Groundwater Sampling in a Permafrost Environment

OBTAINING MEANINGFUL RESULTS

Valérie Bertrand, M.Sc.A., P.Geol.
Senior Geochemist
Golder Associates Ltd

Nunavut Mining Symposium

April 3, 2019

AGENDA

Groundwater issues in the arctic

- Groundwater flow in permafrost environment
- Groundwater quality in talik and sub-permafrost aquifer

Approach to groundwater investigation

- Well installation
- Groundwater sampling
- Water quality data analysis

Summary

Groundwater Basics

RECAP

Groundwater in permafrost environment

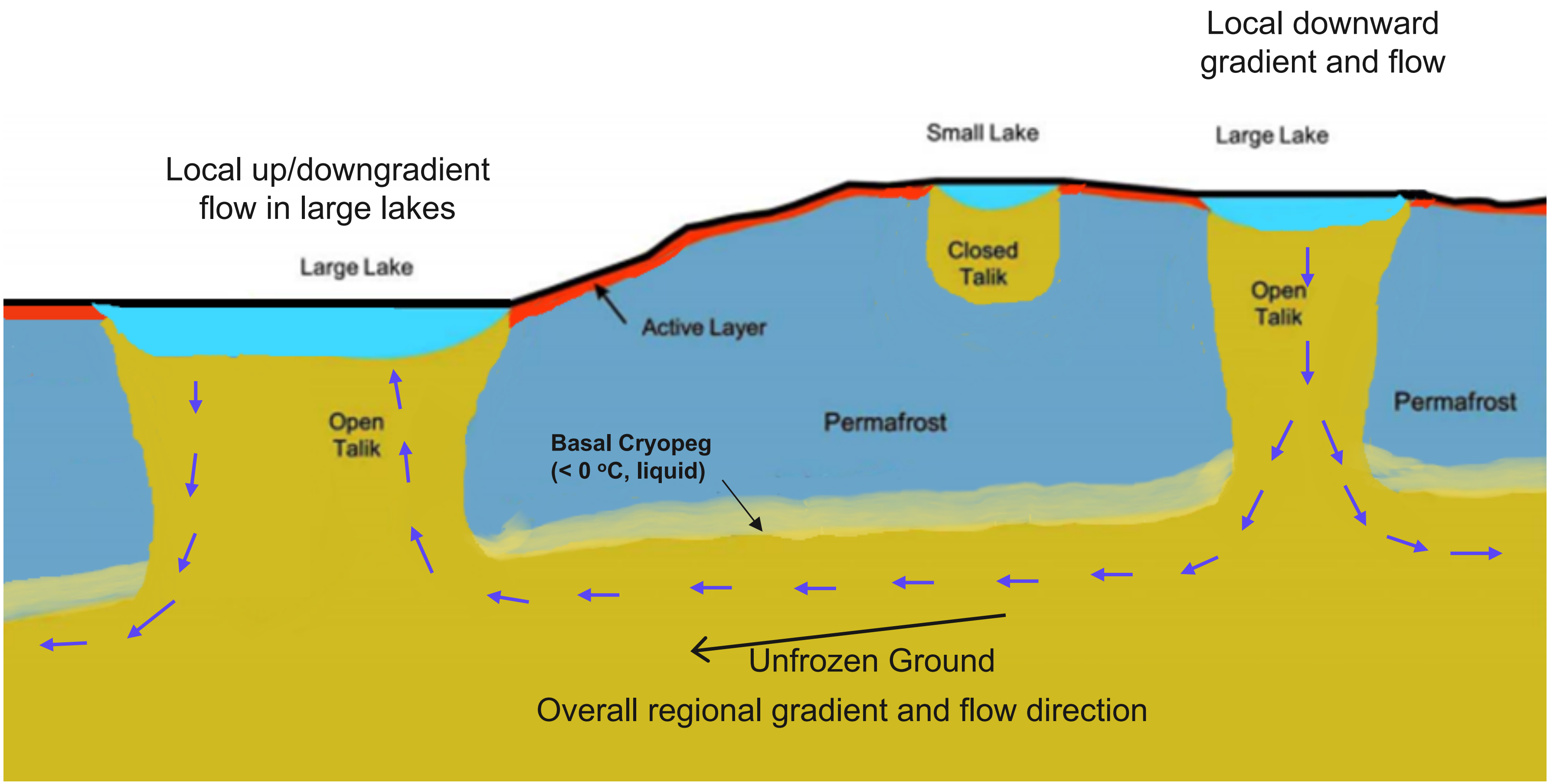
$$Z = I[\,((T_l - T_g)^2\, T_l)^{1/3} - T_l]$$

$$T_z = T_g + \frac{z}{I} + (T_l - T_g)\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$$

$$T_z = T_g + \frac{z}{I} + (T_p - T_g)\left(1 - \frac{z}{\sqrt{z^2+R_p^2}}\right) + (T_t - T_g)\left(\frac{z}{\sqrt{z^2+R_p^2}} - \frac{z}{\sqrt{z^2+R_{p+t}^2}}\right)$$

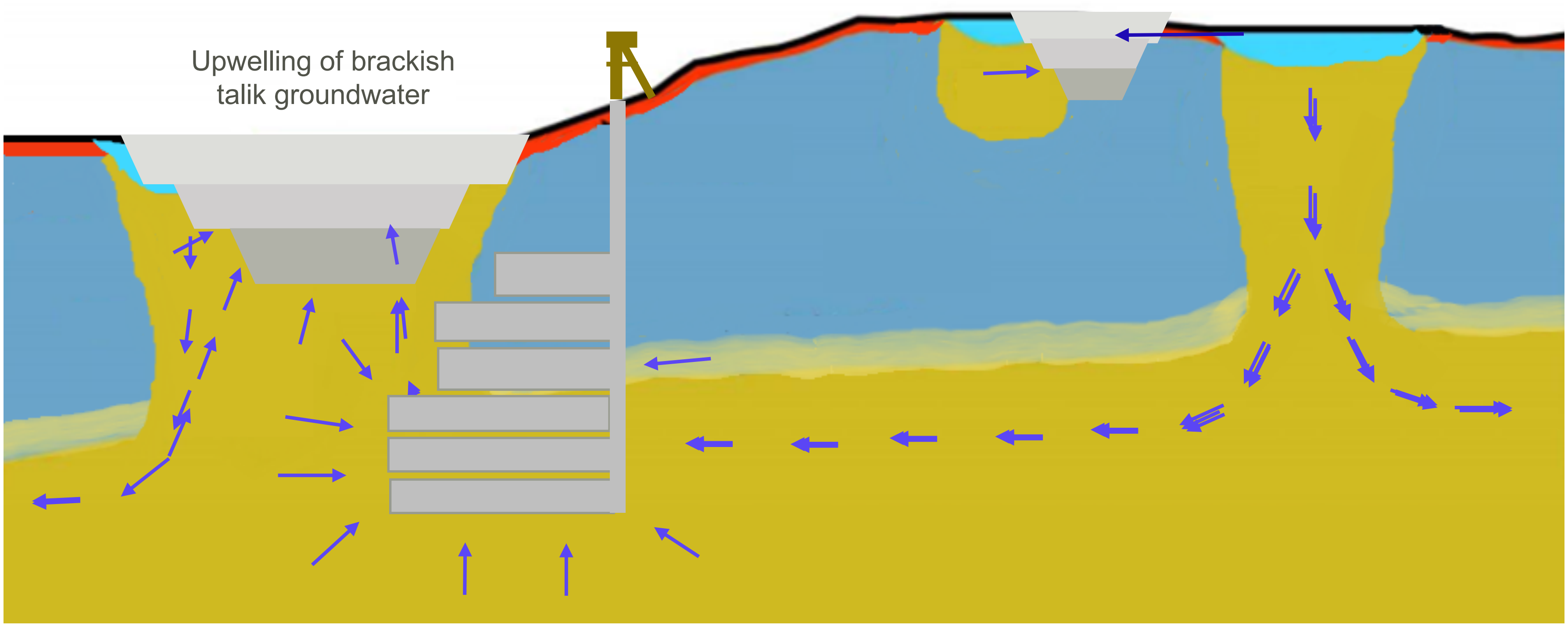
Groundwater Regime in Permafrost

EFFECT OF GROUND CONDITIONS ON GROUNDWATER FLOW



Mining and Groundwater Issues in the Arctic

AQUIFER RESPONSE TO MINING



Mining and Groundwater Issues in the Arctic

WHY CONSIDER GROUNDWATER?

Groundwater inflows add to the volume of water to manage, persist in winter, potential salinity/water quality issue

Open pit within permafrost or closed talik

- Low/no flow if within permafrost;
- Shallow groundwater from the active layer is typically low flow
  - Fractured upper bedrock connection to water body?

Open pit in open talik

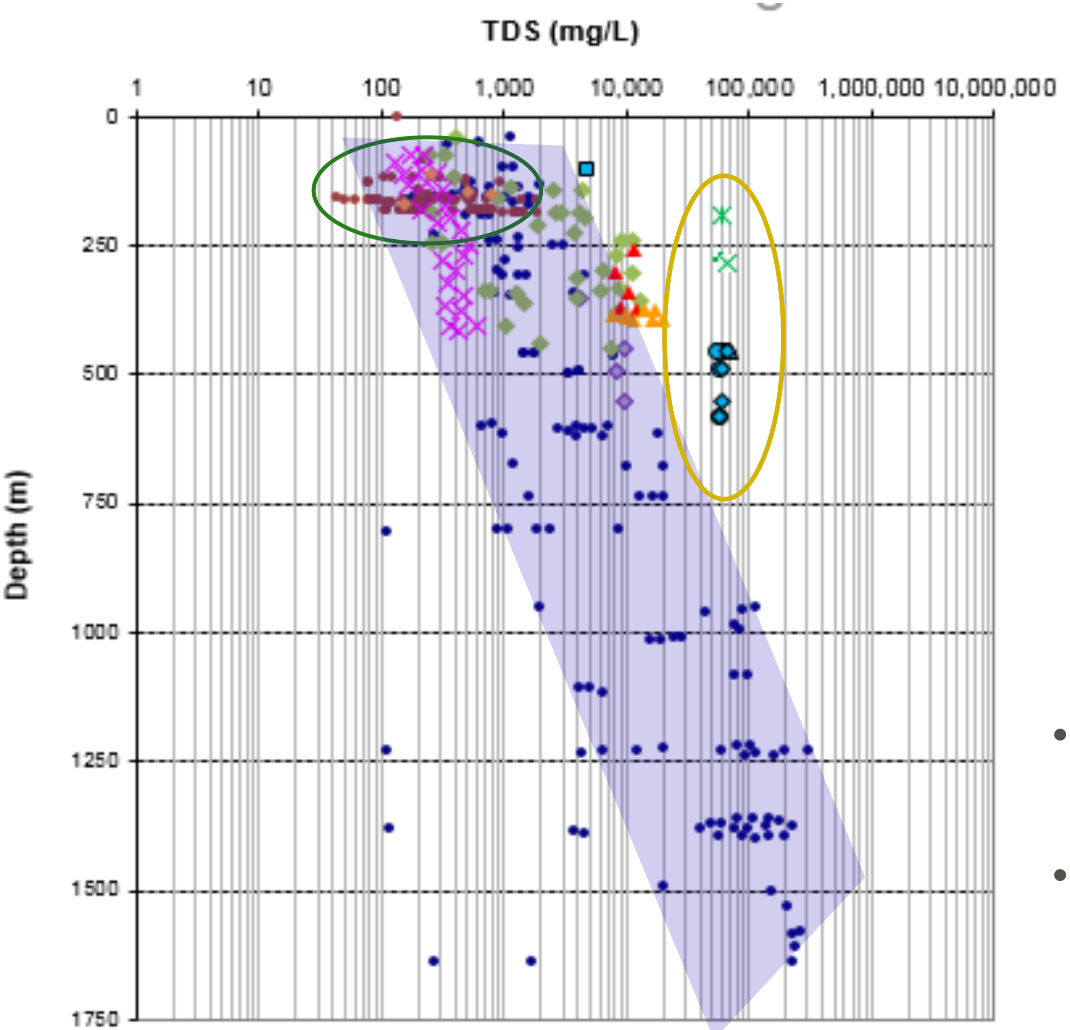
- Inflow from talik area, upwelling of deeper groundwater through pit base
  - Brackish water management

Underground mine development sub-permafrost

- Potential for high inflows, high salinity
- Basal cryopeg inflows

Groundwater Quality in Arctic Aquifers

GROUNDWATER SALINITY



Source: Frape and Fritz 1987

- Most shield brines are calcium chloride signature
- Near-ocean brines can be saltier, sodium chloride signature

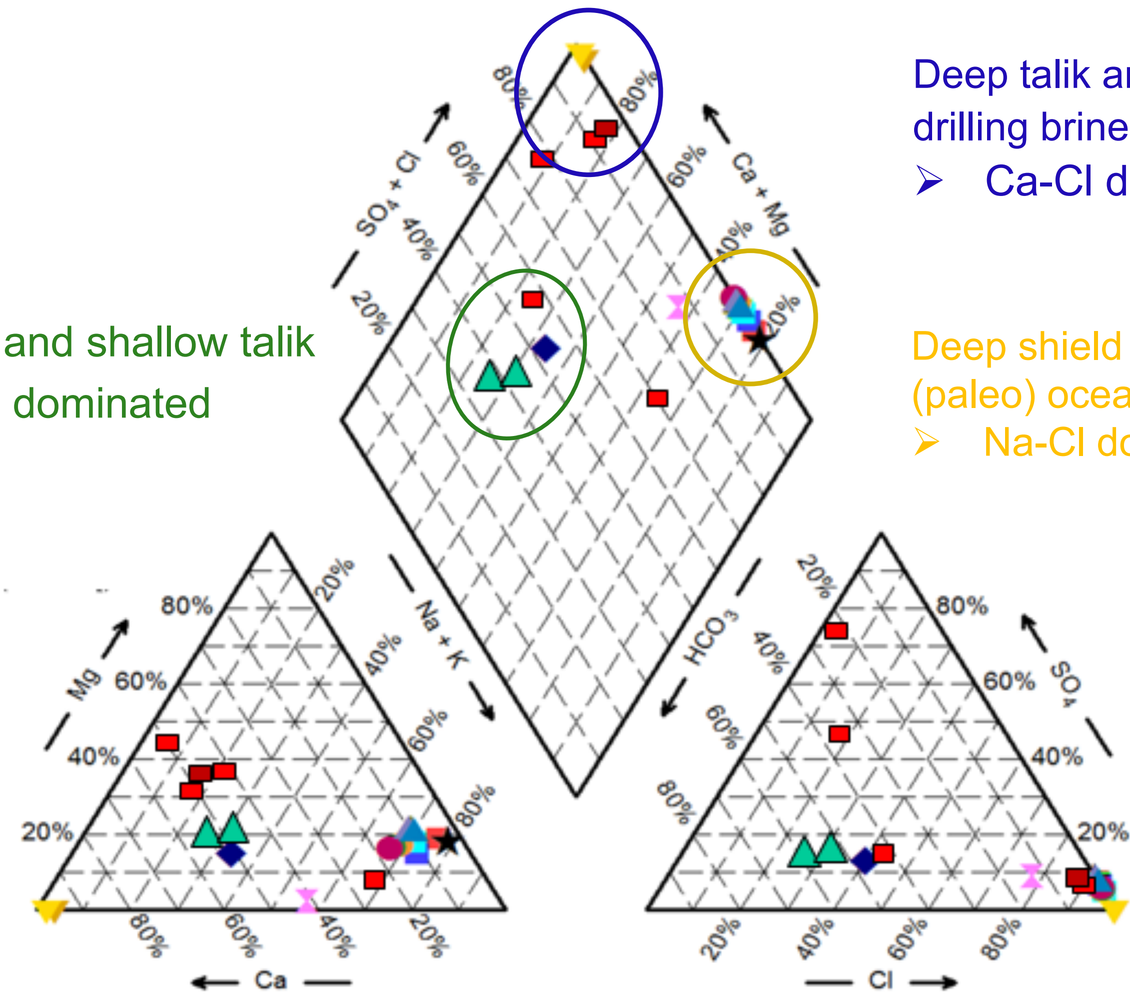
GOLDER

Groundwater Quality in Arctic Aquifers

DEEP AQUIFER GROUNDWATER SALINITY

Fresh lake and shallow talik

- Ca-CO_3 dominated



Deep talik and shield brines and $CaCl_2$ drilling brine

- Ca-Cl dominated, low sodium

Deep shield brines near/beneath (paleo) ocean

- Na-Cl dominated

Groundwater Quality in Arctic Aquifers

PERMAFROST AND CRYOCONCENTRATION IN GROUNDWATER

Freezing Point Depression:

	cryo-concentrated brine	seawater	← brackish talik water		→		unit
					← freshwater, arctic lakes	→	
Salinity (TDS)	64,000	35,000	28,500	10,000	150	10	mg/L
Conductivity	100,000	55,000	44,500	15,600	230	15	µS/cm
Freezing Point	-3.4	-2	-1.6	-0.6	-0.01	0	°C

Freezing water pushes salts out; salinity lowers the freezing point of water

- Brackish talik water → low FPD, thin cryopeg
- Brine, deep aquifer → high FPD, thick cryopeg

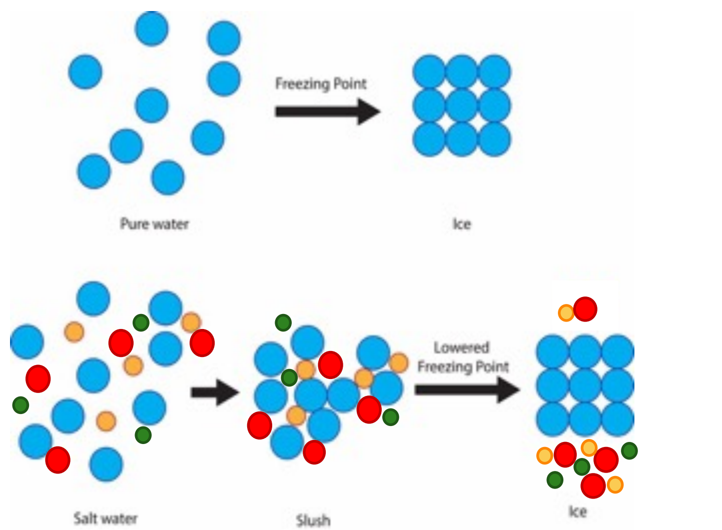


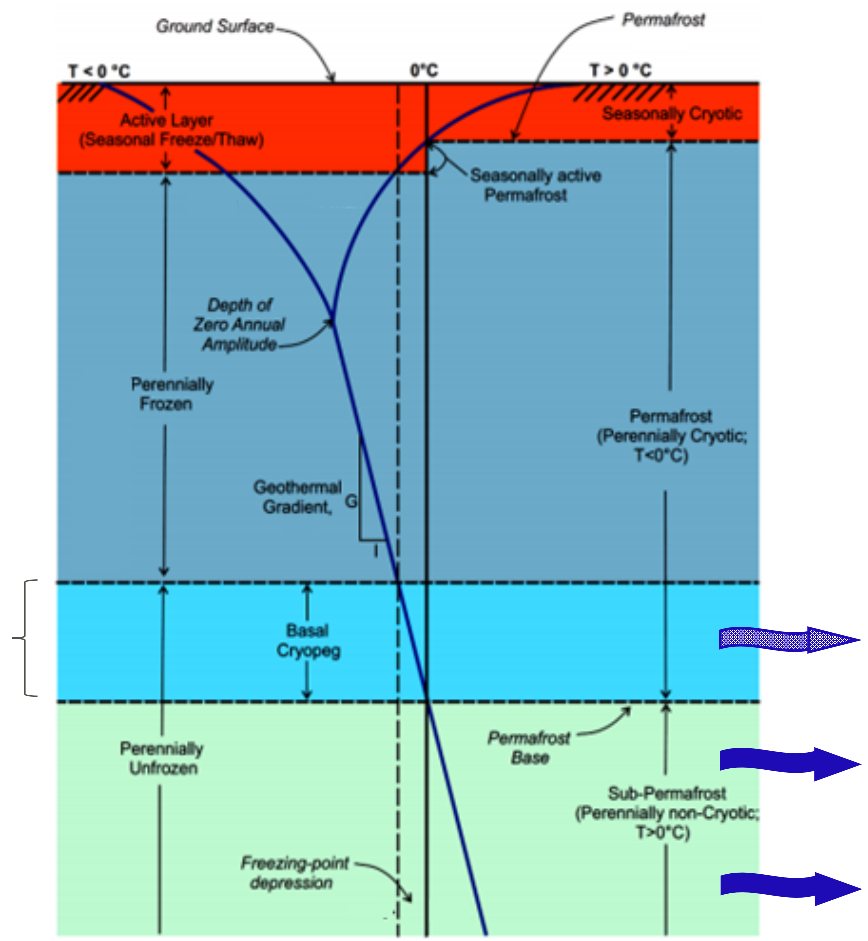
Figure credit: https://phys.org/news/2019-02-salt-doesnt-ice-winter-streets.html

Groundwater Quality in Arctic Aquifers

FREEZING POINT DEPRESSION AND GROUNDWATER FLOW

High TDS affects depth of cryotic ground = Freezing Point Depression

- Groundwater inflows above the base of the 0°C isotherm
- FPD of 1.5°C ~ 100 m shallower cryoptic zone = thickness of basal cryopeg



GOLDER

Summary of Issues

GROUNDWATER FLOW AND SALINITY CONSIDERATIONS

- Groundwater inflow into mine in unfrozen ground
- Inflows can be elevated: high pressure and large gradients, or if connected to surface water bodies
- Deep talik groundwater and sub-permafrost groundwater can be charged chemically, saline
- Groundwater salinity affects the depth of permafrost: inflows shallower than suggested by ground temperature alone
- Groundwater inflows will persist in winter, may require treatment for discharge.

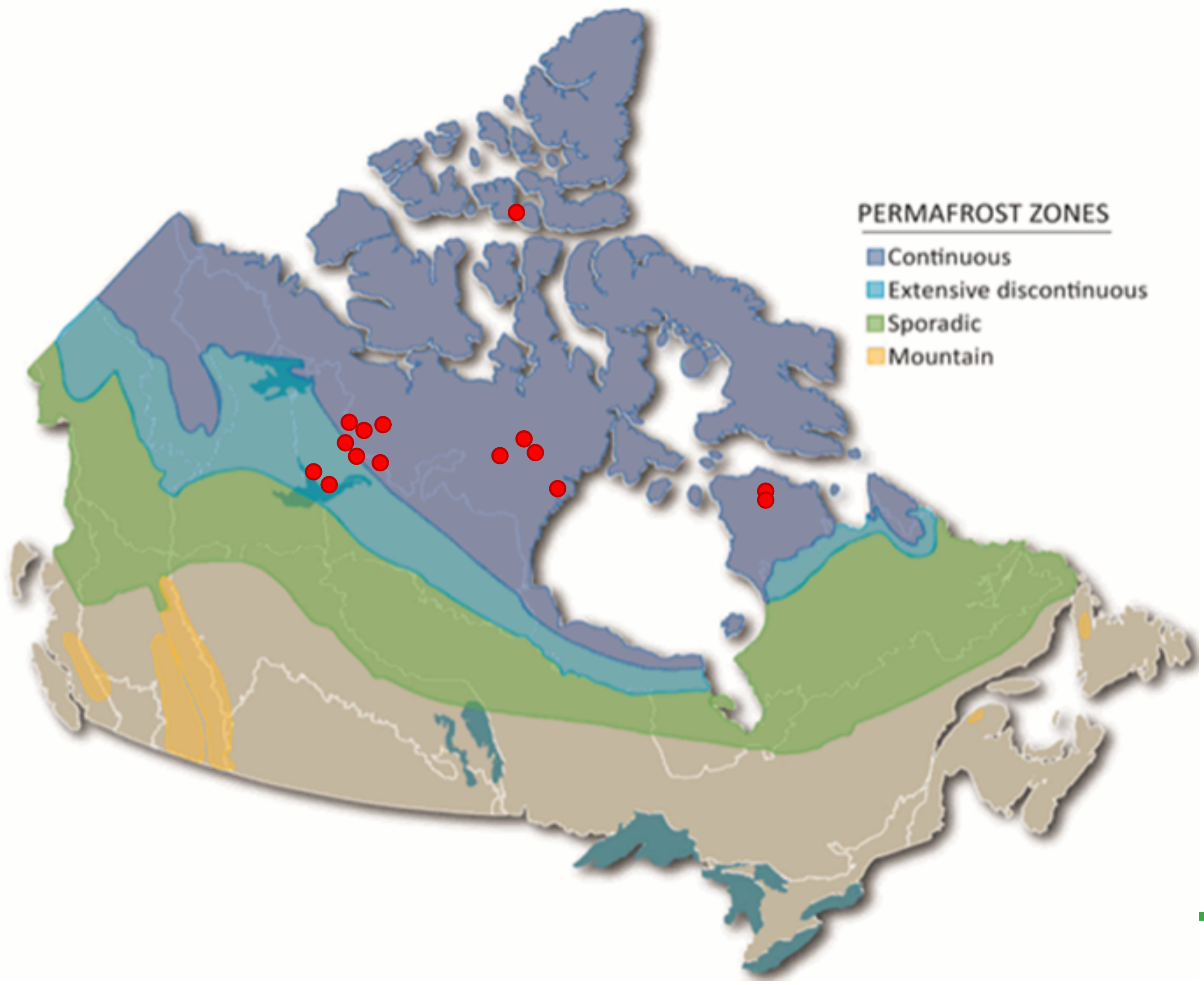
GOLDER

Groundwater Sampling

FOR MEANINGFUL RESULTS

Golder's Experience

GROUNDWATER INVESTIGATIONS IN THE ARCTIC



Groundwater Investigation

STEPS

1. Define thermal regime and permafrost depth
2. Locate borehole/well to target area of interest
3. Identify potential water-bearing structures, sampling zones
4. Properly develop/purge well/sampling zones
5. Collect water sample(s), determine true formation water quality and salinity
6. Estimate FPD and basal cryopeg thickness
7. Evaluate groundwater inflow rate and water quality

Approach to Groundwater Sampling

WELL LOCATION

Define ground thermal regime

- Open or closed talik – lake depth, area, air temperature
- Depth of permafrost – installation of thermistors, stabilization period

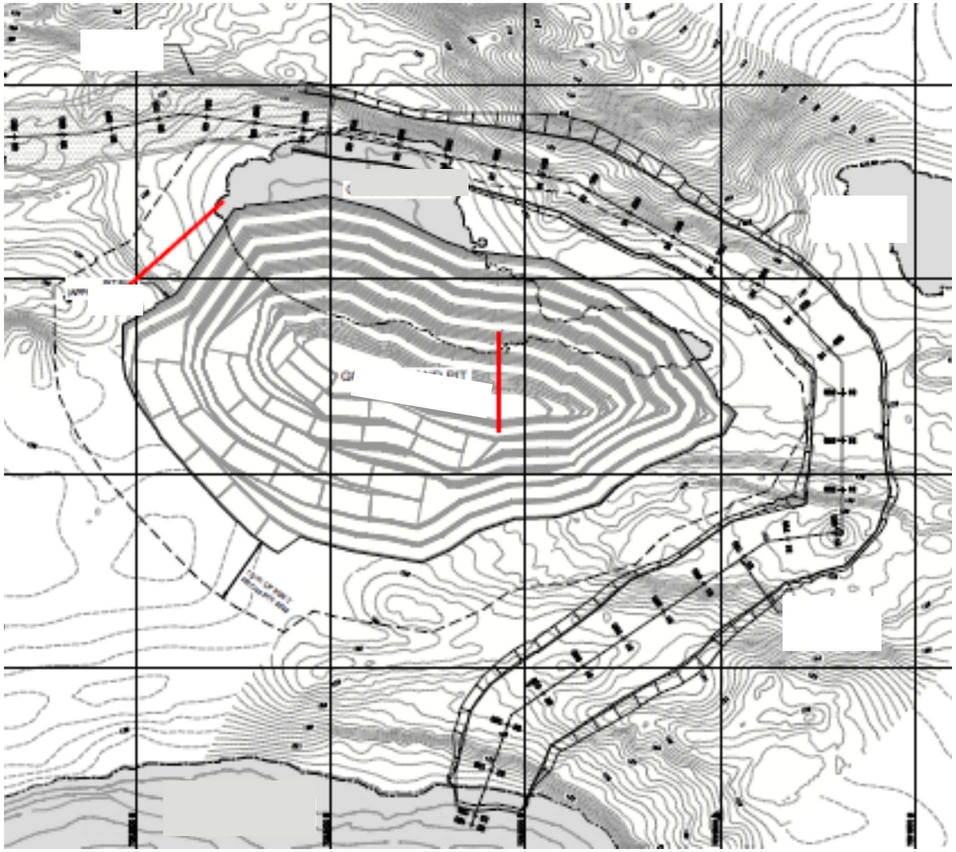
Plan borehole location to achieve target area

- Locate well away from sources of artificial inflow/salinity (ex: exploration boreholes drilled with brine)
- If installation through permafrost interval, considerations on well design, maintenance and purging
- Consider the target rock lithology which can affect groundwater quality

Approach to Groundwater Investigation

WELL LOCATION

- Target deeper part of the lake to reach talik
- Consider target lithology for geochemistry/contact water quality information



Approach to Groundwater Sampling

BOREHOLE DRILLING

Important tasks during drilling

- Tag and monitor all drilling fluids
  - Fluorescence, drilling salt and/or heated salt-free water – consider potential salinity of groundwater!
  - Have a consistent drill water composition: do not mix/change during installation,
  - Continual adjustment of tracer content and monitoring of tracer and conductivity
  - use calibrated meters with adequate precision
  - Monitor water consumption/water return

Approach to Groundwater Sampling

BOREHOLE DRILLING

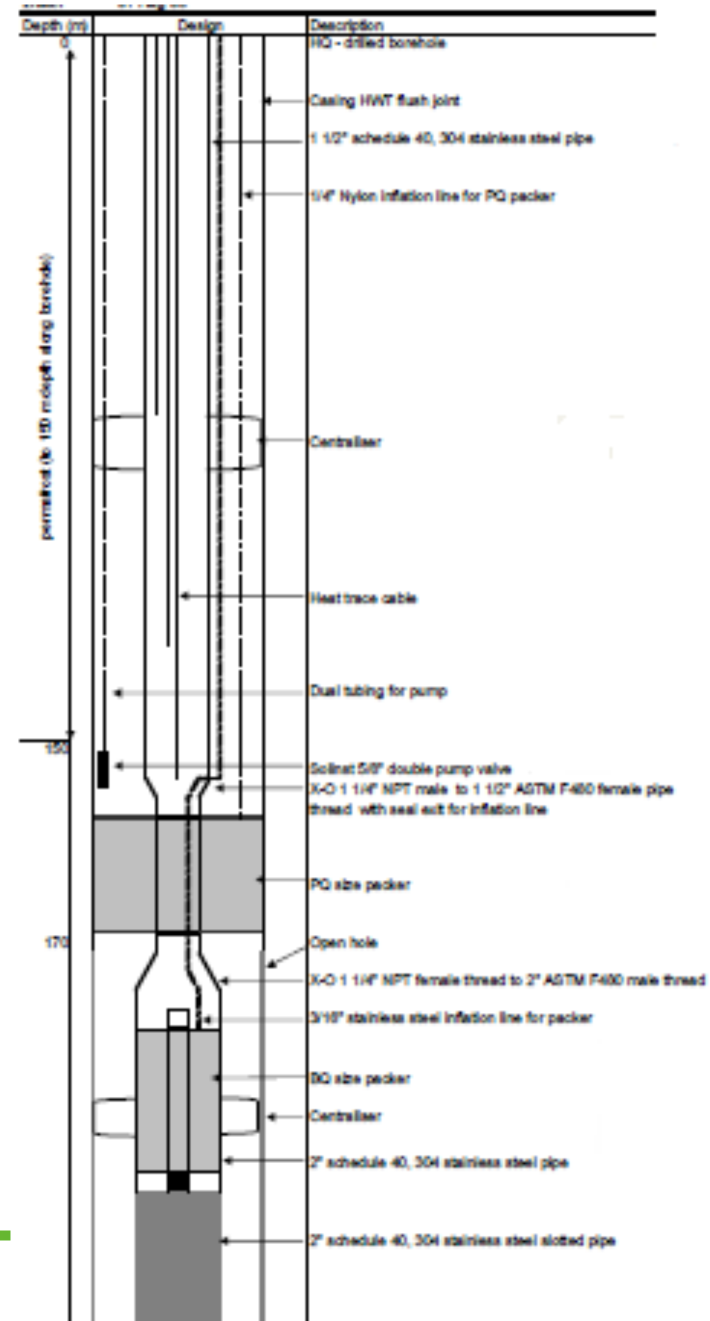
Important tasks during drilling

- Orientation survey to confirm borehole azimuth and dip, true depth of sampling zones
- Log core, map fractures, customize sampling intervals
  - ➢ Identify potential water-bearing fractures, hydraulic test of fractured intervals
  - ➢ Select groundwater sampling intervals, design well screen/sampling ports accordingly

Well Design

Beware of permafrost effects

- Stainless steel casing and screen, heating cables to prevent rising water freezing
- Avoid water remaining in casing or well riser: freezing pressures damage well materials
- Purge with nitrogen gas to avoid oxygenating potentially anoxic water (chemical changes)



Westbay^{TM} Well

- Multiple packers and sampling zones in 1 borehole: vertical profile of water quality and pressure (gradient)
- Select intervals based on lithology, structure and hydraulic conductivity
- Customized well: pre-ordered parts, sampling intervals, build on site 'LEGO'-like
- Sampling zone purge:
  - ✓ Purging by air lift/submersible pump if permafrost interval is short or relatively warm
  - ▪ If long/cold permafrost: use dedicated samplers: very slow!
- ▪ An alternative is in the works

Approach to Groundwater Sampling

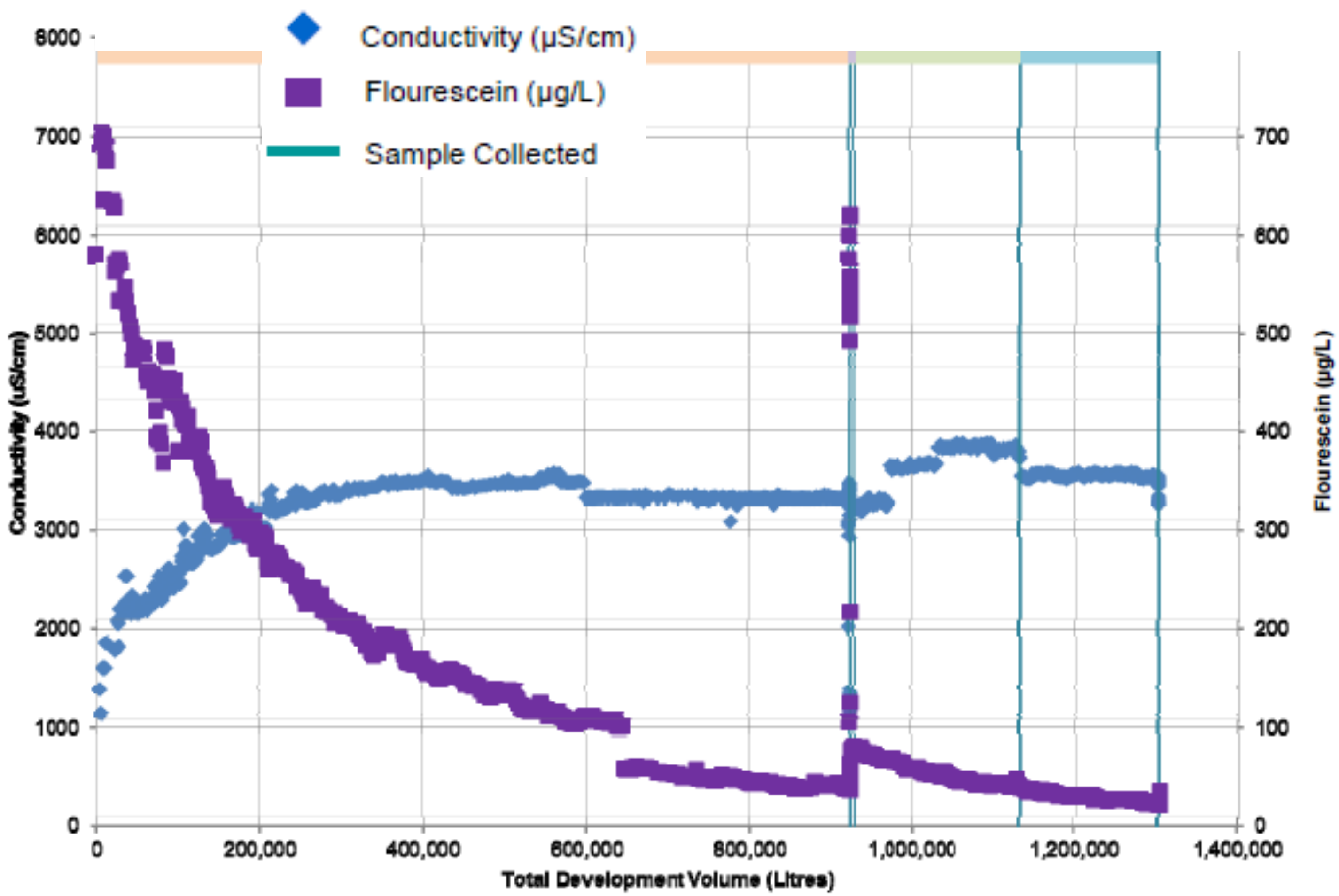
PROPER WELL/SAMPLING ZONE DEVELOPMENT - PURGING

In all cases

- Sample drill water, source water (for drilling) during drilling and well installation, needed to derive true formation water quality
- Continuous, in-situ monitoring of raw groundwater through development, for tracer content, conductivity.
- Remove the drilling fluids from sampling interval prior to collecting the groundwater sample
- Identify tracer target concentration – aim for >95% drilling fluid removal during development,
  - Lower drill water % to remove the uncertainty on drill fluid composition

Development of well interval

MONITORING OF RAW GROUNDWATER DURING PURGING



GOLDER

Groundwater Quality Data Analysis

WATER QUALITY

Analyses

- Major ions: calcium, sodium, chloride, magnesium, potassium, etc. conductivity, alkalinity, pH.
- Radium, gases, radiological parameters (uranium, thorium)
- Hydrocarbons, drilling fluid contaminants
- Trace chemical contents:
  - Tracers in drilling fluids/salt/tracer
  - Chemical signature of water – compare with surface water and drill water results

Groundwater Quality Data Analysis

STABLE ISOTOPES

Isotopes of oxygen, hydrogen, sulphur, strontium used to identify the source and pathway of groundwater

- Oxygen ^{18}O and Deuterium ^{2}H:
  - Fractures conveying surface water to underground or pit inflows via depletion ratios and mixing line assessment
- Tritium ^{3}H:
  - Age dating of groundwater relative to surface waters for the assessment of connectivity of groundwater to surface water bodies in the time frame of mine operation-post closure.

Groundwater Quality Data Analysis

ESTIMATION OF TRUE FORMATION WATER QUALITY

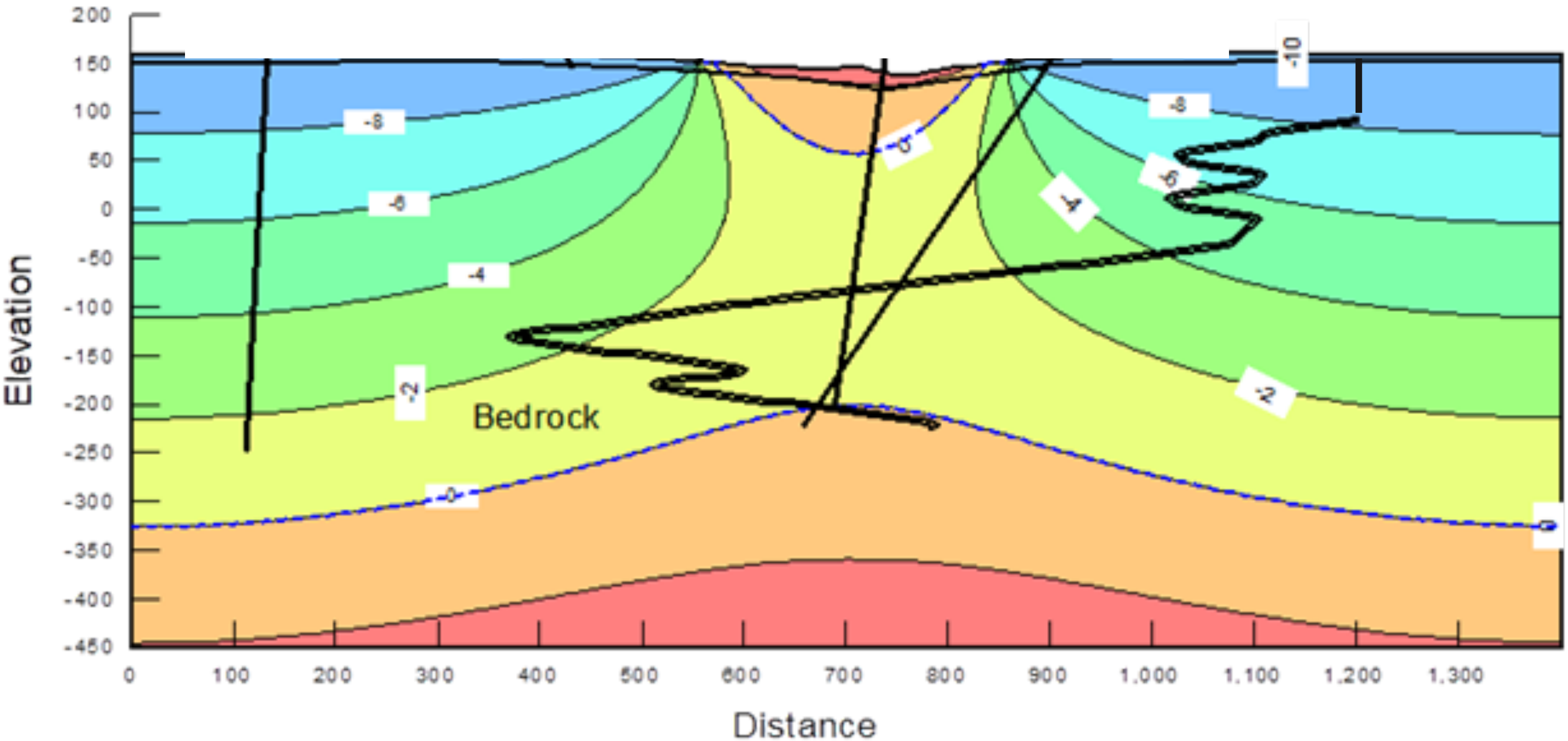
Based on tracer content: if the sample of raw groundwater still contains a proportion of drill water, it must be removed to determine true formation groundwater quality:

$$Groundwater\ Quality_{calculated} = Laboratory\ Result - \frac{Proportion\ of\ Drill\ Brine \times Dilute\ Brine\ Chemistry}{Proportion\ of\ Formation\ Water}$$

- Use true formation water quality to estimate
  - Salinity profile with depth
  - Freezing point depression and thickness of basal cryopeg
  - Location and rate of groundwater inflows.

Groundwater Quality and Thickness of Basal Cryopeg

Know where/when groundwater inflows will occur and their composition



Summary of Key Aspects

KEY TO REPRESENTATIVE GROUNDWATER SAMPLES

- Understand the thermal regime around the proposed mine
- Deep, sub-permafrost aquifer is saline, talik water salinity increases with depth.
- Groundwater salinity lowers freezing point; affects thickness of the basal cryopeg through which groundwater can flow at <0^{o}C
- Position well/sampling interval to intersect hydraulically conductive zones
- Drilling fluids must be tagged to monitor its complete removal during well/zone development prior to sampling
- Use calculated true formation groundwater quality to estimate FPD and thickness of basal cryopeg to evaluate groundwater inflows and their quality

Acknowledgement

THANK YOU

This work is the product of many and varied studies of groundwater in permafrost environments. I wish to thank all who have participated in these studies, including:

Golder clients, external reviewers, Golder staff and contributors Don Chorley, Michal Dobr, Jennifer Levenick, Dale Holtze, Emily Henkemans, Denis Vachon