Impacts of Lake Ice, Shoreline Retrogressive Thaw Slumping, and Fire on the Water Quality and Productivity of Small Tundra Lakes in the Northwestern Arctic

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Introduction

Climate warming is occurring at a faster rate in arctic regions than the rest of the world. In the upland region Northeast of Inuvik, NT, increasing surface air temperatures have contributed to increases in ground temperature and an overall reduction in the thickness and areal extent of permafrost.

An extreme form of permafrost degradation, common to the study region, is shoreline retrogressive thaw slumping (SRTS). SRTS occurs when ice-rich shoreline sediments thaw, making the terrain unstable and causing it to slump. Research has linked SRTS to changes in the water quality of adjacent lakes, due to increased input of sediment from thawed permafrost material.

Over the past 12 years, the Aurora Research Institute (ARI) has worked closely with the Water Climate Impacts Research Centre (WCIRC) to support several research programs. The overall goal of this work was to improve our understanding of how climate change and landscape perturbation, such as SRTS, has and will continue to affect lake ice, water quality, and productivity in small tundra lakes in the Upland Region Northeast of Inuvik.

During the 2013 study season, a fire affected a number of lakes in the study region. In response to this, WCIRC and ARI sampled three lakes affected by the burn, in addition to the pristine and slump-affected lakes we were already looking at.

The purpose of this sampling program was to evaluate how fires, typically caused by lightning strikes, affect the water quality of tundra lakes in the region.

Materials and Methods

In September 2013, ARI deployed one YSI Sonde in each of two comparable small tundra lakes (Lake 5A: Pristine; Lake 5B: Affected by Shoreline Retrogressive Thaw Slumping). The Sondes were deployed at the deepest part of the lake, approximately half way between the lake bottom and the lake surface. Each sonde measured Water Temperature, Dissolved Oxygen (DO), pH, and Specific Conductivity continuously, at 1-hour intervals throughout the year, reflecting both under-ice and ice-free conditions.

In July and August of 2014, ARI collected water samples from the center (at 1m) of 9 additional lakes in the study region (3 affected by SRTS, 3 affected by a recent burn, and 3 pristine), as well as at Lake 5A and Lake 5B. Water samples were immediately packed in coolers, with cooler packs, and sent to the National Laboratory for Environmental Testing, where they were analyzed for Specific Conductivity, pH, Alkalinity ($CaCO_3$), Cations, Anions, Colour, Dissolved Inorganic Carbon, Dissolved Organic Carbon, Hardness, and Nutrients. On August 25, 2014, ARI also used a YSI sonde to measure Dissolved Oxygen (DO), pH, and Specific Conductivity at the surface and bottom of each of the lakes.

The data obtained from the water samples collected in July and August 2014 were analyzed using a Two-Way Repeated Measures ANOVA using SigmaPlot Software (Subject: Lake; Factor 1: Month; Factor 2: Lake Type). All pairwise multiple comparison procedures were performed using the Holm-Sidak Method.

Study Area

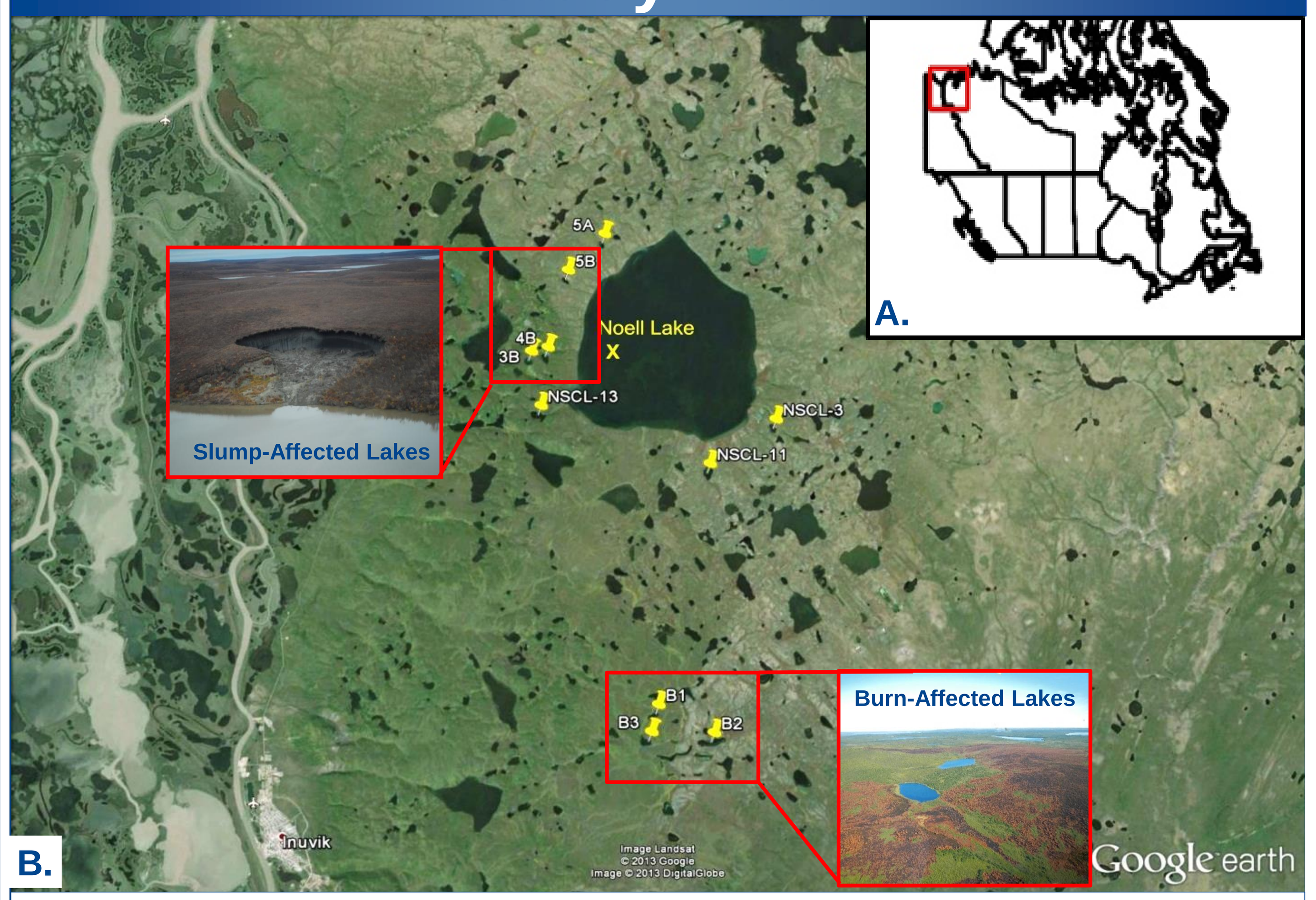

Figure 1: A. The location of Inuvik, NT and B. The location of the study lakes, located Northeast of Inuvik, NT.

Results & Discussion

- The water temperature at Lake 5A decreases throughout September and early October, reaching a minimum on October 11th (see Figure 2)
- Water Temperature did not fluctuate much over the winter months
- Specific conductivity increased steadily over the ice-covered months, likely as a result of ion exclusion during ice formation
- Dissolved Oxygen (DO) increased throughout September and early October, reaching a maximum on October 10th
- DO decreased from October 10th, over the ice-covered months. This likely corresponds with ice formation and a subsequent decrease in primary production
- Similar to DO, pH increases throughout September and early October, reaching a peak on October 9th.
- Following October 9th, pH decreases, likely due to an increase in the concentration of CO_2 associated with decreases in primary production
- Overall, the temporal trends in Water Temperature, DO, and pH in Lake 5B are similar to those of Lake 5A

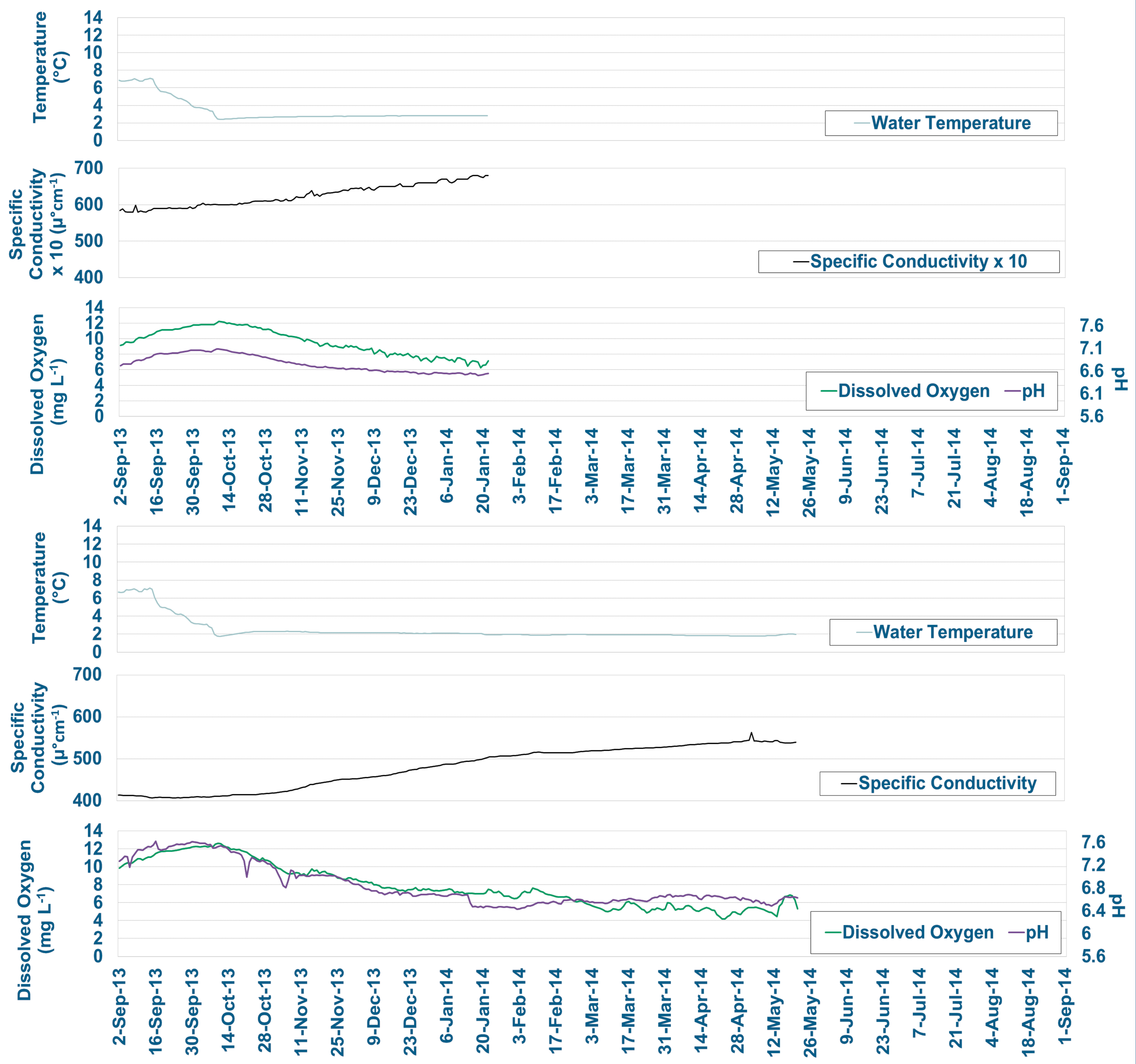

Figure 2: Temporal Trends in water quality over time for Lake 5A (Top; Pristine) and Lake 5B (Bottom; Slumped).

Table 1: Lake Depth at the center of the lake (in meters)

DEPTH AT LAKE BOTTOM									
5B	4-B	3-B	5A	NSCL-13	NSCL-11	NSCL-3	B-1	B-2	B-3
7.3	8.5	11.4	8.5	2	1.8	4.5	1.2	2	2

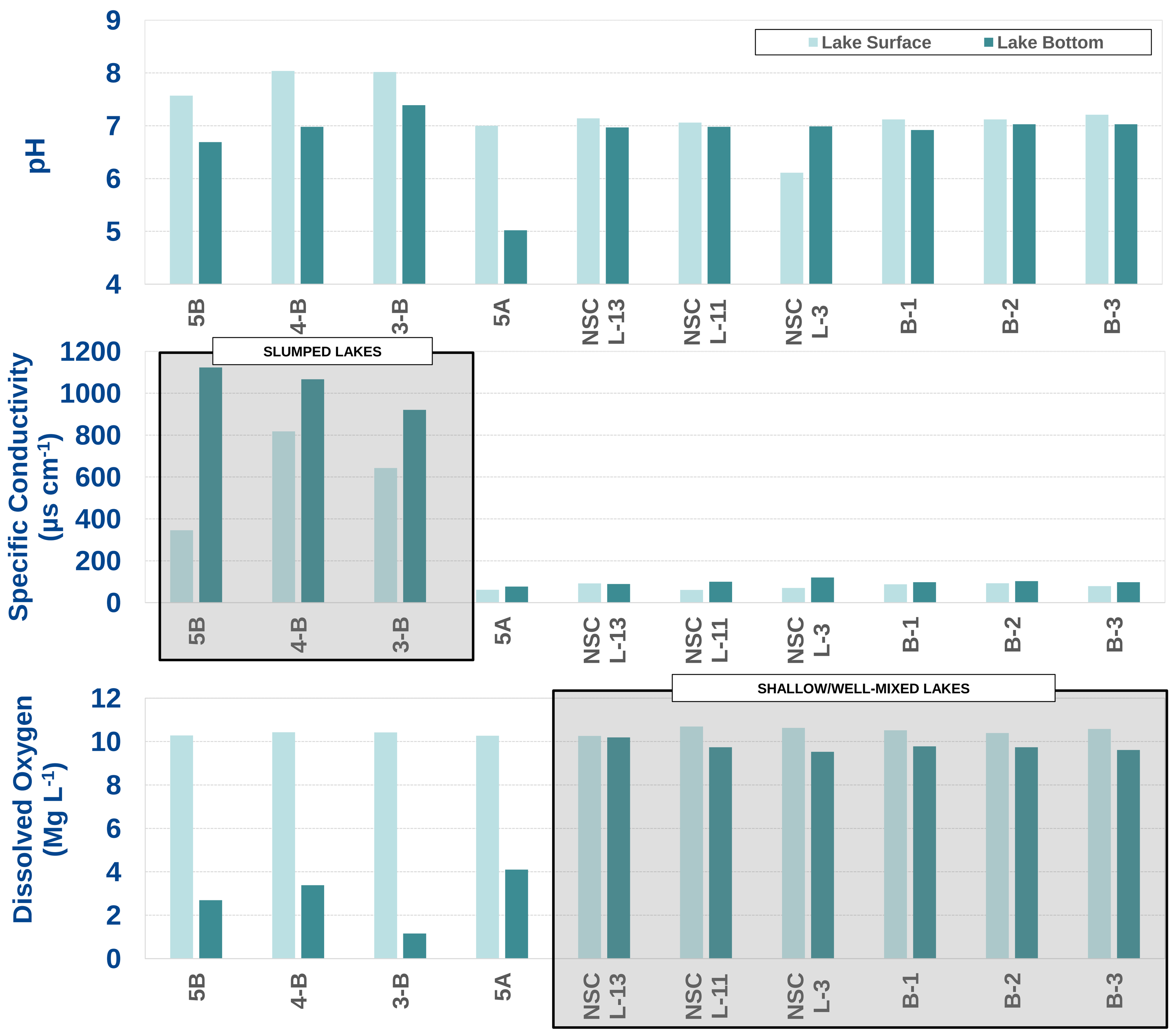

Figure 3: Water quality for slump-affected lakes (5B, 4B, 3B), pristine lakes (5A, NSCL-13, NSCL-11, NSCL-3), and burn-affected lakes (B1, B2, B3).

- Generally speaking, the pH of the Lake Surface is more alkaline than the lake bottom (see Figure 3)
- The Lake Surface of Slump-Affected (SA) lakes appears to be more alkaline than unaffected lakes
- The Specific Conductivity of the Lake bottom is higher than the Lake Surface
- The Specific Conductivity of SA lakes is an order of magnitude higher than unaffected lakes.
- As slump material enters the lake, high amounts of major ions are introduced, creating a high level of conductance
- DO in shallow/well mixed lakes (<2m) remains consistent through out the water column
- Deeper lakes (>2m) show a lower DO level at lake bottom, suggesting that primary production higher at the lake surface than the lake bottom, where it is limited by the availability of Photosynthetically Active Radiation.

Statistics

- The Slump-Affected (SA) lakes had a significantly higher Specific Conductivity, Alkalinity, and Hardness than the Pristine (P) lakes (Table 2). They also had a significantly higher concentration of Major Ions, Dissolved Inorganic Carbon (DIC), and Organic Phosphorus.
- The SA lakes had a significantly lower concentration of Nitrite than the P lakes. Although not significant, the SA lakes also had a lower concentration of Total Dissolved Nitrogen (TDN) than the P lakes and a significantly lower concentration of TDN than the Burned (B) lakes.
- The SA lakes had a significantly higher pH than the P lakes, but not than the B lakes. This suggests that the tundra burn may have affected the pH of the study lakes, even though no significant difference between B and P lakes was observed.
- Similarly, the SA lakes had a significantly higher concentration of Magnesium than the P lakes, but not than the B lakes, suggesting that the tundra burn may have affected the concentration of Magnesium in the study lakes, even though no significant difference between B and P lakes was observed.
- Similar to the SA lakes, the B lakes also had a higher concentration of Organic Phosphorus than the P lakes

Table 2: Statistical differences in the water quality of pristine, burned and Slump-Affected Lakes.

(light yellow)	Affected by Shoreline Slump
(orange)	Affected by Shoreline Slump AND Burn
(pink)	Affected by Burn

Basic Water Quality							
		Mean			Significantly Different?		
Variable (X)	Transformation	Pristine	Burned	Slumped	Pristine vs. Burned	Pristine vs. Slumped	Burned vs. Slumped
Specific Conductivity	None	67.962	81.7	556.333	NO	YES	YES
pH	Ln(X)	1.923	1.968	2.061	NO	YES	NO
Alkalinity	None	13.889	15.933	61.15	NO	YES	YES
Major Ions							
		Mean			Significantly Different?		
Variable (X)	Transformation	Pristine	Burned	Slumped	Pristine vs. Burned	Pristine vs. Slumped	Burned vs. Slumped
Fluorine	1/X	17.812	16.687	8.261	NO	YES	YES
Chlorine	None	1.256	1.11	2.422	NO	YES	YES
Sulfate	None	2.533	2.735	5.294	NO	YES	YES
Calcium	None	7.051	8.885	65.867	NO	YES	YES
Potassium	None	1.031	0.908	2.742	NO	YES	YES
Magnesium	1/(X)	0.515	0.319	0.0495	NO	YES	NO
Sodium	None	1.866	2.007	13.1	NO	YES	YES
Silicate	None	2.033	0.94	1.635	NO	NO	NO
Colour	None	124.988	102.567	56.517	NO	NO	NO
DOC	None	17.912	19.033	12.367	NO	NO	NO
DIC	None	3.262	4.267	14.15	NO	YES	YES
Hardness	Ln(X)	3.277	3.562	5.521	NO	YES	YES
Nutrients							
		Mean			Significantly Different?		
Variable (X)	Transformation	Pristine	Burned	Slumped	Pristine vs. Burned	Pristine vs. Slumped	Burned vs. Slumped
NO2	None	0.00463	0.00317	0.00217	NO	YES	NO
Dissolved Phosphorus	Ln(X)	-5.079	-5.213	-5.687	NO	NO	NO
Ammonia	Ln(X)	-4.411	-4.069	-4.27	NO	NO	NO
Nitrate and Nitrite	None	0.00905	0.00797	0.00545	NO	NO	NO
Organic Phosphorus	Ln(X)	-7.315	-7.564	-8.151	YES	YES	YES
Particulate Organic Carbon	None	0.296	0.256	0.233	NO	NO	NO
Particulate Organic Nitrogen	None	0.0467	0.0257	0.0383	NO	NO	NO
Total Nitrogen	None	0.414	0.467	0.37	YES	NO	YES
Total Phosphorus	None	0.0191	0.0171	0.00942	NO	NO	NO
Total Dissolved Nitrogen	None	0.369	0.415	0.322	NO	NO	YES

Conclusions

- Specific Conductivity, Dissolved Oxygen, and pH exhibit strong seasonal variability, associated with Lake Ice formation. They also vary with Lake Depth.
- Unlike Shoreline Slumping, the tundra burn does not appear to have affected the Specific Conductivity, Alkalinity, Hardness, Major Ion Concentration, Dissolved Inorganic Carbon concentration of the study lakes
- The tundra burn does appear have affected pH, as well as the concentration of Magnesium, Nitrogen and Phosphorus in the study lakes

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