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What explains low young water fractions at high elevations?

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The concept of young water fraction, introduced by Kirchner (2016) and defined as the fraction of streamflow that was stored less than about 2-3 months in the catchment, is increasingly used in catchment intercomparisons studies to understand and conceptualize the hydrological processes governing the catchment's functioning. However, the development of perceptual models is not always as straightforward as it may seem. Past works have shown that high mountainous catchments worldwide reveal small young water fractions. These low young water fractions at high elevations have been explained by different hydrological processes, including deeper vertical infiltration promoted by the presence of both fractured bedrock and freely draining soils (e.g., luvisols and cambisols) and long groundwater flow paths driven by the topographic roughness. But, a harmonious explanation of how the relevant mechanisms in mountainous catchments lead to low young water fractions at high elevations is missing.

Using a data set composed of 27 study catchments, located both in Switzerland and in Italy (of which 22 are from the previous work of von Freyberg et al., 2018), we explore both the drivers and the conceptualization of the processes that potentially clarify this surprising result. We assume that this lowering can be explained by groundwater storage potential and the interplay of the seasonal dominance of hydrological processes. For groundwater storage potential we use the proportion of catchment area covered by Quaternary deposits (a parameter that is readily available for the studied catchments). For the interplay of seasonal processes, we use the length of the low-flow period as a measure for the duration of the groundwater (in terms of age, old water) dominated recession period.

Our results suggest that the length of the low-flow period is clearly the main driver of low young water fractions at high elevation. Here, the long winter period, characterised by absence of liquid water input and hence by a low-flow regime, promotes a progressive emptying of the groundwater storage. Even during summer, recent snowmelt and rainfall that transit through the subsurface push out old groundwater into the stream, as reflected by high proportions of baseflow also during high-flow periods. However, during summer, the relative share of old water remains lower than during winter and accordingly, the longer the winter period (with very low young water

fractions), the lower the annual young water fraction. Quaternary deposits could play a role in reducing young water fractions via their capacity to store groundwater, but further detailed geological information would be necessary for a complete picture about the role of geology.