ESTABLISHING BASELINE LIMNOLOGICAL CONDITIONS IN BAKER LAKE, NUNAVUT

Neil Hutchinson[1*], Kris R. Hadley[1], Richard Nesbitt[1], and Luis Manzo[2]

[1] *Hutchinson Environmental Sciences Ltd., Bracebridge, Ontario, Canada*

[2] *Kivalliq Inuit Association, Rankin Inlet, Nunavut, Canada*

* *neil.hutchinson@environmentalsciences.ca*

Abstract

The Government of Canada and the Kivalliq Inuit Association initiated the Baker Lake Cumulative Effects Monitoring Program, or "Inuu'tuti," to document responses to multiple stressors in the Baker Lake Basin using western science and Inuit Qaujimajatuqangit. Baker Lake has had no systematic limnological investigation beyond a series of profiles documenting saline waters at depth in 1965. A series of limnological surveys (August 2015, open water; May 2016, late-winter; and August 2017, open water) included depth profiles of field parameters, laboratory chemistry analyses using modern-day detection limits and elaboration of the algal community at six sites in Baker Lake. Mixing of saline intrusions from Chesterfield Inlet with surface waters confirmed Inuit observations of a salty taste in drinking water, while the presence of chrysophyte algae may explain Inuit observations of episodic "fishy" taste in Baker Lake waters. The results confirm those from the 1965 study and provide an improved baseline for future assessment.

Résumé

Le gouvernement du Canada et l'Association inuite du Kivalliq ont lancé le Programme de surveillance des effets cumulatifs dans le bassin hydrographique de Baker Lake, ou « Inuu'tuti », afin de documenter les réactions aux multiples facteurs de stress dans le bassin hydrographique de Baker Lake en utilisant la science occidentale et l'Inuit Qaujimajatuqangit. Baker Lake n'a fait l'objet d'aucune étude limnologique systématique au-delà d'une série de profils documentant les eaux salines en profondeur en 1965. Une série de relevés limnologiques (août 2015, eaux libres; mai 2016, fin de l'hiver; août 2017, eaux libres) comprenait des profils de profondeur des paramètres de terrain, des analyses chimiques en laboratoire utilisant des limites de détection modernes et la formation de la communauté d'algues à six endroits à Baker Lake. Le mélange des marées salines de l'inlet Chesterfield avec les eaux de surface a confirmé les observations inuites d'un goût salé dans l'eau potable, tandis que la présence d'algues chrysophytes peut expliquer les observations inuites de goût de poisson épisodique dans les eaux du lac Baker. Les résultats confirment ceux de l'étude de 1965 et fournissent une base de référence améliorée pour les évaluations futures.

Introduction

Climate change and developing industry have the potential to significantly alter aquatic environments in Nunavut. At present, local monitoring programs implemented by various proponents are not standardized and data are not routinely interpreted or presented. This represents a gap in freshwater baseline information, limiting the ability of communities, industry, and regulators to effectively manage aquatic resources in Nunavut. Accordingly, in 2014, the Kivalliq Inuit Association (KIA) and the Nunavut General Monitoring Plan initiated a program to develop and implement an aquatic cumulative effects monitoring framework for the Baker Lake Basin (later named "Inuu'tuti") in recognition of documented climate warming (Medeiros et al. 2012), established and proposed mines, and a growing population.

Baker Lake receives drainage from three major river systems (the Thelon, Kazan, and Dubawnt), which drain much of the central Arctic. Although the watershed is large (1877 km^2), culturally important to Nunavummiut, and the focus of the Inuu'tuti program, limited data are available to characterize its limnology. Johnson (1965) collected a single profile of major ions in April 1964 near Christopher Island and found a marked increase in salinity below the 20 m depth (Fig. 1). Three possible mechanisms were suggested; however, the most likely cause was deemed to be incursions of dilute seawater from Hudson Bay (Johnson 1965). Inuit Qaujimajatuqangit (IQ) has documented occasional salty taste in surface waters near the Hamlet of Baker Lake that coincided with a full moon and low river inflows to the lake (HESL 2017; David Owingayak: personal communication), suggesting that saline incursions may be associated with tidal influence. Analysis of fossil diatoms and chironomids from Baker Lake sediment cores inferred a 2°C increase in water temperature over the past 50 years. This was corroborated with instrumental records over the same period, showing that the lake has responded to the warming climate (Medeiros et al. 2012).

A comprehensive monitoring program was therefore undertaken to (a) establish a baseline of water quality in Baker Lake for comparison with future changes and (b) investigate the dynamics of salinity in the lake, as part of the ongoing Inuu'tuti monitoring program.

Methods

Staff from Hutchinson Environmental Sciences Ltd. (HESL) and KIA monitored seven sites (Fig. 1) in Baker Lake in two open-water events (August 2015 and August 2017) and one under-ice event (May 2016), including four deep-water sites (Baker 1, 2, 3, 4), a nearshore site at the Baker Lake hamlet drinking water intake (Baker 6), and sites at the mouths of the Thelon River (Baker 5) and Kazan River (Baker 7). Profiles of water temperature, dissolved oxygen (DO), conductivity, and pH were measured at 1 m depth intervals from the surface to near the lake bottom at all seven locations using a YSI 6920 MP sonde. Samples were taken at 0.5 m from the surface and 1 m off bottom at Baker 1, 2, 3, 4, 6 and at 0.5 m at Baker 5, and 7. Laboratory analyses included major ions, nutrients, and trace metals to characterize lake chemistry; cyanide as a parameter of interest for gold operations in the basin; a selection of radionuclides in consideration of the potential for uranium mining (Baker 2 only, 0.5 m); and chlorophyll *a* and phytoplankton taxonomy to characterize algae and lake productivity (0.5m). Samples were stored in coolers containing ice packs immediately after sampling and shipped to ALS Laboratories in Yellowknife, Northwest Territories, for analysis. Phytoplankton samples were forwarded by ALS Yellowknife to ALS Winnipeg for taxonomic analysis to genus or species level.

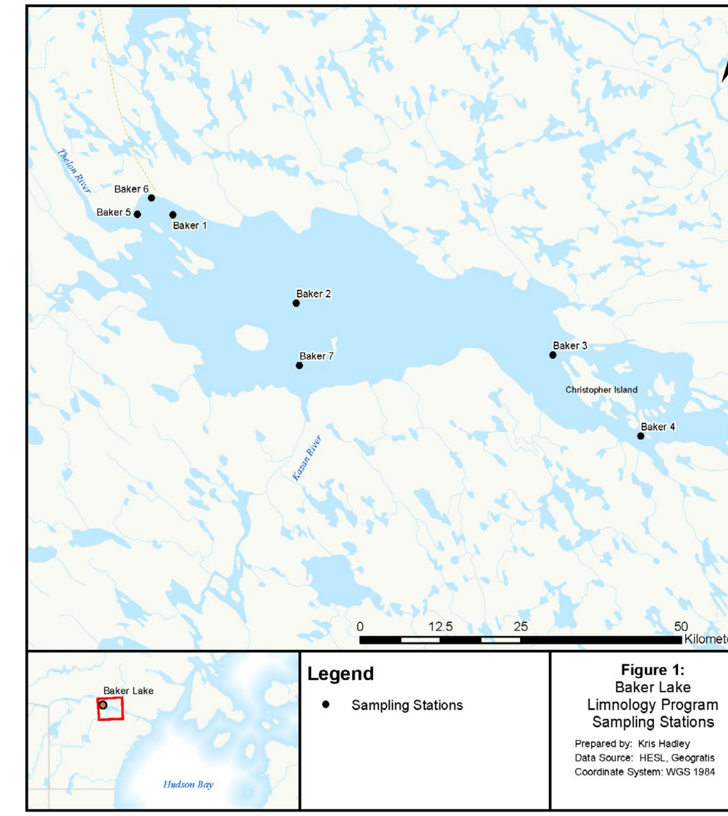

Figure 1: Baker Lake Limnology Program sampling stations.

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Results and discussion

Three-year baseline water quality summary

Average August surface temperatures of 9°C–11°C in Baker Lake were consistent with the value of 10.5°C recorded by Medeiros et al. (2012). August temperature profiles in the deepest portion at the eastern end of Baker Lake (Baker 3) were consistent with weak thermal stratification during fall overturn. DO profiles showed concentrations of 10.1 to 15.9 mg/L, dependent on depth, water temperature, and salinity (Fig. 2).

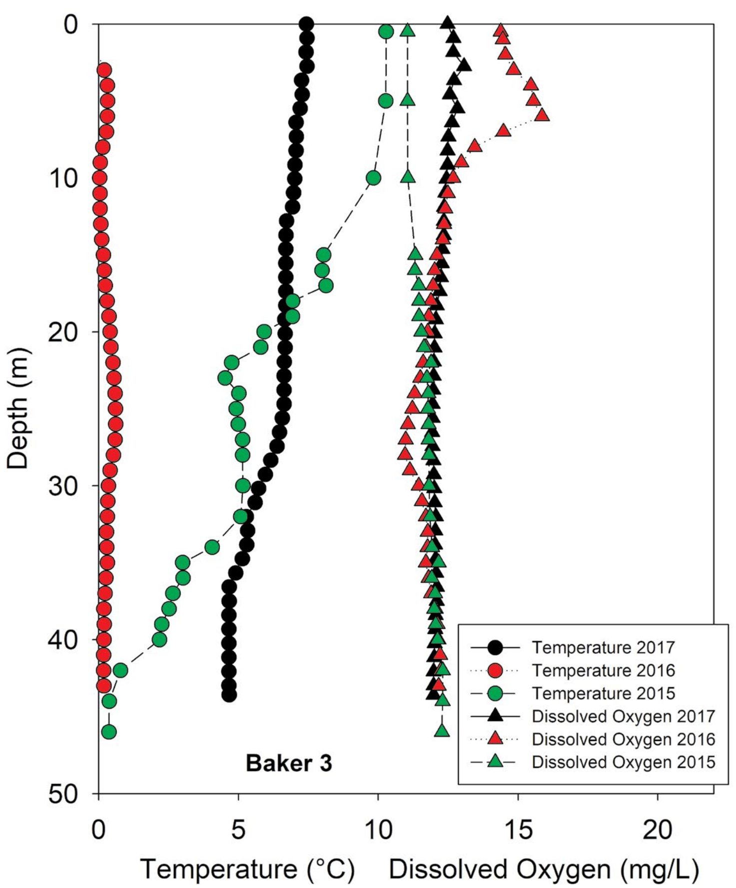

Figure 2: Representative profiles of temperature and dissolved oxygen at east end of Baker Lake in August 2015, May 2016, and August 2017.

Baker Lake is clear (turbidity <1 NTU), soft water (conductivity <100 µS/cm), low alkalinity (8.7–14.7 mg/L as $CaCo_3$), and nutrient-poor with low productivity. Total phosphorus concentrations averaged 4.8 +/- 1.4 µg/L in both surface and bottom water samples, with no marked spatial differences across the lake, and ortho-phosphate concentrations were at or below detection (< 1 µg/L) at all sites. Nitrogen levels were consistently low, with concentrations near or below detection in the majority of samples for total ammonia (<0.01 mg/L), nitrate (<0.06 mg/L), and total Kjeldahl nitrogen (<0.4). Chlorophyll *a* (Chl *a*) concentrations averaged 0.85 +/- 0.55 µg/L, consistent with oligotrophic (nutrient-poor and low primary productivity) conditions (i.e., Chl *a* <2.6 µg/L, Carlson and Simpson 1996).

Metal concentrations were low and typical of dilute Arctic waters. Water samples were analyzed for a suite of 38 metals, of which 19 were detected and none exceeded guidelines for drinking water quality (Health Canada 2014) or guidelines for the protection of freshwater aquatic life (CCME 1999). Sodium concentrations in Baker 3 and Baker 4 bottom samples exceeded the aesthetic water quality objective of 200 mg/L in 2015, consistent with the presence of saline marine waters and IQ identification of taste issues with the water during the open-water season (HESL 2017; Tuupik Iyago: personal communication).

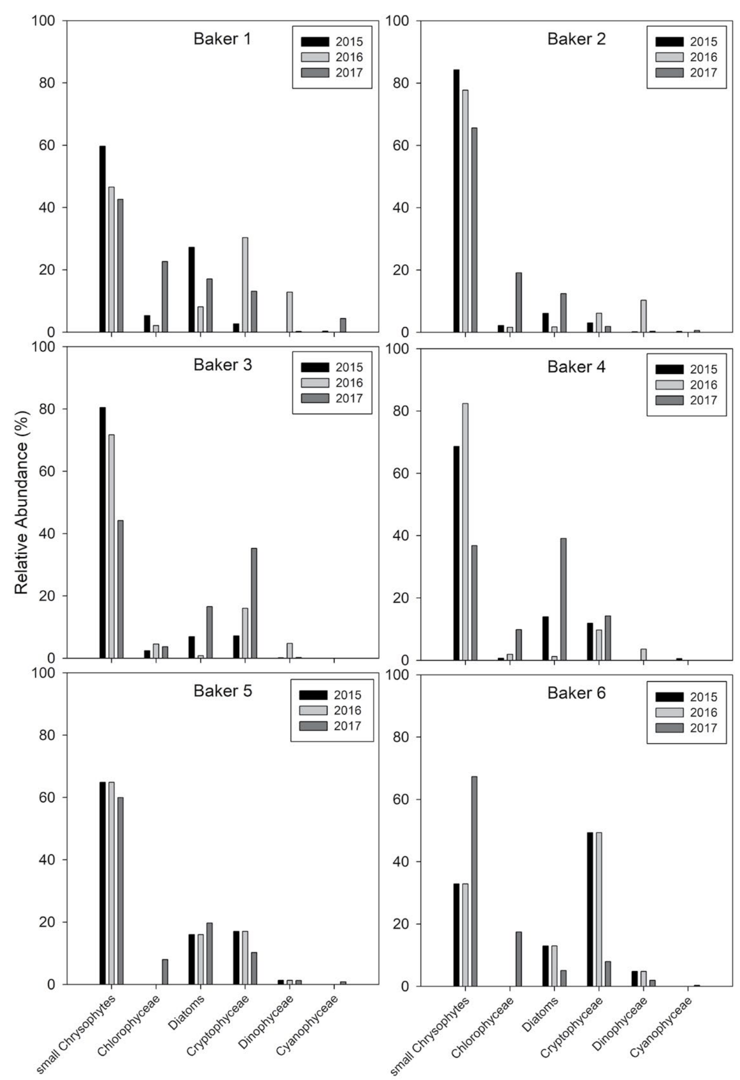

Figure 3: Phytoplankton community composition in Baker Lake in August 2015, May 2016, and August 2017.

The algal community was dominated by small golden algae (chrysophytes), which comprised 37%–84 % of the species enumerated across all sites and sampling seasons (Fig. 3). Chrysophytes are efficient competitors in harsh conditions such as low nutrients, low temperatures, and unpredictable climates, common conditions in the Canadian Arctic (Wilkinson et al. 1996). Some chrysophyte species, specifically *Synura petersenii* and *Uroglena americana*, have been linked to taste and odor issues (Nicholls 1995; Watson et al. 2001), and may explain the occurrence of a fishy taste and smell in the surface water noted by community members in Baker Lake.

Other noteworthy phytoplankton genera that contributed significantly (>5%) to the Baker Lake assemblages included the planktonic diatoms *Asterionella* and *Cyclotella*. *Asterionella formosa* is one of the most common planktonic diatoms in northern hemisphere lakes and was identified in Baker Lake during both August surveys. The occurrence of *A. formosa* can also reflect enhanced stratification, a longer ice-free period, and a longer growing season as a result of a warming climate, irrespective of trophic status (Hadley et al. 2013; Solovieva et al. 2008). *Asterionella* species were not reported during previous limnological studies of Baker Lake, suggesting this change may have occurred recently (Medeiros et al. 2012). Like *Asterionella*, *Cyclotella* species are common planktonic algae in stratified low-nutrient lakes. Cyanobacteria were identified in the majority of sites on Baker Lake but occurred in very low abundance (2-19 cells/mL).

Saline incursion in Baker Lake

Conductivity profiles (Fig. 4) and enriched concentrations of chloride and other major ions at depth indicated marine-water influences in Baker Lake. Marine influence was most pronounced in deep-water samples at Baker 1, 2, 3, 4, and there was no depth gradient close to the Thelon River (Baker 5,6). These data show that the seawater layer described by Johnson (1965) is widespread and not localized in the deepest basin of the lake nor to the eastern portion of the lake near the outflow to Chesterfield Inlet. Conductivity was lower under ice cover in 2016 than during open water in 2015 and 2017, consistent with IQ that saline taste issues with water near Baker Lake were more prevalent during the summer (HESL 2017; Tuupik Iyago: personal communication). Conductivity values at depth were

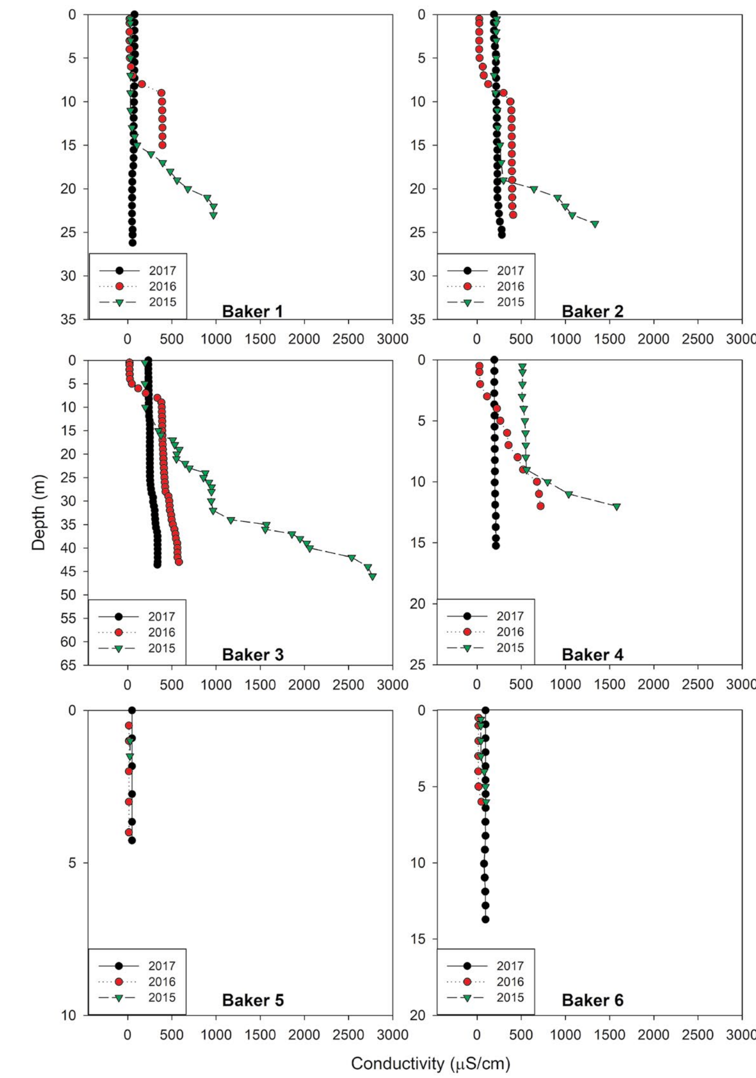

Figure 4: Conductivity profiles in Baker Lake in August 2015, May 2016, and August 2017.

uniform and low in the summer of 2017, varying by less than 100 µS/cm.

Source of saline water

Johnson (1965) postulated three explanations for the seawater incursion into Baker Lake: (1) ancient seawater trapped during isostatic rebound following glacial retreat; (2) seawater seeping through the sill at the outlet of the lake; or (3) seawater incursion over the sill of the outlet, driven by tides and storm activity.

The mixing of seawater into the water column (Johnson 1965) and the changes over time observed in our three-year monitoring program show that salinity was not isolated to the bottom waters of Baker Lake and the degree of salinity changed over time. Ancient origin of seawater is therefore not likely, as bottom waters would have been depleted of salt water by mixing over time, if remnant ancient marine waters were the only source of salinity.

Johnson (1965) suggested that underground seepage of seawater was an unlikely source based on the presence of permafrost as a barrier to saline incursion. The presence of the large water masses of Baker Lake and Chesterfield Inlet, however, are likely to have formed a talik, which would be permeable to seepage, but the hydraulic gradient would generate from Baker Lake (18 masl) to Chesterfield Inlet (11 masl), and this gradient argues against seepage from Chesterfield Inlet through a talik.

The dynamic nature of salinity observed in Baker Lake suggests that the most likely source of saline water is periodic incursion over the sill separating the lake from Chesterfield Inlet. Chesterfield Inlet has stronger tidal currents, higher tidal amplitudes, and more mixing than elsewhere in Hudson Bay (Dohler 1968; Budgell 1976, 1982), and tides could therefore contribute salt water to Baker Lake (Stewart and Lockhart 2005). IQ observations of salty tasting water associated with lunar cycles and low river flows also suggest tidal influence as an important factor in bringing seawater into Baker Lake.

The dynamics of salinity in Baker Lake varied between the open-water surveys in August 2015 and August 2017 and the under-ice survey of May 2016. Significant flushing of the lake would have occurred between the 2015 and 2017 sampling events as a result of the 2016 and 2017 freshets. The melting snowpack accounts for the same amount of runoff during the two-week freshet period as during seven to eight months of precipitation, resulting in dramatic seasonal peak flows in the Thelon, Kazan, and Quoich River systems (Budgell 1976), which would flush the lake and prevent saline waters from accumulating from year to year. Lower summer water levels in Baker Lake would increase the influence of tidal inputs. Ice-mediated tidal dampening would restrict the inflow of seawater from Chesterfield Inlet in winter (NOAA 2011; Georgas 2011), and reduced wind mixing under ice would limit the extent of any saline intrusion. The expression of marine influence in Baker Lake is therefore a complex dynamic between water levels in the lake, tidal influence from Chesterfield Inlet, wind mixing, freshwater inflows to Baker Lake, and ice cover on the lake and Chesterfield Inlet.

Conclusions

The surface water quality of Baker Lake was indicative of a nutrient poor, low alkalinity, soft water Arctic Lake. The lake was weakly stratified during August sampling and well oxygenated with dissolved oxygen concentrations exceeding 10 mg/L at all sites and depths. All water quality parameters and indicators were within federal guidelines for protection of freshwater aquatic life, with the exception of chloride and sodium in bottom waters associated with seawater incursions. The phytoplankton assemblage in Baker Lake was dominated by chrysophyte algae, some species of which can produce compounds that create taste and odor issues (i.e., fishy odor). A fishy odor and taste has been reported by some members of the community (HESL 2017), suggesting that taste- and odor-causing species may be present at high enough concentrations to create a taste issue in Baker Lake.

Saline water at depth in Baker Lake, as observed by Johnson (1965), was most pronounced during the open-water period in 2015 and was less pronounced under ice in the winter of 2016 and the summer of 2017. Periodic saline incursions of marine waters from Chesterfield Inlet in response to tidal cycles, winds, and relative water levels, along with changes in ice cover and freshet-induced mixing of Baker Lake waters, create a dynamic environment of salinity in Baker Lake.

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