Supplement of Biogeosciences, 22, 3899–3914, 2025
https://doi.org/10.5194/bg-22-3899-2025-supplement

Biogeosciences
Open Access

Supplement of

Water chemistry and greenhouse gas concentrations in waterbodies of a thawing permafrost peatland complex in northern Norway

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Table S1 The number of samples of each type collected for each waterbody and the sampling dates

	water chemistry	**dissolved gas**	**CO2 flux chamber**	**dark incubation**	**discharge**
TK-Pond 1	9	9	9	7	0
TK-Pond 2	9	9	8	7	0
TK-Pond 3	9	9	8	7	0
TK-Drain	9	9	9	7	0
Inlet	10	9	9	6	5
Outlet	10	9	10	7	5

Sampling dates	**Notes**
07.09.2020	
03.06.2021	
04.06.2021	limited set of repeat analysis at the inlet and outlet
01.07.2021	
12.08.2021	
01.10.2021	
02.06.2022	
05.07.2022	TK ponds and drain only
06.07.2022	inlet and outlet only
06.08.2022	
22.09.2022	

Table S2 Temperature and thaw/freeze dates in 2022 from sensor data in the ponds and streams

	Ice-off date	**Average T ^{0}C**	**Max T ^{0}C**	**Max T date**	**Ice-on date**	**Days to max T**	**Days ice-free**
TK-Pond 1	15/05/22	8.6	17.7	29/06/22	03/11/22	45	172
TK-Pond 2	20/05/22	8.1	14.8	05/07/22	01/11/22	46	165
TK-Pond 3	18/05/22	8.4	15.4	05/07/22	03/11/22	48	169
TK-Drain	14/05/22	9.4	22.0	29/06/22	26/10/22	46	165
Inlet	20/05/22	7.3	14.5	02/07/22	07/11/22	43	171
Outlet	14/05/22	7.7	17.4	03/07/22	14/11/22	50	184

Table S3 Sampling of cations (calcium: Ca; magnesium: Mg; Potassium: K; and Sodium: Na) in autumn 2020 and summer 2021

site	date	Ca	Mg	K	Na	Cl
TK-Pond 1	2020-09-07	0.64	0.26	0.02	0.91	1.27
TK-Pond 1	2021-06-03	0.48	0.27	0.046	0.81	0.37
TK-Pond 1	2021-06-30	0.45	0.27	0.035	0.34	0.087
TK-Pond 2	2020-09-07	0.65	0.29	0.01	0.41	0.8
TK-Pond 2	2021-06-03	0.21	0.11	0.017	0.46	0.43
TK-Pond 2	2021-07-01	0.41	0.24	0.01	0.52	0.36
TK-Pond 3	2020-09-07	0.22	0.064	0.022	0.16	0.52
TK-Pond 3	2021-06-03	0.32	0.2	0.72	0.99	0.46
TK-Pond 3	2021-06-30	0.32	0.21	0.057	0.57	0.34
TK-Drain	2020-09-07	0.57	0.27	0.026	0.85	0.83
TK-Drain	2021-06-03	0.4	0.19	0.018	0.65	0.39
TK-Drain	2021-07-01	0.47	0.26	0.1	0.65	0.43
Inlet	2020-09-07	2.18	1.05	0.49	1.44	0.92
Inlet	2021-06-02	1.17	0.54	0.59	0.9	0.49
Inlet	2021-06-30	2.26	1.02	0.26	1.41	0.4
Outlet	2020-09-07	1.96	0.9	0.6	1.41	1.01
Outlet	2021-06-03	1.07	0.54	0.79	0.82	0.48
Outlet	2021-06-30	1.63	0.78	0.029	1.33	0.25

Supplementary Methods and Field Procedure Comparison

To evaluate the potential impact of delayed filtration on nutrient and carbon concentrations, a filtration comparison experiment was conducted in September 2022 using samples collected from a subset of representative pond and stream sites in the study area. Four treatment types were applied at each site:

- type 0: untreated (unfiltered and unacidified) which was the routine procedure for field sampling
- type 1: acidified only (unfiltered but acidified on site)
- type 2: filtered only (field-filtered, no acidification)
- type 3: filtered with acidification.

These treatments were used to assess the influence of filtration and acidification on DOC, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, totP, total nitrogen (totN), SiO_2, SO_4^{2-}, TOC, pH, and conductivity. The results of this experiment are summarized in Supplementary Table S4.

In the routine procedure (type 0), water samples for chemical analysis were collected using the following standardized procedures. At each sampling location, 500 mL of water was collected into HDPE rectangular bottles (Emballator Melledrud AB, Stockholm, Sweden), which were rinsed three times with sample water prior to collection. These samples were not filtered. Immediately after sampling, bottles were stored in the dark and kept cool at approximately 4°C using insulated cooling containers. Sampling trips typically lasted no longer than four days including travel, and in nearly all cases, water samples were stored for no more than 36 hours before transport. Samples were transported back to the laboratory by plane and were delivered immediately upon return to the Norwegian Institute for Water Research (NIVA), where they were subjected to established laboratory protocols and stored at 4°C until analysis.

For types 1, 2 and 3 only 250 mL of water was sampled. For type 2 and 3 filtration in the field was performed with pre-combusted 24 mm GF/F filters (glass fiber, nominal pore size ~0.7 µm). For type 1 and type 3 acidification was performed by adding 1 mL 2.5M H_2SO_4.

In the lab, all samples were filtered for nutrient analyses—including DOC, ammonium (NH_4^+), nitrate and nitrite (NO_3^- and NO_2^-), phosphate (PO_4^{3-}), — with 47 mm filters with a 0.45 µm pore size prior to analysis. Other analytes, such as pH, electrical conductivity (EC), silica (SiO_2), sulfate (SO_4^{2-}), total organic carbon (TOC), total phosphorus (totP) and conductivity, were measured in unfiltered water in accordance with laboratory standard procedures for these parameters.

The comparison revealed no significant differences between field-filtered and lab-filtered samples for DOC, TOC, SiO_2, SO_4^{2-}, total nitrogen, pH, or conductivity, suggesting that delayed filtration under cold and dark storage conditions did not compromise sample integrity for these parameters. Minor differences were observed for PO_4^{3-} and totP in TK-Pond 1 and TK-Pond 3, which were likely due to particle flocculation or redistribution between collection and laboratory filtration. The most notable variability was found in NH_4^+ concentrations, although this was only true at one site, TK-Pond 1, indicating some sensitivity of this parameter to storage conditions, possibly due to microbial transformation or desorption processes. Differences in totN concentrations were most pronounced in relation to preservation treatment. However, totN values were excluded from the main analyses, not due to storage and preservation concerns but because of known issues identified in the analytical method itself. Specifically, biases in freshwater totN concentrations associated with the modified NS4743 method used at the time have been documented (Thrane et al., 2020), affecting the accuracy of totN results across multiple years. While the totN values obtained in this study were sufficient to confirm that the dominant nitrogen form was organic, they were not considered quantitatively reliable and are therefore not reported in the main manuscript.

Given the logistical constraints of fieldwork in remote environments and the need to balance water sampling with concurrent high-frequency greenhouse gas measurements and other environmental monitoring, field filtration of all samples was not feasible. Implementing field filtration for all analytes would have significantly limited the scope of other data collection activities. However, the filtration comparison experiment supports the conclusion that our approach—sampling unfiltered water into clean HDPE bottles, storing samples cool and dark, minimizing storage duration before transport, and conducting filtration and analysis promptly upon lab arrival—produced data that are robust and suitable for scientific interpretation.

Table S4 Results from a filtration and preservation comparison experiment conducted at selected pond and stream sites in September 2022. Each sample was subjected to one of four treatments: type 0 is untreated (no filtration or acidification) and was the routine procedure for field sampling; type 1 is preserved only (unfiltered and acidified); type 2 is filtered only (field-filtered); type 3 was filtered in the field and preserved with acidification.

Station name	**Sample date**	**Type**	**Field Treatment**	**DOC mg/L C**	**NH4-N µg/l**	**NO3+NO2-N µg/l**	**pH**	**PO4-P µg/l**	**SiO2 mg/l**	**SO4 mg/L**	**TOC mg/l**	**TOTN_EF _usikker µg/l**	**TOTP µg/l**	**Konduktivitet mS/m**
TK-Pond 1	20.09.2022	0	none	18.5	83	2	4.35	4	5.2	0.2	21.1	340	18	2.78
TK-Pond 1	20.09.2022	1	acidified	19.5	17	3		5	5.18		22.5	570	20	
TK-Pond 1	20.09.2022	2	filtered	20	8	< 1	4.34	2	5.19	0.17	21.2	390	12	2.76
TK-Pond 1	20.09.2022	3	filt + acid	18.7	12	2		3	5.18		20	290	11	
TK-Pond 2	20.09.2022	0	none	24.9	340	3	4.13	1	2.8	0.63	27.8	470	13	4.02
TK-Pond 2	20.09.2022	1	acidified	26	349	3		2	2.8		27.4	760	13	
TK-Pond 3	20.09.2022	0	none	30.9	11	< 1	3.91	4	4.16	0.09	34.9	460	28	5.55
TK-Pond 3	20.09.2022	1	acidified	31.3	13	< 1		4	4.08		33	640	25	
TK-Pond 3	20.09.2022	2	filtered	30.8	10	< 1	3.92	2	4.11	0.08	33.3	400	16	5.56
TK-Pond 3	20.09.2022	3	filt + acid	25.3	12	2		2	4.11		32.3	400	16	
TK-Drain	20.09.2022	0	none	14.5	8	2	4.83	< 1	5.22	0.27	14.6	180	4	1.55
TK-Drain	20.09.2022	1	acidified	14.2	11	3		< 1	5.22		14.9	210	4	
Inlet	22.09.2022	0	none	6.2	< 5	< 1	7	2	10	0.97	6.6	92	5	2.23
Inlet	22.09.2022	1	acidified	6.1	5	1		2	11		6.8	97	5	
Outlet	22.09.2022	0	none	9.3	20	1	6.76	< 1	9.5	0.92	9.4	140	4	2.01
Outlet	22.09.2022	1	acidified	8.5	7	1		1	9.9		9.4	150	5	
Outlet	22.09.2022	2	filtered	7.8	9	< 1	6.8	< 1	9.4	0.8	9.2	110	3	1.95
Outlet	22.09.2022	3	filt + acid	8.4	7	1		< 1	9.5		9.4	130	3	

Figure S1 Spatial variability in water pH (a) and conductivity (b) in September 2023 across the wetland, water bodies of the peat plateau and saturated surroundings. Spatial variability in relative importance of CH_4 global warming potential (GWP) compared to total global warming on a 20-year (c) or 100-year (d) horizon. Aerial images by the Norwegian Mapping Authority (Norgeibilder, 2024).

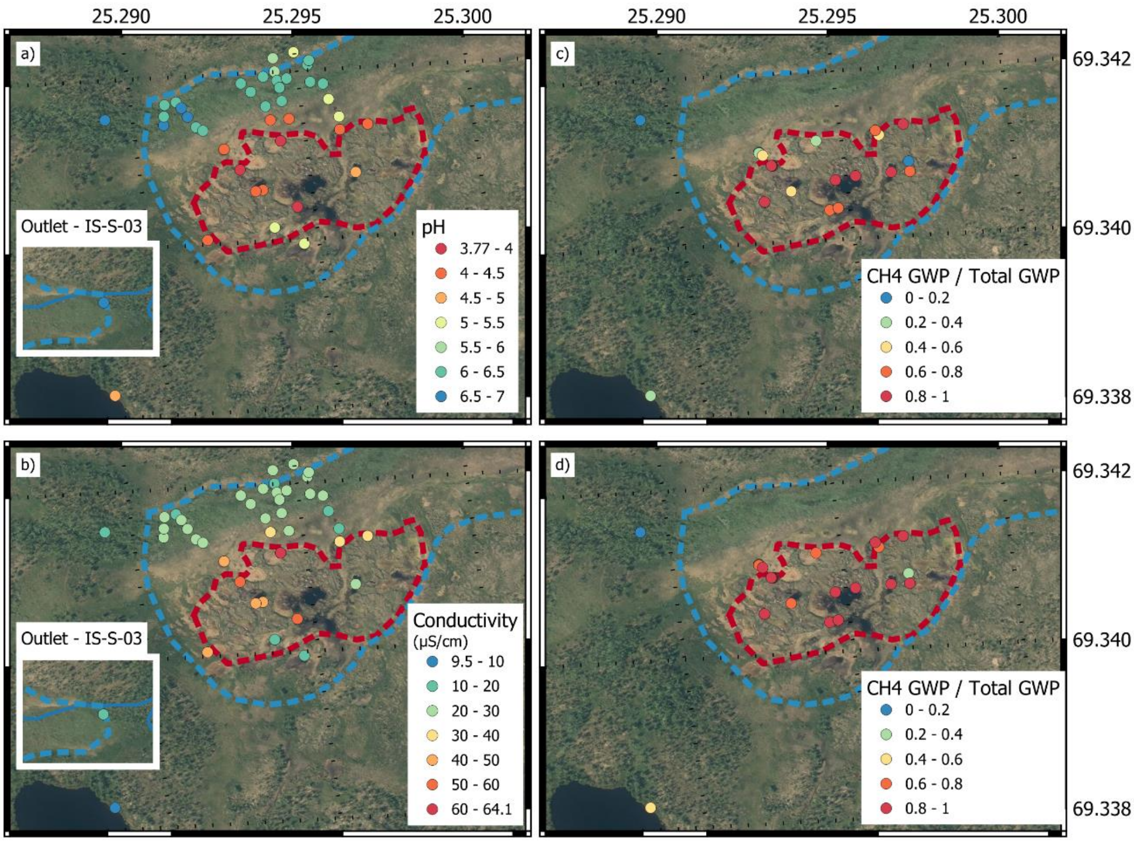
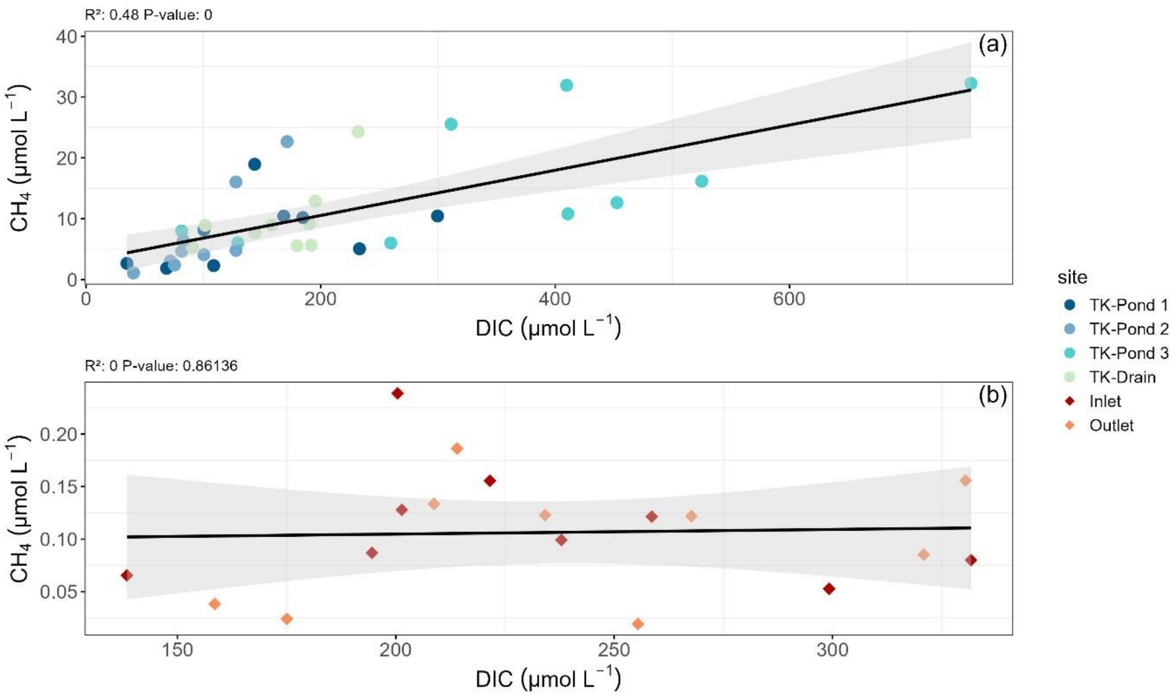


Table S5 Flux and mineralization rates during the ice-free period. CO_2 flux values are reported in g C/m² while DIC mineralization rates are reported in g C/m3/year. These values represent the annual CO_2 flux and total DOM mineralization during the active, ice-free portion of the year.

flux and mineralization rates during ice free	**CO2 flux g C/m2/yr**	**stdev**	**DIC rate g C/m3/yr**	**stdev**
TK-Pond 1	61.2	47.6	116.9	60.0
TK-Pond 2	51.0	37.4	151.0	173.1
TK-Pond 3	86.7	47.6	156.5	148.5
TK-Drain	62.9	25.5	25.5	26.5
Inlet	190.4	78.2	82.2	49.3
Outlet	404.8	211.6	89.7	73.1

Figure S2 Relationships between CH_4 and DIC for thermokarst waterbodies (a) and for Inlet and Outlet (b) sites including linear regression lines and corresponding R^2 and p-value statistics. Note scale differences for CH_4 between thermokarst waterbodies and the wetland streams.



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