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Temporal dynamics in water age distributions and their relation to catchment wetness: what can be learned from flux tracking?

The runoff generation processes underlying the hydrological response of streams remain incompletely understood at the catchment scale. Extensive research has demonstrated the utility of tracers for both inferring flow paths distributions and constraining model parameterizations. While useful, the common use of time-invariance and complete mixing assumptions in these studies provides incomplete understanding of actual process dynamics. Here we use long term (< 20 years) precipitation, flow and tracer data of three contrasting upland catchments in the Scottish Highlands to inform integrated conceptual models investigating different mixing assumptions. Using the models as diagnostic tools in a functional comparison, water and tracer fluxes were tracked with the objective of characterizing water age distributions in the three catchments and establishing the wetness induced temporal dynamics of these distributions.

The results highlight the potential importance of dynamic partial mixing to adequately describe both, stream flow and tracer response in the study catchments. Further, tracking tracer fluxes showed that the various components of a model ca n be characterized by fundamentally different water age distributions which may be highly sensitive to catchment wetness, available storage, mixing mechanisms, flow path connectivity and the relative importance of the different hydrological processes involved. In particular it was found that the average age of transient water is subject to marked hysteresis effects depending on the catchment wetness history, thus describing the degree of connectivity of individual runoff components under different conditions. Flux tracking also revealed that, although negligible for simulating the runoff response, the omission of processes such as interception evaporation can result in considerably biased water age distributions with potentially important implications for adequate representation of diffuse contamination. Finally, the modeling indicated that water age distributions in the three study catchments do have long, potentially power-law tails, which are generated by the interplay of flow path connectivity, the relative importance of different flow paths as well as by the mixing mechanisms involved. In general this study highlights the potential of integrating conceptual hydrological models with simple mixing models to enhance our understanding of catchment responses.