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Managing Water Resources in a Low-to-No-Snow Future

Mountain snowpacks around the world are in decline. And as the planet continues to warm, climate models forecast that snowpacks will shrink dramatically and possibly even disappear altogether on certain mountains, including in the western United States. A new study by researchers at several institutions, including UC Santa Barbara and Lawrence Berkeley National Laboratory (Berkeley Lab), analyzes the likely timing of a low-to-no-snow future, what it will mean for water management, and opportunities for investments now that could stave off catastrophic consequences.

Their review paper, published in the journal Nature Reviews Earth and Environment, analyzes previous climate projections and finds that if greenhouse gas emissions continue along the high-emissions scenario, low-to-no-snow winters will become a regular occurrence in the western U.S. in 35 to 60 years. The study also re-evaluates longstanding assumptions in U.S. water management, stressing the importance of collaboration between scientists and water managers in developing and implementing climate adaptation strategies.

The Sierra Nevada, Rockies, Cascades and other mountain ranges provide a tremendous service by capturing, storing and releasing water for downstream use. Historically, snowmelt would slowly release water from winter precipitation well into the spring and into the summer, when precipitation is low but water demands are at their highest due to agriculture.

“This puts the loss of seasonal snowpacks throughout the Western U.S. into perspective,” said co-author Naomi Tague, an ecohydrology professor at UC Santa Barbara. For example, it highlights that historically in years with an “average” climate, the amount of water stored in snowpacks is more than double that in existing reservoirs. “The take-home message is that changing snowpacks are critical, and that we need to act now to adapt our water use, regulations and infrastructure to avoid water crisis in the future.”

Increasing temperature and shifting precipitation are mostly responsible for the shrinking snowpacks. Warmer temperatures mean that storms drop more water as rain rather than snow, limiting the amount of seasonal snowpack that builds up in the winter.

The research, co-led by authors Erica Siirila-Woodburn and Alan Rhoades of Berkeley Lab’s Earth & Environmental Sciences Area, starts with a literature review distilling several hundred scientific studies on snow loss; of those, they identify and analyze 18 studies that had quantitative snowpack projections for the western U.S.

When will the low-to-no-snow future arrive?

"A recent study highlighted that there has been a 21% decline in the April 1 snowpack water storage in the western U.S. since the 1950s – that's equivalent to Lake Mead's storage capacity," said Rhoades. “In our review, we found that around mid-century we should expect a comparable decline in snowpack. By the end of the century, the decline could reach more than 50%, but with a larger range of uncertainty.

Many water managers use the somewhat arbitrary date of April 1 to make snowpack observations and planning decisions. Snowpack volume has decreased over the last several decades, and the timing of peak snowpack has shifted. The peak occurs approximately 8 days earlier in the year for every 1 degree Celsius (1.8 degrees Fahrenheit) of warming. Many regions have already experienced winters with very little snow in recent years. On April 1, 2015, the Sierras snowpack was 5% of normal, which the authors call an "extreme" event.

"Low snow" is defined as when the snowpack (or more precisely, the snow water equivalent, a measure of how much water will be released when the snowpack melts) is in the 30th percentile or lower of the historical peak. The paper defines two other types of low-to-no-snow conditions. "Episodic low-to-no snow" occurs when more than half of a mountain basin experiences low-to-no snow for five consecutive years. "Persistent low-to-no snow" is when this happens for 10 consecutive years.

Under these definitions, California could experience episodic low-to-no snow as early as the late 2040s and persistent low-to-no snow in the 2060s, according to one high-resolution climate projection. Other parts of the western United States could see persistent low-to-no snow in the 2070s. The authors caution the need for more analyses with a broader set of climate projections to enhance confidence in this timeline.

The authors describe the climate projections in their study, writing: "Through the middle and end of the 21st century, an increasing fraction of the western U.S. is impacted by snow water equivalent deficits relative to the historical period. In particular, only 8 to 14% of years are classified as low-to-no snow over 1950-2000, compared to 78 to 94% over 2050-2099. In all regions, an abrupt transition occurs in the mid-to-late 21st century."

These computer-generated images show data for lowest (left) and highest snowpack conditions over a 36-year period. (Use mouse to move the slider.) An algorithm generated each point on the map, comparing data from 1982 through 2017 and using the lowest or highest values. Because individual years can result in anomalous snowpack in one mountain region and not another, these images convey composites of low and high snow conditions regardless of the year of occurrence. (Credit: Images generated by Ben Hatchett and Alan Rhoades/Berkeley Lab, using data from Zeng, X., P. Broxton, and N. Dawson. 2018. Snowpack Change From 1982 to 2016 Over Conterminous United States, Geophysical Research Letters. 45. 12940-12947)

Impacts on water resources

The impacts of a low-to-no-snow future extend beyond just decreased streamflow, although that is certainly a significant consequence. In the Sierra Nevada, for example, the amount of water in the snowpack on a typical April 1 is nearly double the surface reservoir storage in California.

“A low-to-no-snow future has massive implications for where and when water is stored in the western U.S.,” said Siirila-Woodburn. “In addition to the direct impacts on recreation and the like, there are a lot of secondary effects on natural and managed systems, from a hydrologic perspective. So that's anything ranging from increased wildfire occurrence to changes in groundwater and surface water patterns and changes in vegetation type and density."

Snowmelt more effectively infiltrates the subsurface than does rainfall. So more rain and less snow could significantly impact the groundwater levels in mountainous systems. Further, less snow at lower elevations will decrease the overall surface area of snowpack stored in the mountains, potentially resulting in less available snowmelt that infiltrates into the ground.

Now for the good news …

The study's goal was to spur a conversation about adaptation strategies. "We want society to be proactive about these changes in snowpack rather than reactive," said Rhoades.

"Even with existing uncertainties, our estimates of snowpack and climate can be used to improve how we regulate and plan our use of water storage," added Tague. Investing in and adopting improved water infrastructure and techniques can reduce our vulnerability in low snow years.

The paper outlines potential adaptation strategies, including a technique known as managed aquifer recharge in which excess surface water is stored as groundwater for later use. Another relatively new method is forecast-informed reservoir operations, in which weather and hydrological forecasts are used to inform decisions about retaining or releasing water from reservoirs, was recently shown to increase water storage at Lake Mendocino in California by 33%.

These and other techniques show promise for increasing water supply, but the authors also recommend more cross-collaboration, both among scientists and within society as a whole, to expand the portfolio of climate adaptation strategies.

"We are advocating for the idea of engagement with best scientific practices and more collaboration or partnership between researchers and stakeholders," said Siirila-Woodburn. "For example, city managers are concerned with flood control; farmers are concerned with water storage; everyone has their own objectives. Even within science, the disciplines are typically siloed. If everyone were working together to manage water rather than working independently for their own purpose, there would be more water to go around."

About UC Santa Barbara

The University of California, Santa Barbara is a leading research institution that also provides a comprehensive liberal arts learning experience. Our academic community of faculty, students, and staff is characterized by a culture of interdisciplinary collaboration that is responsive to the needs of our multicultural and global society. All of this takes place within a living and learning environment like no other, as we draw inspiration from the beauty and resources of our extraordinary location at the edge of the Pacific Ocean.