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Isotopes and water flow dynamics – Is the thrill already gone? The added value of high-frequent isotope data for understanding soil water flow

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Water stable isotopes have been used in catchment hydrology to investigate runoff generation processes for decades and have considerably shaped our process conceptualization in a number of different environmental settings. However, typically water stable isotopes have been collected at the outlet of catchments or at selected locations in the stream channel network. These samples represent an integral signature of all runoff generation processes and soil water storage along various flow paths to the stream. However, an experimental setup to directly sample the individual fast and delayed flow components and the vertical and lateral fluxes in the soil is rare and is typically restricted to certain snapshot sampling times.

Here we present results from an experiment where high-frequent isotopic sampling of the lateral and vertical flow components and from the soil matrix at various soil depths was achieved over 3 months following a large artificial sprinkling experiment with 60.000 liters of deuterium labeled water on a 200 m2 experimental hillslope in the Black Forest, Germany. A trench with drains at three soil depths and zero-tension lysimeters at four soil depths allowed sampling the lateral and vertical flow components during the sprinkling experiment and the consecutive natural rainstorms. A soil pit with 6 in-situ isotope probes (Volkmann et al., 2016) attached to an isotope analyzer in the field allowed high-frequency monitoring of the isotopic signature of the soil matrix between 20 to 135 cm soil depth.

The near-surface lateral and vertical flow components responded with short delays and experienced highest sprinkling water fraction during the sprinkling experiment while the drains and lysimeters in deeper soil depth and at the soil bedrock interface responded delayed and had sprinkling water fractions lower than 50%. During the consecutive natural rainstorms the isotopic composition of the lateral flow component approached the isotopic signature of natural precipitation faster than the vertical flow components at similar depth. This suggests that preferential flow paths play a more important role for the lateral flow components than for the vertical flows in this well textured soil. The isotopic composition in the soil profile indicated decreasing sprinkling water fractions with increasing soil depth during and right after the sprinkling experiment but with the following natural precipitation the pulse of labeled water was further pushed to deeper soil depths finally leading to a reverse of the isotopic soil profile (i.e. increasing d-excess values with soil depth). While one can argue that the thrill of using water isotopes in catchment hydrology in the classical way is gone, our study shows that new experimental setups with high-frequent, depth specific isotope sampling of the lateral and vertical subsurface flow components and the soil matrix can still increase our process understanding of runoff generation in catchments.