Climate Change and Water in the Southwest: A summary of a special peer-review article series

By Zack Guido

The Southwest is hot, and it has been getting hotter in recent years. Since around 1970, average temperatures have increased by about 2 degrees Fahrenheit, making warming in the region among the most rapid in the nation.

This has caused more rain to fall instead of snow and large swaths of piñon pine forests to die, the victims of high temperatures and severe drought. To make matters worse, the dry landscape and withered trees have combined to increase the frequency of large wildland fires. These and other changes are expected to continue. But the greatest impact of climate changes likely will be felt in changes to the water supply.

The Southwest has experienced prolonged drought in recent years. In 2002, 2003, 2007, and 2009 the average precipitation across California, Nevada, Utah, Arizona, and New Mexico was less than 25 percent of the 20th century average. Storage in Lakes Powell and Mead, which provide water to more than 30 million people in seven states and Mexico, plunged from nearly full in 1999 to about 49 percent of capacity at the end of December.

Many scientists also believe that the future will become drier at the same time that tens of millions of people flock to the region. The confluence of population growth, recurring droughts, and climate change raises a critical question: Is the increasing aridity in the Southwest capable of posing significant challenges to socioeconomic and environmental sustainability?

To help answer this question, the journal Proceedings of the National Academy of Sciences (PNAS) devoted a special series in December 2010 to water and climate change in the Southwest. The eight articles in the series help answer burning questions for the region, such as how will projected future warming impact water supplies and what strategies can be employed to create sustainable water use. Together, the articles suggest climate changes will likely make water scarcer in the region, accelerating the need for new innovative water use and management strategies.

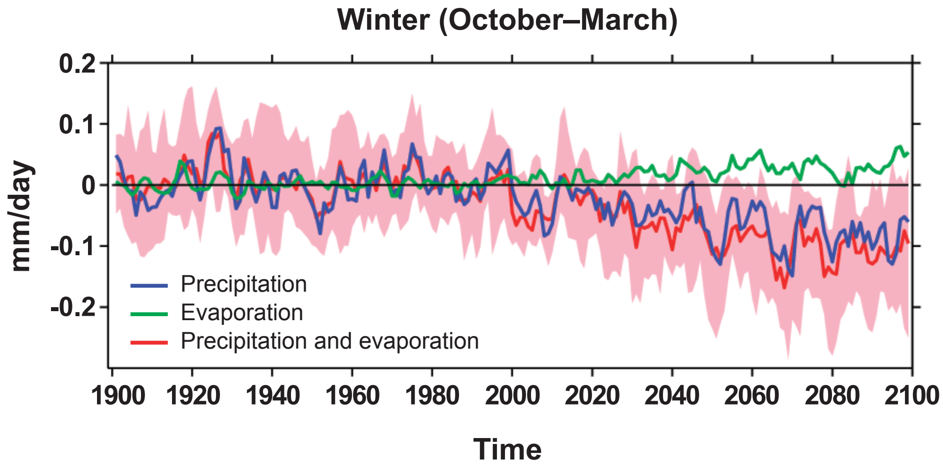

Figure 1. Many climate models project lower precipitation in the Southwest in the future driven predominantly by decreasing winter rain and snow. The combination of decreasing precipitation and increasing evaporation compound each other and make the region drier. The pink shading corresponds to the combined precipitation and evaporation and denotes the range in which half of the 24 models analyzed fall. Source: Seager and Vecchi, 2010, PNAS.

A worst-case drought scenario

Tree rings, which are wider during wet years, have allowed researchers to extend the observational drought record in the Southwest back more than 1,200 years. The expanded account has helped scientists determine that recent dry conditions, which kicked off during the 1998–1999 La Niña event, have been warmer than past drought episodes.

Because observations from weather stations and models suggest that temperatures will continue to increase in the future, and because the region is naturally plagued by drought, scientists scrutinized the 1,200-year record for a dry period that can serve as a worst-case scenario for future episodes.

They found the most severe and widespread of all past droughts smothered the western U.S. in the mid-12th century. It has been dubbed the megadrought and lasted more than 50 years.

"The drought in the mid-12th century far exceeded the severity, duration, and extent of subsequent droughts. The driest decade of this drought was anomalously warm, though not as warm as the current drought," Connie Woodhouse and co-authors wrote in their article "A 1,200-year Perspective of 21st Century Drought in Southwestern North America."

During the driest decade in the mid-12th century, drought covered more than 65.5 percent of the Southwest, more than double the average drought extent during the last 100 years. Colorado River flows were consequently low, averaging an estimated 11.5 million acre-feet per year, which is about 3.3 million acre-feet less than the average during 1900–2006. That decrease is also more than Arizona's total allocation of Colorado River water.

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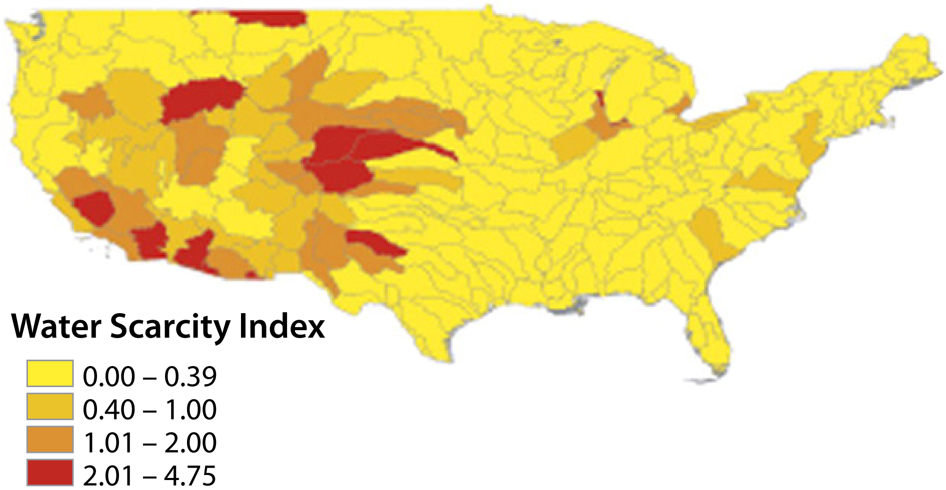

Figure 2. Water stress is commonly defined when the WSI is greater than 0.4, meaning more than 40 percent of the natural river flow is withdrawn. Many river basins in the Southwest are currently stressed; some have more water allocated than naturally flows in the river, requiring the use of groundwater to balance the deficit. Source: Sabo et al., 2010, PNAS.

These numbers beg the question: If a drought comparable to the mid-12th century were to occur today, would there be enough water to go around?

"I believe if we got to that stage, people would be rethinking the way water was allocated, and we might see some very creative approaches to at least making sure domestic and municipal water needs were met," Woodhouse said in an email. "As far as agriculture goes, I'm sure fields would be fallowed."

Future warming and its effect on water

Woodhouse and co-authors state that despite the severity and duration of the 12th century episode, the megadrought should be considered a best worst-case scenario for future droughts because it was at least 0.7 degrees F cooler than the current drought and likely cooler than severe future droughts.

Warmer temperatures make the landscape more arid by increasing evapotranspiration, the amount of water consumed by evaporation and vegetation growth. Past events, therefore, likely underestimate warm future droughts, all else being equal.

To assess possible future conditions, researchers also turn to sophisticated computer models. In their paper "Greenhouse Warming and the 21st Century Hydroclimate of Southwestern North America," Richard Seager and Gabriel Vecchi analyze changes in the combined values of precipitation and evaporation in 24 climate models used in the most recent Intergovernmental Panel on Climate Change (IPCC) Assessment.

The researchers focus on the broad region extending from the California–Oregon border to southern Mexico, and slightly east of the Rocky Mountains to the Pacific Ocean. The models were driven by a "middle of the road" greenhouse gas (GHG) emission scenario known as the A1B scenario. (For a comprehensive description of GHG emission scenarios, see the August 2009 Southwest Climate Outlook feature article "Two or 12 degrees warmer? Greenhouse gas emission scenarios that drive future climate outlooks" on the Web at www.climas.arizona.edu/feature-articles/august-2009).

The authors report that the models robustly predict drying in the region throughout the current century due to rising greenhouse gases and that the drying is driven by a reduction in winter precipitation (Figure 1). Drier winters, the researchers explain, are caused by a poleward shift in storm tracks that originate in the Pacific Ocean.

However, changes in climate that have occurred in the last 30 years clearly demonstrate that natural climate variability also causes drying. El Niño–Southern Oscillation (ENSO) events and changes in sea surface temperatures in the north Pacific and Atlantic oceans play a role, and it is unclear how these natural oscillations will evolve in a warmer world. In fact, the authors are concerned with the inability of the climate models to accurately simulate Pacific sea surface temperatures, which cause precipitation projections to be less certain.

Modeling tests suggest slight warming or cooling in the tropical Pacific would both cause drying, although the severity of drying changes considerably between the warming and cooling scenarios. Temperature projections, however, do not suffer the same uncertainty because ENSO events do not influence temperature as strongly as they affect precipitation.

Nonetheless, the authors conclude that "despite ample uncertainties in model projections of hydroclimate change, and the continuation of natural climate variability on all timescales, it seems very probable that the southwest North America will be drier in the current century than in the one just past."

In a complimentary study, Dan Cayan and co-authors combine future climate projections with a hydrology model to assess how climate changes alter surface water. Their research, presented in the article "Future Dryness in the Southwest US and the Hydrology of the Early 21st Century Drought," relies on climate projections generated from "medium high" and "moderately low" greenhouse gas emis-

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sions scenarios, or the A2 and B1 scenarios, providing bookends for future projections.

Results suggest the Southwest would experience decreases in snowpack and soil moisture. This would cause the number of years of extreme drought—defined by the authors as water years (October 1–September 30) in which the averaged soil moisture spanning the entire study area is equal to or below the 5th driest year in the 1951–1999 period—to increase from five events observed during the historical period to between six and thirteen during the second half of the century, depending on the GHG emission scenario. The number of extreme events is higher for the medium-high emission scenario than for the moderately-low scenario.

The authors also point out that there is no change in the number of years of extreme drought in the first half of the 21st century for either scenario. Their results imply future extreme droughts are more likely; those droughts would in turn drive reductions in stream flows.

"Inevitably, there will be precipitation shortages, and during these times the resulting hydrological drought is aggravated by a trend toward much less snowpack, warmer temperatures, and diminished runoff and soil moisture," the authors conclude.

Other research corroborates this conclusion, stating that for each 1.7 degree F (1 degree Celsius) rise in temperature, runoff will decrease between 2 and 8 percent in the Colorado River basin. To put that number in perspective, if the Southwest warmed by 4 degrees F, reductions in the Colorado River could be as much as 2.8 million acre-feet, which equals Arizona's total Colorado River water entitlements.

Rethinking sustainable water use

In several of the articles in the series, including those mentioned above, the authors suggest a need for new water management strategies to deal with likely reductions in future water supply.

"We are entering a new era in water management," Peter Gleick writes in the paper "Roadmap for Sustainable Water Resources in Southwestern North America." Unlimited population growth, irrigation of crops in certain places, and water use habits that mimic areas with bountiful supplies can no longer be sustained in the region.

The ways of the past are no longer prudent in the Colorado River and other southwestern water systems, Gleick writes, because it is nearly impossible to withdraw additional water supplies.

John Sabo and co-authors illustrate this in their paper "Reclaiming Freshwater Sustainability in the Cadillac Desert." They compare the average amount of water withdrawn each year to the amount naturally available and show that on average, more water leaves many river basins in the Southwest than is available; reservoirs and groundwater makes this possible (Figure 2).

Other limitations also curtail future water supplies. Federal funding for traditional water systems such as reservoirs has largely evaporated, Gleick writes, while water withdrawals from every major aquatic ecosystem in the region, including the Colorado River Delta and the Salt, Verde, Gila, Santa Cruz, Rio Grande rivers, cause more ecological harm than benefit.

While the situation may appear bleak, it is not all bad news. Numerous strategies can help attain sustainable water use.

On the supply side, sources of water that were previously ignored or unusable could be tapped, including the desalination of brackish groundwater, reuse of treated wastewater, and rainwater harvesting.

On the demand side, limiting water used for residential landscaping and applying drip irrigation systems can help conserve huge amounts of water. For example, nearly half of the crops in California are grown with flood irrigation, Gleick writes.

Improving water management is also necessary. Institutions could generate and apply up-to-date information on water availability and use, and integrate climate change impacts into management.

"These new approaches have been used successfully here and there in the western U.S. and offer a way to effectively move toward water sustainability, but they have yet to be adopted in a comprehensive and widespread manner," Gleick concludes.

Take home messages

These PNAS highlighted articles and the other three in the series provide an overview of the state-of-the-science on water and climate change in the Southwest and represent the leading edge of research on the impacts of climate on water in the region. Several insights broadcasted from these articles strengthen several previously held beliefs:

- The most severe past drought, which presents a near worst-case scenario for future episodes, reduced Colorado River flows by about 3.3 million acre-feet.
- Many different climate models, each representing the climate dynamics in slightly different ways, predict drying in the Southwest.
- Future drying is principally controlled by reductions in winter precipitation as a result of a shift to the north in storm tracks.
- Water use strategies that will help the region attain sustainable water use include more efficient irrigation, limited residential landscape watering, desalination of brackish groundwater, reuse of treated wastewater, rainwater harvesting, and the use of climate change information in management decisions.