Effects on Southwest Water Resources

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During a recent meeting, a colleague remarked, "What do you really need to tell people about climate change and water? It's getting hotter. We'll get less snow. The snow will melt earlier. That's all you need to say." "Oy, vey! You mean my entire career boils down to three short sentences?" I replied.

Those glib remarks, of course, are built upon a foundation of over a decade of study by my colleague and several decades of studies by many others. At face value, those remarks are the take-home message of this article. However, looking beyond the face value, there really is more to say and the ramifications will differ depending on the reader's hydrologic, operational, or managerial specialty.

The Big Picture

Historical climate observations reveal changes in the composition of our winter precipitation and the timing of spring snowmelt, both of which strongly influence the Southwest's surface water supplies and soil moisture levels. Compared with the mid-20th century, more of our winter precipitation now falls as rain rather than snow at lower-to-middle elevations (below 9,000 feet). The major pulse of spring snowmelt occurs earlier than it did during the mid-20th century (see page 26). Both of these changes relate to well-documented increases in temperature. Change is seldom limited to a single part of the hydrologic cycle, watershed, or ecosystem. It reverberates throughout the system. Temperature increases and earlier snowmelt have also been correlated to landscape-scale die-off of conifers in the West, as well as increases in the timing and duration of wildland fire. What's more, non-native vegetation seems to love disturbance, which fosters its easy establishment and can give it a competitive advantage over some native species.

> *The certainty of the temperature increase trumps the uncertainty of precipitation changes.*

What Do Observations Really Show?

Tree-ring and other paleoclimatic records show that long-term droughts more severe than historical droughts occurred in combination with higher-than-average temperatures during a period commonly referred to as the Medieval Warm Period, roughly 900 to 1300 A.D. The combination of high temperature and increased aridity during that period is seen as a possible analog for the effect of increased temperature in a warmer Southwest. On the other hand, the Colorado River sustained what is probably its lowest flow in the last 500 years during the relatively cool mid-1800s. These inconsistent responses of precipitation to temperature highlight the challenge in predicting future changes in overall precipitation with high confidence—but they clearly show the region could face long-term droughts more severe than those observed in the last century or so.

A rapid and sustained rise in temperature during the 20th century is the most striking feature of reconstructions of temperature and precipitation spanning the last 1,400 years for the southern Colorado Plateau. And temperature is a hydrological variable, particularly in light of our reliance on snow for regional water supplies. Instrumental records of temperature, precipitation, and snow from the past century through today conclusively demonstrate that ongoing temperature increases are linked to:

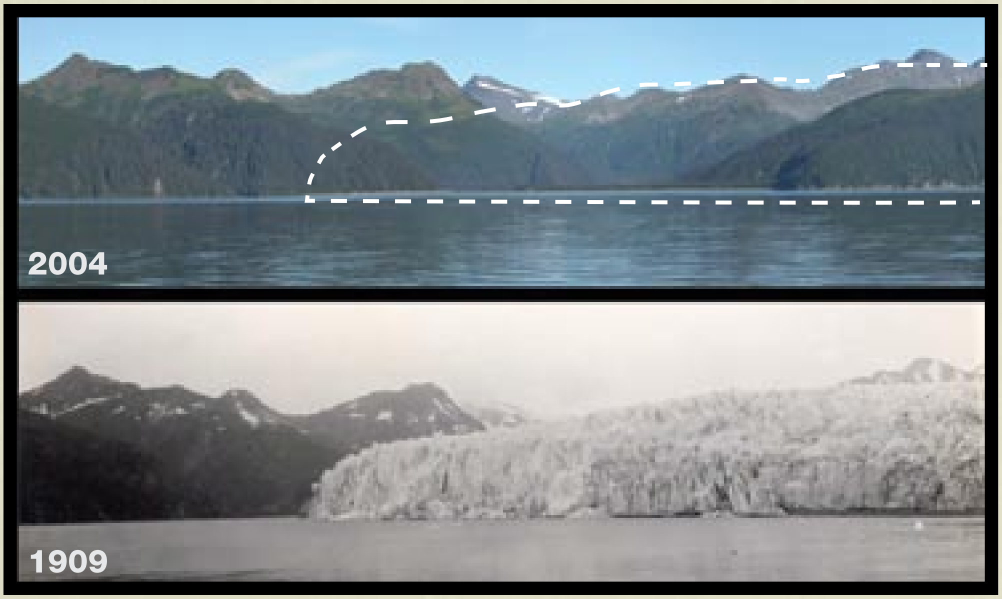
- decreases in snow-water equivalent at lower elevations (below 6,000 feet);
- measurable trends toward a greater fraction of winter precipitation falling as rain rather than snow; and
- significant trends toward an earlier pulse of snowmelt-driven streamflow.

In the Southwest, these trends are generally strongest toward the Sierra Nevada and most pronounced at mid-elevations (6,000 to 9,000 feet). Natural causes, such as multi-year to multi-decade variations in Pacific Ocean-atmosphere interactions, play a role in these trends, especially in the Lower Colorado and Rio Grande basins. However, a large fraction of these trends closely relate to temperature increases that cannot be accounted for by historically observed natural climate variability, especially in the headwater regions of our lifeblood rivers: the San Joaquin-Sacramento, the Colorado, and the Rio Grande.

The Certain, the Less Certain, and the Ugly

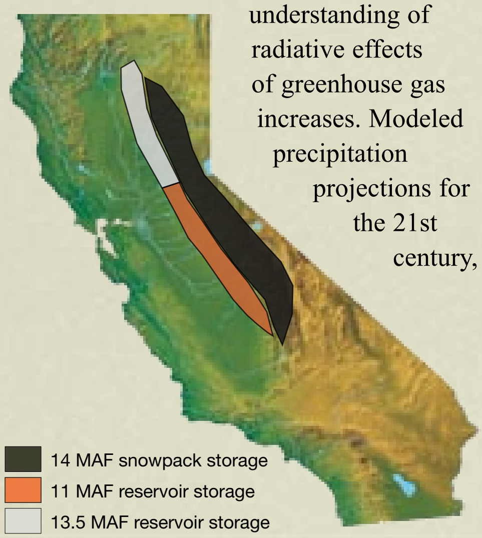
Climate scientists have developed realistic general circulation models (GCMs) that simulate global atmosphere and ocean circulation at fine temporal scales (as small as three hours) based on some of the fundamental physics of the land-ocean-atmosphere system. These models produce plausible results, consistent with our understanding of climatology, and they are good at simulating most observed features of the land-ocean-atmosphere system. What these models do really well is simulate the earth's radiation balance, at relatively coarse spatial resolution, and changes to the radiation balance from natural and human atmospheric inputs. What the global models do not do well is simulate fine spatial-scale processes, watershed-scale precipitation, the precise timing of phenomena like the monsoon, and any processes that require realistic topography to produce realistic results. Predicting the influence of cloud cover, which can reduce incoming solar radiation yet retain outgoing heat, also remains challenging.

Scientists compensate for some of the limitations of the GCMs by feeding their output into regional climate models that have much finer spatial resolution and more accurate topography. Another strategy to compensate for spatial coarseness in GCMs is to use statistical relationships developed from observational data to estimate climate parameters at finer spatial scales. For instance, increases in elevation lead to relatively predictable decreases in temperature and increases in precipitation compared to sea level.



Retreating glaciers, such as McCarty Glacier in Alaska, shown here in 1909 and 2004, dramatically illustrate the effects of warming on the hydrologic cycle. Source: USGS photo library, Robert A. Rohde, and Global Warming Art (www.globalwarmingart.com).

The average predictions of 18 of the latest and greatest climate models show annual temperature increases of 4 to 5°F throughout the Four Corners states and Nevada by mid-century (2046-2055), as described in more detail by Hoerling (page 18). Such increases are consistent with observed increases in temperature, especially since the 1970s, and with our understanding of radiative effects of greenhouse gas increases. Modeled precipitation projections for the 21st century, however, diverge considerably, although annual precipitation decreases by mid-century are anticipated for the Lower Colorado River Basin (CRB).



Current storage capacities in northern and southern California reservoirs and the Sierra snowpack. A 3°C increase in temperature is projected to result in a 4- to 5-million-acre-feet (maf) decrease in Sierra snowpack from its current 14 maf capacity (from the California Department of Water Resources).

Illustration: Mike Buffington

Studies that synthesize information on western snowpack, streamflow timing, and CRB hydrology indicate that projected temperature increases will severely strain water resources in the basin. By mid-century, the main pulse of spring snowmelt runoff in the Upper CRB is expected to come approximately two weeks earlier than at present. By the end of the century, snowmelt runoff is expected four weeks earlier in virtually all of the six southwestern states. Runoff is also expected to decrease, in part due to the higher evaporation rates that come with higher temperatures. With a decrease in runoff, storage and power generation would decrease, unless changes in allocation and demand can compensate for present stresses on the system.

The basic message of these studies is that the certainty of the temperature increase trumps the uncertainty of precipitation changes. Warming oceans contribute to the growing expectation for more frequent El Niño events, which tend to boost winter and spring precipitation in the Southwest, as well as spring temperatures. Overall, though, temperature increases

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are expected to decrease the ability of our mountain "water towers" to reliably deliver water in the quantities we have come to expect and when we most need it.

Society and Water in the Southwest

It would be short-sighted to consider climate change in isolation from other aspects of the human-environment system. We need to consider the confluence of population growth, agricultural and recreational values, power generation needs, environmental laws, and other societal priorities. Our bountiful groundwater supplies built up over hundreds to thousands of years but, in the Southwest's major urban areas, it has taken less than a century to deplete these supplies to levels that require active and vigilant management. Groundwater is renewable on relatively long time scales, and is considered by many water managers to serve as a back-up for fully renewable surface water supplies.

Increasing temperatures, due to expanding urban heat islands as well as regional climate trends, will increase power and water demands during the time of year when our water supplies are most vulnerable. The National Renewable Energy Laboratory estimates that, nationally, thermoelectric freshwater use for power generation roughly equals freshwater use for irrigation. For each kilowatt-hour of power consumed, Arizona and Nevada consume more than 7 gallons of water, Utah and California between 3 and 5 gallons, and Colorado and New Mexico about 1 gallon (Torcellini and others, 2003). Thus, increases in cooling system use as temperatures rise must be considered part of the effects of climate change and population growth on the water supply.

What Does it Mean for Me?

According to the best science to date, we can reasonably expect changes in the timing of peak streamflow (earlier), rates of evapotranspiration (higher), and the duration and severity of future droughts (longer, more severe). We can also expect water and energy demand to increase as a result of increased temperatures, longer heat waves, and urban warming. The combination of these changes, as well as others that are less predictable, will require resource management that is flexible and that can incorporate the latest scientific knowledge. From the imperfect but valuable body of information that bridges observed and projected climate changes, we can develop plausible scenarios to guide management options.

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Reference

Torcellini, P., N. Long, and R. Judkoff, 2003. Consumptive Water Use for U.S. Power Production. National Renewable Energy Laboratory report, NREL/CP-550-35190, www.nrel.gov/docs/fy04osti/35190.pdf.

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