Table S1: Site characteristics describing distance range, glacier source of headwaters, name of river, coordinates (in degrees, decimal minutes), approximate distance of sampling site from glacier terminus (estimated from Google Earth), and the number of times each site was visited in this study.

Distance Range	Glacier headwaters	River	Latitude	Longitude	Distance from glacier terminus (km)	Number of times visited
Headwater	Athabasca	Sunwapta	52°12'25.8"	-117°14'05.9"	0	16
Near	Athabasca	Sunwapta	52°12'59.5"	-117°14'01.9"	3	15
Mid	Athabasca	Sunwapta	52°18´38.1"	-117°19´57.3"	25	17
Far	Athabasca	Sunwapta	52°31´58.7"	-117°38´39.2"	50	17
Far	Athabasca	Athabasca	52°34' 59.6"	-117°44'21.9"	50	14
Far	Athabasca	Athabasca	52°39´46.5”	-117°52´51.7"	70	18
Far	Athabasca	Athabasca	52°48´43.4"	-118°02´33.2"	100	16
Near	Saskatchewan	NSR	52°10´10.1"	-117°04´34.9"	7	18
Mid	Saskatchewan	NSR	52°4'9.1"	-116°54'54.9"	18	16
Mid	Saskatchewan	NSR	51°58´14.0"	-116°43´16.0"	35	16
Near	Bow	Bow	51°39'42.3"	-116°29'12.98"	2	14
Mid	Bow	Bow	51°37'53.04"	-116°20'6.6"	15	15
Mid	Bow	Bow	51°25´43.2"	-116°11´20.4"	40	17

Table S2: Description of characteristics for various the absorbance- and fluorescence-based metrics used in this study.

Measurement	Calculation	Purpose
$SUVA_{254}$	Normalization of UV absorbance at 254 nm to DOC	Increasing values indicate increasing aromaticity (Weishaar et al. 2003)
$S_{275\text{-}295}$	Slope over the 275nm-295nm wavelength range	Decreasing values indicates increasing molecular weight (Helms et al. 2008)
BIX	The ratio of emission at 380nm by 430nm at excitation of 310nm	Biological Index: Increasing values indicate recently produced organic carbon (Huguet et al. 2008)
HIX	Fluorescence intensity over 300-340nm divided by the combined fluorescence in the 300-345nm and 435-480nm	Humification Index; Increasing values indicate increasing humification (Ohno 2002)
FI	The ratio of emission at 400nm to 500nm at an excitation of 370nm	Fluorescence Index: Higher values indicate microbially derived fulvic acids, lower values indicate terrestrially derived fulvic acids (McKnight et al. 2001)

Table S3: Outputs from a two-way ANOVA to show the effect of distance range and hydrological season on the relative percentage of deuterium excess in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

Deuterium excess						
Factor	**Df**	**SumSq**	**F value**	**p**	**Tukey Comparison**	**p**
Distance Range	3	95.76	44.74	**< 0.0001**	Headwater=Near	0.15
					Headwater>Mid	**<0.0001**
					Headwater>Far	**<0.0001**
					Near>Mid	**<0.0001**
					Near>Far	**<0.0001**
					Mid>Far	**<0.0001**
Season	2	20.83	14.6	**< 0.0001**	PreMelt<Melt	**<0.0001**
					PreMelt=PostMelt	**0.003**
					Melt=PostMelt	0.55
DistRange: Season	6	11.35	2.651	**0.0173**		
Residuals	186	3217				

Table S4: Outputs from a two-way ANOVA to show the effect of distance range and hydrological season on the relative percentage of $\delta^{18}O\text{-}H_2O$ in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

$\delta^{18}O\text{-}H_2O$						
Factor	**Df**	**SumSq**	**F value**	**p**	**Tukey Comparison**	**p**
Distance Range	3	1.71	1.802	0.15		
Season	2	326	9.424	**< 0.0001**	PreMelt<Melt	**<0.0001**
					PreMelt=PostMelt	**<0.0001**
					Melt=PostMelt	**<0.0001**
DistRange: Season	6	146	1.403	**0.02**		
Residuals	186	3217				

Table S5: Outputs from a three-way ANOVA to show the effect of distance range, hydrological season, and year on the DOC concentration in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

DOC						
Factor	**Df**	**SumSq**	**F value**	**p value**	**Tukey Comparison**	**p**
Distance Range	3	8.531	26.983	**<0.0001**	Headwater = Near	0.99
					Headwater = Mid	0.081
					Headwater < Far	**<0.0001**
					Near < Mid	**0.0034**
					Near < Far	**<0.0001**
					Mid < Far	**<0.0001**
Hydrological Season	1	5.488	52.074	**<0.0001**	PreMelt > Melt	**<0.0001**
Year	2	0.997	4.731	0.0102	2019>2020	**0.033**
					2019>2021	**0.014**
					2020=2021	0.93
DistRange: Season	3	1.365	4.318	0.006		
DistRange: Year	6	1.431	2.263	0.041		
Season: Year	1	3.480	33.025	**<0.0001**		
DistRange: Season:Year	3	1.344	4.25113	0.007		
Residuals	152	15.492	NA	NA		

Table S6: Outputs from a three-way ANOVA to show the effect of distance range, hydrological season, and year on the POC concentration in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

POC						
Factor	**Df**	**SumSq**	**F value**	**P value**	**Tukey Comparison**	**p**
Distance Range	3	1.746	3.281	**0.023**	Headwater > Near	**0.019**
					Headwater = Mid	0.31
					Headwater = Far	0.077
					Near = Mid	0.23
					Near = Far	0.69
					Mid = Far	0.72
Hydrological Season	1	0.240	1.352	0.246		
Year	2	1.110	3.129	**0.046**	2019=2020	0.67
					2019>2021	**0.05**
					2020=2021	0.21
DistRange: Season	3	0.390	0.463	0.71		
DistRange: Year	6	1.649	1.550	0.166		
Season: Year	1	0.01	0.056	0.813		
DistRange: Season:Year	3	0.0431	0.081	0.970		
Residuals	149	26.425	NA	NA		

Table S7: Excitation and emission maxima associated with PARAFAC components and associated DOM character as assessed by cross reference with the Open Fluor database.

Component	Emission peak	Excitation peak	Character	Number of Open Fluor Matches
C1	271	230	Terrestrial / humic (Shutova et al., 2014)	118
C2	409	230	Terrestrial / humic (Catalán et al., 2018; Coulson et al., 2022; Shutova et al., 2014),	105
C3	340	230	Microbial/tryptophan like (Murphy et al., 2008; Stedmon & Markager, 2005)	27
C4	300	230, 270-275	Microbial/tyrosine like(Graeber et al., 2012)	14

Table S8: Outputs from a three-way ANOVA to show the effect of distance range, hydrological season, and year on the POC concentration in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

Protein-like components						
Factor	**Df**	**SumSq**	**F value**	**P value**	**Tukey Comparison**	**p**
Distance Range	3	3.215	29.183	**<0.0001**	Headwater > Near	0.21
					Headwater > Mid	**<0.0001**
					Headwater > Far	**<0.0001**
					Near > Mid	**<0.0001**
					Near > Far	**<0.0001**
					Mid > Far	**0.025**
Season	1	0.357	9.729	**0.00216**	PreMelt - Melt	**0.002**
Year	2	0.236	3.216	**0.043**	2019=2020	0.12
					2019=2021	0.071
					2020=2021	0.95
DistRange: Season	3	0.057	0.518	0.67		
DistRange: Year	6	0.423	1.922	**0.08**		
Season: Year	1	0.001	0.016	0.9		
DistRange: Season:Year	3	0.077	0.701	0.55		
Residuals	158	5.802				

Table S9: Outputs from a three-way ANOVA to show the effect of distance range, hydrological season, and year on δ^{13}C-DOC ‰ in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

δ^{13}C-DOC						
Factor	**Df**	**SumSq**	**F value**	**p**	**Tukey comparison**	**p**
Distance Range	3	11.2	1.014	0.39		
Season	2	45	6.088	**0.003**	PreMelt=Melt	0.12
					PreMelt<PostMelt	**0.003**
					Melt<PostMelt	**0.03**
Year	2	225	30.455	**<0.0001**	2019>2020	**<0.0001**
					2019>2021	**<0.0001**
					2020=2021	0.45
DistRange: Season	6	86.8	3.916	**0.0014**		
DistRange: Year	6	115.2	5.197	**<0.0001**		
Season: Year	2	46.1	6.245	**0.0027**		
DistRange: Season:Year	3	5.1	0.459	0.71		
Residuals	115	424.9				

Table S10: Outputs from a three-way ANOVA to show the effect of distance range, hydrological season, and year on δ^{13}C-POC ‰ in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

δ^{13}C-POC						
Factor	**Df**	**SumSq**	**F value**	**p**	**Tukey Comparison**	**p**
Distance Range	3	14.5	1.743	0.16		
Season	2	69.8	12.604	**<0.0001**	PreMelt<Melt	**<0.001**
					PreMelt<PostMelt	**0.002**
					Melt=PostMelt	0.93
Year	2	489.4	88.35	**<0.001**	2019<2020	**<0.001**
					2019<2021	**<0.001**
					2020=2021	0.19
DistRange: Season	6	35.2	2.118	**0.05**		
DistRange: Year	6	52.2	3.139	**0.006**		
Season: Year	3	6.1	0.732	0.53		
DistRange: Season:Year	7	37.2	1.92	**0.07**		**.**
Residuals	146	404.4				

Table S11: Outputs from a two-way ANOVA to show the effect of distance range and hydrological season on Δ^{14}C-DOC ‰ in stream water. Interaction effects and Tukey's HSD comparisons for main effects are also shown. Significant main effects and post-hoc comparisons are bolded.

Δ^{14}C-DOC						
Factor	**Df**	**SumSq**	**F value**	**p**	**Tukey comparison**	**p**
Distance Range	3	142056	2.37	0.085		
Season	2	269461	6.743	**0.003**	PreMelt = melt	0.47
					PreMelt > postmelt	**0.0044**
					melt > PostMelt	**0.011**
DistRange: Season	3	5032	0.084	0.97		
Residuals	40	799220				

Table S12: perMANOVA test outputs showing the variation between proportion of microbial communities by distance range, hydrological season, year, and river. perMANOVA pairwise comparisons with holm adjusted p values are shown. Significant interactions are bolded.

Factor	R^2	significance	PERMANOVA pairwise comparison	p (holm adjusted)
Distance Range	0.09	< 0.001	Headwater - Near	0.1659
			Headwater - Far	**0.0044**
			Near - Far	**0.0003**
Year	0.08	<0.001	2019-2020	**0.0003**
			2019-2021	**0.0024**
			2020-2021	**0.0068**
Season	0.06	0.002	PreMelt – Melt	**0.0039**
			PreMelt – PostMelt	0.0602
			Melt – PostMelt	0.2125
River	0.08	<0.001	Sunwapta-Athabasca	**0.0027**
			Sunwapta-NSR	**0.0003**
			Athabasca-NSR	**0.0003**

Table S13: Potential OC sources to glacially-influenced streams, and their associated expected fluorescence signature and δ^{13}C-OC and Δ^{14}C-OC ranges.

Source	**δ^{13}C-OC**	**Δ^{14}C-OC**	**Expected DOM fluorescence**
Vegetation	-26 to -28‰ (Peterson and Fry, 1987)	Downstream (contemporary) vegetation will be modern whereas subglacial over-ridden vegetation likely represents an aged OC source (Bhatia et al., 2013)	Humic-like (Gabor et al., 2014)
Soils and associated pore water	-26 to -28‰ (Peterson and Fry, 1987)	Modern at the surface with increasing age with depth (Shi et al., 2020)	Humic-like with decreasing humification and increasing protein-like fluorescence with depth and increased soil residence time (Gabor et al., 2014) (McDonough et al., 2022)
Phytoplankton	-22 to -30‰ (Chanton & Lewis, 1999)	Ranging from modern to slightly aged depending on CO_2 source	Protein-like (Fellman et al., 2010)
Benthic algae	Greater than -7 to -15‰ due to decreased isotopic fractionation, following carbon limitation associated with benthic boundary layers (Hecky & Hesslein, 1995)	Ranging from modern to slightly aged depending on CO_2 source	Protein-like (Fellman et al., 2010)
Fossil fuel deposits	-27‰ (Peterson & Fry, 1987)	Ancient (radiocarbon dead)	Variable (Mladenov et al., 2010)
Wildfire derived soot	-26 to -28‰ (Peterson & Fry, 1987)	Modern (Masiello & Druffel, 2003)	Variable (Mladenov et al., 2010)
Chemosynthesis	Very depleted -30 to -80‰, via sulfur oxidizing and methanogenic microbes (Blaser & Conrad, 2016; Rau & Hedges, 1979; Ruby et al., 1987)	Ranging from modern to slightly aged depending on the CO_2 source. Notably, subglacial CO_2 can represent an aged C source	Protein-like (Fellman et al., 2010)

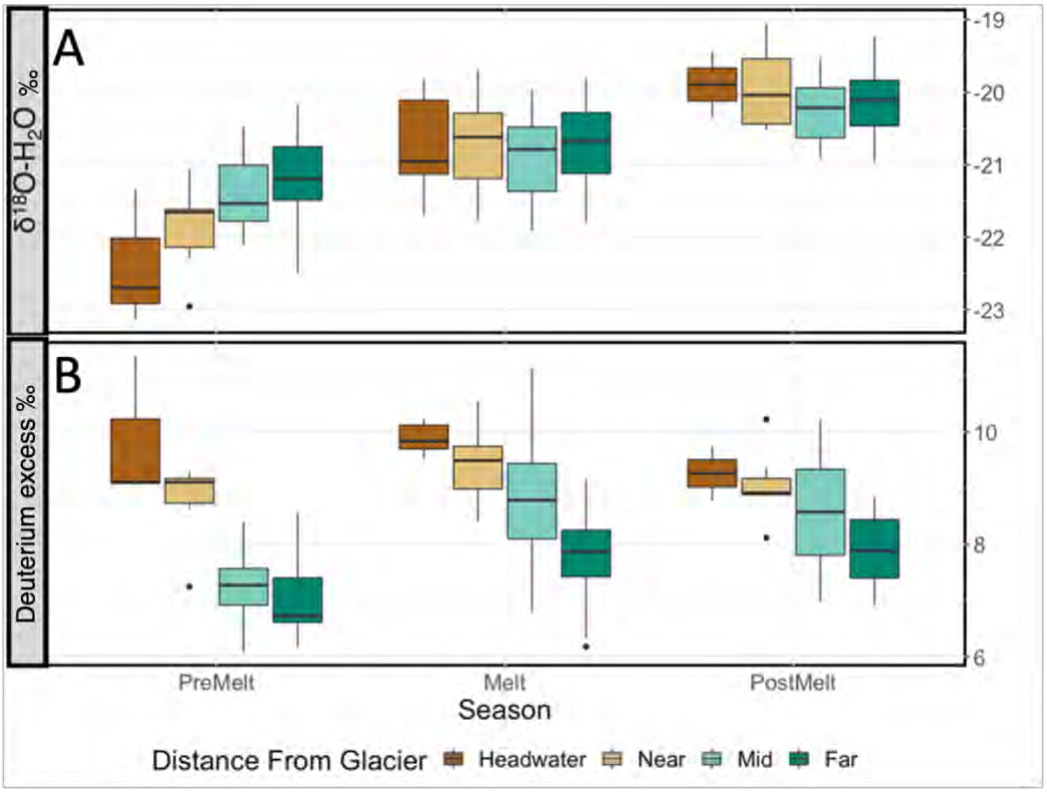

Figure S1: Boxplots of (a) $\delta^{18}O$-H_2O, and (b) deuterium excess within streams across pre-melt, melt and post-melt hydrological periods grouped by distance range downstream from glacial terminus. The boxes represent the interquartile range, the black line represents the median value, and the points represent outliers.

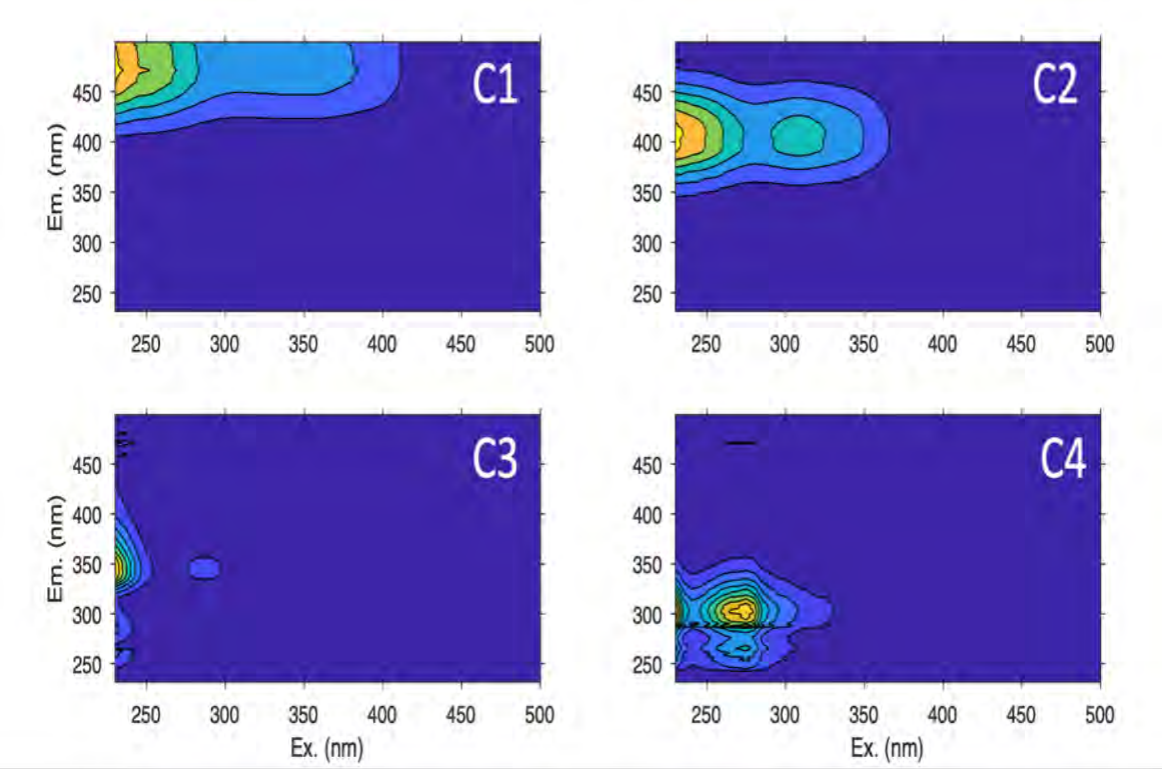

Figure S2: Component plots for the four-component PARAFAC model

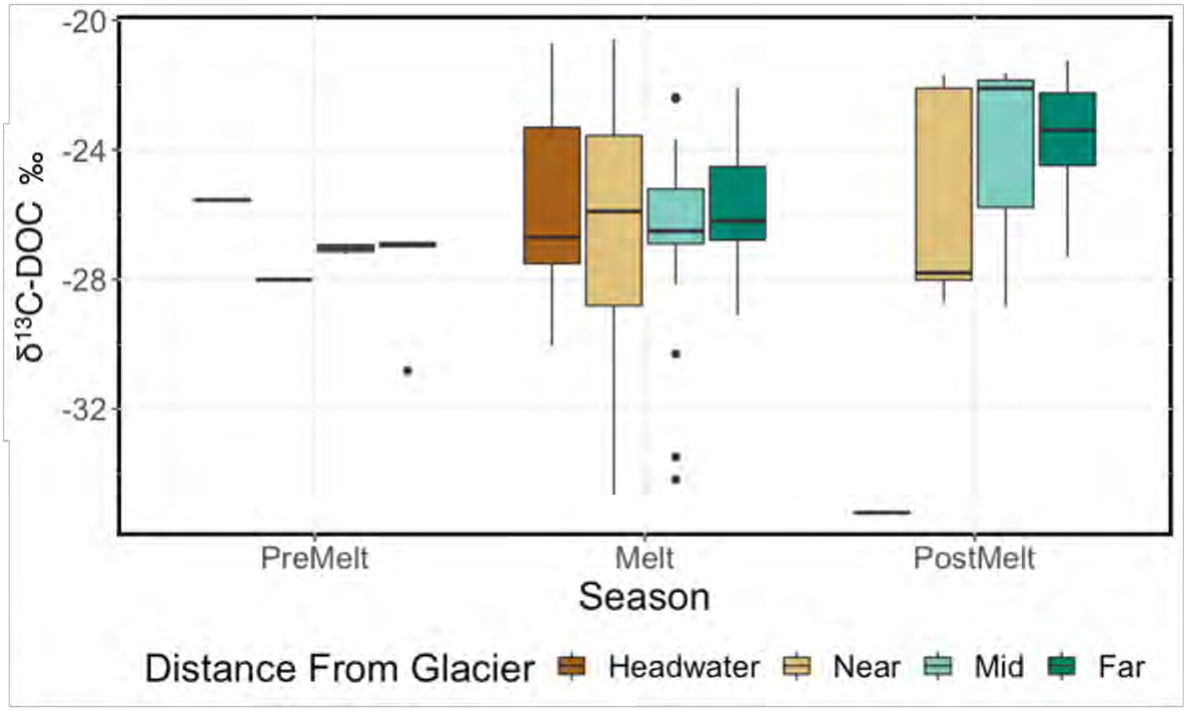

Figure S3: Boxplot of stream δ^{13}C-DOC values for pre-melt, melt and post-melt hydrological periods grouped by distance range. The boxes represent the interquartile range, the black line represents the median value, and the points represent outliers.

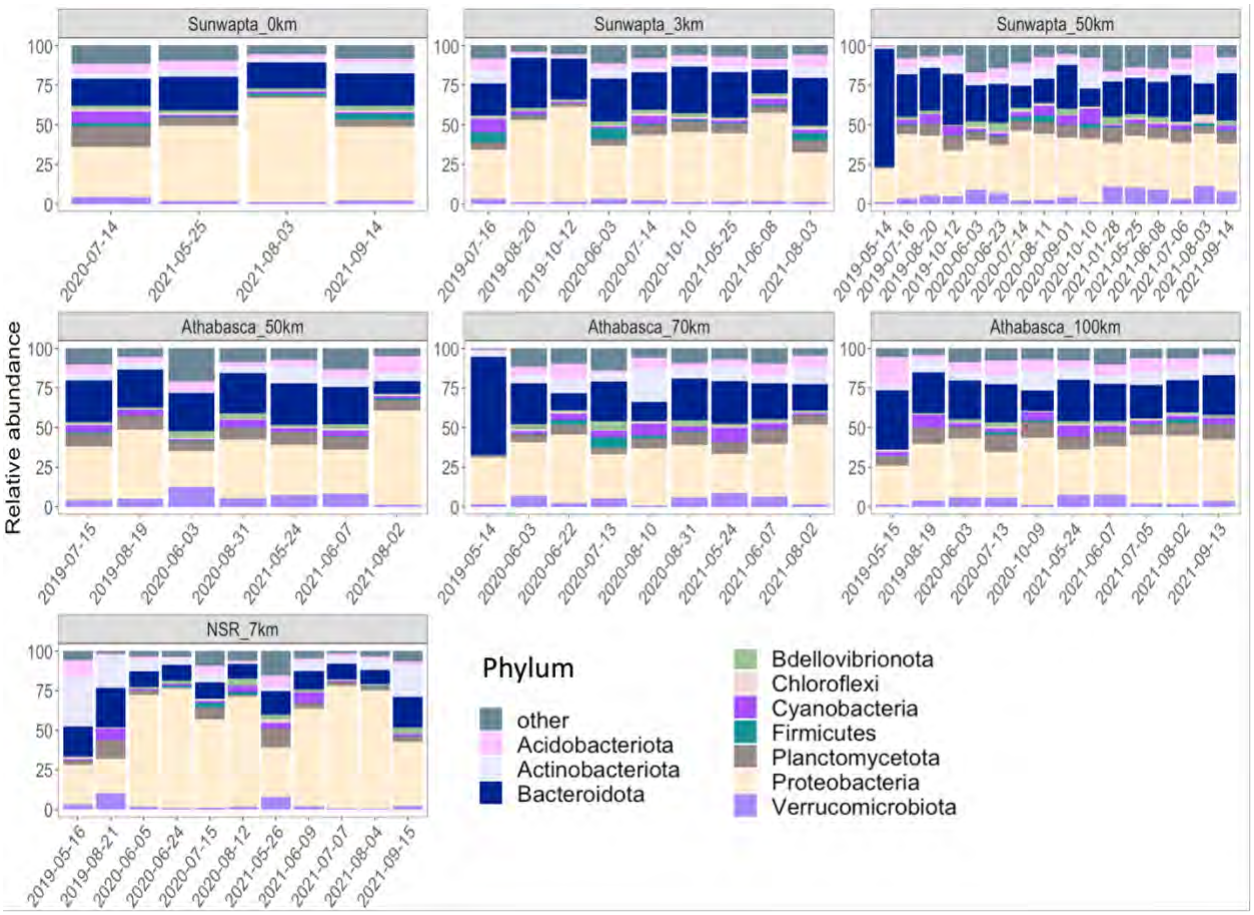

Figure S4: Relative abundance of the top ten most abundant taxonomic phyla across all sampling dates at the near and far sites in the Sunwapta-Athabasca and North Saskatchewan rivers. The category "Other" represents classes not included in the top ten.

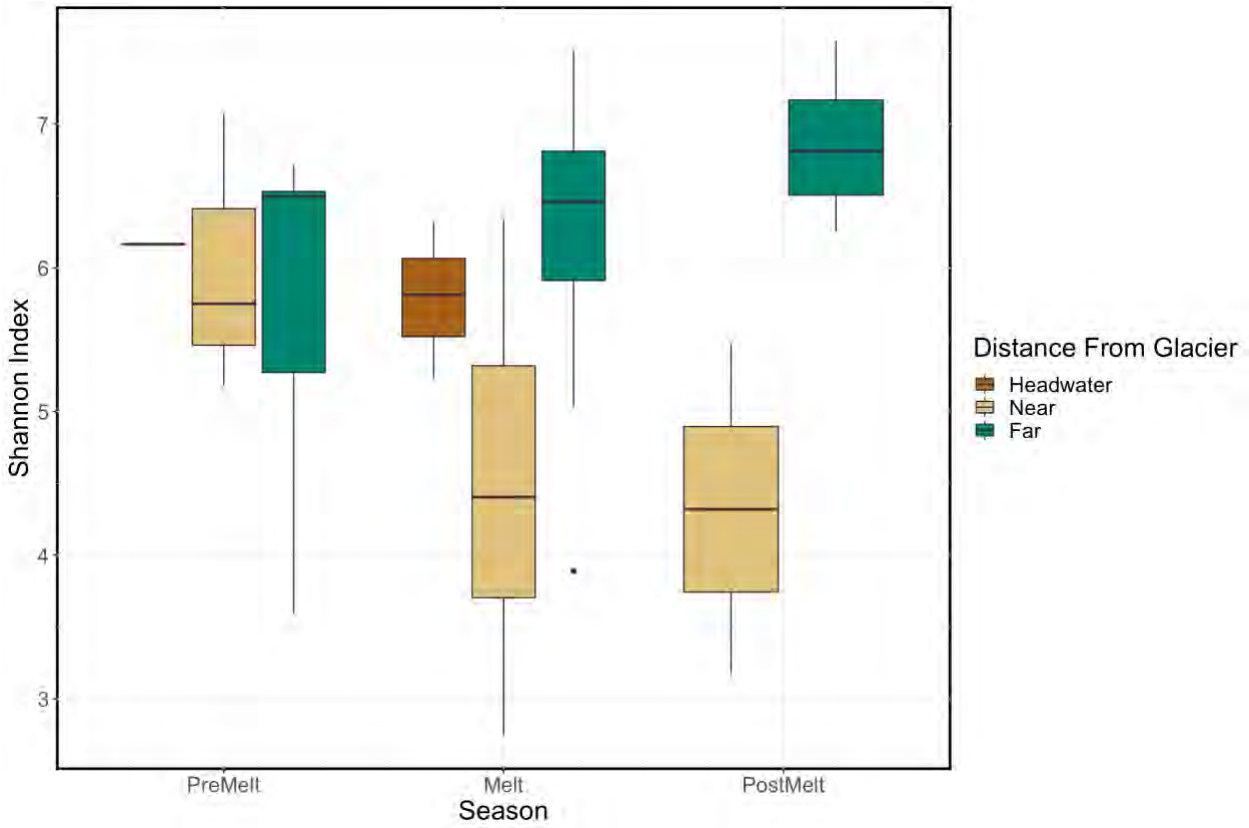

Figure S5: Boxplots showing variation in alpha diversity across hydrological periods and distance range, using the Shannon diversity index. The boxes represent the interquartile range, the black line represents the median value, and the points represent outliers.

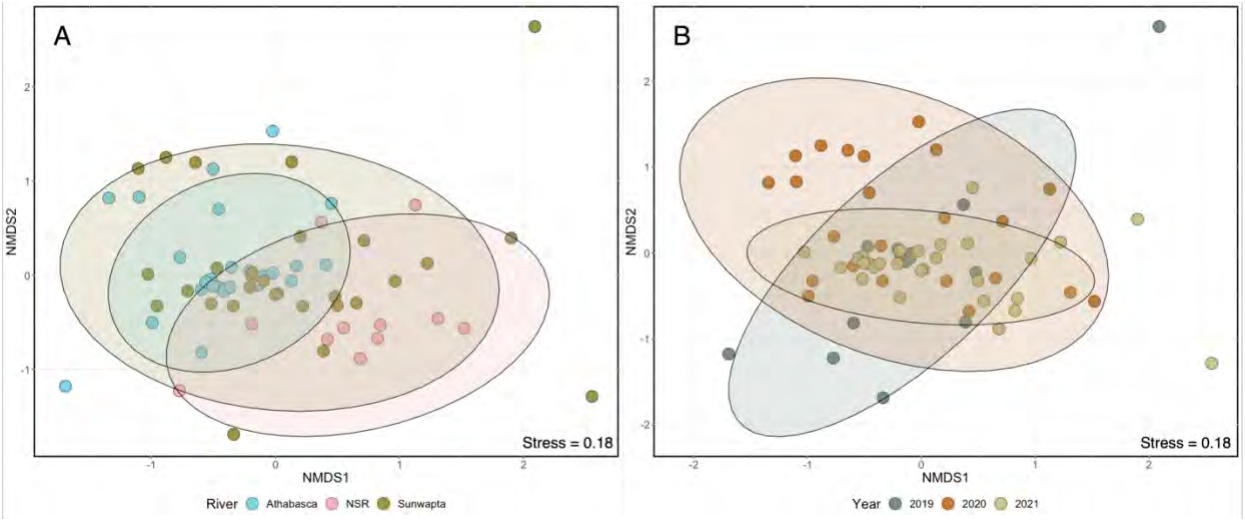

Figure S6: NMDS of microbial community composition based on Bray Curtis distances of Hellinger transformed ASV data. Colour represents different (a) study rivers and (b) sampling years. Shaded circles represent the 95% confidence interval for significantly different groupings (pairwise perMANOVA $p < 0.01$ (holms adjusted) see Table S12).