

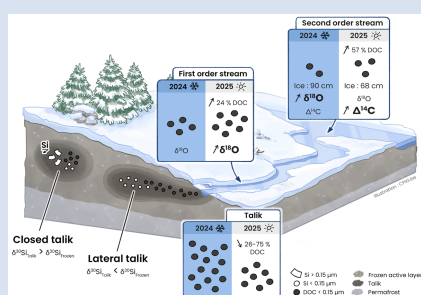
Deep winter dissolved organic carbon transfer from taliks in permafrost landscapes

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Abstract



In permafrost landscapes, taliks (unfrozen ground zones) represent year round hydrological pathways that can transfer dissolved organic carbon (DOC) to streams during winter. When laterally connected, taliks enhance winter hydrological flow and DOC transfer to streams, yet their connectivity and biogeochemical role remain poorly constrained. Here, we use silicon isotopes ($\delta^{30}\text{Si}$) in soil pore waters to distinguish closed from lateral taliks at a water track in Alaska, and study DOC transfer to first and second order streams across two contrasting winters (2025 warmer than 2024). Silicon isotopes emerge as a promising tracer of talik connectivity, with lateral taliks showing systematically lighter Si isotope composition than in the frozen soil, whereas closed taliks exhibit systematically heavier Si isotope compositions. Stream water data reveal enhanced transfer of younger, soil derived DOC from lateral taliks during the warmer winter, with up to 57 % higher DOC concentrations compared to the colder winter, despite similar dissolved CO_2 and CH_4 concentrations. This offers a first biogeochemical view of talik connectivity (closed/lateral) in deep winter and calls for integration with geophysical approaches to fully resolve its role in winter carbon cycling.

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Introduction

Across the northern permafrost region, 1,662 Tg of carbon *per* year is released to the atmosphere as carbon dioxide (CO_2) and methane (CH_4) during the winter season (October–April; Natali *et al.*, 2019; Arndt *et al.*, 2023). Winter carbon emissions may be preceded by subsurface mobilisation and transfer of dissolved organic carbon (DOC) within taliks (Parazoo *et al.*, 2018; Walter Anthony *et al.*, 2024; Bergman *et al.*, 2025), processes that remain poorly constrained. A talik is defined as “a part of the ground at a site with permafrost that remains unfrozen year round” (Lewkowicz *et al.*, 2024) and may be either between the base of the active layer and permafrost (supra-permafrost talik), or within a permafrost profile (intra-permafrost talik; Devoie *et al.*, 2024). Supra-permafrost taliks can be either closed or lateral (O'Neill *et al.*, 2020): closed taliks are surrounded by frozen ground with talik water relatively stagnant, having only a localised sphere of influence and limited flow potential; and lateral taliks can form lateral water flow pathways, leading to an increase in DOC transfer from soil to streams in winter (Connon *et al.*, 2018; Devoie *et al.*, 2024). Thus, distinguishing between closed and lateral taliks is crucial for determining how supra-permafrost taliks regulate winter carbon transfer from soils to streams (Kurylyk and Walvoord, 2021; Zhao *et al.*, 2026).

Water tracks are unchanneled zones overlying permafrost that concentrate water flow downslope, and exhibit higher soil moisture and snow thickness than the surrounding areas (Del Vecchio and Evans, 2025). Moreover, soil moisture increases along the water tracks, leading to wetter areas downstream of the water tracks, mainly fed by water from upstream during the growing season (Tananaev *et al.*, 2021). Increasing soil moisture associated with water flows enhances advective heat transfer, promoting the development of taliks, potentially favouring closed taliks where the soil moisture is lower upstream, and lateral taliks where the soil moisture is higher downstream of the water track (Devoie *et al.*, 2021). Existing methods for talik detection are based on mechanical, geophysical and thermal approaches (O'Neill *et al.*, 2020). The gap in biogeochemical methods reflects the exceptional logistical challenges of collecting soil pore water from taliks during deep winter, when frozen surface conditions and extreme cold make *in situ* sampling difficult.

Talik connectivity may be assessed using the stable isotope composition of silicon ($\delta^{30}\text{Si}$), based on Hirst *et al.* (2023), who measured $\delta^{30}\text{Si}$ in soil pore waters to distinguish isolated from connected soil pore water during the late winter to snow melt transition. We apply it here to a colder, earlier stage of winter, prior to any onset of thaw. Upon freezing of soil pore water under a closed system, the decrease in liquid water volume drives an increase in the silicic acid concentration in soil pore waters

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over the amorphous silica solubility (Dietzel, 2005). Amorphous silica precipitation induces silicon isotope fractionation by preferentially incorporating lighter isotopes into solid phases (from nanosized solid phases termed colloids to particulate sized phases), leaving the dissolved soil pore water fraction isotopically heavier (Oelze *et al.*, 2015). This process may happen in closed taliks (Hirst *et al.*, 2023), leaving the soil pore water from taliks isotopically heavier than soil pore water from the surrounding frozen soil (soil pore water $\delta^{30}\text{Si}_{\text{talik}} > \delta^{30}\text{Si}_{\text{frozen}}$). In lateral taliks, water flow prevents silicic acid concentration. In addition, the freezing front facilitates colloid mobilisation through preferential flow paths (Mohanty *et al.*, 2014) from the frozen ground to the lateral talik. This leads to a soil pore water isotopically lighter in lateral taliks with the accumulation of light $\delta^{30}\text{Si}$ bearing-colloids compared to the surrounding frozen soil (soil pore water $\delta^{30}\text{Si}_{\text{talik}} < \delta^{30}\text{Si}_{\text{frozen}}$).

This study aims to biogeochemically distinguish supra-permafrost taliks located upstream, downstream, and outside a water track from Eight Mile Lake (Healy, Alaska; Fig. 1), using soil pore water chemistry (pH, conductivity, DOC concentrations, and $\delta^{30}\text{Si}$) from the taliks and the frozen portions of the soil within the active layer. The chemistry of local first order (inlet) and second order stream waters (Panguingue Creek River) is investigated to assess the implications of talik connectivity for DOC transfer to streams (pH, conductivity, $\delta^{18}\text{O}$, DOC concentrations, radiocarbon of DOC ($\Delta^{14}\text{C}$ -DOC), dissolved CO_2 and CH_4 concentrations, Si concentrations, and $\delta^{30}\text{Si}$). As winters become increasingly warmer in permafrost regions (Graham *et al.*, 2017), we compare two contrasted winters to examine how interannual differences in air temperature (winter 2025 warmer than winter 2024) influence carbon transfer to streams (see SI).

Contrasting Interannual Winter Conditions

At Eight Mile Lake, winter air temperatures in 2023–2024 and 2024–2025 were significantly higher compared to the previous ten winters ($-11.3 \pm 9.1^\circ\text{C}$; $p < 0.001$; Wilcoxon test; Kennedy *et al.*, 2026), and the winter freezing degree day was higher in 2024–2025 (-1528°C) than in 2023–2024 (-1911°C ; calculated by summing all negative values between 1 November and 14 May; Farquharson *et al.*, 2022). Winter 2024–2025 was then warmer than winter 2023–2024 overall, and this was also observed more specifically during the sampling period (February–March): air temperatures were significantly higher (p value < 0.001) of 1.9°C in 2025 ($-7.4 \pm 6.9^\circ\text{C}$ (mean $\pm$ s.d.) with a minimum of -25°C) than in 2024 ($-9.3 \pm 10.6^\circ\text{C}$ (mean $\pm$ s.d.) with a minimum of -34°C ; Fig. 1d). As a result, February–March soil temperatures were significantly higher (p value < 0.001) in 2025 than in 2024 for each depth at each site, with increases ranging from 1.5 to 2.4°C (Fig. 1e). Snow depth at the site was thinner both upstream and outside of the water track in 2025 (15 ± 8 cm, $n = 6$) than in 2024 (23 ± 13 cm, $n = 6$; Fig. 1b). Despite a large variability in snow depth, this trend is consistent with regional observations of thinner snow depth in 2025 (42 ± 23 cm) than in 2024 (50 ± 23 cm) in Healy (Thompson *et al.*, 2025). These contrasting air and soil temperatures and snow layer thicknesses between the two winters may then influence talik biogeochemical connectivity.

Chemical Composition of the Soil Pore Waters and Streams

In soil pore waters from the taliks and the frozen portions of the soil, pH, conductivity, and DOC concentrations varied from 2.9 to 5.1 (3.9 ± 0.6), 10.3 to 105 $\mu\text{S cm}^{-1}$ ($53.5 \pm 28.5 \mu\text{S cm}^{-1}$), and

25.4 to 299 mg L^{-1} ($100 \pm 59.0 \text{ mg L}^{-1}$) respectively (Fig. 2a–c). In soil pore waters from the taliks sampled both in 2024 and 2025 ($n = 6$; upstream and downstream of the water track), DOC concentrations are 45 (U2), 26 (D1) and 75 % (D3) lower in 2025 compared to 2024, respectively, suggesting DOC dilution within a wetter water track under warmer conditions in 2025 (Del Vecchio and Evans, 2025).

At the inlet (first order stream), water pH and conductivity varied respectively between 6.3 and 4.3, and between 136 and 65 $\mu\text{S cm}^{-1}$ (Fig. 2, Table 1). Water $\delta^{18}\text{O}$ values and DOC concentrations were respectively 4 % and 24 % higher in 2025 compared to 2024. Values of $\Delta^{14}\text{C}$ -DOC were slightly higher in 2025 (-1.7‰) than in 2024 (-19.4‰), corresponding to young DOC radiocarbon ages of ~ 0 and 86 years BP, respectively, potentially derived from recently fixed plant litter in the downslope area close to the inlet (Benner *et al.*, 2004). Dissolved CO_2 and CH_4 concentrations in inlet waters were considered stable between 2024 ($420 \mu\text{mol L}^{-1} \text{CO}_2$ and $19.4 \mu\text{mol L}^{-1} \text{CH}_4$) and 2025 ($443 \mu\text{mol L}^{-1} \text{CO}_2$ and $11.9 \mu\text{mol L}^{-1} \text{CH}_4$) given the typical variability of these quantities in streams in permafrost areas (Street *et al.*, 2016).

At the Panguingue Creek River (second order stream), water pH and conductivity varied respectively between 7.4 and 6.0, and between 274 and 317 $\mu\text{S cm}^{-1}$ (Fig. 2, Table 1). Water $\delta^{18}\text{O}$ values were 3 % lower, and DOC concentrations were 57 % higher in 2025 compared to 2024. Values of $\Delta^{14}\text{C}$ -DOC were higher (*i.e.* less depleted) in 2025 (-508.2‰ , 5628 years BP) compared to 2024 (-521‰ , 5841 years BP), indicating a younger DOC source in 2025. Dissolved CO_2 and CH_4 concentrations remained similar in 2024 ($139 \mu\text{mol L}^{-1} \text{CO}_2$ and $0.030 \mu\text{mol L}^{-1} \text{CH}_4$) and 2025 ($91 \mu\text{mol L}^{-1} \text{CO}_2$ and $0.045 \mu\text{mol L}^{-1} \text{CH}_4$) in the Panguingue Creek River water, in agreement with the absence of changes observed at the inlet.

Silicon Isotopes Reveal Talik Connectivity (Closed versus Lateral)

In soil pore waters from the taliks and from the frozen portions of the soil, Si concentrations varied from 4.0 to 18.1 mg L^{-1} , and the silicon isotope compositions ($\delta^{30}\text{Si}$) varied from -0.02 to 2.88‰ (Fig. 2d–e). To characterise talik connectivity (closed *versus* lateral), we consider the difference in $\delta^{30}\text{Si}$ values between soil pore waters from the taliks and from the frozen portions of the soil, *i.e.* the $\Delta_{\text{Frozen-Talik}}\delta^{30}\text{Si}$ (Fig. 2f).

In 2024, the $\Delta_{\text{Frozen-Talik}}\delta^{30}\text{Si}$ (Fig. 2f) had two distinct patterns depending on the locations of the cores along the slope: upstream of the water track, $\delta^{30}\text{Si}$ was higher in the taliks than in the frozen portions of the soil ($\Delta_{\text{Frozen-Talik}}\delta^{30}\text{Si} < 0$) with a mean difference of -1.08‰ ; whereas downstream of the water track, $\delta^{30}\text{Si}$ was lower in the taliks than in the frozen portions of the soil ($\Delta_{\text{Frozen-Talik}}\delta^{30}\text{Si} > 0$) with a mean difference of $+0.86\text{‰}$, consistent with Si isotope fractionation during freezing processes (Hirst *et al.*, 2023). Upstream of the water track ($\delta^{30}\text{Si}_{\text{talik}} > \delta^{30}\text{Si}_{\text{frozen}}$), the heavier signature is consistent with closed system Si isotopic fractionation (Hatton *et al.*, 2019): in *closed taliks*. Downstream of the water track ($\delta^{30}\text{Si}_{\text{talik}} < \delta^{30}\text{Si}_{\text{frozen}}$), the lighter signature indicates an open system without Si isotopic fractionation in *lateral taliks*. Downstream taliks were also shallower (40 ± 17 cm) than upstream (64 ± 5 cm; Fig. 1b, Table S-1), consistent with a wetter, more connected zone that may transfer carbon to streams in deep winter.

In 2025, $\Delta_{\text{Frozen-Talik}}\delta^{30}\text{Si}$ was negative upstream of the water track and positive downstream of the water track, which confirms the results obtained in 2024 (Fig. 2f): closed taliks are upstream and lateral taliks are downstream of the water track.

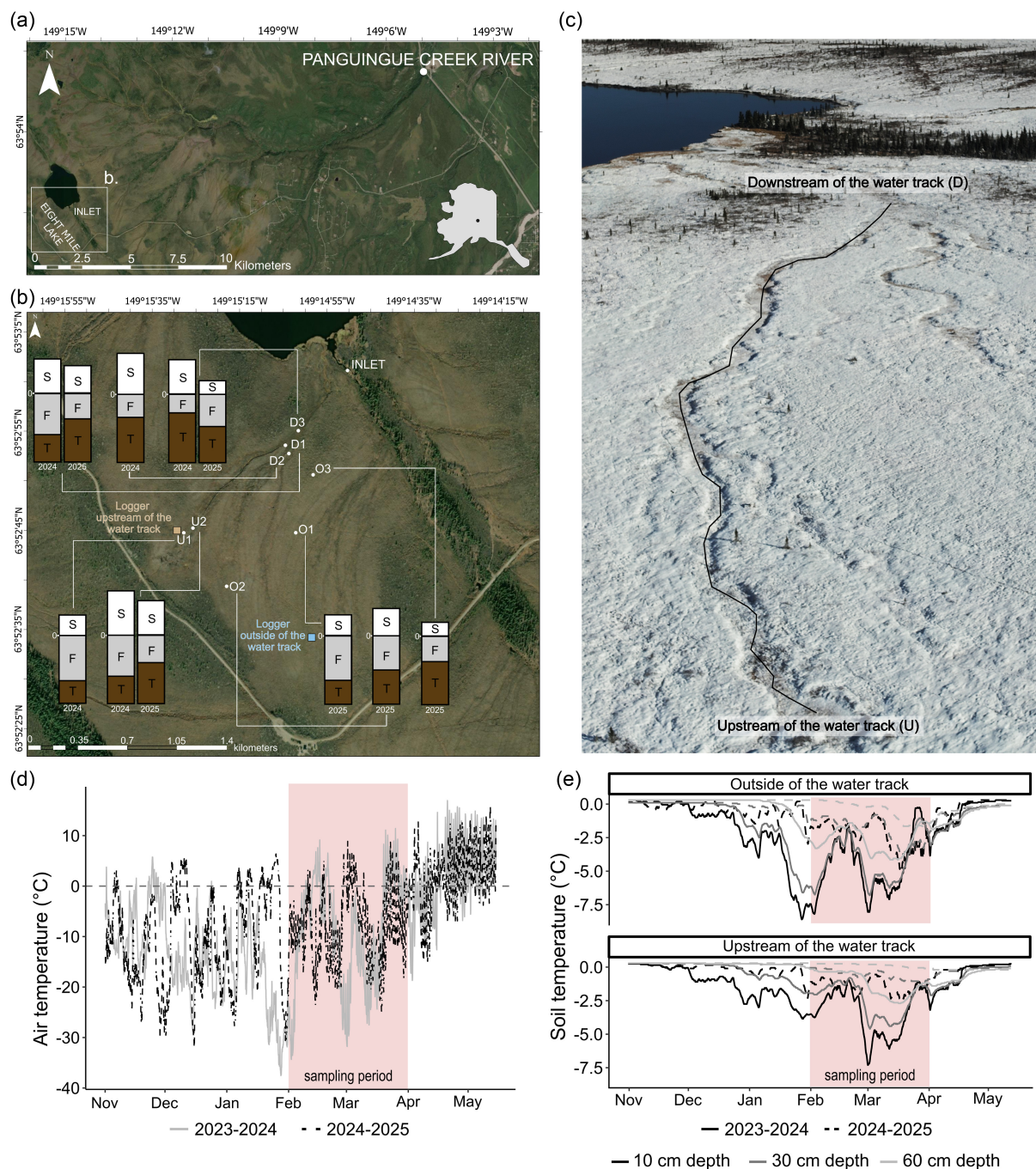


Figure 1 (a) Eight Mile Lake (details in (b)), the first order stream (inlet), and the second order stream (Panguingue Creek River). (b) Study site showing core positions outside (O1-O3), upstream (U1-U2), and downstream (D1-D3) of the water track, the inlet, and temperature loggers; core schematics show snow depth (S), frozen soil thickness (F), and talik depth (T), to scale (Table S-1). (c) Drone photograph (October 2023) showing the water track. (d) Air and (e) soil temperatures (10, 30, 60 cm depth) from November 1 to May 15 at locations in (b).

Moreover, $\delta^{30}\text{Si}$ values from soil pore waters outside of the water track exhibit patterns similar to those measured upstream of the water track: $\Delta_{\text{Frozen-Talik}} \delta^{30}\text{Si}$ was negative with $\delta^{30}\text{Si}$ in the taliks and 0.70 ‰ higher than in the frozen portions of the soil. As a result, taliks from outside of the water track are closed, like upstream of the water track.

Tracing Lateral Talik Contributions to Streams Using Silicon Isotopes

At the inlet (first order stream), dissolved Si concentrations and $\delta^{30}\text{Si}$ values were 47 % and 35 % lower, respectively, in

2025 compared to 2024 (Fig. 2d,e, Table 1). Inlet $\delta^{30}\text{Si}$ was lower in 2025 (1.33 ‰) than in 2024 (2.04 ‰), a shift toward lighter values, consistent with an increased contribution of soil pore waters from lateral taliks (0.59 ± 0.58 ‰) in 2025. The increase in $\delta^{18}\text{O}$ values from the inlet waters in 2025 compared to 2024 also supports this higher contribution of soil pore waters under warmer conditions (Table 1; Hirst *et al.*, 2022). As a result, our data suggest that, under warmer conditions (2025), winter inlet waters reflect an increased input from lateral talik pore waters, in addition to a persistent contribution from deep sub-permafrost groundwater (O'Donnell *et al.*, 2012; Roux *et al.*, 2026).

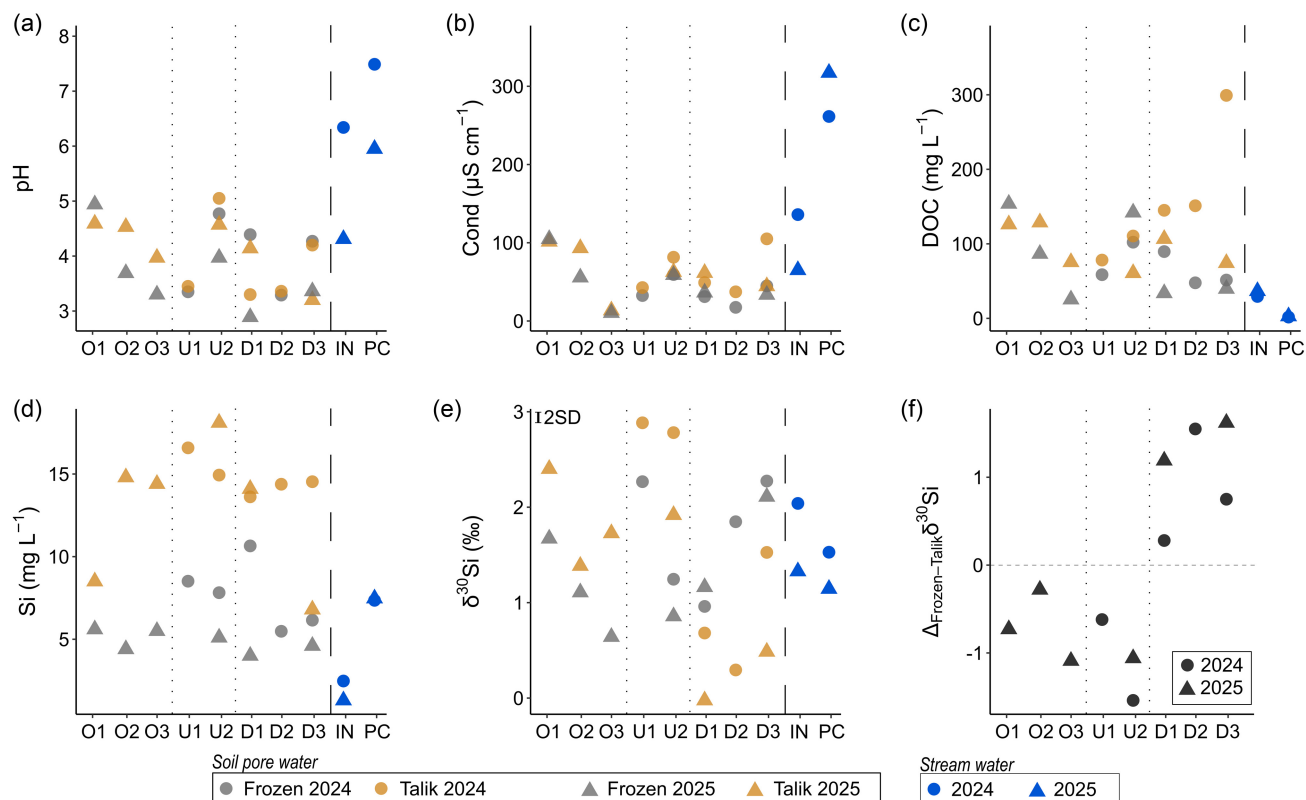


Figure 2 (a) pH, (b) conductivity ($\mu\text{S cm}^{-1}$), (c) DOC and (d) Si concentration (mg L^{-1}), (e) $\delta^{30}\text{Si}$ (‰), and (f) $\Delta_{\text{Frozen-Talik}} \delta^{30}\text{Si}$ in soil pore waters from the taliks (in yellow; $n = 11$) and the frozen portions of the soil (in grey; $n = 11$) from coring outside (O), upstream (U), and downstream (D) of the water track in 2024 and 2025; and in stream waters ($n = 4$; in blue: IN = inlet and PC = Panguingue Creek River; Table 1).

Table 1 pH, conductivity ($\mu\text{S cm}^{-1}$), water isotopes ($\delta^{18}\text{O}$ and δD , ‰), DOC concentration (mg L^{-1}), $\Delta^{14}\text{C}$ -DOC (‰), dissolved concentrations of CO_2 ($\mu\text{mol L}^{-1}$) and CH_4 ($\mu\text{mol L}^{-1}$), Si concentrations (mg L^{-1}), and $\delta^{30}\text{Si}$ (‰) from the inlet and the Panguingue Creek River. (*) Shown in Figure 2.

Parameters (units)	Inlet (first order stream)		Panguingue Creek River (second order stream)	
	2024	2025	2024	2025
*pH (-)	6.3	4.3	7.4	6.0
*Conductivity ($\mu\text{S cm}^{-1}$)	136	65	274	317
$\delta^{18}\text{O}$ (‰)	-17.2	-16.4	-18.5	-19.1
δD (‰)	-145.6	-137.2	-148.2	-146.1
*DOC (mg L^{-1})	29.4	36.6	1.7	2.7
$\Delta^{14}\text{C}$ (‰)	-19.4	-1.7	-521.0	-508.2
CO_2 ($\mu\text{mol L}^{-1}$)	420	443	139	91
CH_4 ($\mu\text{mol L}^{-1}$)	19.4	11.9	0.030	0.045
*Si (mg L^{-1})	2.5	1.3	7.5	7.5
* $\delta^{30}\text{Si}$ (‰)	2.04	1.33	1.71	1.14

At the Panguingue Creek River (second order stream), Si concentrations remained similar in 2024 and 2025 (7.5 mg L^{-1}), and $\delta^{30}\text{Si}$ values were 33 % lower in 2025 compared to 2024 (Fig. 2d,e, Table 1). Panguingue Creek $\delta^{30}\text{Si}$ was lower in 2025 (1.14 ‰) than in 2024 (1.71 ‰), a shift toward lighter values, consistent with an increased contribution of soil pore waters from lateral taliks ($0.59 \pm 0.58 \text{ ‰}$) in 2025, similar to the pattern observed at the inlet. The decrease in $\delta^{18}\text{O}$ in 2025 compared to 2024 (Table 1) likely reflects intra-river processes (Gibson and Prowse, 2002), including reduced river ice thickness during the warmer winter (90 cm in 2024 and 68 cm in 2025; see SI), rather than a direct soil signal. This indicates that Panguingue

Creek, as a second order stream, reflects an increased input from talik pore waters under warmer conditions (2025), in addition to a persistent contribution from deep sub-permafrost ground-water (O'Donnell *et al.*, 2012; Roux *et al.*, 2026), and intra-river processes.

Implications for Winter Carbon Mobilisation and Transfer into Streams

Lateral taliks being hydrologically connected during winter (Zhao *et al.*, 2026), they likely enhance the transfer of DOC to

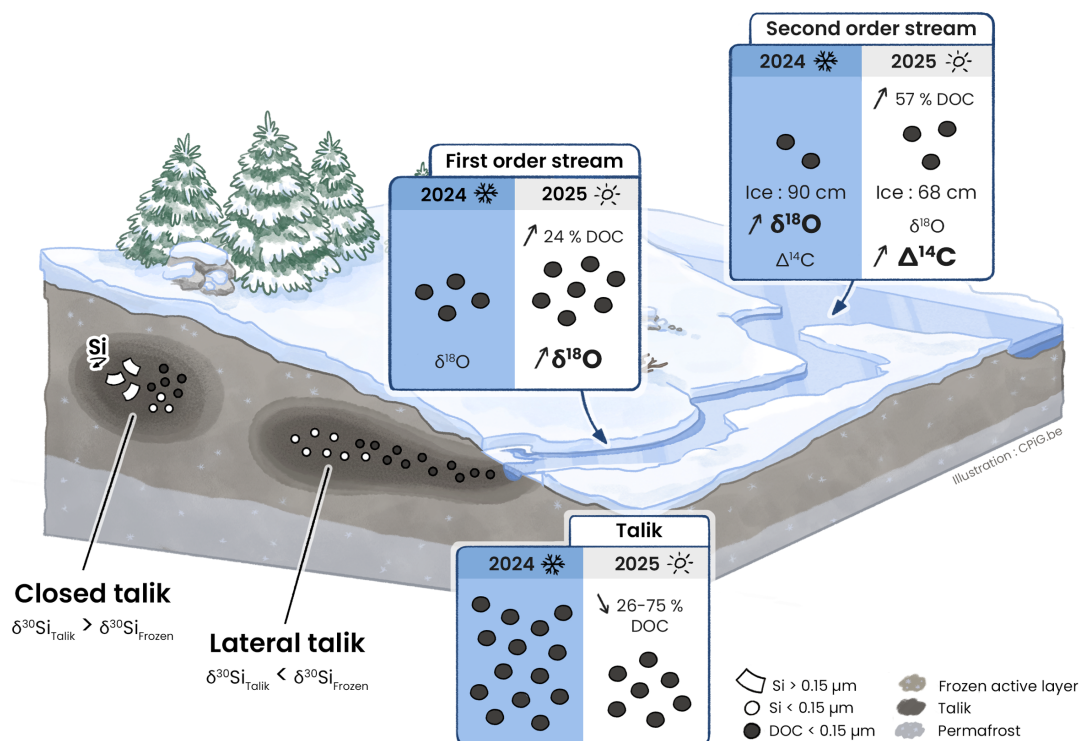


Figure 3 Synthesis of winter biogeochemical processes in between February-March 2024 and 2025. The first order stream represents the inlet, and the second order stream represents the Panguingue Creek River in this study. (The figure was designed by CPIG-Carolina Levicek)

streams. As the sampling period in 2025 was warmer than in 2024, the increase in DOC concentrations in the first and the second order stream waters in 2025 compared to 2024 suggests an increase in this mobilisation and the transfer of DOC from soils to streams (Fig. 3). The parallel increase in $\Delta^{14}\text{C}$ values at the second order stream (from -521.0 in 2024 to -508.2 ‰ in 2025; Table 1) under warming conditions also supports a greater contribution of younger DOC from talik pore waters ($\Delta^{14}\text{C}$ -DOC = -123.5 ± 120.2 ‰; Fig. S-1a). This increase in transfer of young DOC from lateral taliks in 2025 is in line with $\delta^{30}\text{Si}$ and $\delta^{18}\text{O}$ values at the first order stream, and $\delta^{30}\text{Si}$ at the second order stream (Fig. 2, Table 1). Stream waters were sampled once *per* year at each site, precluding formal statistical testing of interannual differences. However, the consistent direction of change across several independent parameters (DOC concentration, $\Delta^{14}\text{C}$ -DOC, $\delta^{30}\text{Si}$, and $\delta^{18}\text{O}$) demonstrates that these shifts reflect an increase in lateral talik contribution to streams under warmer conditions, rather than sampling variability alone.

At both the first and second order streams, dissolved CO_2 and CH_4 concentrations were stable between 2024 and 2025, (Table 1), suggesting that the mobilisation of DOC from lateral taliks in 2025 compared to 2024 does not translate into a change in the production of CO_2 and CH_4 and transfer to streams. A similar decoupling between DOC mobilisation and CO_2/CH_4 production was reported in Yedoma thaw affected lakes, where highly labile permafrost DOC nonetheless accumulated rather than being rapidly mineralised (Ollivier *et al.*, 2026). This decoupling contrasts with conditions in the soil itself: in free standing water from a shallow unconfined saturated zone at the most downstream site (Fig. S-1b; D4), dissolved CO_2 and CH_4 concentrations increased ~ 2 and ~ 17 fold, respectively, between 2024 ($\text{CO}_2 = 303 \mu\text{mol L}^{-1}$, $\text{CH}_4 = 2.7 \mu\text{mol L}^{-1}$) and 2025 ($\text{CO}_2 = 590 \mu\text{mol L}^{-1}$, $\text{CH}_4 = 45.0 \mu\text{mol L}^{-1}$), pointing to stronger CO_2 and CH_4 production in saturated soils under warmer conditions. This enhanced soil production, however, provides no

evidence of a corresponding transfer of dissolved CO_2 and CH_4 to streams. Alternatively, we cannot exclude that part of the transferred DOC is mineralised along the flow path between the first and second order streams, without being captured by our fixed point sampling. Enhanced winter DOC transfer from lateral taliks and active microbial CO_2 and CH_4 production in talik soils (Fig. S-1b) may also have delayed effects on riverine greenhouse gas dynamics during subsequent high flow period after deep winter (Castro-Morales *et al.*, 2022), contributing to the permafrost driven increase in annual stream CO_2 emissions (Mu *et al.*, 2025).

Conclusion

This study provides geochemical evidence of lateral talik connectivity using silicon isotopes. Contrasting $\delta^{30}\text{Si}$ signatures between taliks and frozen soil pore waters (heavier upstream and lighter downstream of the water track) distinguish closed from lateral taliks. The higher DOC concentrations in stream waters in 2025 than in 2024 suggest a greater lateral talik contribution to streams under warmer conditions. Together, these results indicate that lateral taliks act as critical subsurface pathways linking winter soil pore waters DOC mobilisation to aquatic carbon cycling. As winters continue to warm, the expansion of lateral taliks may enhance DOC transfer to streams, but do not necessarily lead to immediate increases in riverine dissolved CO_2 and CH_4 concentrations during winter. This study represents a first step toward understanding talik biogeochemical connectivity, given the logistical challenges of winter sampling in remote permafrost environments. Expanding observations across multiple sites and combining geochemical tracers with existing geophysical and thermal characterisation of taliks will be essential to fully assess the biogeochemical significance of lateral taliks in permafrost ecosystems.

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Data Availability

The data related to this article is available online at: <https://doi.org/10.14428/DVN/LPFBWO>

Additional Information

Supplementary Information accompanies this letter at <https://www.geochemicalperspectivesletters.org/article2636>.

During the preparation of this work the author used ChatGPT in order to assist with language editing and rephrasing of specific sentences. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.



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Deep winter dissolved organic carbon transfer from taliks in permafrost landscapes

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Supplementary Information

The Supplementary Information includes:

- Materials and Methods
- Supplementary Table S-1
- Supplementary Figures S-1 and S-2
- Supplementary Information References

Materials and Methods

Study sites

Two field campaigns took place near Eight Mile Lake (63°52' N, 149° 15' W; 700 m a.s.l), in Alaska, USA during winter 2024 (February – March) and 2025 (March; Fig. 1). These two field missions, each lasting two weeks, enabled soil pore water and inlet (first-order stream) water collection from the Eight Mile Lake catchment, and river water from the Panguingue Creek catchment (second-order stream). These catchments share similar characteristics, these are moist acidic tundras with an organic layer of 45–65 cm thick (> 20% OC) which covers cryoturbated mineral soil (< 20% OC) that is a mixture of glacial till (small stones and cobbles) and windblown loess, and an active layer thickness between 50 and 120 cm (Kelley *et al.*, 2021; Natali *et al.*, 2011). Their geology is composed of Tertiary sedimentary rocks, overlain by gravelly glacial till and aeolian silt including the Pliocene Nenana gravel (Soil Survey Staff, 1999). The mean annual temperature at the ACCLIMATE observatory was -1.7 ± 13 °C between 2004 and 2023 with a non-summer (October–April) average of -10 ± 10 °C and summer (May–September) average of 9.8 ± 6.2 °C (Celis *et al.*, 2024). The mean annual precipitation (rain and snow) is 378 mm, and the snow cover present from mid-September to mid-May is on average 52 cm thick (Natali *et al.*, 2012; Osterkamp *et al.*, 2009; Vogel *et al.*, 2009). The Eight Mile Lake catchment is characterized by high spatial heterogeneity, including differences in permafrost degradation, thermokarst subsidence, soil geochemistry, and vegetation (Hirst *et al.*, 2023; Mauclet *et al.*, 2023; Monhonval *et al.*, 2023; Villani *et al.*, 2022). Water tracks are present on the Eight Mile Lake catchment and are identifiable on the map (Fig. 1b,c). Water tracks have expanded upslope in the watershed since 1954 (Rodenhizer *et al.*, 2022). With permafrost thaw, water tracks are

often combined with subsidence (Del Vecchio and Evans, 2025). Compared to the surrounding area, water tracks at the study site have deeper permafrost, a thicker superficial organic-rich horizon (Monhonval *et al.*, 2023), and support dense vegetation (Rodenhizer *et al.*, 2022). Ground-penetrating radar surveys at this site show that supra-permafrost taliks are not continuous beneath the hillslope, but are preferentially located within and beneath the water track, where the active layer fails to fully refreeze in winter; surrounding soils outside the water track remain frozen year-round (Henrion *et al.*, 2025). This was corroborated by lateral coring conducted in 2025 at distances of 2–5 m from the center of the water track (cores U2, D2, D3), reaching just beyond its margin, where coring did not intersect any talik, confirming that the unfrozen zone remains spatially confined to the water track.

Air and soil temperatures, and snow depth

The air and soil temperatures were monitored continuously between November 1 and May 15 2023–2024 and 2024–2025 (winter period) using ZL6 Pro Data Logger connected to TEROS-12 (Meter Group) probes with a temporal resolution of one hour. These loggers were installed outside of the water track and upstream of the water track (Fig. 1b), and the soil temperature was monitored in two replicates at 10, 30 and 60 cm depth in each location. Within 2 m diameter around each logger, snow depth was measured in triplicates in February – March 2024 and 2025.

Soil coring and water sampling

At the Eight Mile Lake catchment, five (2024) and six (2025) cores were sampled using a gas-powered auger where snow and talik surface depth were measured. In 2024, all cores were carried out in the main water track of the study site (two upstream U1 and U2 and three downstream D1, D2 and D3 of the water track) and in 2025, three cores were carried out in the main water track (one upstream U2 and two downstream D1 and D3 of the water track) and three cores were carried out outside the water track (O1, O2, and O3, parallel to the main water track). Between 2024 and 2025, three cores (U2, D1 and D3) were sampled at the same place to enable year-on-year comparison. Each core was split between the surface frozen portion of the core within the active layer and the underlying talik portion (Table S-1). The talik depth reaches at least 1 m at all sites in 2024 and 2025: as the organo-mineral transition occurs at 33 ± 11 cm across the study site (Mauclet *et al.*, 2023; Monhonval *et al.*, 2023), taliks extend into both the organic and mineral soil layers. No permafrost was included in the sampling. After thawing frozen portions of the core (< 24 h after sampling) to allow ground ice to melt, macrorhizons with a pore size of $0.15 \mu\text{m}$ and a 10 cm porous part (Rhizosphere, Wageningen, The Netherlands) connected to a 60 mL polypropylene syringe (BD Plastipak luer lock), were inserted in soil sample to collect the soil pore water from the frozen portion of the core and from the talik, resulting in 22 soil pore water samples. In addition to these cores, liquid free-standing water was collected from a shallow unconfined saturated talik zone at the most downstream site in 2024 (at 48 cm depth) and 2025 (at 40 cm depth; D4; Fig. S-1). Within the same soil core, we compared soil pore waters from the frozen portion of the core and from the taliks at the vertical scale, using $\delta^{30}\text{Si}$ to trace the processes that constrain talik connectivity (i.e., closed versus lateral taliks).

Stream waters, at the inlet (first-order stream) and the Panguingue Creek river (second-order stream), were collected in winter 2024 ($n = 1$ for the inlet, and $n = 1$ for the Panguingue Creek river) and winter 2025 ($n = 1$ for the inlet and $n = 1$ for the Panguingue Creek river) at the same position under the ice (38 cm thick at the inlet; 90 cm thick in 2024 and 68 cm thick in 2025 for the Panguingue Creek river) using an ice auger, resulting in 6 stream water samples.

Chemical analyses

pH and conductivity measurements

In soil pore waters ($n = 22$), pH and specific electrical conductivity (“conductivity” in the text; measured at 25°C) were measured in the laboratory (UCLouvain, Belgium) within one week using a SevenCompact™ Duo S213 probe in a clean room. In stream waters ($n = 4$), the pH and electrical conductivity ($\mu\text{S cm}^{-1}$) were directly measured on the field using a probe from HANNA Instruments (HI991300). pH and conductivity are reported throughout as general background parameters.

Water isotopes measurements

In stream waters ($n = 4$, Fig. S-2), the water isotopes ($\delta^{18}\text{O}$ and δD) values were determined on unfiltered water using Cavity Ring-Down Spectroscopy on a Liquid Water Isotope Analyzer (L2130-i, Picarro®, Earth and Life Institute, UCLouvain, Belgium). Values are normalized between SLAP and VSMOW and reported in per mil deviation relative to VSMOW. Three reference materials were used: USGS46, USGS47 and USGS48. The reproducibility is $> 0.1\text{‰}$ for $\delta^{18}\text{O}$ and $> 0.6\text{‰}$ for δD .

Dissolved organic carbon concentration measurements

In stream waters and soil pore waters ($n = 26$), the concentration in dissolved organic carbon (DOC) was measured using high-temperature catalytic oxidation (Shimadzu® TOC-VCPH) with a detection limit of 0.1 mg L^{-1} and an accuracy of $\pm 2\%$.

Radiocarbon analysis

In stream waters ($n = 4$) and the talik pore waters with enough volume (U2, D1-D4; $n = 5$), the radiocarbon signature of the DOC was analyzed at the Arizona Climate and Ecosystems (ACE) Isotope Laboratory (Northern Arizona University) following the published method (Lang *et al.*, 2016). Briefly, to determine the radiocarbon signature of DOC, samples underwent wet chemical oxidation to convert them to CO_2 , which was analyzed on a Miniaturized Carbon Dating System (MICADAS) with a carbonate handling system (CHS2) and gas interface system (GIS). DOC radiocarbon measurements were calibrated using gaseous OX-II and radiocarbon-dead C dioxide (IonPlus, Switzerland). A standard deviation of 8‰ and a blank radiocarbon age of 38,000 years are spec. Within our analyses, OX- II replicates had a standard deviation of 7.4‰ . Samples were blank subtracted using the chemical glycine standard with an average radiocarbon age of $30,760 \pm 4701$ years ($n = 7$). Additionally, a replicate of a known environmental DOC sample was run on each day of analysis to assess instrument performance. Across two replicates representing the two days of analysis, the standard deviation of this internal standard was 3‰ . Radiocarbon ages are reported in years BP (Before Present, where present = 1950). The radiocarbon value reported for 2024 for the second order stream (Panguingue Creek) is from Roux *et al.* (2026) following the same protocol.

Dissolved gas concentrations (CO_2 and CH_4)

In stream waters ($n = 4$) and free-standing water from D4 ($n = 2$), the concentrations in dissolved CO_2 and CH_4 were analyzed. A syringe was filled with 30 ml of water and 30 ml of ambient air, shaken for 5 minutes, and injected into a pre-evacuated 12 ml exetainer (Labco UK). The water temperature was measured in-situ and in the syringe using a HANNA Instruments (HI991300) probe. Gas concentration measurements were made using a gas chromatograph (SRI 8610C, University of Liège) with a flame ionization detector with a methanizer calibrated with $\text{CH}_4:\text{CO}_2:\text{N}_2$ gas mixtures (Air Liquide Belgium) with mixing ratios of 1, 10 and 30 ppm for CH_4 , and 404, 1018, 3961 ppm for CO_2 . The precision of measurement was $\pm 3.9 \%$ for CH_4 , and $\pm 5.0 \%$ for CO_2 .

Silicon concentration measurements

In stream waters and soil pore waters ($n = 26$), the concentration in silicon (Si) was measured by an inductively coupled plasma-optical emission spectrometer (ICP-OES, iCAP 6500 ThermoFisher Scientific). The accuracy is $\pm 0.3 \%$ and the detection limit is 0.2 mg L^{-1} .

Silicon isotope measurements

In stream waters and soil pore waters ($n = 26$), the silicon isotope composition ($\delta^{30}\text{Si}$) was measured using a MC-ICP-MS (Neptune Plus™ High Resolution Multicollector ICP-MS, Thermo Fisher Scientific, Earth and Life Institute, UCLouvain, Belgium) following the published method (Hirst *et al.*, 2023). Sample preparation was done in clean lab conditions (ISO 6) under a laminar flow hood (ISO 5). A volume equivalent to $10 \mu\text{g}$ Si was dried down. The dissolved organic carbon in solution was removed by repeated cycles of heating ($60 \text{ }^\circ\text{C}$) with concentrated HNO_3 and H_2O_2 and evaporating ($80 \text{ }^\circ\text{C}$) cycles (Hughes *et al.*, 2011). The sample was digested in 0.125 M NaOH for four hours at $100 \text{ }^\circ\text{C}$,

then acidified with HNO₃. Silicon was purified from the matrix with a one-stage column chemistry using a cation exchange resin (Biorad AG50W-X12; Georg *et al.*, 2006). The Si recovery was typically > 90% and Na⁺ concentrations below the detection limit.

The silicon isotope composition ($\delta^{30}\text{Si}$) was measured by MC-ICP-MS in wet plasma mode in high resolution ($\Delta m/m \approx 9000$) using a PFA nebulizer of 100 $\mu\text{L min}^{-1}$ uptake rate. The instrumental mass bias was corrected using the standard-sample bracketing technique and an external Mg doping (Cardinal *et al.*, 2003). The analyses were performed in 2% HNO₃ matrix, with a typical sensitivity of 3.5 V for 1 mg L⁻¹ Si and an instrumental blank < 30 mV. The $\delta^{30}\text{Si}$ compositions are expressed in relative deviations of $^{30}\text{Si}/^{28}\text{Si}$ ratio from an in-house standard (Quartz Merck) isotopically similar to NBS28 reference standard using the common δ -notation (‰) as follows (Abraham *et al.*, 2008): $\delta^{30}\text{Si} = [(^{30}\text{Si}/^{28}\text{Si})_{\text{sample}} / (^{30}\text{Si}/^{28}\text{Si})_{\text{Quartz Merck}} - 1] \times 1000$.

The long-term precision and accuracy of the MC-ICP-MS was assessed from diatomite standard measurements ($\delta^{30}\text{Si} = 1.29 \pm 0.05$ ‰, SD, n = 7) which are consistent with previously reported values ($\delta^{30}\text{Si} = 1.26 \pm 0.10$ ‰; Reynolds *et al.*, 2007).

Data treatment

All graphs and statistics were performed using R 4.0.2 (RStudio Inc., Boston, Massachusetts, USA) and plots using the ggplot2 package.

The significant differences in temperature, pH, electrical conductivity, DOC concentrations, $\Delta^{14}\text{C}$ -DOC, CO₂ and CH₄ concentrations, Si concentrations, and $\delta^{30}\text{Si}$ between locations (downstream – upstream), between core type (frozen – talik) or between years (2024 – 2025) were compared with a Wilcoxon test. The 95% confidence intervals of the statistic were used to test for a significant difference between values, which is equivalent to a p-value cutoff of 0.05 (*, p-value < 0.05; **, p-value < 0.01; ***, p-value < 0.001).

Supplementary Tables

Table S-1 Coordinates (longitude and latitude), snow depth and talik depth (top of the talik) from each core sampled in 2024 and 2025 at Eight Mile Lake (Alaska)

Core	Longitude (°)	Latitude (°)	Year	Snow depth (cm)	Talik depth (top) (cm)
O1	-149.25043498	63.87922008	2025	30	65
O2	-149.25483020	63.87771930	2025	40	50
O3	-149.24932890	63.88084321	2025	20	37
U1	-149.25755024	63.87921807	2024	30	67
U2	-149.25696778	63.87935029	2024	65	60
			2025	50	40
D1	-149.25109299	63.88166974	2024	50	60
			2025	40	37
D2	-149.25087137	63.88143836	2024	60	34
D3	-149.25027074	63.88207837	2024	50	27
			2025	20	47
D4	-149.248389574	63.8830855675	2024	80	18
			2025	10	40

Supplementary Figures

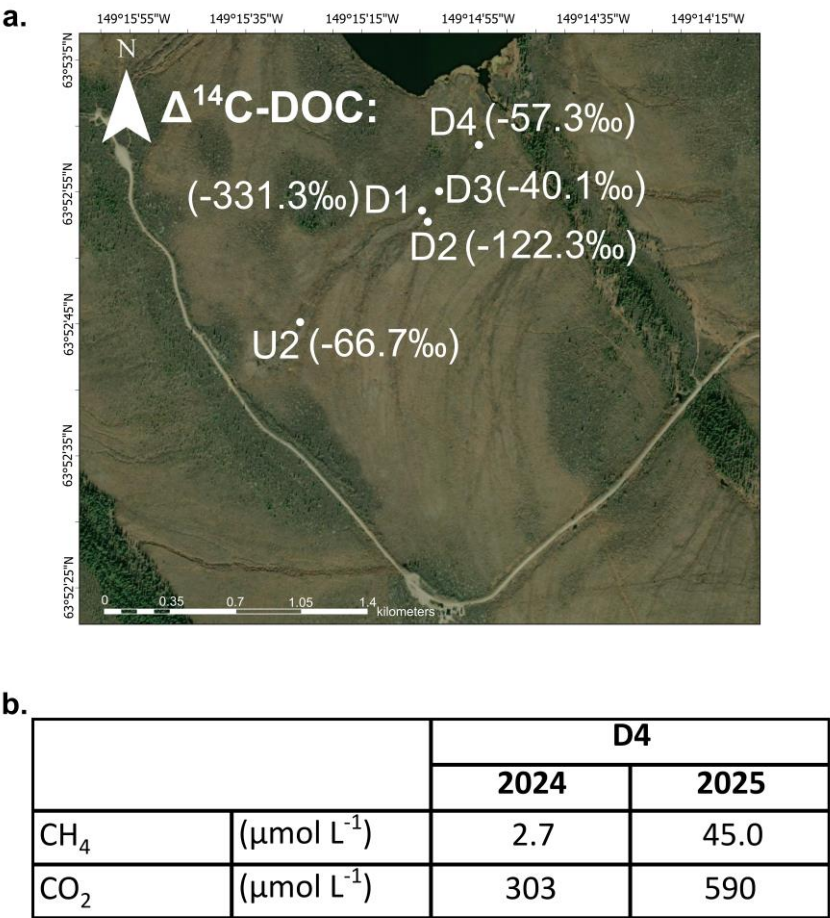


Figure S-1 (a) Radiocarbon of DOC ($\Delta^{14}\text{C-DOC}$, in ‰) in taliks from U2, D1-D4, where D4 corresponds to free-standing water collected from a shallow unconfined saturated zone at the most downstream site. **(b)** Dissolved concentration of CO₂ (in μmol L⁻¹) and CH₄ (in μmol L⁻¹) in the free-standing water from the talik at D4 in 2024 and 2025.

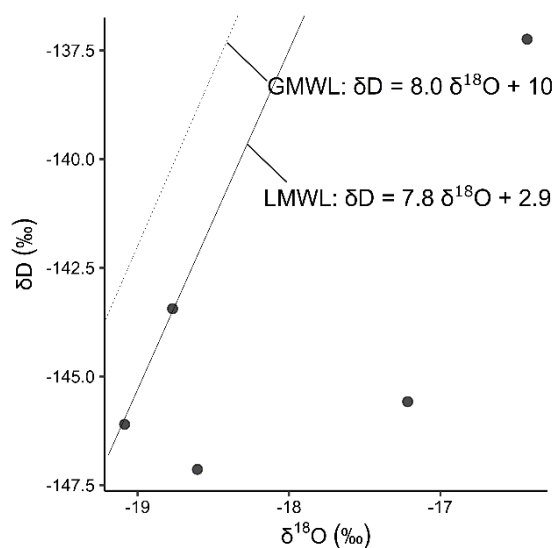


Figure S-2 ($\delta^{18}\text{O}$) and deuterium (δD) isotope composition for river waters collected in the streams (inlet and Panguingue Creek river) in 2024 and 2025. The Global Meteoric Water Line (GMWL) and the Local Meteoric Water Line (LMWL) for precipitation are presented (Hirst *et al.*, 2022).

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