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Pronounced Water Age Partitioning Between Arid Andean Aquifers and Fresh-Saline Lagoon Systems

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The challenge of deciphering connections between groundwater systems and surface water bodies and by extension connections to hydroclimate represent major unsolved questions in the hydrology community. Within the UPH framework, under the Interfaces in hydrology theme, this includes aspects of both questions *twelve* and *thirteen*. In arid regions, disentangling these processes is an especially difficult challenge due to the large spatial and temporal scales over which these systems are integrated. Yet we must improve our understanding if we are to use water sustainably in these landscapes. In the dry Andes, very deep water tables develop groundwater flow paths with long transit times, often crossing topographic boundaries before emerging at basin floors. These factors combined with the complex evaporite stratigraphy in which surface and groundwaters interact make it quite difficult to close water budgets and quantify groundwater fluxes across hydrological boundaries. As a result, many fundamental questions about connections across these interfaces remain unresolved. This study presents a novel examination of processes controlling fluxes across critical boundaries (groundwater recharge, inter-catchment flow, and riparian/stream/aquifer exchange) by employing a comprehensive set of ~150 ^{3}H samples from waters across the entire dry Andes paired with a large dataset (>1,500 samples) of ^{18}O, ^{2}H in water and dissolved major ions.

We present an integrated process-based conceptual framework describing the dominant controls on water compartment connections intrinsic to these arid mountain systems. The large range in mean transit times and the persistence of hydrologic features here allow for reliable delineation of multiple distinct source and flow path groupings. Repeat sampling over several years provides further constraints on connections between these compartments and the modern hydroclimate. Our results outline a few novel findings regarding the hydrological attributes of these environments: i) most of the water sustaining both the regional and local hydrological systems is old (0-10 % modern and 100-10000 yrs old) yet modern water (days-10 yrs old) is critical to sustaining many surface water bodies. ii) transit time distributions in specific water compartments (Groundwaters, Springs, Streams, Saline lagoons, and Vegas) are remarkably stable over time and show consistent patterns across the entire plateau; iii) the existence of surface water bodies and their connection to groundwater compartments is regulated by persistent hydrological features

(regional flow paths, hydrogeology, fresh-saline interfaces); and iv) sharp divergence in mean residence and transit time of source waters occurs over very short spatial scales (<<1km). By describing water age distributions and geochemical attributes of these features we define the dominant controls on several discrete water compartments and delineate clear distinctions between long-term average source waters and the decoupling of modern hydroclimate from the hydrologic system as a whole. This analysis represents a significant advancement in our understanding of controls on fluxes across boundaries in arid mountainous regions and freshwater-salt lagoon systems. An improved understanding of the primary controls on water source and transport will allow us to better protect communities and fragile ecosystems from the most damaging potential impacts of water extraction in these environments.