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A hillslope scale sprinkling experiment to resolve the double paradox in hydrology

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The double paradox in catchment hydrology is a source of major debate and discussion in hydrology at present. A simple definition of the double paradox is the rapid mobilization of mostly stored pre-event water to the stream during storm events while the response of different chemical constituents (e.g. dissolved organic carbon (DOC)) of this mostly stored pre-event water is highly variable. We resolved this paradox at the hillslope scale with a 24-day sprinkler experiment in Watershed 10, H.J. Andrews Experimental Forest in the western Cascade Mountains of Oregon. Using water provided by a sprinkler tank, the experimental hillslope (174 m2) was brought to steady state flow conditions, where a constant application of irrigated water was balanced with steady measured outputs and internal state conditions. Lateral subsurface flow measured at a 10 m wide hillslope trench remained at steady state for 20 days. A pulse of deuterated water was applied to the irrigated hillslope via the sprinkling system for 24,5 hours beginning on Day 1 of the experiment to investigate the breakthrough of deuterium in lateral subsurface flow, soilwater and groundwater. Maximum new water contribution was defined as deuterium (D) labeled sprinkler water applied at the start of the sprinkler experiment and reached a maximum of 26% in lateral subsurface flow 20 hours after application. We modeled the D breakthrough curve in lateral subsurface flow with the advection-dispersion model incorporating first order mass transfer. This approach suggested a mobile water fraction of 30% of the available porosity. The fast initial breakthrough of D in lateral subsurface flow was caused by preferential flow in mobile flowpaths. Mass transfer to the immobile domain, dispersive mixing and rapid transport via lateral subsurface flow explained rapid mobilization of old water and thus the first part of the double paradox in a plausible mechanistic way. We identified two main flow paths: rapid lateral subsurface flow and vertical flow through the unsaturated zone. Additionally, lateral subsurface flow, soilwater and groundwater were sampled for DOC to characterize variable runoff chemistry. Hydrometric data and deuterium in soil- and groundwater showed that the fast initial D and DOC breakthrough was mainly derived from a shallow soil source ($\tilde{3}0$ cm). Furthermore, relatively high D and DOC concentrations in transient groundwater showed a strong connection between the organic horizon/shallow soil layer and transient groundwater. We concluded that DOC in the organic horizon was supply limited, i.e. production and/or desorption lagged behind flushing/removal from the soil. The supply limitation of DOC, in combination with the vertical and lateral flowpaths, controlled the variable DOC chemistry in lateral subsurface flow. Utilizing a combination of isotopic, biogeochemical and internal physical measurements during a long duration sprinkler experiment, with steady sprinkler rates, and 1-D modeling of the D BTC in lateral subsurface flow, we demonstrated a mechanistically plausible conceptual model that resolved the double paradox at our site.