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Hierarchical Controls on Runoff Generation: Topographic Hydrologic Connectivity, Vegetation and Geology

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Understanding the relative influence of catchment structure (topography and topology), underlying geology, and vegetation for stream network hydrologic connectivity and runoff response is key to interpreting catchment hydrology. Hillslope-riparian-stream (HRS) water table connectivity serves as the hydrologic linkage between a catchment's uplands and the channel network and facilitates the transmission of water and solutes to streams. While there has been tremendous interest in the concept of hydrological connectivity to characterize catchments, there have been relatively few studies that have quantified hydrologic connectivity with data at the stream network and catchment scales. Here, we examine how catchment topography, vegetation, and geology influenced patterns of stream network HRS connectivity and resultant runoff dynamics across 11 nested headwater catchments in the Tenderfoot Creek Experimental Forest (TCEF), MT. This study builds on the empirical findings of Jencso et al. (2009) who found a strong linear relationship ($r2 = 0.92$) between the upslope accumulated area (UAA) and the duration of shallow ground water table connectivity observed across 24 HRS transects (146 groundwater recording wells). We applied this relationship to the entire stream network across 11 nested catchments to quantify the frequency distribution of stream network connectivity through time and quantify its relationship to catchment-scale runoff dynamics. Each catchment's hydrologic connectivity duration curve (CDC) was highly related to its flow duration curve (FDC) and the slope of the relationship varied across catchments. The regression slope represents the streamflow yield per unit connectivity (Conyield). We analyzed the slope of each catchment's CDC-FDC relationship or Conyield (annual, peak, transition and baseflow periods) in multiple linear regression models with common terrain, land cover-vegetation, and geology explanatory variables. Significant predictors ($p<0.05$) across 11 catchments included the ratio of flow path distances and flow path gradients to the creek (DFC/GTC), geology, and a vegetation index. The order and strength of these predictors changed seasonally and highlight the hierarchical controls on headwater catchment runoff generation. Our results highlight direct and quantifiable linkages between catchment structure, vegetation, geology and hydrologic dynamics.