University of Massachusetts Amherst

HYDROGEOLOGY

University of Massachusetts Amherst

Recent Findings Using Environmental Tracers in Salar de Atacama

Hydrological and water budget Insights

Presenter: Brendan Moran

LITHIUM SOLUTIONS

SUSTAINABILITY OF THE LITHIUM INDUSTRY:

Monitoring and environmental challenges in the face of climate change

Santiago, Chile
15/03/2024

MOTIVATIONS

Water budgets in these systems reflect/integrate long temporal & spatial scales – Balance?

Need to better describe & quantify connectivity between modern climate, surface water, and groundwater?

What are the primary controls and time scales of these connections – responses to natural & anthropogenic perturbations?

A simple "relative age" method is a highly effective way to constrain these questions in this environment

Outline

Part 1

Water Tracer Methodology Overview

Part 2

Recent Findings and Conceptual Model

Part 3

New Basin Water Budget Insights

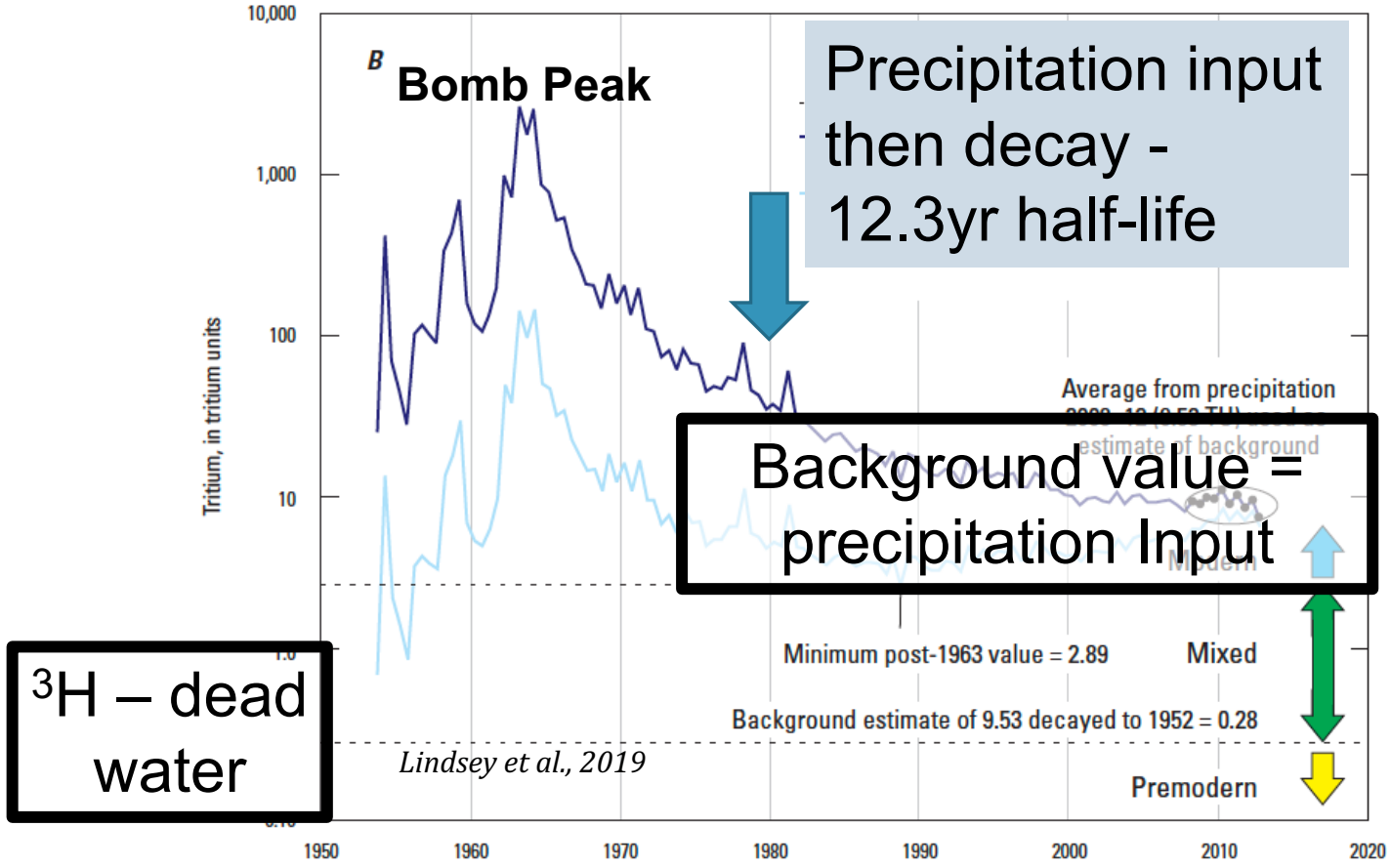
01

Water Tracer Methodology Overview

Photo by Nicole Blin

Water Age Tracing - Tritium

- Water source signature is **imprinted – then decays**
- ^{3}H activity in water – **% Modern** content
- Water with very little ^{3}H activity is **relic**
- U of Utah Noble Gas Lab – precise (+/- 2%; 0.05 TU)



^{3}H – dead water

$$\%_{modern} = \frac{{}^{3}H_{Sample}}{{}^{3}H_{modern\ Precipitation}}$$

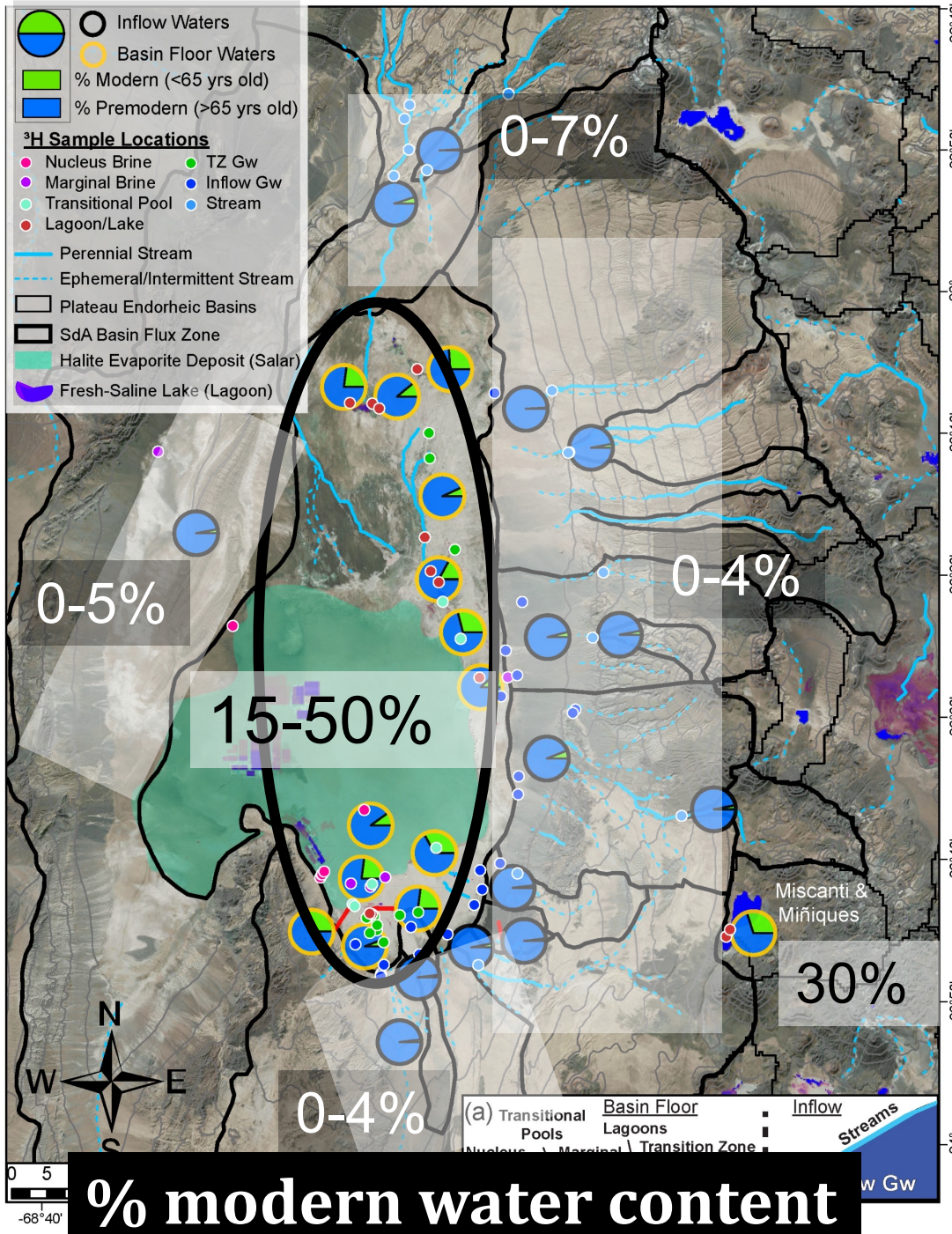
Differentiate *source components:* ***Pre-modern or Relic*** *(>65 yrs) from those with substantial* ***Modern*** *component*

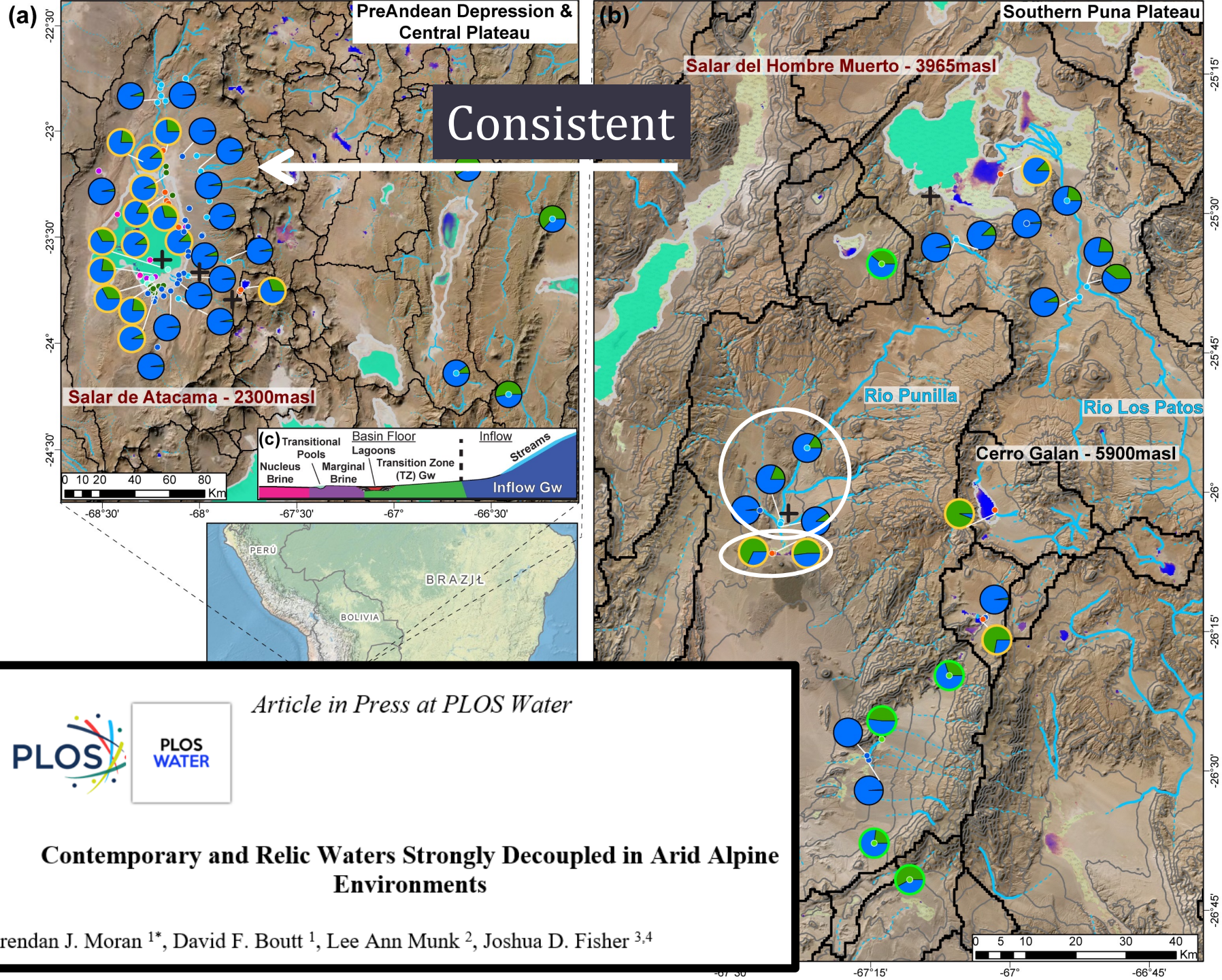
02 Recent Findings and Updated Conceptual Model

Photo by Nicole Blin

Water Sources at SdA

- ^{3}H paired with $^{18}O/^{2}H$ isotopes in water – surveyed all waters in the basin
  - Consistent patterns by water type, and >10 years of repeat sampling
- Predominant source is from high divide regions and outside the watershed
- **Nearly all inflow** to the basin is relic
  - Logic and modeling suggest most is much older
- Surface waters are very unique
- ***Takeaway:*** Most water is <u>ancient</u> but wetlands and shallow groundwaters are unique





Article in Press at PLOS Water

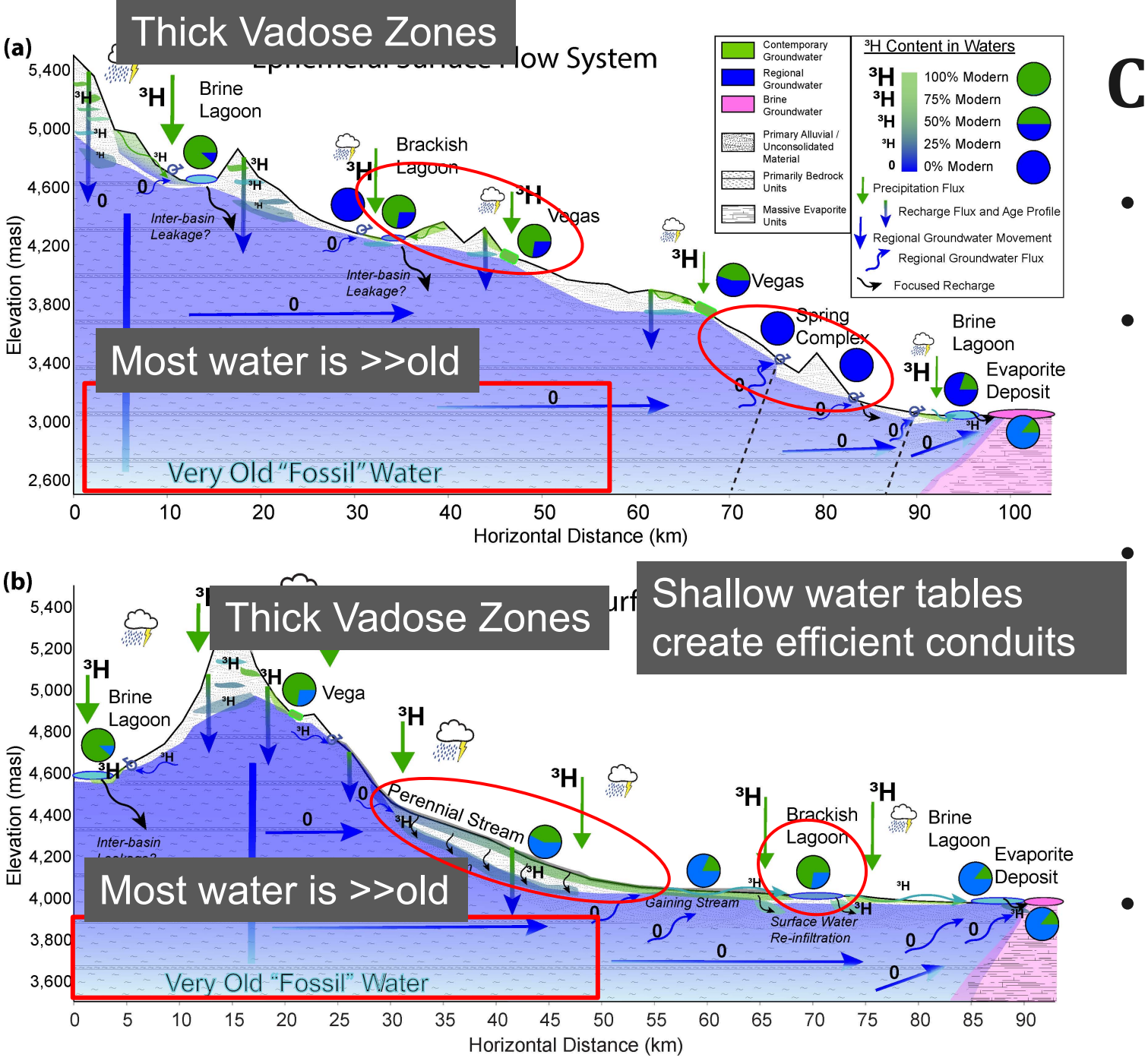
PLOS WATER

Contemporary and Relic Waters Strongly Decoupled in Arid Alpine Environments

Brendan J. Moran [1*], David F. Boutt [1], Lee Ann Munk [2], Joshua D. Fisher [3,4]

Lithium Triangle Region

- **142** ^{3}H samples of all water types over multiple years
- **Consistent patterns** regionally – insights into fundamental processes
- Strong **distinctions** over short spatial distances



Conceptual Model

- Very deep water tables cause strong **decoupling**
- **Coupling** only occurs when water tables are persistently near the surface

- **Preferential flow 'conduits'** are the primary control on:
  - Recent water inputs to aquifers and surface waters
  - Location and magnitude of response time
- Their existence (or absence) strongly influences **responses to perturbations**

Combining Tracers

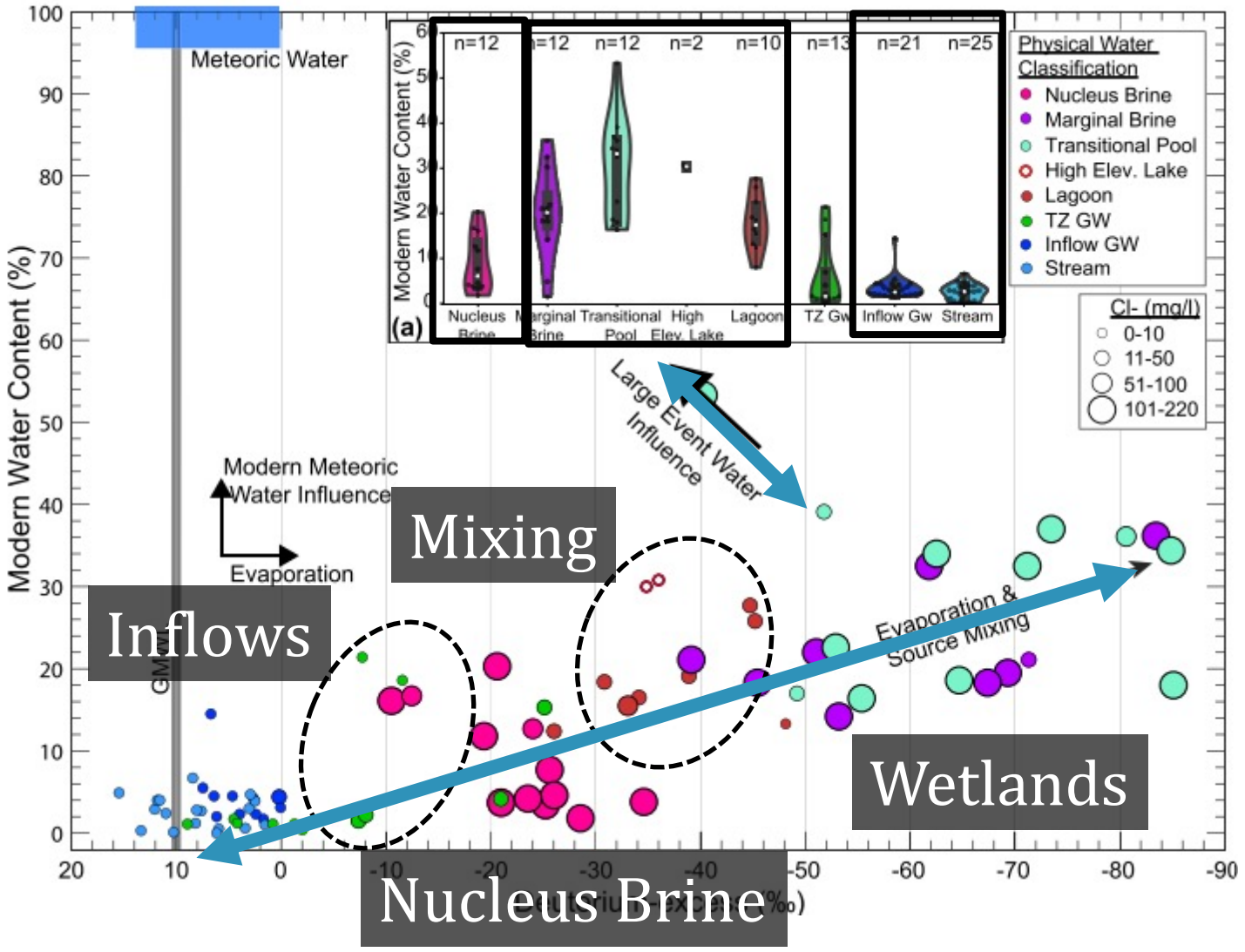
Tritium 3H
- Relative water age

Deuterium-excess ($^{18}O/^{2}H$)
- Evaporation Influence

Chloride content
- Interaction with brine body

Competing influences of Recent Rainfall – Relic water – Evapoconcentration

Defines water compartments and interconnections



KEY TAKEAWAYS

Salar hydrologic systems are decoupled from modern climate except through specific pathways

- Specific, strong controls on this connectivity

Responses to perturbations (in space & time) dependent on these connections

Local or recent (modern) precipitation is a small but important input to these systems

Contemporary inputs are highly focused in nature

- An important part of near-surface salar water bodies but almost nonexistent elsewhere

These conduits are critical to mining and climate resilience

03 New Basin Water Budget Insights

Photo by Nicole Blin

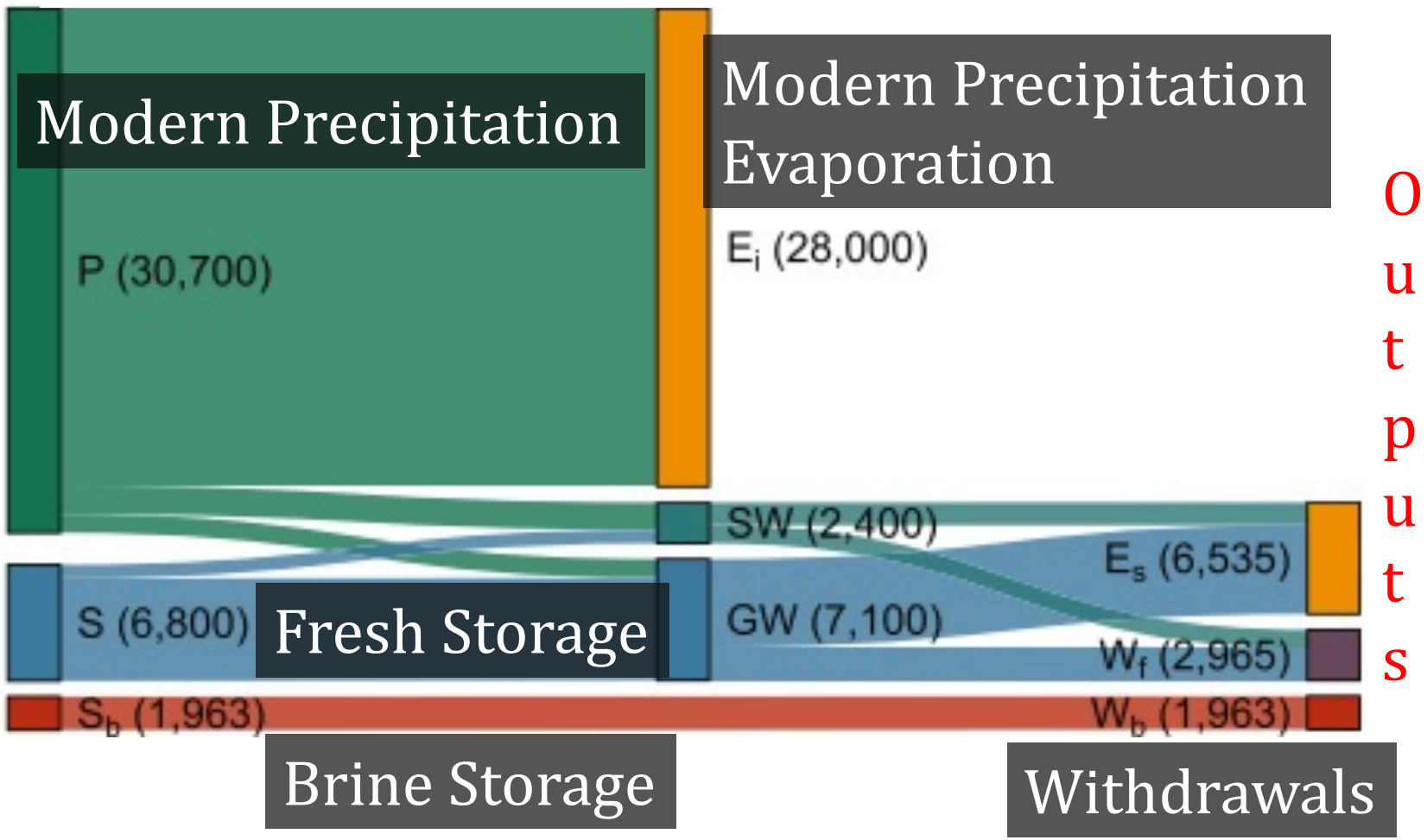
Basin-wide post-development water budget

*Units in L/s

In Moran et al., 2022 we quantified post-development water budgets with Boutt et al., 2021 using:

- Uncertainty-bounded flux estimates of Precipitation-Recharge, and Evaporation
- Isotopic tracers and relative water age averages

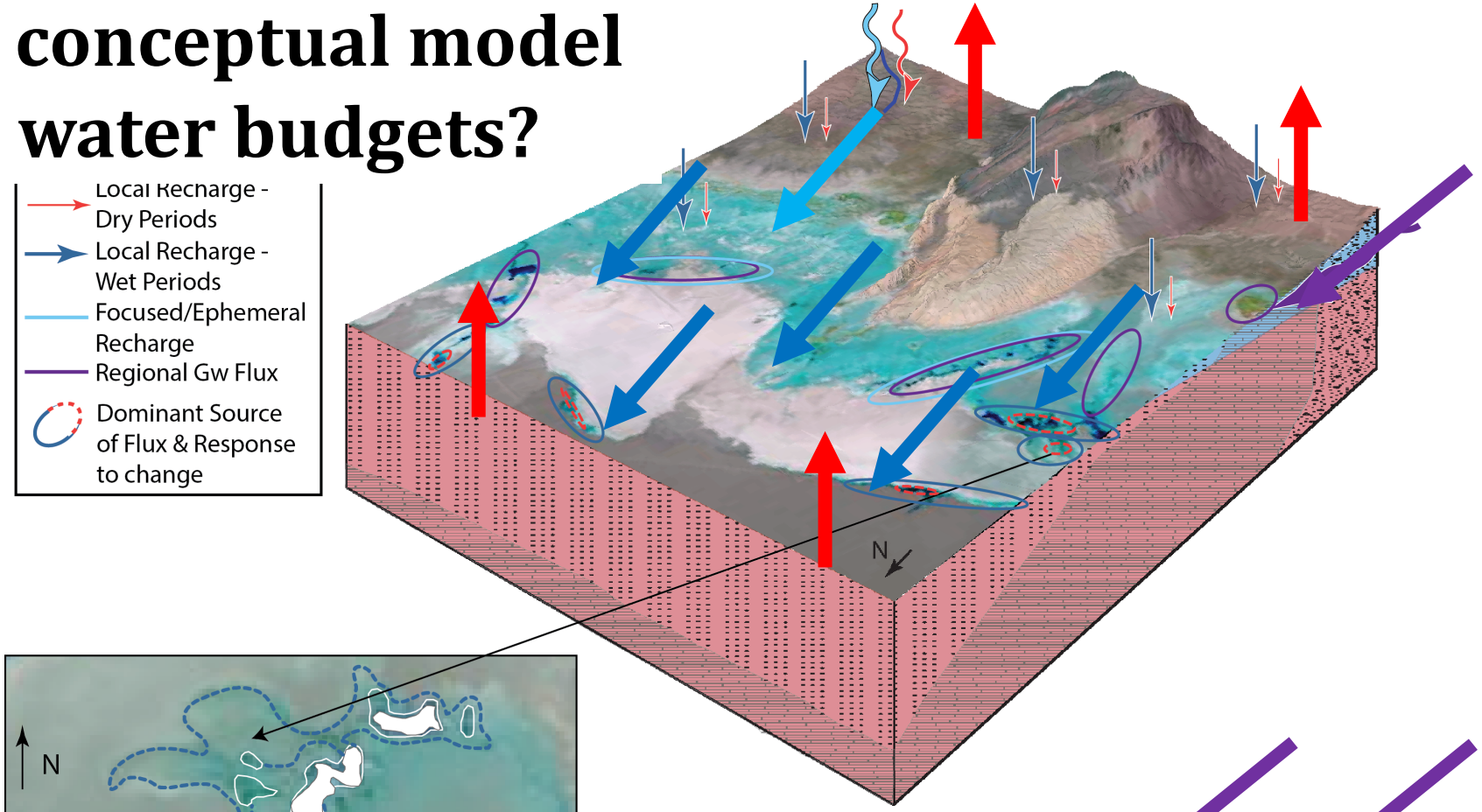
Revised Post Development water budget estimate

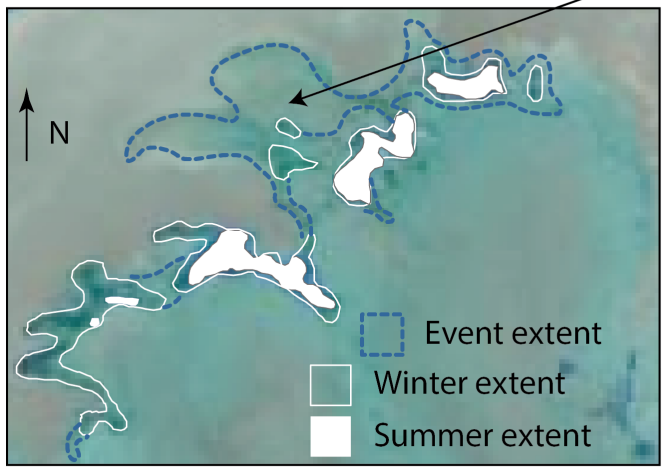


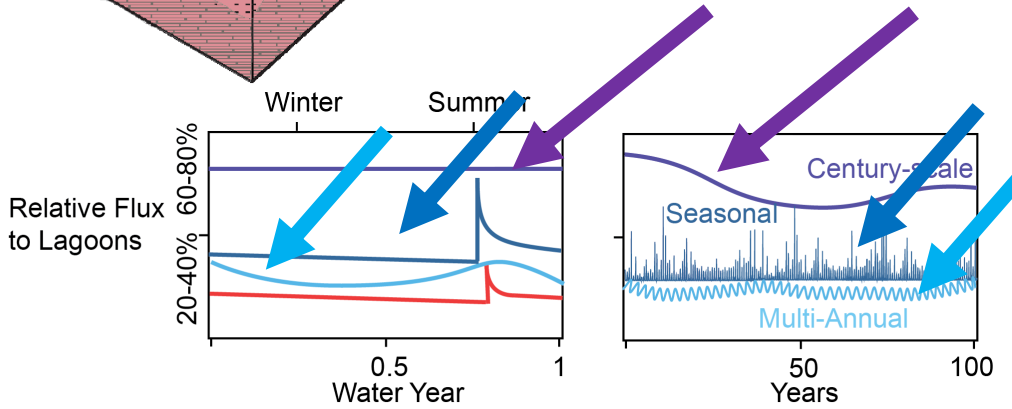
How does our new conceptual model inform basin-wide water budgets?

Total basin outflow is composed of:

1. Precipitation and brine groundwater storage ET losses
2. Fresh relic groundwater inflow
3. Very recent water in the shallow wetlands
4. Intermediate age marginal inflows







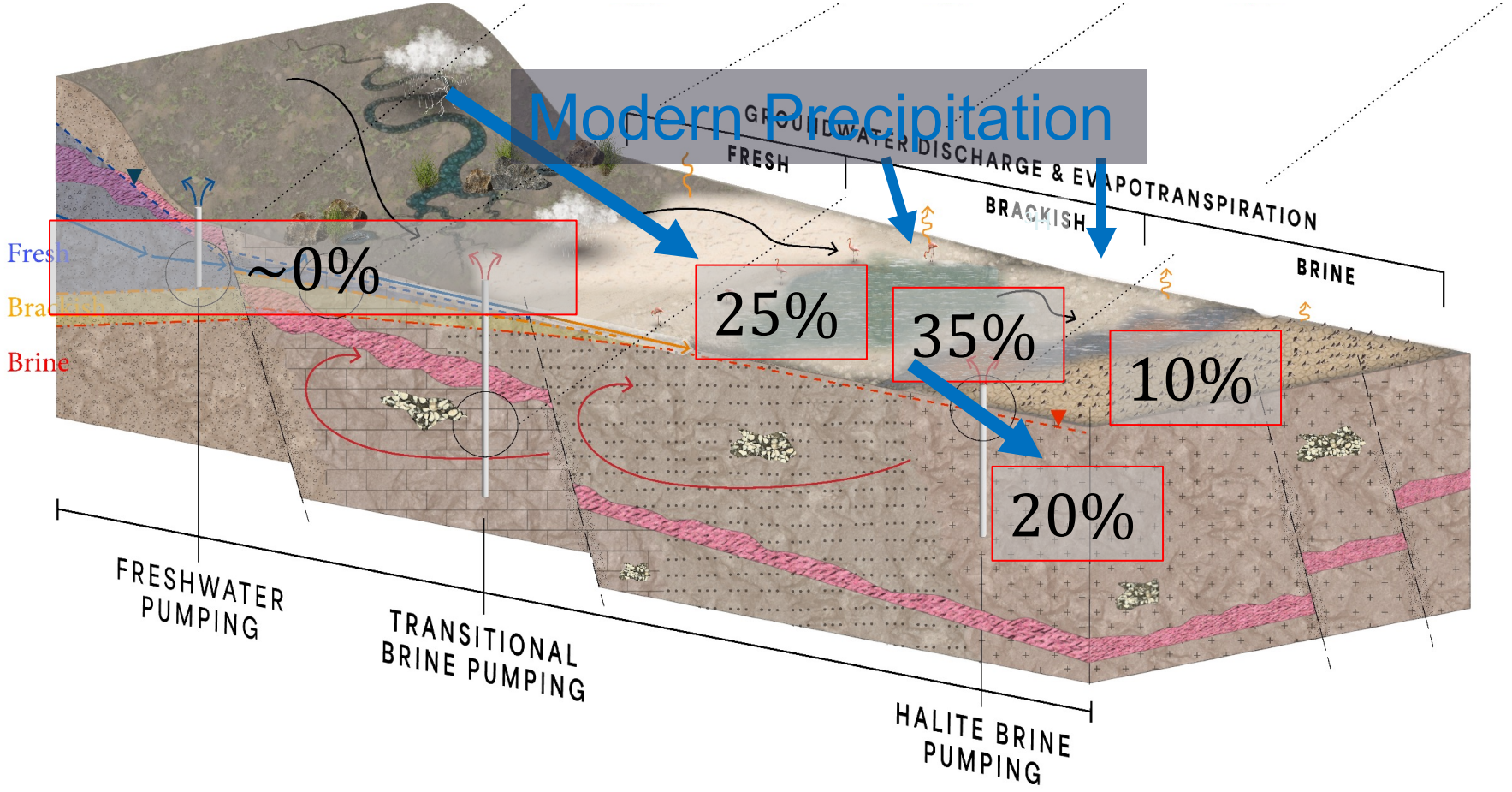
Updated water budgets need to integrate these time scales

Thank You!

Extra Slides

Ancient v. Modern Water

- How water moves through marginal zones
- Old water is dominant but short-term climate has major impacts by affecting the recent water component of input – **very focused**



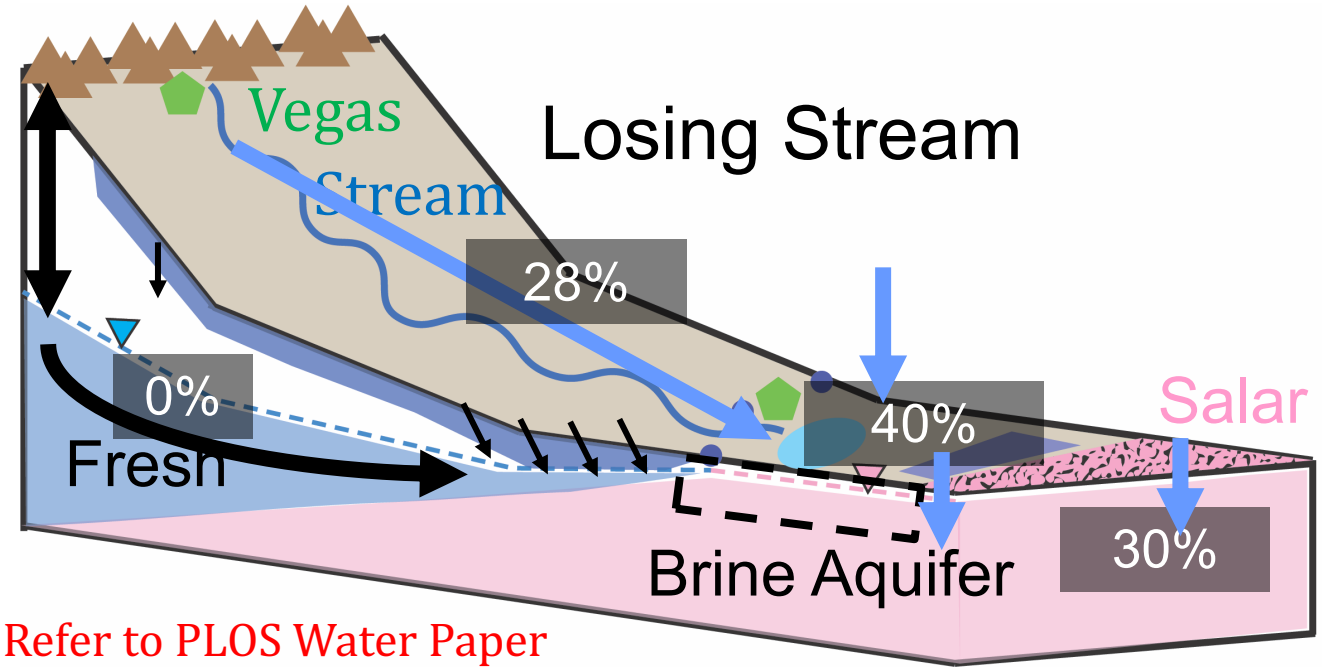
New Conceptual Model

Key hydrological Controls:

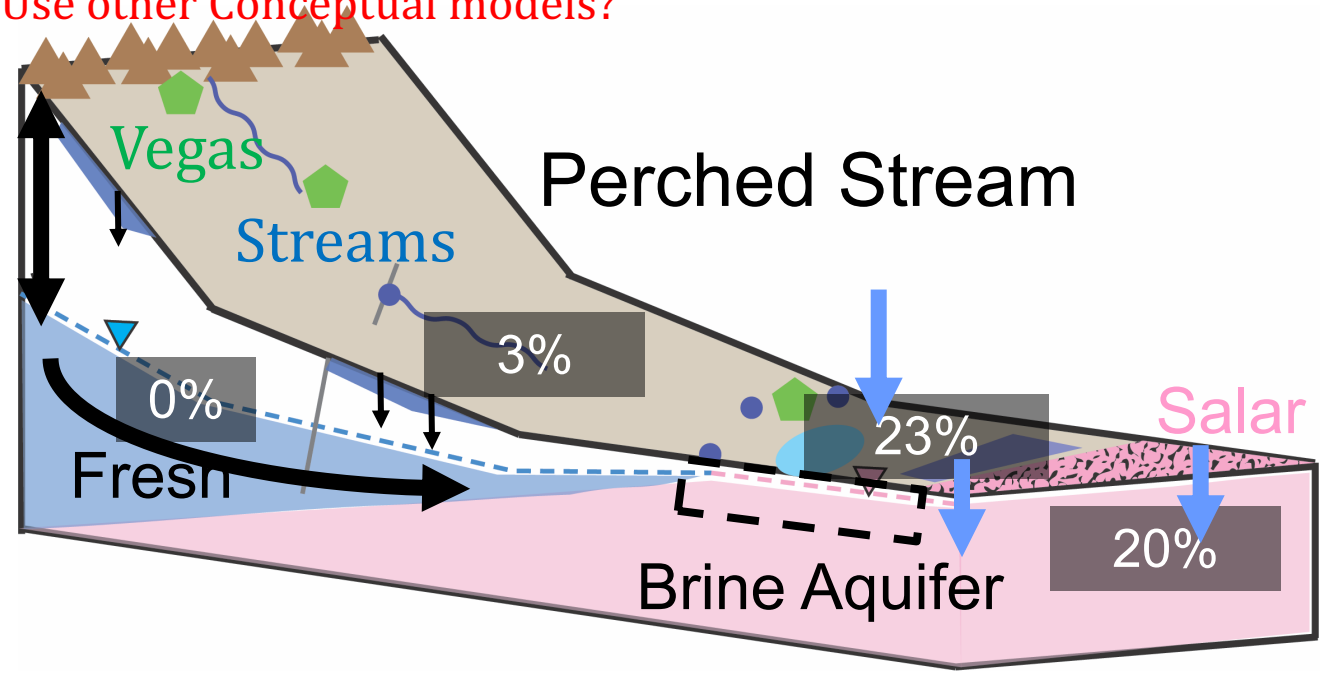
- Very long transit times – decoupled from modern climate
- Losing Streams - Perched Streams
- Fine-grained sediments – wetlands
- Brine aquifers
- Modern climate inputs - pathways

Modern water conduits:

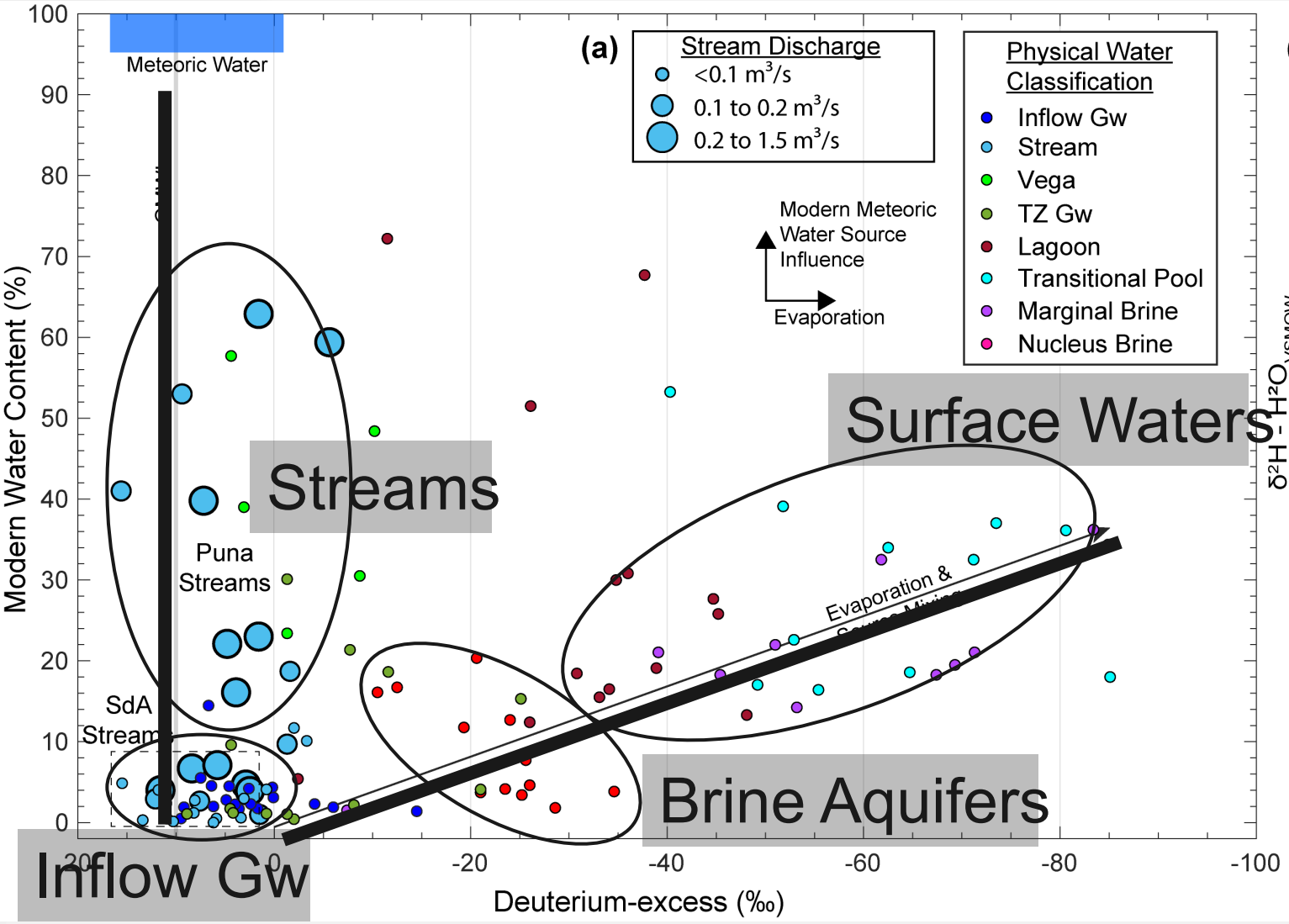
1. Persistent sw bodies
2. Shallow water tables (Vegas)
3. **Preferential pathways** in coarse grained units & karst

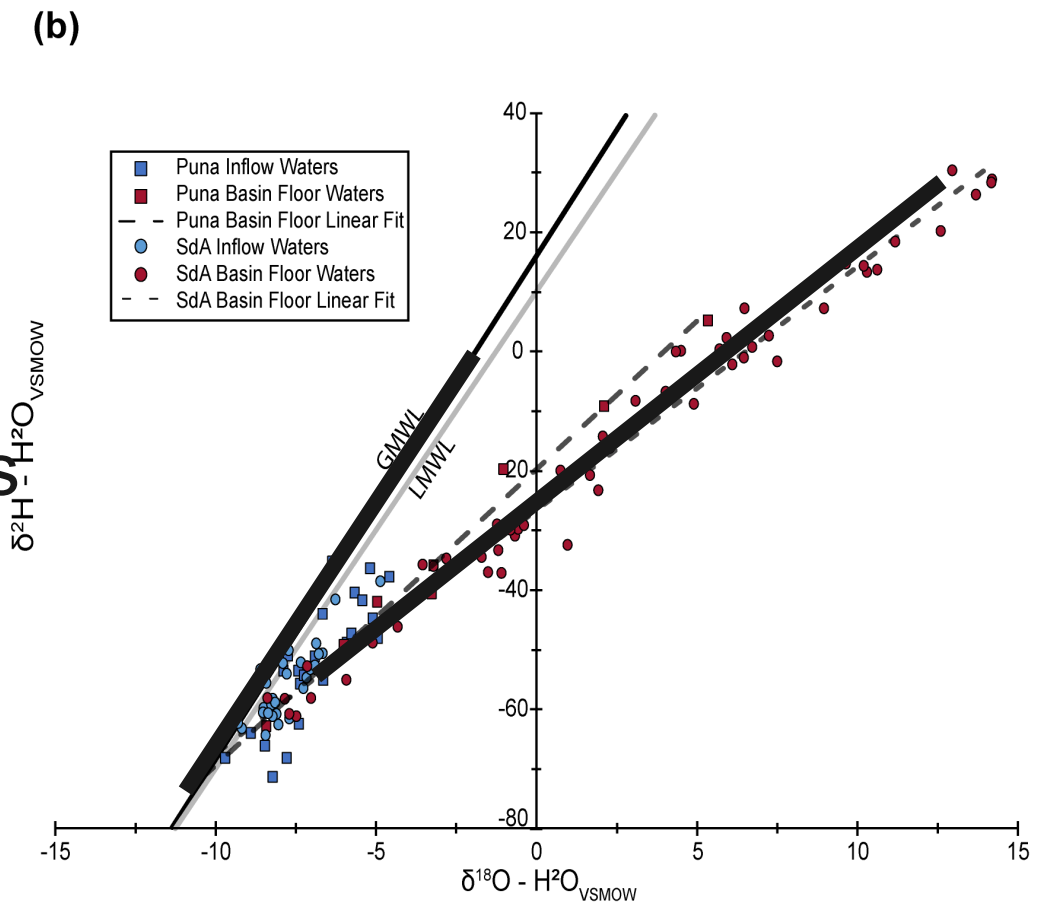


Refer to PLOS Water Paper
Use other Conceptual models?

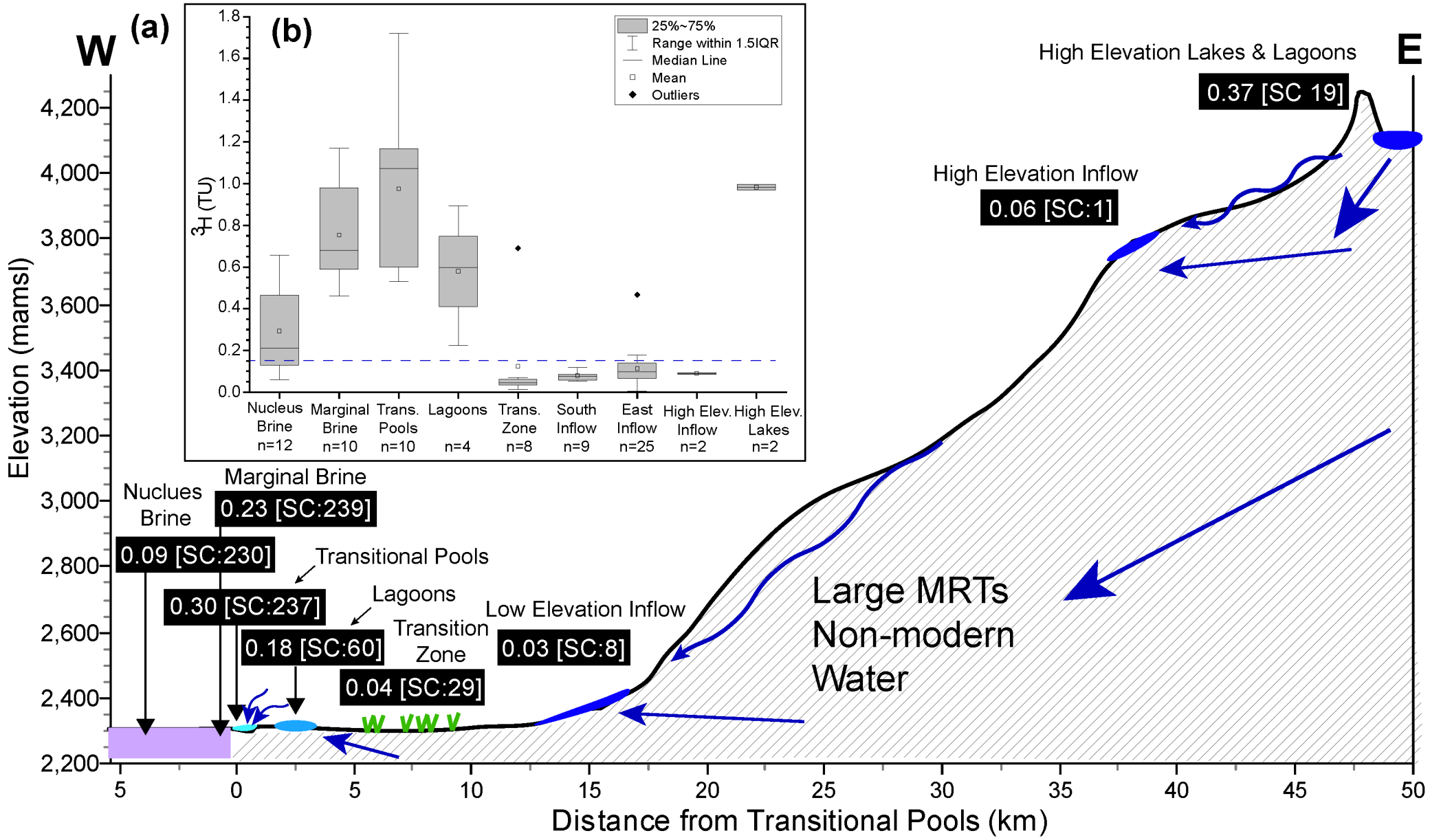


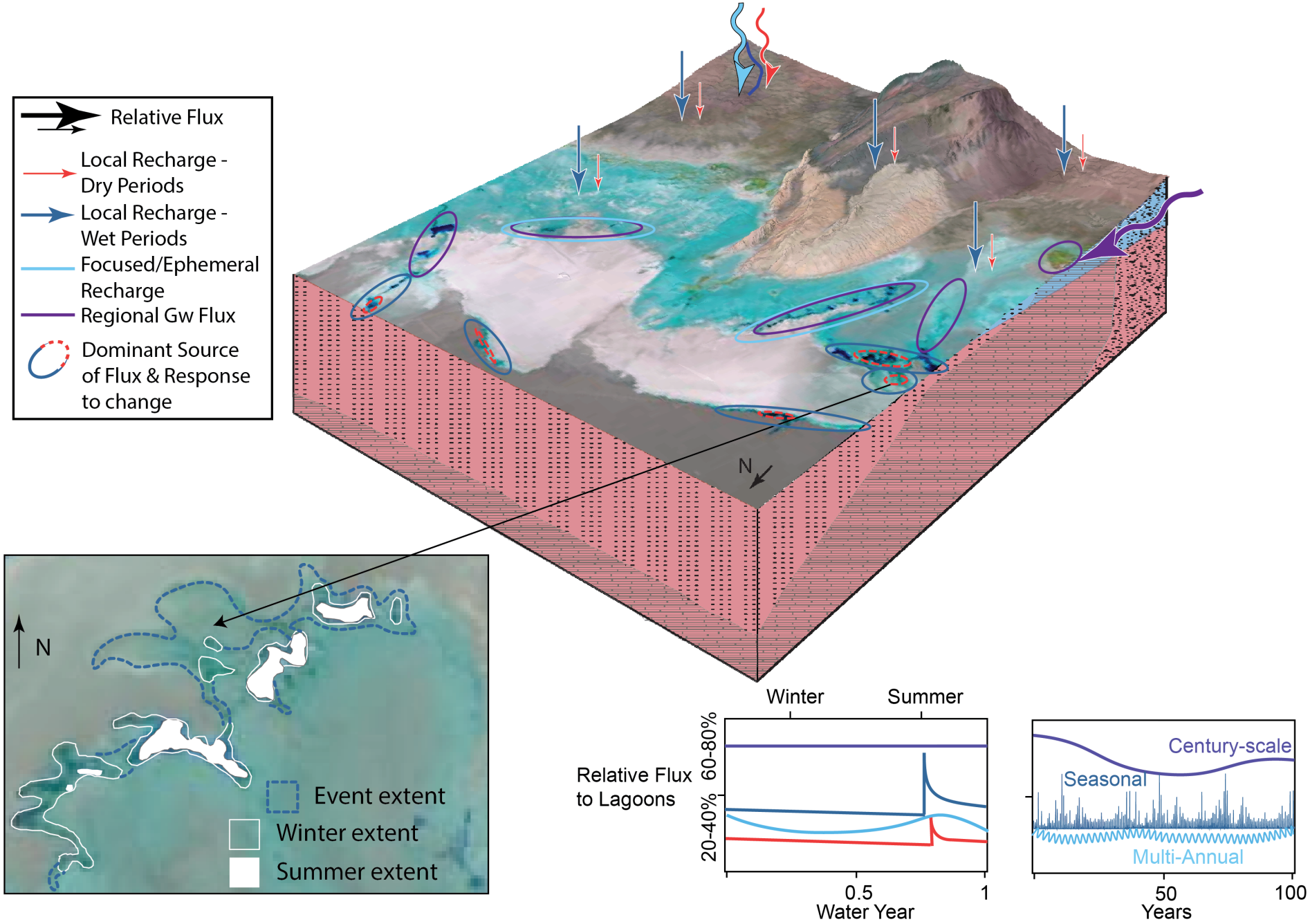
% modern paired with its d-excess signature

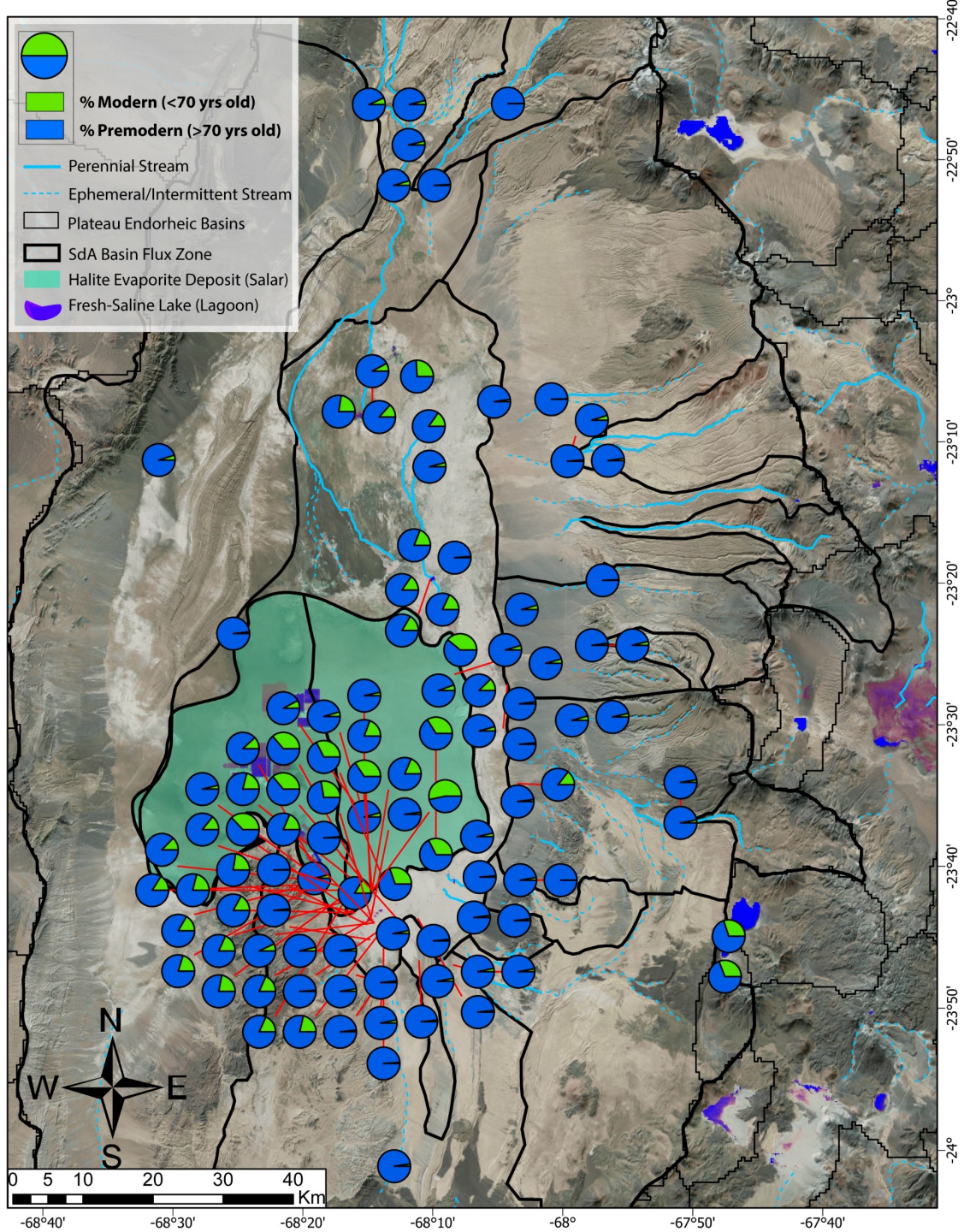




Effectively ***discretize*** *hydrological systems by:*
source, average residence time and ***modern climate connectivity***


W
(a)
(b)
E
High Elevation Lakes & Lagoons
0.37 [SC 19]
High Elevation Inflow
0.06 [SC:1]
Nuclues Brine
0.09 [SC:230]
Marginal Brine
0.23 [SC:239]
Transitional Pools
0.30 [SC:237]
Lagoons
0.18 [SC:60]
Transition Zone
0.04 [SC:29]
Low Elevation Inflow
0.03 [SC:8]
Large MRTs
Non-modern
Water
Elevation (mamsl)
Distance from Transitional Pools (km)
3H (TU)
25%~75%
Range within 1.5IQR
Median Line
Mean
Outliers
Nucleus Brine n=12
Marginal Brine n=10
Trans. Pools n=10
Lagoons n=4
Trans. Zone n=8
South Inflow n=9
East Inflow n=25
High Elev. Inflow n=2
High Elev. Lakes n=2

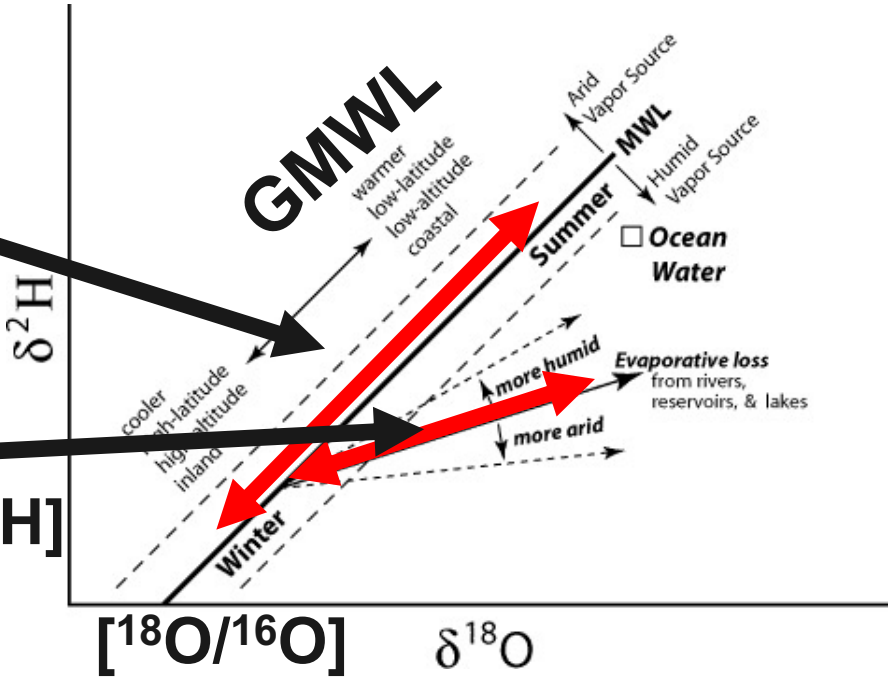

Relative Flux
Local Recharge - Dry Periods
Local Recharge - Wet Periods
Focused/Ephemeral Recharge
Regional Gw Flux
Dominant Source of Flux & Response to change
N
N
Event extent
Winter extent
Summer extent
Winter
Summer
Relative Flux to Lagoons
60-80%
20-40%
0.5
1
Water Year
Century-scale
Seasonal
Multi-Annual
50
100
Years


% Modern (<70 yrs old)
% Premodern (>70 yrs old)
Perennial Stream
Ephemeral/Intermittent Stream
Plateau Endorheic Basins
SdA Basin Flux Zone
Halite Evaporite Deposit (Salar)
Fresh-Saline Lake (Lagoon)
N
W
E
S
0 5 10 20 30 40
Km
-22°40'
-22°50'
-23°
-23°10'
-23°20'
-23°30'
-23°40'
-23°50'
-24°
-68°40'
-68°30'
-68°20'
-68°10'
-68°
-67°50'
-67°40'

Tracing with stable isotopes in water

- **Source signature** conserved in recharge
- **Gw** source signature - integrates larger spatial and temporal scales
- Evaporative fractionation - **surface waters**

Differentiate *source waters and pathways through cycle by these patterns*



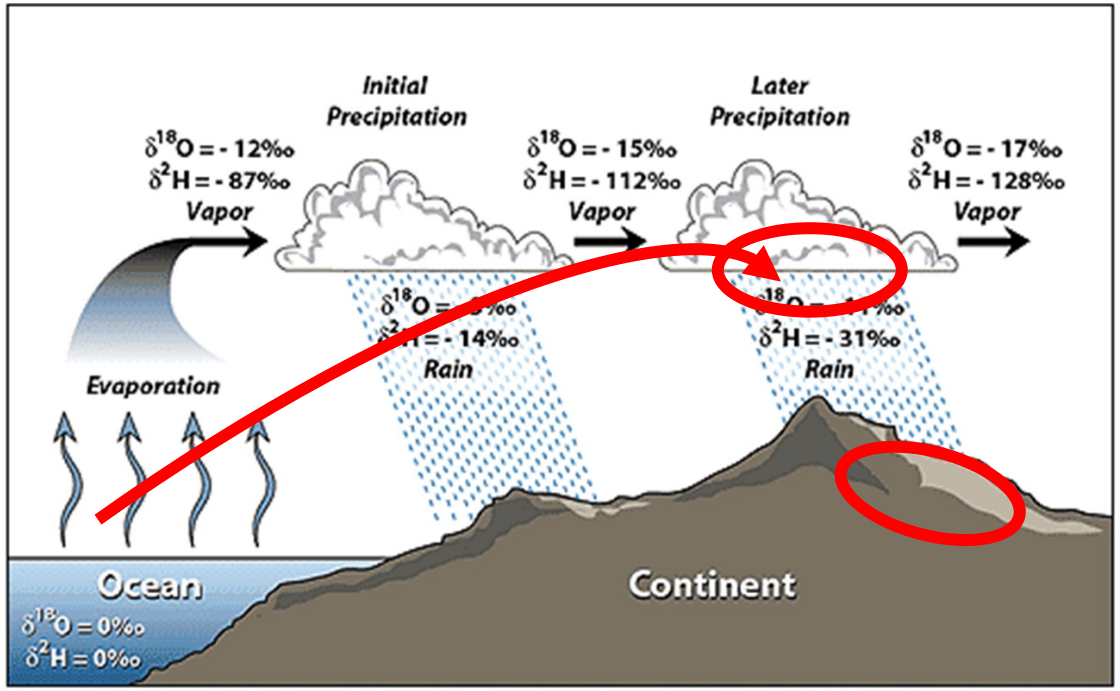


Figure 2. Rainout effect on d²H and d¹⁸O values (based on Hoefs 1997 and Coplen et al. 200