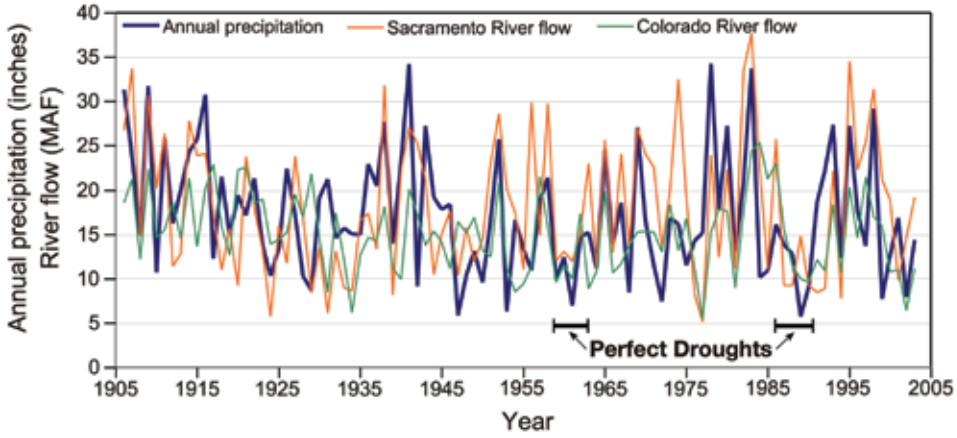

FIGURE 4 *Measured annual precipitation in Southern California compared to measured annual flow of the Sacramento and Colorado rivers. Times of perfect drought impacting all three regions are indicated.*

Perfect Droughts in the Past Century

How often have perfect drought-like conditions occurred during which Southern California, Northern California and the Colorado Basin have all been impacted? A comparison of historical records of Southern California precipitation and flows of the Sacramento and Colorado rivers shows that flows in both river systems and precipitation in southern California were 30% below normal during periods of drought in late 1950s-early 1960s and late 1980s-early 1990s (Figure 4). In both cases, these were periods of multi-year drought in southern California. A map of drought conditions during 1990 shows the presence of severe aridity centered on the headwaters of the Colorado River extending west to eastern California and a second center of drought directly over southern California (Figure 5). During other severe drought episodes in southern California the flows in the Colorado and Sacramento basins were either not as severely depressed or were at average or above conditions.

The climatology associated with dry years such as 1990 typically includes development of a particularly extensive and sustained blocking high over western North America with a low developed in the east. The westerly storm track is diverted north and then eastward producing dry conditions across the west with moist conditions often developing eastward of the continental divide. In some cases, depending upon position and extent of the high, the far Pacific Northwest may or may not experience dry conditions at the

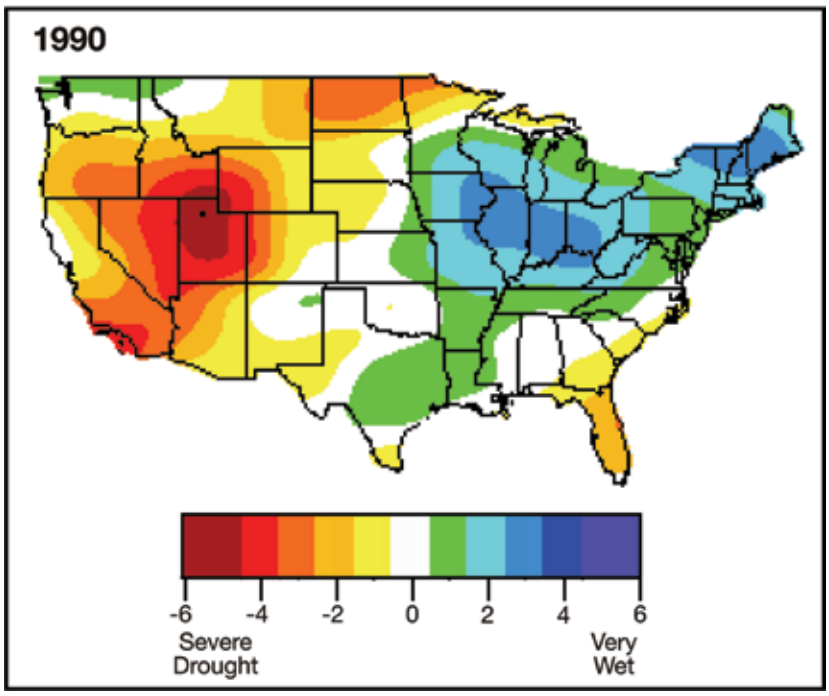

FIGURE 5 *The geographic extent of drought during 1990, measured using the Palmer Drought Severity Index (from http://www.ncdc.noaa.gov/paleo/pdsiyear.html).*

same time. The configuration of dry and wet regions and general climatological conditions during 1990 are typical of some, but not all, periods when synchronous droughts have impacted the Sacramento and Colorado basins. Attempts to find a consistent link between driving factors (such as sea surface temperatures) and this climatic pattern have not yielded a complete answer to their genesis or predictability, and continue to be pursued.

Searching for Evidence of Prehistoric Perfect Droughts

Analysis of historical records indicates that perfect droughts, including severe droughts (decreases in precipitation and river flow of greater than 30%), can indeed occur. However, our instrumental records of precipitation and river flow extend back in time only 100 years or so. This time span is insufficient to capture the full range of natural variability in the climate of California and the west.

Tree-ring analysis (dendrochronology and dendroclimatology) offers a means of extending hydrological records back in time for hundreds to thousands of years (Figure 6). Standard methods of sample collection, processing and analysis are applied in such studies and many tree-

FIGURE 6 *Obtaining a tree-ring core from an ancient pine in the mountains above the Los Angeles basin.*

ring based reconstructions of climate and river flow are available for the West. The rings of trees growing in water stressed locations are typically narrow during years of low precipitation as the lack of water causes physiological stress to the tree. Low precipitation also results in decreased river flow, and this allows tree-rings to be useful in reconstructing both precipitation and the resulting impact of precipitation variability on river flow.

Tree-ring based reconstructions of annual precipitation are available for Southern California. Reconstructions are also available for the Sacramento and Colorado rivers. These reconstructions extend our hydrological records back over 400 years and allow us to look for evidence of prehistoric perfect droughts that might exceed those of the past century. Comparison of the tree-ring records of Southern California annual precipitation and annual flow of the Sacramento and Colorado rivers show several instances in the period 1500 to 1900 when prolonged drought conditions impacted all three regions simultaneously (Figure 7). Examples include the mid-1800s, the late 1700s and a particularly prolonged period of low flow on the Colorado in the late 1500s. Tree-ring based maps of annual drought extent are available for the mid-1800 and late-1700 drought periods and show a geographic pattern (Figure 8) that is similar to the

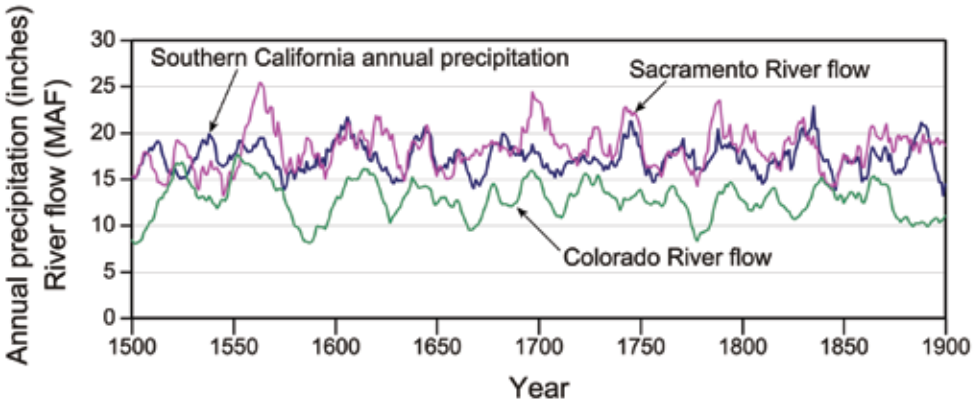

FIGURE 7 *Comparison of tree-ring based reconstructions of Southern California annual precipitation and flow of the Sacramento and Colorado rivers from 1500 to 1900. The series are smoothed with an 11-year running average (data from Rian, S. and MacDonald, G.M. unpublished; Hidalgo H. G., Piechota T C., Dracup J. A., 2000: Alternative Principal Components Regression Procedures for Dendrohydrologic Reconstructions. Water Resources Research, 36, 3241-3249; Meko, D.M., Therrell, M.D., Baisan, C.H., and Hughes, M.K., 2001, Sacramento River flow reconstructed to A.D. 869 from tree rings: J. of the American Water Resources Association, v. 37, no. 4, p. 1029-1040).*

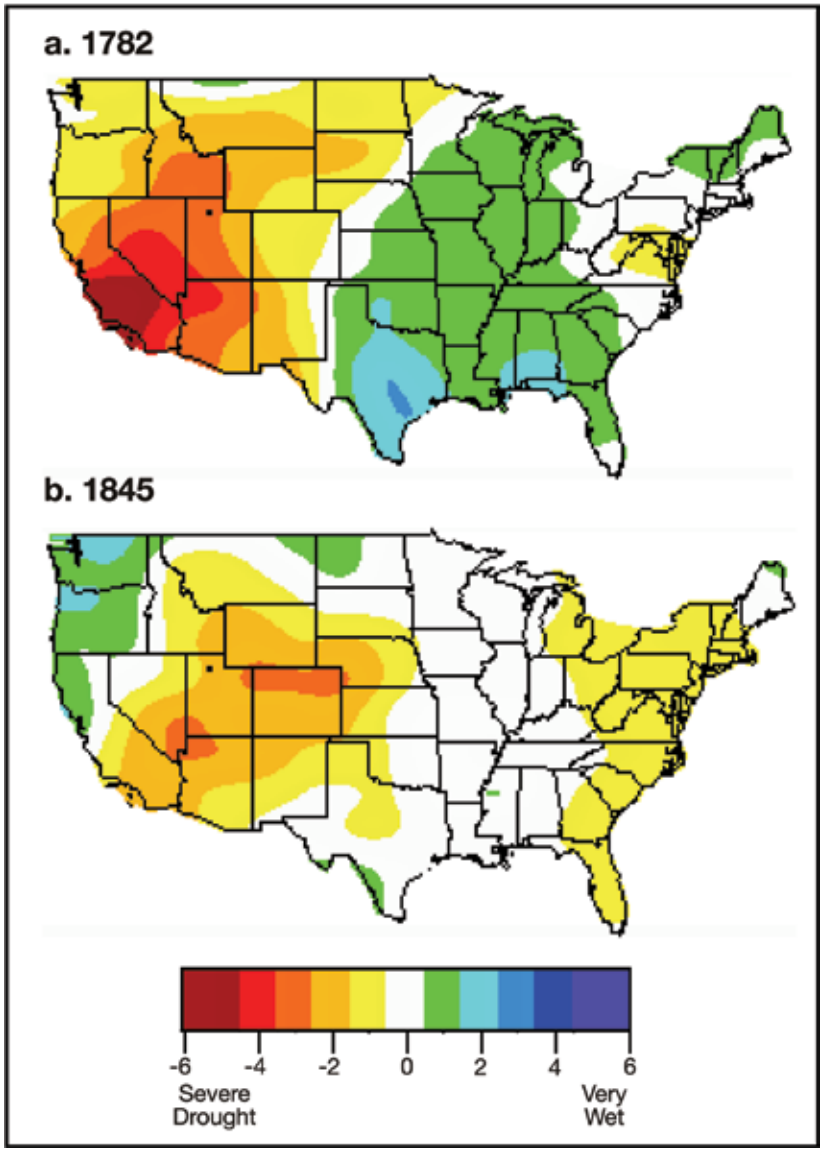

FIGURE 8 *The geographic extent of drought during the perfect drought of 1782 and 1845 measured using the Palmer Drought Severity Index (from http://www.ncdc.noaa.gov/paleo/pdsiyear.html).*

1990 example. In all cases a broad band of aridity extended from California northeastward to the headwaters of the Colorado. The spatial patterning of the pre-historic drought is similar to that recorded in the historical period and substantiates the conclusion that perfect droughts are a natural and expected phenomenon in the West. In addition, the tree-ring records indicate that generally dry conditions may persist in all three regions for lengths of time ranging from several years to well over a decade.

Conclusions

Instrumental climate and hydrological records for the past 100 years and tree-ring based reconstructions for the past 500 years show that multi-year perfect droughts simultaneously impacting Southern California, the Sierra-Sacramento system and the Colorado River have occurred. Such perfect drought episodes should be considered a normal part of the long-term climatic regime in the western United States. Fortunately, water management strategies and storage capacities on the Colorado and in southern California and the state in general have allowed for significant mitigation of the impacts of relatively short perfect droughts, such as during the early 1990s. In addition, both the instrumental and tree-ring records suggest that perfect droughts may only occur once or twice each century. However, the tree-ring record also provides a cautionary note through evidence of more prolonged severe events, such as the multi-decadal drought on the Colorado in the late 1500's.

Future water use planning for southern California is complex, having to account for increasing population size coupled with decreasing availability of water for import as Northern California waters are drawn upon for ecological functioning in areas such as the San Francisco Bay and Owens Valley, or Colorado River waters are fully used by the Lower Basin States. In addition, the possible impact of global climate change remains an open question. However, it is also important to at least consider the potential impacts and mitigation strategies for prolonged multi-year episodes (greater than 5 to 10 years) of widespread drought that would impact local supplies, storage capacity and demands, while at the same time limiting water available for import from Northern California and from the Colorado River Basin due to simultaneous prolonged droughts in those regions.

Further Reading

Meko D. M. and Woodhouse C. A., 2005, Tree-ring footprint of joint hydrologic drought in Sacramento and Upper Colorado River Basins, western USA. Journal of Hydrology 308: 196-213.