HARNEY BASIN HYDROLOGY: A GEOCHEMICAL PERSPECTIVE

Harney Basin Groundwater Study Advisory Committee

October 17, 2019

U.S. Department of the Interior
U.S. Geological Survey

Geochemical Tracers

deuterium, tritium, carbon-14

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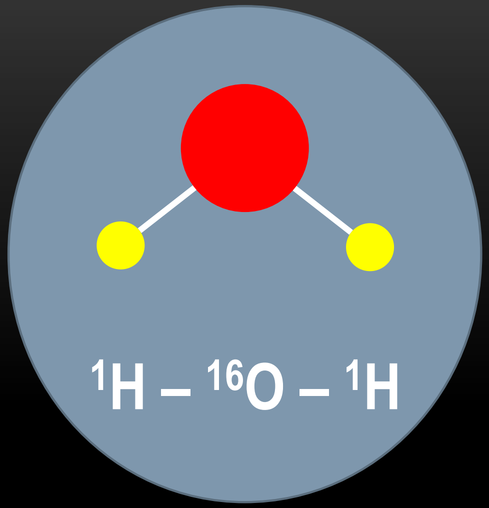
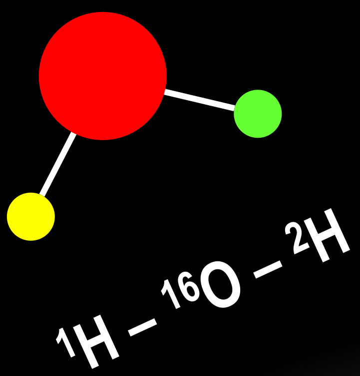
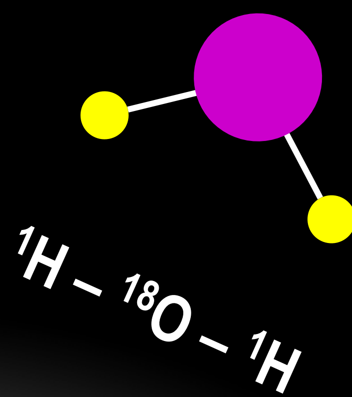
Deuterium (hydrogen-2) and oxygen-18

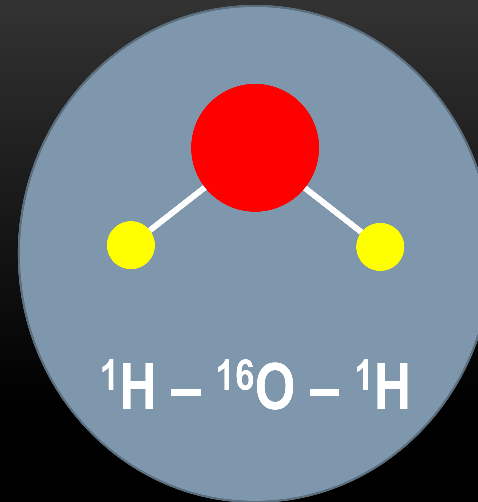


- “Stable isotopes” of water
- Inexpensive
- Robust
- Interpretation requires a large data set
- Flowpath delineation
- Relative age when calibrated with tritium and carbon-14

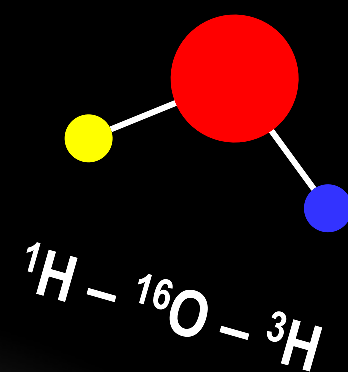




Tritium



- Radioactive isotope of hydrogen
- Half-life of 12.3 years
- Undetectable after about 70 years
- Sample cost is 7x more than stable isotopes
- Robust
- Easy to interpret
- Absolute indicator of young recharge (<70 years)
- Relative age of young water
- Good indicator of mixed waters



Carbon-14

https://commons.wikimedia.org/wiki/File:Woolly_Mammoth-RBC.jpg

- Radioactive isotope of carbon
- Half-life of 5,730 years
- Undetectable after about 40,000 years
- Sample cost is 11x more than stable isotopes (1.6X more than tritium)
- Samples can be contaminated by mixing with modern air
- Complicated interpretation (^{14}C dilution)
- Absolute indicator of old recharge (>500 years)
- Good indicator of mixed waters

Constraining the geochemistry of modern recharge

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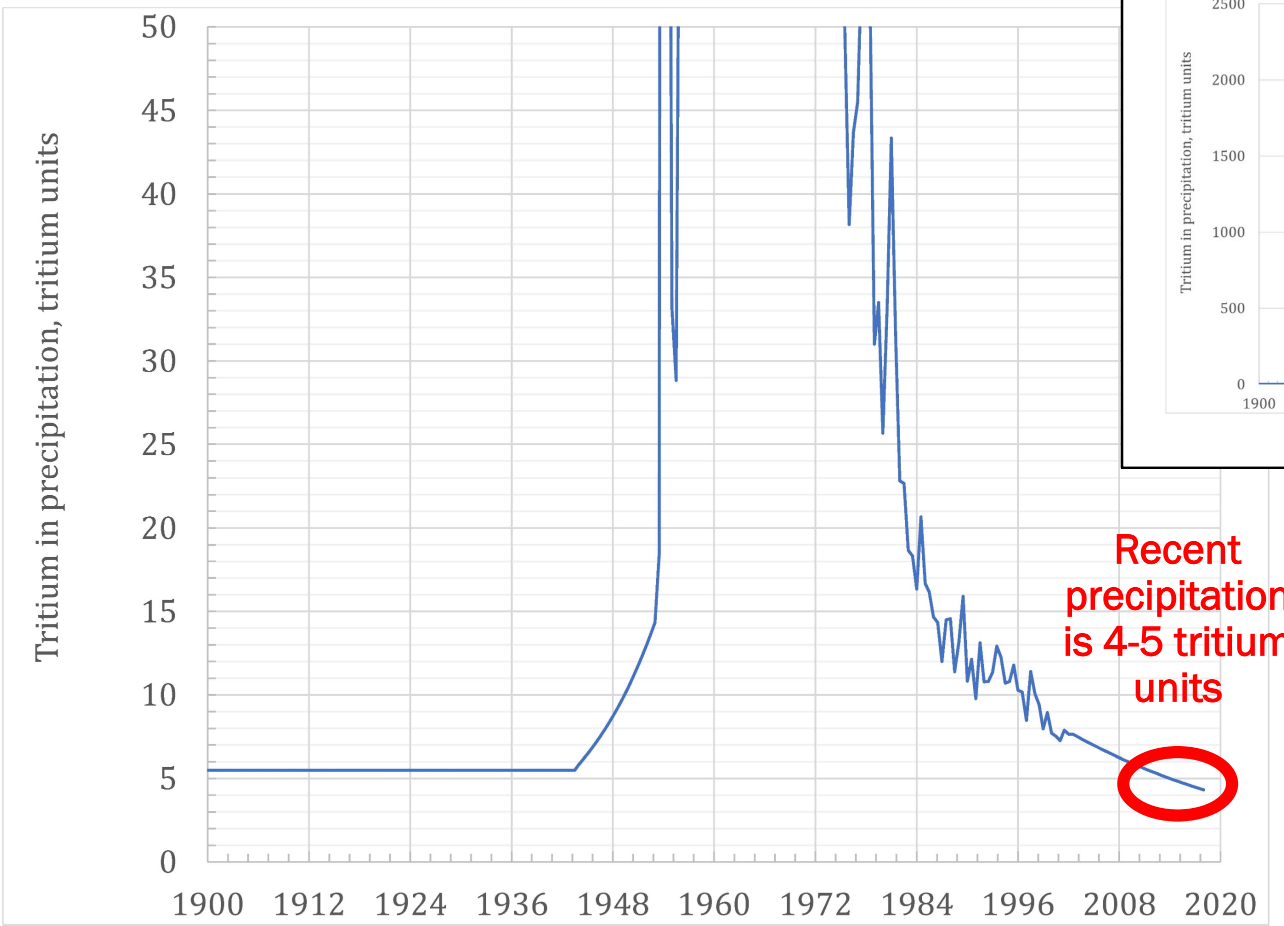
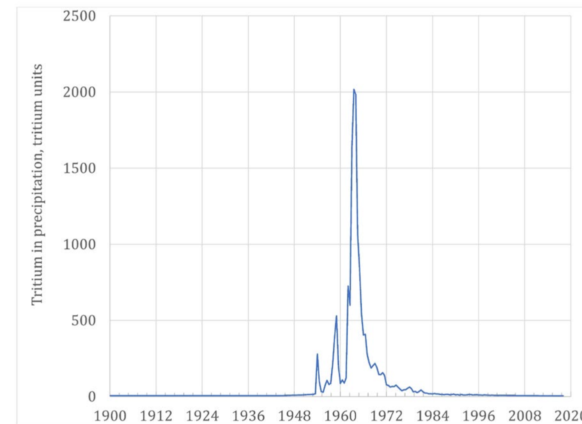
Characterizing “modern” recharge allows us to distinguish modern water from “old” water in the basin

- Where do we find “modern” groundwater?
- What is the distribution of “old” groundwater?
- How do these distributions relate to our understanding of recharge from the physical hydrology and water budget?
- What is the connectivity among waters in Harney basin?

Tritium in Modern Precipitation -- From Published Literature



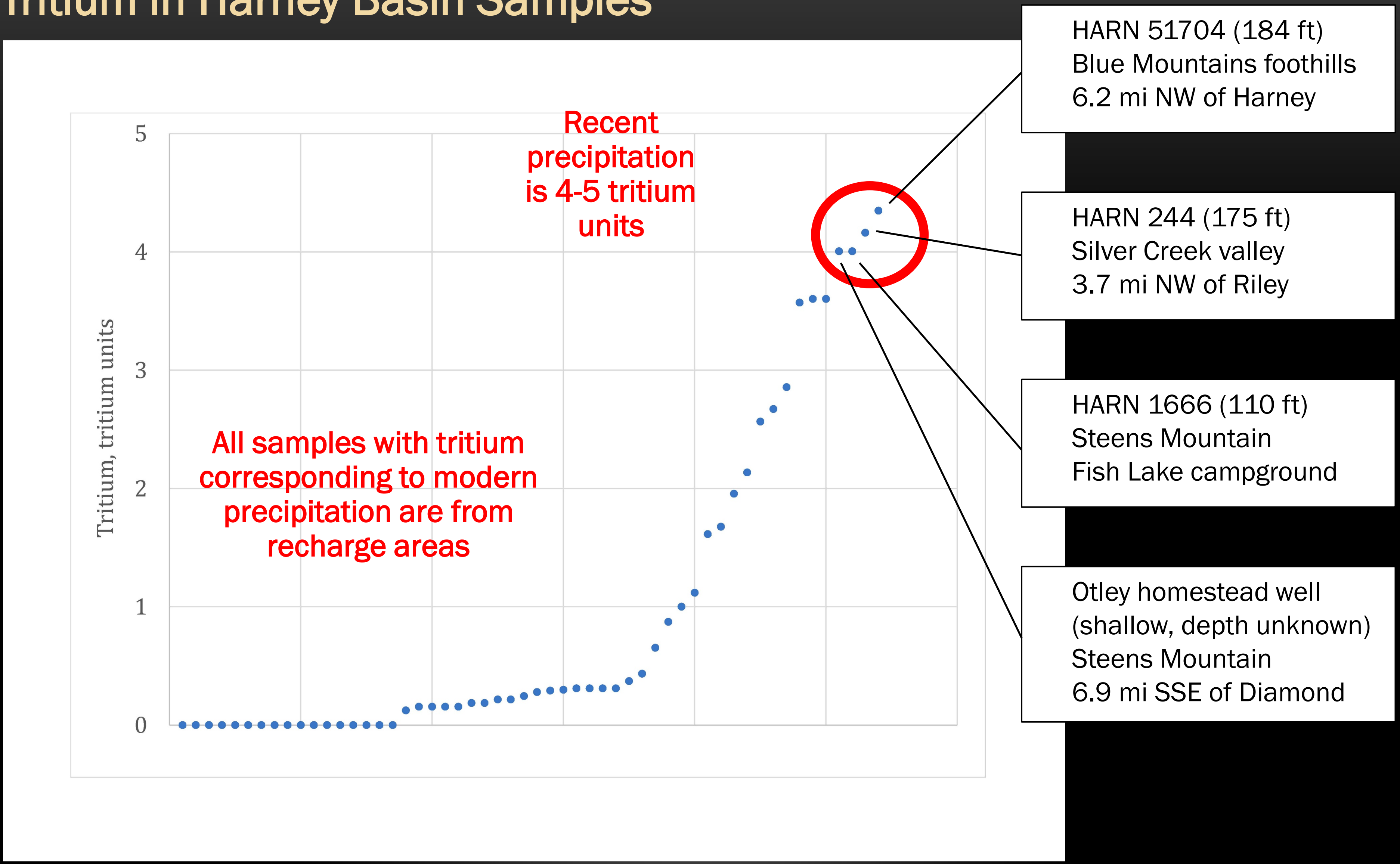


Data from:

Jurgens et al., 2012

Michel et al., 2018

Tritium in Harney Basin Samples



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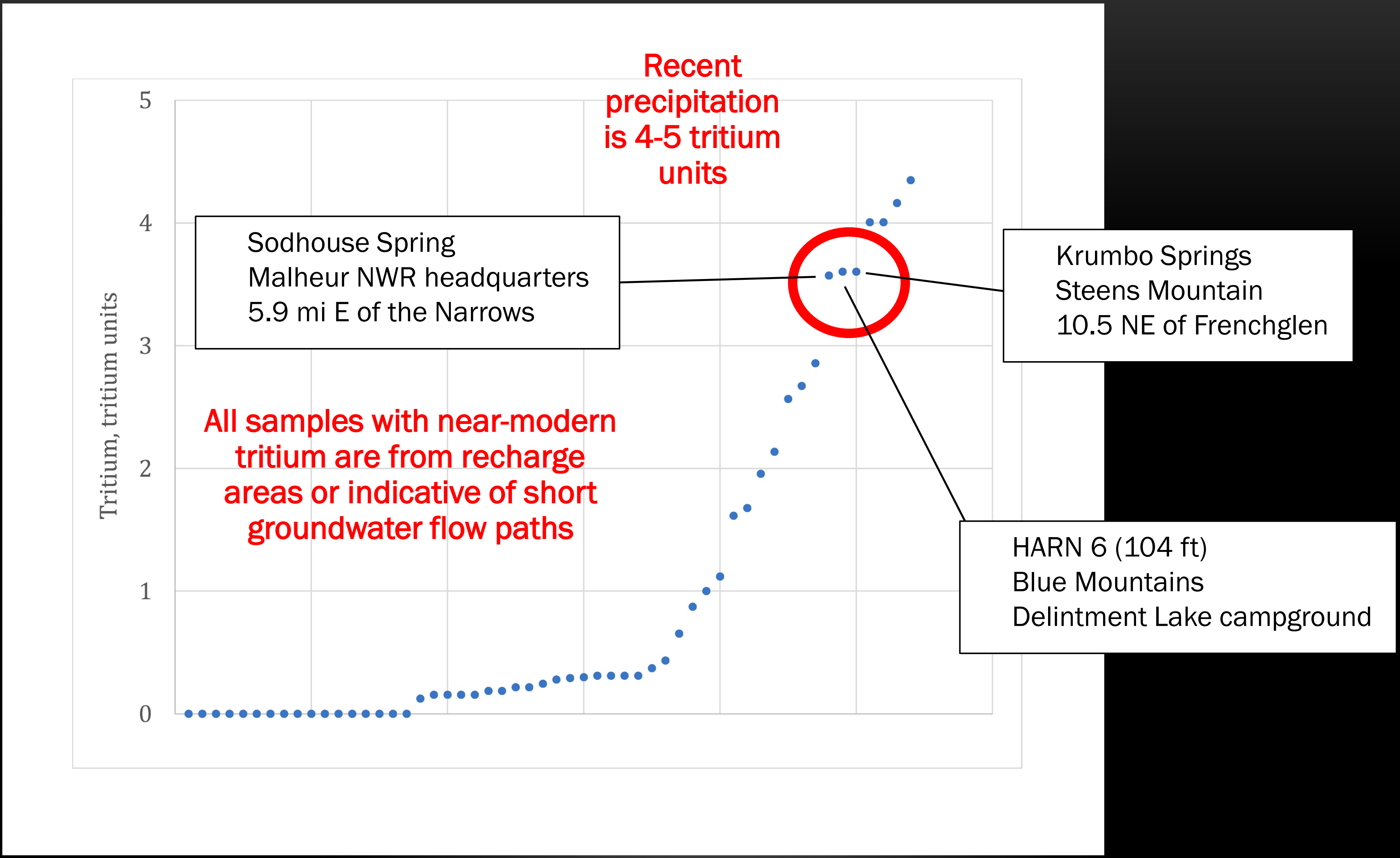
Modern Recharge - Tritium

Tritium in Harney Basin Samples



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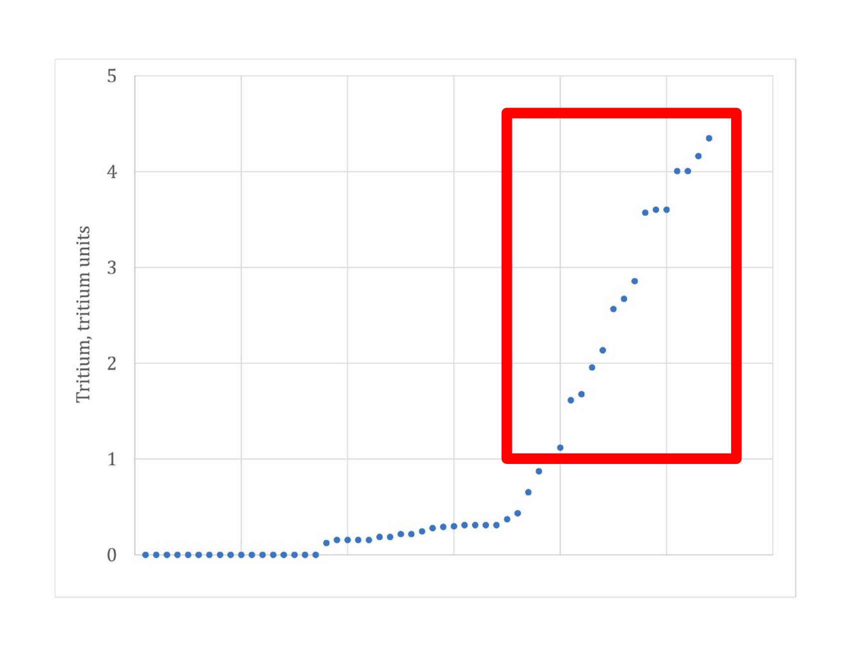
Modern Recharge - Tritium



Samples containing more than 1 TU of tritium are in the uplands, along the margin of the basin, or adjacent to reservoirs

No tritium concentrations greater than 1 TU from wells deeper than 200 ft in the basin

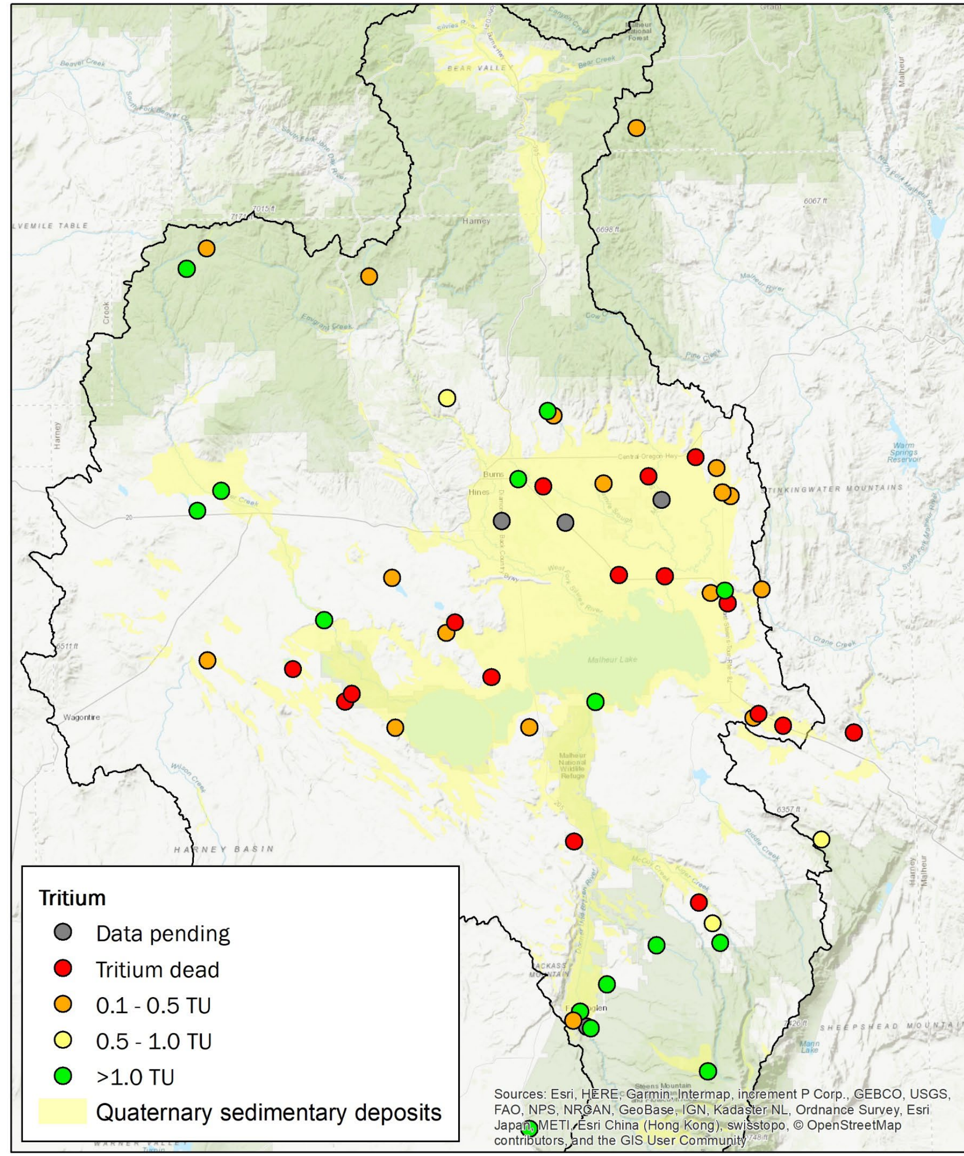


Figure X. Tritium in well and springs samples, Harney Basin, Oregon.

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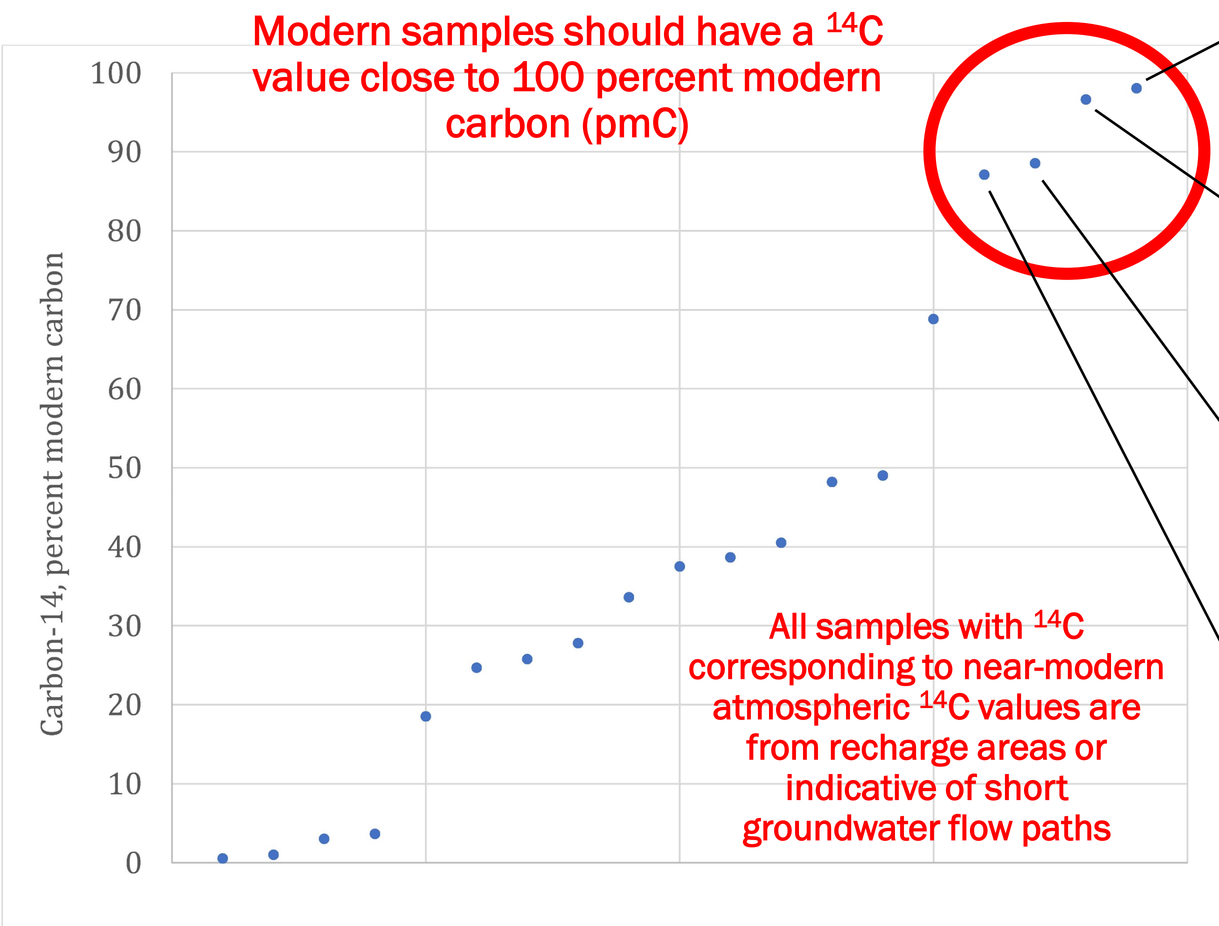
Modern Recharge - Tritium

Carbon-14 (^{14}C) in Harney Basin Samples



HARN 52274 (95 ft)
Basin fill near Stinkingwater Mountains
9.6 mi N of Crane
^{3}H = 0.4 TU

Page Springs
Steens Mountain
3.0 mi SE of Frenchglen
^{3}H = 2.6 TU

Spring 432513118310101
Stinkingwater Mountains
3.1 mi E of Crane
^{3}H = 0.3 TU

HARN 1655 (325 ft)
Steens Mountain
2.5 mi SE of Frenchglen
^{3}H = TBD

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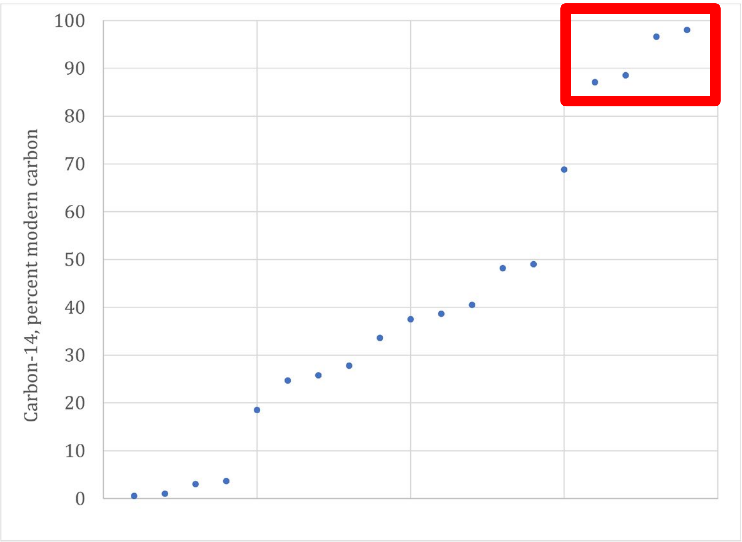
Modern Recharge – ^{14}C



Samples containing more than 80 pmC ^{14}C are:

- in the uplands and valley margins
- less than 200 ft deep

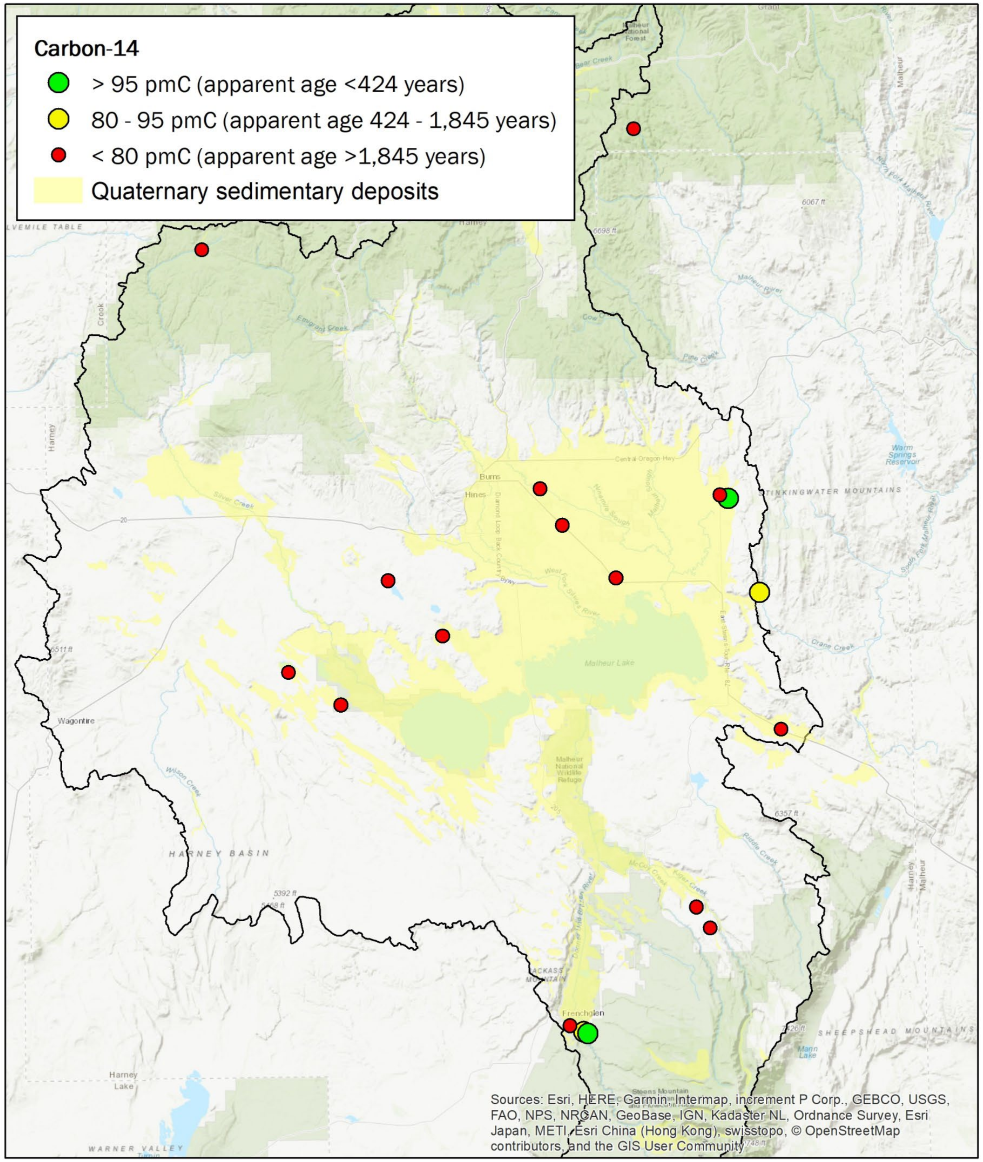


Figure X. Carbon-14 activity in well and springs samples, Harney Basin, Oregon.

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Modern Recharge – ^{14}C

Deuterium ratios (δ^2H) in precipitation, 1991-1997

Volumetrically weighted mean δ^2H, in permil (‰)

Burns	-115 ‰
McDermitt	-119 ‰

Data from Friedman, 2001

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The Precipitation-Recharge Isotope Puzzle

- Isotopic composition of precipitation varies within and between storms
- Isotopic composition of precipitation varies somewhat from year-to-year
- Isotopic composition of precipitation changes prior to recharge due to evaporation (rain and snow) and sublimation (snow)

How do we define isotopically modern groundwater?

The Precipitation-Recharge Isotope Puzzle: Path to a Solution

- Infiltrating precipitation takes months to decades to reach the water table
- Recharge reaching the water table reflects the long-term average isotopic composition of precipitation of the local area

✓ Shallow groundwater in recharge areas provides a good estimate of modern isotopic ratios

✗ Unfortunately, people don't often drill to the water table and stop

✗ Wells tend to be sparse in upland recharge areas

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Modern Recharge – δ^2H

The Precipitation-Recharge Isotope Puzzle: The Solution!

- Water in streams during baseflow conditions (late summer) is groundwater discharge (not necessarily true in irrigated areas)
- In recharge areas, water in streams during baseflow conditions is usually shallow groundwater discharge

Isotope samples from streams in recharge areas during baseflow conditions commonly reflect the long-term average isotopic composition of modern recharge

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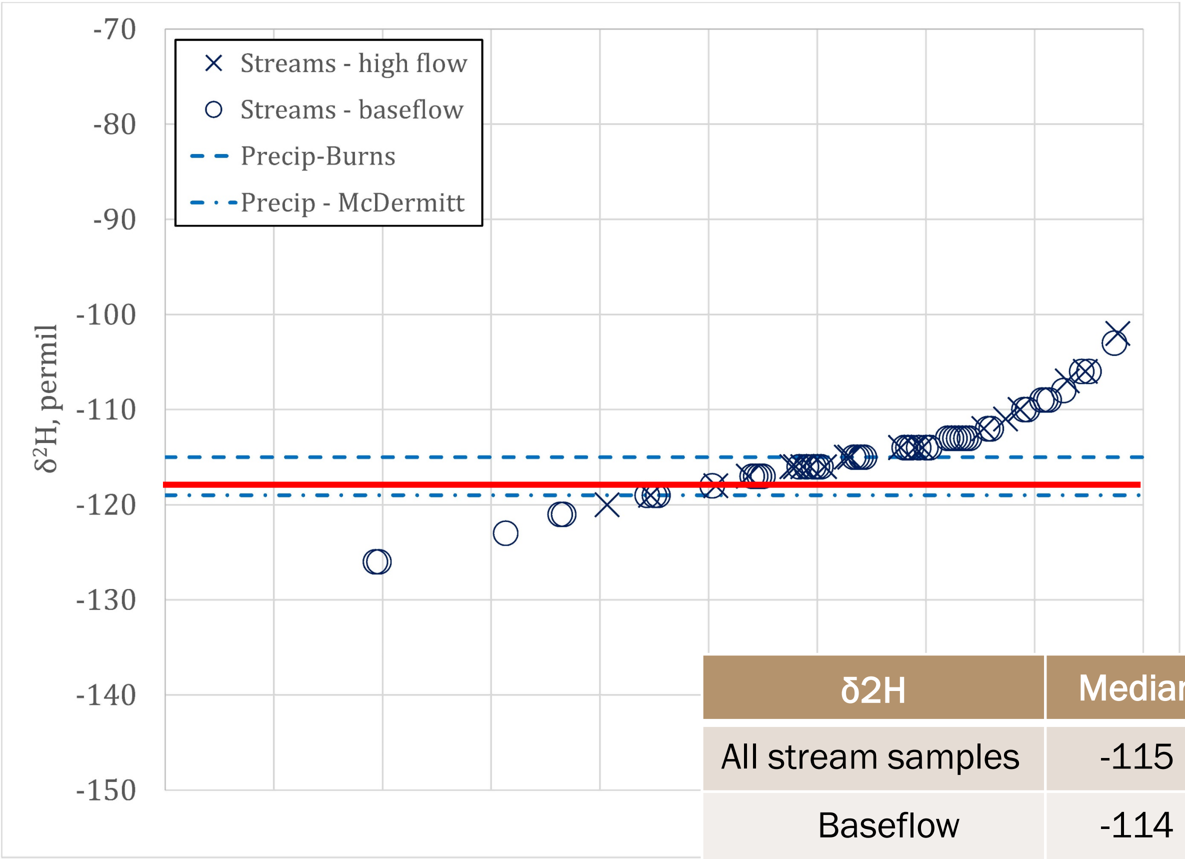
Deuterium in Harney Basin Stream Samples



δ2H	Median
All stream samples	-115
Baseflow	-114
High flow	-115

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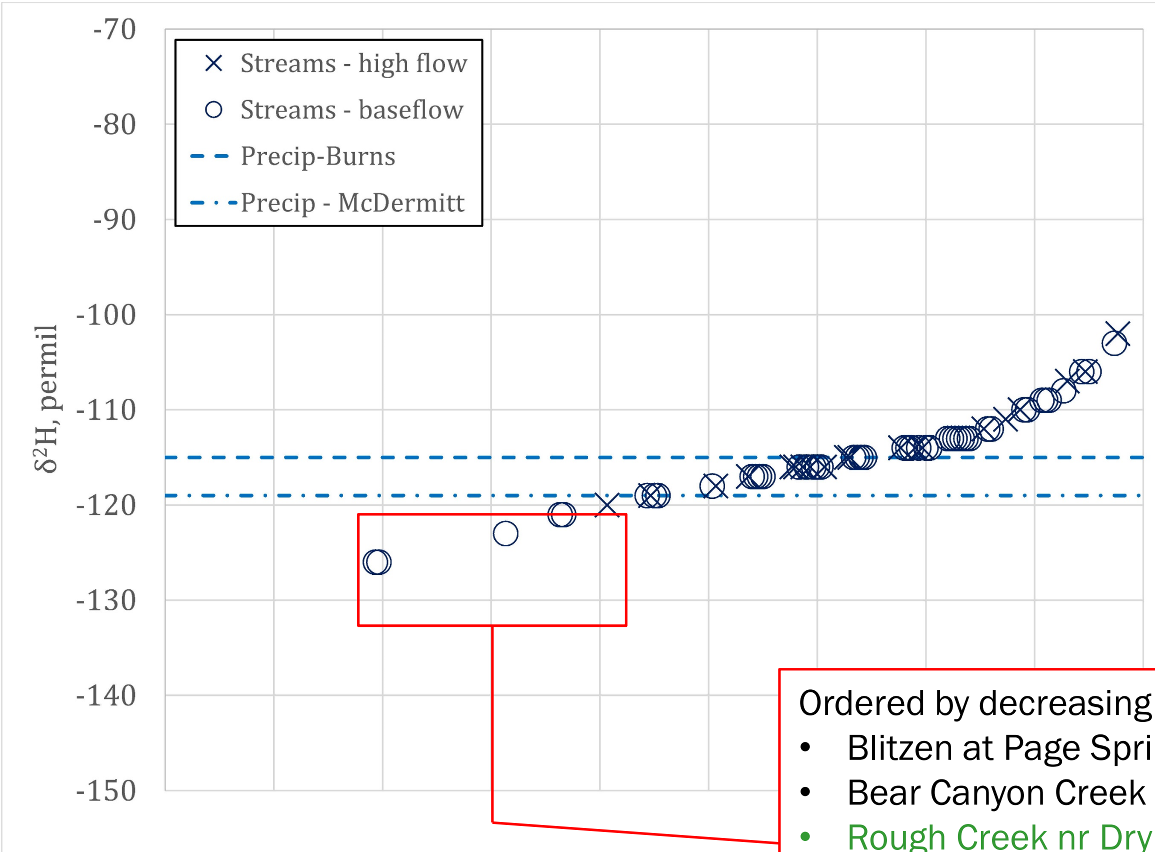
Modern Recharge – δ^2H

Deuterium in Harney Basin Stream Samples

- 4 of 6 samples are from spring-fed streams (green text)
- 1 sample is from Blitzen River during snowmelt runoff
- No first-hand knowledge of Bear Canyon Creek watershed hydrology, but many mapped springs in basin



Ordered by decreasing δ^2H:
- Blitzen at Page Springs (runoff)
- Bear Canyon Creek (trib to Emigrant Ck)
- Rough Creek nr Dry Mountain (trib to Silver Ck)
- Thousand Springs Creek nr Burns
- Curry Gordon Creek nr Burns
- Wolf Creek nr Van

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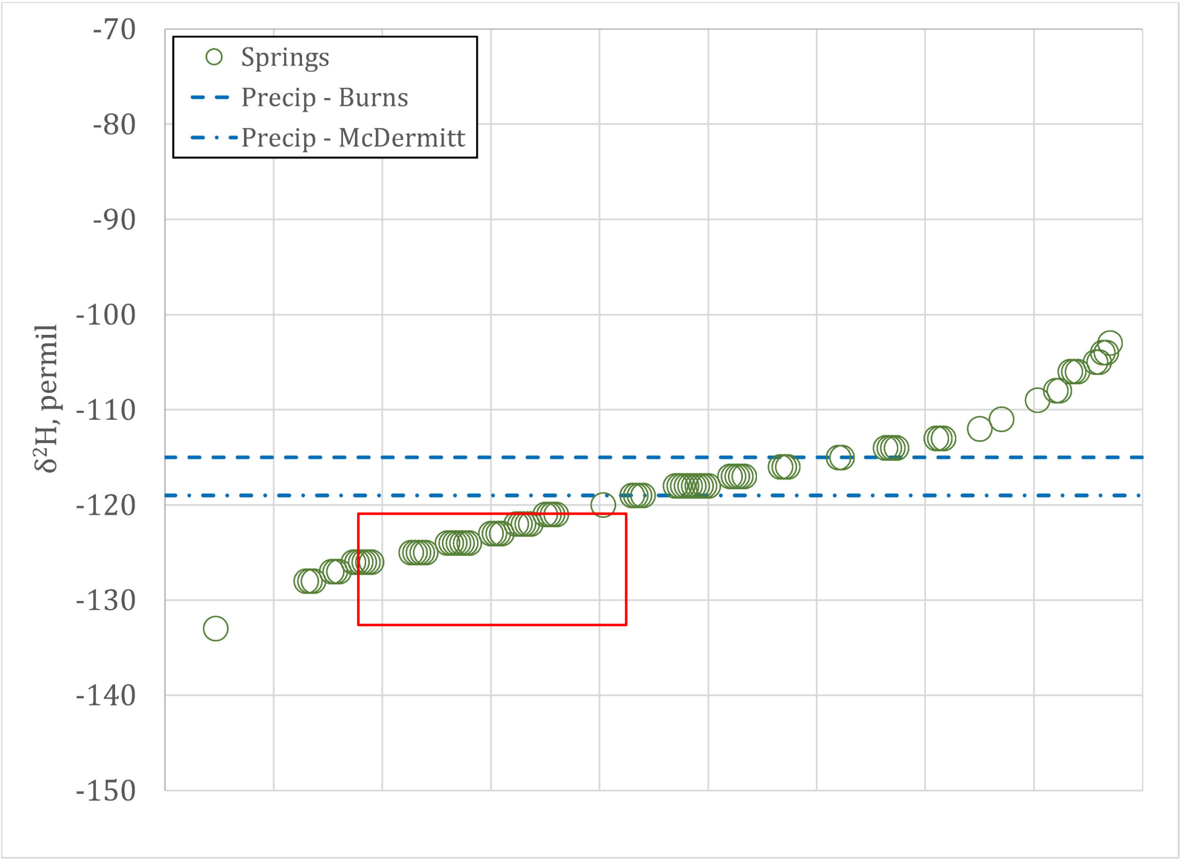
Modern Recharge – δ^2H

Deuterium in Harney Basin Spring Samples



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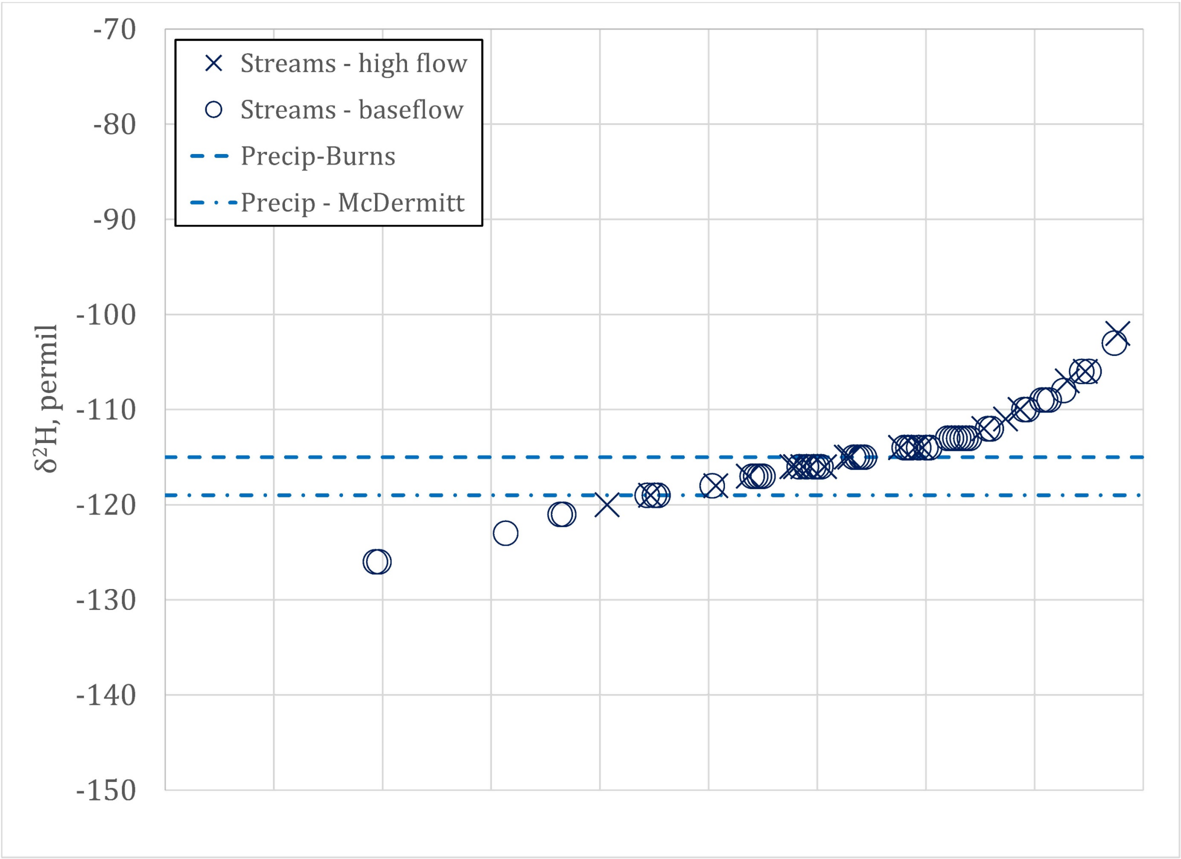
Modern Recharge – δ^2H

Deuterium in Harney Basin Stream Samples



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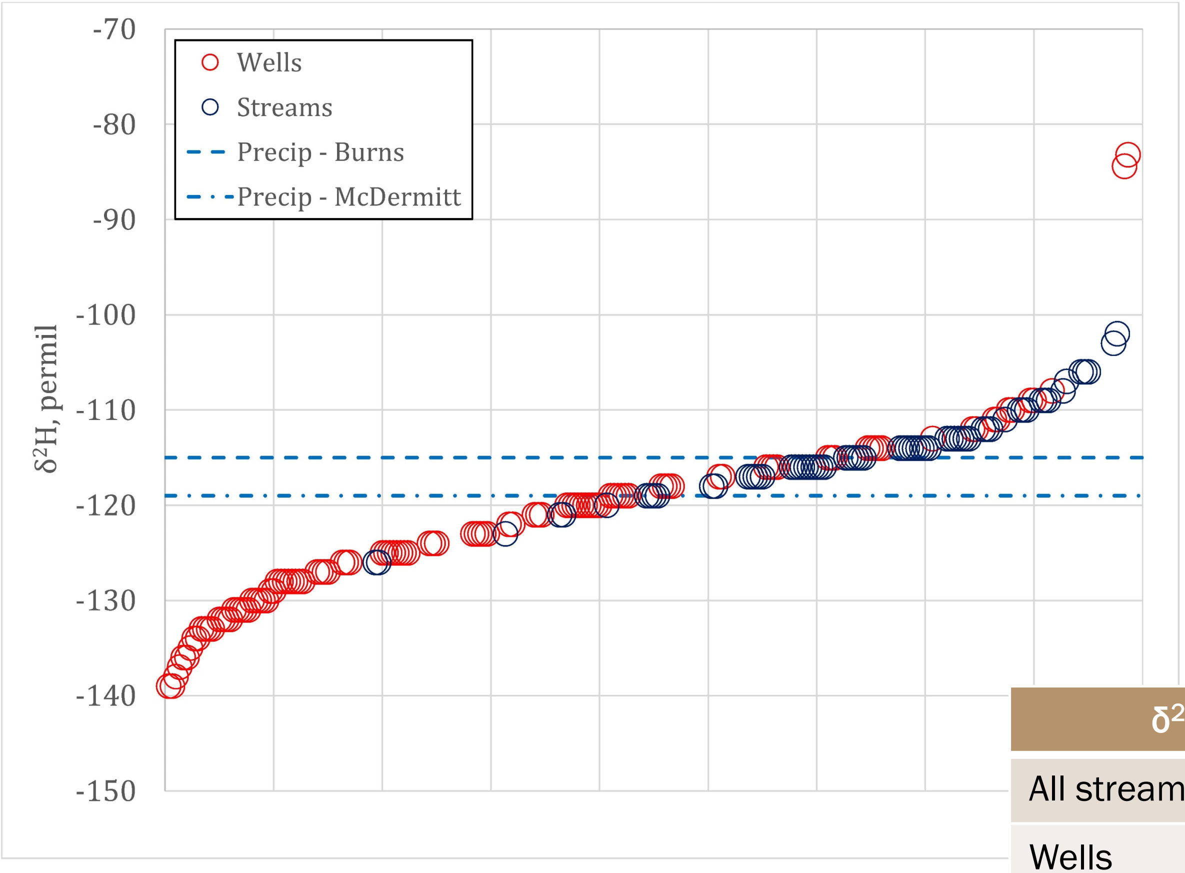
Modern Recharge – δ^2H

Deuterium in Harney Basin Stream and Well Samples



δ^2H	Median
All stream samples	-115
Wells	-123

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Modern Recharge – δ^2H

Geochemical Characteristics of Modern Water

- Tritium between 4 and 5 TU
- Carbon-14 greater than 98 pmC
- Deuterium greater than -120 ‰

Modern or near-modern groundwater and spring samples based on multiple tracers

Site	Tritium	Carbon-14	Deuterium
HARN 51704	4.3	*not analyzed*	-119
HARN 244	4.2	*not analyzed*	-118
HARN 1666	4.0	*not analyzed*	-115
Otley homestead well	4.0	*not analyzed*	-113
HARN 52274	0.4	98	-123
Page Springs	2.6	97	-118

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Relationship between deuterium (δ^2H) tritium carbon-14

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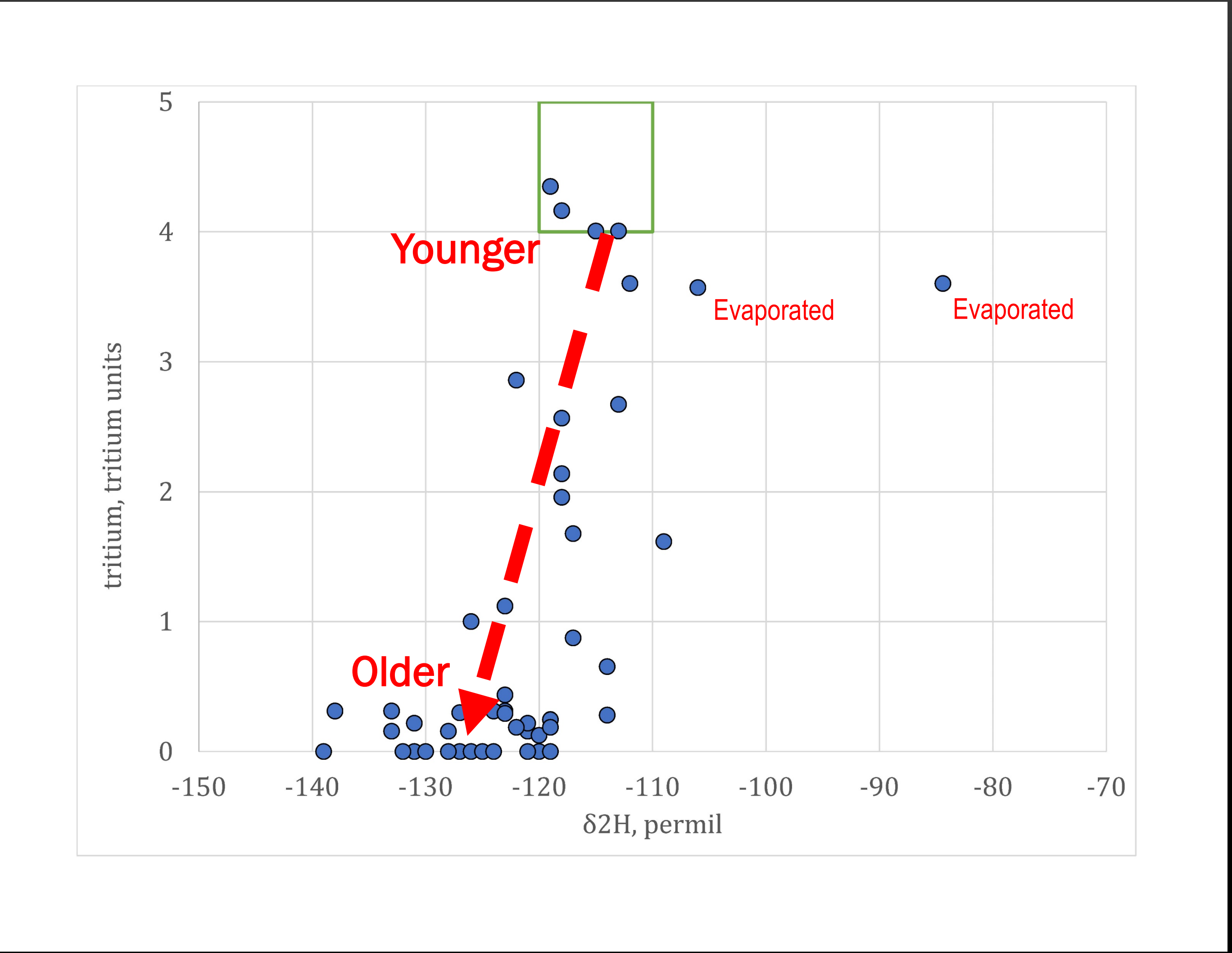
Relation between δ²H and tritium



Key Points

No δ²H values less than -119 among samples having modern tritium

No δ²H values greater than -119 among tritium-dead samples

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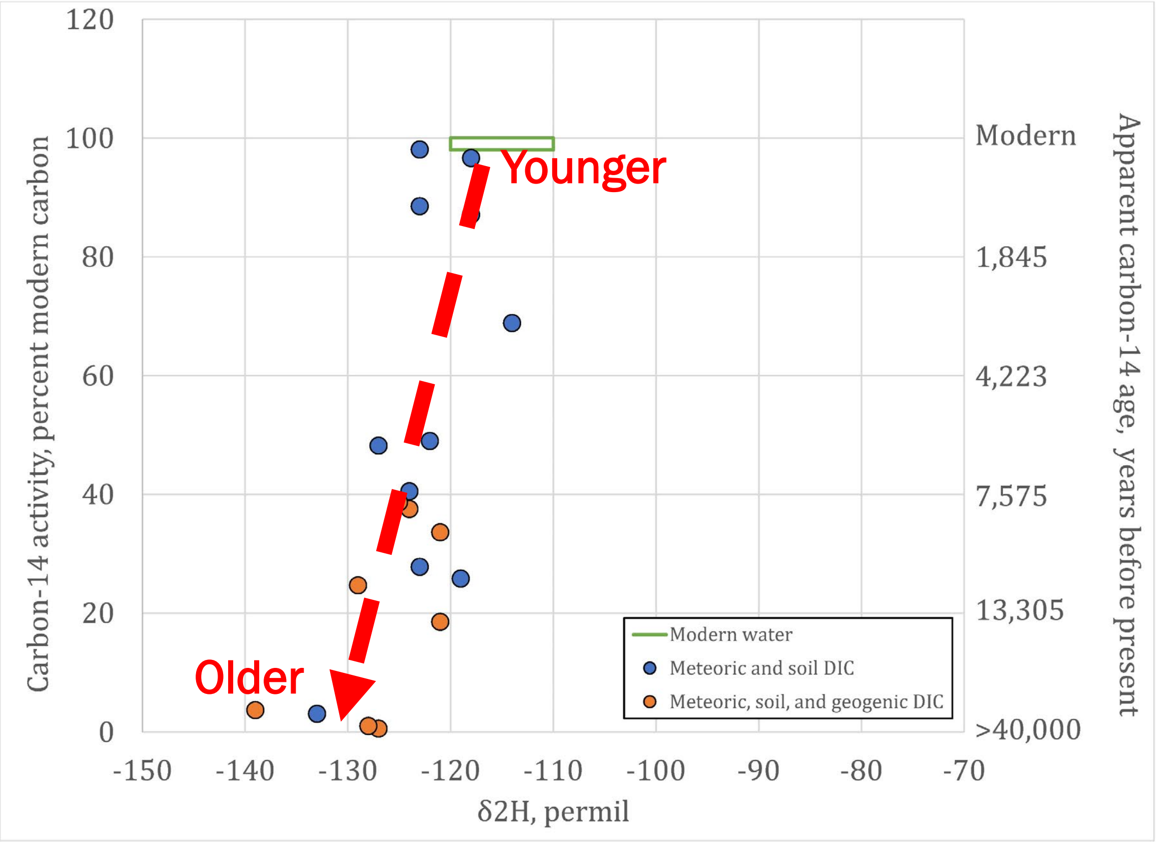
Age Tracer Relationships

Relation between δ²H and ¹⁴C

Key Point

^{14}C activity decreases as δ^2H becomes more negative



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Age Tracer Relationships

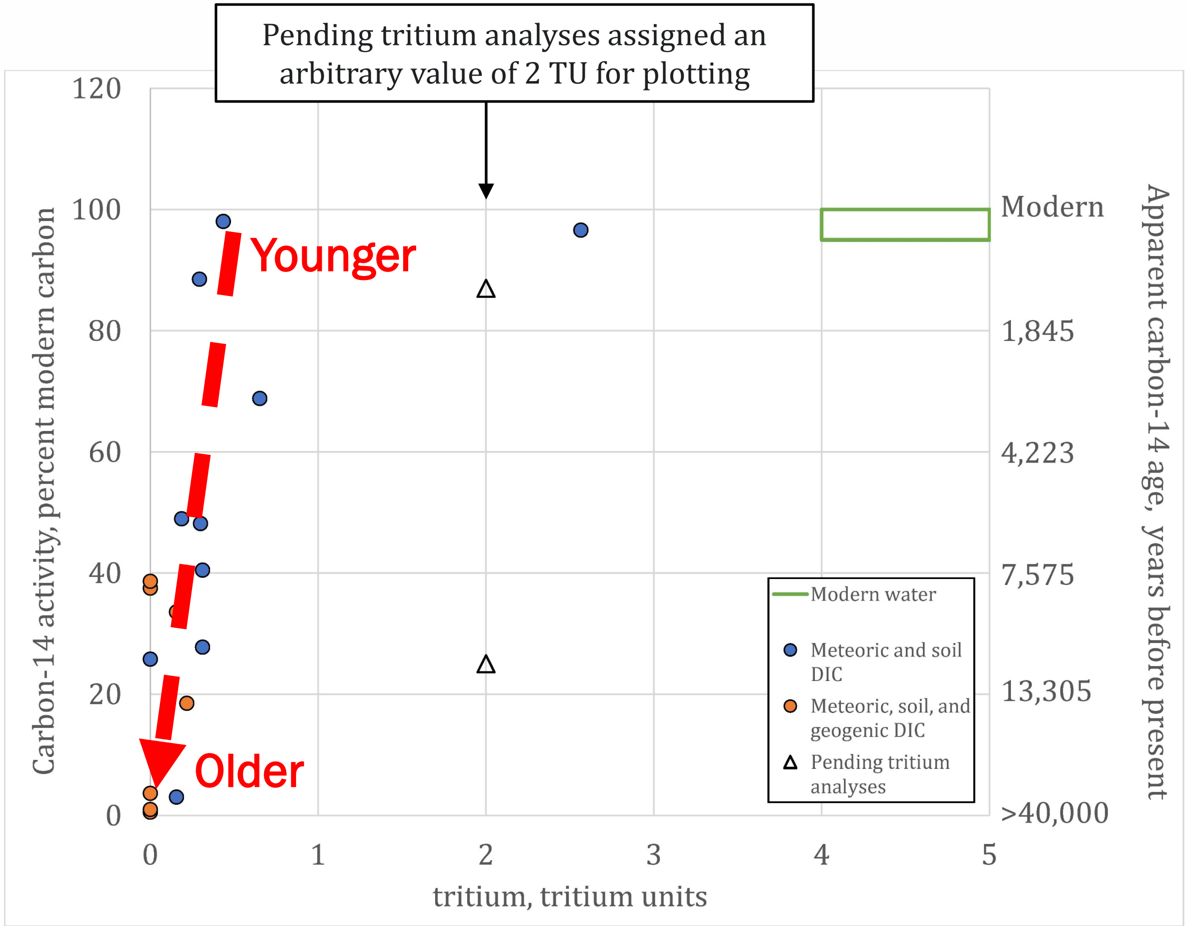
Relation between tritium and ^{14}C

Key Points

Tritium decreases as ^{14}C activity decreases

Most of the water in samples containing tritium <1TU is more than 2,000 years old

These waters contain a small fraction of water less than 70 years old



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Age Tracer Relationships

Relationship between deuterium (δ^2H), tritium, and carbon-14

Summary

- The mean age of the water sample increases as the deuterium ratio (δ^2H) becomes more negative, as the tritium concentration decreases, and as carbon-14 activity decreases
- There is evidence for "old" groundwater in most of Harney basin
- "Old" groundwater is 1,000's to more than 10,000 years old
- Discordant ages from different tracers are indicative of mixed-age water

Age-Depth Relationships in Harney Basin Groundwater

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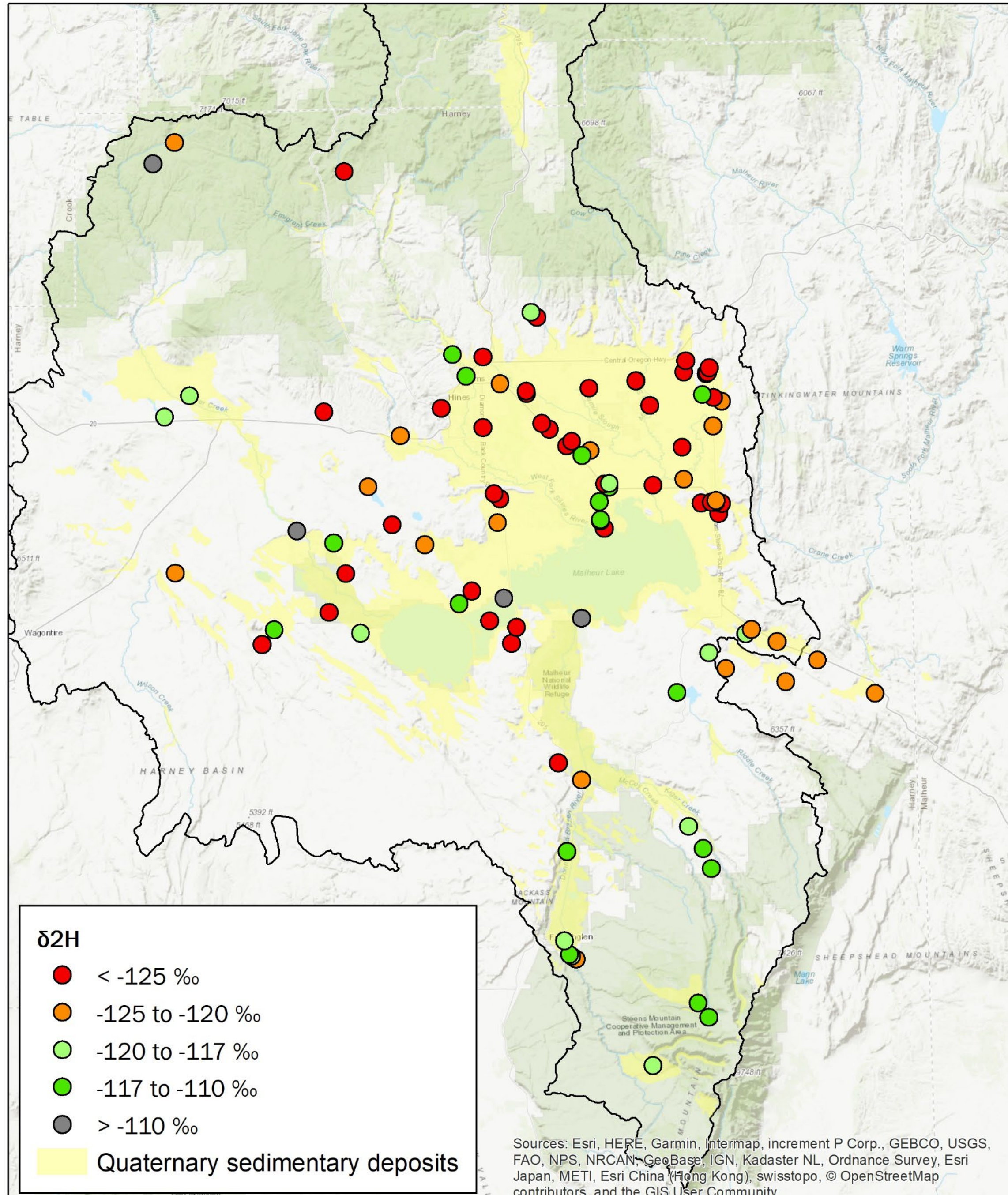
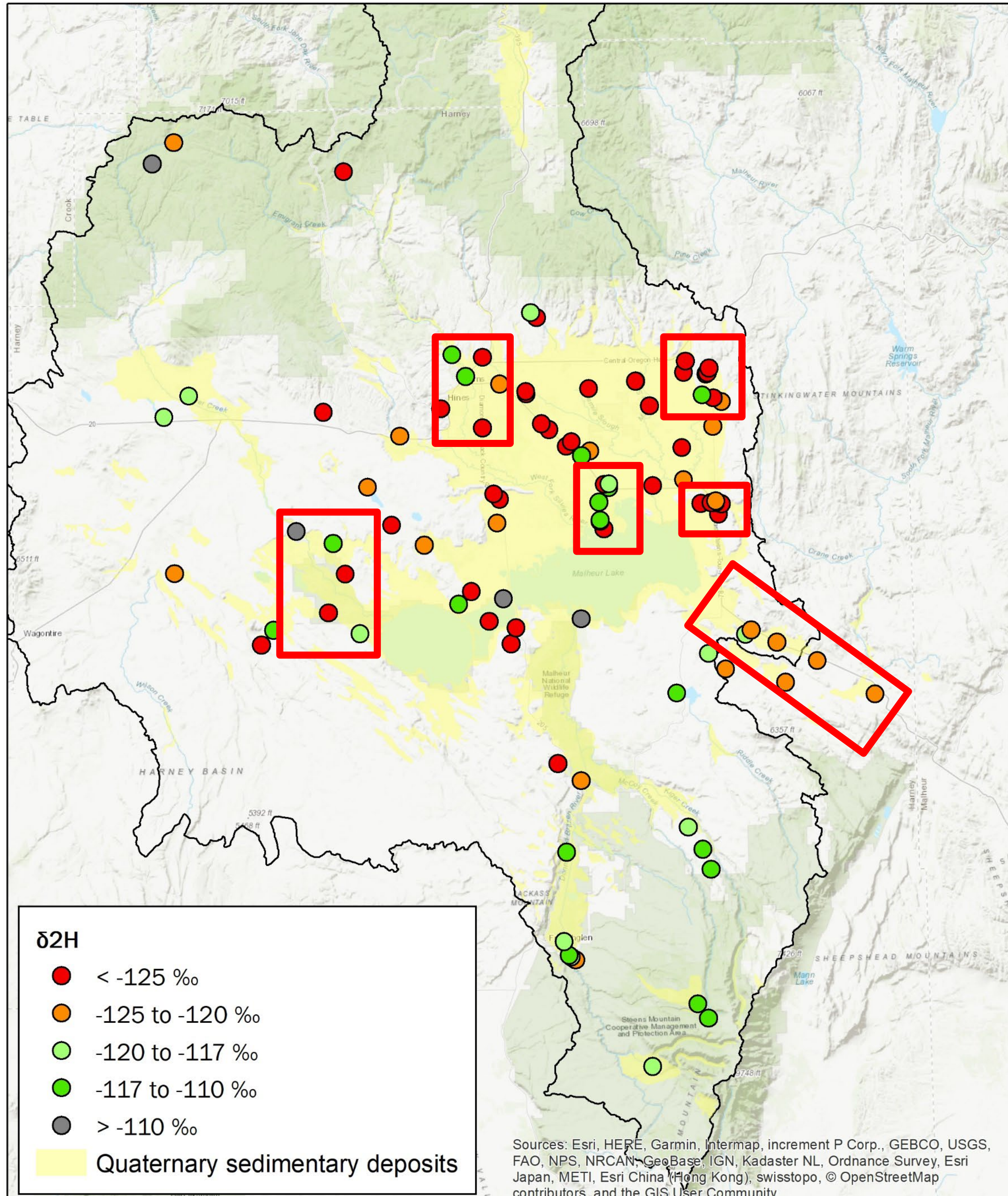


Figure X. δ2H ratio in well samples, Harney Basin, Oregon.



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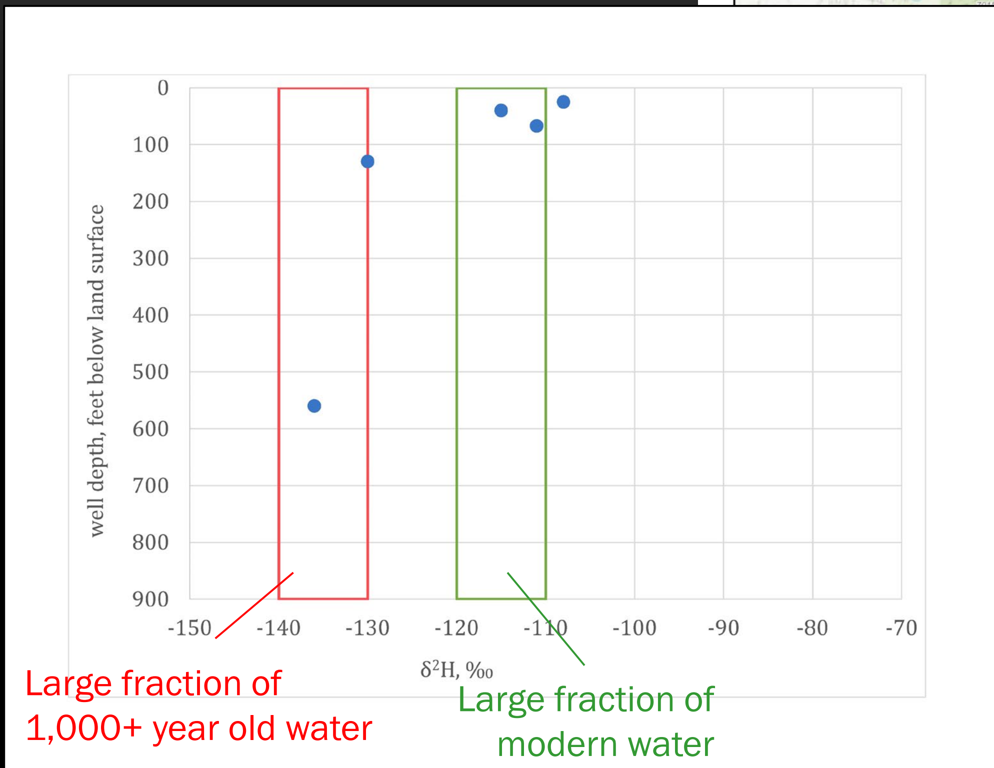
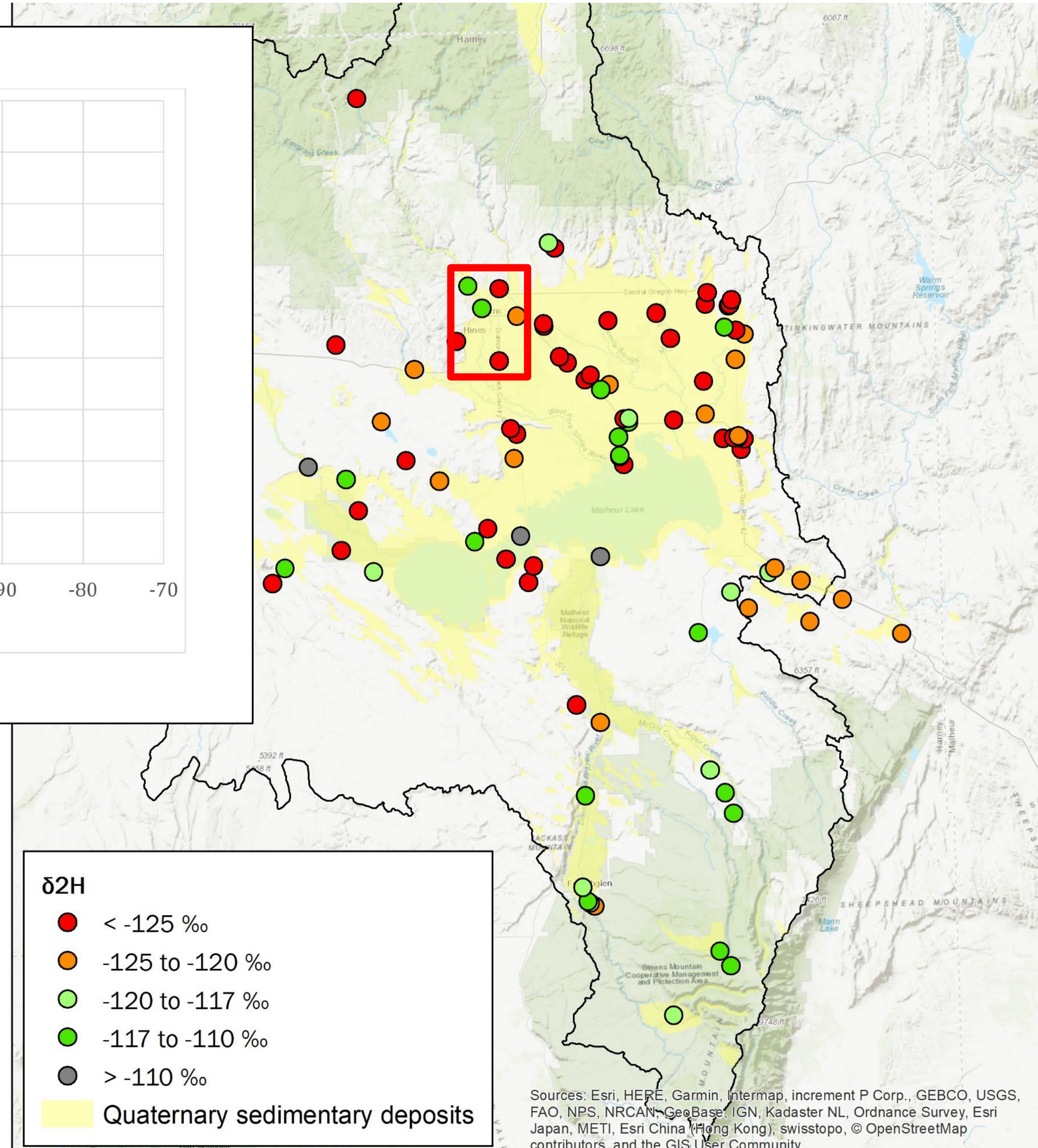
Burns





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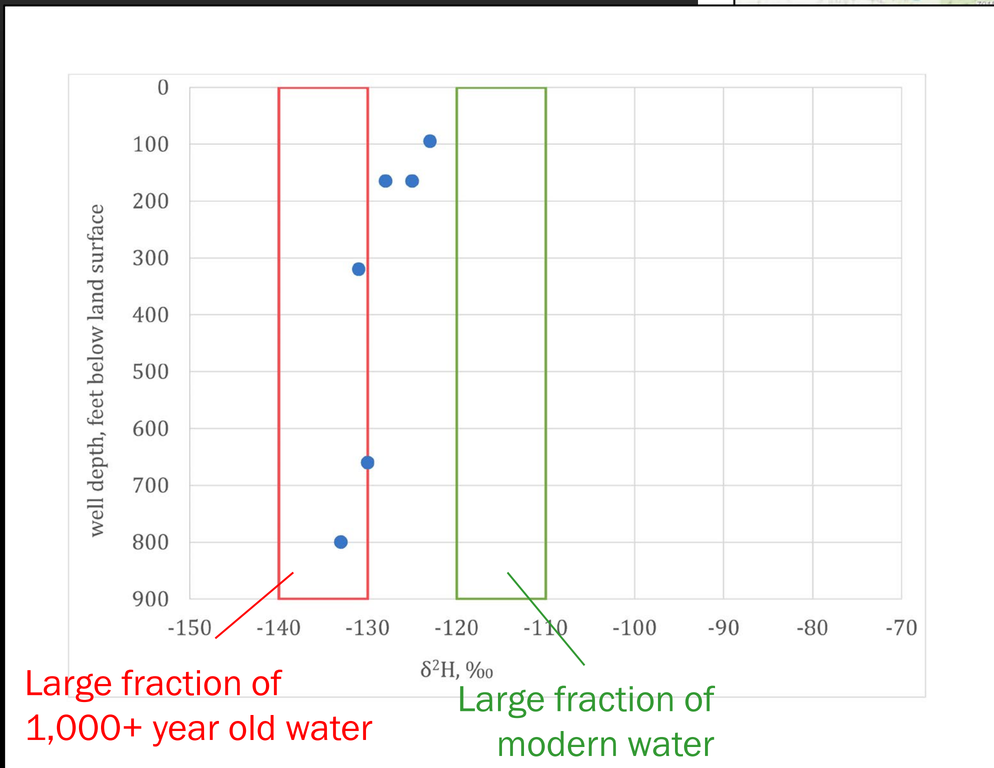
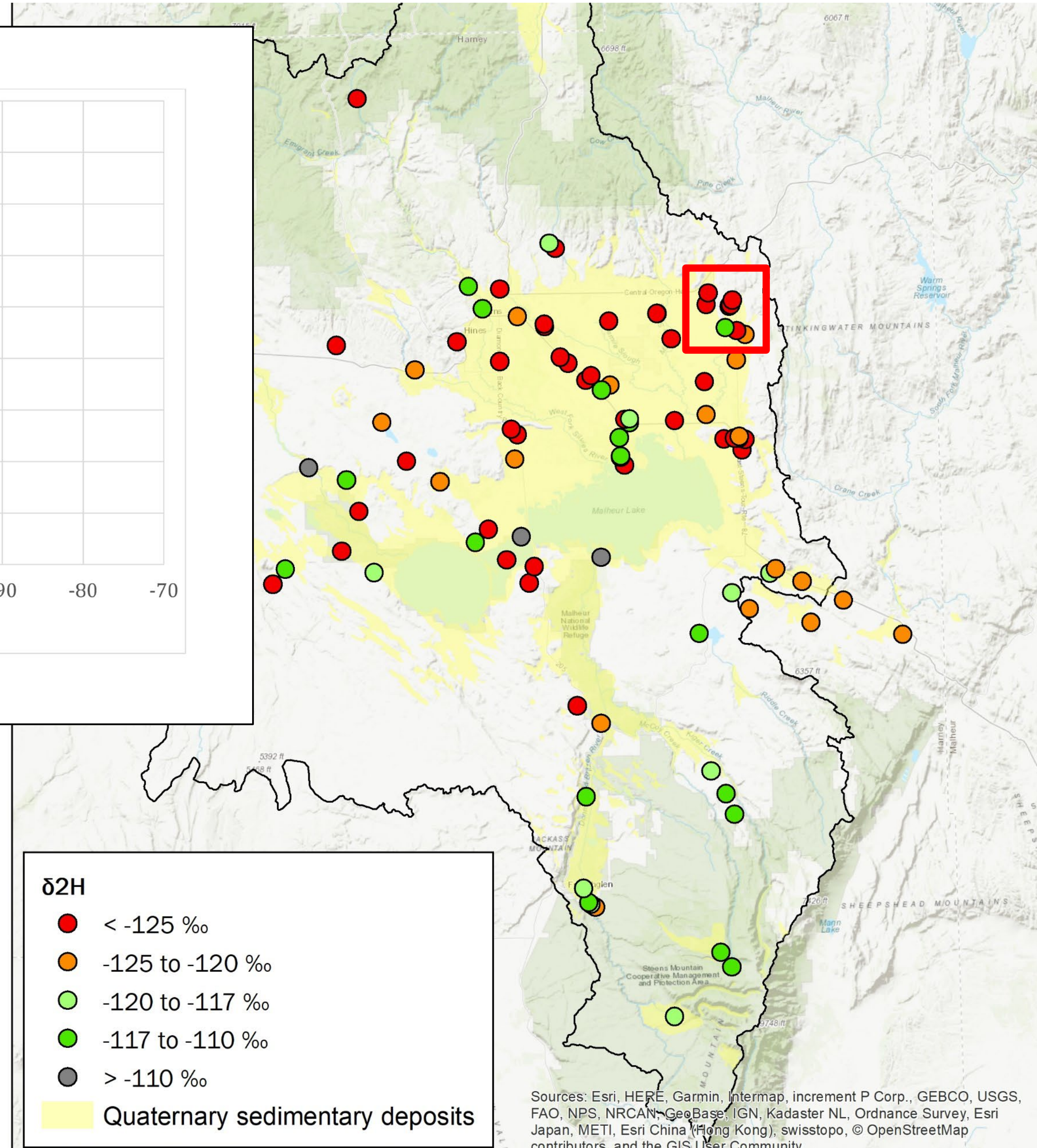
Buchanan





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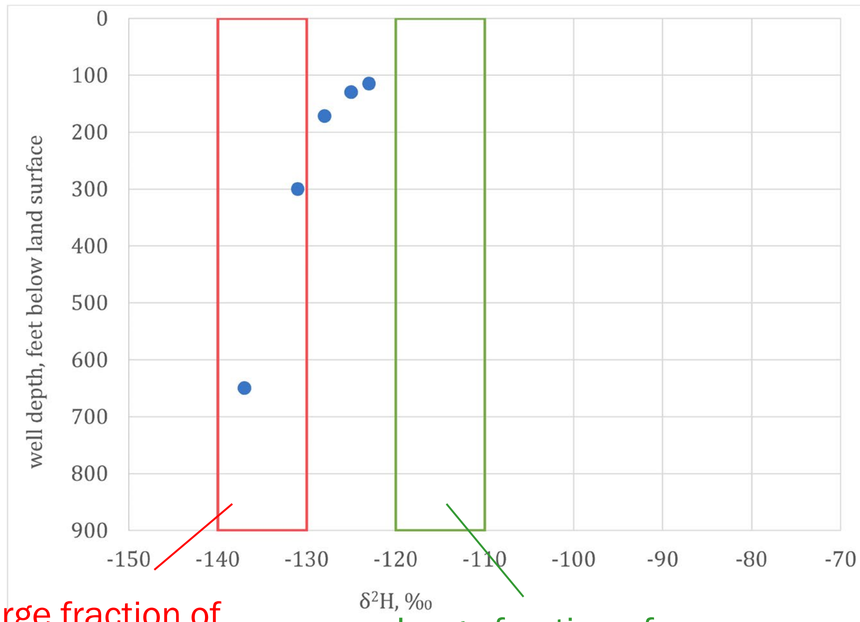
Crane



Large fraction of 1,000+ year old water

Large fraction of modern water

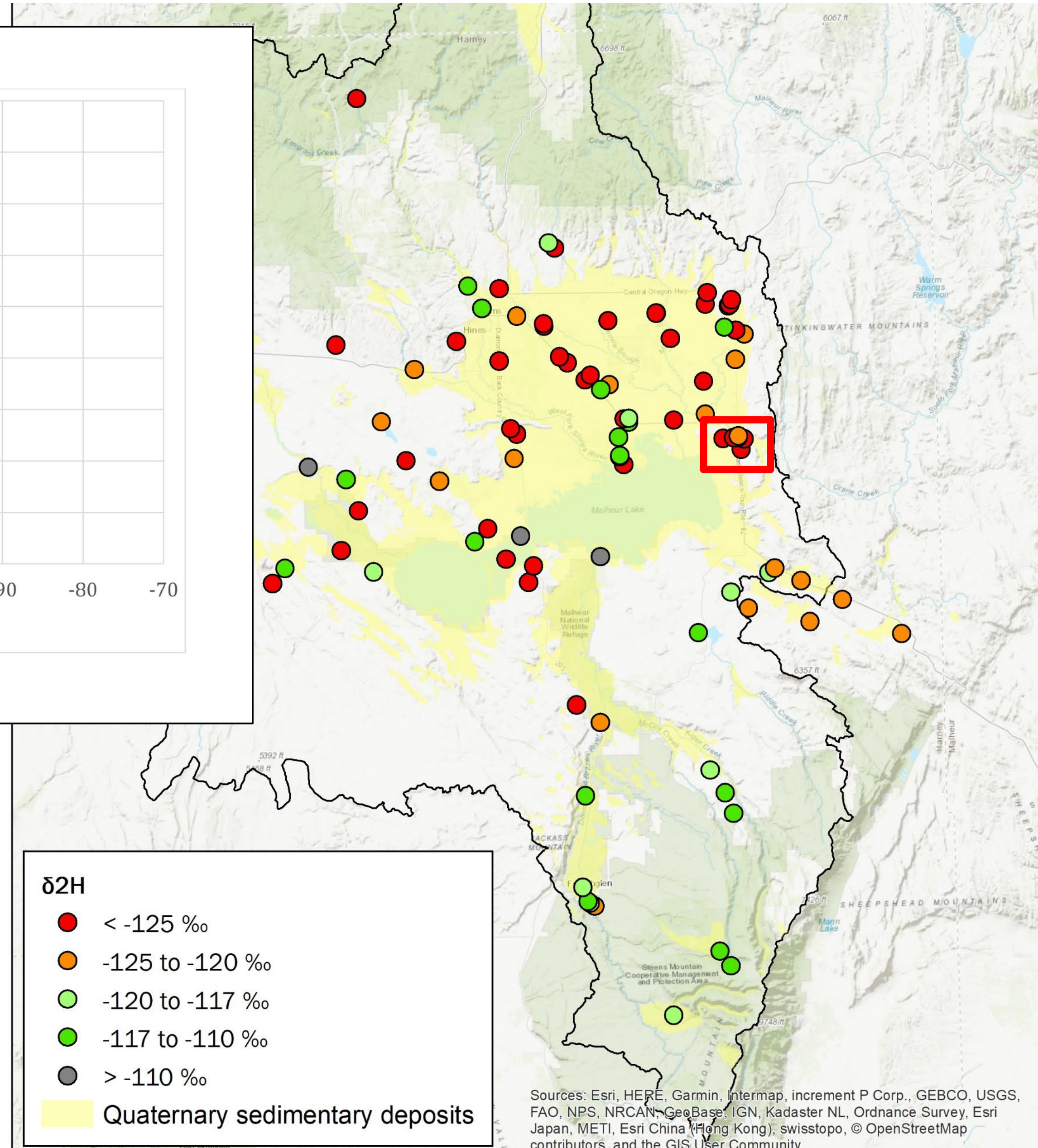


Figure X. δ2H ratio in well samples, Harney Basin, Oregon.

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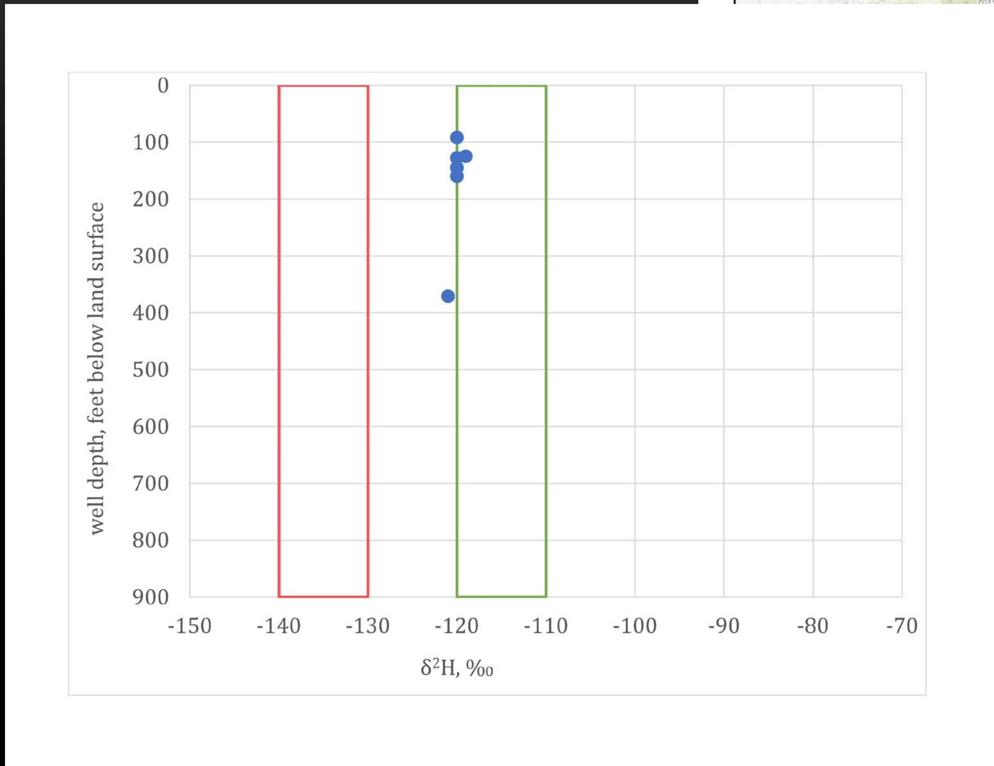
Virginia Valley and Anderson Valley



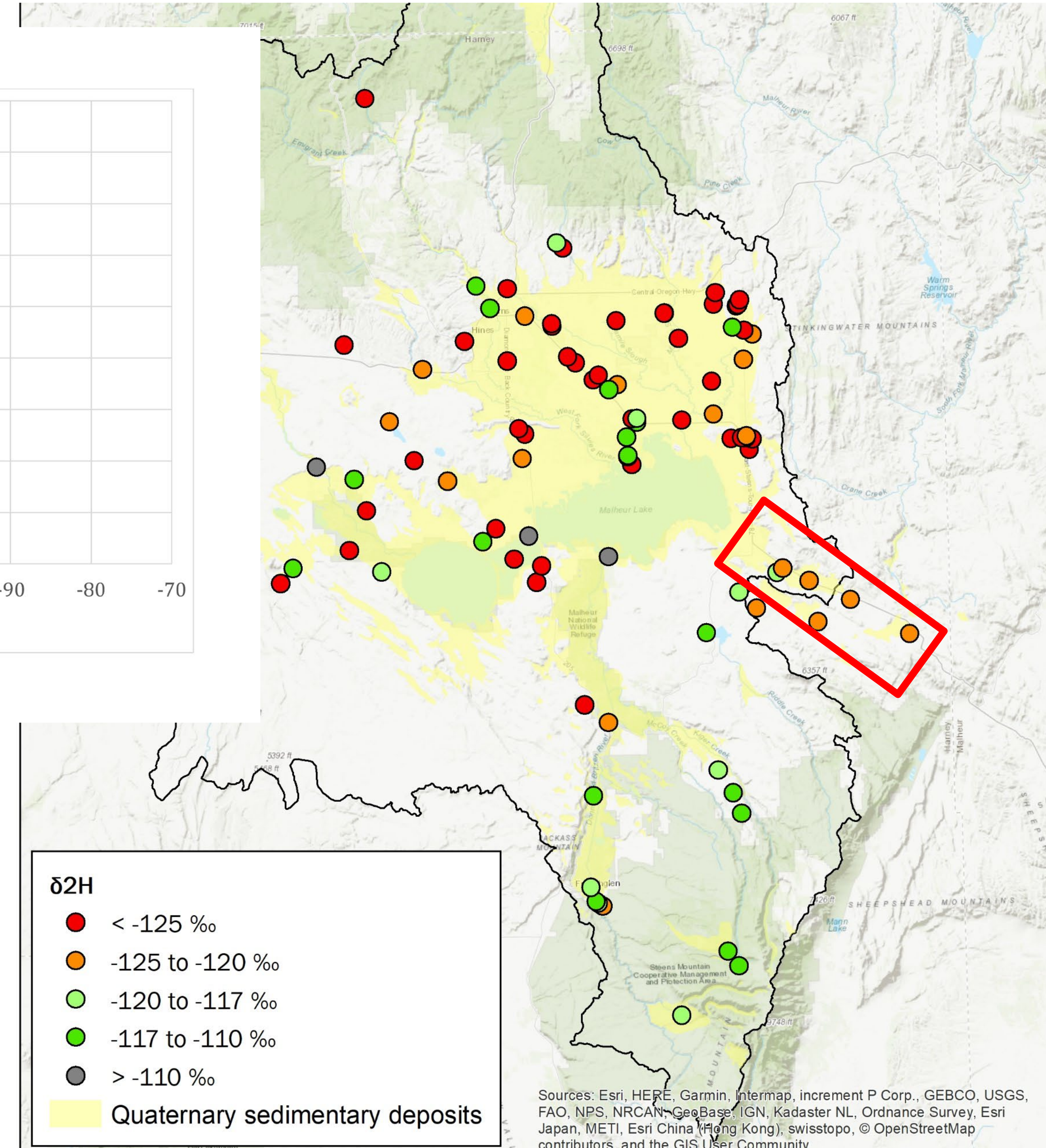


Figure X. δ2H ratio in well samples, Harney Basin, Oregon.

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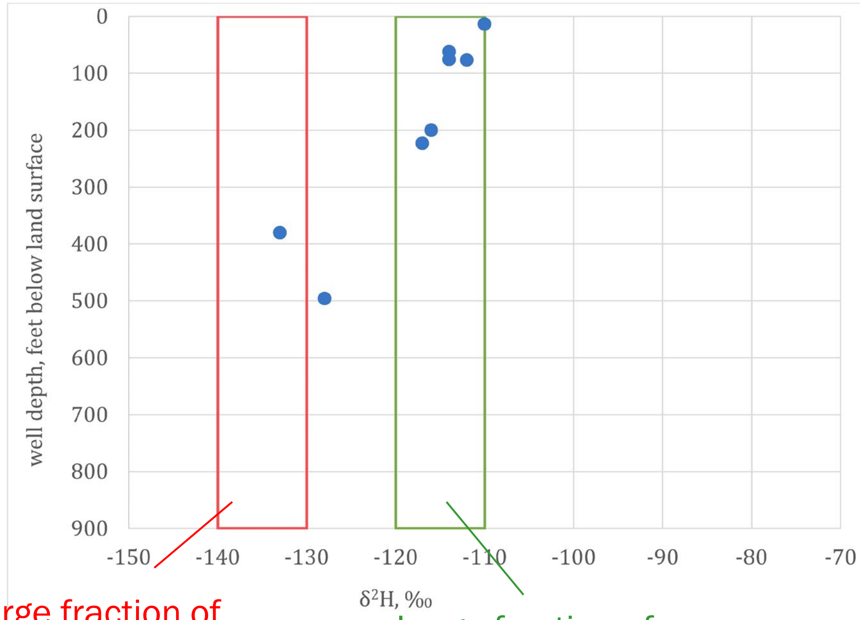
Silvies River near Malheur Lake



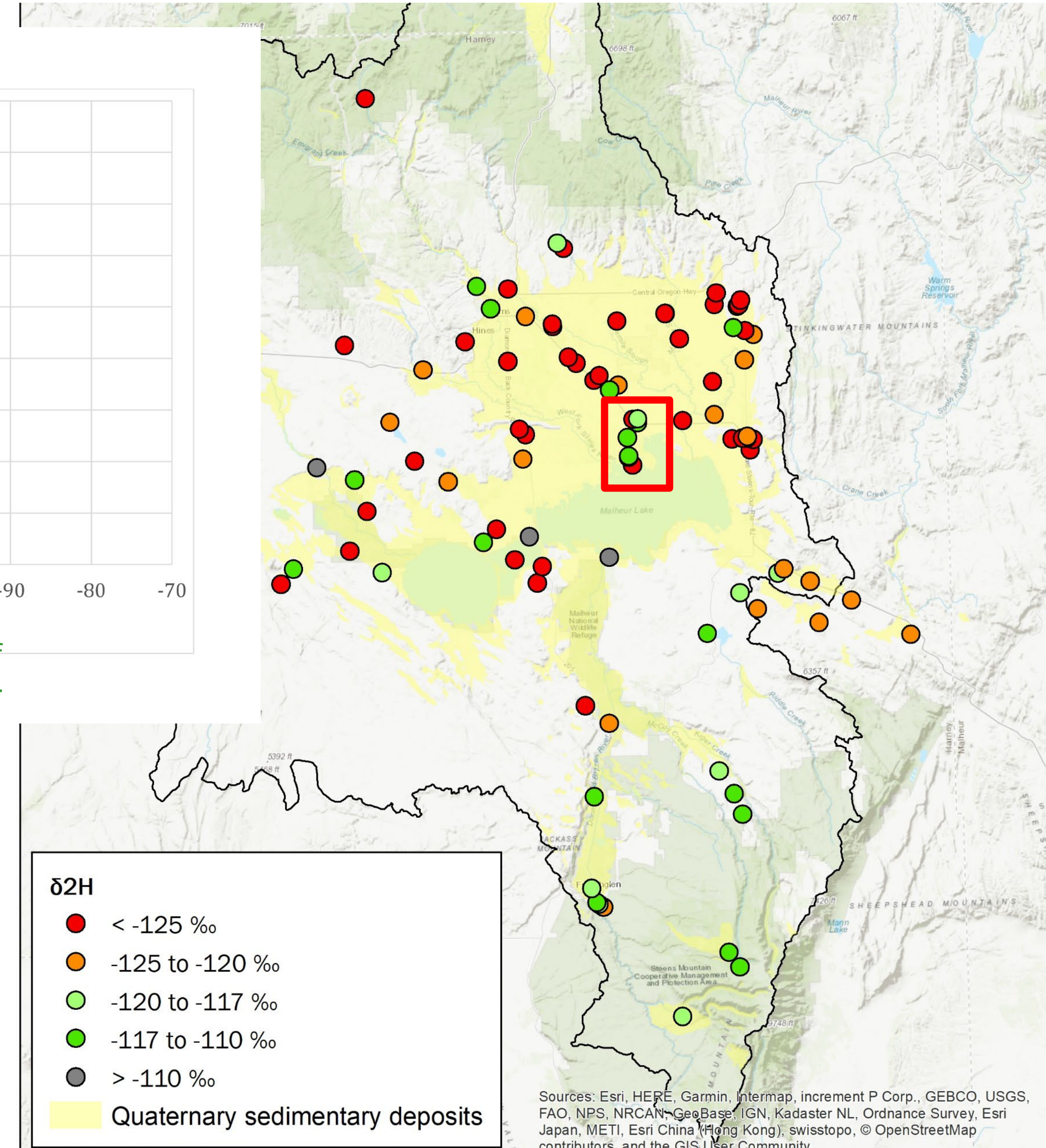


Figure X. δ2H ratio in well samples, Harney Basin, Oregon.

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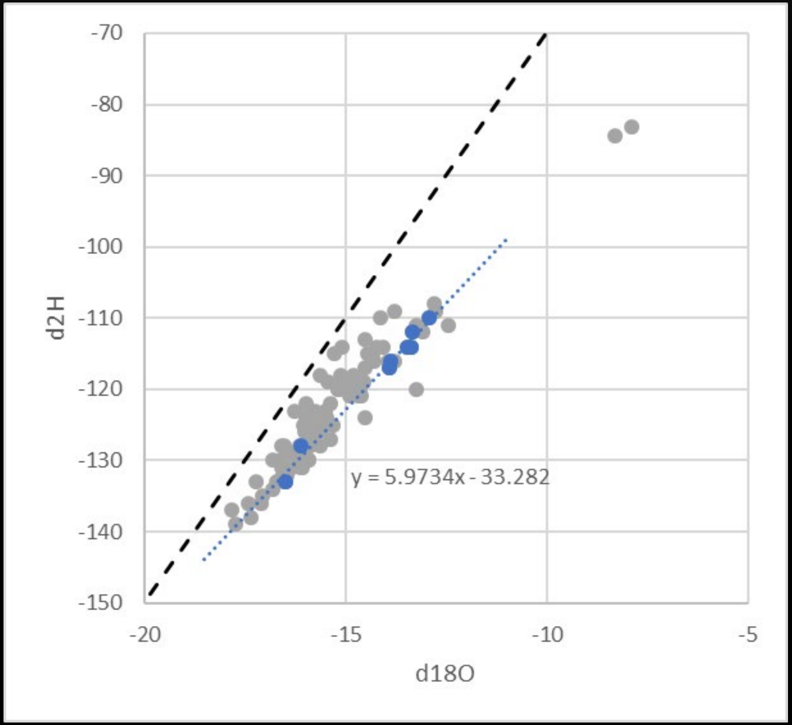
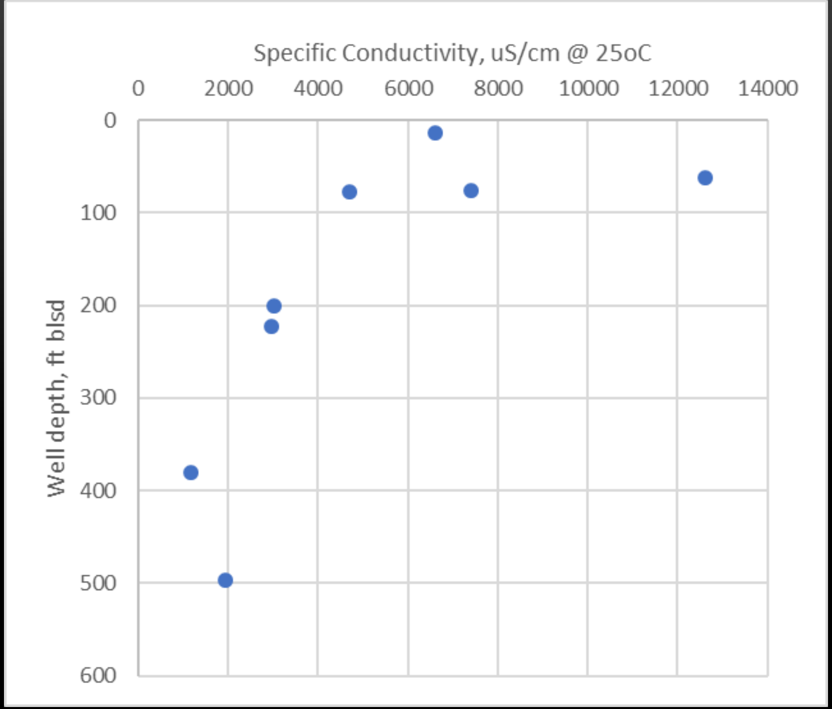
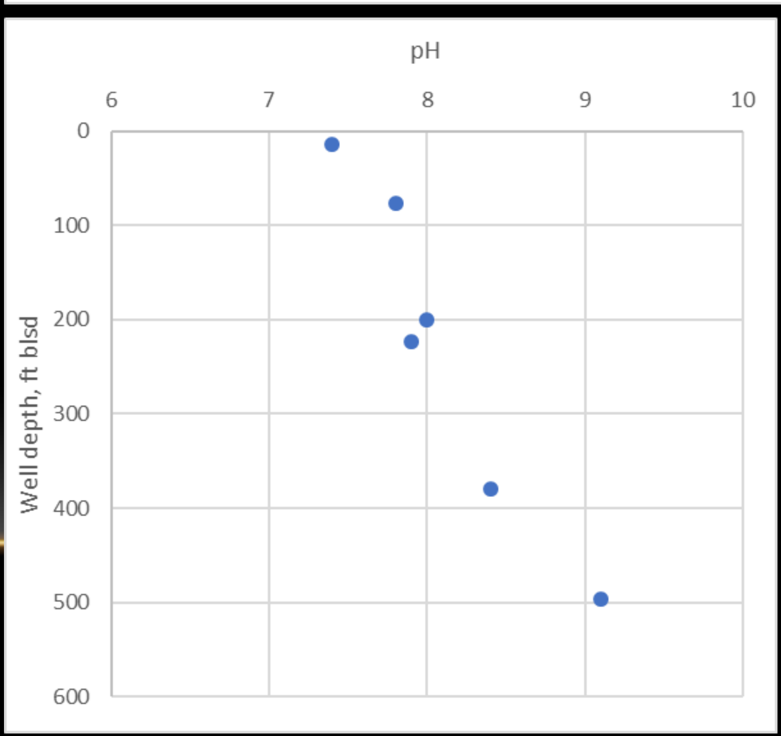
A peek behind the curtain…







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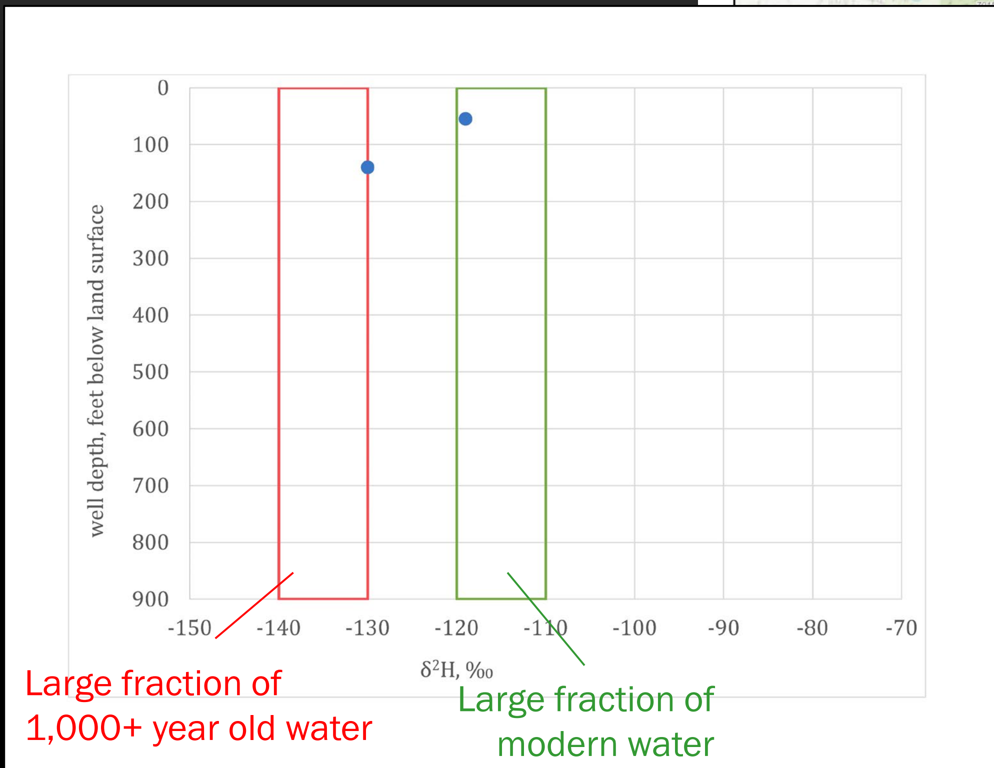
Silver Creek below Moon Reservoir



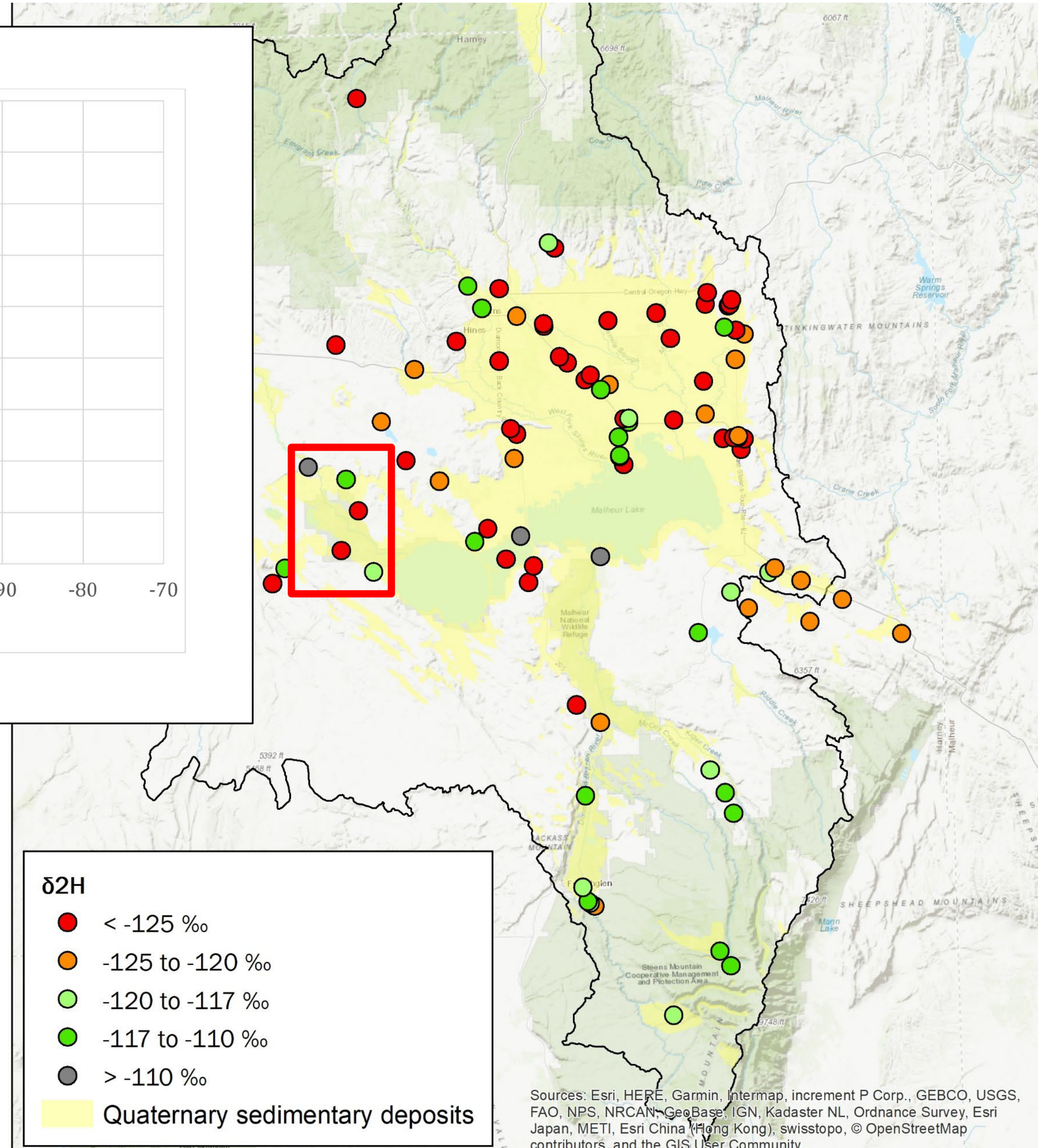


Figure X. δ2H ratio in well samples, Harney Basin, Oregon.

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We are consistently seeing water 1000’s of years old at depths greater than 200 ft

And sometimes at depths of 100 ft or less

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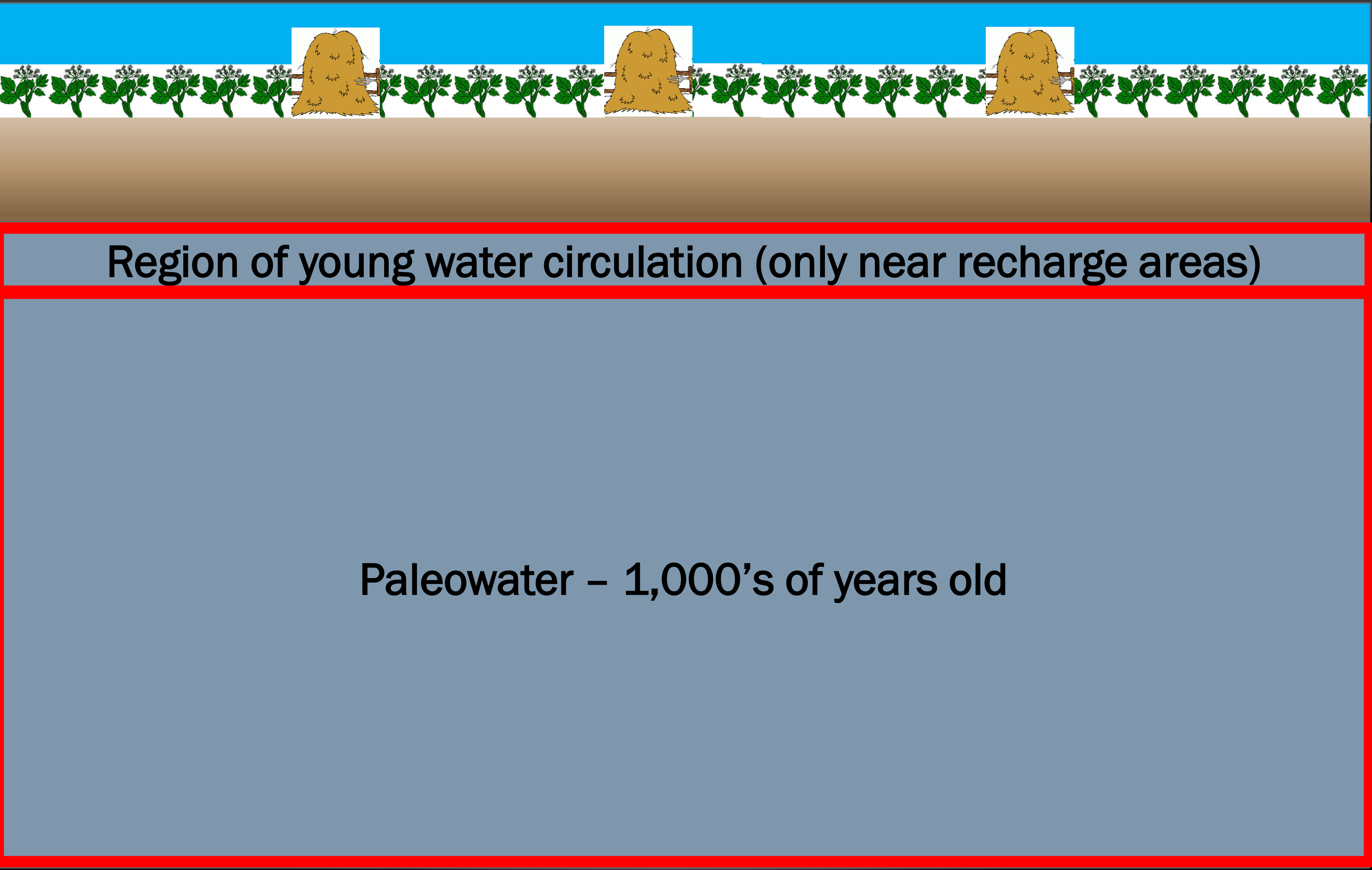
Why is there so much old water and little modern water?

“Moderate-size lakes existed in the Harney Basin ca. 70,000–80,000 yr ago, at 32,000 to 29,500 yr B.P., and ca. 9,500 yr B.P. Shallower paleolakes were present ca. 8,400, 7,800, and 7,400 yr B.P.”

“Beginning ca. 5,000 yr B.P., based on shells in the Malheur Lake dune islands, the Malheur Lake system’s environmental history is marked by fluctuating water levels, a pattern apparently characterizing the remainder of Holocene time.”

-- Daniel Dugas, 1998

Conceptual model



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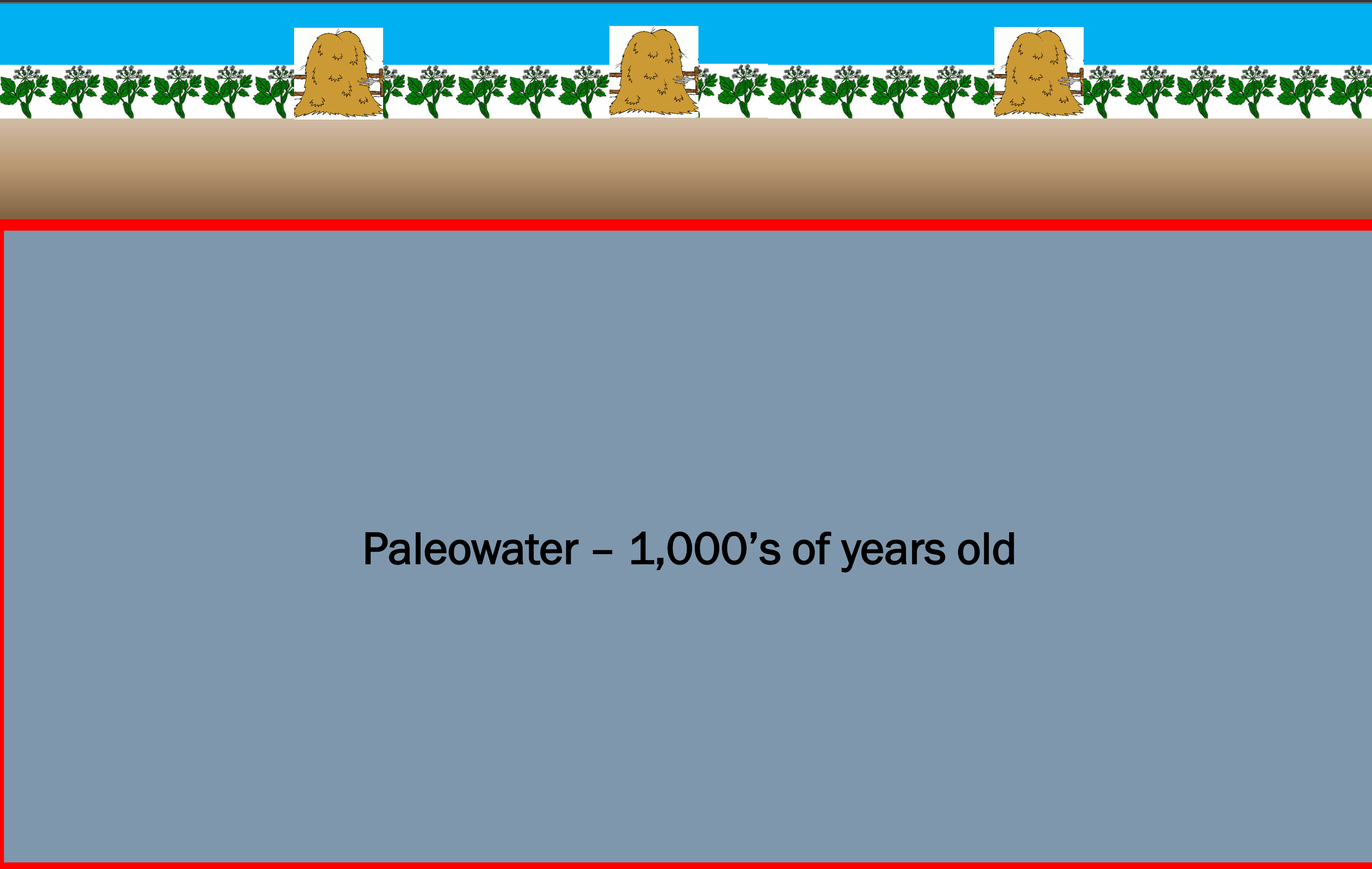
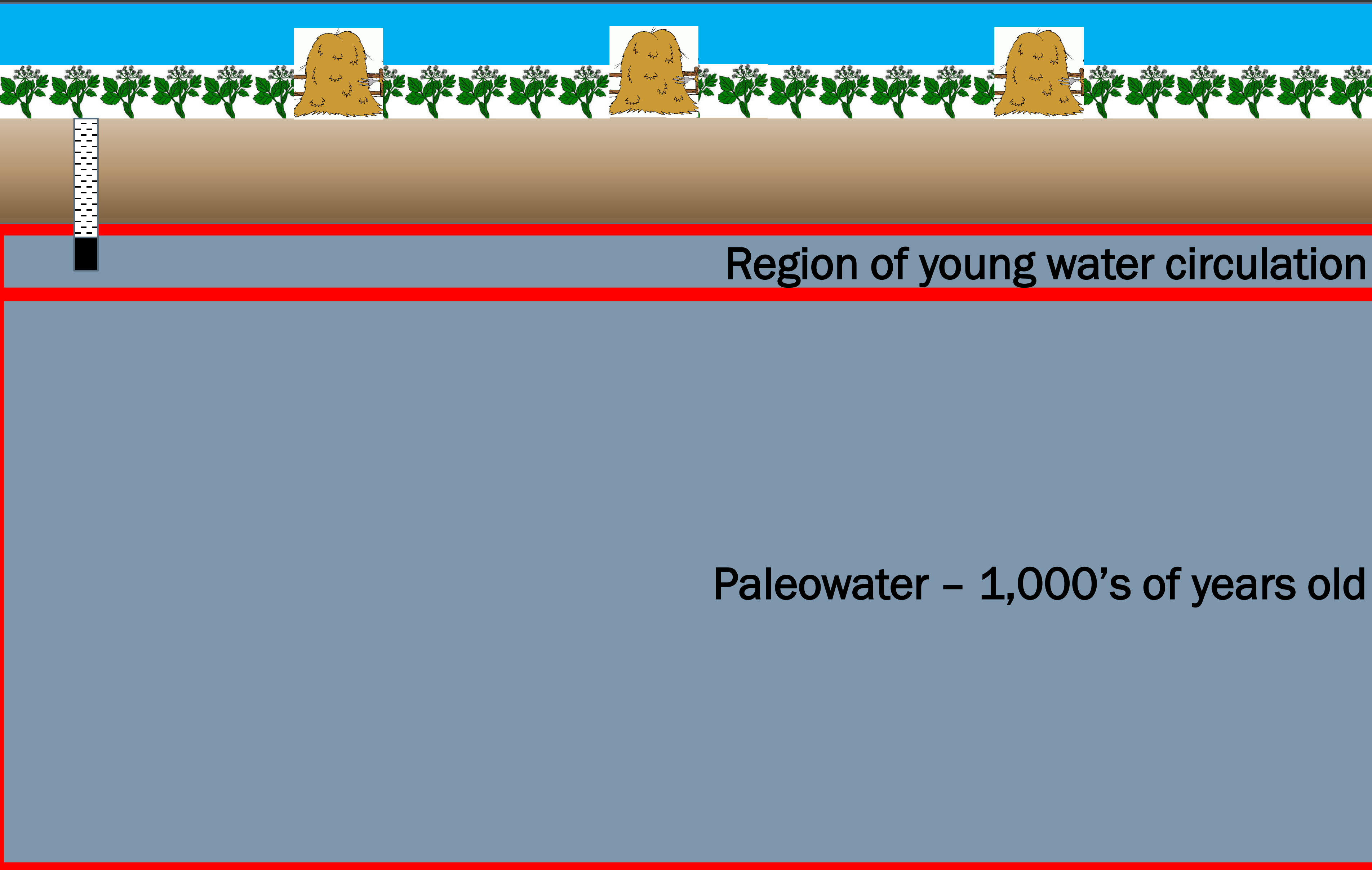
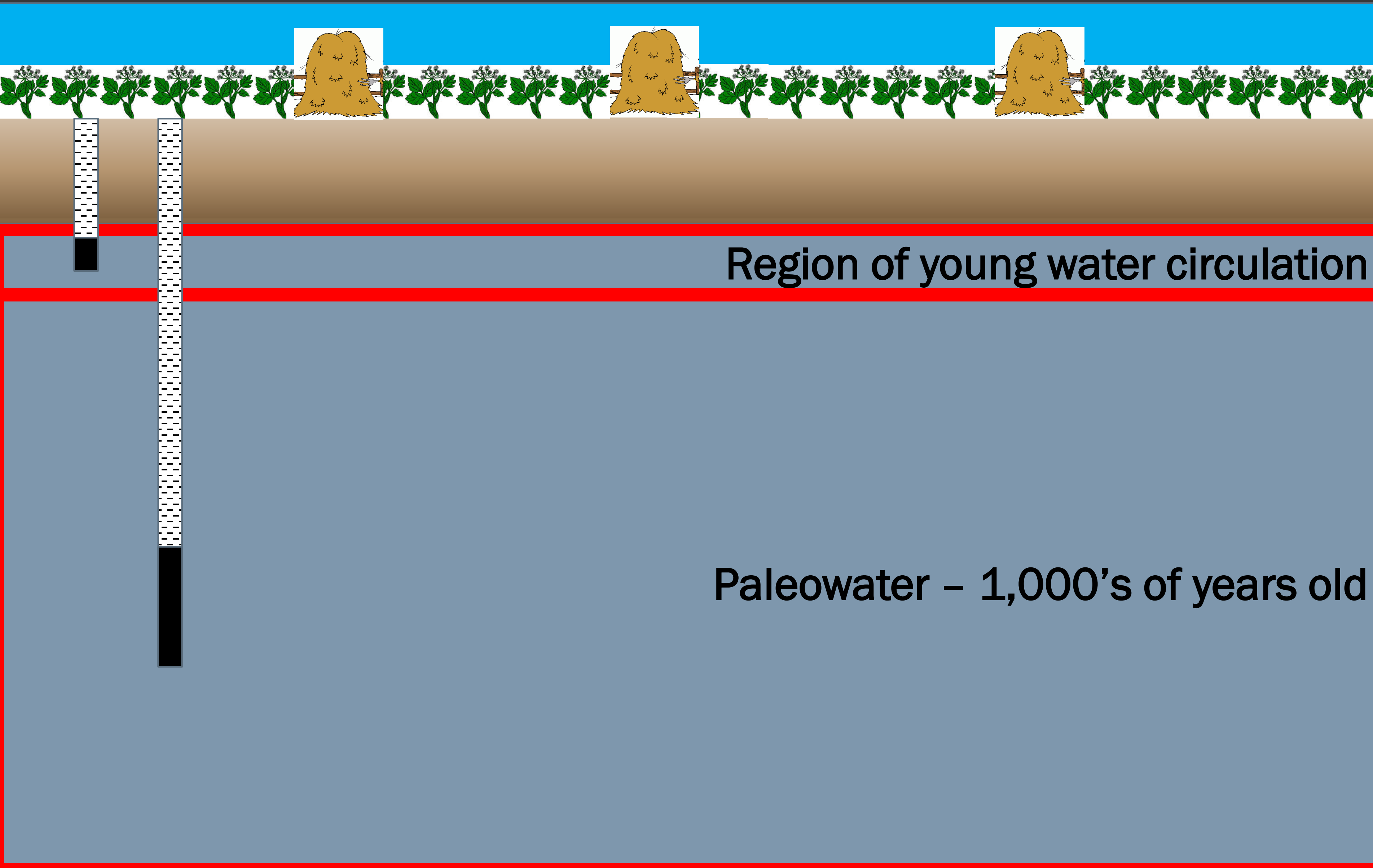

Paleowater – 1,000’s of years old


Region of young water circulation
Paleowater – 1,000's of years old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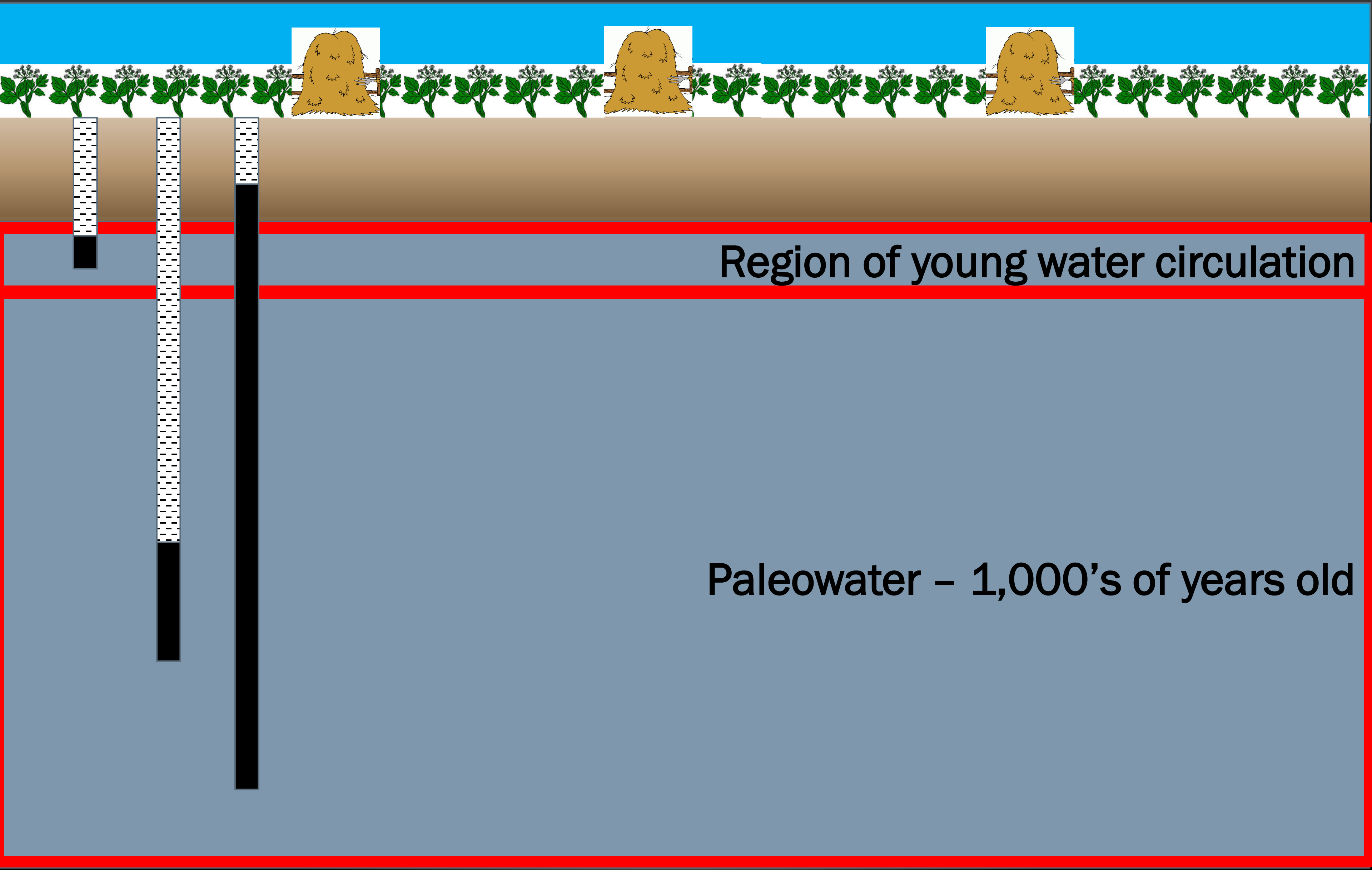
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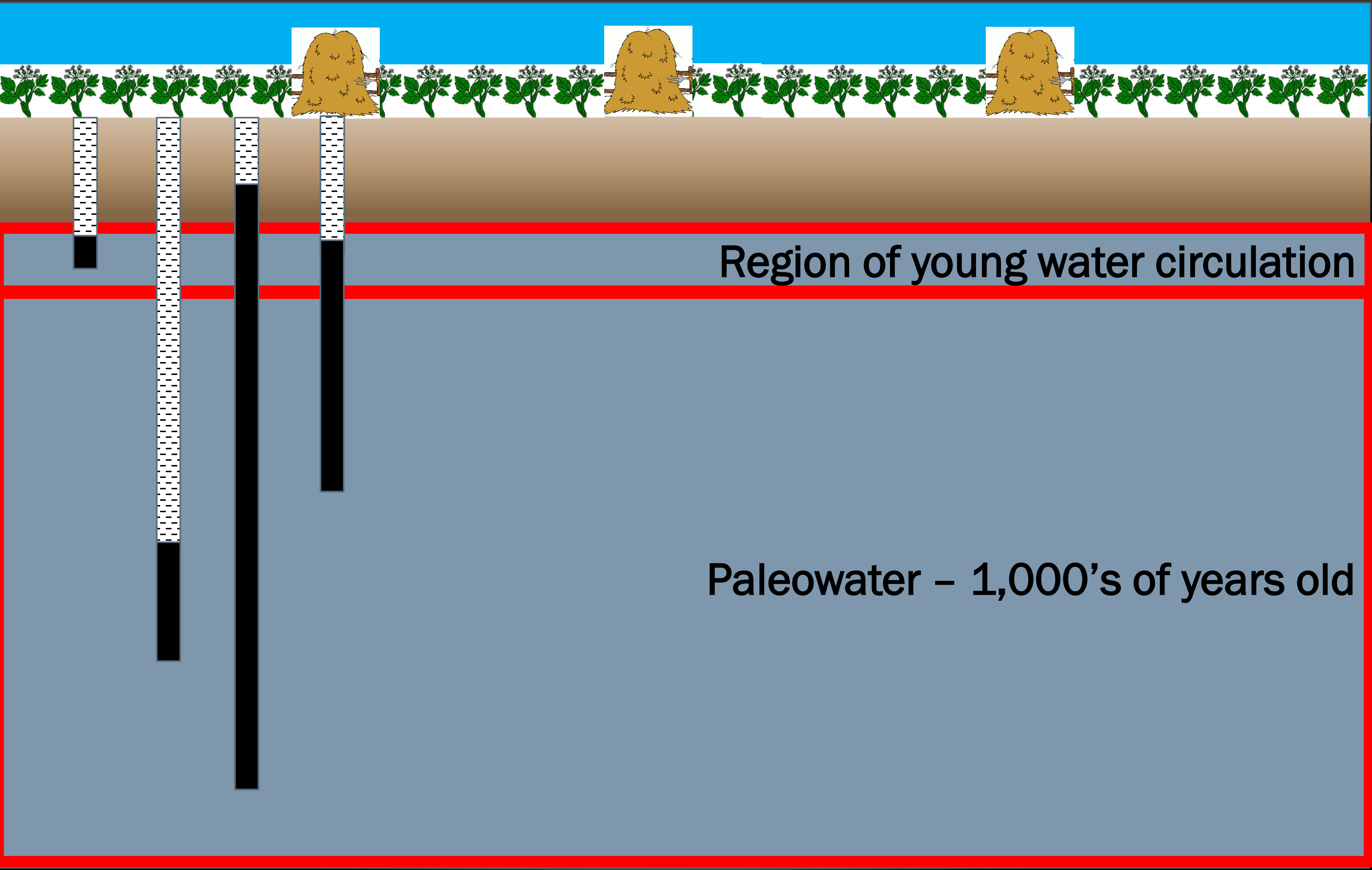

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Implications

- Most groundwater in the basin fill and deeper groundwater in the upland mountains was recharged when region was markedly wetter than it is today
- This is typical of other groundwater systems in the Great Basin
- Decades vs Millenia -- Recharge in today's climate is insufficient to meet and replenish current groundwater use at a timescale relevant to humans

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Implications

- Implies very little active recharge in regions distant from the uplands

- The geochemistry is consistent with the water budget and physical hydrology

References

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End of Presentation

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