Phase I: Written Proposal

Using water stable isotopes and tritium to characterize the age and travel paths of the Santa Cruz headwaters

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1. Scientific Gap

The San Rafael Valley is a geologically complex basin in southern Arizona that contains the headwaters of the Santa Cruz River and serves as one of the last intact grassland ecosystems in the United States. Despite its ecological and hydrologic importance, previous studies have largely focused on basic water quality characterization rather than recharge mechanisms or groundwater age structure. Critical unknowns include: the dominant recharge sources, seasonality and elevation of recharge, the spatial distribution of groundwater residence times, and the degree of surface water–groundwater interaction in the valley. This region faces numerous issues such as drought and groundwater extraction from nearby mining operations and installment of the border wall, making further characterization of this basin important.

2. Scientific & Societal Value

This study integrates stable water isotopes ($\delta^{18}O$, $\delta^{2}H$) and groundwater age tracers (^{3}H) to understand recharge sources, flow paths, and residence times across the San Rafael Valley.
By comparing isotope signatures to regional precipitation datasets and nearby studies, this work will: identify recharge elevation, differentiate modern from older groundwater, and clarify connections between surface water and groundwater. This work will contribute to broader understanding of recharge processes in arid and semi-arid environments.

The San Rafael Valley also supports baseflow, riparian ecosystems, ranching operations, wildlife, and downstream water resources in both Arizona and Mexico. This region is facing hydrologic stress from drought and groundwater extraction. Determining whether groundwater is actively replenished (modern) or largely legacy storage has direct implications for: sustainable groundwater management, climate resilience planning, legal water considerations, and ecosystem conservation.

3. Analysis Plan (Data Collection and Measurements)

Groundwater and surface water samples will be collected across the San Rafael Valley from wells, springs, and streams reaching a wide variety of recharge zones. Samples will be analyzed for water stable isotopes $\delta^{18}O$ and $\delta^{2}H$ to distinguish recharge derived from higher-elevation precipitation versus lower-elevation or evaporatively modified sources, and tritium (^{3}H) to identify modern recharge zones and constrain relative groundwater residence times. Isotope measurements will be compared to precipitation isotope data and results from nearby regional studies.

The analytical approach for this project will be comparing groundwater isotope values to local meteoric water lines, evaluating deviations indicating evaporation prior to recharge, and assessing spatial isotope gradients to infer elevation to determine recharge source identification. Groundwater age characterization will be done by classifying waters as modern or pre-modern based on ^{3}H presence and spatial distribution of relative groundwater ages. Finally, we will integrate isotopic and age data to refine recharge zones and groundwater flow paths while also evaluating evidence of surface water–groundwater interaction in headwater areas.

4. Key Figure

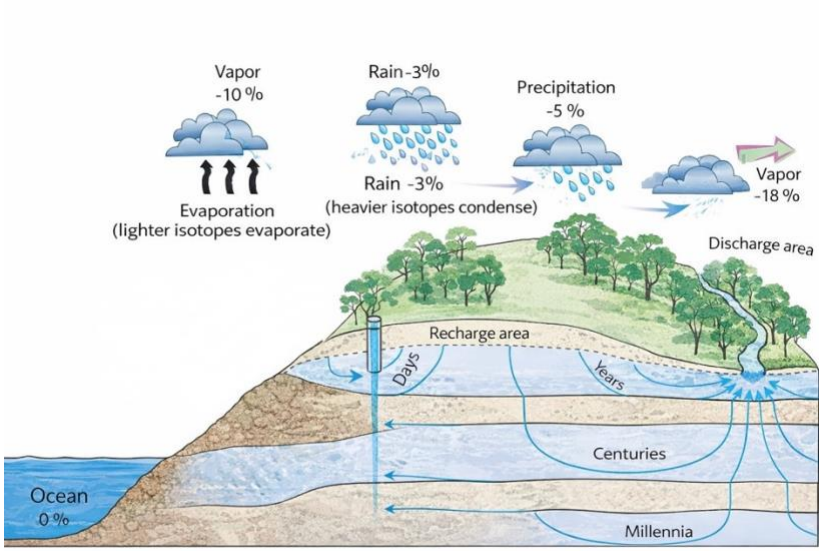

Figure 1. Conceptual hydrogeologic model illustrating isotopic fractionation processes and groundwater flow paths that will be investigated in the San Rafael Valley, Arizona.

5. Timeline & Milestones (February–July 2026)

February

- Compile existing dataset
- Coordinate additional sampling access
- Conduct targeted reanalysis where needed
- Continue literature review on SRV hydrogeology

March–May

- Conduct at least three rounds of field sampling
- Submit samples for isotope and age-tracer analysis
- Draft study site and methods sections
- Receive laboratory results
- Construct isotope plots ($\delta^{18}O$ vs $\delta^{2}H$)
- Interpret tritium data
- Draft results and preliminary discussion

June

- Revise full proposal manuscript

July

- Final revisions and preparation of presentation materials

Measurable Milestones

1. Completion of ≥3 additional sampling campaigns
2. Laboratory analysis of all isotope and tritium samples
3. Basin-wide isotope and groundwater age analysis constructed
4. Full written proposal draft completed
5. Presentation of results