Does limited underground water storage make plants less susceptible to drought?

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David Dralle of Sacramento State University investigates water emerging from a spring. Researchers at the Eel River Critical Zone Observatory, led by UC

Berkeley geomorphologist William Dietrich, have used hillslope-scale insights into how water is stored below ground to explain state-wide patterns of plant drought response. Credit: Jesse Hahm, UC Berkeley

You might expect that plants hoping to thrive in California's boom-or-bust rain cycle would choose to set down roots in a place that can store lots of water underground to last through drought years.

But some of the most successful plant communities in the state—and probably in Mediterranean climates worldwide—that are characterized by wet winters and dry summers have taken a different approach. They've learned to thrive in areas with a below-ground water storage capacity barely large enough to hold the water that falls even in lean years.

Surprisingly, these plants do well in both low-water and rainy years precisely because the soil and weathered rock below ground store so little water relative to the rain delivered.

"The key point from our study is that, in many sites on the North Coast, the storage capacity is small relative to how much it rains," said Jesse Hahm, a graduate student at the University of California, Berkeley, and one of two first authors of the study. "Because the capacity for the subsurface to store water over the wet season is small, it still rains enough, even in the dry years, to replenish the water supply. The limited below-ground storage capacity is the key mechanism that decouples the plants and how much water availability they have in the summer from big swings in winter rainfall."

As a result, these plants are much more resilient in drought years, as evidenced by California's relatively unscathed North Coast during recent droughts that killed hundreds of millions of trees in the Sierra Nevada.

"Because the subsurface water gets replenished even in drought years, in the summer these plants feel the same amount of water supply below ground, no matter how much rain fell during the winter," Hahm said. "They don't really know if it rained a lot or a little, because they have the same amount of water stored below ground each summer."

On the flip side, plants growing today on ground that can soak up as much water as the winter rains can provide are hosting plants that will have to deal with the state's increasingly drier climate, putting them at risk as the climate changes. This may be a problem for Sierra Nevada plant communities that are relying less on a persistent snowpack and increasingly on stored subsurface water to last through the dry summer.

Hahm and David Dralle, the other first author and a former Berkeley graduate student who is an assistant professor at Sacramento State University, describe their findings, along with their colleagues, in a paper recently accepted by the journal *Geophysical Research Letters* and now online.

UC Berkeley graduate student Jesse Hahm levels an automated rain gauge deployed as part of an effort to track water fluxes across the landscape in order to measure seasonal subsurface water storage. Credit: Wendy Baxter, UC Berkeley

Rock moisture

While most people think plants rely only on water stored in the topsoil, Berkeley's William Dietrich, professor of earth and planetary science, and recent graduate Daniella Rempe, an assistant professor at the University of Texas, Austin, recently discovered that water stored in fractured and weathered rock underneath the soil plays an equal or greater role. What Dietrich and Rempe call "rock moisture" can amount to a significant proportion of what plants rely on annually.

A major implication of the new study, Dietrich says, is that global climate models need to incorporate rock moisture into their calculations to accurately represent and predict the impacts of drought or heavy rainfall. In recent years, drought- or heat-killed trees have fueled catastrophic wildfires in California, Spain, Greece, Australia and many regions with a dry, Mediterranean climate.

"Understanding how water is stored deep within the weathered bedrock and how variations in that water supply and in rainfall affect plant water supply in that zone is extremely important in a seasonally dry climate," Hahm said.

In their study, the researchers looked at 26 sites statewide. All were below the snow belt, so that winter rain stored below ground was the dominant source of water for the plants during the summer dry season. Using rainfall data and U.S. Geological Survey stream flow data to calculate the amount of water stored annually underground, they were able to assess the below-ground storage capacity of the soil and the weathered rock.

Of the 26 sites, only seven—all in the Northern Coast Ranges—had limited subsurface water storage capacity and fared well during the state's recent protracted drought, between 2011 and 2016. These sites ranged from grass and oak savanna and chaparral to dense Douglas fir forests, but all were characterized by low subsurface storage relative to average annual rainfall in the area, which tends to be high. The excess water that the subsurface couldn't store in the winter ran through the soil and fractured bedrock and ended up in the streams.

The other sites, including most sites in Southern California, suffered in the drought, with vegetation die-offs and less healthy, less green plants. All were characterized by below-ground storage that is sufficient to sop up most of the rainfall that falls yearly, but that had been left depleted in drought years.

Using satellite images to gauge the productivity and health of the vegetation at each site, the researchers concluded that the sites with high relative storage capacity were the ones that varied the most between wet and dry years in how green the plants were. Sites with low below-ground storage capacity relative to average annual precipitation fared better, remaining similarly green and healthy in drought years and wet years alike.

Hahm noted that many plants in the Sierra Nevada rely on the snowpack to quench their thirst during typical rainless summers. But as temperatures rise with global warming, winter precipitation will increasingly occur as rain.

"In a way, this is a glimpse into the future," Hahm said. "As the climate warms, and as the snowline elevation increases in these mountain ranges, more and more places will switch from being reliant on snowpack to being reliant on water stored in the subsurface. Understanding how this storage capacity limitation will impact plants across the state in high montane areas needs to be explored more."

The insights about rock moisture emerged from a long-term project at the Angelo Coast Range Reserve in Northern California, part of the UC Natural Reserve System, where scientists at the Eel River Critical Zone Observatory followed water from the sky through vegetation, soil and rock into the streams and back up into the atmosphere via evaporation and transpiration to chart the life cycle of water in the environment. Primary funding for the observatory, which Dietrich directs, comes from the National Science Foundation (EAR 1331940).

More information: W.J. Hahm et al, Low subsurface water storage capacity relative to annual rainfall decouples Mediterranean plant

productivity and water use from rainfall variability, *Geophysical Research Letters* (2019). DOI: 10.1029/2019GL083294

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