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Deconstructing the hydrologic response: pattern and dynamics of water age

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The water storage and release dynamics at the catchment scale are still incompletely understood. This is in particular true when considering actual particle transport rather than only the hydraulic response. The use of environmental tracers is frequently instructive for getting insights into these transport process patterns. However, the potential of tracers is frequently underexploited. Although known since the early days of tracer hydrology that the composition of water in the runoff, i.e. the water age distribution can be highly variable as a function of flow volumes, it is often treated as being time- and thus flow-invariant. Here we use long term (< 20 years) precipitation, flow and tracer (chloride) data of three contrasting upland catchments in the Scottish Highlands to inform integrated conceptual models. Using the models as virtual laboratories, water and tracer fluxes were tracked through the system in order to get a better understanding of the patterns and temporal, wetness induced dynamics in the composition of stream water and its age distributions.

Tracking fluxes through the system showed that the various components of a model, representing individual flow processes, such as preferential or groundwater flow, can be characterized by fundamentally different water age distributions. As a consequence, the wetness dependent dynamics and connectivity patterns of these distinct pools of water are responsible for potentially fast and substantial switches in water age distributions. Further, modeled flux water age distributions were found to be highly sensitive to variable catchment wetness conditions and exhibited considerable hysteresis effects, depending on the catchment wetness history. While the water age during wetting-up conditions is controlled by fast processes (e.g. preferential flow), it is controlled by slow processes (e.g. groundwater flow) under drying-up conditions. This non-linearity is caused by the fact that water age distributions are not only influenced by the total water volume stored in a catchment but also and more importantly by where the water is stored at a given time. In other words, to better understand the effects of wetness history or antecedent wetness on the hydrological response it is crucial to understand how the water stored in a catchment is distributed among the various components of the system such as the unsaturated zone or the groundwater. In general this study highlights the potential of customized integrated conceptual models, to infer system internal transport dynamics and their sensitivity to catchment wetness states.