Direct single well measurement of groundwater flux in permafrost-impacted aquifers in Nunavik, Canada.

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Overview

Permafrost thaw is a complex process resulting from the interaction between the atmosphere, soils, snow cover, vegetation, surface water and groundwater.

Although advective heat transport by groundwater flow is aknowledged as an important factor in permafrost thaw, there is a lack of direct measurements of groundwater parameters due to the difficulty of accessing these remote territories and associated high costs for field work.

Finite Volume Point Dilution Method was proven to be a versatile and robust single well method that was successfully applied at 4 piezometers to accurately measure groundwater fluxes varying from 0.58 to 0.84 m/d, in aquifers located above and below permafrost.

1. The importance of advective heat transport by groundwater in permafrost thaw

Permafrost is likely to decrease by 30 to 75% over the next century.

Permafrost thaw is a complex process resulting from the interaction between the atmosphere, soils, snow cover, vegetation, surface water and groundwater.

There is a lack of direct measurements of groundwater parameters due to the difficulty of accessing these remote territories and associated high costs for field work.

> Crucial need for direct single well groundwater flux measurements.

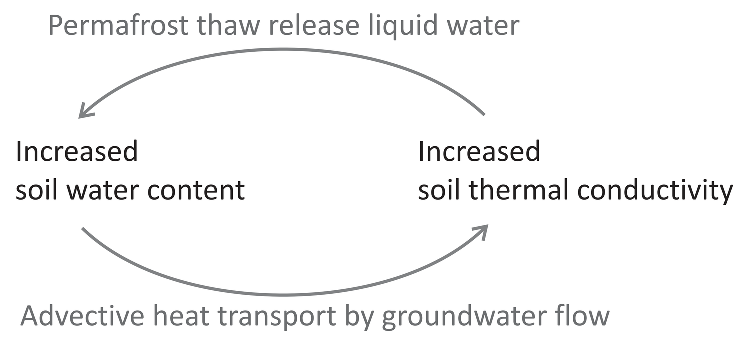

Fig 1: Permafrost thaw feedback loop.

2 The Tasiapik valley, Umiujaq.

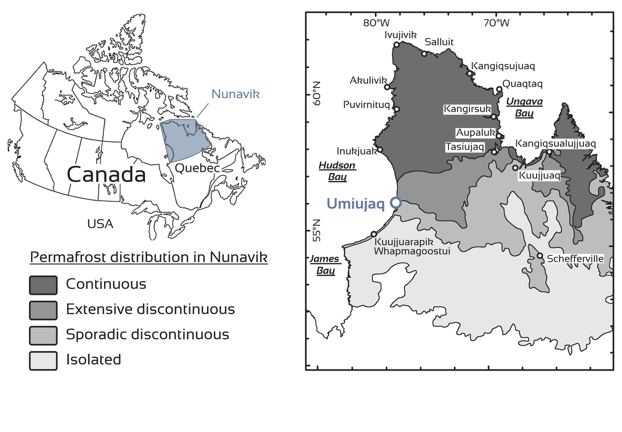

Fig 2: Umiujaq in the discontinuous permafrost zone.

2km² watershed of the Tasiapik valley, Umiujaq, Nunavik (Québec) (Fig 2) (Lemieux et al. 2016).

Superficial aquier: 10m thick, unconfined, littoral and intertidal sands (Fig 6).

Deep aquifer: unconfined to confined, coarse grained fluvioglacial/moraine sediments (Fig 6).

Initial Darcy flux estimates in the deep aquifer range from 0.01 to 0.49 m/d.

> Challenges: - small diameter (1.5") vs deep (35m+) piezometers
- harsh conditions in a remote environment vs need of 24h+ continuous power supply and running equipment

3 Single well groundwater flux measurement

Direct groundwater flux measurement by the Finite Volume Point Dilution Method (Brouyère et al. 2008).

The FVPDM consists in the continuous injection and mixing of tracer into a well and in the monitoring of the evolution of the tracer concentration. It generalizes all type of point dilution methods.

Experimental setup includes one pump to inject the tracer continuously and at a controlled flow rate, one pump for mixing the water column of the tested well and ensure homogeneous repartition of the tracer mass and one detector able to measure precisely the tracer concentration (Fig 3).

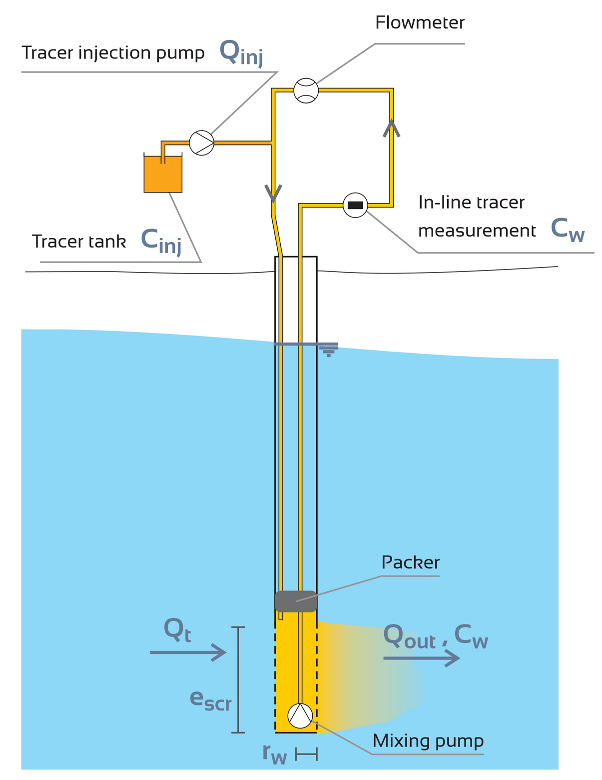

Fig 3: FVPDM experimental setup.

Eq 1: FVPDM analytical solution. Q_t is the transit flow rate corresponding to the groundwater flow intercepted by the well screen that is directly related to qD (apparent Darcy's flux). V_w is the volume of water in the injection well, assumed to be constant.

$$C_w(t) = \frac{Q_{in}C_{in} - (Q_{in}C_{in} - Q_{out}C_{w,0})\exp\left(-\frac{Q_{out}}{V_w}(t-t_0)\right)}{Q_{out}} \quad \text{with } Q_{out} = Q_{in} + Q_t$$

Experimental challenges

1. Shallow water levels + deep piezometer = large mixing volume This led to theoretical required FVPDM duration of several days.

> A packer is used to reduce Vw 80% and shorten the required FVPDM experiment duration to less than two days

2. Harsh conditions and need for continuous running equipment.

> Use of robust pumps + adaptation of an external fuel tank to the generator = reliable setup able to run flawlessly during more than 30h.

4 The FVPDM provided reliable assessment of groundwater fluxes

Groundwater fluxes measured by FVPDM vary from 0.58 to 0.84 m/d, significantly higher than initial estimates of 0.01 to 0.49 m/d. The underestimation is due to the fact that the initial estimated Darcy fluxes were based on hydraulic gradients measured from piezometers that are obviously not aligned along the main groundwater flow direction.

Groundwater fluxes within the deep aquifer decrease along the flow direction from the piezometer Pz9 to Pz4. This distribution of groundwater fluxes is consistent with the hydrogeological setting of the valley.

Although the FVPDM test might be time consuming (around 30 hours of continuous experiment), this long time is valuable in terms of increased accuracy with a maximum error on the groundwater fluxes about ±1 % for this campaign.

These measured groundwater fluxes within the sub-permafrost aquifer are currently used to constrain numerical modelling of advective-conductive heat transfer and assess the impacts of groundwater flow on permafrost dynamics (Dagenais et al. 2018).

> FVPDM provided precise and reliable assessment of groundwater fluxes.

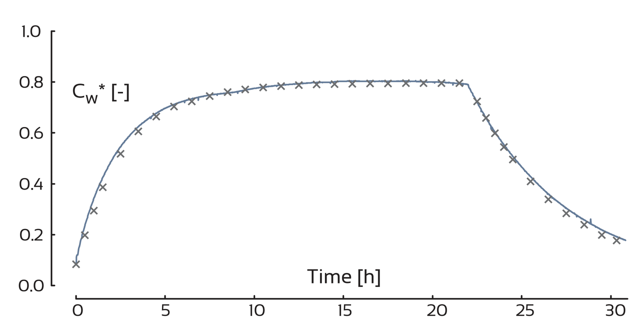

Fig 4: Experimental result in the piezometer Pz4. The measured groundwater flux is 0.58 m/d. (C_w^* = normalized tracer concentration C_w/C_{in})

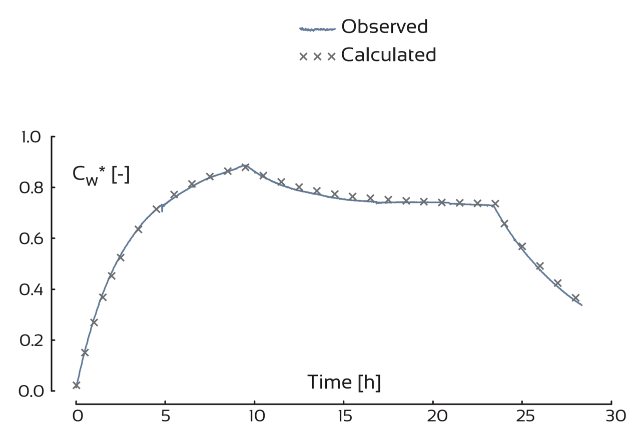

Fig 5: Experimental result in the piezometer Pz6. The measured groundwater flux is 0.73 m/d. (C_w^* = normalized tracer concentration C_w/C_{in})

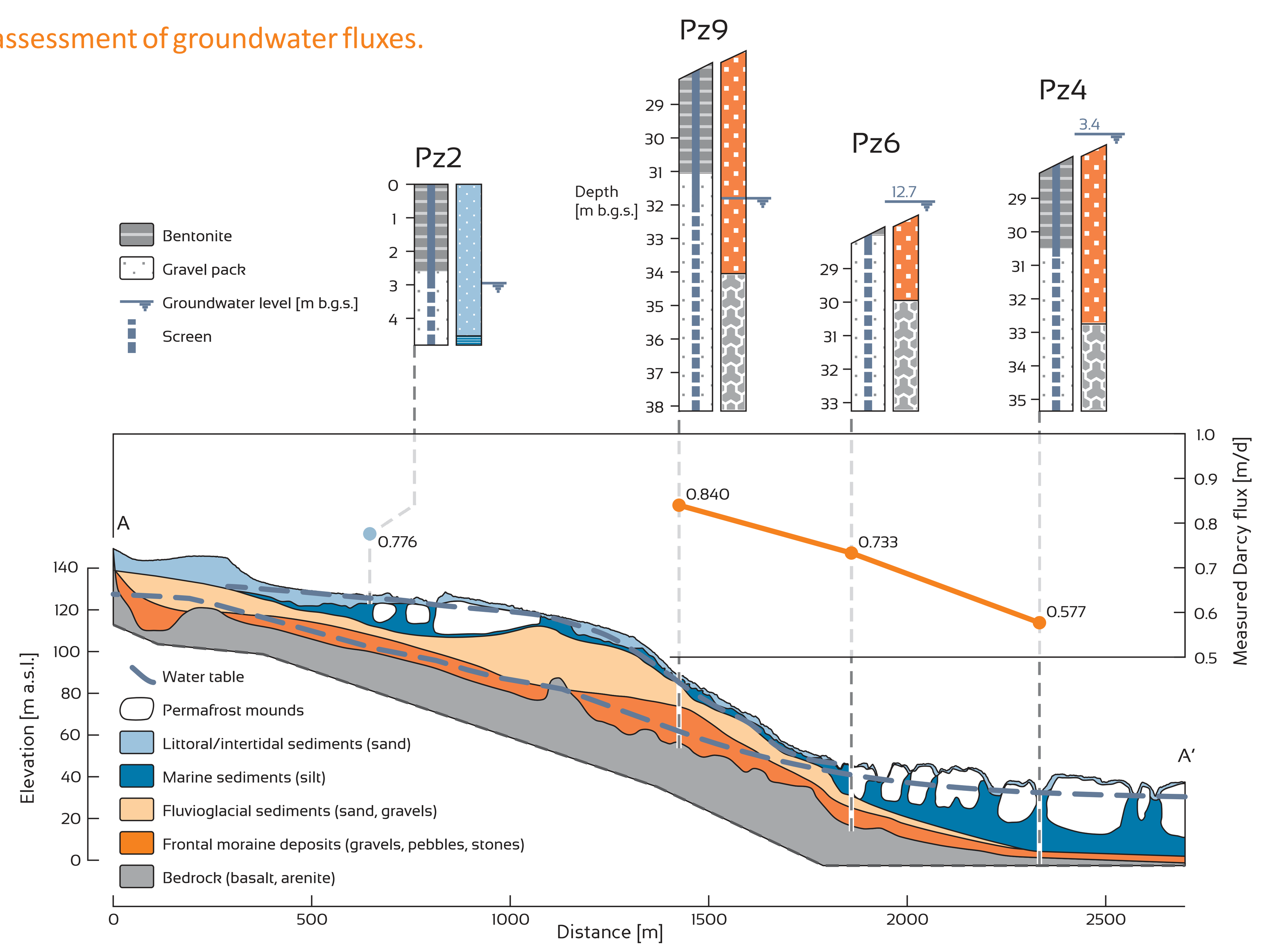

Fig 6: Cross-section of Quaternary deposits in the Tasiapik Valley.
Note: for piezometers Pz4, Pz6, and Pz9, only the part of the screens that is located in the deep aquifer is considered representative of the flow system for the calculation of groundwater fluxes.

The FVPDM, a useful and versatile method

FVPDM provided reliable assessment of groundwater fluxes in shallow supra-permafrost and deep sub-permafrost aquifers.

Measured groundwater fluxes range from 0.577 to 0.840 m/d with a precision varying from ±0.003 to ±0.012 m/d.

These field data are essential for constraining numerical modelling of advective-conductive heat transfer to better understand permafrost dynamics.

Major challenges were overcome by the used of a robust equipment and adapted experimental setup, proving the versatility of the FVPDM.

Jamin P. *et al.* 2018, Direct measurement of groundwater flux in aquifers in the discontinuous permafrost zone: an application of the finite volume point dilution method in Umiujaq. Submitted to Hydrogeology Journal Topical collection TC-04: Hydrogeology of a cold-region watershed in Nunavik (Umiujaq, Canada)

Dagenais S. *et al.* 2018, Coupled cryo-hydrogeological modelling of permafrost degradation at Umiujaq (Nunavik, Canada). Submitted to Hydrogeology Journal, Topical collection TC-04: Hydrogeology of a cold-region watershed in Nunavik (Umiujaq, Canada).

Brouyère S. *et al.* 2008, A new tracer technique for monitoring groundwater fluxes: the Finite Volume Point Dilution Method. Journal of Contaminant Hydrology, 95(3–4), 121–40.

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