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# Regolith controls on mountain evapotranspiration and runoff during multi-year drought

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Recent research in the semi-arid western United States highlights the critical importance of regolith properties in predicting drought resistance. A wide suite of spatially distributed measurements of evapotranspiration, precipitation as rain and snow, snowpack and soil-water storage and stream runoff were initiated in the Southern Sierra Critical Zone Observatory well before the 2011-15 drought, and continue through present. These unique time-series measurements build upon site characterization at four focal measurement sites from 400 to 2700 m elevation to provide a consistent picture of the feedbacks between climate, evapotranspiration, regolith water storage, and vegetation density. This integrated, critical-zone approach to science explains how the existing forests were sustained over past decades to centuries, locations of recent tree mortality and the vulnerability of these forests in a warmer and more-variable climate. The hydrology across a major river basin responds to multi-year dry periods, with the annual water balance given as $Q = P - ET - \Delta S$, where Q is basin discharge (runoff), P is precipitation, ET is evapotranspiration, and $\Delta S$ is the change in subsurface storage within the basin. Major droughts reduce precipitation, which directly reduces runoff; but quantifying this non-linear impact is complicated by the additional effects of drought on ET and $\Delta S$. Two mechanisms intensified the impact of the most recent drought on runoff: i) evaporative processes have first access to local precipitation, which reduced runoff relative to previous years, and ii) 2012-15 was 1 degree C warmer than the previous decade, which increased ET relative to previous years. However, drought-associated dieback and wildfire thinned the forest and decreased ET. The estimated 600 mm of subsurface storage at a pine-oak forest site (1100 m) was apparently sufficient to sustain a high ET during the first year of drought, but in later years winter precipitation was insufficient to replenish plant-accessible water storage. Thus ET declined and tree mortality became apparent. Higher elevations had sufficient precipitation and multi-year subsurface storage to both sustain vegetation and provide runoff throughout this dry period. More broadly, sites with a Mediterranean climate were observed to depend on plant-accessible-water storage for over half of their annual ET in both average and dry years, much higher than for sites with some year-round precipitation. Using satellite-derived indices of vegetation with climate data, we scaled estimates of plant-accessible water storage across the landscape. After accounting for precipitation and temperature, regolith properties are the primary determinant of the vulnerability of different sites to the effects of multi-year drought. Enhanced understanding of subsurface water storage will improve prediction of future impacts of climate change, including drought, forest mortality, wildland fire, and strained water security.