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Geological controls on isotopic signatures of streamflow: results from a nested catchment experiment in Luxembourg (Europe)

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Controls of geology and topography on hydrological metrics, like summer low flow (Grant and Tague, 2004) or dynamic storage (Sayama et al., 2011), have been identified in nested catchment experiments. However, most tracer-based studies on streamflow generation have been carried out in small (10 km^2) homogenous catchments (Klaus and McDonnell, 2013). The controlling effects of catchment physiography on how catchments store and release water, and how this eventually controls stream isotope behaviour over a large range of scale are poorly understood.

Here, we present results from a nested catchment analysis in the Alzette River basin (Luxembourg, Europe). Our hydro-climatological network consists of 16 recording streamgauges and 21 pluviographs. Catchment areas range from 0.47 to 285 km^2, with clean and mixed combinations of distinct geologies ranging from schists to marls, sandstone, dolomite and limestone.

Our objective was to identify geological controls on (i) winter runoff ratios, (ii) maximum storage and (iii) isotopic signatures in streamflow. For each catchment we determined average runoff ratios from winter season precipitation-discharge double-mass curves. Maximum catchment storage was based on the dynamic storage change approach of Sayama et al. (2011). Changes in isotopic signatures of streamflow were documented along individual catchment flow duration curves.

We found strong correlations between average winter runoff ratios, maximum storage and the prevailing geological settings. Catchments with impermeable bedrock (e.g. marls or schists) were characterised by small storage potential and high average filling ratios. As a consequence, these catchments also exhibited the highest average runoff ratios. In catchments underlain by permeable bedrock (e.g. sandstone), storage potential was significantly higher and runoff ratios were considerably smaller.

The isotopic signatures of streamflow showed large differences between catchments. In catchments dominated by permeable bedrock, isotopic signatures of streamflow remained stable throughout the entire flow duration curve consistent with a large storage and mixing potential. On less permeable bedrock substrate, we have observed that isotopic signatures in streamflow were much more variable, due to reduced storage volume and comparatively smaller mixing potential.

Other metrics such as catchment size and flowpath length exerted a smaller secondary control on isotopic signatures of streamflow in the Alzette River sub-basins.

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