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Recharge Pathways and Vulnerability in a Mountain-Front Aquifer: A Multi-Tracer Study from Cache Valley, Utah, USA

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Cache Valley is an intermontane basin in northern Utah and southern Idaho (USA) that is heavily reliant on groundwater for municipal water supply. Agricultural land use dominates, but population growth of ~2% annually over the past three decades has accelerated conversion of irrigated farmland to urban development, altering recharge pathways and potential contaminant loading. Despite this reliance, there is insufficient characterization of recharge sources, groundwater residence times, and resulting aquifer vulnerability. We collected and analyzed environmental tracers (^{3}H, noble gases, stable water isotopes, ^{14}C) from 39 wells and 5 springs spanning the valley to (1) quantify the relative contribution of mountain block and valley recharge to the Cache Valley aquifer using a two endmember mixing model based on noble-gas derived recharge elevation and deuterium excess, (2) constrain groundwater age gradients and recharge rates, and (3) assess aquifer vulnerability to contamination and climate-driven recharge change.

The land surface elevations in the study area range from ~1200 m to ~2800 m. Noble gas recharge temperatures range from 1.4 °C to 12.5 °C, with corresponding recharge elevations of 1400 to 2600 m. The mixing model indicates 18% of samples are dominated by mountain block recharge (mountain fraction > 0.75), 19% are dominated by valley recharge (mountain fraction ≤ 0.25), and the remaining 63% represent intermediate mixtures of both sources. Tritium-helium ages for the principal flow system range from 5 to 47 years, with increasing age with distance from the mountain block. These ages are consistent with modern recharge and imply aquifer turnover timescales that leave the system vulnerable to land-surface contamination and recharge reductions within decades. Two wells yielded tritium-dead water with corrected radiocarbon ages of 6 to 15 ka, indicating a deeper, isolated flow system containing Pleistocene to mid-Holocene recharge. We combine groundwater age and recharge provenance into a vulnerability framework in which mountain-derived wells are susceptible to recharge reduction from changes in snowpack magnitude and melt-timing, while valley-recharged wells face both contamination risk from land-use change and recharge losses from continued urbanization.