BASELINE WATER QUALITY IN THE LAKES AND RIVERS OF THE KAKISA WATERSHED, 2011-2016

A report summarizing the first 5-years of water quality information from a community-based water quality monitoring program in the Kakisa watershed

Mike Palmer, M.Sc., Alexis Jorgensen, B.Sc.
Produced by PlanIt North for Ka'a'gee Tu First Nation
31 March 2019

CONTENTS

INTRODUCTION

Ka'a'gee Tu First Nation (KTFN) established a local water quality monitoring program in the Kakisa watershed in partnership with the GNWT Cumulative Impact Monitoring Program (CIMP) in 2011. The objective of the program was to develop a better understanding of baseline water quality conditions in the region so that the community is prepared to monitor future changes that may occur in the watershed with projected climate change and increased industrial development. The program began with quarterly water sampling at five locations across the Kakisa watershed and has expanded to include the installation of continuous water quality and passive hydrocarbon samplers during the summer and fall of each year near the community of Kakisa in partnership with the NWT Community-Based Monitoring Program (Fig. 1). This report provides an outline of the original program and includes water quality results for important environmental parameters during the first 5 years of the program.

STUDY AREA

The study area is located within the Taiga Plains Mid-Boreal Ecozone (Ecosystem Classification Group 2007) and includes several streams and rivers in the watersheds of Tathlina Lake and Kakisa Lake. These watersheds are culturally and economically important for KTFN since members have long used the area for subsistence harvesting and Tathlina and Kakisa lakes support small commercial fisheries.

The landscape of the region is a mosaic of peatlands, pine dominated forest, and mixed or pure stands of poplar, white and black spruce (Ecoregions Classification Group, 2007). The area is within the zone of sporadic discontinuous permafrost and permafrost is isolated to areas of peat plateaus, where thick covers of organic material preserve permafrost at depth. The area is undergoing rapid environmental change through the collapse of permafrost supported peatlands and this is resulting in widespread changes to the landscape and downstream aquatic environments (Quinton et al., 2011; Coleman et al., 2015; Korosi et al., 2015).

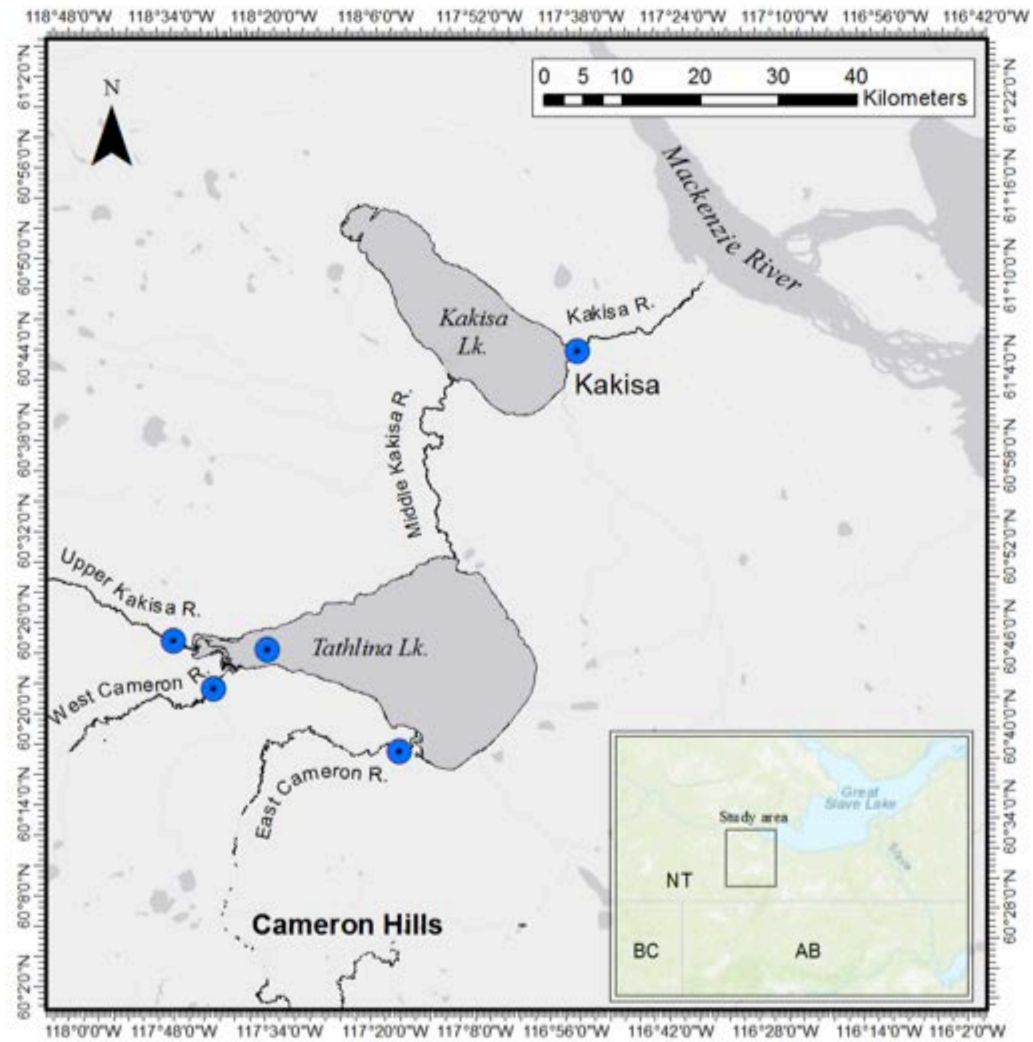

Fig. 1 Map of the study area, including an inset map which indicates the location of the study area in the Northwest Territories. The individual study sites are marked by blue circles. The direction of flow in the Kakisa watershed is from the south and west edges of the map through Tathlina Lake into Kakisa Lake and ultimately the Mackenzie River.

STUDY SITES

Five locations within the Kakisa watershed were selected for frequent water quality sampling to gain an understanding of baseline water quality conditions in the region and to contrast the water quality of rivers and streams in the watershed (Fig. 1). These sampling locations included: a) three streams that flow in to Tathlina Lake, which drain separate physiographic areas of the Tathlina watershed; b) Tathlina Lake; and c) the Kakisa River at the community of Kakisa. Specific descriptions of each of the study sites are presented below and the number of sampling visits at each site are presented in Table 1.

Data presented in this report was downloaded from the Mackenzie DataStream database and forwarded to PlanIt North. Only those data that were forwarded to PlanIt North were included in the report.

Table 1. The number of sampling visits to each of the sampling sites, including record of whether sites were sampled in the winter or summer.

Site Name	Open-water visits	Ice-covered visits	Total number of sampling trips
Upper Kakisa River	6	5	11
West Cameron River	7	6	13
East Cameron River	3	3	6
Tathlina Lake	6	4	10
Kakisa River at Kakisa	5	3	8

1) <u>Upper Kakisa River:</u>

Water samples from the Upper Kakisa River were collected in front of a set of KTFN cabins approximately 1 km from the mouth of the river (Figs. 1 and 2). Samples are presented in this report from 11 trips to the site. The watershed of the Upper Kakisa River drains a large area extending west of the sampling site that includes many large wetlands and bogs, including a traditionally important inland delta.

Fig. 2. Photo of the sampling site on the Upper Kakisa River. Note, water samples were collected from the middle of the river channel using a boat in the summer and snow machine in the winter.

2) West Cameron River:

Water samples were collected in the West Cameron River approximately 1 km upstream from the mouth of Tathlina Lake (Figs 1 and 3) to limit the influence of storm waters from Tathlina Lake on the sampling location. This report presents water quality data from 13 visits to the site between December 2011 and October 2016. The West Cameron River originates on the western edge of the Cameron Hills. The watershed is smaller than the adjacent Upper Kakisa River but drains a similar landscape characterized by interspersed black spruce forests and low-lying wetlands and bogs.

Fig. 3 Darcy Simba navigating the West Cameron River towards the water quality sampling location.

3) East Cameron River:

Water samples were collected in the East Cameron River approximately 500m from Tathlina Lake (Figs. 1 and 4). Access to the sampling site was difficult in the open-water season due to low water levels. The site was visited 6 times over the study period.

The East Cameron River originates in the Cameron Hills approximately 1000 ft (elevation) above Tathlina Lake. The upper section of the river meanders across the Cameron Hills plateau through black spruce forests and wetlands. Along its route towards Tathlina Lake, the East Cameron River cuts through the Cameron Hills and is a relatively high energy stream running over cobbles and boulders (Fig. 5). After cutting through the Cameron Hills, the East Cameron river meanders towards Tathlina Lake. Oil and gas operations in the upper watershed of the East Cameron River in the Cameron Hills were suspended in 2015. A small-scale conventional oil and gas operation with pipelines, roads and 50+ oil and gas wells operated in the area from the early 1960s until its recent suspension (Coleman et al., 2019).

Fig. 4 Melaine and George Simba travelling on the East Cameron River near the water sampling site June 2013.

Fig. 5 The upper section of the East Cameron River as it cuts through the Cameron Hills (left) and the lower section of the East Cameron River, after leaving the Cameron Hills, meandering towards Tathlina Lake (right).

4) Tathlina Lake:

Water samples were collected at the west end of Tathlina Lake at a location that has frequently been used by the commercial fishery (Figs. 1 and 6). The site was visited 10 times over the study period. The location of sampling is close to the inflows of the Upper Kakisa River and the West Cameron River, therefore, water quality is influenced by the incoming water of these two rivers and in-lake processes occurring within Tathlina Lake. Tathlina Lake is remarkably shallow for a lake of its size, and lake depth does not typically exceed 2m. Water depths at the location of sampling were approximately 1 m. There was extensive aquatic plant growth at the west end of the lake, which often made travelling from the camp on the Upper Kakisa River to Tathlina Lake difficult.

Fig. 6 Pete Cott pulling a net at the water sampling location in Tathlina Lake (left) and a photo depicting the extensive aquatic plant growth at the west end of Tathlina Lake, August 2013 (right).

5) Kakisa River at Kakisa:

Water samples were collected in the Kakisa River approximately 200m from the outlet of Kakisa Lake in front of the community of Kakisa (Figs. 1 and 7). The site was visited 8 times over the study period. The proximity of the sampling location to Kakisa Lake suggests that water quality at the sampling location is dominated water from Kakisa Lake and can be considered a surrogate for water quality at the east end of Kakisa Lake. Kakisa Lake is similar in size to Tathlina Lake, but is much deeper.

Fig. 7 The Kakisa River at the community of Kakisa looking downstream. The location of water sampling is just beyond the float plane.

METHODS

Surface water samples were collected at each sampling location in polyethylene containers that were rinsed three times with sample water. Water samples were kept cool (< 4^{o}C) and in the dark until delivered for analysis at Taiga Environmental Laboratory in Yellowknife. Surface water samples were analysed for a suite of nutrients, major ions, metal(loid)s, and physical parameters (Appendix 1). These data are publicly available through the Mackenzie DataStream website (mackenziedatastream.ca). Due to low water levels and changes in project funding, not all sites were sampled each year.

Since 2013, YSI multiparameter sondes (Yellow Springs Instruments, Yellow Springs, Ohio) have been deployed in the Kakisa River at the community of Kakisa from June to the end of October each year. These devices record physical parameters of river water several times a day, including pH, specific conductivity, temperature, turbidity, dissolved oxygen and oxidation-reduction potential (ORP).

RESULTS AND DISCUSSION

NUTRIENTS AND MAJOR IONS

Dissolved organic carbon

Dissolved organic carbon (DOC) is the proportion of the total amount of carbon in a water sample that will pass through a filter membrane (< 0.45μm in this study). This carbon can come from sources within the waterbody itself, such as the decomposition of aquatic plants and algae (referred to as autochthonous carbon), or from sources in the surrounding landscape, such as the degradation of terrestrial plants and organic-rich soils which is added to water sources via runoff (allochthonous carbon).

It is important to measure the amount of dissolved organic carbon in a water source for several reasons. First, organic carbon is an energy source for microbial and biological communities. Second, DOC measurements help us to understand organic loadings to water systems. A long-term record of DOC measurements (i.e. decades) is useful in monitoring changing organic matter loading to aquatic systems, which may be the result of increased productivity within the waterbody or changes in the surrounding landscape (such as permafrost degradation).

The monitoring of DOC in the Tathlina watershed (Fig. 8) shows that DOC concentrations for the measured streams are typically between 10 and 20 mg/L. There are also distinct differences in DOC concentrations between the sampling locations. Concentrations of DOC are highest at the Upper Kakisa River site and in Tathlina Lake, likely because the watershed for the Upper Kakisa River contains large wetland areas and low-lying bogs and peatlands, which can contribute large amounts of DOC to downstream areas. The sampling location for Tathlina Lake is close to the outflow of the Upper Kakisa River and likely represents waters contributed from the Upper Kakisa River. In addition, Tathlina Lake is a shallow and productive environment which may also contribute to the higher DOC concentrations.

There have been relatively few studies in the region that have measured DOC in lakes and rivers. DOC measurements from this study were comparable to values recorded in a series of small lakes in the Cameron Hills (Coleman et al., 2019), but lower than reported for a series of small organic-rich lakes on the Tathlina Plain east of Tathlina Lake (Coleman et al., 2015). These concentrations are comparable to levels of DOC that were measured in small lakes in the Yellowknife area (Palmer et al., 2015) and in a series of lakes along a transect from the southern Yukon to the Tuktoyaktuk peninsula (Pienitz et al., 2011).

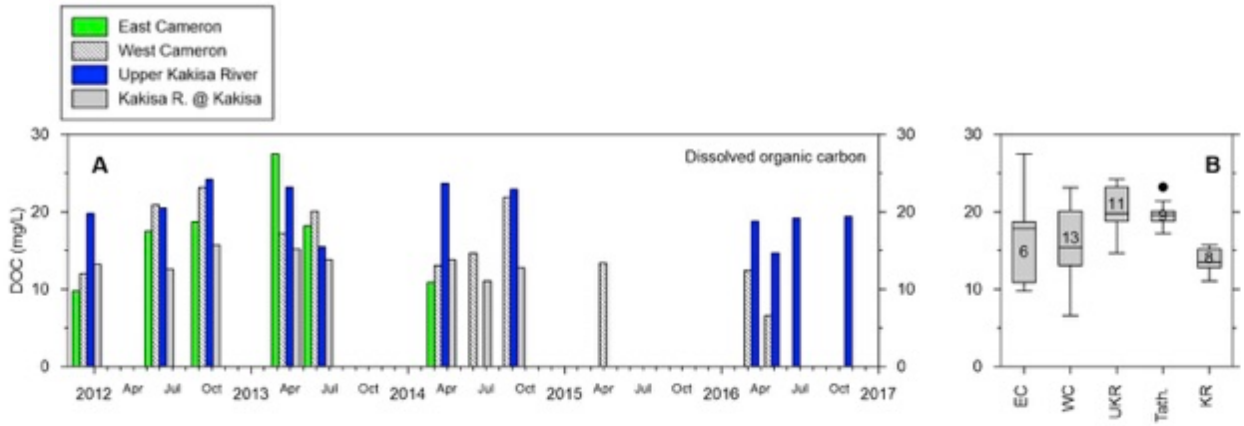

Fig. 8 Dissolved organic carbon at the study sites from December 2011 to October 2017. The figure on the left presents a time-series of changing DOC at the sampling locations over time. The figure on the right presents the same data as a series of box-whisker plots that allow for comparisons between sites. The upper and lower limits of the boxes contain 75% of the measured data (first quartile to third quartile) at each of the sites. The horizontal line in the boxes represents the median. The whiskers represent 2 x the interquartile range. Data beyond 2 x the interquartile range is considered an outlier and is marked with a circle.

Dissolved nitrogen and phosphorous

Nitrogen and phosphorous are important nutrients in aquatic environments. Nitrogen is used for production of plant and animal tissue, and phosphorous is used to convert sunlight into useable energy for aquatic plants. The monitoring of these nutrients is important since these data provide information on the productivity of aquatic environments. Phosphorous concentrations are typically low in natural systems and high concentrations of phosphorous (> 100µg/L) can lead to excessive algal growth and a deterioration in water quality.

The lakes and streams in this study contain moderate nutrient levels and can be classified as mesotrophic based on measured total phosphorous levels (< 20µg/L total phosphorous).

There was little difference in dissolved nitrogen levels between sites and concentrations were typically less than 1 mg/L (Fig. 9). Dissolved nitrogen concentrations exceeded 2 mg/L on two occasions, both during late-winter sampling, at the East Cameron River and the Upper Kakisa River in 2013 and 2014, respectively. Dissolved phosphorous levels were also comparable between sites and only exceeded 20 µg/L during the June 2013 sampling period for the streams that flow into Tathlina Lake.

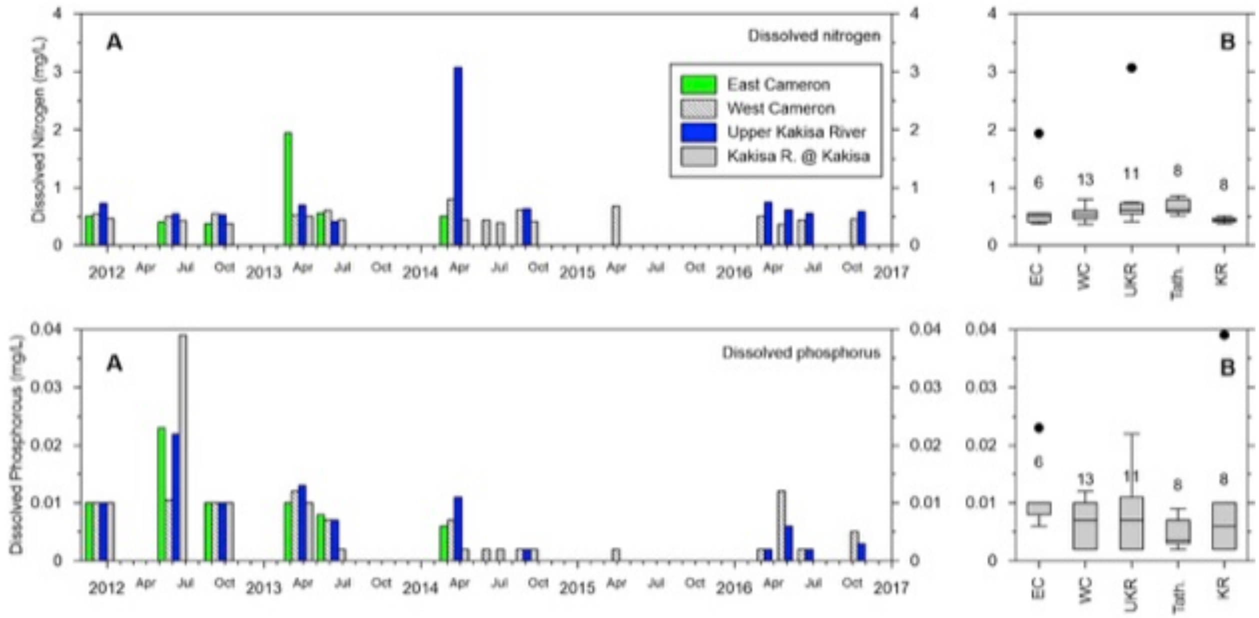

Fig. 9 Dissolved nitrogen (DN) at the study sites from December 2011 to October 2017. The figure on the left presents a time-series of changing DN at the sampling locations over time. The figure on the right presents the same data as a series of box-whisker plots that allow for comparisons between sites. The upper and lower limits of the boxes represent contain 75% of the measured data (first quartile to third quartile) at each of the sites. The horizontal line in the boxes represents the median. The whiskers represent 2 x the interquartile range. Anything beyond 2 x the interquartile range is considered an outlier and is marked with a circle.

Major ions

The total amount of major ions (Ca^{2+}, Cl^{-}, Mg^{2+}, Na^{2+}, and K^{+}) in lakes and rivers generally reflects the amount of weathering of bedrock and soils in the surrounding watershed. Concentrations are typically low in catchments dominated by low precipitation and hard rock geology, such as the Canadian Shield, where the weathering of material will be slow. Concentrations of major ions can be much higher in areas with higher precipitation and in catchments dominated by more easily weathered materials, such as found in the Tathlina and Kakisa watersheds.

The long-term monitoring of major ions in the lakes and streams in the region is important because this information will help our understanding of the influence of changing landscape processes on aquatic environments in the region. Several studies from large arctic river systems have noted an increase in major ion concentrations over the recent past and have attributed these changes in stream chemistry to changes in landscape processes and an increase in groundwater contributions from river catchments associated with climate change (Frey and McClelland, 2009).

There was little variation in the total amount of major ions (sum of Ca^{2+}, Cl^{-}, Mg^{2+}, Na^{2+}, and K^{+}) between the sampling sites in the Tathlina watershed (Fig. 10). In the three streams flowing into Tathlina Lake concentrations of major ions were typically higher during winter, which is likely the result of lower winter baseflow, which limits the dilution of the ionic composition of stream waters.

Concentrations of major ions were comparable at the Kakisa River site with the rest of the sites, but there was substantially less variation in major ion concentrations in the Kakisa River. The sampling site in the Kakisa River at Kakisa reflects lake water from Kakisa Lake since it is located at the lake outlet. Seasonal variation in major ion composition in a large lake like Kakisa Lake is expected to be small because seasonal effects are dampened by the large lake water volume.

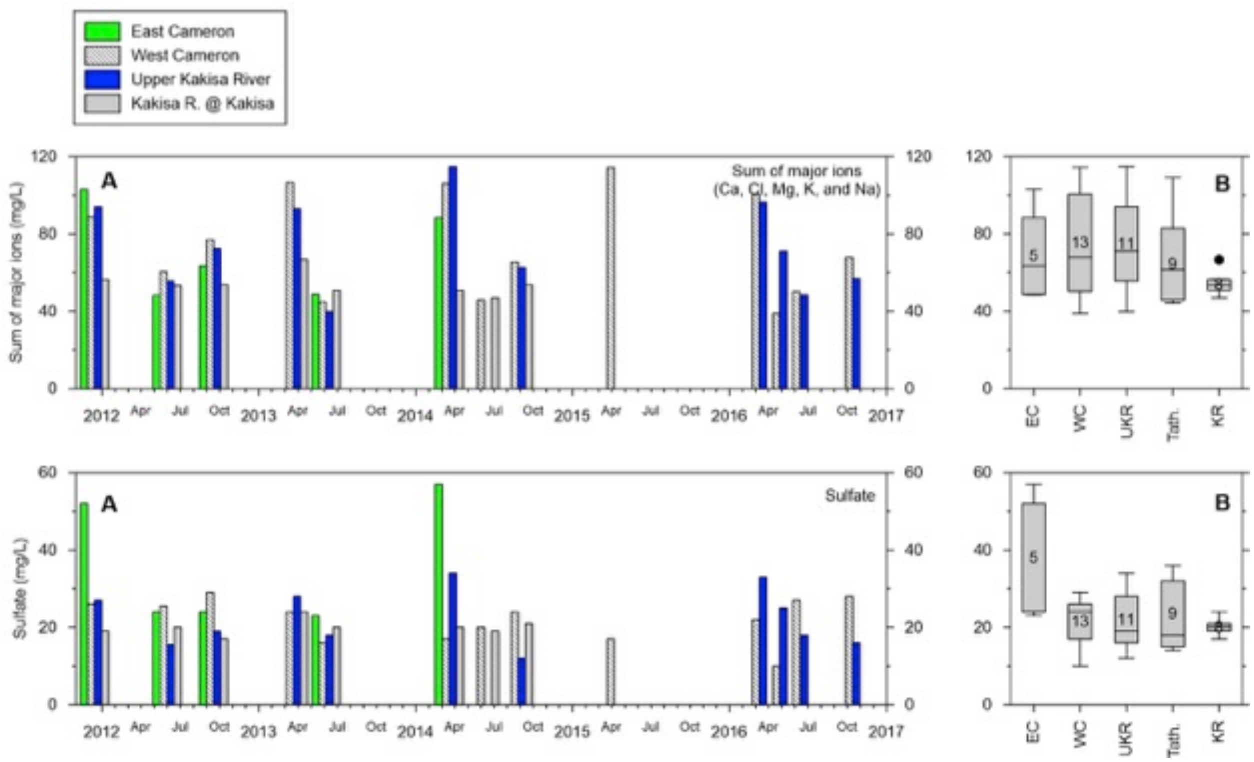

Fig. 10 Total concentration of major ions (sum of Ca^{2+}, Cl^{-}, Mg^{2+}, Na^{2+}, and K^{+}) (upper panels) and sulfate (lower panels) at the study sites from December 2011 to October 2017. The figures on the left presents a time-series of changing major ion and sulfate concentrations at the sampling locations over time. The figure on the right presents the same data as a series of box-whisker plots that allow for comparisons between sites. The upper and lower limits of the boxes represent contain 75% of the measured data (first quartile to third quartile) at each of the sites. The horizontal line in the boxes represents the median. The whiskers represent 2 x the interquartile range. Anything beyond 2 x the interquartile range is considered an outlier and is marked with a circle.

Metals

All natural surface waters contain metals, which are derived from the weathering of soils and rocks from the surrounding landscape, from natural sources in the atmosphere such as volcanic eruptions and forest fires, and/or from human activities, such as mining and oil and gas development. The amount of metals in surface waters only becomes a problem for aquatic life and drinking-water sources if concentrations exceed thresholds where known toxicological effects occur. In Canada, a set of Canadian water quality guidelines for the protection of aquatic life have been developed by the Canadian Council of Ministers of the Environment (CCME). These guidelines are values based on the most current, scientifically defensible toxicological data for the parameter of interest. These values are typically lower and more conservative than guidelines developed by Health Canada for the maximum allowable concentration in drinking water sources because they have been developed for the most sensitive life stages of the most sensitive species over the long term.

The most common metals of concern in freshwater environments are arsenic, cadmium, chromium, copper, nickel, lead, and mercury. In this section of the report, concentrations of metals are compared with existing guidelines to develop an understanding of how surface waters in the Kakisa watershed compare with Canadian guidelines. The second objective of this section is to explore whether there are distinct differences in metal concentrations between sites and/or between seasons. The data presented here are total metal concentrations in unfiltered water samples. The full list of metals that were included for analysis are presented in Appendix 1. All of this data can be accessed through the Mackenzie DataStream website (www.mackenziedatastream.ca).

In general, metal concentrations were low in surface waters in the study region (Fig. 11), reflecting the relatively pristine nature of the water sources. Many samples had trace element concentrations close to or below the method detection limit, including: beryllium, cadmium, cesium, cobalt, silver, selenium, and thallium. The upper quartile of data (>75%) for copper and all data for arsenic was below CCME guideline values during the entire study period for all sites (Fig. 11).

Iron levels were an exception and often exceeded the CCME guideline for the protection of aquatic life and Canadian drinking water guidelines (300 µg/L) (CCME, 2014; Health Canada, 2017) (Fig. 11). Iron concentrations were highest in the East and West Cameron Rivers, which drain the central and western edge of the Cameron Hills, respectively. In the Kakisa River at Kakisa, iron concentrations were low and rarely exceeded guidelines. Concentrations of iron higher than the Health Canada drinking water guideline should not be a public health concern, since this guideline is an aesthetic objective and no evidence exists of dietary iron toxicity (Health Canada, 2017).

High concentrations of several metals were noted in the Upper Kakisa River in June 2013 and were associated with high turbidity and sediment load, likely associated with the freshet period. Snow melt mobilizes terrestrially stored metals into aquatic environments. The fine-grained texture of suspended sediments provides ample binding sites for metals, therefore higher metal concentrations are often associated with high sediment loads.

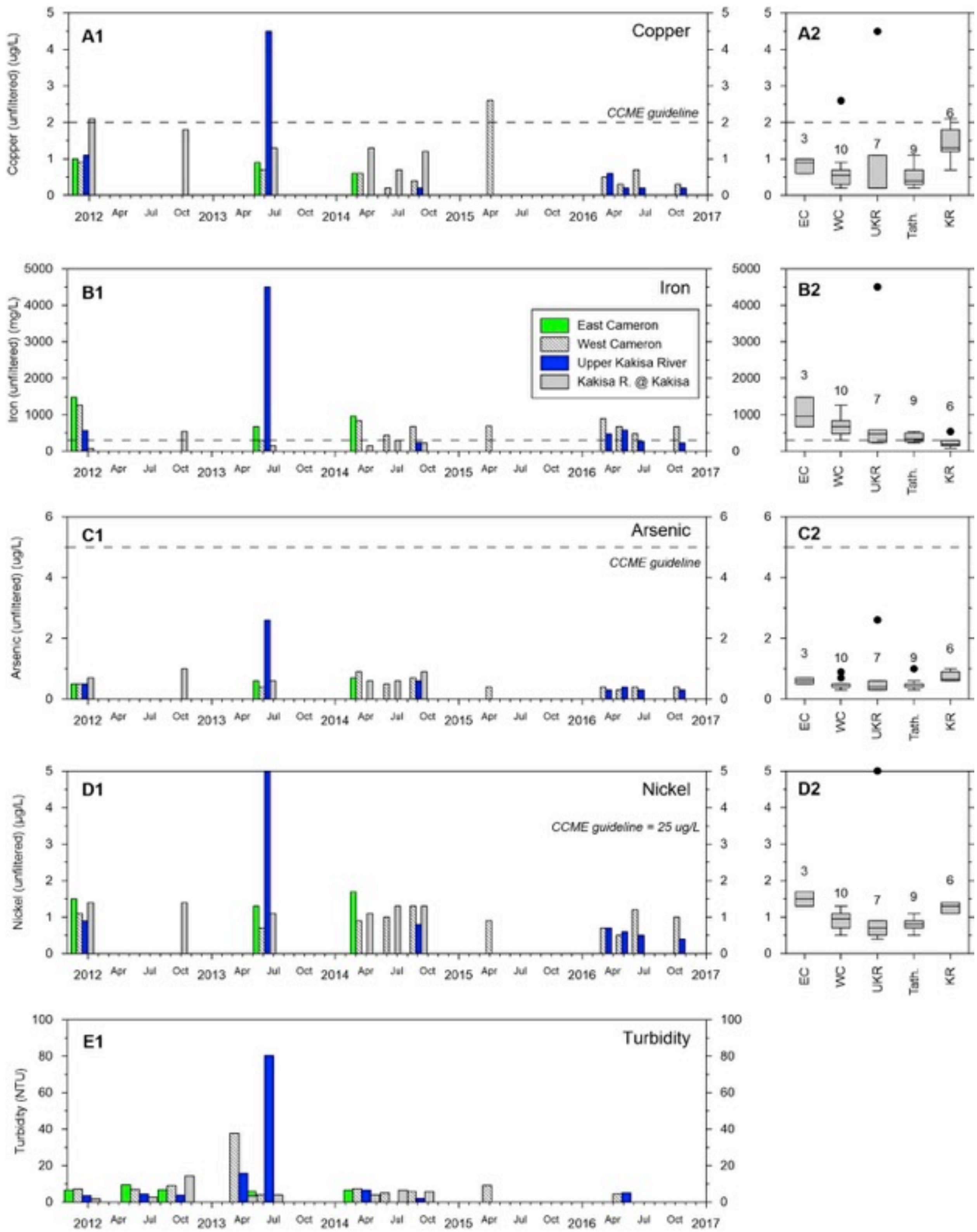

Fig. 11. Total concentration of metals (Cu, Fe, As, Ni) and turbidity at the study sites from December 2011 to October 2017. The figures on the left present a time-series of changing metal and turbidity

levels at the sampling locations over time. The figure on the right presents the same data as a series of box-whisker plots that allow for comparisons between sites. The upper and lower limits of the boxes represent contain 75% of the measured data (first quartile to third quartile) at each of the sites. The horizontal line in the boxes represents the median. The whiskers represent 2 x the interquartile range. Anything beyond 2 x the interquartile range is considered an outlier and is marked with a circle.

MULTIPARAMETER SONDES

Multiparameter sondes were deployed in the Kakisa River at the community of Kakisa during the summers of 2013, 2014, and 2015. The following sections present results for temperature, specific conductivity, turbidity, pH, dissolved oxygen and oxidation-reduction potential at the sampling location.

Specific Conductivity

Specific Conductivity measures how well a substance (in this case, river water) can conduct electricity. Specific conductivity generally increases with the temperature and the amount of dissolved solutes in the water. The amount of flow also influences specific conductivity through its influence on water temperature and salinity, with lower flows generally associated with higher conductivity. This is evident in Fig. 12 which shows that specific conductivity of surface waters in the Kakisa River are generally between 240 and 280 µs/cm during the summer months, and specific conductivity values are typically lowest during the earlier part of the summer when water levels are closer to freshet levels.

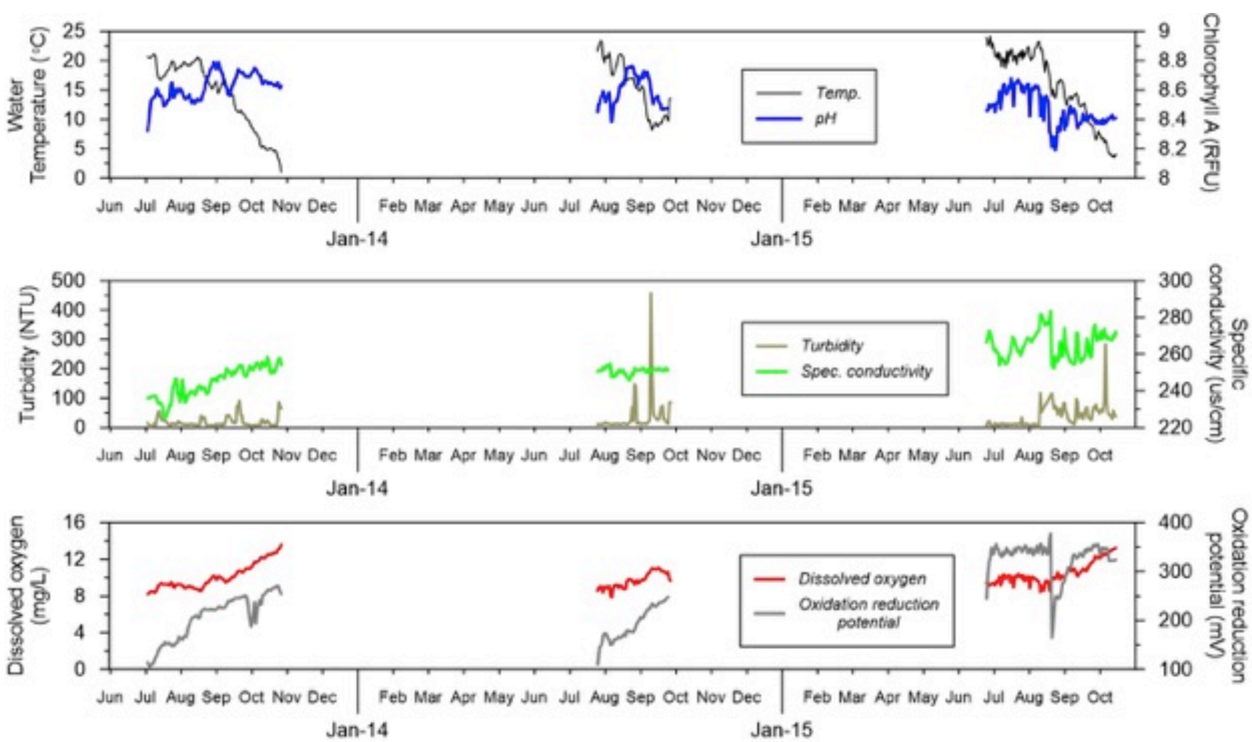

Fig. 12 Physical parameters of surface waters measured in the Kakisa River at the community of Kakisa during the summers of 2013-2015.

pH

The pH of surface water is a measure of how acidic or basic the water is. The pH of water is influenced by the types of rock or soil it encounters and inputs from rain and runoff. The pH of Kakisa River water is slightly alkaline and typically ranges between 8.2 and 8.8 (Fig. 12).

Turbidity

Turbidity is a measure of the degree to which water loses its transparency. This is typically due to the presence of suspended particulates. High turbidity water generally has more total suspended solids and is murkier. Surface waters in the Kakisa River are moderately turbid and turbidity levels are generally less than 100 normalized turbidity units (NTU). Several high turbidity events are noted in the time series record presented in Fig. 12. These may be due to high runoff events during storms or more local disturbance of the river bottom near the sonde.

Dissolved oxygen

The monitoring of dissolved oxygen is important since fish species require a certain level of oxygen present in the water column for survival. Typically, a minimum of 3 mg/L of oxygen is required to support healthy populations of fish species. Fig. 12 shows that surface waters in the Kakisa River remained well-oxygenated throughout the summer sampling periods.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE SAMPLING

There is often the temptation to use the data from broad regional monitoring programs, such as this, to assess project specific effects in a region. It should be clearly understood that this program was not designed to measure project specific effects from development in the Cameron Hills. Community concerns regarding the impact of oil and gas development and climate change on the Tathlina watershed were addressed with several focused research projects that were initiated as part of the original CIMP proposal (CIMP#149) and have been published in annual reports to CIMP and in scientific journals (see Coleman et al., 2015; Coleman et al., 2019; Korosi et al., 2015; Korosi et al., 2016; Stewart et al., 2015; Thienpont et al., 2017).

The initiation of a regional water quality monitoring program served two main purposes. The first was to gain a better understanding of baseline water quality in important lakes and rivers in the region, since no water quality information had been collected in the region prior to this program. The second was to develop community environmental monitoring capacity within the KTFN band staff. The idea was that government scientists could train and mentor KTFN band staff in the collection of water quality samples and the deployment of field monitoring equipment. In terms of these two primary objectives this project has been a success. In 2019, the program continues to run with financial and logistical support from the NWT Community-based Monitoring Program, but all field work is conducted by KTFN band members. There are still significant strides that need to be made until this will be a comprehensive and robust monitoring program (as outlined below), but the 5 years of data that are presented in this report have generated important knowledge about water quality in the lakes and rivers of the Kakisa watershed and have greatly increased the environmental monitoring capacity within the community.

In going forward, the following recommendations will help to strengthen the regional monitoring program and ensure that the information collected will be generate important new information on water quality of lakes and rivers in a region that is undergoing rapid environmental change and is downstream of a long-term oil and gas operation.

1. *Continuation of quarterly sampling, including under ice.*
   The availability of water quality data for this report was quite patchy. This may have been due to infrequent sampling trips or difficultly in accessing the data through the Mackenzie DataStream database. The goal of the program was to collect water quality information four times per year at each of the sampling sites. A long-term program that generates water quality data from the open-water and under ice seasons in the rivers and lakes in this understudied region would provide a novel dataset. One of the most interesting aspects would be the evaluation of the influence of seasonality on water quality in the region. Unfortunately, we were not able to compare under ice and open-water conditions because of a lack of available data but going forward this would be an important knowledge gap to address. We recommend sampling during key periods of the annual hydrological cycle, including freshet (~June), late-summer (~August), early-winter (November), and late-winter (March). The suite of parameters for water quality analysis are adequate and do not need to be modified.

2. *Deployment of water quality sondes under ice.*
   As mentioned in the previous recommendation, it would be valuable to continue collecting water quality information under ice. The lakes and rivers in the region are ice-covered for almost half of the year, therefore under ice conditions represent a large part of the year. Winter baseflow also typically reflects a period of increased solute concentrations due to lower flows. Water quality conditions during this period may represent important exposure levels for aquatic organisms. Water quality sondes provide an excellent method of logging physical properties in the water and can be deployed to record this information at regular intervals over long periods. Deploying these sondes under ice would provide important information on winter conditions.

   Specifically, it is recommended that dissolved oxygen levels at the west end of Tathlina Lake are monitored, since this area supports a small commercial fishery and low oxygen levels have been recorded in this area under ice in the past (see Stewart et al., 2015).

3. *Data management and quality control*
   All of the data presented in this report was downloaded from the Mackenzie DataStream database. A centrally managed database like this is an invaluable resource for managing water quality information that is coming from across the Northwest Territories from disparate sources. We suggest that this platform continue to be used for managing the water quality data collected in the Kakisa and Tathlina watersheds. That being said, there was a substantial amount of post-download quality control that was required, including identifying duplicates and field blanks,

and screening out samples that had clearly been compromised (i.e. values that were well above reasonable values). Without undertaking a thorough review of the Mackenzie DataStream application it is difficult to provide detailed recommendations regarding the quality control aspects of this application, but careful review of the data prior to uploading the data and quality control capacity within the application is important.

REFERENCES

Coleman, K.A., Palmer, M.J., Korosi, J.B., Kokelj, S. V., Jackson, K., Hargan, K.E., Courtney Mustaphi, C.J., Thienpont, J.R., Kimpe, L.E., Blais, J.M., Pisaric, M.F.J., Smol, J.P., 2015. Tracking the impacts of recent warming and thaw of permafrost peatlands on aquatic ecosystems: A multi-proxy approach using remote sensing and lake sediments. Boreal Environ. Res. 20, 363–377.

Coleman, K.A., Palmer, M.J., Korosi, J.B., Thienpont, J.R., Blais, J.M., and Smol, J.P. 2019. Assessing long-term changes in aquatic ecosystems near a small conventional oil and gas operation in the Cameron Hills, southern Northwest Territories, Canada. Fundamental and Applied Limnology. DOI: 10.1127/fal/2019/1191

CCME, 2014. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Council of Ministers of the Environment, Ottawa, ON. 146 pp.

Ecosystem Classification Group. 2007 (rev. 2009). Ecological Regions of the Northwest Territories – Taiga Plains. Department of Environment and Natural Resources, Government of the Northwest Territories, Yellowknife, NT, Canada. viii + 173 pp. + folded insert map.

Frey, K.E., McClelland, J.W., 2009. Impacts of permafrost degradation on arctic river biogeochemistry. Hydrol. Process. 23, 169–182. https://doi.org/10.1002/hyp.7196

Health Canada, 2017. Guidelines for Canadian drinking water quality - Summary Table. Ottawa, ON.

Korosi, J.B., Eickmeyer, D.C., Chin, K.S., Palmer, M.J., Kimpe, L.E., Blais, J.M., 2016. Examining spatial patterns in polycyclic aromatic compounds measured in stream macroinvertebrates near a small subarctic oil and gas operation. Environ. Monit. Assess. 188, 189. https://doi.org/10.1007/s10661-016-5175-9

Korosi, J.B., Mcdonald, J., Coleman, K.A., Palmer, M.J., Smol, J.P., Simpson, M.J., Blais, J.M., 2015. Long-term changes in organic matter and mercury transport to lakes in the sporadic discontinuous permafrost zone related to peat subsidence. Limnol. Oceanogr. 60, 1550–1561. https://doi.org/10.1002/lno.10116

Palmer, M.J., Galloway, J.M., Jamieson, H.E., Patterson, R.T., Falck, H., Kokelj, S. V, 2015. The concentration of arsenic in lake waters of the Yellowknife area, NWT Open File 2015-06.

Pienitz, R., Smol, J.P., Lean, D.R., 2011. Physical and chemical limnology of 59 lakes located between the southern Yukon and the Tuktoyaktuk Peninsula, Northwest Territories (Canada). Can. J. Fish. Aquat. Sci. 54, 330–346. https://doi.org/10.1139/f96-274

Stewart, E.M., Coleman, K.A., Korosi, J.B., Thienpont, J.R., Palmer, M.J., Blais, J.M., Smol, J.P. 2015. Assessing environmental stressors on a commercial walleye fishery from a large northern ecosystem (Tathlina Lake) using water chemistry and paleolimnology. Journal of Great Lakes Research. 42(2)

Thienpont, J.R., Desjardins, C., Kimpe, L.E., Korosi, J.B., Kokelj, S.V., Palmer, M.J., Muir, D.C.G., Kirk, J.L., Smol, J.P., Blais, J.M. 2017. Comparative histories of polycyclic aromatic compound accumulation in lake sediments near petroleum operations in western Canada. Environmental Pollution 231(Pt 1):13-21

APPENDICES

Appendix 1. List of elements and physical parameters measured in surface water samples, including the analytical method used and the method detection limit.

Parameter	Method	Method detection limit	Units
MAJOR IONS			
Calcium	Ion chromatograph	0.1	mg/L
Chloride	Ion chromatograph	0.7	mg/L
Fluoride	Ion chromatograph	0.1	mg/L
Magnesium	Ion chromatograph	0.1	mg/L
Potassium	Ion chromatograph	0.1	mg/L
Sodium	Ion chromatograph	0.1	mg/L
Sulphate	Ion chromatograph	1	mg/L
NUTRIENTS			
Nitrate as Nitrogen	Ion chromatograph	0.01	mg/L
Nitrate+Nitrite as Nitrogen	Ion chromatograph	0.01	mg/L
Nitrite as Nitrogen	Ion chromatograph	0.01	mg/L
Organic Carbon, Dissolved	High temperature combustion on a total carbon analyzer	0.5	mg/L
Nitrogen, Dissolved	DN	0.06	mg/L
Phosphorous, Dissolved	Colorimetric	0.002	mg/L
PHYSICAL PARAMETERS			
Conductivity, Specific (@25C)	Conductivity probe	0.4	µS/cm
METALS			
Aluminum	ICP-MS	0.6	µg/L
Antimony	ICP-MS	0.1	µg/L
Arsenic	ICP-MS	0.2	µg/L
Barium	ICP-MS	0.1	µg/L
Beryllium	ICP-MS	0.1	µg/L
Cadmium	ICP-MS	0.04	µg/L
Cesium	ICP-MS	0.1	µg/L
Chromium	ICP-MS	0.1	µg/L
Cobalt	ICP-MS	0.1	µg/L
Copper	ICP-MS	0.2	µg/L
Iron	ICP-MS	5	ug/L
Lead	ICP-MS	0.1	µg/L
Lithium	ICP-MS	0.2	µg/L
Manganese	ICP-MS	0.1	µg/L
Molybdenum	ICP-MS	0.1	µg/L
Nickel	ICP-MS	0.1	µg/L
Rubidium	ICP-MS	0.1	µg/L
Selenium	ICP-MS	0.3	µg/L
Silver	ICP-MS	0.1	µg/L
Strontium	ICP-MS	0.1	µg/L
Thallium	ICP-MS	0.1	µg/L
Titanium	ICP-MS	0.1	µg/L
Uranium	ICP-MS	0.1	µg/L
Vanadium	ICP-MS	0.1	µg/L
Zinc	ICP-MS	0.4	µg/L