EGU24-10603, updated on 22 May 2024
https://doi.org/10.5194/egusphere-egu24-10603
EGU General Assembly 2024

Exposing Seasonal and Spatial Variability in Storage and Release Upstream of the Outlet

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Understanding the seasonal interplay of subsurface storage and release of water is critical to drought risk assessment in alpine environments because of the substantial carry-over effects of snow. Spatial variation across the catchment and its compartments governs the seasonal interplay and can shift dramatically according to annual fluctuations in snowfall. This analysis investigates the interaction between scale and yearly anomalies in assessing seasonal patterns of storage and release interpreted through the annual stable isotope signal (δ^2H, $\delta^{18}O$, and $\delta^{17}O$) within the Vallon de Nant catchment in the Swiss Alps. We explore the limitation of simplifying catchment processes to a single outlet that integrates upstream water storage and release but overlooks nuanced variations within different compartments, including upstream springs, tributaries, near-surface groundwater, and vegetation (*Larix decidua*) and years with more and less snow.

Furthermore, using a mixing model, we explore the effects of seasonal precipitation dynamics by examining the summer-to-winter precipitation ratio based on the variation of stable isotopes (δ^2H, $\delta^{18}O$, and $\delta^{17}O$) within these distinct compartments and across multiple observation years. Notably, our findings highlight a pronounced anomaly in the fraction of summer-to-winter precipitation within springs, particularly following the snow-drought year of 2022. This observation raises critical questions regarding the long-term sustainability of groundwater resources in alpine regions. To ascertain the broader implications of this drought-induced anomaly, we extend our investigation to include 51 National Groundwater Monitoring (NAQUA) sites across Switzerland to assess the potential recurrence of this phenomenon on a broader scale.