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Using high temporal resolution isotope sampling to re-conceptualize rainfall-runoff processes in an upland catchment

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Recent developments in laser spectroscopy have the potential to underpin major advances in hydrology by enabling the inexpensive and rapid processing of large number of stable isotope samples. As a result, sampling rainfall, runoff and other water sources at high temporal resolution, facilitates rigorous testing of hypotheses of runoff generation processes and a robust means of evaluating hydrological models. This paper reports insights from such high resolution sampling which resulted in a re-evaluation of how runoff generation is conceptualized in a 3.6km2 upland catchment in northern Scotland. Water isotopes were determined in daily rainfall and runoff samples over a hydrological year, along with routine (bi-weekly) sampling of soil water and groundwater. Previous field work using hydrometric and geochemical tracer data showed that the dynamic expansion and contraction of saturation areas in valley bottom riparian zones is the dominant mechanism for storm runoff generation. This non-linear runoff response was incorporated into a conceptual rainfall-runoff model (the dynamic Saturation Area Model - SAMdyn) that was constrained by hydrometric and geochemical tracer response. This facilitated reasonable runoff simulations with plausible geochemical tracer validation of the dominant runoff sources. Initial incorporation of isotope data into SAMdyn to simulate stable isotope signatures of groundwaters and soil water in riparian saturated zones were also consistent with the model conceptualization. However, the model was unsuccessful in simulating daily variability in the isotopic composition of stream flows. Sensitivity analysis suggested that groundwater mixing in riparian saturation zones, along with fractionation of near-surface water are critical processes that need to be incorporated into the models to improve simulations. This reconciled what initially seemed to be a paradox indicated by the geochemical and isotope tracers. The study has underlined the value of high-resolution isotope data in improving our understanding of non-linearities in catchment-scale hydrological processes and conceptualizing these in rainfall-runoff models.