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Understanding and quantifying the depletion of a mineral water aquifer

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Slowly regenerating groundwater systems must be considered finite resources if withdrawal rates exceed their replenishment rates and changes in their hydrochemical composition and age structure become apparent. Various concepts have evolved to ensure the long-term availability and protection of groundwater resources, including groundwater stress, safe yield, and different definitions of renewable groundwater. Most of these concepts focus on the quantitative availability of groundwater. The most recent concept, "peak groundwater", describes the maximum total withdrawal rate from an aquifer before reductions in withdrawal rates become necessary due to effects of depletion, such as reduced well yields and water quality issues (1). Here, deterioration of groundwater quality is interpreted in terms of contamination. However, for mineral water, deterioration also requires changes to the original hydrochemical characteristics (2), which tightens the evaluation framework.

This study aims to determine the modified peak groundwater withdrawal for a fractured bedrock aquifer that has been used for mineral water production since the mid-1900s, until it ceased in 2020. We have been closely monitoring the system since the 1990s. The recorded data enables us to quantitatively assess the changes due to production, as well as the rates and extent of the recovery. To develop a 4D understanding of the aquifer, we combined the extraction rates from the last 30 years of production with a comprehensive geological model, hydraulic measurements, and hydrochemical analyses (wellhead and depth-resolved) were combined.

The aquifer has been explored by five wells, which are oriented along a fault zone. It exhibits stratification of mineralization, with increasing concentrations of total dissolved solids (TDS) and CO_2 with depth. The presence of persistent trace chemicals and the decrease in TDS during production indicate that the mineral water in the upper part of the aquifer is being replenished by freshwater, forming a lens of freshwater on top of the mineral water. This effect is more pronounced at the center of the explored area and correlates with individual withdrawal volumes. Measurements taken after production ceased reveal a trend toward aquifer regeneration. While the aquifer has almost returned to its initial hydraulic state with some wells flowing freely, it is unclear whether the original hydrochemical composition will be re-established or if a new hydrochemical steady state will be reached. The latter would confirm the mining operation of a finite resource, whereas the former would suggest a temporary excess of peak groundwater with no lasting impact on long-term use.

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(2) Dietmaier, A. & Baumann, T. (2023). Assessing sustainable development of deep aquifers. Water Resources Management. https://doi.org/10.1007/s11269-023-03529-6