Environmental Tracer Study of Dry Brook Hill Aquifer, South Hadley, MA

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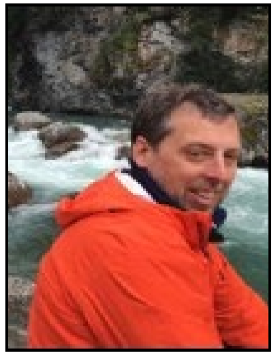
HYDROGEOLOGY
University of Massachusetts Amherst

Project Team



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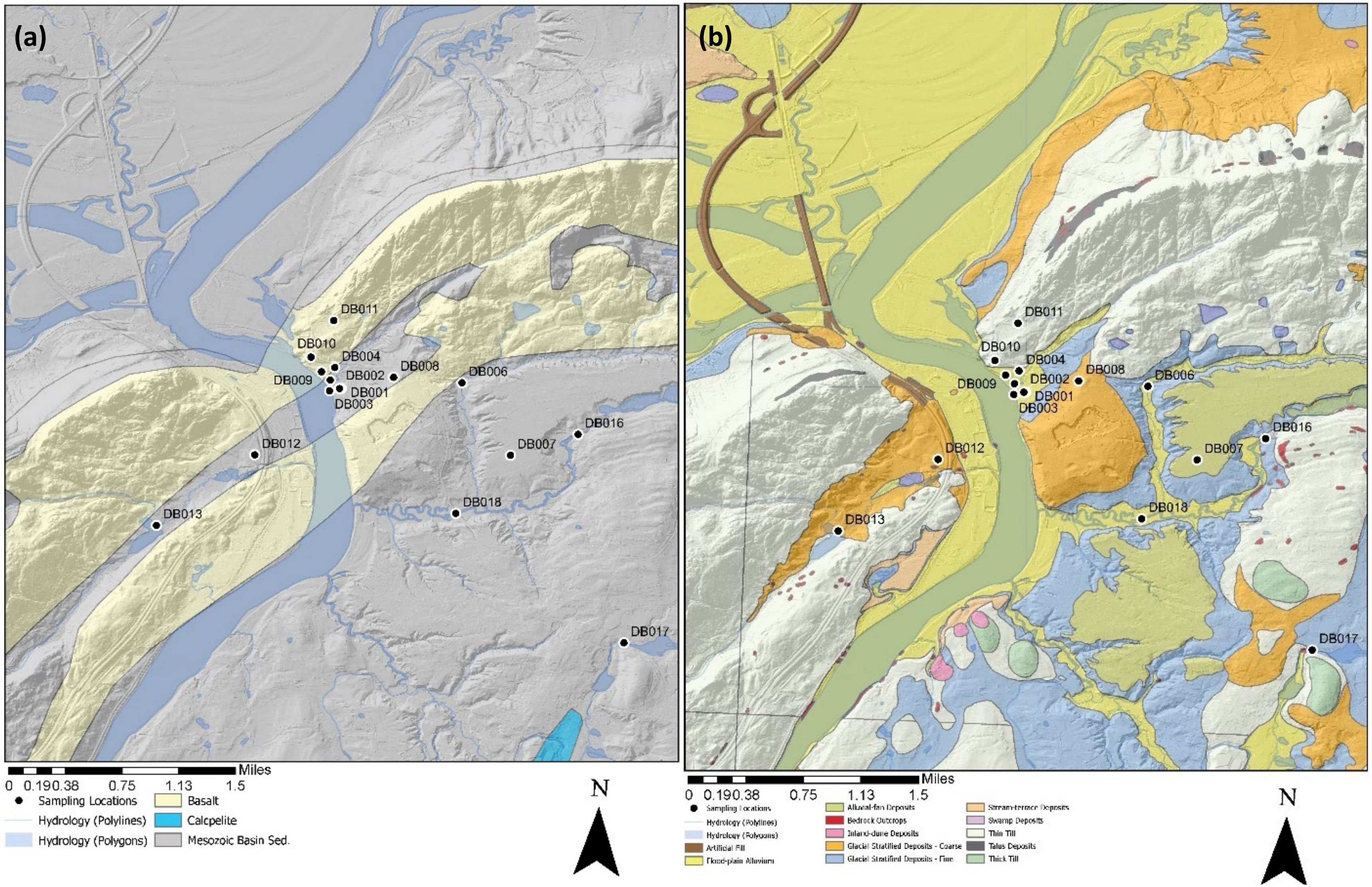
USGS - Garabedian & Stone, 20024 Hydrogeologic Conceptual Model

- Physical hydrologic data suggest that groundwater flows from the recharge area towards the CT River with a strong hydraulic connection between observation wells and the river itself.
- A physical hydrogeologic model that solves the groundwater flow equation determined the steady-state contributing area of the aquifer at 2 sustained pumping rates.
- The lower sustained rate of 300 gpm produced 90% of water from local recharge vs 10% from the Connecticut River while the 914 gpm pumping rate produced 50% from both sources.
- Refining the contributing area of the aquifer is critical for making informed decisions to protect the water quality of the well.

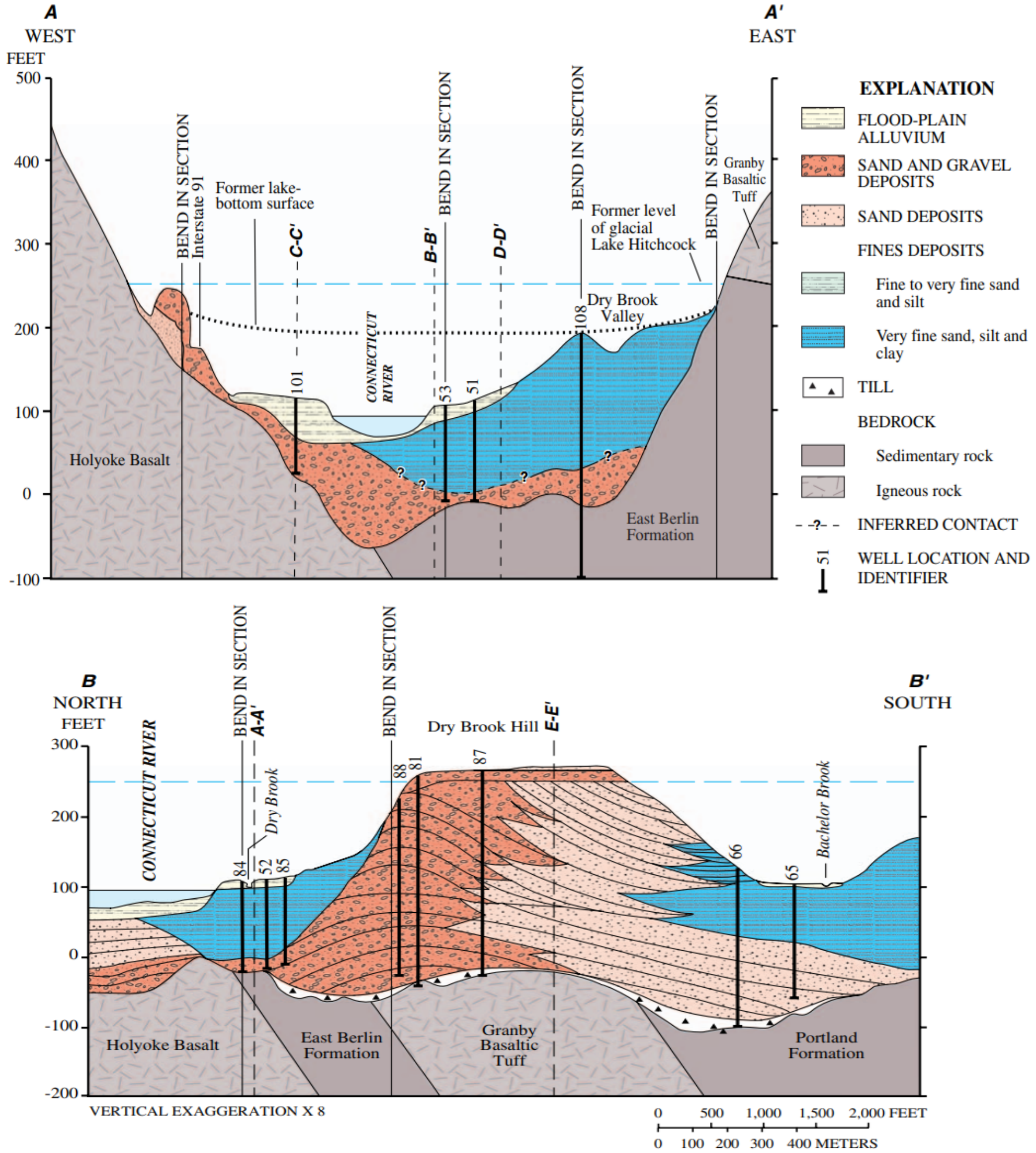
Geology Background

- Local Geology:
  - **Two bedrock units** – Mesozoic-age basin sediments (Sandstone, Shale, and Conglomerate) and Holyoke Basalt
  - **Surficial geology** – coarse and fine glacially stratified deposits, floodplain alluvium, and alluvial-fan deposits
  - **Dry Brook Hill** – large subaqueous lacustrine fan and delta formed during the last glacial retreat by sediment deposition into glacial Lake Hitchcock from a meltwater tunnel that was likely near where the Connecticut River cuts through the Holyoke Range



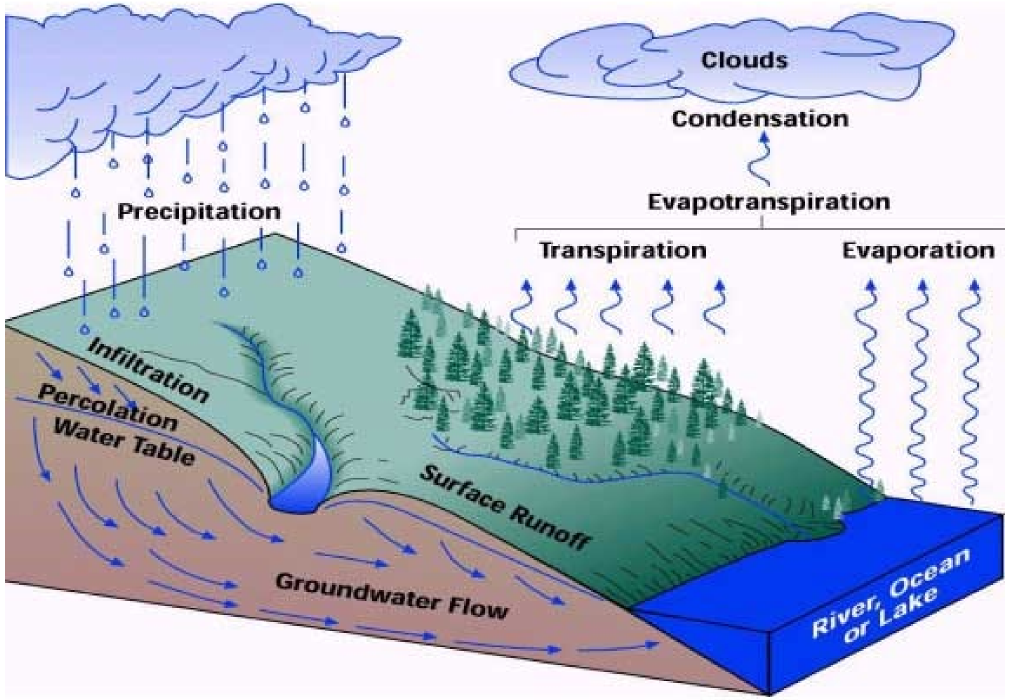
Hydrogeology Background

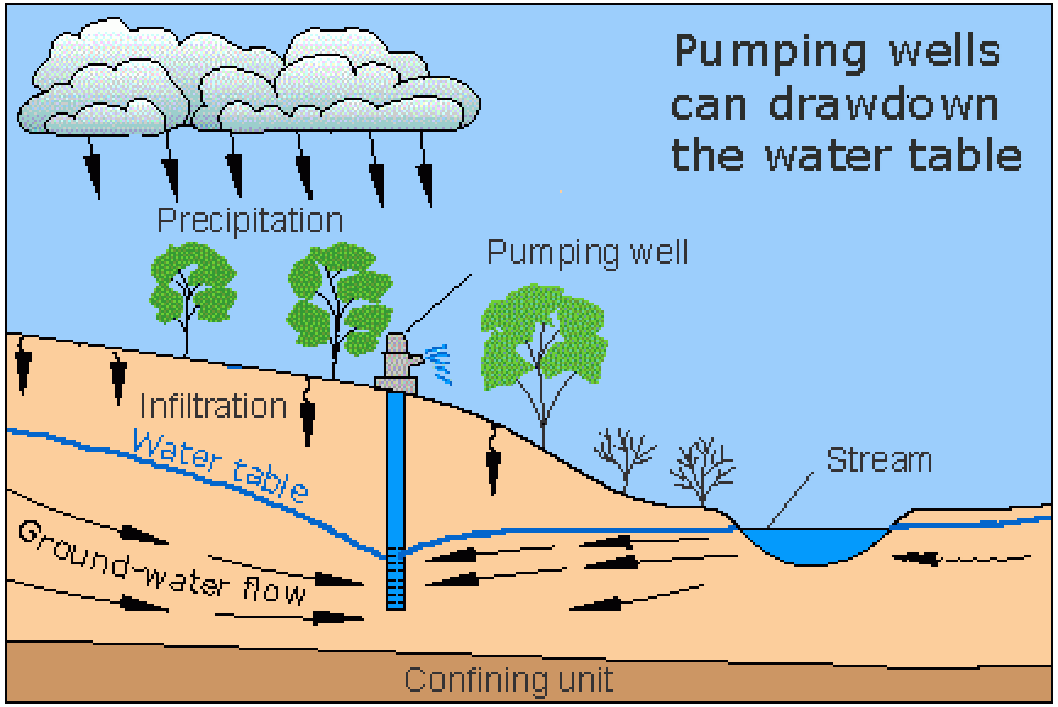
- **Dry Brook Aquifer**: sand and gravel deposits overlain by **confining lacustrine deposits**
- Surface waters:
  - Connecticut River
  - Dry Brook
  - Elmer Brook
  - Bachelor Brook
- Recharge:
  - Primarily through precipitation
  - Highest recharge on the northern part of Dry Brook Hill - coarse sediments
  - Lowest recharge in areas underlain by lacustrine deposits - surrounding Dry Brook Well



Conceptual Background

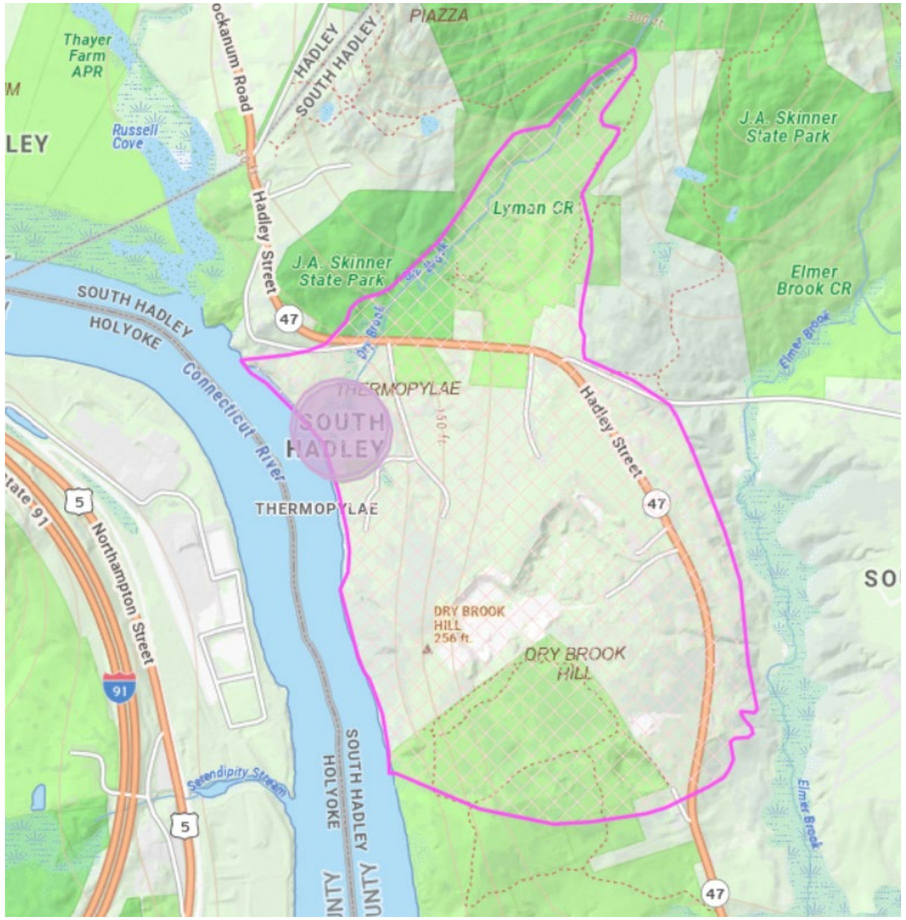
- Water cycle - Groundwater and surface waters are connected





USGS Study Background

- Groundwater flows to the Connecticut River under normal conditions
- Pumping Dry Brook Wells:
  - Calibrated to 8 observation wells, aquifer test by pumping the supply well for 10 days at 914 gallons per minute
  - Drawdown cone elongated in a northern direction
  - Evidence of River water flowing to supply wells when pumped



Groundwater drawdown cone: pink outline
Dry Brook Wells: purple circles

USGS Study Background

- Dry Brook Aquifer hydraulically connected to the Connecticut River
  - Correlation between River stage and groundwater elevation

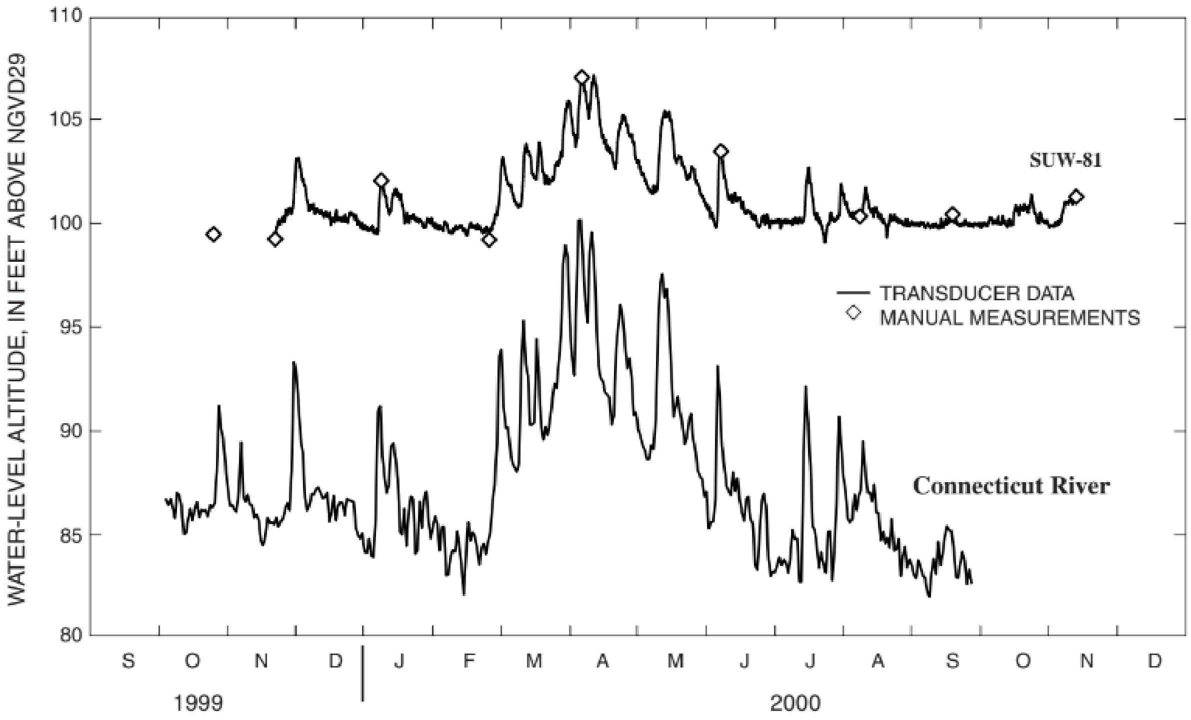
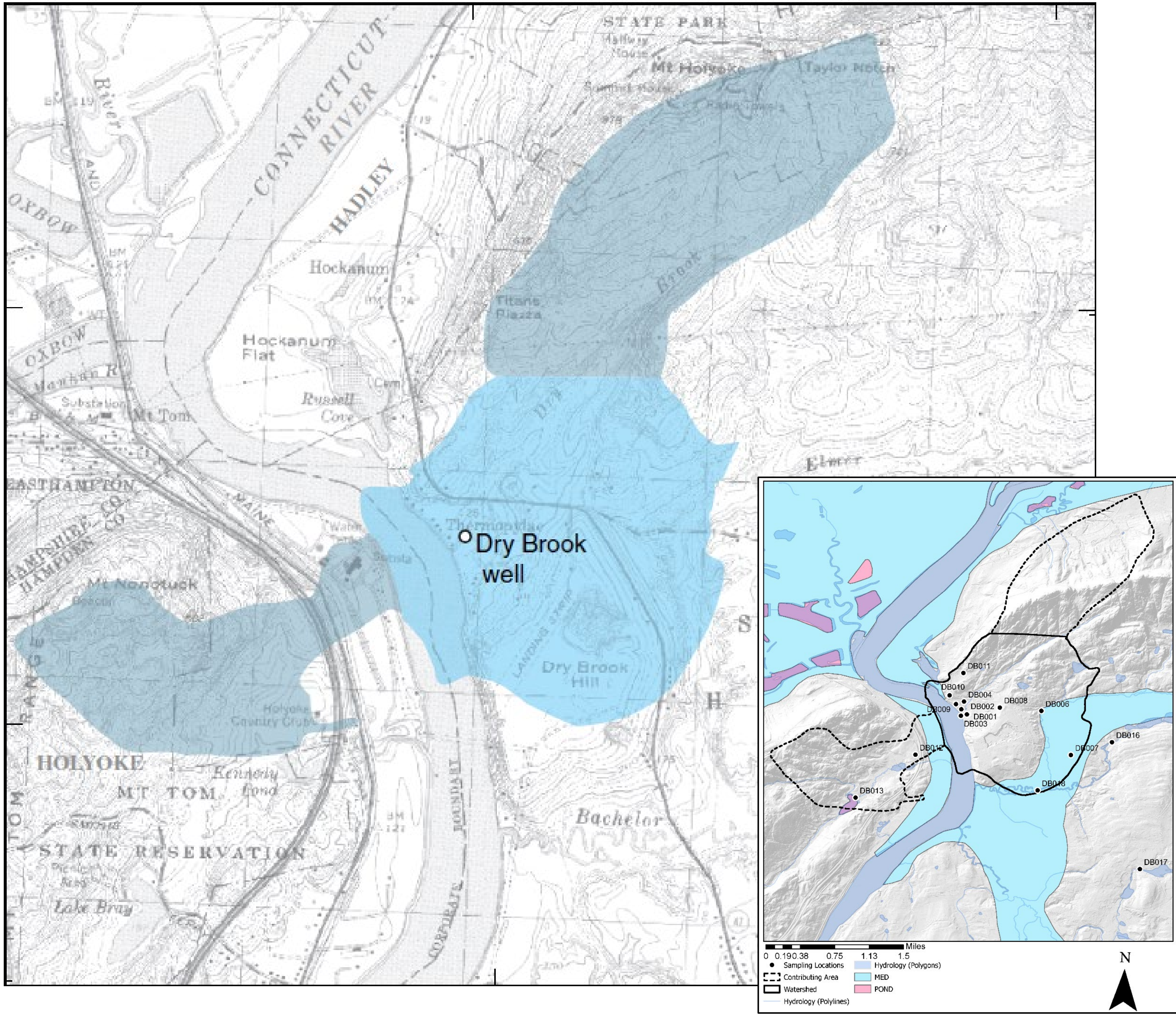


Figure 10. Ground-water levels measured in well SUW-81 compared to the stage of the Connecticut River at Montague, Massachusetts. Connecticut River stage 75 feet above arbitrary datum.

- Watershed
- Contributing Area

The USGS Study goal was to define the contributing area to the DB well field through numerical simulation using the best estimate of aquifer properties and dimensions



Our goal: to refine the definition of water sources & connections within the dry brook aquifer area

1. Does the geochemistry of the pumped water support a connection to the CT river?

2. What fraction of produced water is local recharge (i.e., Dry Brook Hill) vs. Induced infiltration from the Connecticut River?

3. What can be concluded from this data regarding the size and residence time of water in the aquifer system?

Fundamental Questions

- Has the chemistry of DB changed from the start to the end of the pumping test?

- How different is DB from other groundwaters?

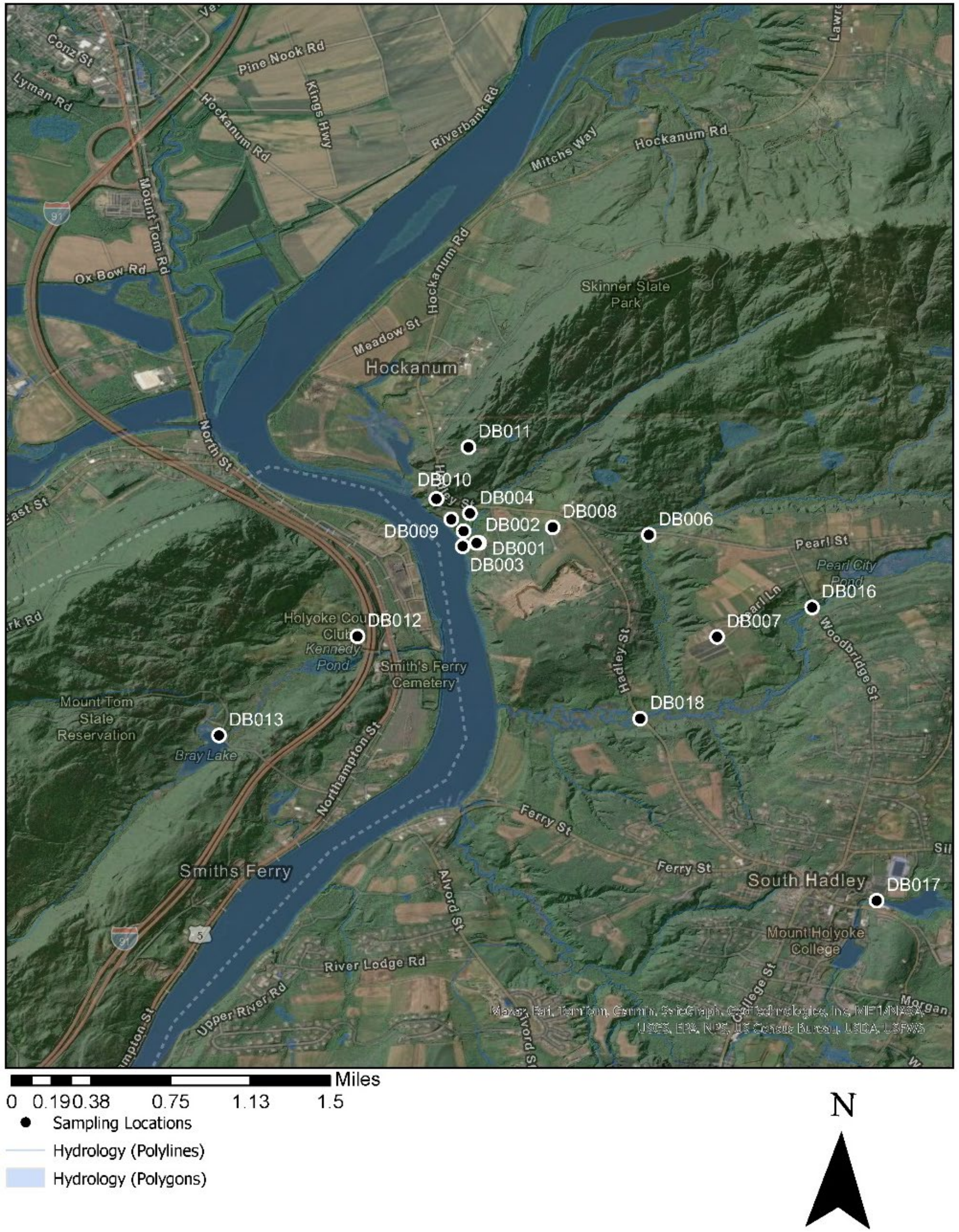
- How different is the surface water from the groundwater?

- How variable is the DB well over time?

- Does the geochemistry of the pumped water support a connection to the Connecticut River?

Water Sampling

- 63 Samples taken in 18 Locations
- Locations selected include a mix of surface waters, residential wells, production wells, and observation wells
  - Locations picked are in the immediate vicinity of the watershed area of contribution



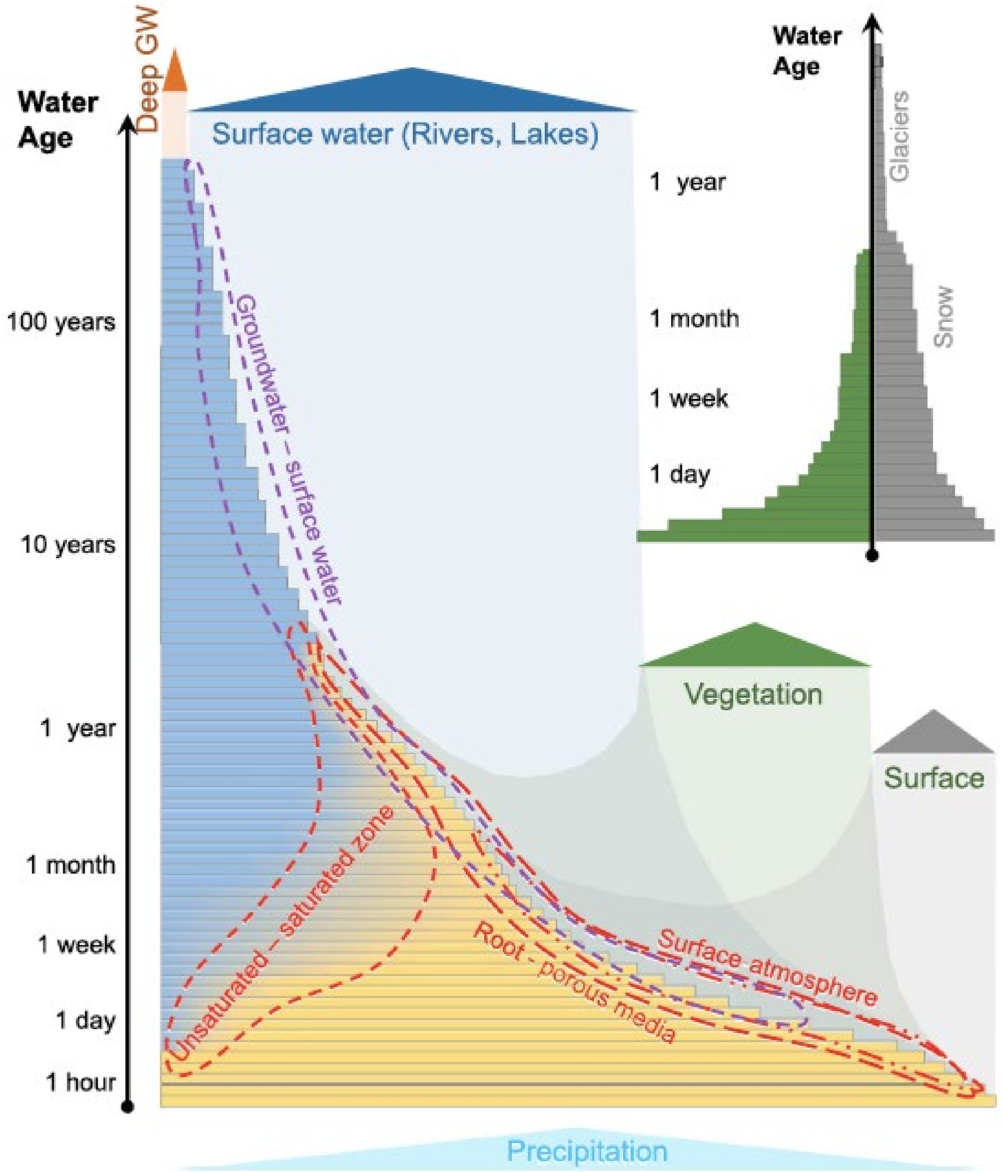
What is an Environmental Tracer?

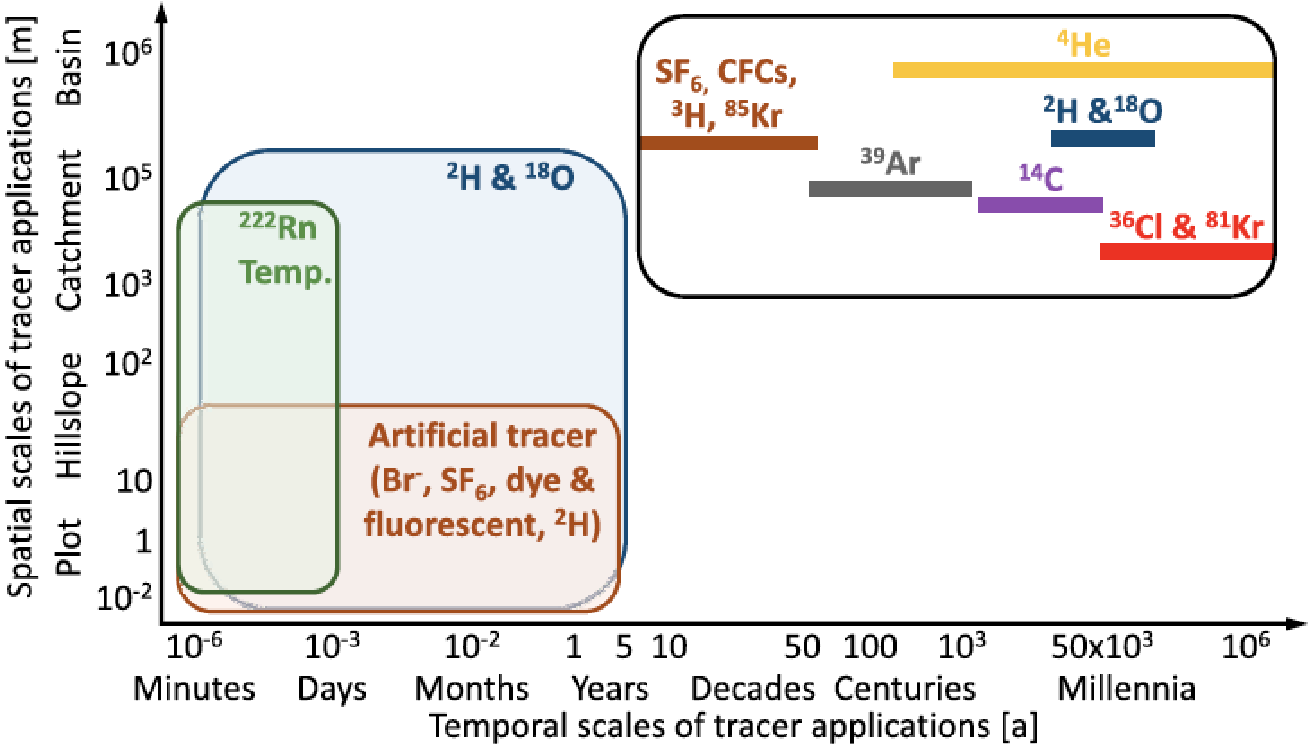
- As water moves through the terrestrial hydrologic cycle it transports with it dissolved inorganic and organic solutes, gases, and other complexes
  - Some ... es an unders... hat control them
  - Some a... he tempo...

All tracers require a scientific and theoretical framework within which to interpret the results in the context of question being asked

- Some tracers tell us about how long the water was in the ground
- Some tracers tell us what hydrologic processes impacted that water
- Some tracers tell us what rocks/sediment the water has interacted with

Common Environmental Tracers

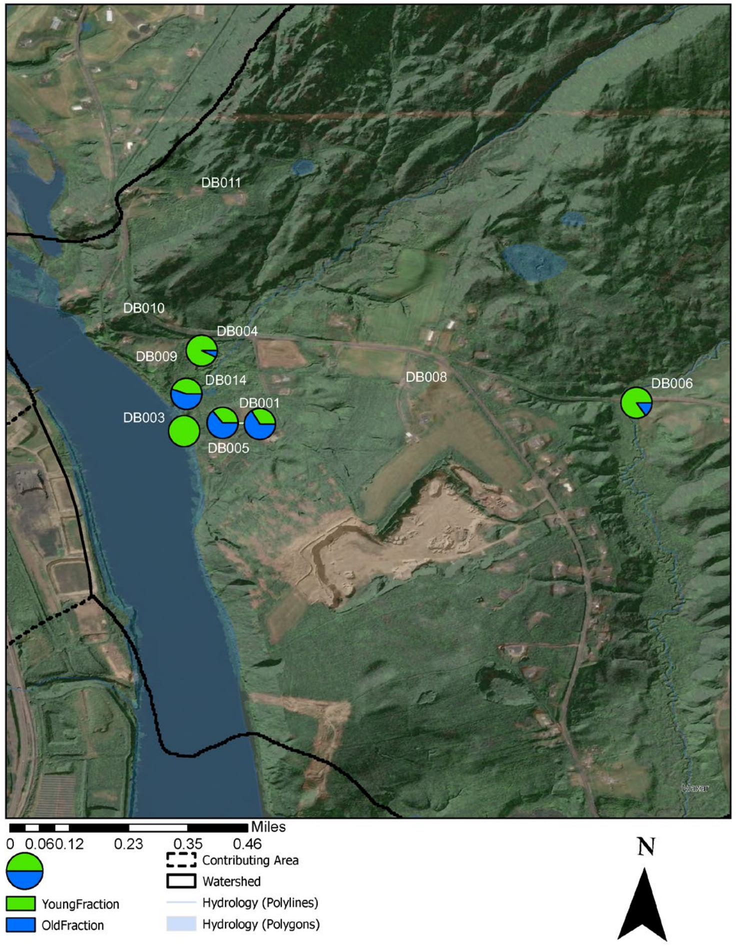




Sprenger, M. et al. (2019). The demographics of water: A review of water ages in the critical zone. Reviews of Geophysics, 57.

Results

- ^3H analysis allows assessment of relative water age and connection between surficial hydrology and groundwater
- Results from 8 samples show some important distinctions
  - Surface waters strongly connected to climate – young (stream has 5-15% older gw inputs)
  - Confined aquifer waters connected largely over decadal scales – **wide distribution** (70-50% old water)
  - Younger with time after pumping initiates and proximity to the CT river



Sample ID	Name	Sample Date	Analysis Date	^3H Concentration (TU)	1 Sigma Analytical Error	^3H Sample/^3H Background - Young Fraction (%)
	Boston, MA ^3H in Precipitation Background	2005-2022		7.90	-	-
DB006	Elmer Brook @ Pearl St.	7/31/2023	12/22/2023	6.71	0.28	85%
DB004	Dry Brook Stream	7/31/2023	12/22/2023	7.36	0.30	93%
DB003	CT River, neighbor's dock	7/31/2023	12/22/2023	8.70	0.38	110%
DB001	Dry Brook Well #2 - Before test	7/28/2023 - 10:40 am	12/27/2023	2.70	0.12	34%
DB001	Dry Brook Well #2 - Start of test	7/31/2023 - 6:55 am	12/22/2023	3.01	0.16	38%
DB001	Dry Brook Well #2 - End of test	7/31/2023 - 6:14 pm	12/14/2023	3.28	0.23	42%
DB005	OBS Well 6-97	7/31/2023	12/8/2023	2.87	0.16	36%
DB014	OBS Well 7-97	7/31/2023	12/22/2023	3.52	0.63	45%

Results

SF6

Sample ID	Name	Sample Date	SF6 Conc. - Raw (fMol/L)	SF6 Conc. in Water - HS Corrected (fMol/L)	Piston Flow Model SF6 Rech. Year	Piston Flow Model SF6 Rech. Age, Years
DB001	Dry Brook Well #2 - Before test	7/28/2023 - 10:40 am	1.34	1.37	1997	26.6
DB001	Dry Brook Well #2 - Start of test	7/31/2023 - 6:55 am	1.44	1.48	1998.5	25.1
DB001	Dry Brook Well #2 - End of test	7/31/2023 - 6:14 pm	2.19	2.25	2007.5	16.1
DB005	OBS Well 6-97	7/31/2023	1.20	1.23	1995	28.6
DB014	OBS Well 7-97	7/31/2023	2.71	2.78	2013	10.6

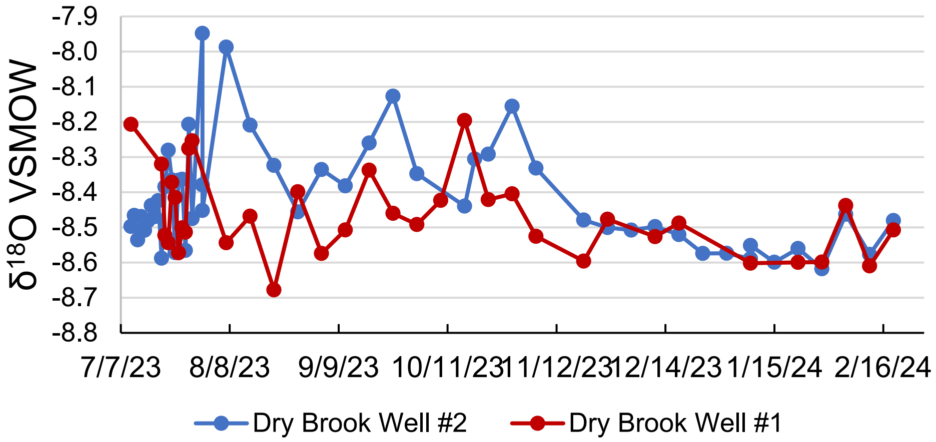
CFC

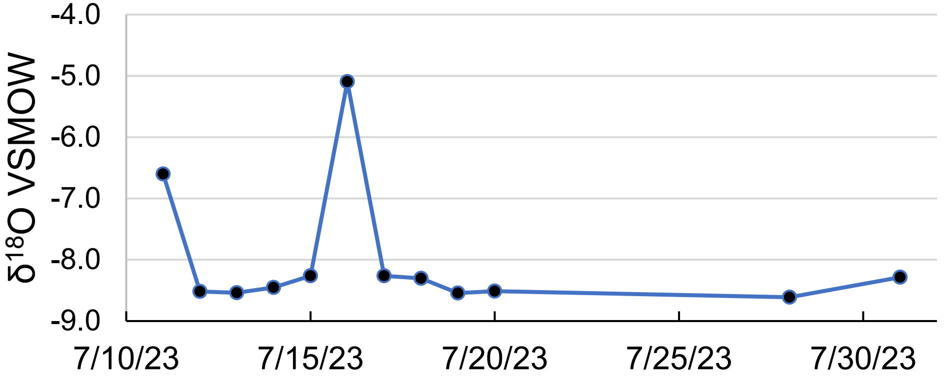
Sample ID	Name	Sample Date	CFC-11 (pmoles/kg)	CFC-12 (pmoles/kg)	CFC-113 (pmoles/kg)	CFC-11 Rech. year	CFC-12 Rech. year	CFC-113 Rech. year
DB001	Dry Brook Well #2 - Before test	7/28/2023 - 10:40 am	7.02	2.94	0.21	1981.5	1980.5	1977.5
DB001	Dry Brook Well #2 - Start of test	7/31/2023 - 6:55 am	6.84	3.16	0.21	1981	1981.5	1977.5
DB001	Dry Brook Well #2 - End of test	7/31/2023 - 6:14 pm	6.80	2.83	0.22	Post 2001	Post 2001	1984

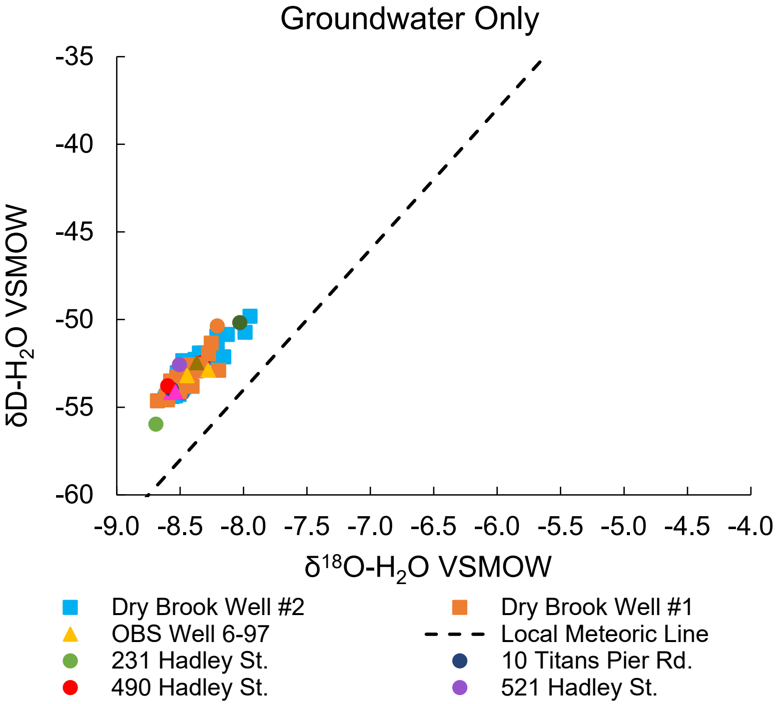
- Anthropogenic atmospheric tracers
- Become younger with time after pumping
  - Apparent age decreased from between 46-27 years old to between 39-16 years old
- Younger closer to the CT river
  - OBS well 7-97 closer to the Connecticut River appears younger water than OBS well 6-97

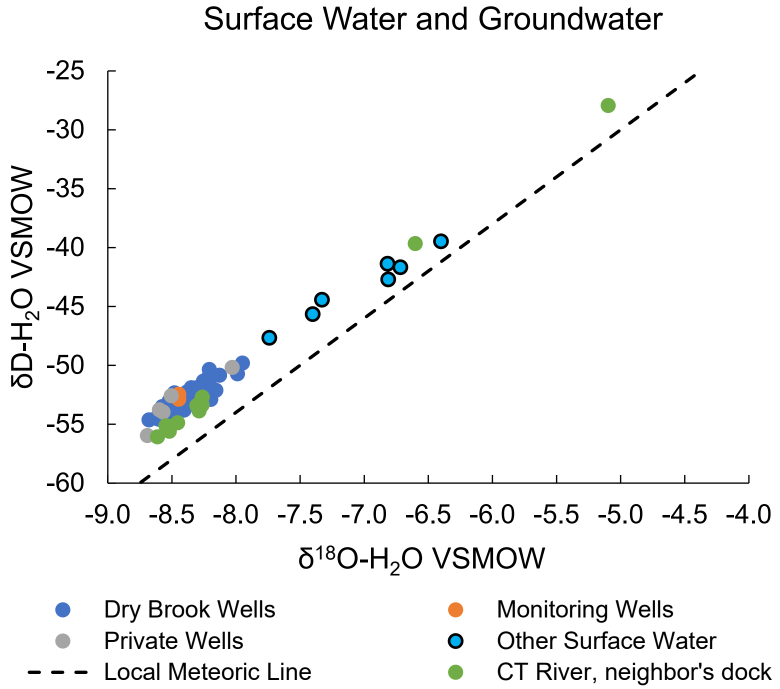
Results

- 114 total samples from 18 surface water and groundwater sites
- Much larger range and seasonal variability in SW
    - Distinct from local rainfall
- GW cluster together
- Overlap in signatures and slight seasonal signal indicate some hydrogeologic connection
    - Evidence of more infiltration from the river to DB aquifer during water months
    - **Caution:** 1 year, very wet









Key Findings

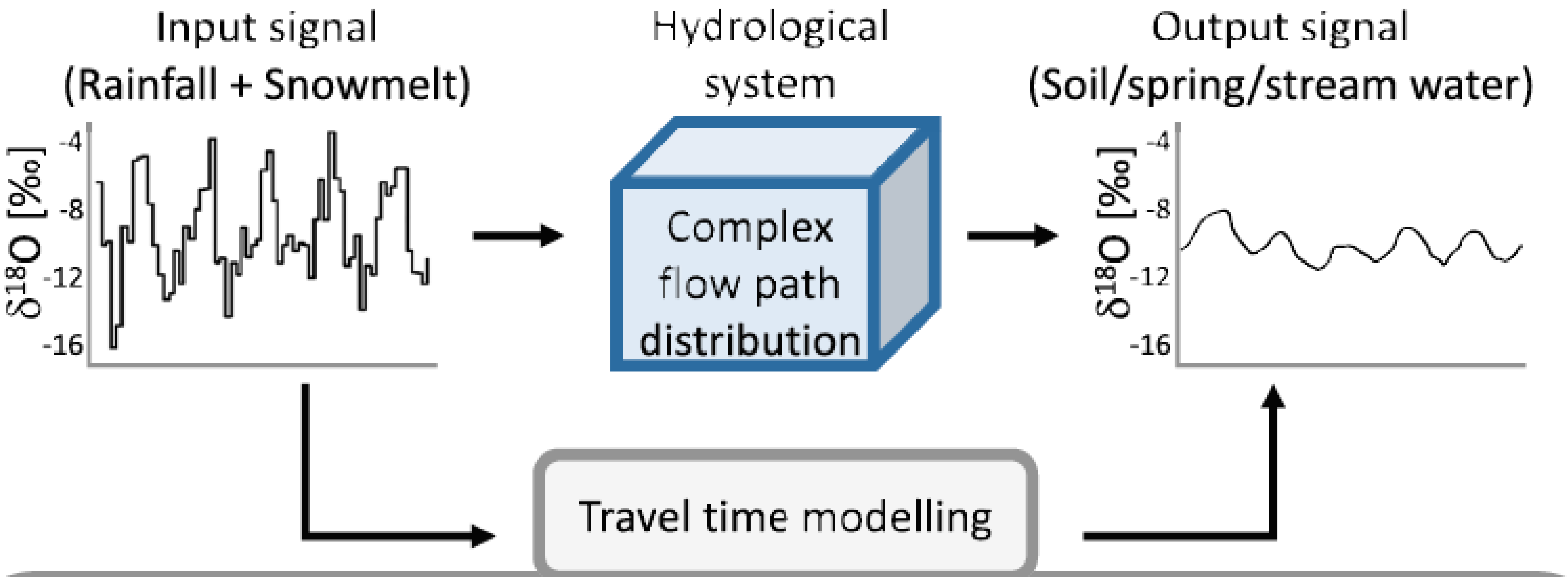
1. Hydrogeochemistry of the DB well changes (slightly) before to after pumping
2. Hydrogeochemically and isotopically the Dry Brook pumping wells are distinct from the other groundwaters sampled
3. The surface waters are very distinct from the groundwaters in the study area – **in bulk**
4. The aquifer has some connection to the SW hydrology (namely the CT River) but receives the majority of its water volume from longer flow path groundwater storage in the aquifer
5. Evidence of a connection between aquifer and river, two end-member mixing models using Cl^-, ^3H, and $\delta^{18}O$ indicate between 10% and 42% (likely ~20%) of DB well water likely comes from the river

Next Steps?

- We addressed the questions sought to answer
- Key limitations created uncertainty in the results and required assumptions to be made about the hydrogeological representativeness of the samples collected
  - Additional sampling of stable isotopes over time and broader area in the aquifer
  - Long-term pumping test paired with regular sampling
  - Support conclusions, reduce uncertainty in source mixing
- Geophysical surveys (TEM, AEM, NMR, etc.) to better map out the aquifer
- Multipiezometer well nest with piezometers screened in the bedrock, deep alluvium, and shallow alluvium

Extra Slides

How do Geoscientists use Tracers?



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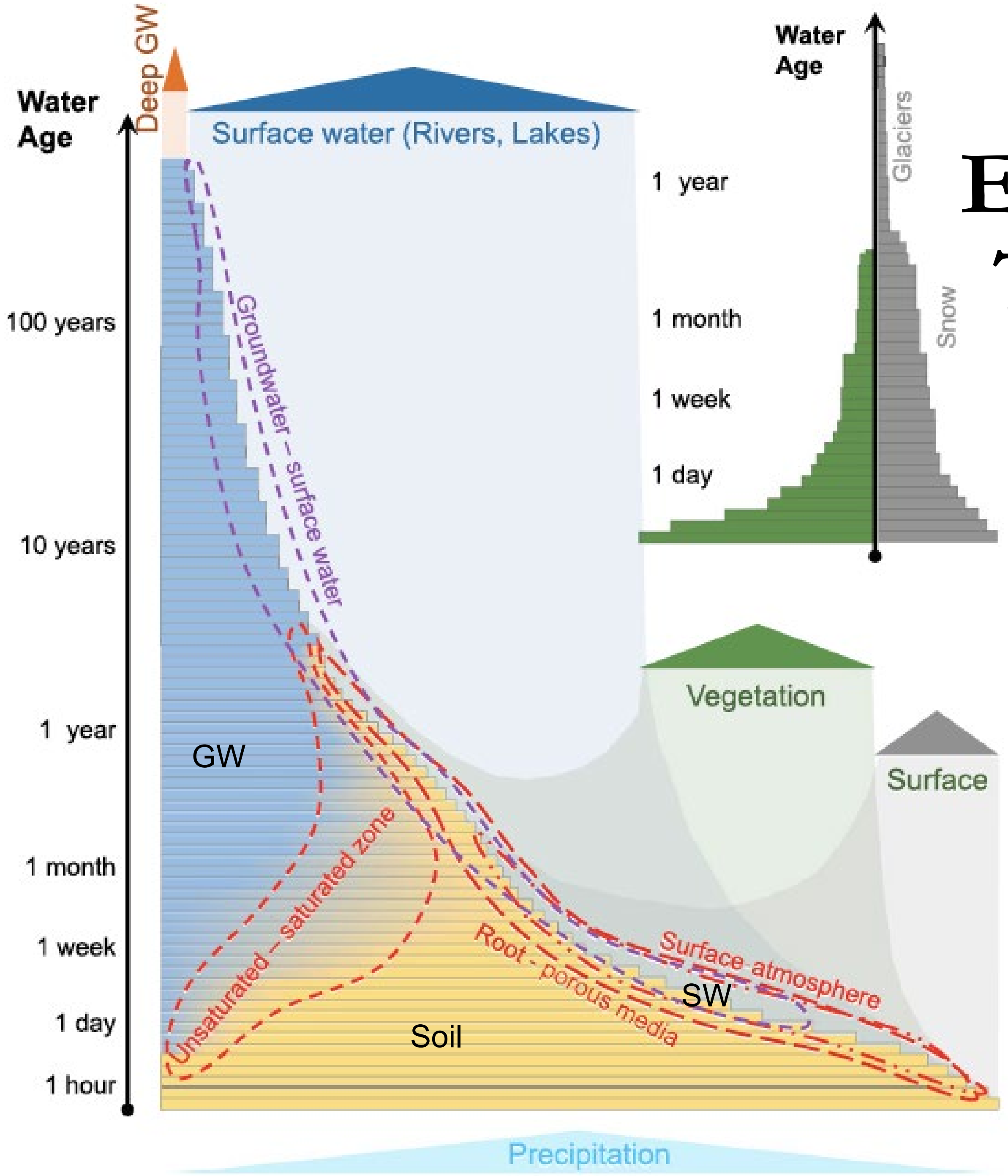
What do Environmental Tracers tell us about Water "Ages"?



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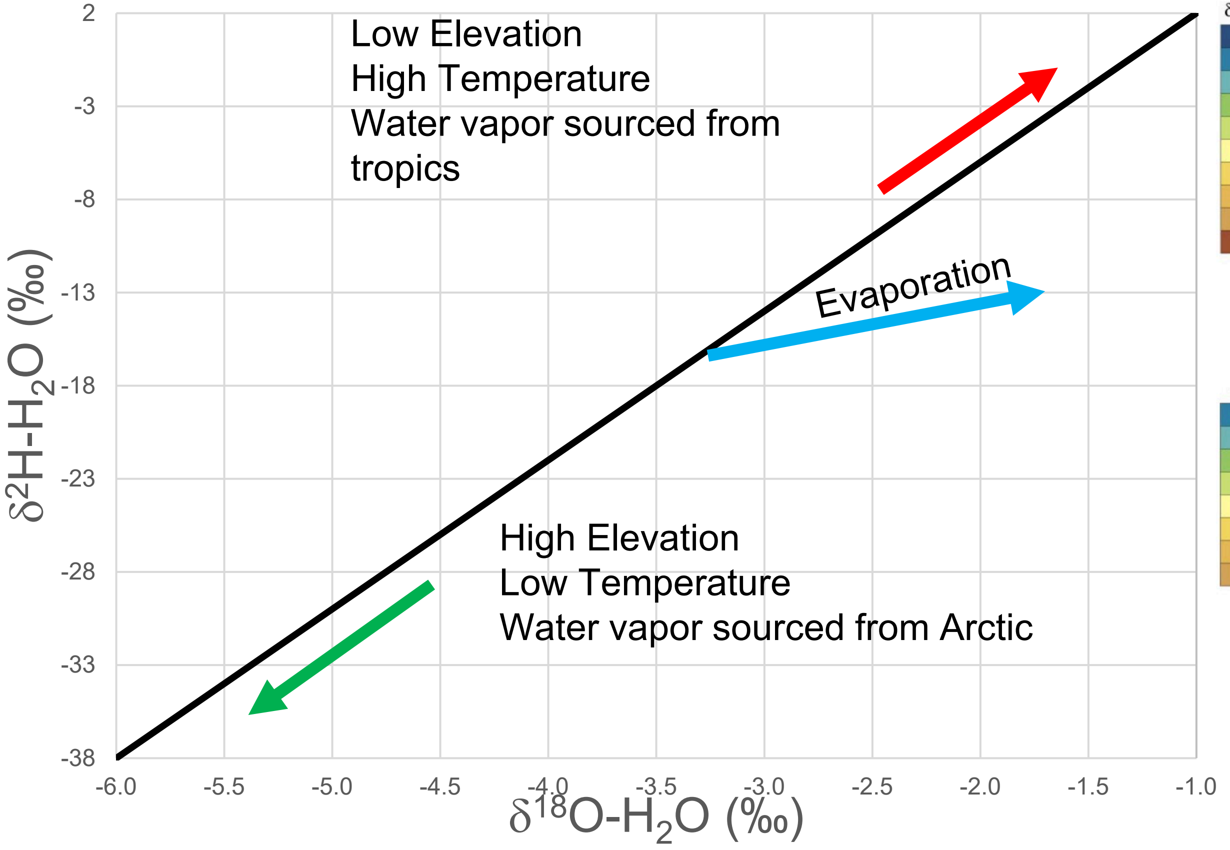
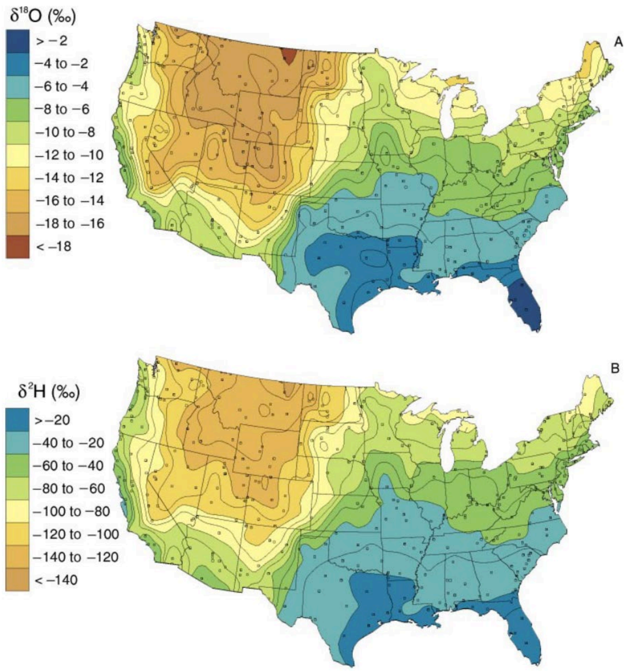
Stable Isotopic Composition of the Water Molecule

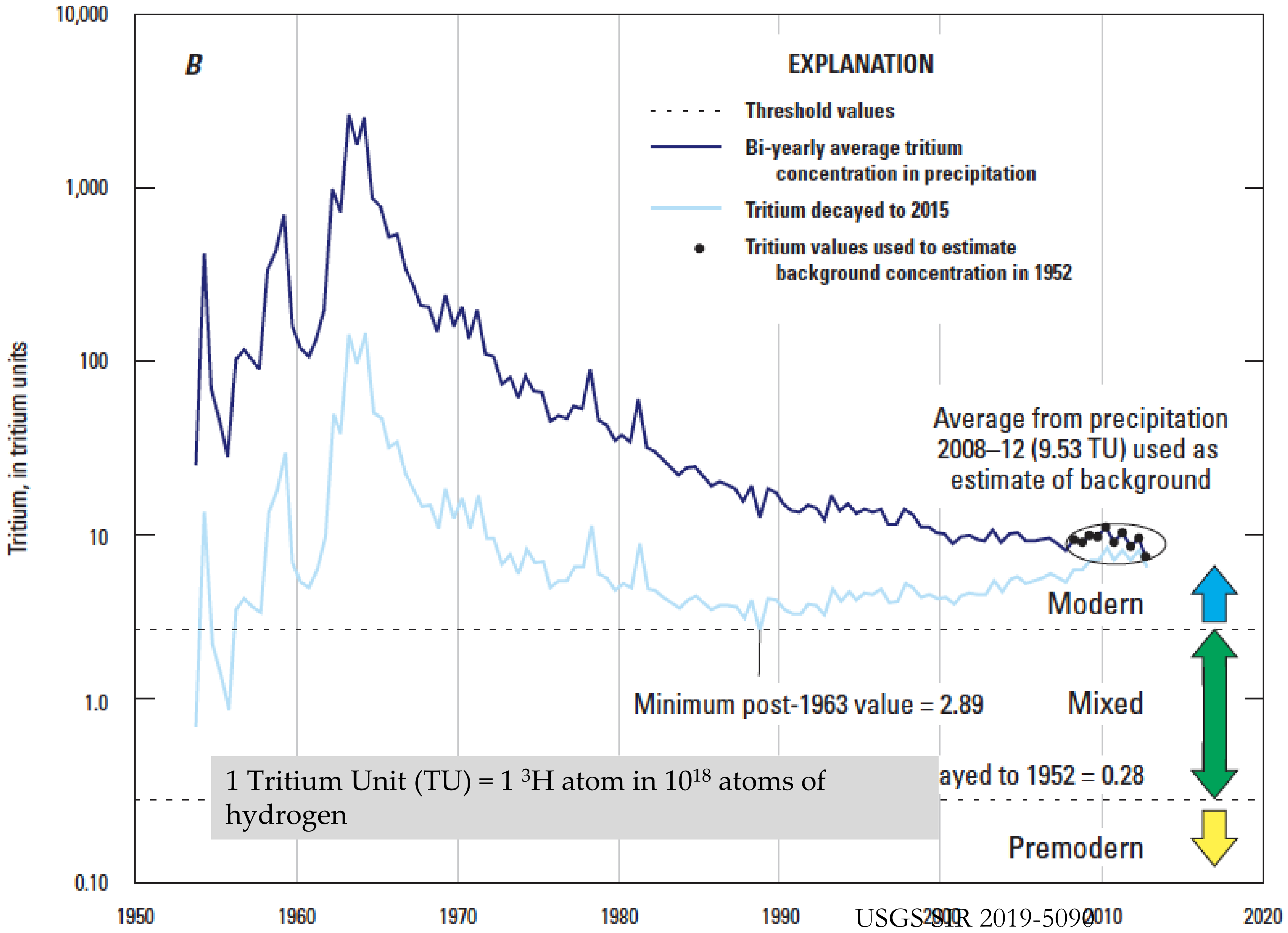




Kendall and Coplen, 2001

$$\delta^2 H = \frac{R_{sample}}{R_{standard}} \times 1000$$

^3H Tritium in Precipitation



1 Tritium Unit (TU) = 1 ^3H atom in 10^{18} atoms of hydrogen

USGS SIR 2019-5090

Oxygen and Hydrogen isotope fractionation in hydrosphere – *evaporation* and *latitude/elevation*

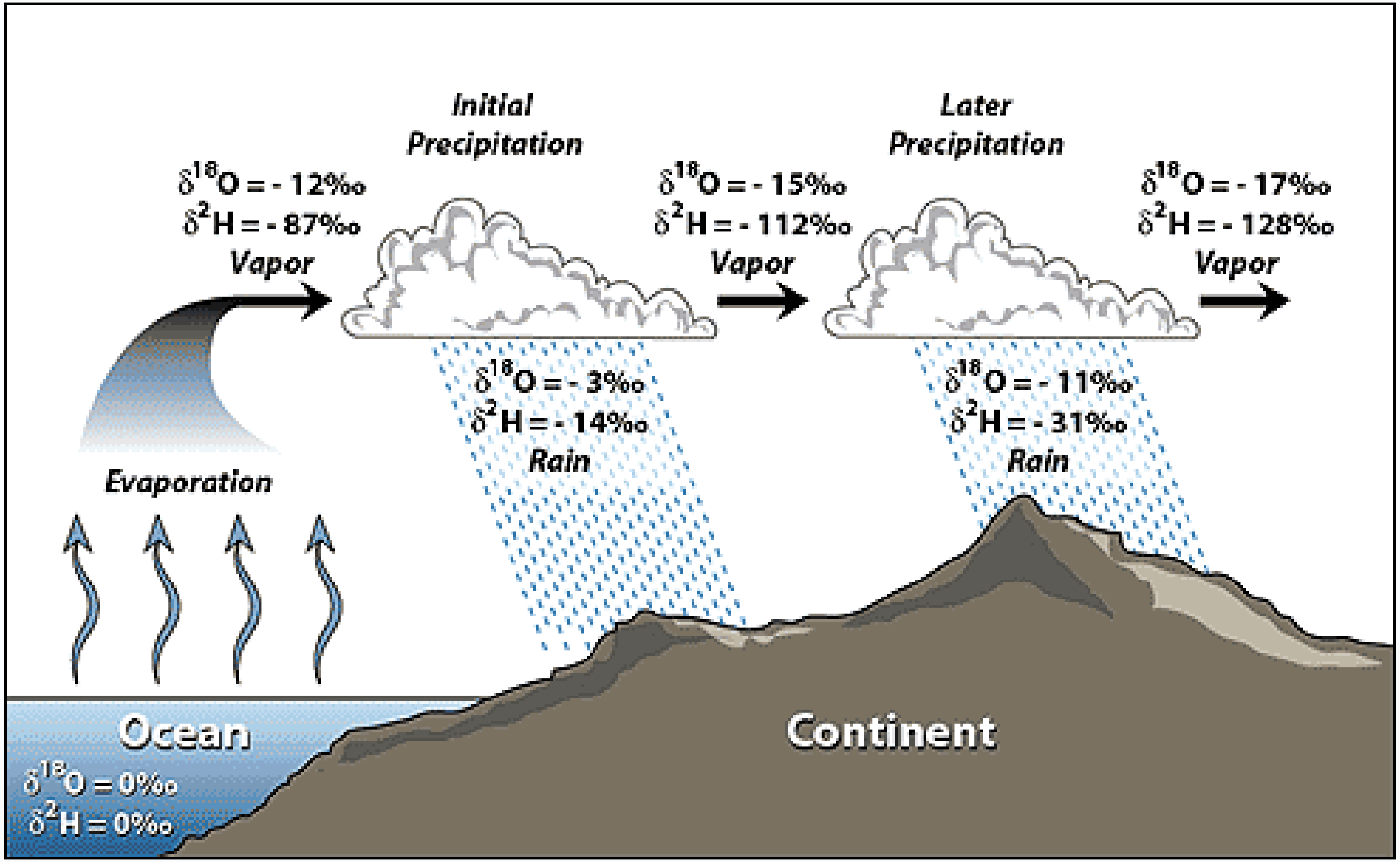
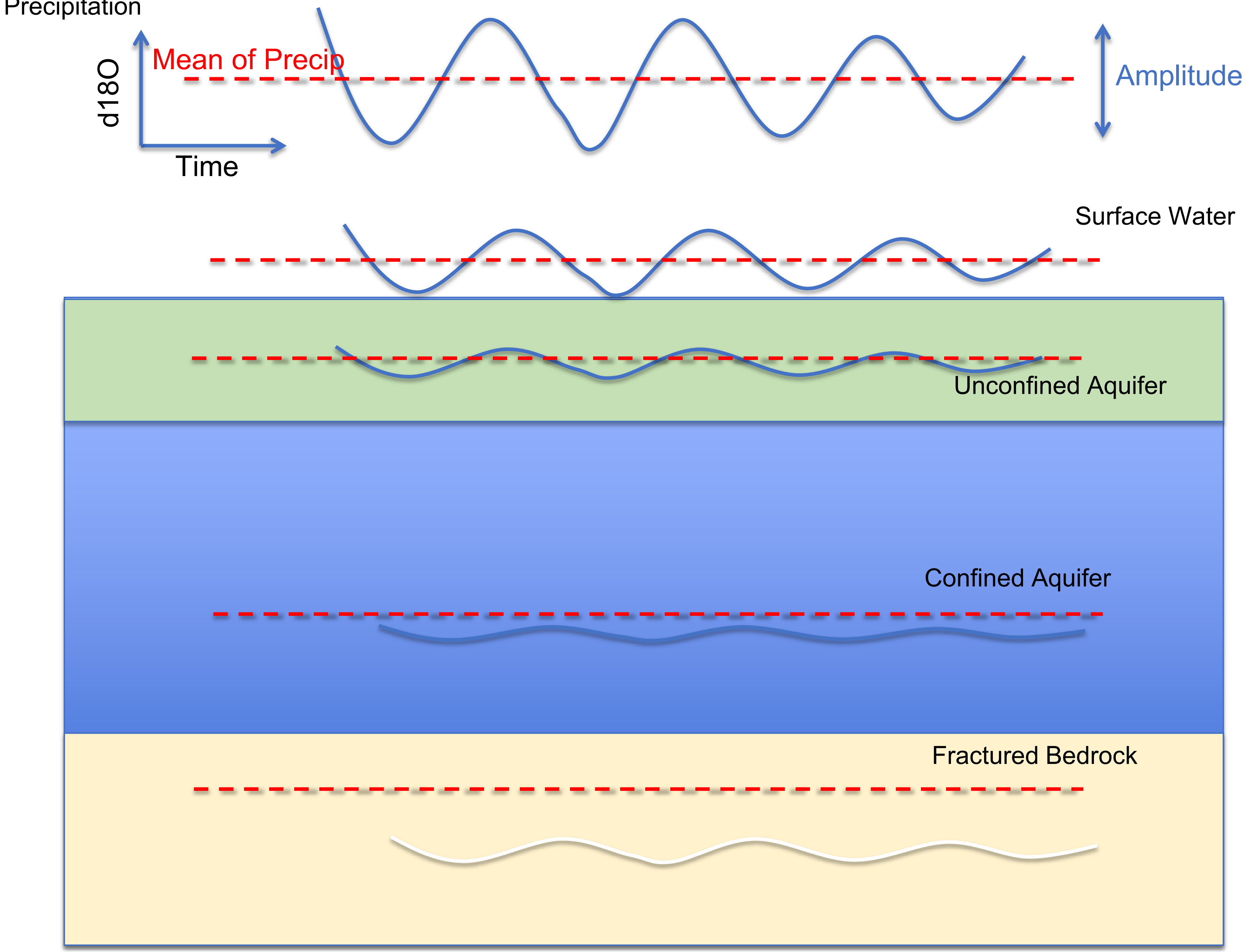


Figure 2. Rainout effect on d²H and d¹⁸O values (based on Hoefs 1997 and Coplen et al. 2000).


Precipitation
Mean of Precip
d18O
Time
Amplitude
Surface Water
Unconfined Aquifer
Confined Aquifer
Fractured Bedrock