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Winter streamflow analysis in frozen, alpine catchments to quantify groundwater contribution and properties

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Alpine catchments are often considered as quickly responding systems where streamflow contributions from subsurface storages (groundwater) are mostly negligible due to the steep topography, low permeable bedrock and the absence of well-developed soils. Many studies in high altitude catchments have hence focused on water stored in snowpack and glaciers or on rainfall-runoff processes as the dominant streamflow contributions. Interestingly less effort has been devoted to winter streamflow analysis when melt- or rainfall-driven contributions are switched off due to the frozen state of the catchment. Considering projected changes in the alpine cryosphere (e.g. snow, glacier, permafrost) quantification of groundwater storage and contribution to streamflow is crucial to assess the social and ecological implications for downstream areas (e.g. water temperature, drought propagation). In this study we hypothesize that groundwater is the main streamflow contribution during winter and thus being responsible for the perennial regime of many alpine catchments. The hypothesis is investigated with well-known methods based on recession and breakpoint analysis of the streamflow regimes and temperature data to determine frozen periods. Analyzing nine catchments in Switzerland with mean elevation between 1000 and 2400 m asl, we found that above a mean elevation of 1800 m asl winter recessions are sufficient long and persistent enough to quantify groundwater contribution to streamflow and to characterize the properties of subsurface storage. The results show that groundwater in alpine catchment is the dominant streamflow contribution for nearly half a year and accountable for several hundred millimeter of annual streamflow. In sub-alpine catchments, driven by a mix of snowmelt and rainfall, a clear quantification of groundwater contributions is rather challenging due to discontinuous frozen periods in winter. We found that the inter-annual variability of different streamflow contributions is helpful to assess the water sustainability of alpine catchments functioning as water towers for downstream water basins. We outline how well-known hydrograph and recession analyses in alpine catchments can help to explore the role of catchment storage and to advance our understanding of (ground-)water management in alpine environments.