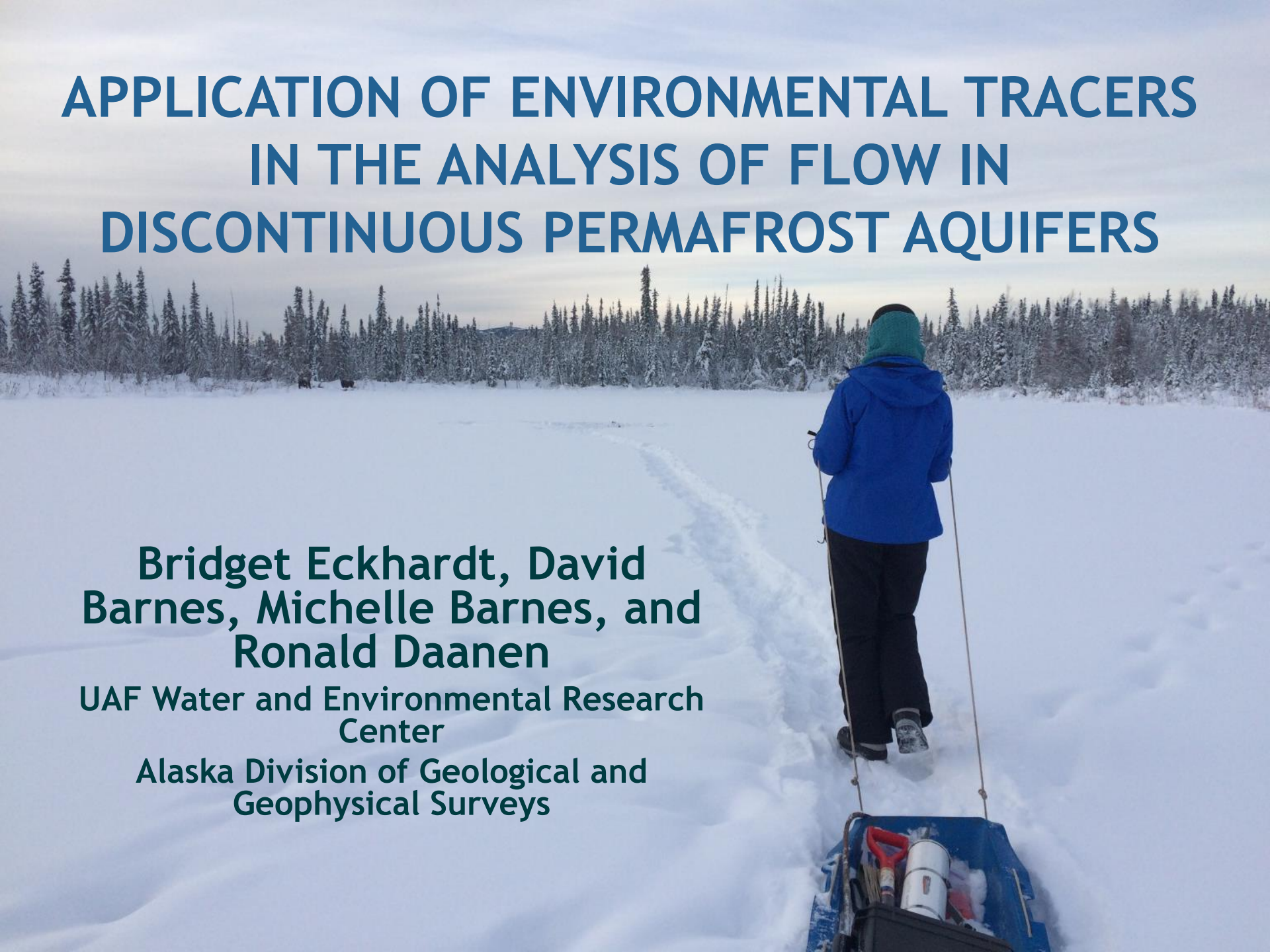
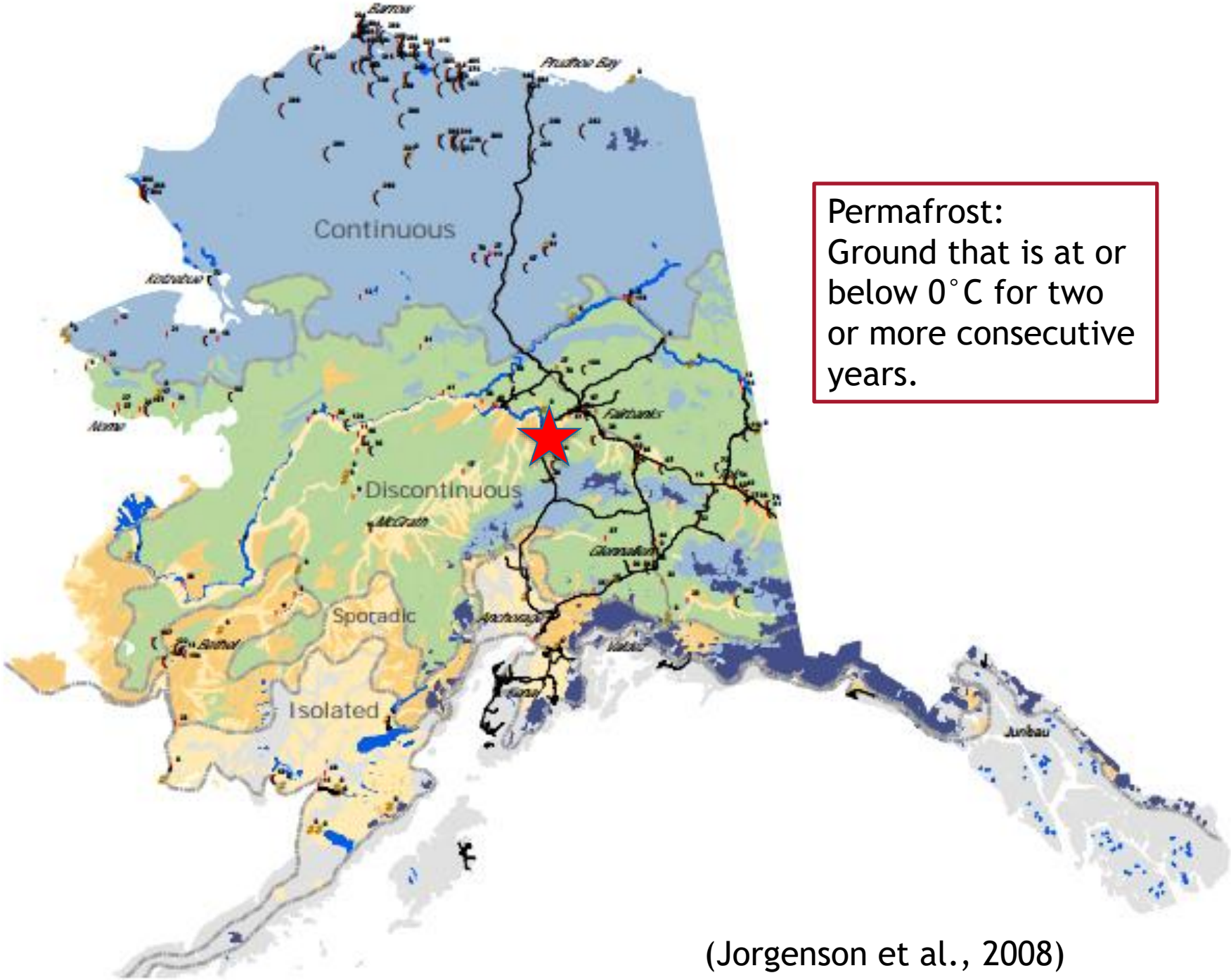
APPLICATION OF ENVIRONMENTAL TRACERS IN THE ANALYSIS OF FLOW IN DISCONTINUOUS PERMAFROST AQUIFERS



Bridget Eckhardt, David Barnes, Michelle Barnes, and Ronald Daanen

UAF Water and Environmental Research Center

Alaska Division of Geological and Geophysical Surveys

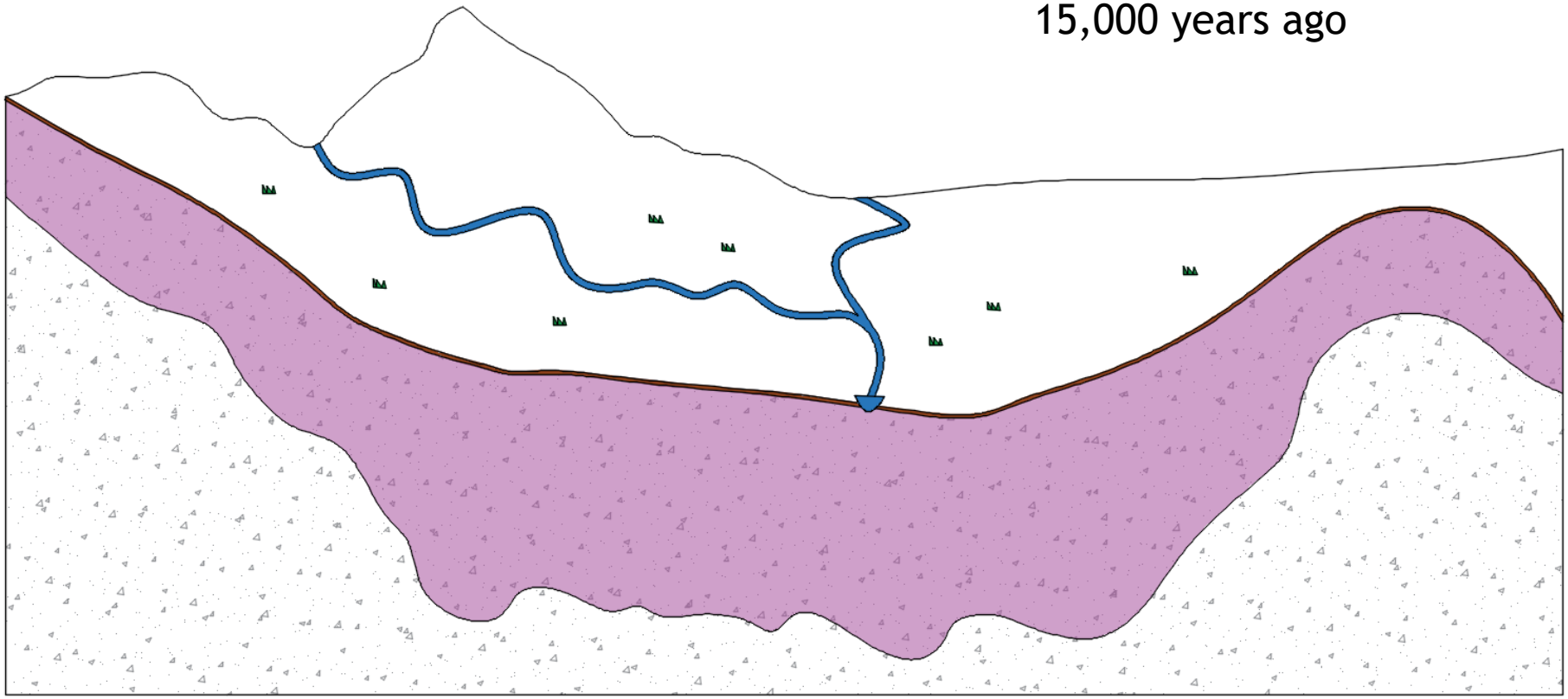


Permafrost:
Ground that is at or below 0°C for two or more consecutive years.

(Jorgenson et al., 2008)

FROM CONTINUOUS TO DISCONTINUOUS

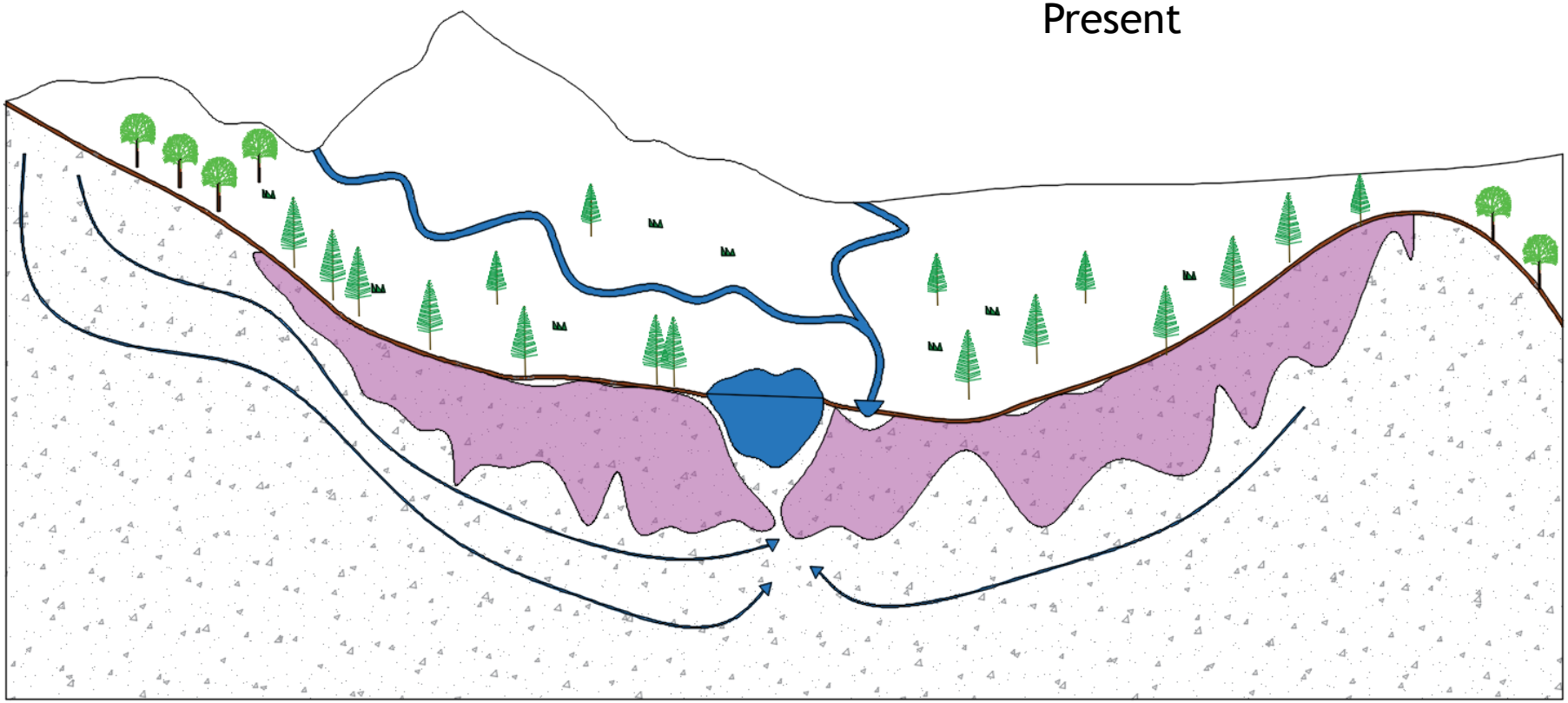
15,000 years ago



(Daanen, 2015)

FROM CONTINUOUS TO DISCONTINUOUS

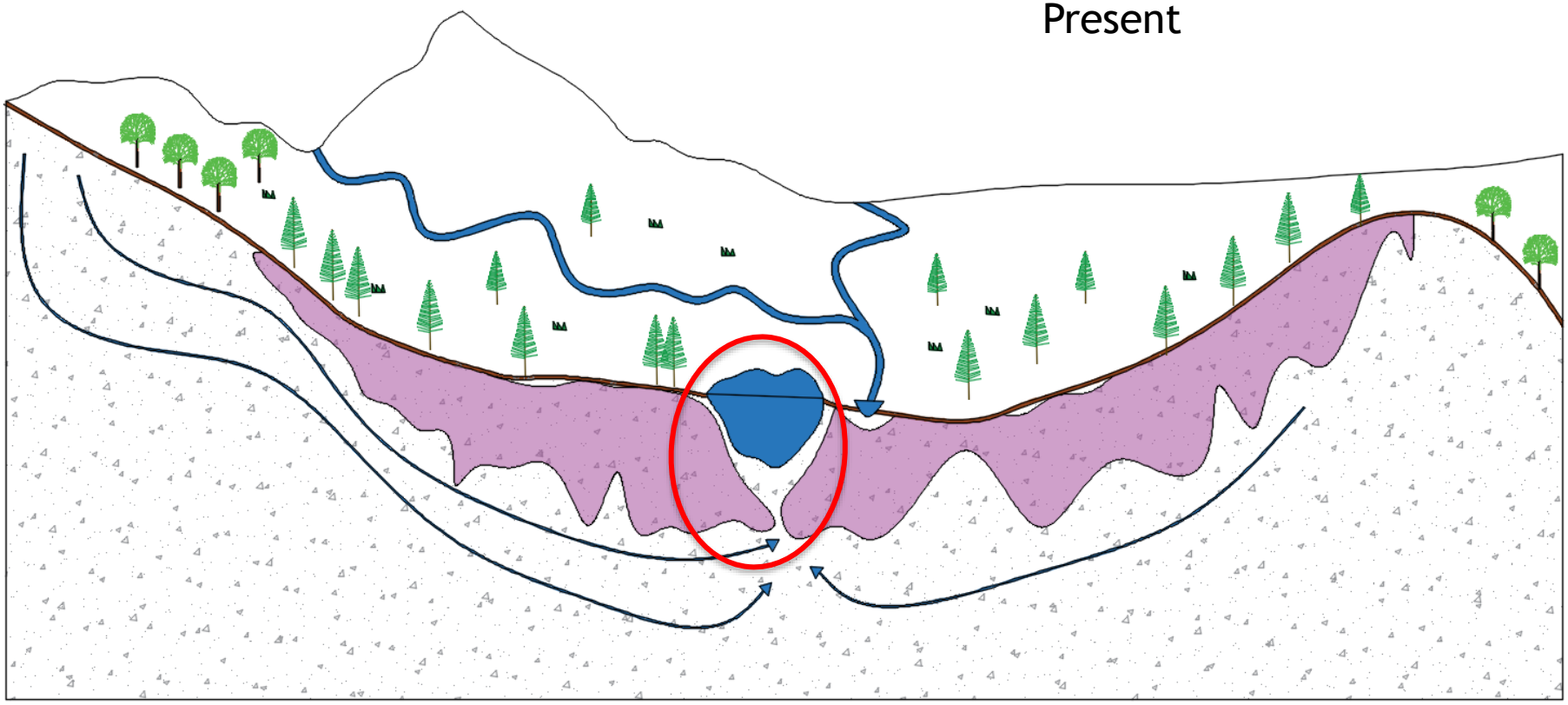
Present



(Daanen, 2015)

FROM CONTINUOUS TO DISCONTINUOUS

Present



(Daanen, 2015)

FROM CONTINUOUS TO DISCONTINUOUS

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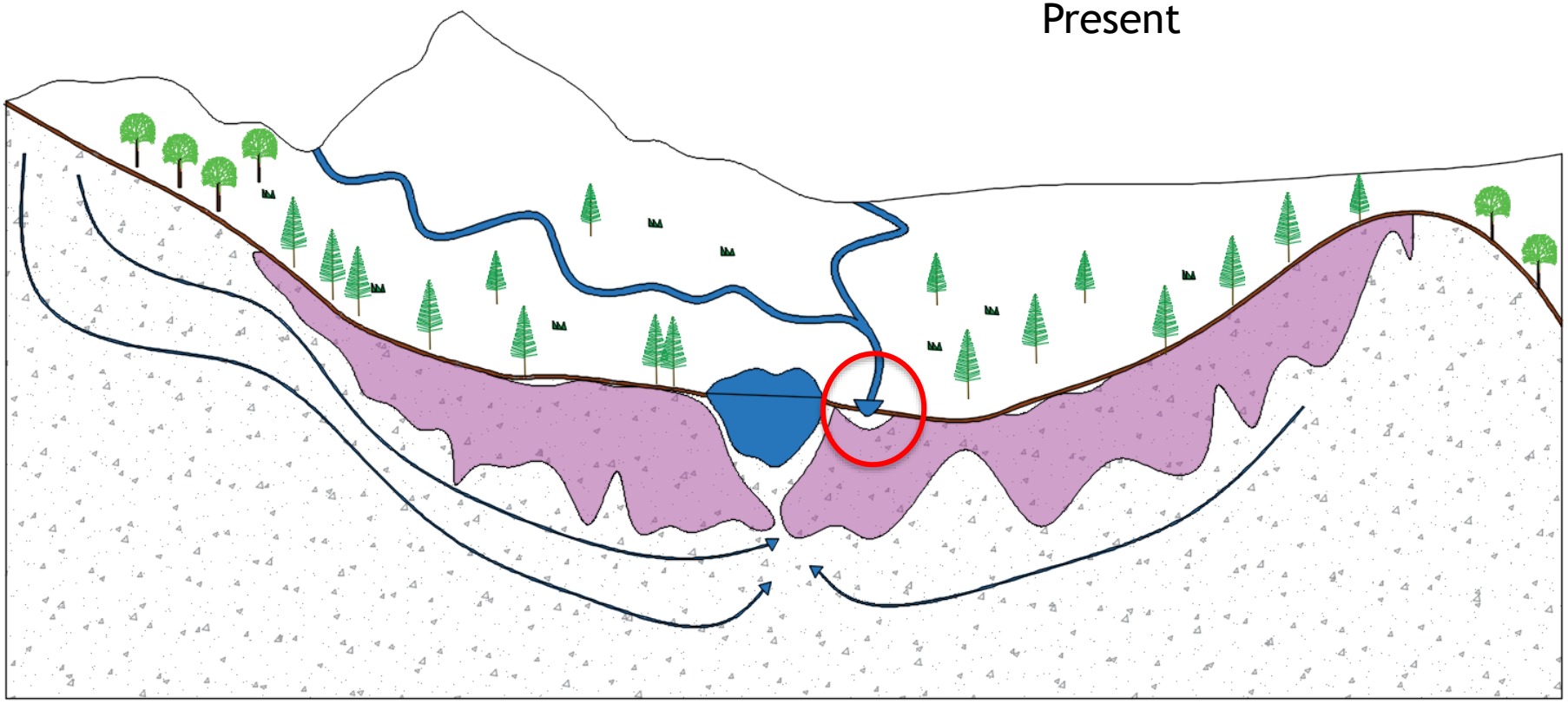
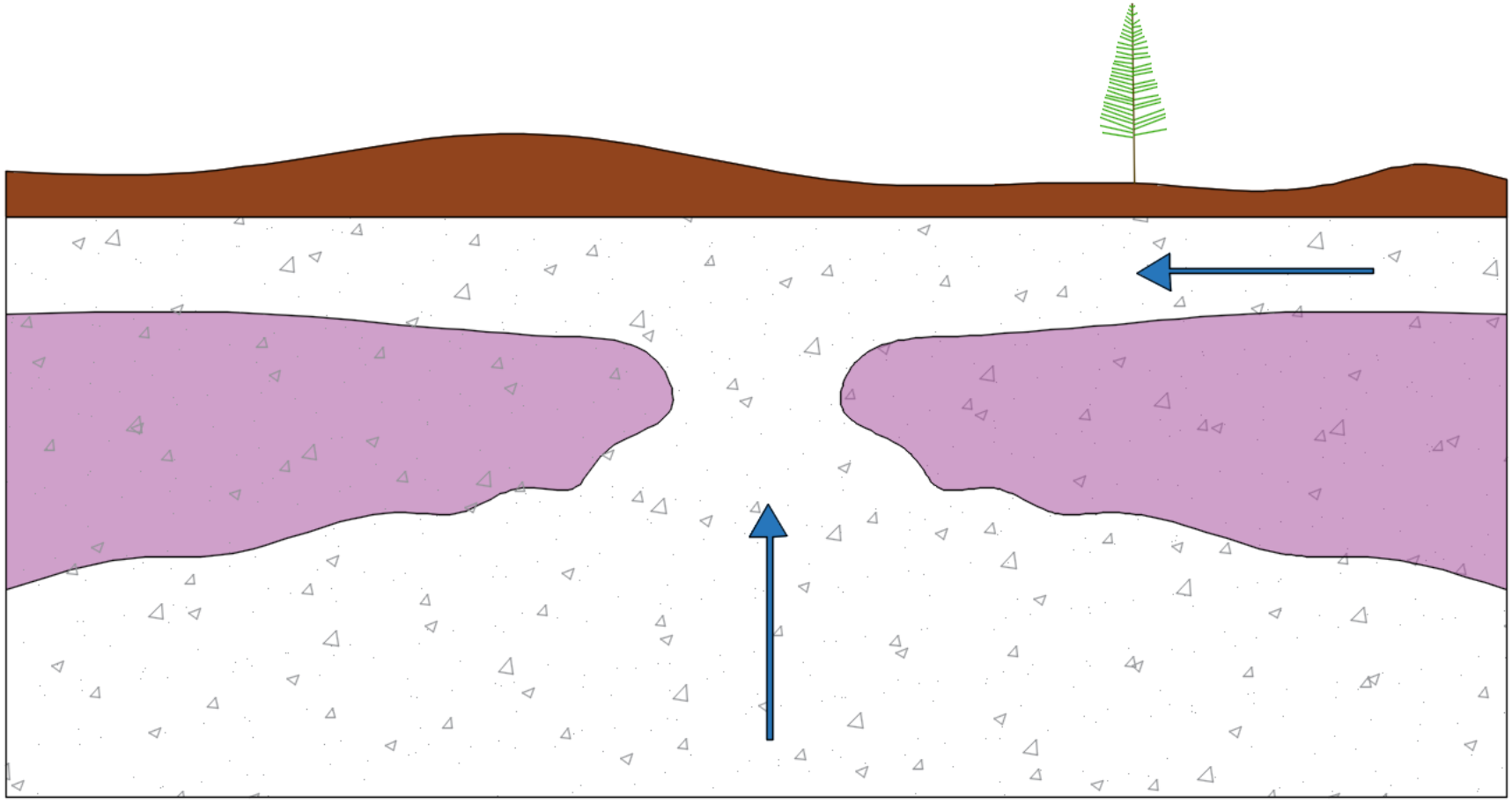
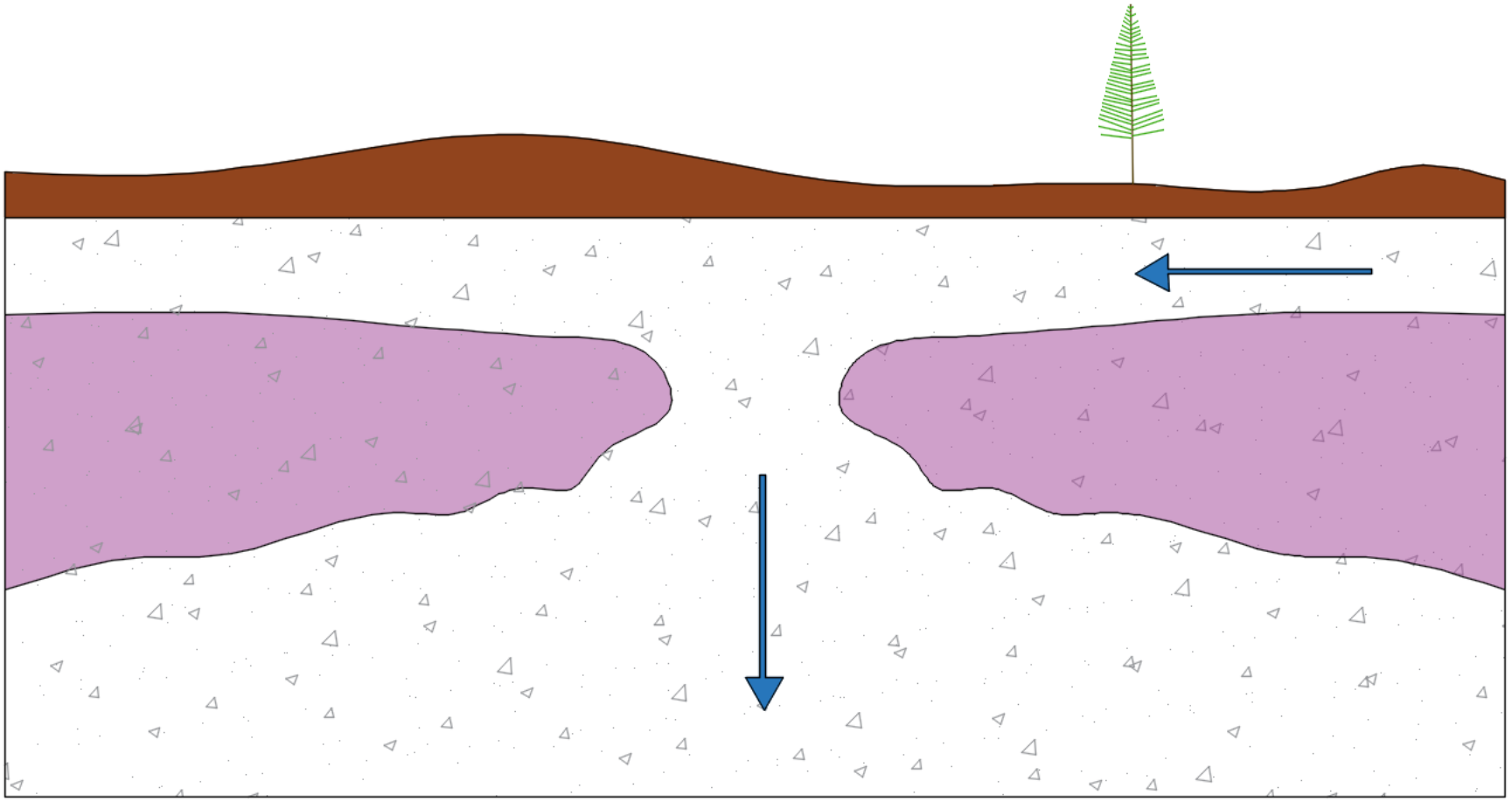


(Daanen, 2015)

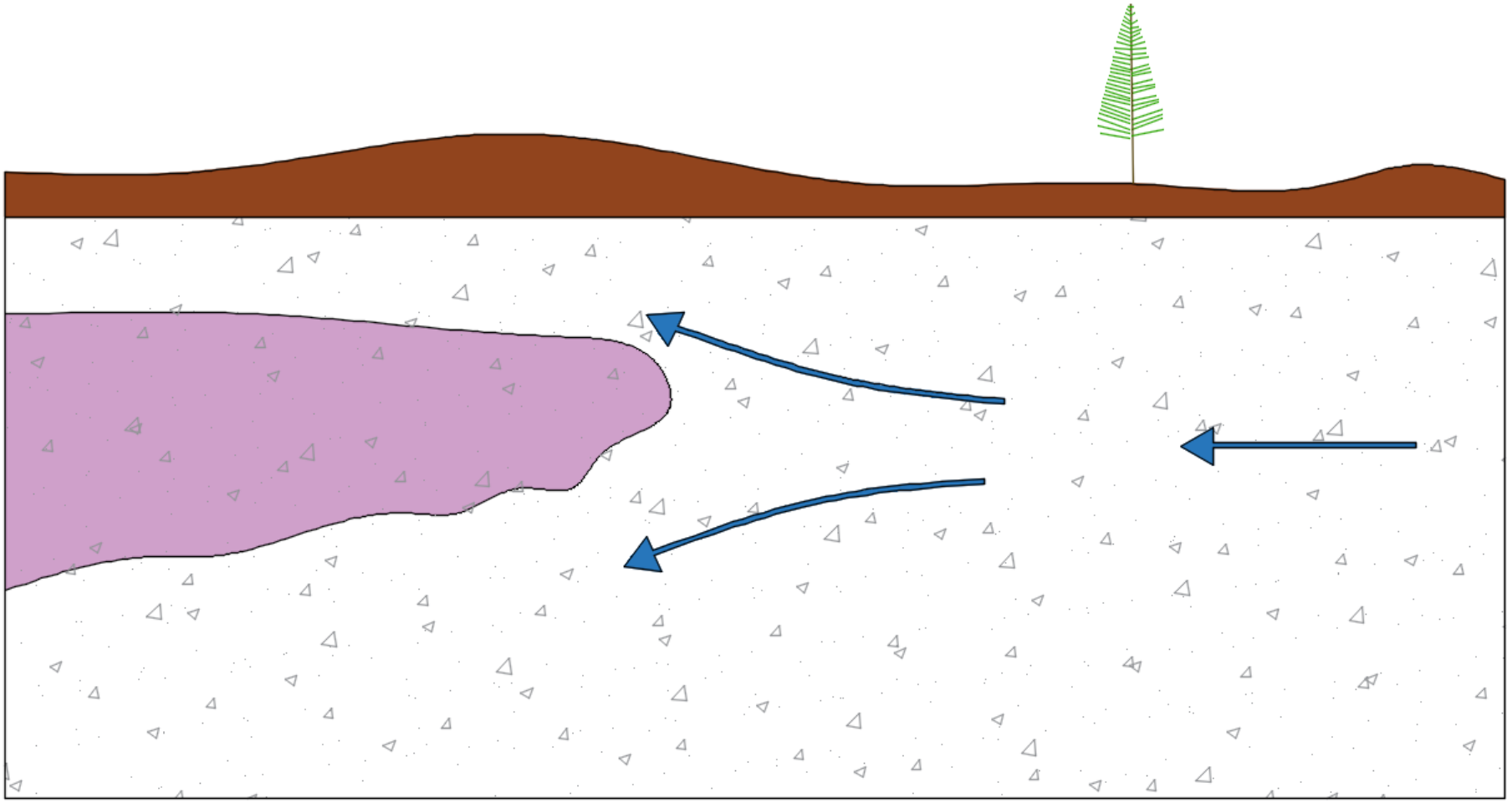
UPWARD FLOW



DOWNWARD FLOW



BIFURCATION OF FLOW



RESEARCH LIMITATIONS

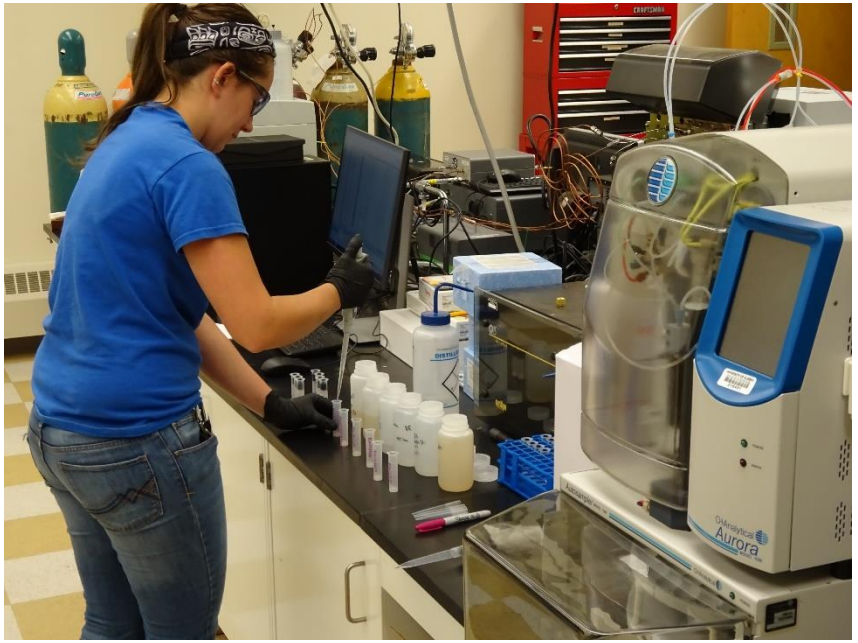
- Permafrost configuration
  - Expensive drilling
    - Large risk of artesian conditions
  - Remote locations
  - Remote sensing can be expensive and still requires ground-truthing
- Equipment Complications
  - Cold temperatures and long-term freezing

STUDIES-TO-DATE

- Majority are modeling studies
- Few studies are ground-based
- Many studies assume simplistic permafrost configuration and flow behavior

BENEFITS OF ENVIRONMENTAL TRACERS

- Relatively inexpensive
- May provide more insight than water level measurements alone



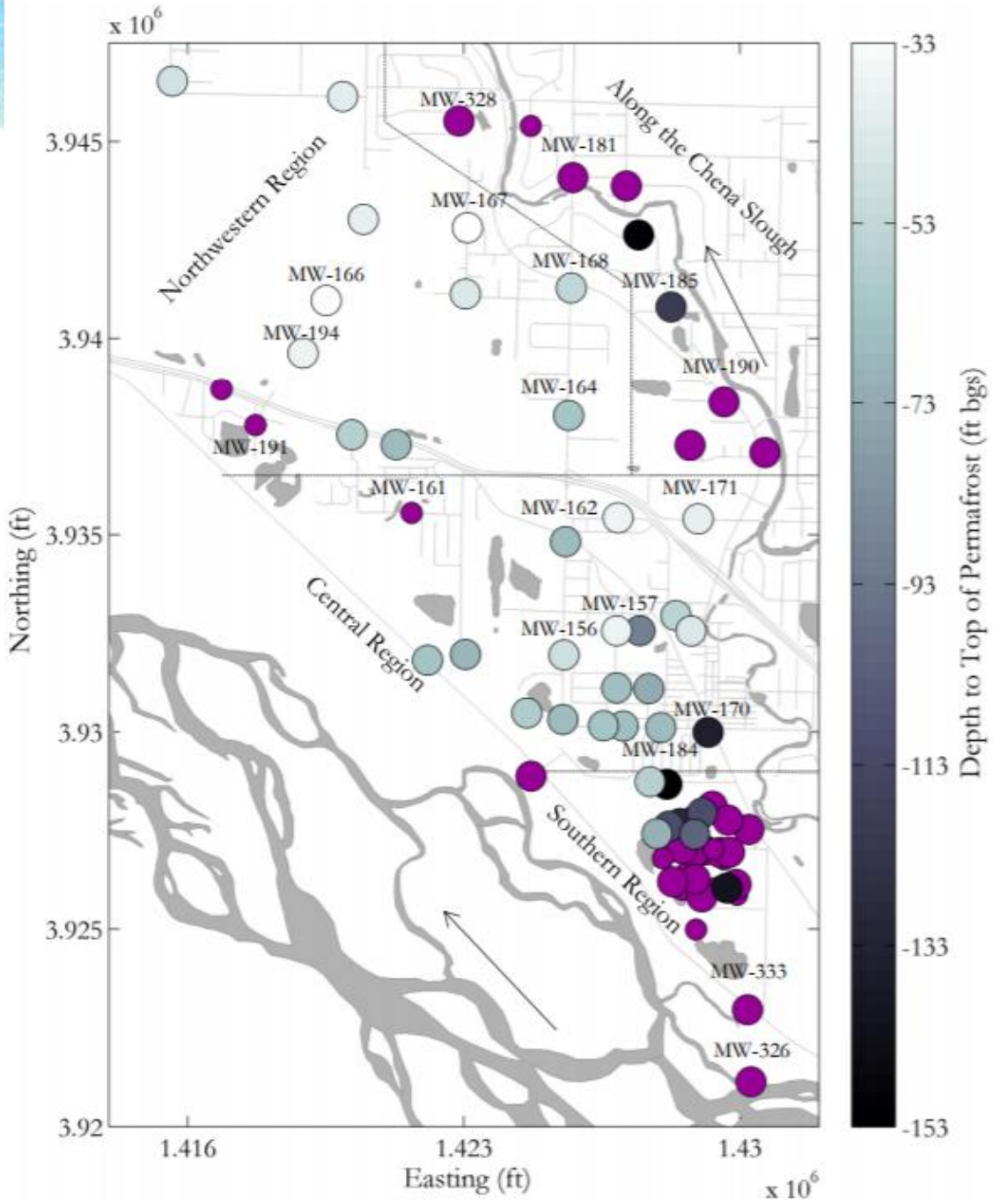
ASSUMPTIONS

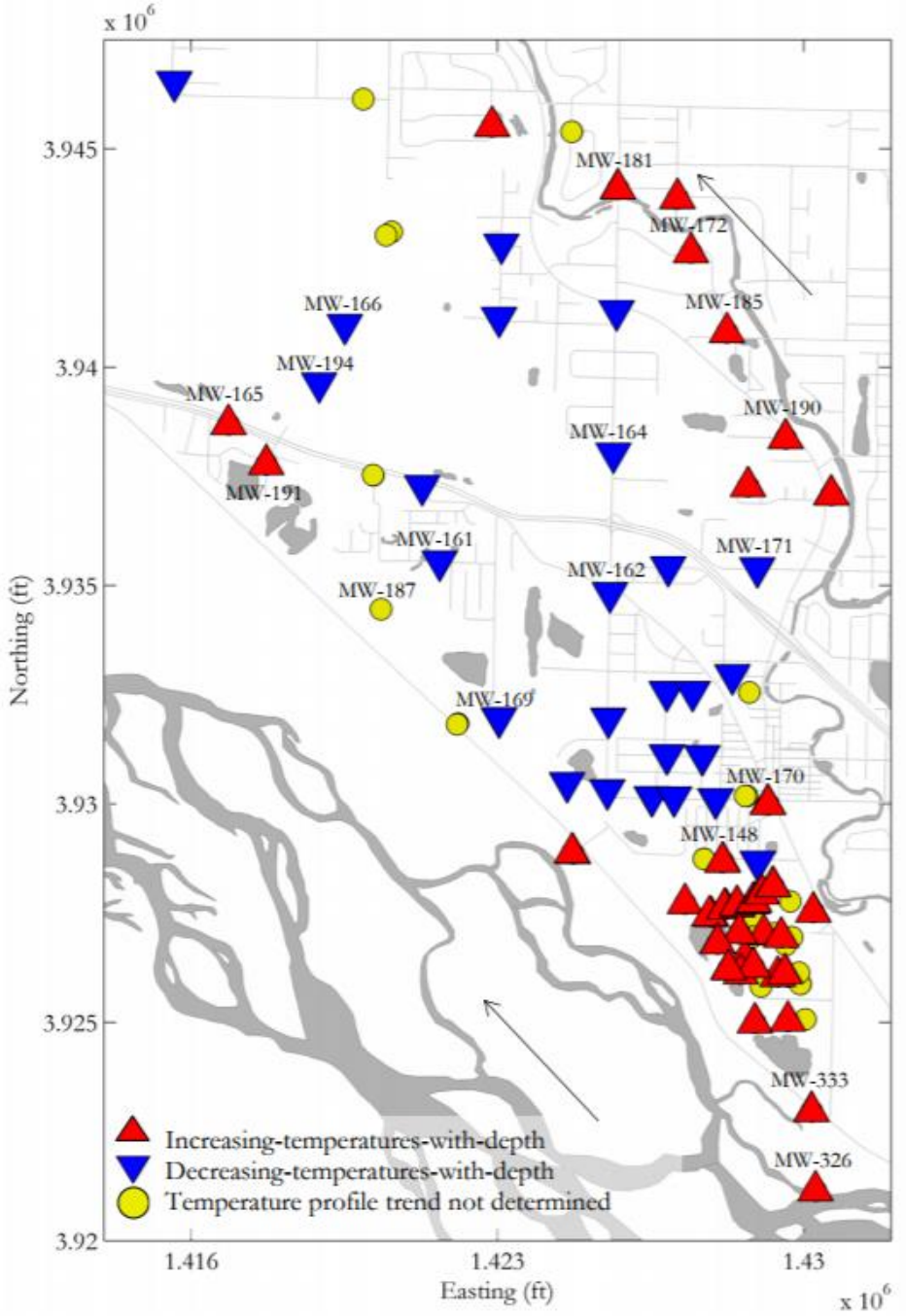
- SUPRApermafrost Groundwater
  - Relatively young
  - Influenced by recent precipitation, evaporation freezing/thawing, and snow melt
  - Potentially large seasonal temperature fluctuations
- SUBpermafrost Groundwater
  - Relatively old (longer residence time)
  - High dissolved solids concentration
  - Contact with bedrock
  - More consistent temperatures (often warmer with depth)

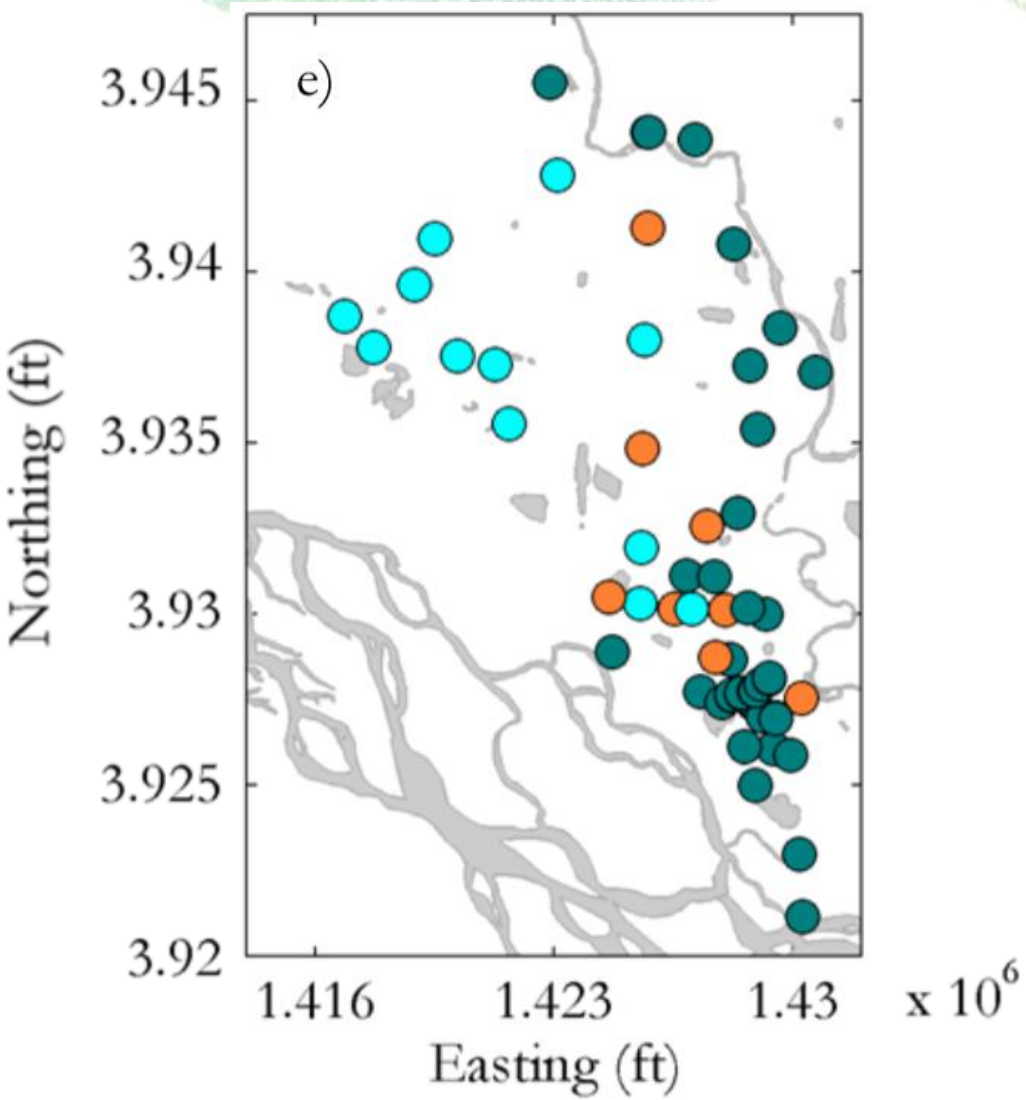
STUDY 1: TANANA FLOODPLAIN

- Contaminant plume from local refinery leads to extensive monitoring well network
- Complexity of flow, contaminant found in unexpected places
- Temperature
- Stable water isotopes

Purple circles signify where permafrost was not encountered to 60-100 ft (small circles) below 100 ft (large circles).

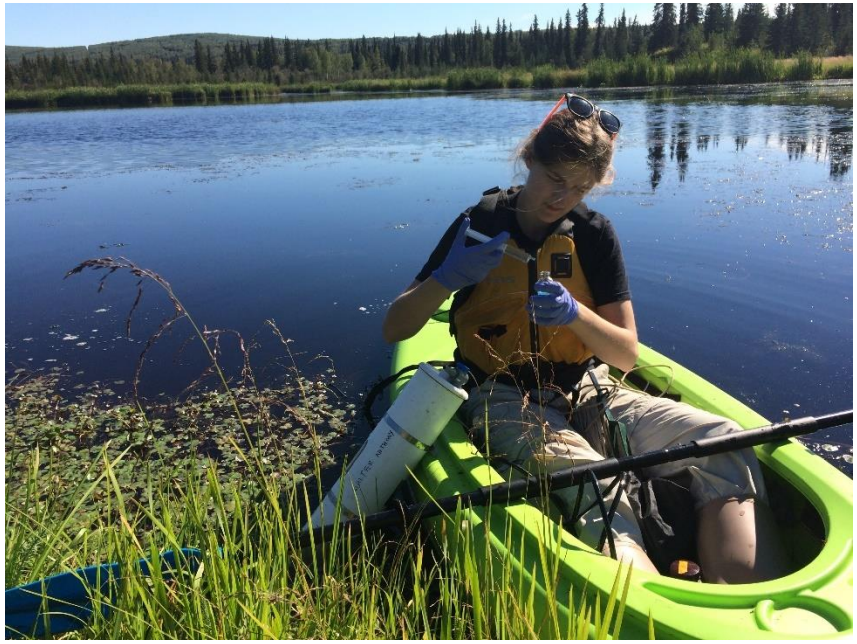



x 10^6
3.945
3.94
3.935
3.93
3.925
3.92
Northing (ft)
MW-181
MW-172
MW-166
MW-185
MW-194
MW-165
MW-190
MW-164
MW-191
MW-161
MW-171
MW-162
MW-187
MW-169
MW-170
MW-148
MW-333
MW-326
Increasing-temperatures-with-depth
Decreasing-temperatures-with-depth
Temperature profile trend not determined
1.416
1.423
1.43
Easting (ft)
x 10^6

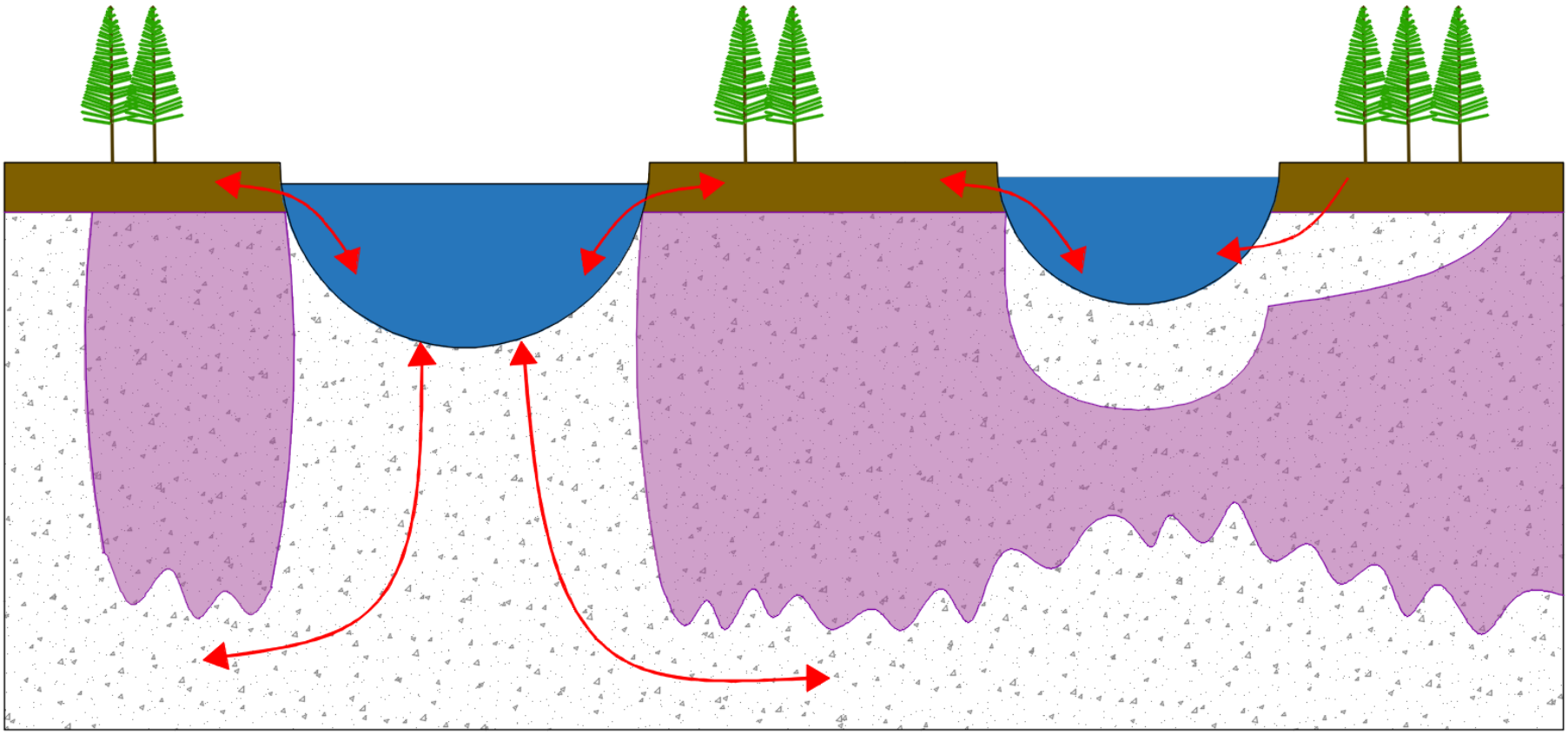

e)
3.945
3.94
3.935
3.93
3.925
3.92
Northing (ft)
1.416
1.423
1.43
x 10^6
Easting (ft)
Depleted in δ²H and δ¹⁸O
Enriched in δ²H and δ¹⁸O
Depleted in δ²H and Enriched in δ¹⁸O
Depleted in δ¹⁸O and Enriched in δ²H

STUDY 2: GOLDSTREAM VALLEY LAKES

- Transport of subpermafrost CH_4
- Two lakes
  - Open talik
  - Closed talik
- Electromagnetic imaging



CONCEPTUAL MODEL



GOLDSTREAM VALLEY SITES

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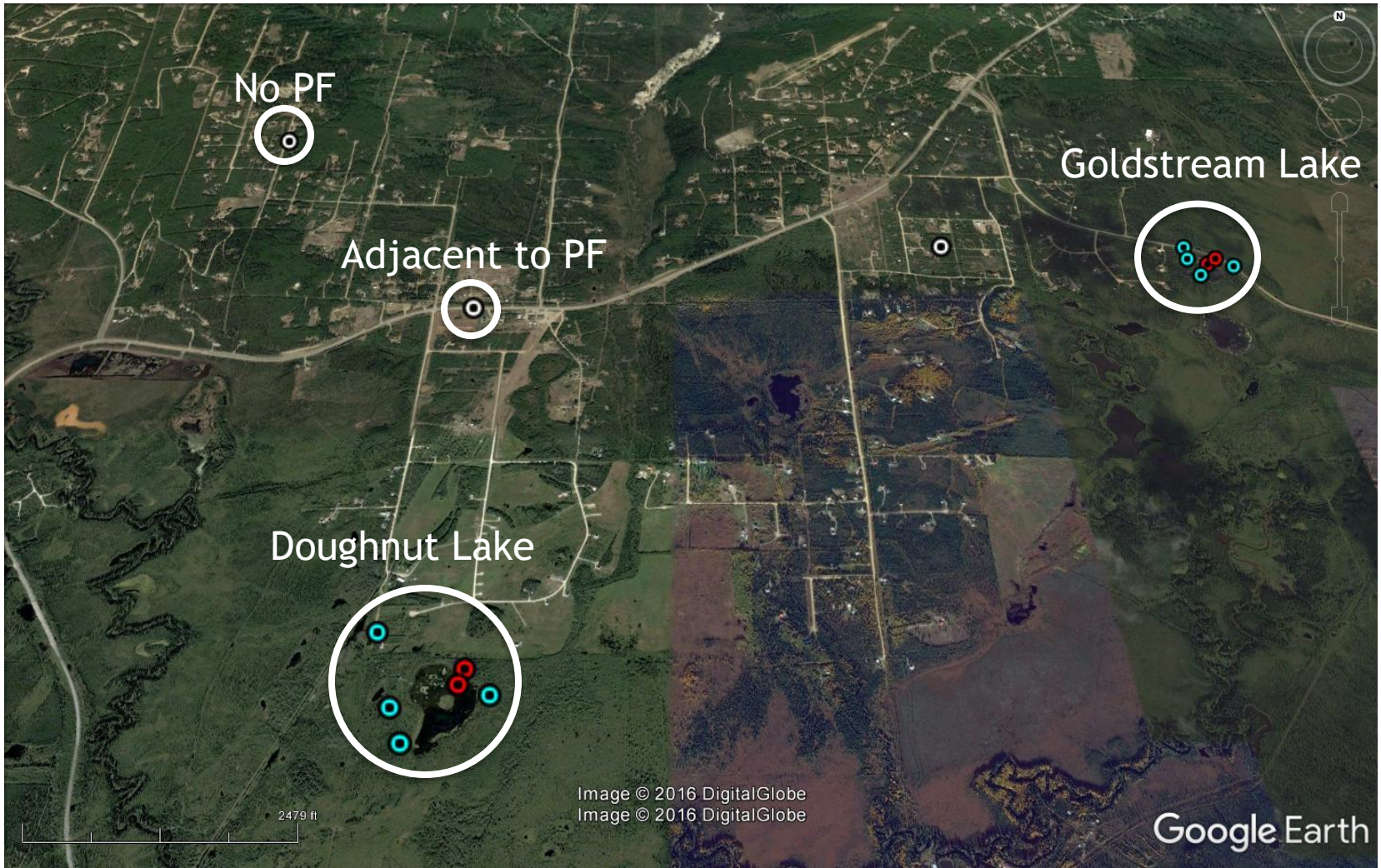
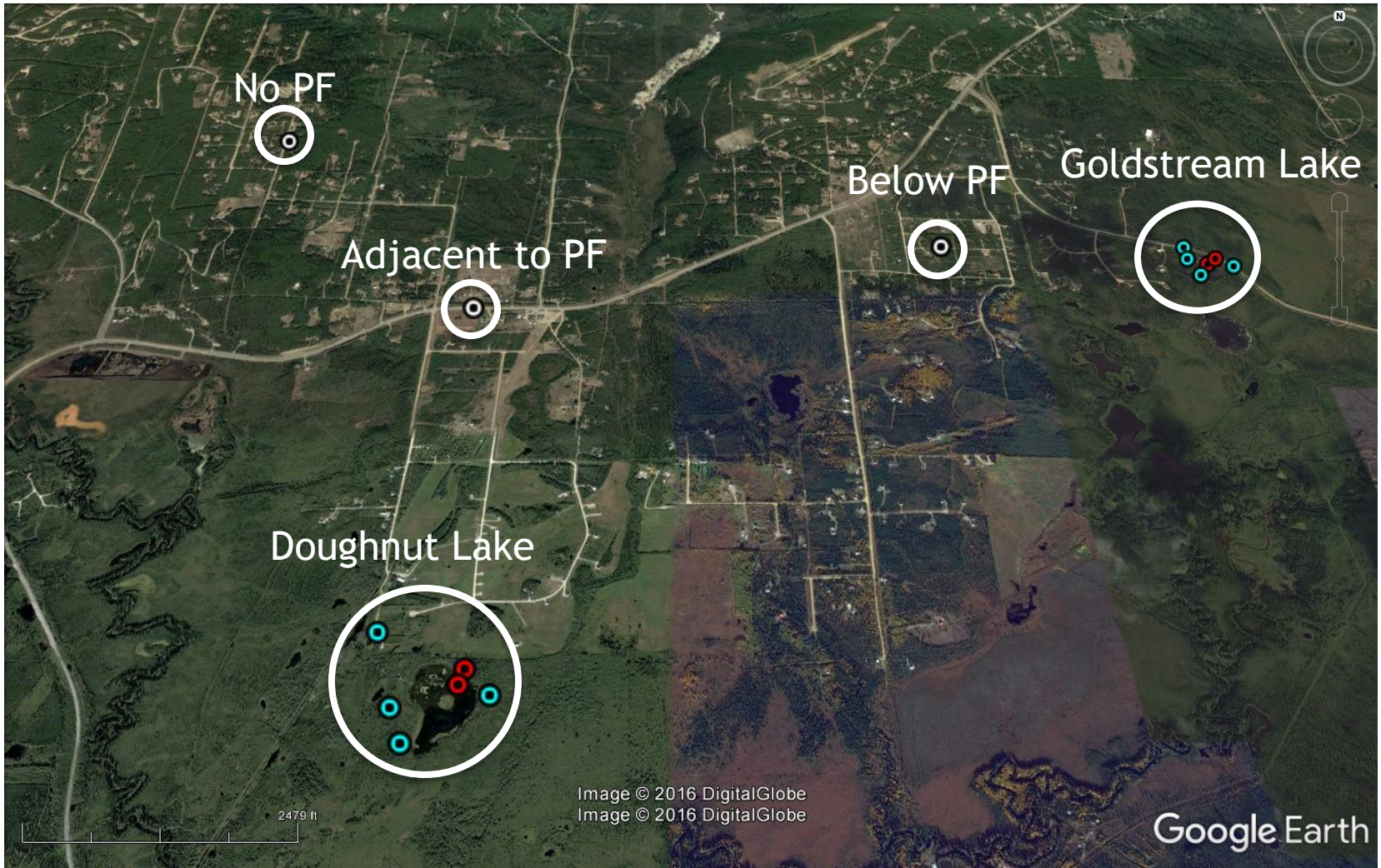
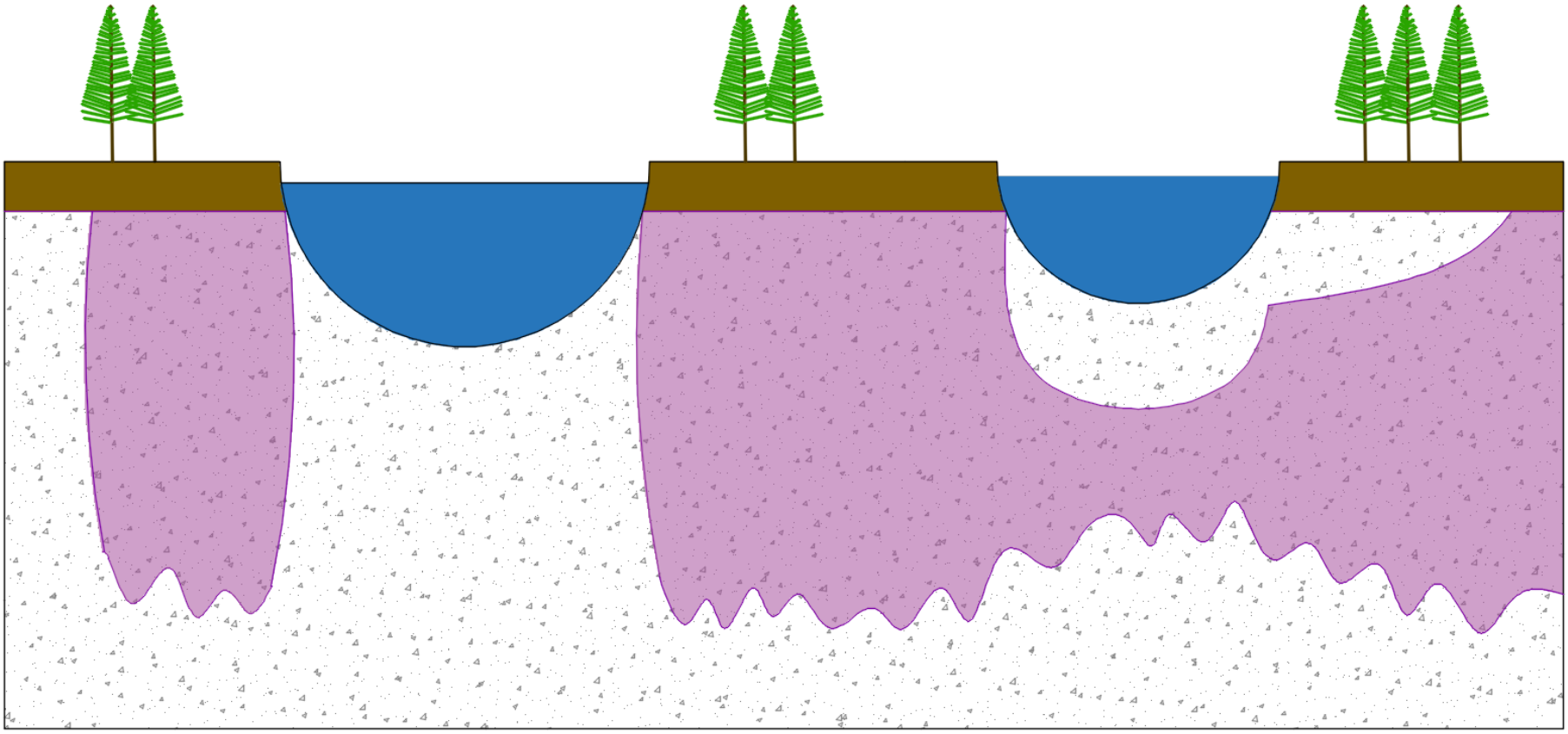


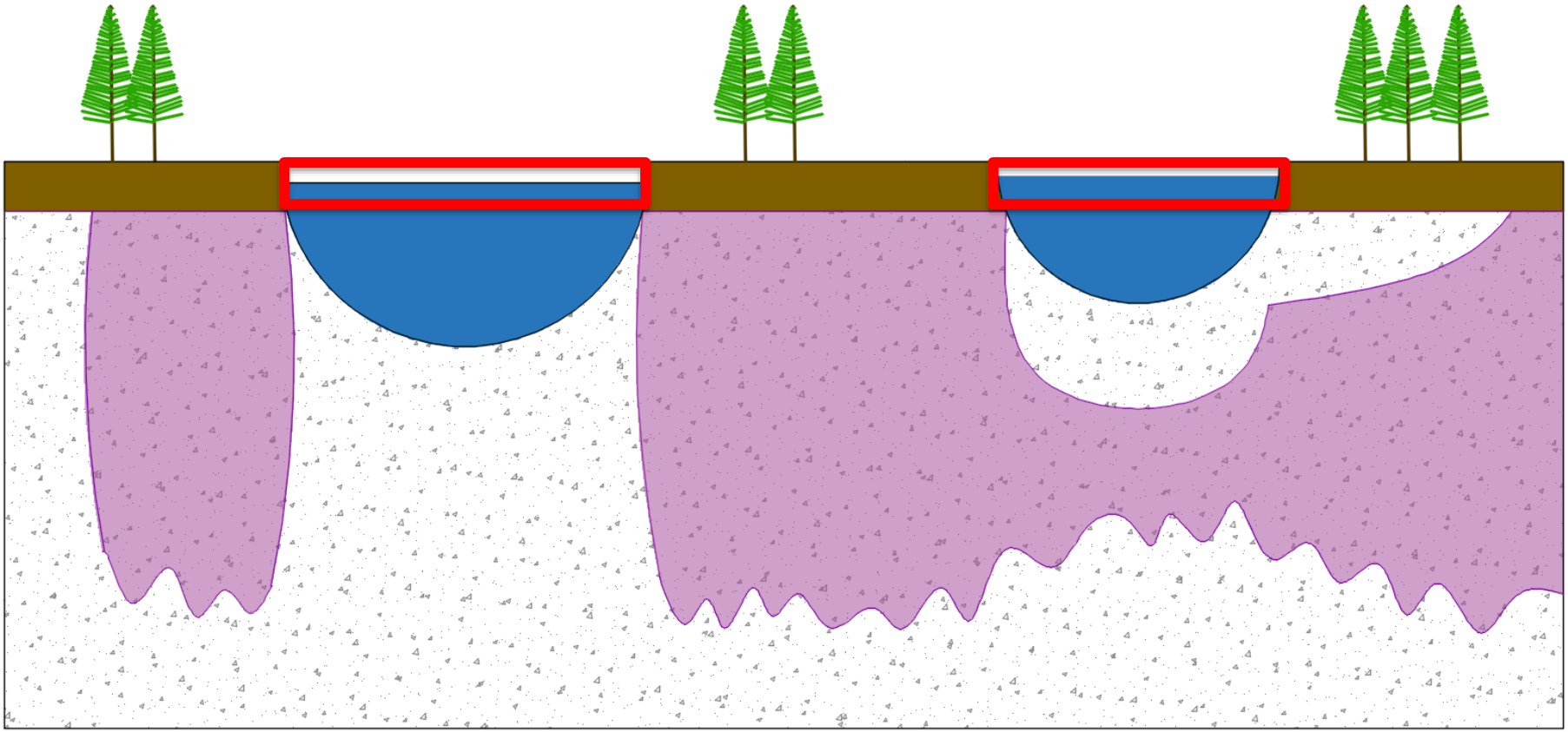
GOLDSTREAM VALLEY SITES



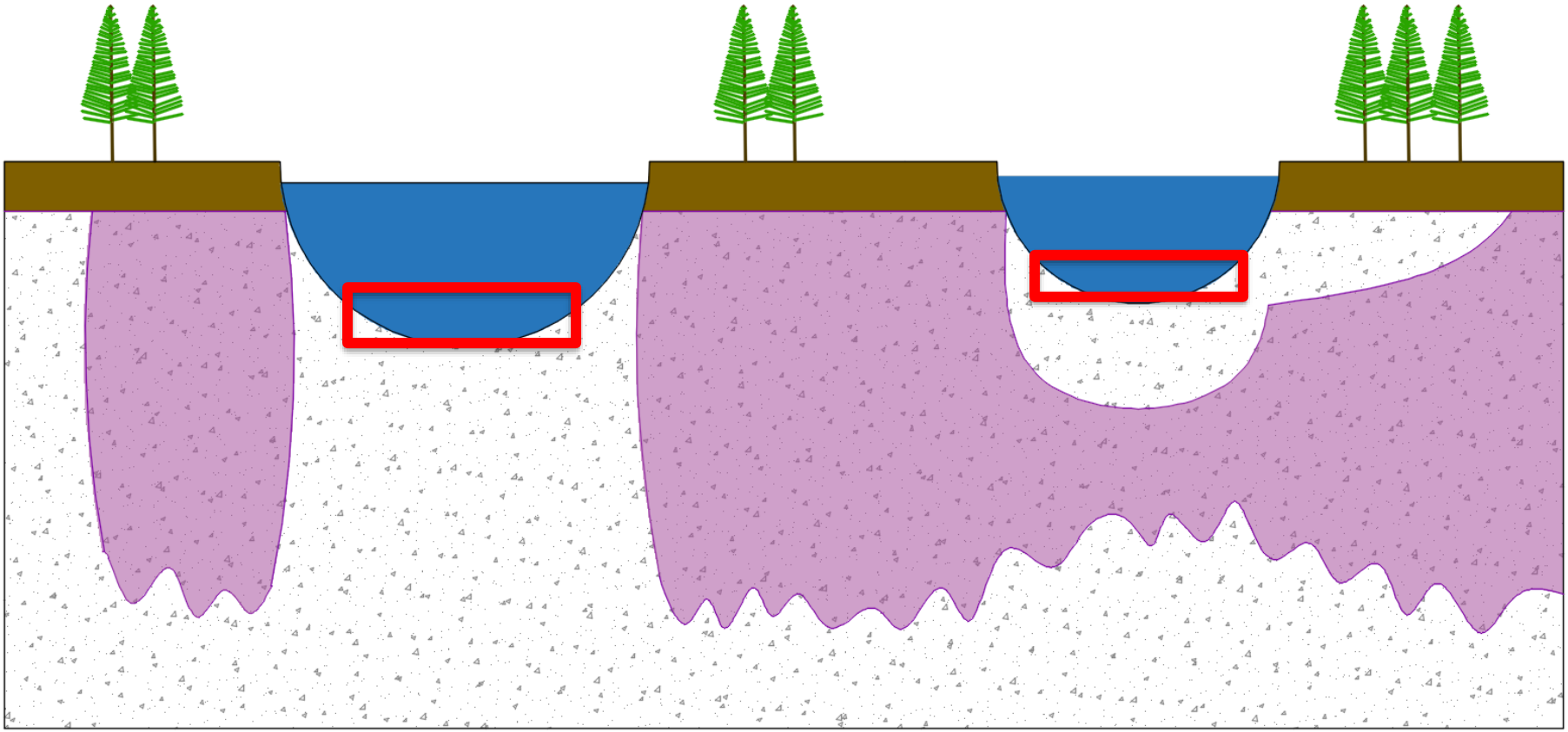
DATA COLLECTION POINTS



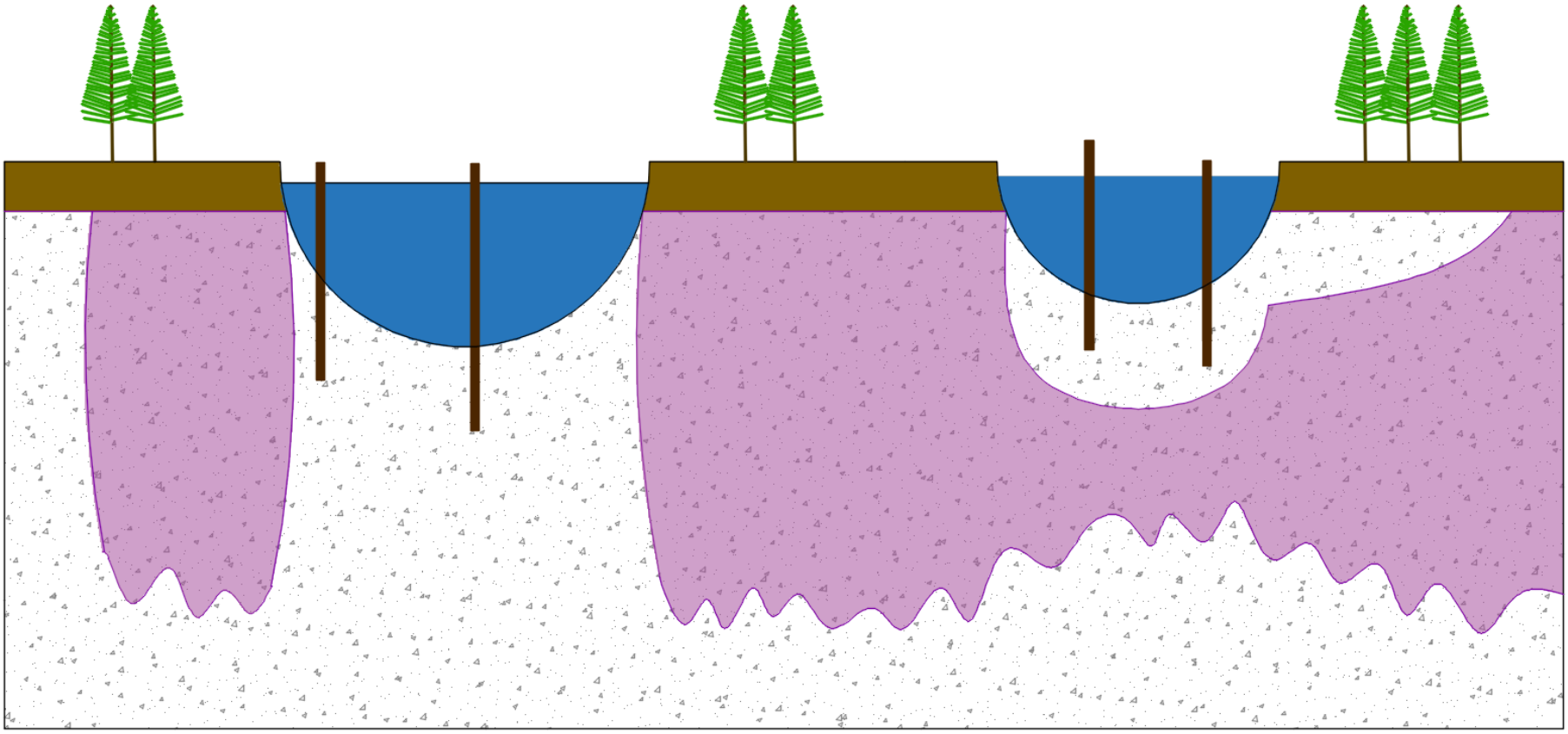
WATER COLUMN SAMPLING



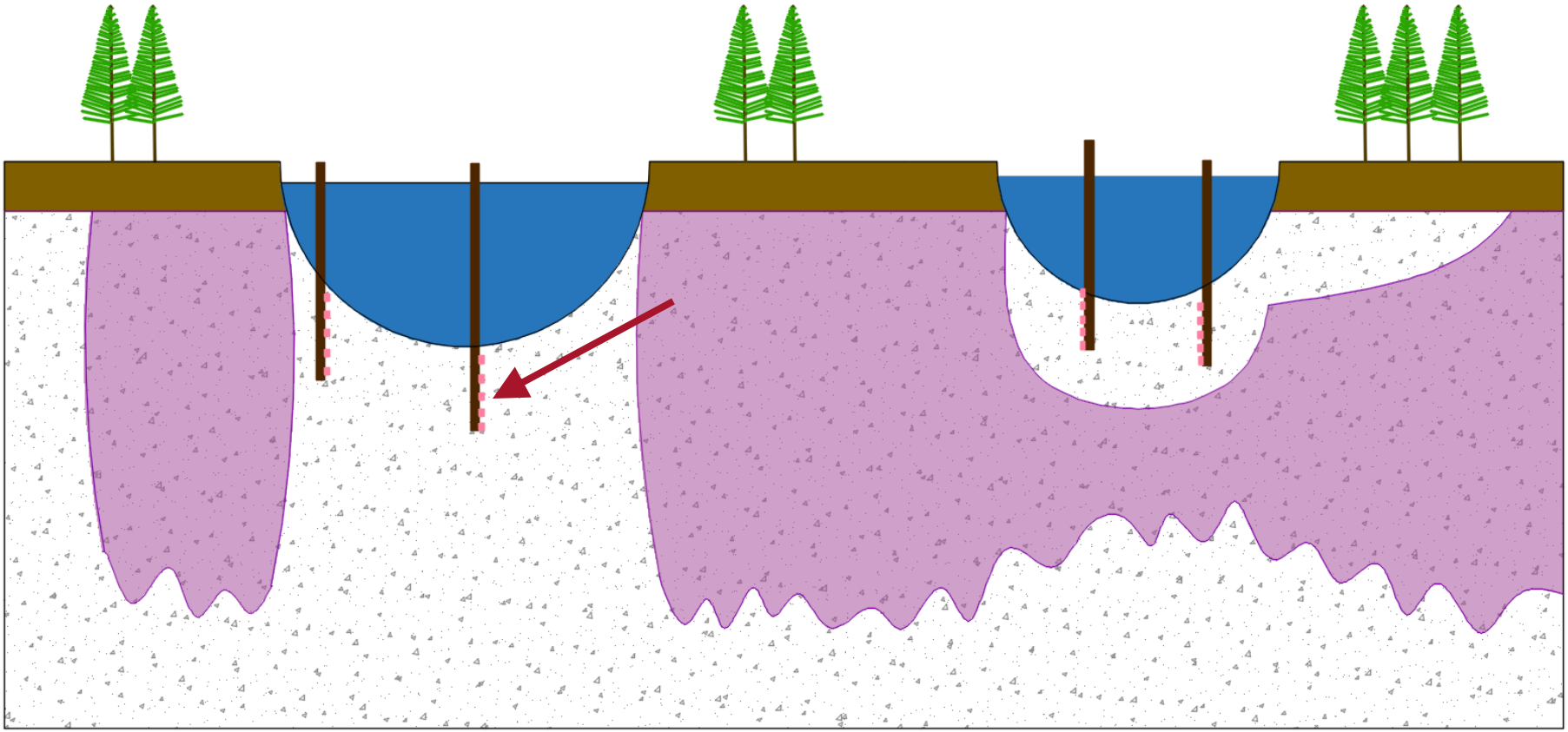
WATER COLUMN SAMPLING



TALIK MONITORING POLES



SOIL SOLUTION SAMPLERS



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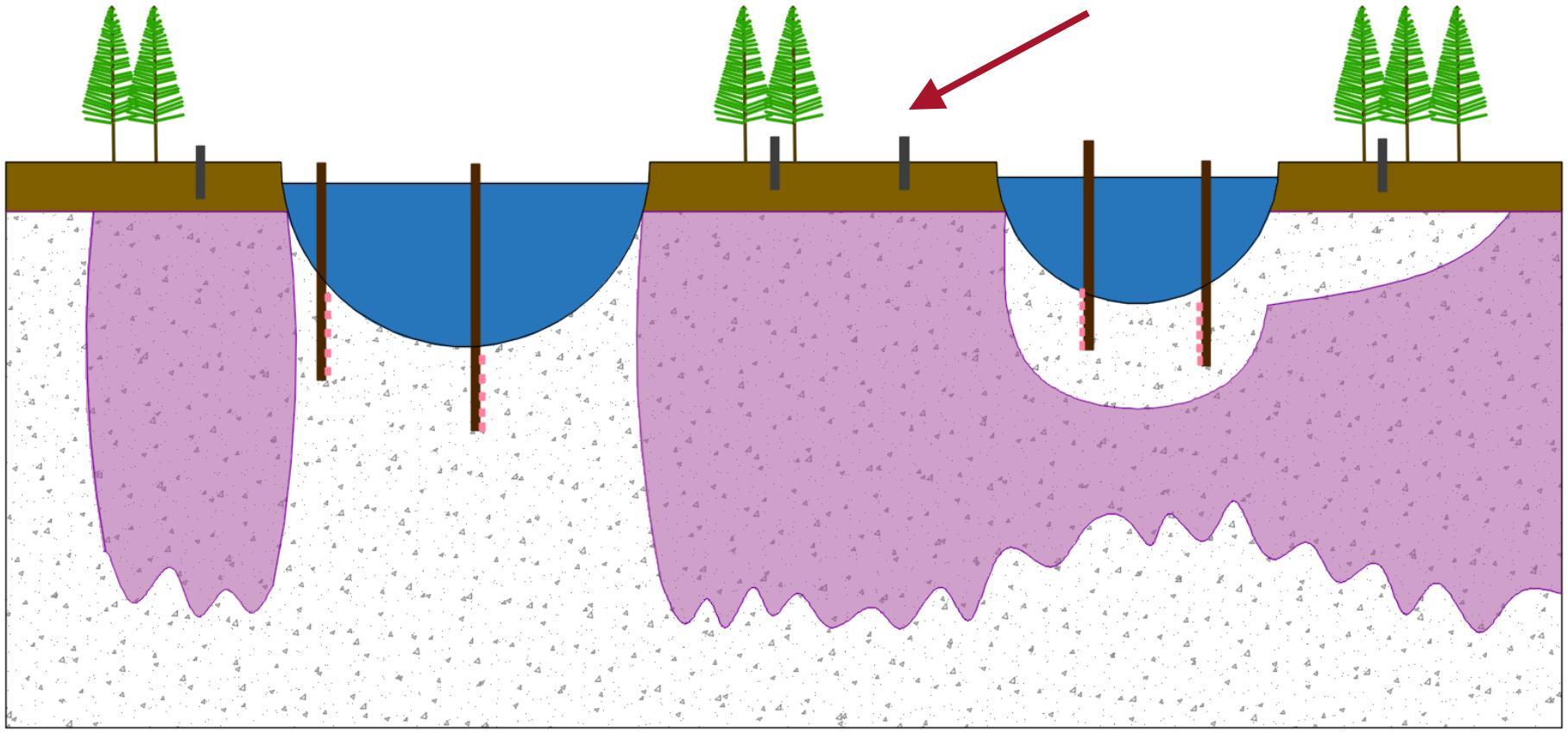
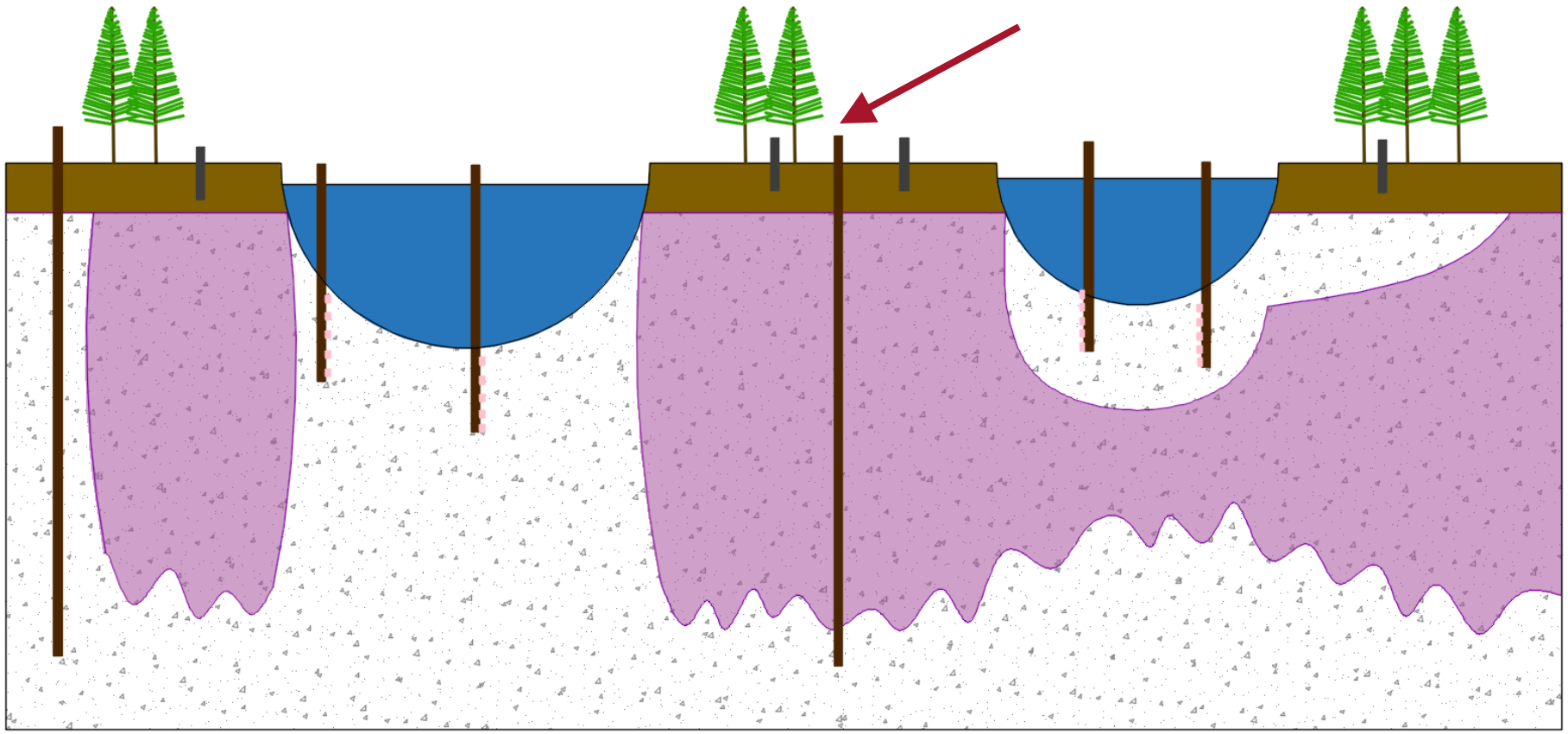
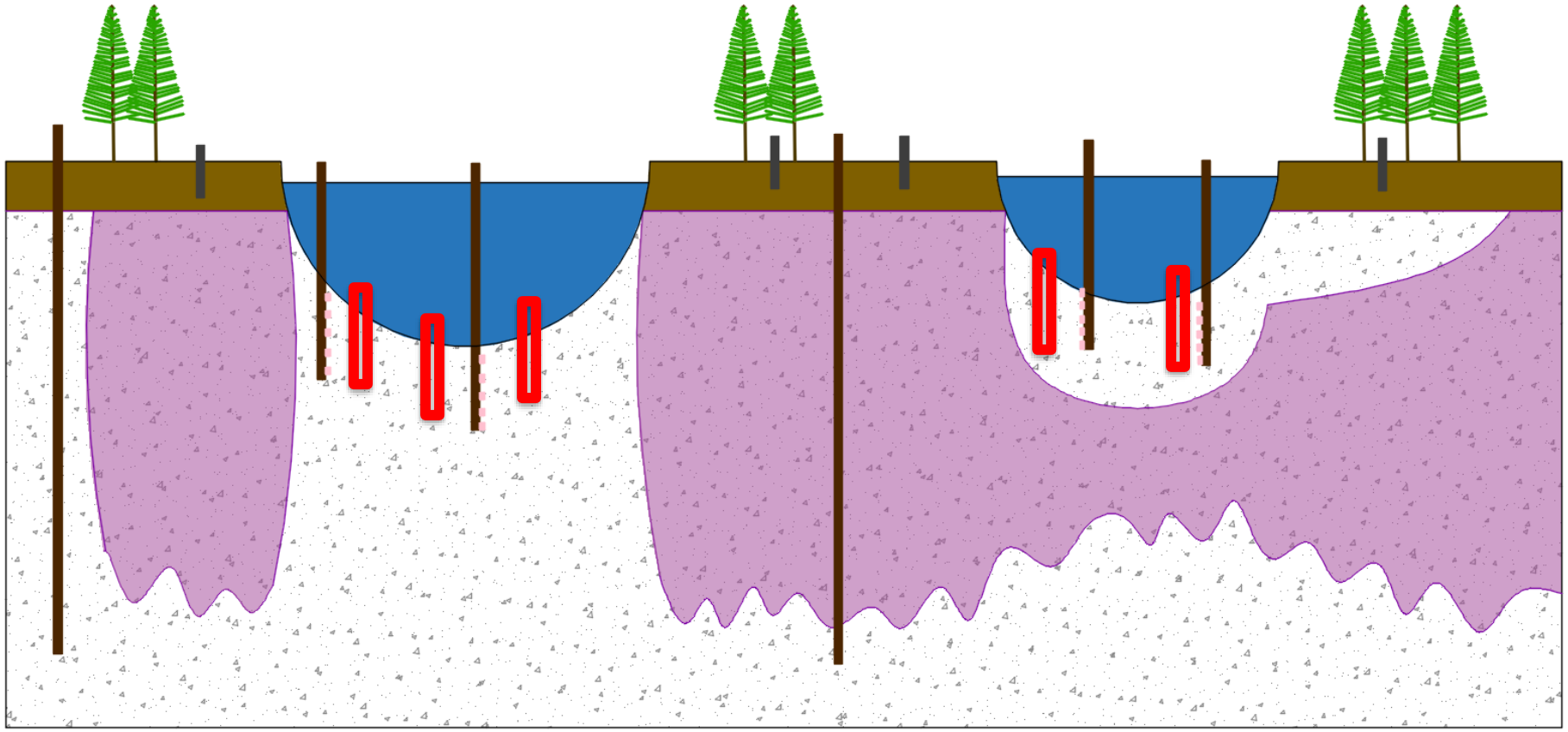
ACTIVE LAYER DRIVE POINTS



RESIDENTIAL DRINKING WATER WELLS

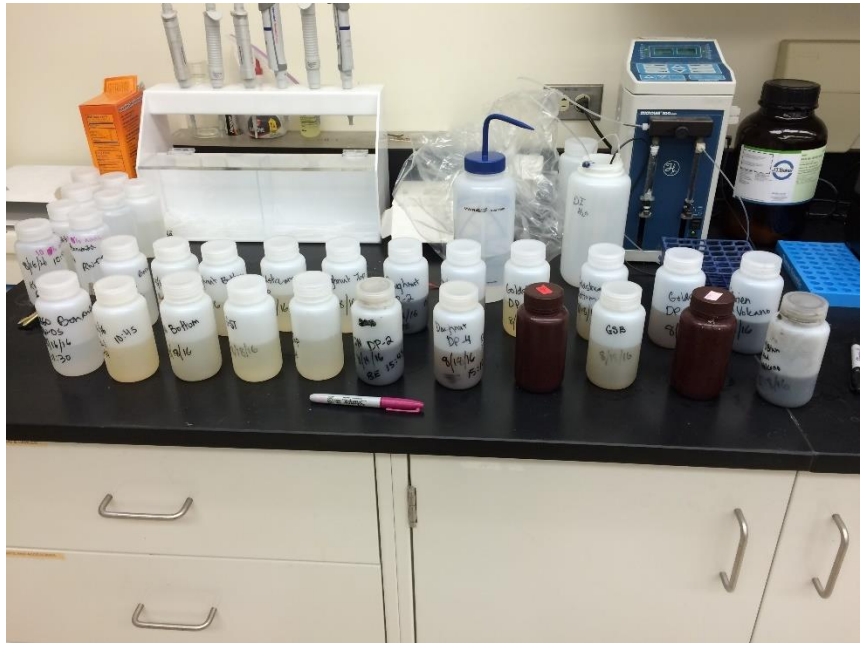


HAMMER CORE SAMPLES

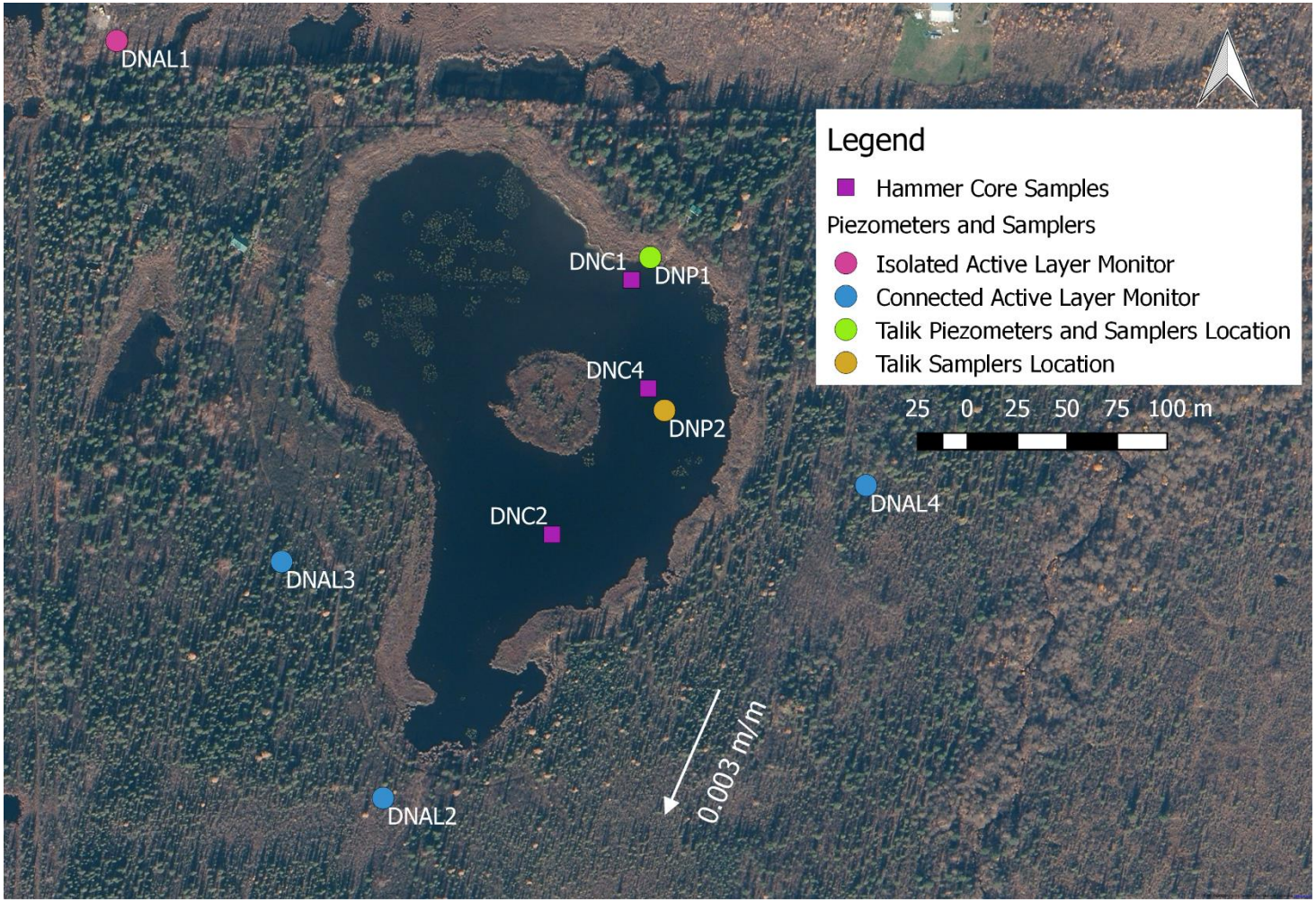


TRACERS

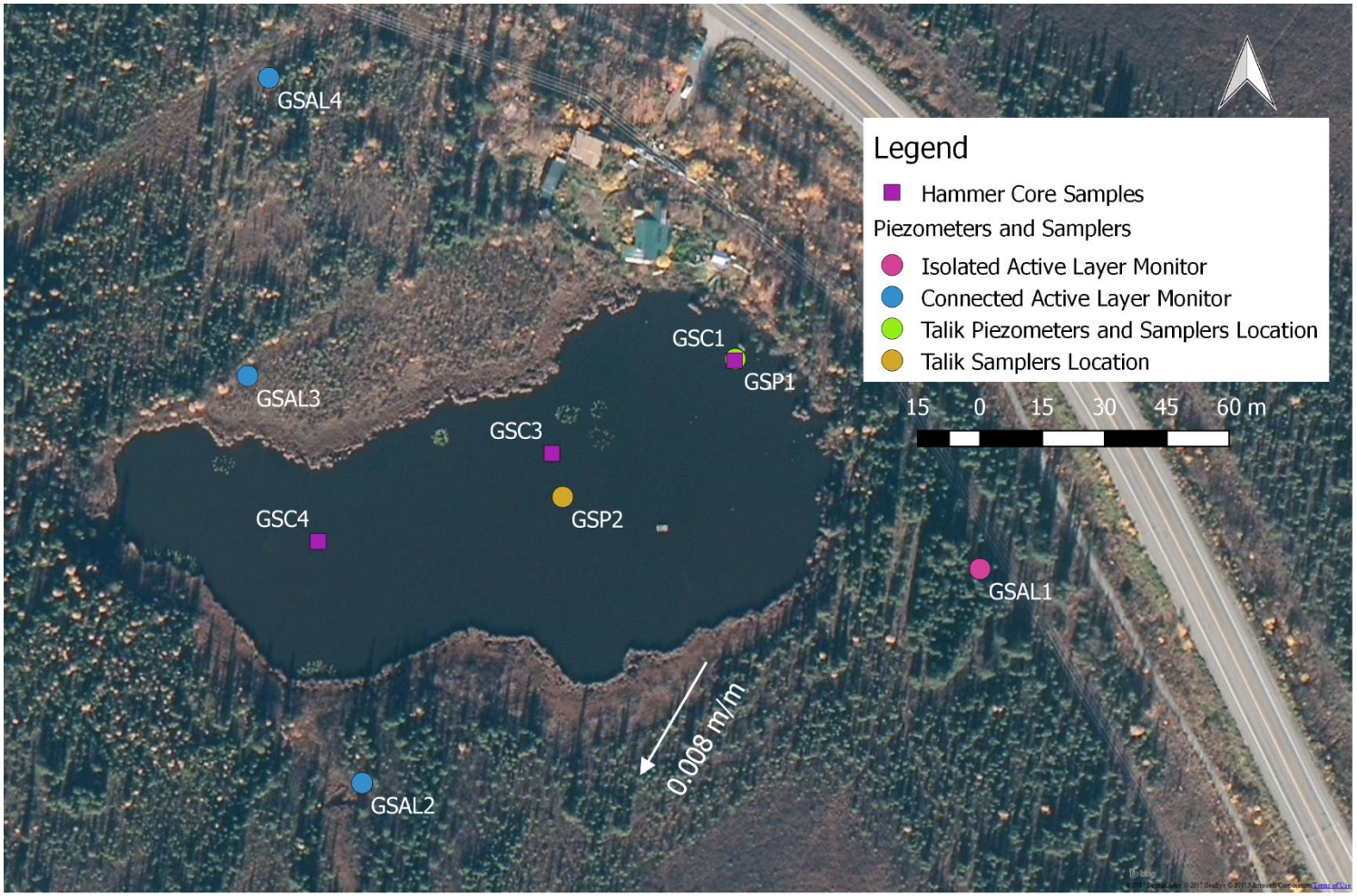
- Geochemical tracers
  - Stable water isotopes
  - Conductivity, pH, DO, ORP, alkalinity
  - Major cations/anions
- Physical tracers
  - Surface water level
  - Pressure heads
  - Water temperature

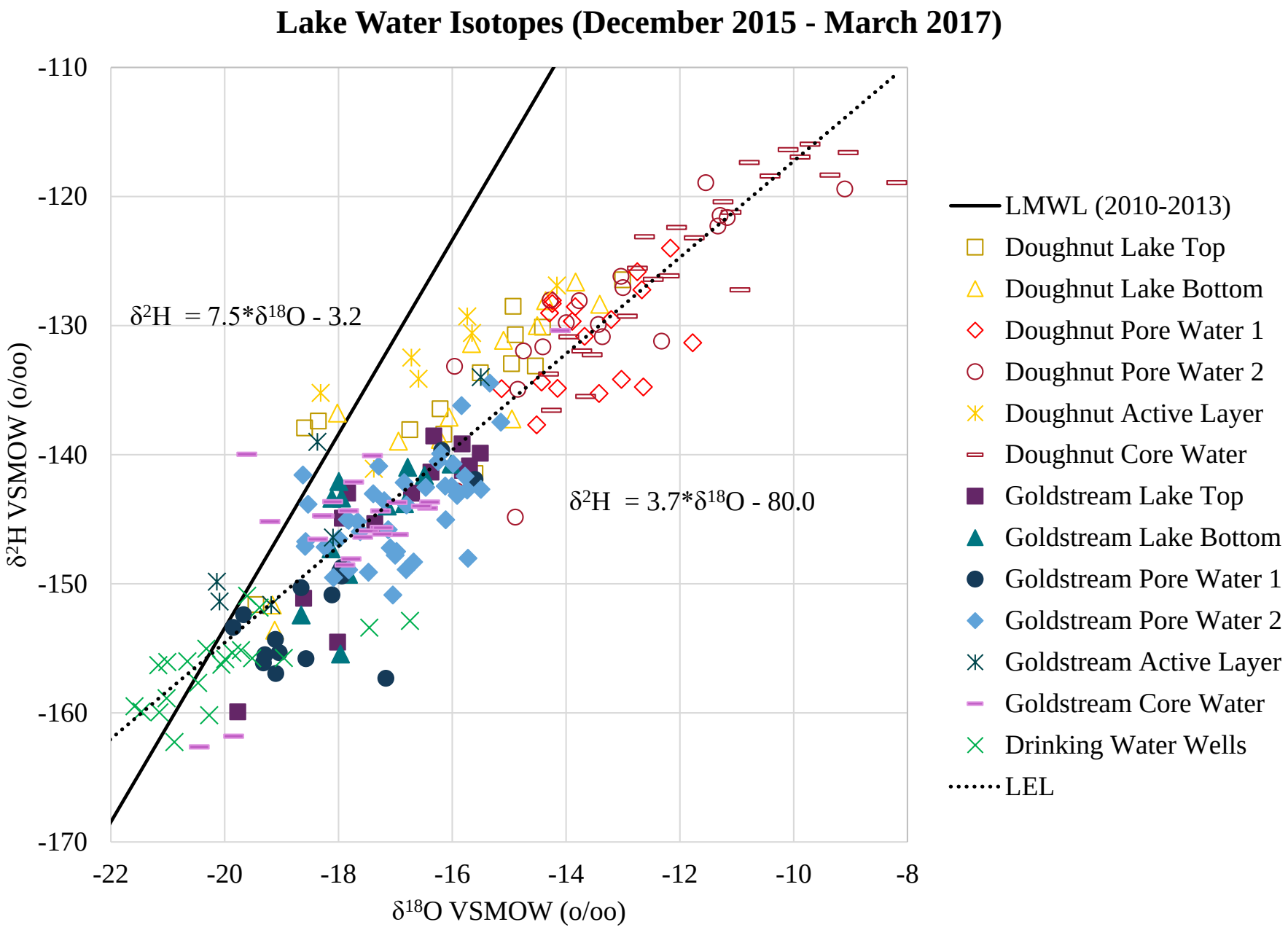


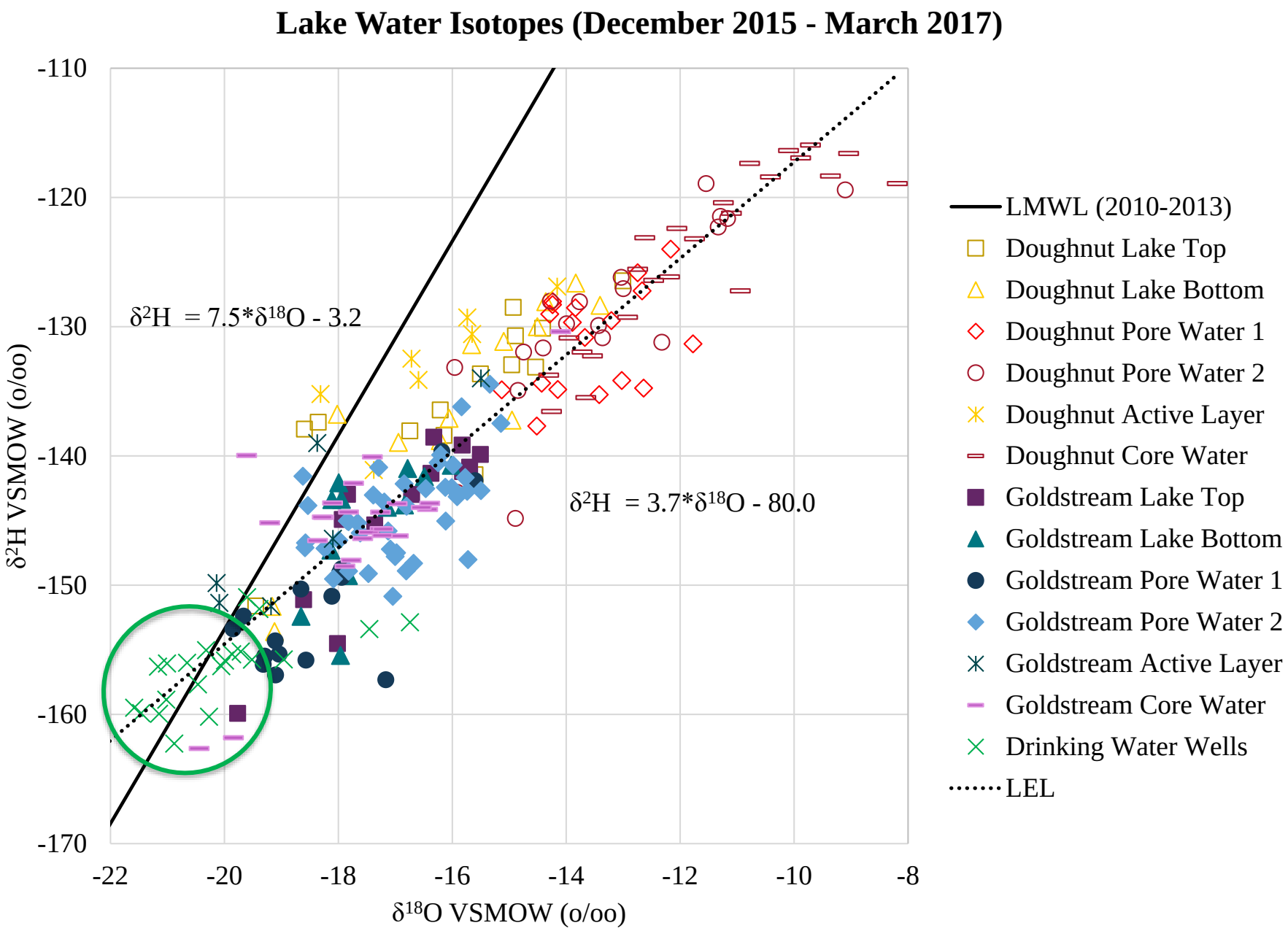
DOUGHNUT LAKE



GOLDSTREAM LAKE




Lake Water Isotopes (December 2015 - March 2017)
δ²H = 7.5*δ¹⁸O - 3.2
δ²H = 3.7*δ¹⁸O - 80.0
δ²H VSMOW (o/oo)
δ¹⁸O VSMOW (o/oo)
-110
-120
-130
-140
-150
-160
-170
-22
-20
-18
-16
-14
-12
-10
-8
LMWL (2010-2013)
Doughnut Lake Top
Doughnut Lake Bottom
Doughnut Pore Water 1
Doughnut Pore Water 2
Doughnut Active Layer
Doughnut Core Water
Goldstream Lake Top
Goldstream Lake Bottom
Goldstream Pore Water 1
Goldstream Pore Water 2
Goldstream Active Layer
Goldstream Core Water
Drinking Water Wells
LEL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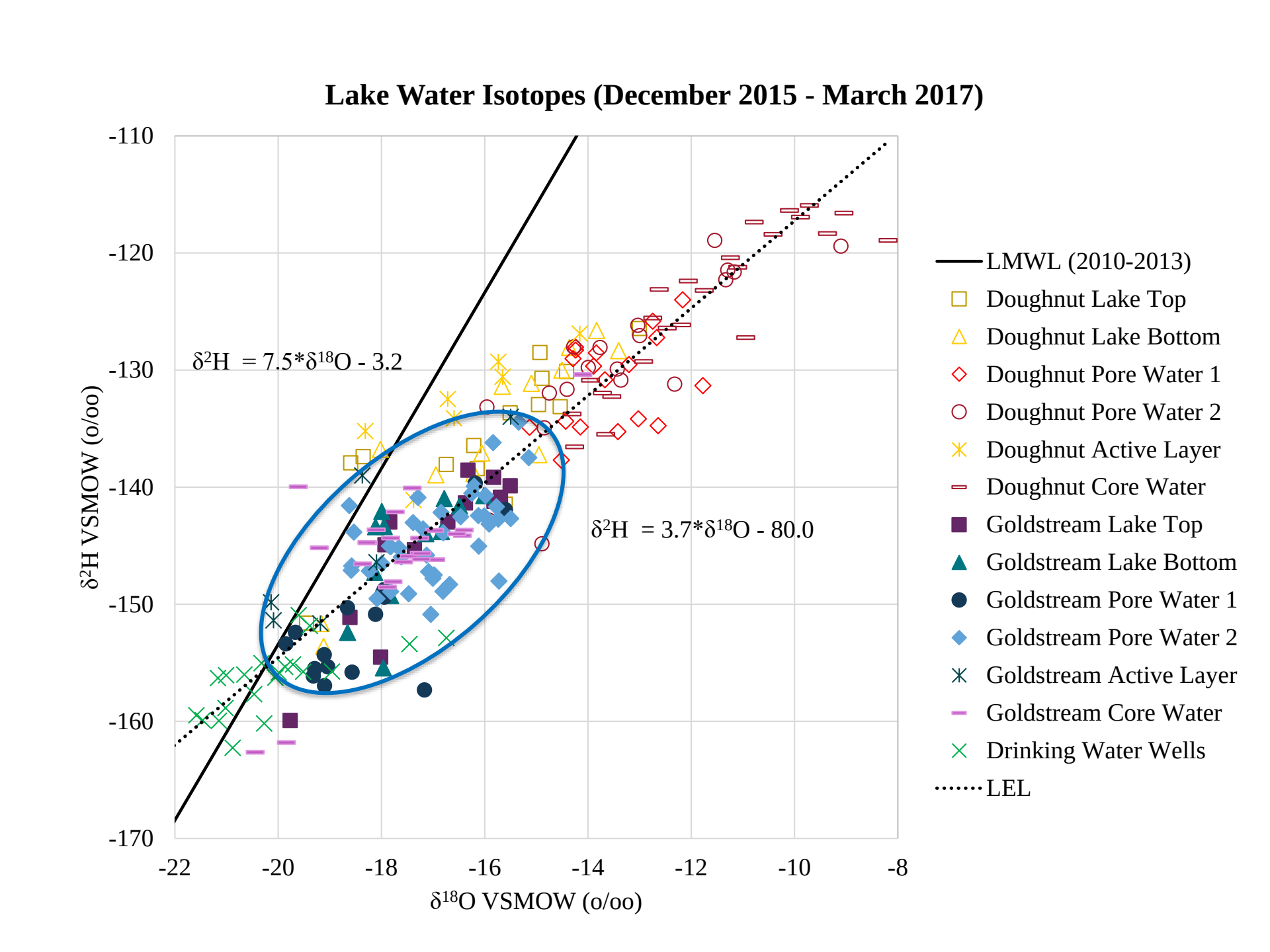
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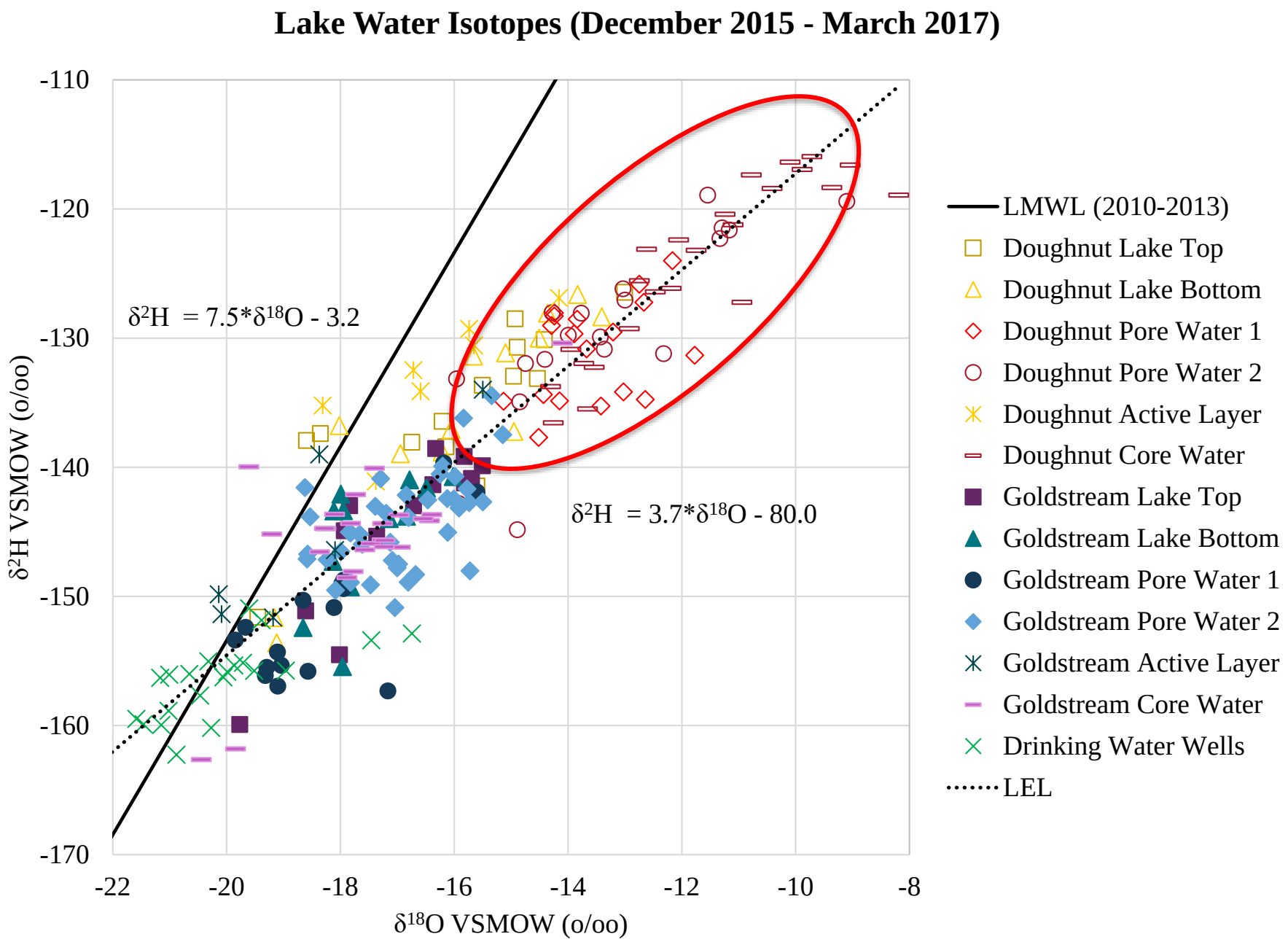
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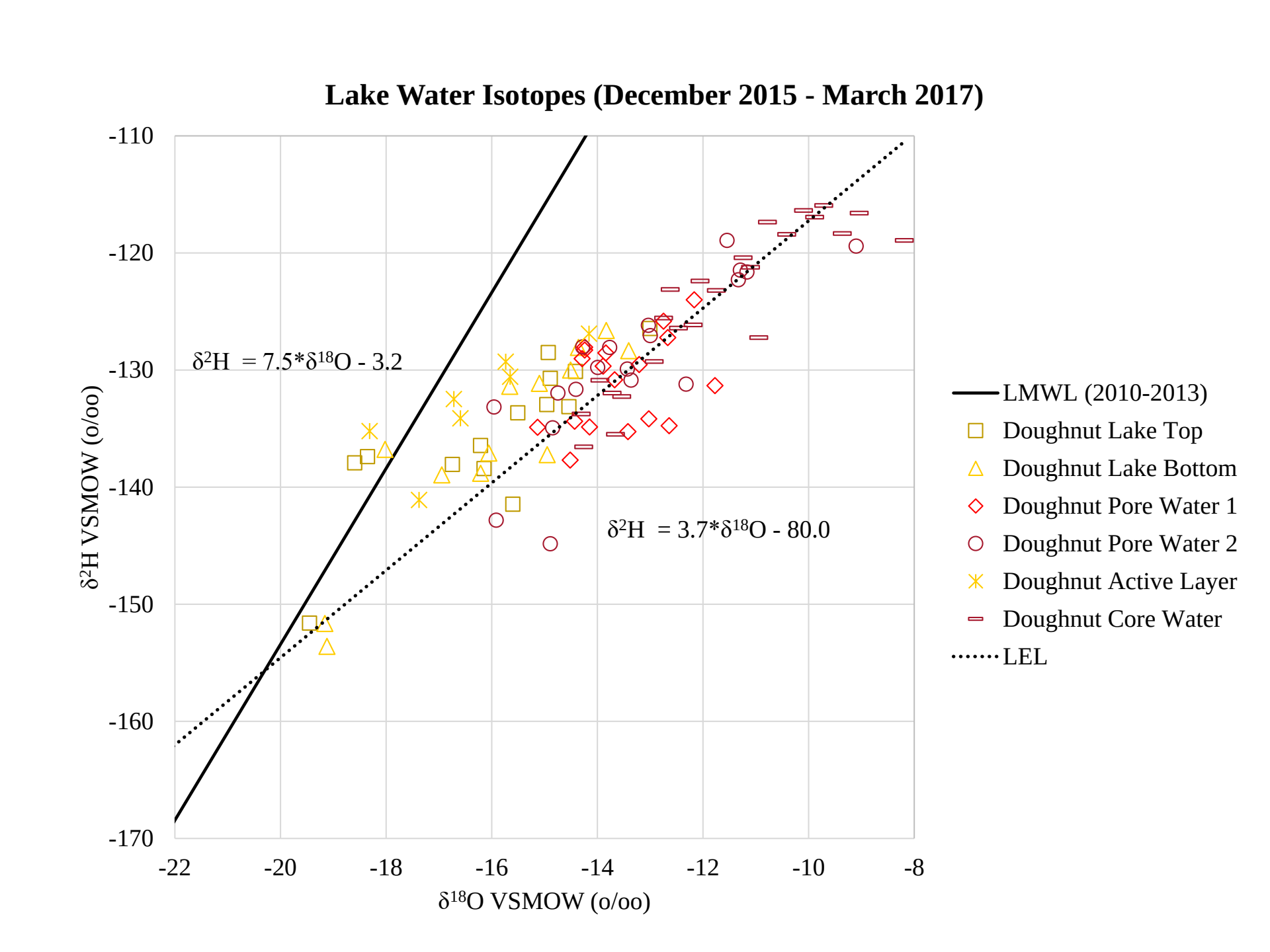
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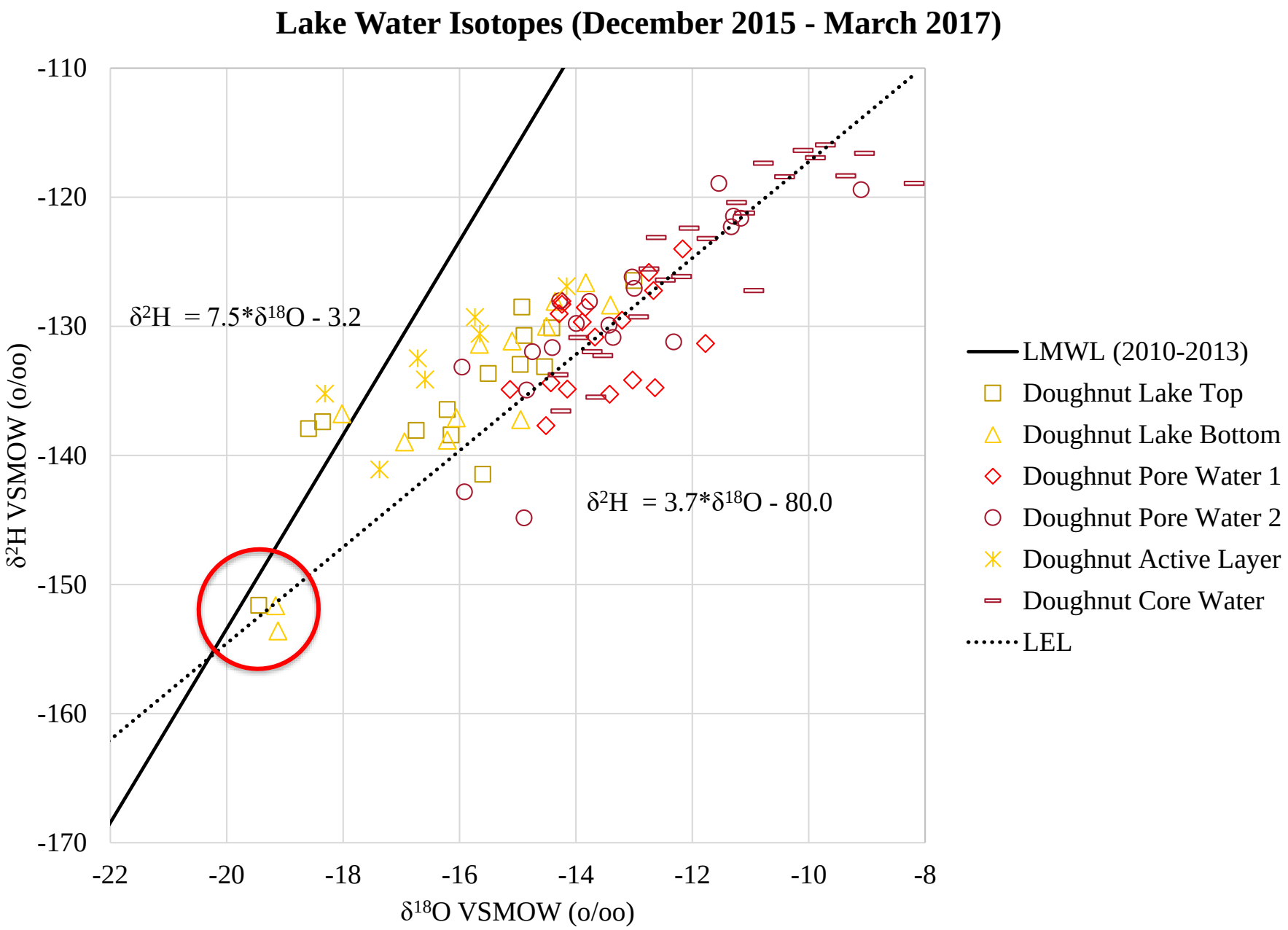
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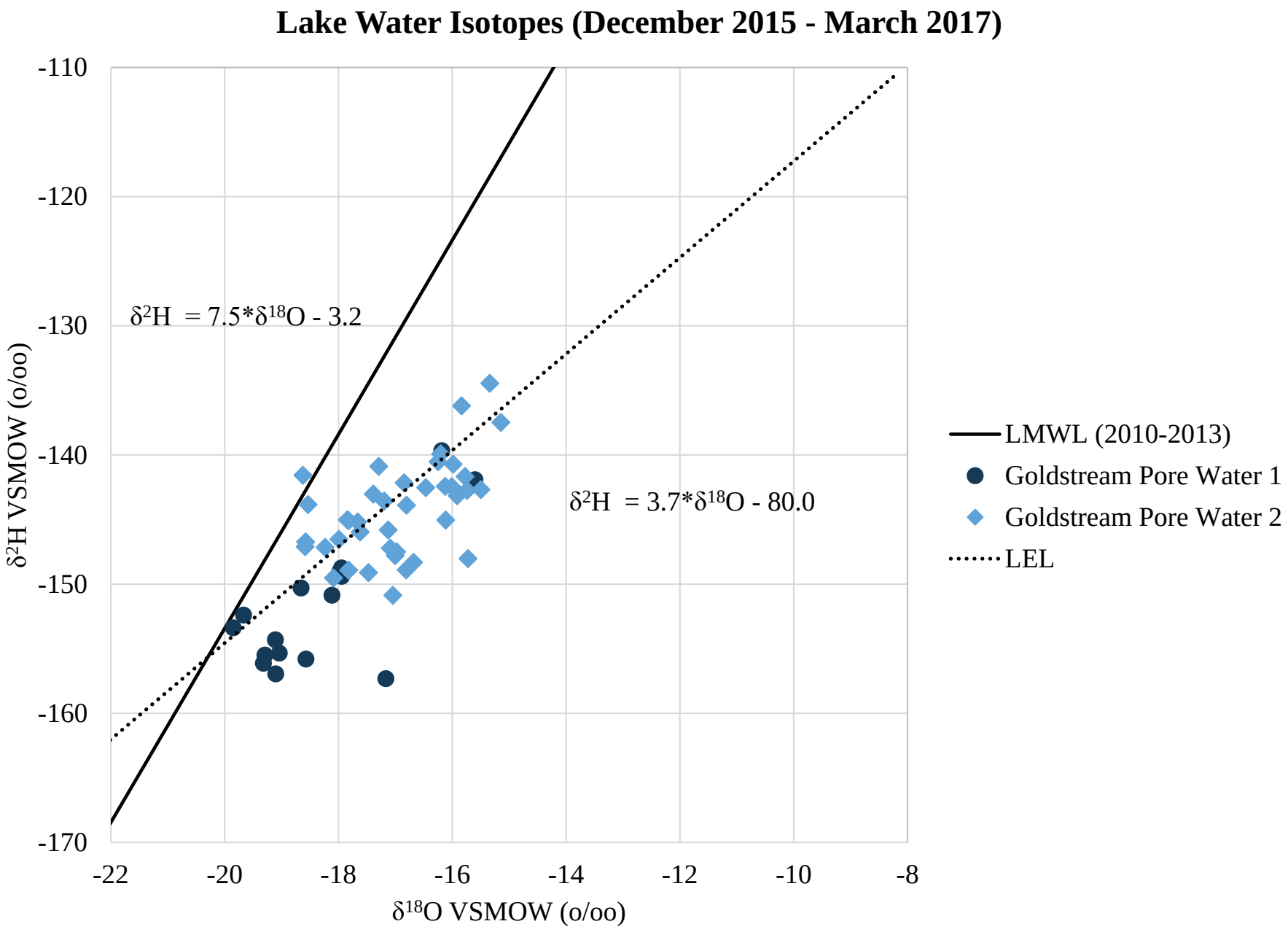
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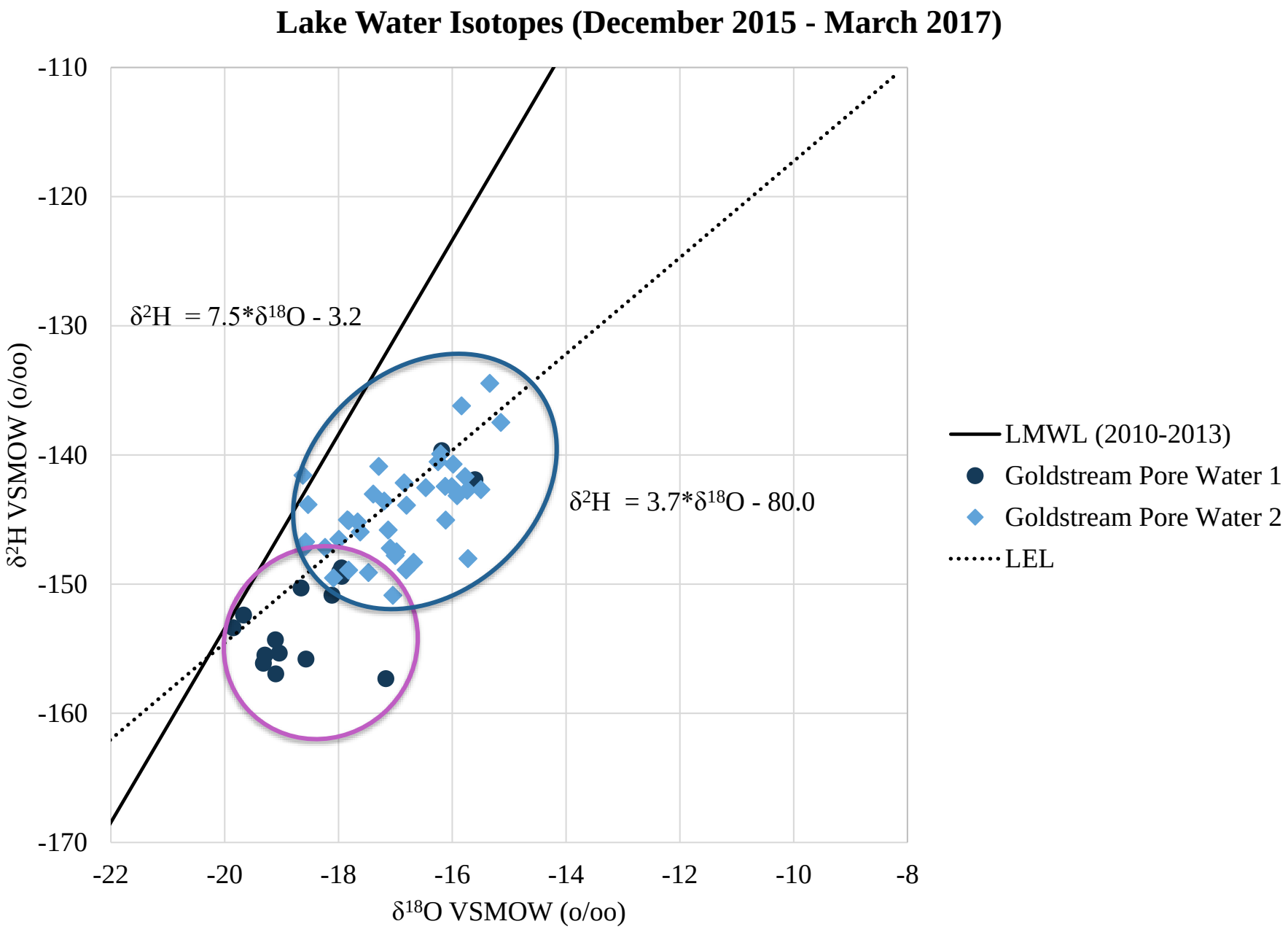
-110
-120
-130
-140
-150
-160
-170
δ²H VSMOW (o/oo)
-22
-20
-18
-16
-14
-12
-10
-8
δ¹⁸O VSMOW (o/oo)
δ²H = 7.5*δ¹⁸O - 3.2
δ²H = 3.7*δ¹⁸O - 80.0
LMWL (2010-2013)
Goldstream Pore Water 1
Goldstream Pore Water 2
LEL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-110
-120
-130
-140
-150
-160
-170
δ²H VSMOW (o/oo)
-22
-20
-18
-16
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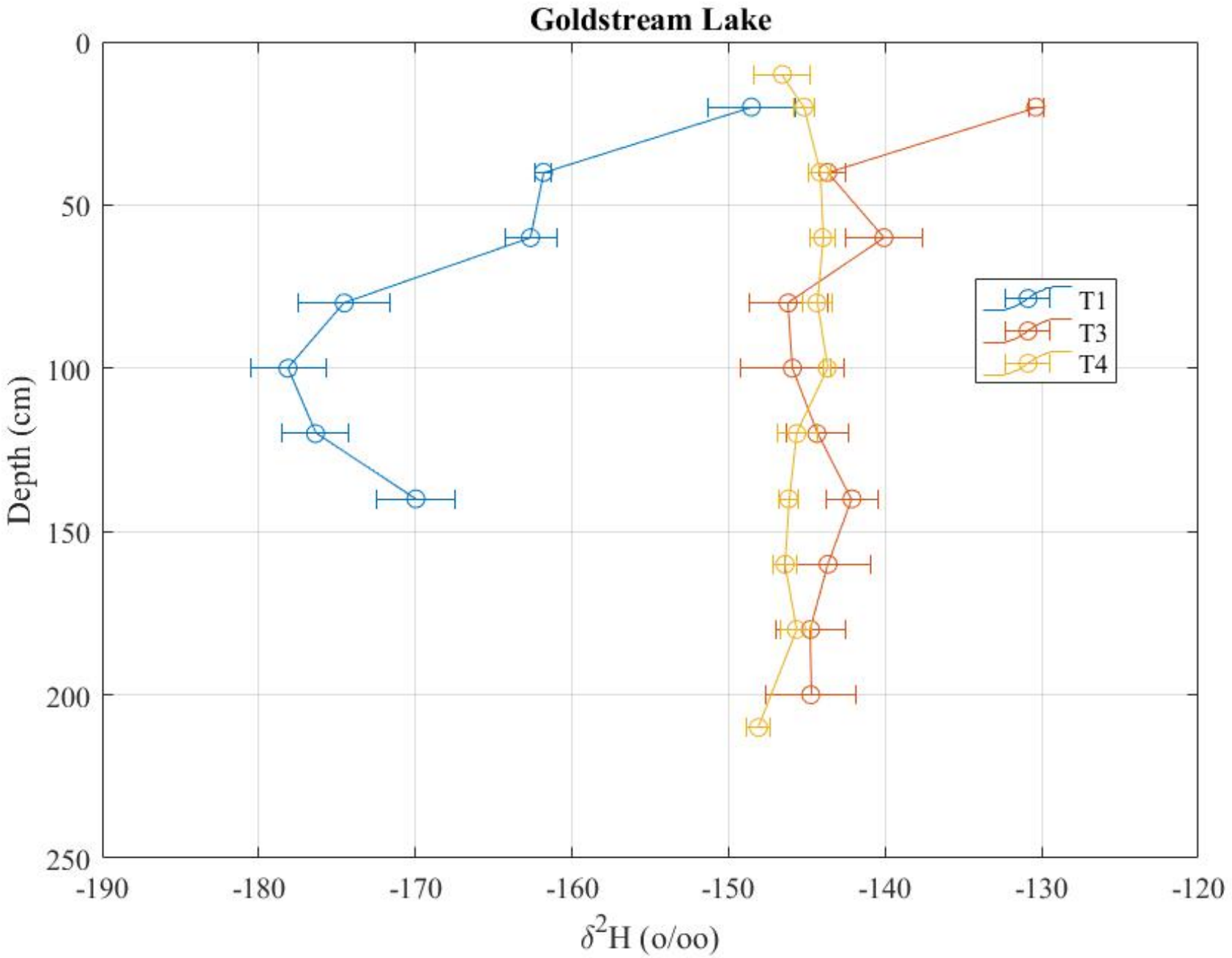
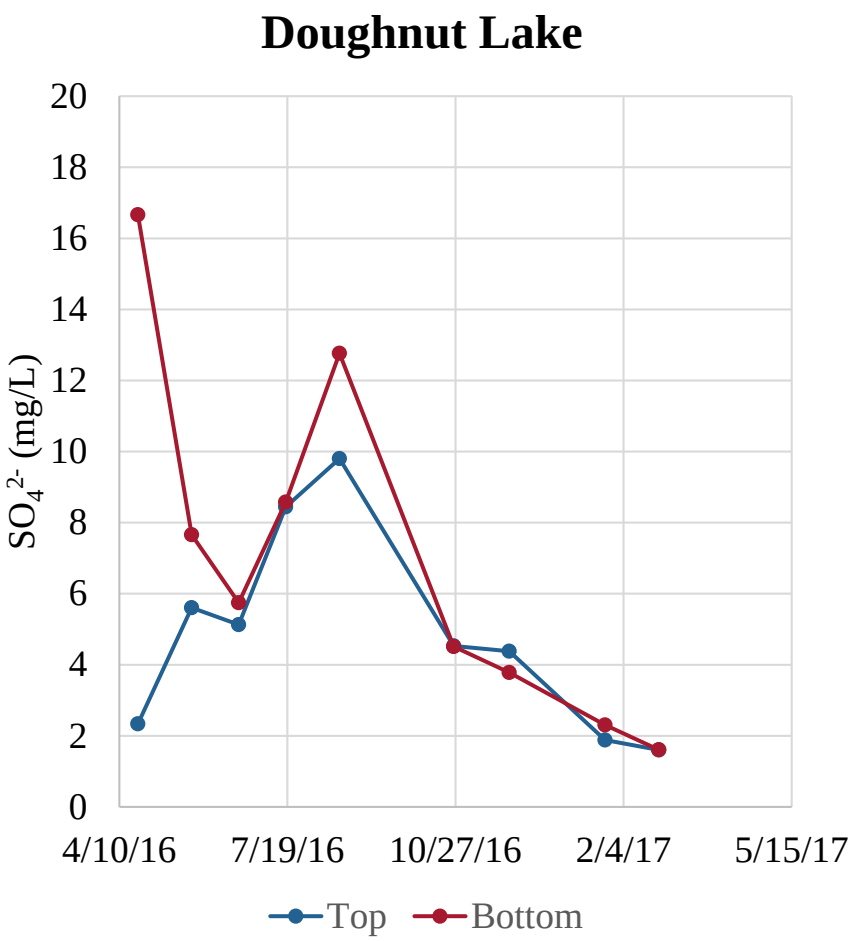
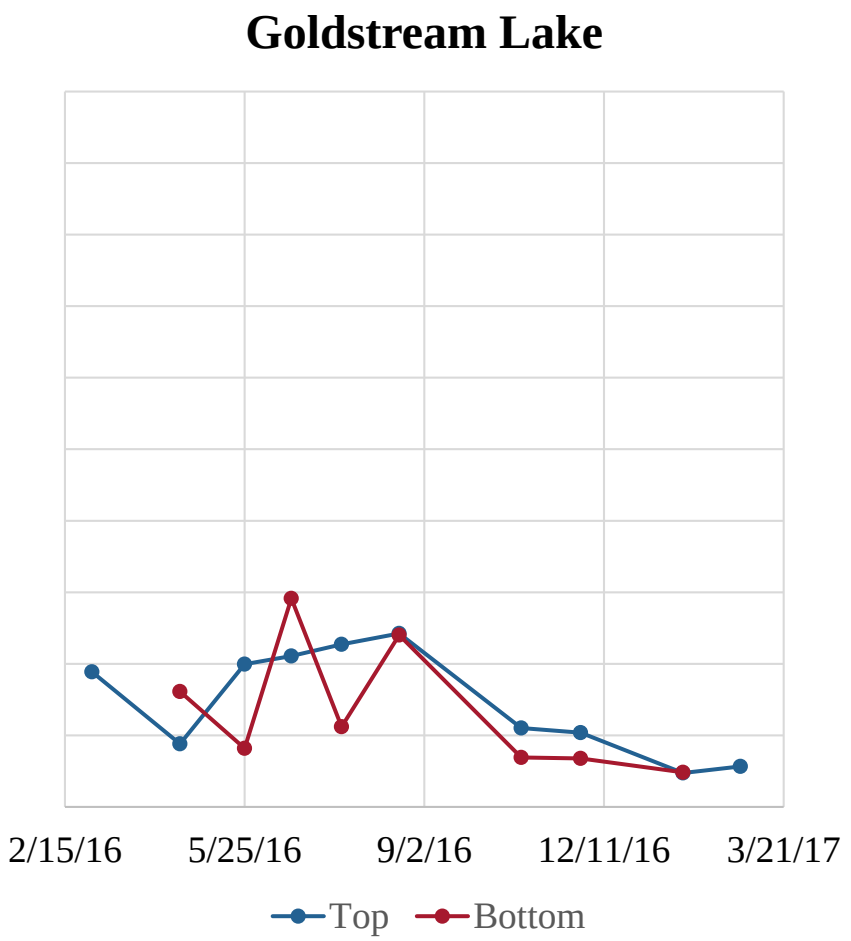
LEL

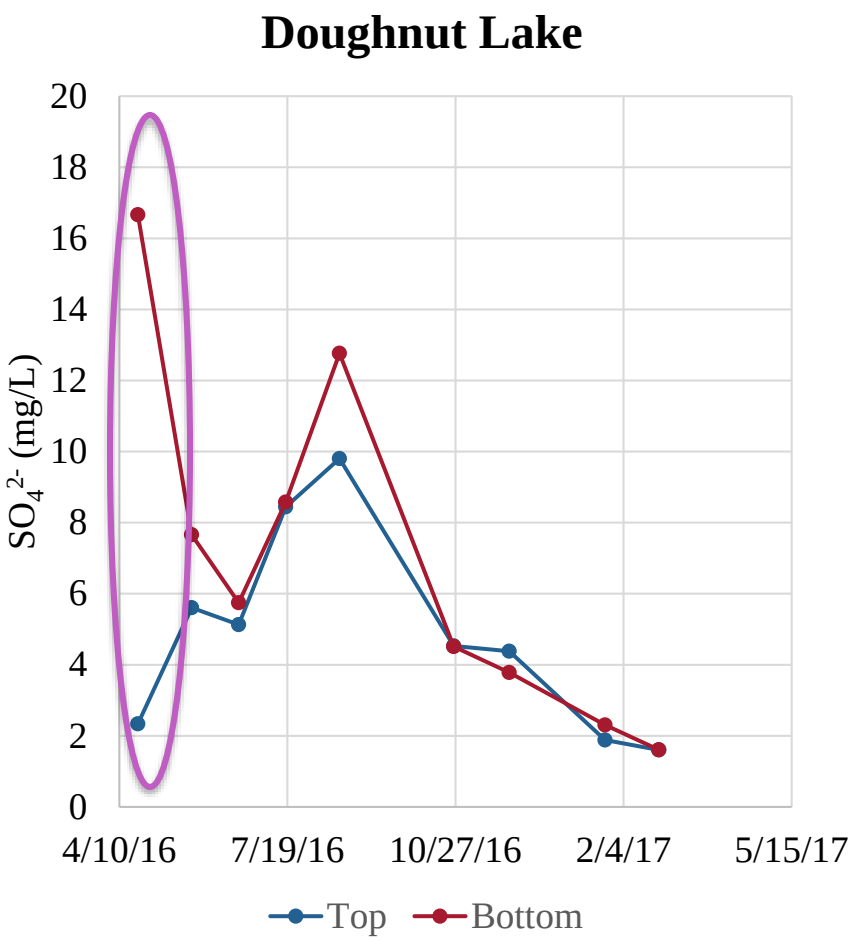

Goldstream Lake
Depth (cm)
0
50
100
150
200
250
-190
-180
-170
-160
-150
-140
-130
-120
δ2H (o/oo)
T1
T3
T4

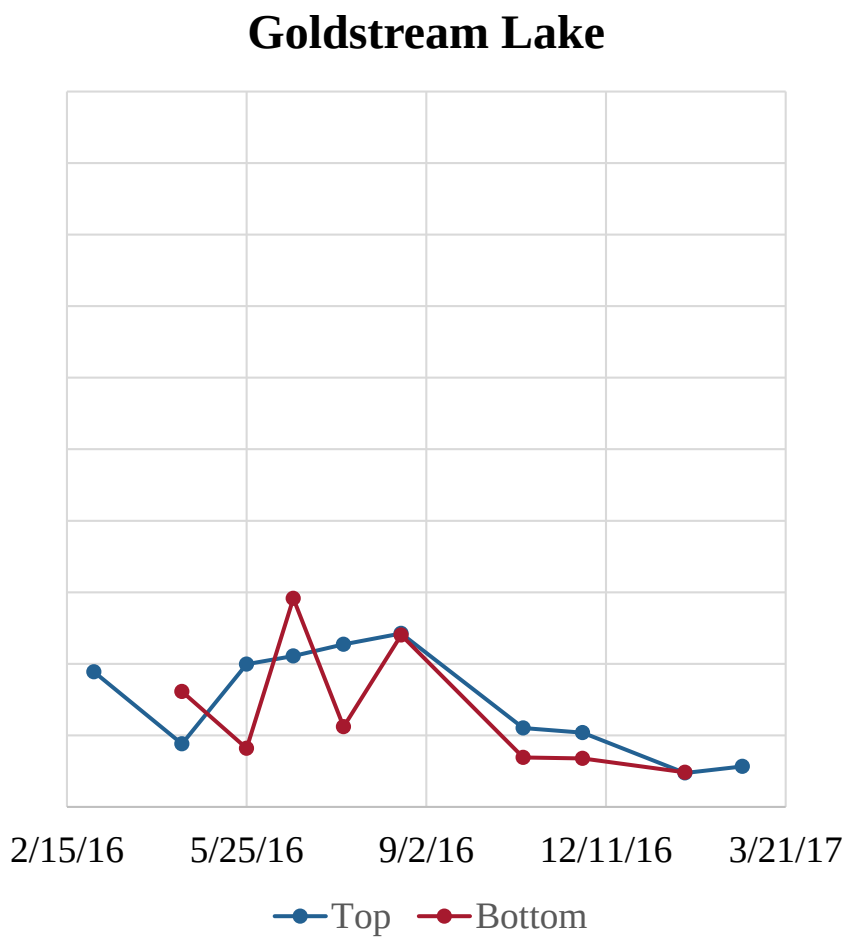
SULFATE CONCENTRATIONS





SULFATE CONCENTRATIONS





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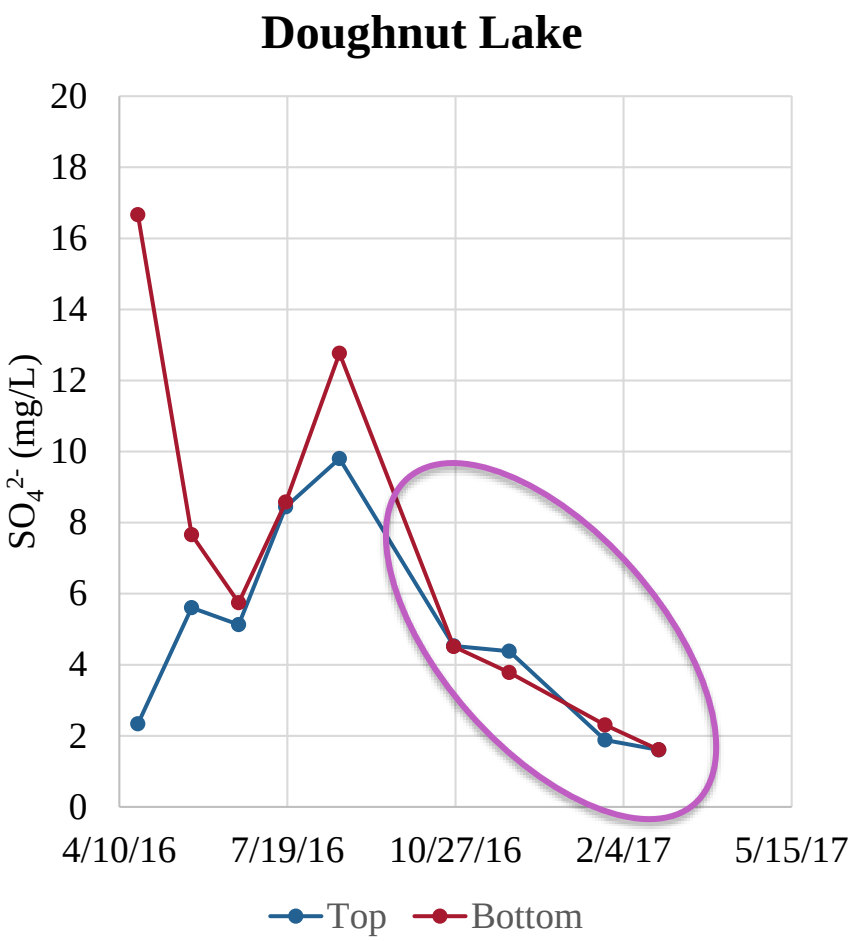

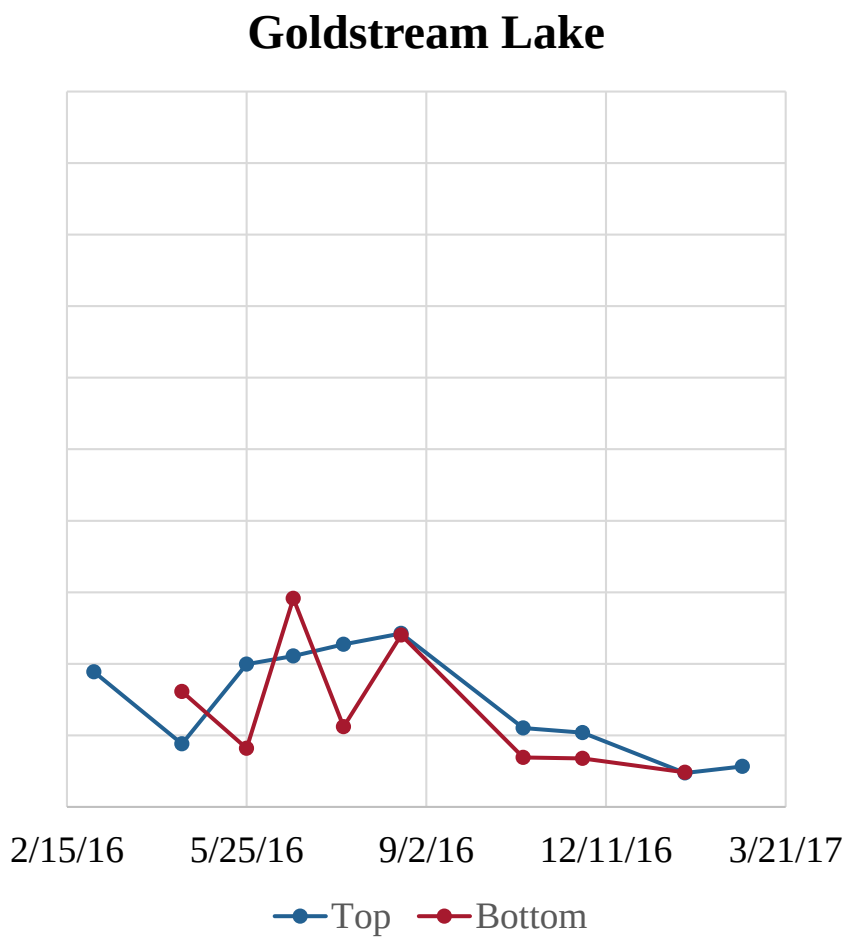

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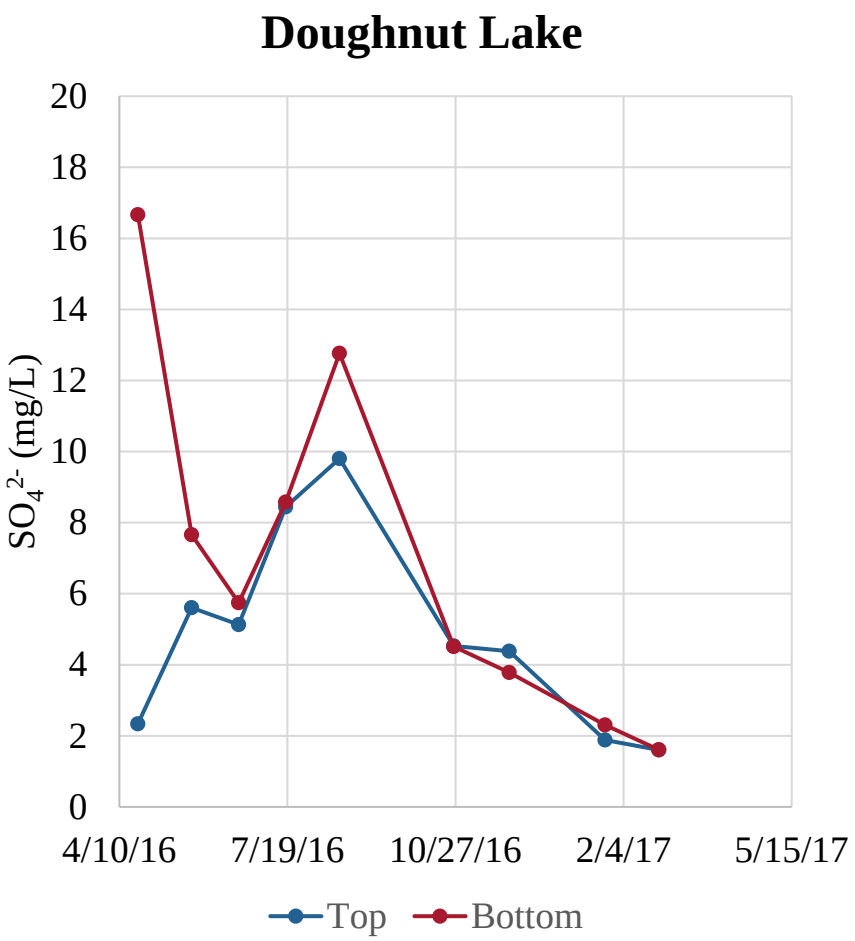

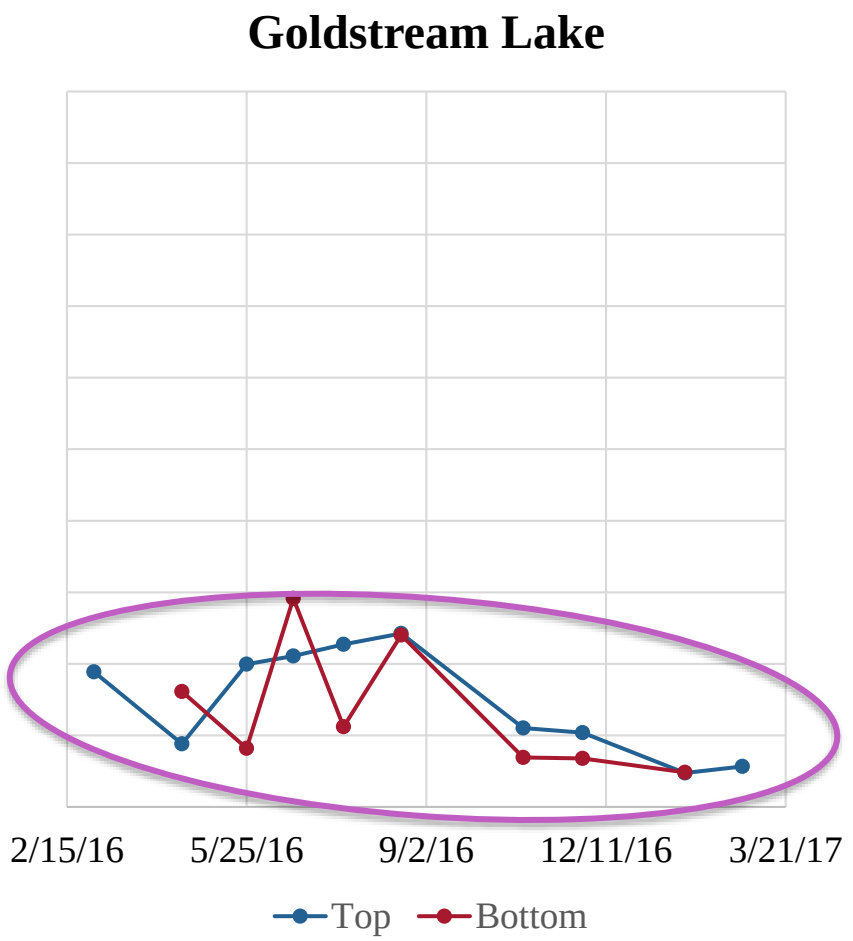

CONCLUSIONS

- Groundwater flow in discontinuous permafrost is complex!
- Environmental tracers may help describe flow dynamics.

CONCLUSIONS

- Flow dynamics in discontinuous permafrost plays a large role in contaminant and climate studies and water resources!

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QUESTIONS?