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Subsurface mechanisms control hydrologic response to a multi-year drought in a mountainous watershed with a Mediterranean climate

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Mountain watersheds often act as water towers that supply water to large human populations in valley aquifers. Therefore, their susceptibility and resilience to droughts are of outsize importance particularly, as global climate change projections suggest more frequent droughts in the future. Previous studies have examined the impact of climate warming on mountain hydrology, but they have not explicitly linked impacts of multi-year droughts to subsurface water storage. In this study, we use the 2012-2015 California drought to examine the mechanisms via which subsurface flow paths and storage affect the hydrologic response to drought in the Kaweah River watershed in the Sierra Nevada mountains. We build and test an integrated hydrologic model using the coupled land surface-groundwater model ParFlow.CLM. The model is able to simulate the observed hydrology with a high degree of accuracy. Results reveal that mountain aquifer recharge sourced from snowmelt (MAR_{snow}) is the primary input to the groundwater system, and much of the simulated streamflow. We find that increases in air temperature and decreases in precipitation during the drought reduces snow water equivalent (SWE), and causes a 73% reduction in MAR_{snow} compared to the pre-drought period. Reduction in MAR_{snow} initially results in subsurface storage losses along the ridgelines and areas of low topographic convergence. Topography induced draining of the regolith storage causes groundwater depletion and provides supplemental water to maintain streamflow and riparian evapotranspiration (ET). As the drought develops, drying of the subsurface alters lateral connectivity of the shallow groundwater system, and reduces streamflow and riparian ET. We apply machine learning models to examine the spatial patterns in groundwater storage depletion and recovery. These models reveal that topography induced draining and filling of subsurface storage in response to drought and precipitation recovery, respectively, is the key control on the streamflow response in this mountainous watershed. Warmer conditions and more frequent droughts that reduce SWE in the future are likely to amplify this cycle.