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Physical and meteorological controls on variable hydrologic catchment response

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Hydrologic catchment response varies in space and time. We used stable isotope tracers in ten nested subcatchments over the course of three years to observe that the mean velocity with which water transits through a catchment is neither spatially nor temporally invariant but changes between catchments, between seasons and also between individual precipitation events. Hydrologic response controls also vary in time. We found that there is not one parameter that controls hydrologic catchment response at all times. In fact there are different parameters that correlate most closely with hydrologic catchment response at different times. We identified soil depth to be the dominating control during times with high antecedent moisture content and high precipitation intensity. Hydraulic conductivity is the main control when antecedent moisture content is high and precipitation intensity is low. Planiform curvature explains most of the variation in mean transit time when both antecedent moisture content and precipitation intensity are low.

The reason for this varying control behavior can be found in the changing dominant flow paths that transport the water to the catchment outlet. In times of high antecedent moisture content the probability of an activation of fast flow paths (overland flow, macropore flow) is high once the soil water storage threshold is exceeded (soil depth control). However, if the precipitation intensity is low, matrix flow can still continue to dominate (hydraulic conductivity control). If both antecedent moisture content and precipitation intensity are low, most incoming water will take deeper slow flow paths (baseflow) that are more prone to be controlled by topographic parameters (curvature control).

Therefore, in order to better predict hydrologic catchment response, we need an integrating indicator (e.g. a dimensionless number) that takes into account both storage and precipitation event parameters to sort events into the response classes described above. Important parameters that need to be considered are soil depth, antecedent moisture content and subsequent precipitation amount. Combining all of them into a dimensionless number, the storage-forcing number, relates available storage in the numerator to incoming flux in the denominator and indicates when the storage threshold for the activation of fast flow paths is exceeded. The apparent threshold values for this number are <1 (threshold for dominant overland and macropore flow when incoming fluxes exceed available storage) and >10 (threshold for dominant baseflow when available storage exceeds incoming fluxes by a factor of 10). In a second step, within the response classes, the known dominant response controls (soil depth, hydraulic conductivity, curvature) can be used to improve response predictions.