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Understanding hydrologic partitioning: Combining mechanistic modelling with signature analysis to understand controls on hydrologic behaviour in headwater catchments

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Headwater streams are the most abundant portion of the river network but the least monitored. As such, we have a limited understanding of headwater stream behaviors and how they are influenced by watershed properties such as topography, geology, and vegetation. Given the lack of runoff monitoring within headwater streams, improving an understanding of how catchment properties influence hydrologic behavior is necessary for transferring information from instrumented areas to ungauged sites. We utilize this concept to understand physical controls on similarities and differences in hydrologic behavior for five adjacent sub-catchments located in the Tenderfoot Creek Experimental Forest in central Montana with variable topographies and vegetative cover. We use an uncalibrated, distributed, physically-based watershed model, the Distributed Hydrology-Soil-Vegetation Model (DHSVM) combined with global, variance-based sensitivity analysis to investigate physical controls on a range of model-predicted hydrologic behavior (i.e. states) across multiple time scales. We implement comparative hydrology to improve our understanding of headwater watershed runoff behavior within this framework by directly relating physical properties of a given catchment to process-based predictions of hydrologic behavior, i.e. signatures. We find that across different hydrologic fluxes, including streamflow, evapotranspiration, and snow water equivalent change, only a few vegetation and soil parameters control the variability in hydrologic behavior for all sub-catchments. These controls are similar at the annual and weekly scale, though parameter influence varies seasonally from wet to dry periods. Three of the five watersheds exhibited different controls on hydrologic behavior, likely resulting from past vegetation treatments and differing surficial geology within these sub-watersheds. This framework has strong potential to inform how similarities and differences in headwater watershed characteristics can influence the variability in spatially and temporally varying hydrologic signatures. We ultimately demonstrate that the influences of soil and vegetation across headwater watersheds vary, using a modeling framework to understand physical controls on hydrologic signatures at a high resolution. We suggest that this approach can especially enhance estimation of controls on headwater watershed behavior at unmonitored sites.