Fate of Heavy Metals in Passive Wastewater Treatment Systems of the Northwest Territories

ENVS 4902 Environmental Science Undergraduate Honours Thesis

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Abstract

Due to unique climatic, geologic, and biologic conditions of northern Canadian landscapes, wastewater management in this region is complex and geographically distinctive. Many regions of the Northwest Territories (NWT) employ passive, semi-engineered systems for municipal wastewater treatment as they are low-cost and require minimal maintenance; however, it is unclear if these natural systems are effective in treating effluent and improving water quality. A major lack of research exists surrounding heavy metals in passive treatment systems in northern environments. The current study distinguishes and quantifies the relationship between anthropogenic wastewater disturbances and ambient levels of heavy metals in receiving environments in the communities of Yellowknife, Hay River, and Fort Providence, NWT. Comparisons are made between federal environmental quality guidelines and levels of heavy metals found in wastewater system effluents. Water samples were collected during August of 2019 in wastewater lagoon, wetland, and reference sites for analysis of eight heavy metals. Data mining of water quality reporting from NWT databases and studies was conducted to compare ambient levels of heavy metals to samples collected form wastewater systems. A 2-way ANOVA analyzed variance between locations (Yellowknife, Hay River, and Fort Providence) and environments types (lagoon, wetland, and ambient) and found six of eight heavy metals indicated significant differences between locations while two metals exhibited significant differences between environment types. Generally, lagoons contained greater heavy metal samples above Canadian guidelines. However, there were fewer wetland samples above Canadian guidelines compared to ambient samples. The results suggest underlying geology and anthropogenic disturbances influence heavy metal occurrence in northern environments and passive systems may be improving water quality in wetlands by reducing heavy metal concentrations.

Key words: Heavy metals, water quality, passive wastewater treatment, wetland treatment, northern aquatic ecosystem, Northwest Territories

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1 Introduction

Municipal wastewater effluent is one of the most significant sources of pollution to surface waters in terms of volume in Canada (Environment and Climate Change Canada, 2017). As a result, sustainable wastewater management is essential in conserving aquatic ecological habitats and protecting public health. Communities across Canada employ varying levels of wastewater treatment and processes to mitigate potential environmental and health impacts from organic pollutants such as pathogens and inorganic pollutants such as heavy metals (Environment and Climate Change Canada, 2017).

Presently, the Northwest Territories (NWT), Nunavut, Québec (regions above the 54th parallel), and Newfoundland and Labrador are not included in Canada's Wastewater Systems Effluent Regulations of the federal Fisheries Act (CCME, 2014a; Government of Canada, 2012). Due to unique climatic, geologic, and biologic conditions of northern Canadian landscapes, wastewater management in this context is complex and geographically distinctive (CSA Group, 2019). For these reasons, federal municipal guidelines are unable to be enforced in northern regions. Many communities in Canada's northern regions of the NWT employ passive, semi-engineered wetland systems for municipal wastewater treatment as they are low cost and require minimal maintenance (Balch et al., 2018). Currently, NWT governments and community stakeholders are unsure whether natural wetland systems are effective in treating effluent and improving water quality. If passive treatment systems are realized as ineffective, human impacts will have eventually degraded the natural environment as well as directly and indirectly lead to threats to human health via effluent exposure pathways (Balch et al., 2018; Daley et al., 2018). Ultimately, the uncertainties of long-term ecological effects related to passive wetland systems, coupled with a lack of clear regulations and standards, create limitations surrounding wastewater management in the north.

With more than 500 organic and metallic compounds documented as occurrent in natural wetland systems from mainly municipal effluent, these systems require increased study in terms of mobility of compounds in the aquatic environment (Haarstad et al., 2011). Additionally, the lack of research surrounding heavy metals in passive treatment systems in northern environments indicates the need for increased analyses that examine the fate of heavy metals in a northern framework. The current study will distinguish and quantify the relationship between anthropogenic wastewater disturbances and background levels of heavy metals in receiving environments. Additionally, federal environmental quality guidelines will be compared to the levels of heavy metals in northern wastewater effluents.

1.1 Background & Context

Within the context of this study, northern areas are considered those regions not included in Canada's Wastewater Systems Effluent Regulations. These areas are often limited by unique conditions associated with climatic, economic, and social challenges (CSA Group, 2019). For example, previously set national standards surrounding wastewater management cannot be applied to northern areas because they do not fully consider the extreme cold and persistent temperatures; geographically isolated small communities with poor transportation connections; physical geologic challenges such as the presence of permafrost in some arctic regions; limitations in funding for new infrastructure, construction, and maintenance of facilities; and shortages of skilled labourers and professionals (CSA Group, 2019; Hayward et al., 2014; Yates et al., 2012). As a result, conventional wastewater management that use mechanical systems is not feasible in the north.

Wetlands are inundated areas of land characterized by indicators of water, substrate, and biota (National Research Council,1995). Additionally, wetlands are productive ecosystems providing many ecosystem services to humans, plants, and other species (Environment and Climate Change Canada, 2016). In northern regions of Canada, the term wetland is used in a general sense, encompassing water features such as open streams and ponds, bogs, emergent grasses, and fens. (Jamieson et al., 2016). Wetlands have an intrinsic ability to improve water quality through basic functions of the wetland and humans have learned to capitalize on this service with the use of wetlands to treat wastewater (Kennedy & Mayer, 2002).

Passive wastewater treatment systems, ranging from natural to engineered, use sophisticated environmental mechanisms such as biogeochemical cycling and natural attenuation (un-enhanced natural processes to remediate potential pollutants) as the main driving force to treat wastewater (Rittmann, 2004; Werker et al., 2002). Mechanical treatment systems are not prevalent in the north due to economic, demographic, and social causes (Yates et al., 2012). Compared to mechanical systems, passive wetland systems are generally not favoured in the broader context of wastewater treatment due to environmental and public health risks and uncertainties associated with passive systems (Kadlec & Wallace, 2008).

In municipal and industrial wastewater, heavy metals are the main causes of pollution to water and soil systems (Chipasa, 2003). Heavy metals are toxic, persistent, and non-biodegradable compounds with the ability to biomagnify and bioaccumulate in the food web, constituting a significant risk to public health (Daley et al., 2018; Wu et al., 2016). Even at low dosages, individual heavy metals pose a risk to human health, while the mixing of metals potentially increases synergistic health effects (Wang & Fowler, 2008; Wu et al., 2016).

Ultimately, heavy metals in passive wastewater treatment systems pose a severe risk to ecological health when present and mobile in the environment.

1.2 Knowledge Gaps & Summary of Literature

Although the literature has demonstrated multiple studies in which passive wetland treatment systems are in fact effective in their ability to improve water quality, many studies recognized the need for further research within the parameters of a hydraulic and biogeochemical framework (Balch et al., 2018; Chouinard et al., 2014a; Hayward et al., 2018; Hayward & Jamieson, 2015; Hayward et al., 2014). There exists no research in the northern regions regarding passive sewage disposal facilities and their impacts as sources or sinks for heavy metals; therefore, initial research attempts are considered novel in the field.

Given the lack of research regarding heavy metals in passive treatment systems of northern Canadian regions, researchers are left with a limited set of resources for comparison. However, numerous studies conducted in the United States and Scandinavia demonstrated the feasibility of wastewater treatment in cold climates (Wittgren & Maelum, 1997). Similarly, past northern Canadian research in passive arctic Tundra wetland systems in Nunavut demonstrated significant contaminant concentration diffusion with some systems capable of contaminant reductions below federally set regulations (Hayward et al., 2018; Hayward & Jamieson, 2015; Hayward et al., 2014; Yates et al., 2012). The current literature lacks research related to boreal wetland environments as the Boreal wetland biome differs significantly from that of Tundra wetland; as a result, compounds found in passive treatment systems may behave differently.

A review of the literature reveals context behind different system types and configurations and offer a rationale for usage. Mechanisms that drive treatment systems, and climate factors that reflect the system in a northern framework are not well studied; however, initial studies have demonstrated water quality improvements (Balch et al., 2018; Chouinard et al., 2014a). The literature review demonstrated that research regarding wastewater treatment in Canada's north is increasing; however, heavy metals are yet to be explored. This lack of research can pose potential long-term health hazards (Daley et al., 2018). Ultimately, the accumulation of literature demonstrates the trade-offs of employing a treatment system in Canada's north, causing uncertainties related to heavy metal exposure to humans and aquatic ecosystems.

1.3 Introduction to the Study

As part of a three-year cumulative effects monitoring study in partnership with the Government of the Northwest Territories (GNWT), the overarching objective of this preliminary study is to understand the mobility and transport of heavy metals associated with anthropogenic disturbances on aquatic systems. The research questions this study aims to address are: How do the variations and levels of heavy metals differ between water quality in passive wastewater treatment systems of Yellowknife, Hay River, and Fort Providence, NWT and between treatment environments? Additionally, how do these variations and levels compare to Canadian Environment Quality Guidelines (CEQG) for the protection of aquatic life as set forth by the Canadian Council of Ministers of the Environment (CCME guidelines)? This study's aims are two-fold, including:

1. Determine further data gaps and sampling locations for additional research; and
2. Assess how wastewater treatment systems are performing in relation to human health and environmental guidelines.

Ultimately, the study's findings will be useful in investigating uncertainties related to the fate of heavy metals in passive wastewater treatment systems to make better-informed decisions regarding setting new standards and regulations for the management of wastewater systems in Canada’s northern regions.

It is hypothesized that there will be higher concentrations of heavy metals found in passive wastewater systems compared to their ambient environment (past water quality data and reference sites) due to the nature of the system affected by wastewater. Likewise, it is predicted that the levels of heavy metals show significant differences between locations (Yellowknife, Hay River, and Fort Providence) and environment types (lagoon, wetland, and ambient) due to distinct underlying geology of locations and biogeochemical differences between environment types.

Given the research objectives and questions, the scope of the study includes spatial, and temporal related parameters. The spatial limits of the current study areas are confined to the watershed areas affected by the wastewater treatment systems in the communities of Yellowknife, Hay River and Fort Providence, NWT. Temporal limits exist within the single sampling event conducted during the of Summer 2019 in Hay River and Fort Providence. Sampling was not conducted in Yellowknife as an on-going monitoring program is currently in place.

The research question will be addressed by collecting field samples and mining open-source data. Water samples will be collected at sampling locations for analysis of heavy metal concentrations. Extensive data mining of environmental quality reporting from land and water resource boards of the NWT and government environmental reporting resources will be conducted to compare background levels of heavy metals to field samples. Data will be analysed to infer interactions between field sampling data and background ambient quantities while frequency of samples exceeding CCME guidelines will be determined.

2 Literature Review

This literature review will outline and assess existing studies related to passive wastewater treatment systems, mainly from water science, ecological engineering, waste management, and environmental science journals and government resources. As the literature regarding the fate of heavy metals in passive treatment systems in northern Canada is limited, the current state of treatment and practices will be reviewed, and relevant northern environmental characteristics will be described. Additionally, the fate and mechanisms surrounding heavy metals in cold climate environments will be examined. While many knowledge gaps surround the fate of heavy metals in northern wastewater treatment systems, the need for further research in the field is critical to support wastewater management in northern Canada. Relevant federal guidelines and regulations will also be examined to support human and environmental health criteria. Ultimately, this literature review will focus on the science of wetland treatment systems, the potential impacts they may cause, and their role in a northern framework to encompass the current study of heavy metals in treatment systems.

2.1 Passive Wastewater Treatment Systems

2.1.1 System Types & Configurations

The effectiveness and capacity of wastewater management from varying systems fall along a scale of treatment levels ranging from preliminary, primary, secondary, and tertiary levels of treatment (Fig. 1). Treatment levels can exist in combination to optimize treatment efficiency with goals of reducing costs while decreasing pollution concentration in the effluent to be released to the environment (Bitton, 2005; Biswas et al., 2007; Chipasa, 2003). Specifically, preliminary treatment is an essential step for all treatment facilities: large debris and solids of raw wastewater are screened and removed at this stage. Next, primary treatment aids in depositing and removing organic and inorganic wastewater by the process of sedimentation that helps in the breakdown process of organic materials present. Subsequently, secondary treatment uses aerobic biological/chemical processes and other suspended microorganisms or “activated sludge” to remove biodegradable materials (National Research Council, 1996). The final level of tertiary treatment is more sophisticated and case-specific as this level of treatment is deployed when secondary treatment is unable to remove wastewater constituents entirely (Bitton, 2005; Daley et al., 2018; FAO 1992). Within treatment levels, heavy metals are removed in primary treatment. At this stage, solid heavy metals are removed due to a portion of metals combining with particles; however, dissolved heavy metal compounds are still present (Chipasa, 2003; FAO, 1992). Finally, secondary treatment removes remaining metals by the process of biosorption (Brown et al., 1973; Chipasa, 2003).

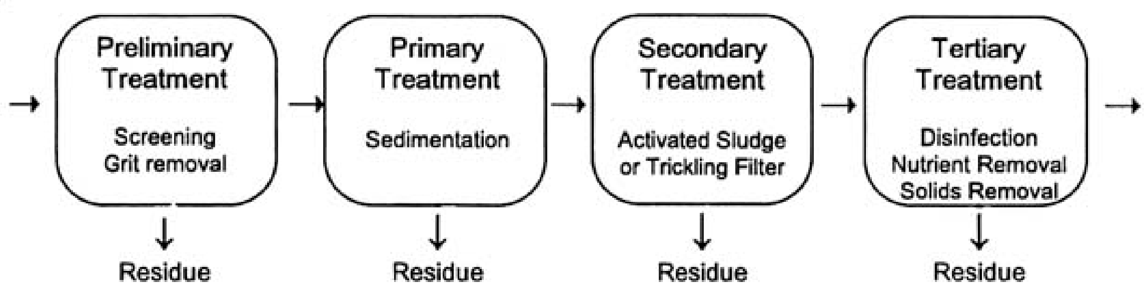

Figure 1 Municipal wastewater treatment levels ranging from preliminary, primary, secondary, and tertiary levels of treatment. Leftover residues from each treatment is called “sludge” (National Research Council, 1996).

Constructed wetland systems are preferred over natural wetland systems as the main concerns of natural systems are unknown long-term ecological effects and loss of engineered control creating uncertainties during operation (Knox et al., 2008). The United States Environmental Protection Agency decreased usage of natural wetland systems in 1987 mainly due to intensifying concerns over potential synergistic effects associated with toxic substances, aquatic and human exposure to contaminants, and degradation of the wetland environment (U.S.

EPA, 1987; Knox et al., 2008). Kadlec & Wallace (2008) stated that natural wetlands pose a higher risk to environmental health compared to constructed wetlands due to the unknown long-term ecological effects. Constructed wetlands are more manageable in terms of hydrology, hydraulic residence time, and suitability of vegetation compared to natural wetland systems (Hayward et al., 2014). Kadlec & Wallace (2008) and Hammer & Bastian (1989) both do not recommend the usage of passive wetland systems for wastewater treatment due to potential long-term landscape effects. Increased protection of natural wetlands has also prevented the implementation of passive wetland systems in parts of Canada and the United States (Yates et al., 2012). Despite evidence from past studies demonstrating improved water quality, feasibility, and economic advantages associated with choosing a passive wetland system design, these systems should not be fully accepted as an effective treatment measure. In cases where usage of passive systems is employed when all other alternatives are unavailable, precautionary measures such as increased monitoring should be implemented.

In terms of the different kinds of wastewater treatment systems, the two extremes that exist are mechanical and passive systems, while hybrids of the two are possible. To an extent, all systems can treat wastewater effluent through a combination of chemical, biological, and physical processes (Wallace et al., 2015; Daley et al., 2018). In the NWT, the standard system configuration includes a passive semi-engineered wastewater treatment system with wastewater stabilization ponds (WSPs), natural boreal wetland, and a receiving environment within a watershed. In these systems, preliminary or primary treated effluent is discharged into WSPs (also referred to as sewage lagoons with a varying array and number of lagoon cells), which release effluent into natural boreal forest wetland. From here, effluent uses passive treatment mechanisms to pass through the wetland which eventually reaches the receiving environment of a river, lake, or ocean environment (CSA Group 2019; Daley et al., 2018; Hayward & Jamieson, 2015; Hayward et al., 2014).

2.1.2 Treatment Mechanisms

Past studies in similar geographic regions demonstrate different scopes of wastewater treatment study with distinctive analysis parameters. Wetlands are capable of purifying wastewater containing heavy metals through physical, chemical, biological, and biochemical processes in wetland water, biota, substratum, and suspended solids (Matagi et al., 1998). Treatment mechanisms associated with natural wetland systems are sedimentation, nutrient transformation, solar radiation to disinfect, and microbial and plant uptake to improve water quality (Knox et al., 2008). Matagi et al. (1998) listed reactions involving "sedimentation, flocculation, absorption, co-precipitation, cation and anion exchange, complexation, precipitation, oxidation/reduction, microbiological activity and plant uptake" as specific mechanisms that remove heavy metals in wetland systems (p.1). Yates et al. (2012) conducted the first season-long study of passive wetland systems in the tundra for six wetland systems servicing several small communities in Nunavut. The performance of the wetland systems for wastewater treatment was found to be an appropriate technology for this northern region. A main finding of this study was that natural wetlands act as sinks and can transform nutrients, organic material, and pathogens despite harsh cold climates and barren and low biomass producing ecosystems. Chaves-Barquero et al. (2016) found a significant removal of nutrients occurring when dilution of the receiving environment occurred during spring freshet in Cambridge Bay, Nunavut. Ultimately, natural attenuation was effective in the lagoon input of the treatment system, especially in the WSP where concentrations of organic compounds were highest. Concentrations of contaminants and nutrients were minimal in the study area which suggest negligible wastewater runoff. Overall, past studies have demonstrated effective wastewater treatment and increased understanding of treatment mechanisms in northern conditions.

2.1.3 Cold Climate Treatment Systems

Globally, wastewater treatment in cold climates is feasible, as demonstrated through numerous studies in North America and throughout Scandinavia (Wittgren & Maelum, 1997). Treatment wetlands in cold and temperate regions of the northern United States are effective in reducing pollution concentration after primary and secondary wastewater treatment (Wallace et al., 2001). Mitigation techniques and design approaches exist for common wetland treatment problems, such as preventing freezing of the treatment system (Wallace et al., 2001). In Scandinavian countries, treatment wetlands in cold and temperate climates are gaining widespread use (Kallner & Wittgren, 2001; Wittgren & Maelum, 1997). Andersson et al. (2002) and Yates et al. (2012) described a 23-hectare wetland system establish in 1993 in Oxelösund, Sweden that removed nitrogen before discharging into the receiving environment of the Baltic Sea. As a result, nitrogen removal in the treatment wetland had improved during the first five years of operation, removing more than 50% of nitrogen. Andersson et al. (2002) stated that based on successful nitrogen removal results, treatment wetlands can be used in combination with conventional mechanical treatment plants to optimize and decrease operation costs. It is important to consider the climate types as influencers to the design and operation of wastewater systems and the influence of effluents on the receiving environments. Smith & Emde (1999) stated that ecosystems in cold regions are fragile to some extent and variable compared to southern climates. As a result, the environmental consequences of anthropogenic disturbances to a system suffers from increased magnitudes of impacts and difficult remediation problems. Overall, past studies in the US and Sweden demonstrate the feasibility and treatment capabilities of passive treatment systems in cold climate conditions. Some studies utilized a combination of constructed and natural system components to achieve optimal levels of treatment.

The study area of northern climates demonstrates ecologic, geographic, and social-economic challenges that are not well studied in terms of wastewater treatment and management. Low biological diversity and ambient temperatures often characterize northern climates leading to an increase in vulnerability of the ecosystem to environmental contaminants due to direct wastewater discharge (Gunnarsdóttir et al., 2013; Hayward et al., 2014). The main wetland system concerns in cold climates includes ice formation and impacts on water flow and pressure (hydraulic performance); hydrology and hydraulic issues not related to ice formation; and thermal consequences of biological treatment processes (Wittgren & Maehlum, 1997). Krkosek et al. (2012) stated that wastewater stabilization ponds of passive treatment facilities are dynamic systems that have a significant spatial and temporal variation in temperature, dissolved oxygen, and pH. Additionally, Chouinard et al. (2014b) explained that performing sound research including, collecting samples, replicates, and datasets suitable for further analysis is a difficult task in this region due to logistical and geographic hurdles. As a result, increased research uncertainties and lack of understanding environmental impacts are increased in the region. Many accessibility and sampling challenges related to research in northern regions have risen, causing difficulties in developing comprehensive wastewater management research and management standards.

2.2 Human & Environmental Health Criteria for Heavy Metals

2.2.1 Human & Environmental Health Effects

The increased presence and abundance of heavy metals in receiving aquatic systems pose adverse effects on humans and the ecosystem. While passive wetland systems have been proven to be effective in improving water quality, there exist concerns related to the capacity of these systems to treat certain contaminants (Haarstad et al., 2011). Metals are considered heavy if their density is above 5 g/cm^3 (Nies, 1999). Particular heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) are bioavailable and transferable in the environment to human exposure pathways (Wu et al., 2016). Another area of concern related to heavy metals present in the environment is the mixing of metals leading to synergistic effects (Wang & Fowler, 2008).

Poor wastewater management of municipal effluents can lead to dire human health implications and degradation of the aquatic environment. Gunnarsdóttir et al. (2013) stated that wastewater treatment in arctic regions is inadequate and can pose harm to the environment and human health. Additionally, bioaccumulation and biomagnification are major concerns to aquatic species and humans. Environmental Signals (2003) described municipal wastewater effluents as one of the biggest threats to water quality in Canada. Releasing untreated or minimally treated effluents can put humans at risk of contaminated drinking water due to the risk of harmful bacteria and toxic substances. Heavy metal exposure is also toxic to microorganisms found in wastewater systems (Chipasa, 2003; Lester et al.,1979). Aquatic organisms absorb heavy metals directly from surrounding water and indirectly through the food web. Toxic heavy metal affect aquatic organisms by impairing developmental growth, increasing mutations in growth, decreasing survival rates, and potentially leading to extirpation or extinction of a species (Khayatzadeh & Abbasi, 2010). Ultimately, anthropogenic disturbances are influencing major aquatic ecosystems, altering fluxes of growth-limiting nutrients in downstream waters.

2.2.2 Relevant Guidelines & Regulations

Relevant guidelines and regulations on the federal and territorial levels are important sources of information that establish improved wastewater management and ensure best practices in system design. The CCME released a Canada-wide strategy for management of municipal wastewater in 2009 to allow facilities to operate under a clear and harmonized national framework that protects public health and the environment (CCME, 2009). Additionally, this strategy states that all treatment facilities need to achieve National Performance Standards (NPS), which regulate the amount of pollutant concentrations found in most wastewater effluent (CCME, 2009). The NPS regulate carbonaceous biochemical oxygen demand ($CBOD_5$), Total Suspended Solids (TSS), and Total Residual Chlorine (TRC), which at increased concentrations can have negative impacts on the environment and human health. (CCME, 2009). The 2009 strategy recognized limitations and special considerations when it came to Canada's northern region; therefore, northern regions were allocated a grace period of five years (2009 to 2014) for research regarding wastewater system performance and to develop specific northern treatment standards (CCME, 2009). Currently, the development of northern performance standards regarding the design and implementation of wastewater facilities is still underway (CCME, 2014a, Government of Canada, 2012). The CCME also provides Canadian Environmental Quality Guidelines (CEQGs) which are recommended guidelines with the goal of protecting aquatic and terrestrial ecosystems (CCME, 2014b). The Canadian Water quality Guidelines for the Protection of Aquatic Life was established to protect all forms of marine and freshwater life as well as aquatic cycles from anthropogenic stressors. These guidelines are based on current toxicological data for specified water quality parameters (CCME 1999).

3 Methodology

3.1 Study Areas

The study areas were located in the NWT, where 41,786 total inhabitants reside over a mostly barren land area of 1.14 million km^2 (Statistics Canada, 2016). Of the 33 communities in the NWT, Yellowknife, Hay River, and Fort Providence were identified by the GNWT and by the research team as suitable study sites to represent the range of communities and treatment system configurations found in the region. Additionally, the relative sizes and improved transportation accessibility to these communities increased the potential sources of available data. Similar studies assessing the performance of passive wetland systems have already been conducted in passive Tundra treatment systems in Nunavut (Balch et al., 2018; Chouinard et al., 2014a; Hayward et al., 2018; Hayward & Jamieson, 2015; Hayward et al., 2014, & Yates et al., 2012). Although the wetland biomes between Boreal and Tundra are inherently different, the configuration of the treatment systems are the same. Therefore, similar methodologies were appropriate and valid for achieving the desired research goals.

3.1.1 Yellowknife

Yellowknife is the largest community in the NWT, with a population size of 20,607 citizens located in the South Slave administrative region of the territory (NWT Bureau of Statistics, 2018). The treatment network consists of trucked and piped sewage brought to Fiddler's lake (WSP), a wetland drainage area (13km of wetland), and Great Slave Lake as the receiving environment (City of Yellowknife, 2019) (Fig. 2). This treatment system is only able to achieve preliminary and primary treatment levels of wastewater treatment, mainly due to the increased population and volumes of wastewater, as well as the increase in industrial and mining activity near the community. Yellowknife's treatment wetland system is decanted once a year during the end of the summer. Sampling was not conducted by the research team in Yellowknife during the sampling campaign of August 2019 as an on-going monitoring program is currently in place by The City of Yellowknife. Ten sampling events were provided by The City of Yellowknife for analysis in the current study.

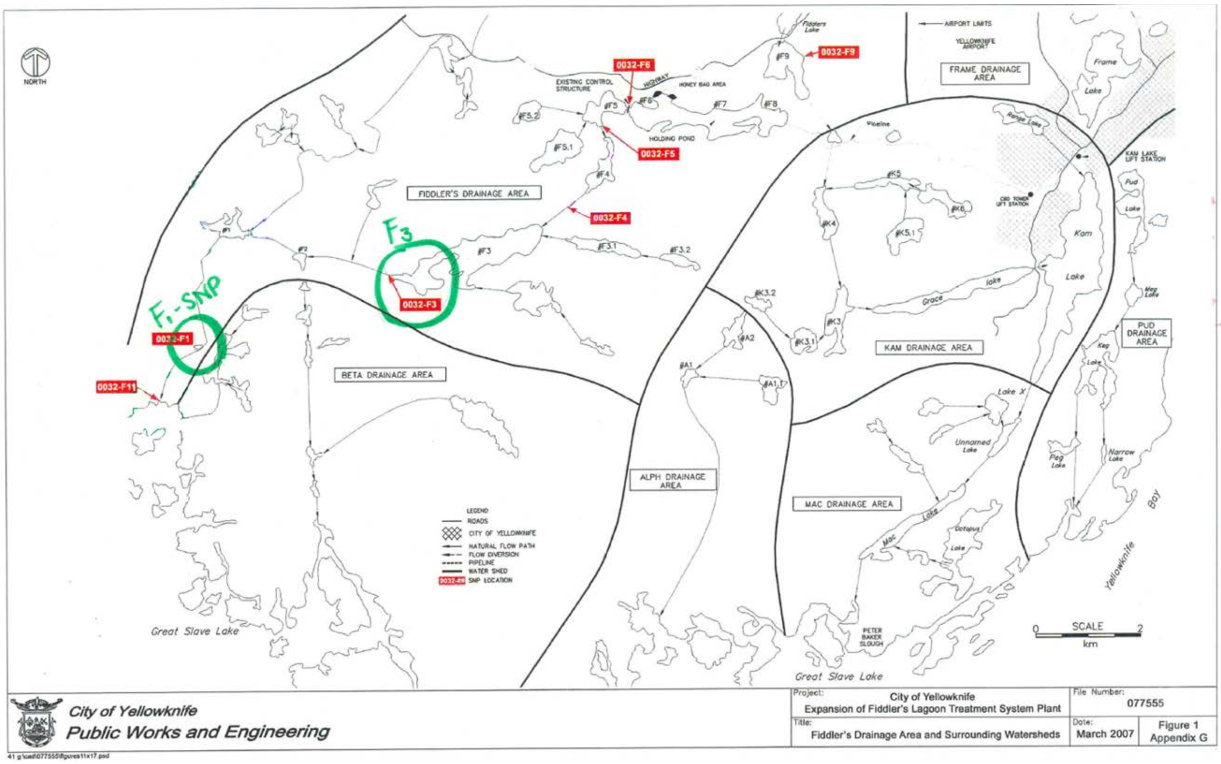

Figure 2 Watershed delineation of treatment lagoons and wetland in Yellowknife, NWT. F_1-SNP and F_3 indicate sampling sites and station identification. Retrieved from City of Yellowknife (2007).

3.1.2 Hay River

Hay River is the second-largest community in the NWT, also located in the South Slave region with a population of 3,824 citizens (NWT Bureau of Statistics, 2018). The community's current state of wastewater treatment includes multiple levels of treatment, where some instances of secondary level treatment are possible. Hay River's treatment wetland system is continuously loaded throughout the year. The configuration of multistage treatment includes the usage of engineered WSP systems that flows into a passive wetland, ultimately discharging into Great Slave Lake (Fig. 3).

Figure 3 Watershed delineation (yellow dotted line) of lagoons and treatment wetland in Hay River, NWT. Red points indicate sampling sites and station identification. Created by Lindsay Johnson, Dalhousie University, 2019.

3.1.3 Fort Providence

Fort Providence, in the Deh Cho region of the NWT, has a population of 719 citizens (NWT Bureau of Statistics, 2018). This community employs a similar treatment configuration to that of Hay River, in which some aspects of secondary treatment is achieved. The community's current state of wastewater treatment includes multiple engineered WSPs flowing into a passive wetland, ultimately discharging into the Mackenzie River, the longest river in Canada (Fig. 4). Fort Providence's treatment wetland system is decanted once a year during the end of the summer.

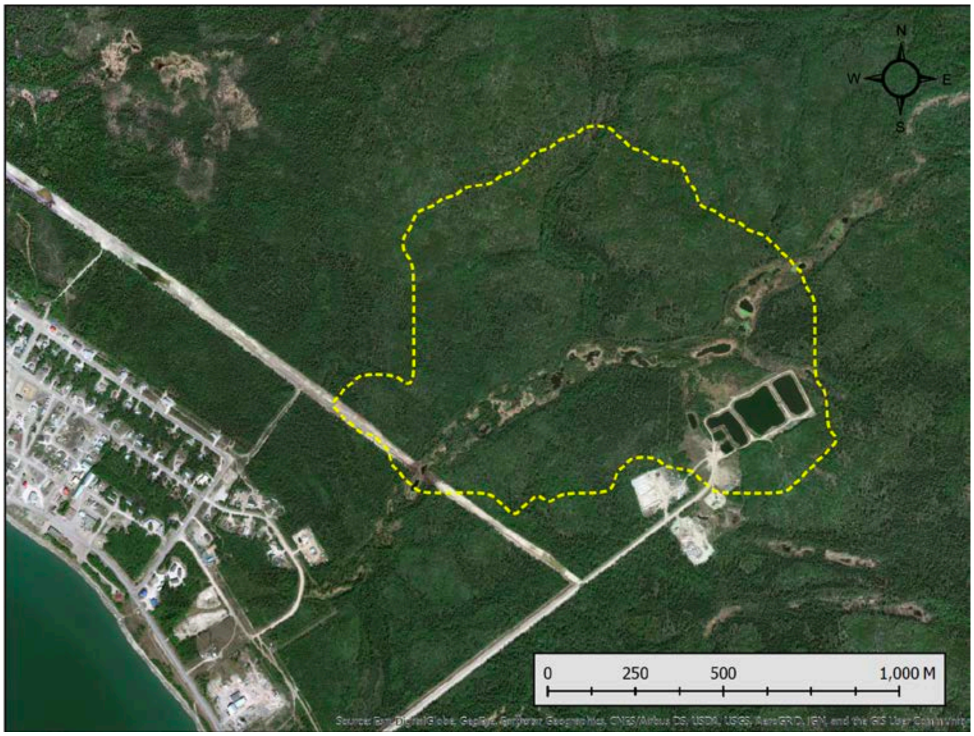

Figure 4 Watershed delineation (yellow dotted line) of lagoons and treatment wetland in Fort Providence, NWT. Created by Lindsay Johnson, Dalhousie University, 2019.

3.2 Sampling Design

The sampling scheme used in Hay River and Fort Providence consisted of sample collection throughout systematic locations in the treatment systems. The watersheds were first modelled and delineated using ESRI ArcGIS Geographic Information Systems (GIS) software to outline watershed study area boundaries. Each system was divided into functional locations of lagoon inlet and outlet, and wetland inlet and outlet. Sampling was conducted at each of these locations and at reference sites outside of the treatment area which contributed to the ambient environment type. Intermediate locations within the wetlands were also sampled (Fig. 5). Within each location, the specific sample site was selected based on accessibility.

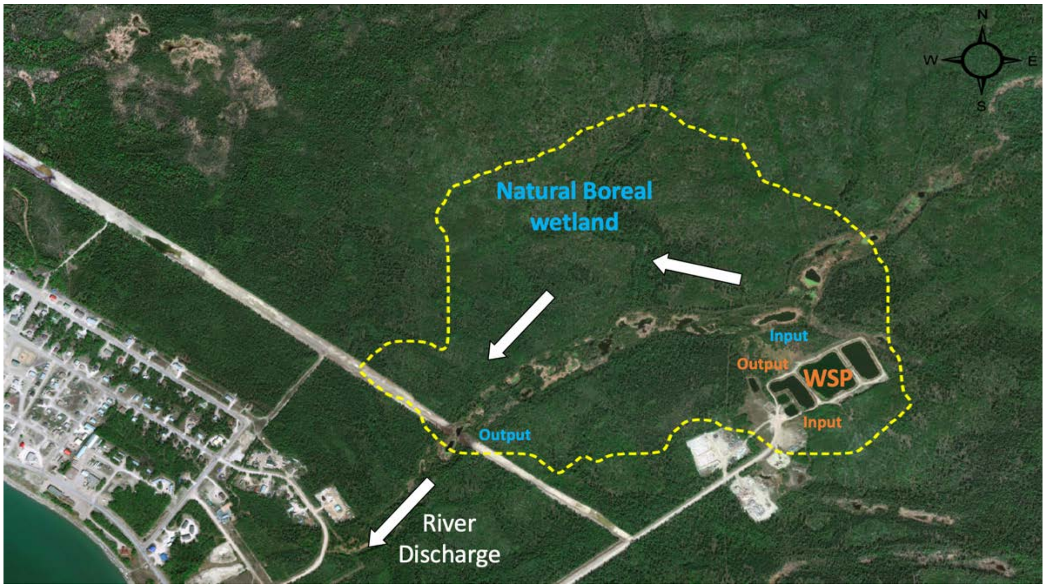

Figure 5 Sampling scheme diagram of a passive wastewater treatment system. Yellow dotted line indicates affected treatment wetland area. Wetlands were divided into locations of WSP inlet and outlet (indicated in orange), and wetland inlet and outlet (indicated in blue). In the specific case of this sampling scheme, the receiving environment was a river. Sampling was also conducted at reference sites outside of the treatment wetland and at intermediate locations within the wetlands. White arrows indicate the directional flow of the treatment system. Created by Lindsay Johnson and modified by Trisa Ngo, Dalhousie University, 2019.

3.3 Sample Description & Procedures

3.3.1 Field Sampling Procedures

The field sampling took place in Hay River and Fort Providence during August 2019. Water samples were collected at each treatment wetland location, reference wetland, and intermediate treatment wetland sites (Fig. 5) for testing of dissolved metals, total metals, cation and anions. Standard laboratory procedures outlined in CCME (2011) protocols for water sampling were followed for grab sampling of surface waters (Appendix A.i). Sampling containers of 50 mL and 500 mL were provided by the GNWT’s certified Canadian Association for Laboratory Accreditation (CALA) Taiga Environmental Laboratory. Additionally, filtration of water samples for dissolved metals, total metals, and cation/anions was conducted in the field using standard 0.45 µm cellulose acetate membrane filters (Appendix A.ii).

Overall, quality control and quality assurance (QAQC) and proper Chain of Custody procedures, including proper storage and transportation of samples, was practiced as outlined by CCME protocols (Appendix A.iii & Appendix A.iv). Due to the biologically hazardous nature of the samples and potential for contamination, sampling equipment and containers were sterilized using 70% ethyl-alcohol between each sampling site. CALA certified commercial laboratories analyzed samples in Yellowknife, NWT and Halifax, NS (Taiga Environmental Laboratory and AGAT Laboratories, respectively).

3.3.2 Data Mining

Extensive data mining of water quality data in the NWT was conducted to compare the ground-truth dataset with previously sampled datasets and CCME guidelines. Heavy metal water quality data were collected from land and water boards of the NWT. These boards include the Mackenzie Valley Land and Water Board, Sahtu Land and Water Board, Gwich'in Land and Water Boards, and Wek'èezhìi Renewable Resource Board. Federal, territorial, and municipal government environmental reporting resources were also consulted for environmental datasets and results. Background mined data will be included in the 'ambient' environment type. Some datasets contained censored data where the sample concentration values were below detection limits. In this case, standard practice suggests dividing the detection limit concentrations by two as the resultant value.

3.4 Sample Analysis

The research team identified eight heavy metals that would be analyzed based on the availability of open data: arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), and zinc (Zn). Ultimately, two overarching comparisons will be conducted in the data analysis phase, including:

1. Comparing wastewater system concentrations to background “ambient” concentrations; and
2. Comparing all sample data to CCME CEQGs for the protection of aquatic life.

A 2-Way ANOVA was conducted using Minitab statistical software (Minitab, LLC) to compare heavy metal concentrations between locations (Fort Providence, Hay River, and Yellowknife) and environment types (ambient, lagoon, and wetland). For clarity, the ambient environment type includes water samples that were mined and not located in the wastewater treatment system (Fig. 6). Reference points sampled in the field during August 2019 are also included in the ambient environment. A significance level of 5% for alpha ($\alpha = 0.05$) was established when testing for significance in the results. When comparing field sampling data to the CEQGs, each result was checked against guidelines within each environment type and location.

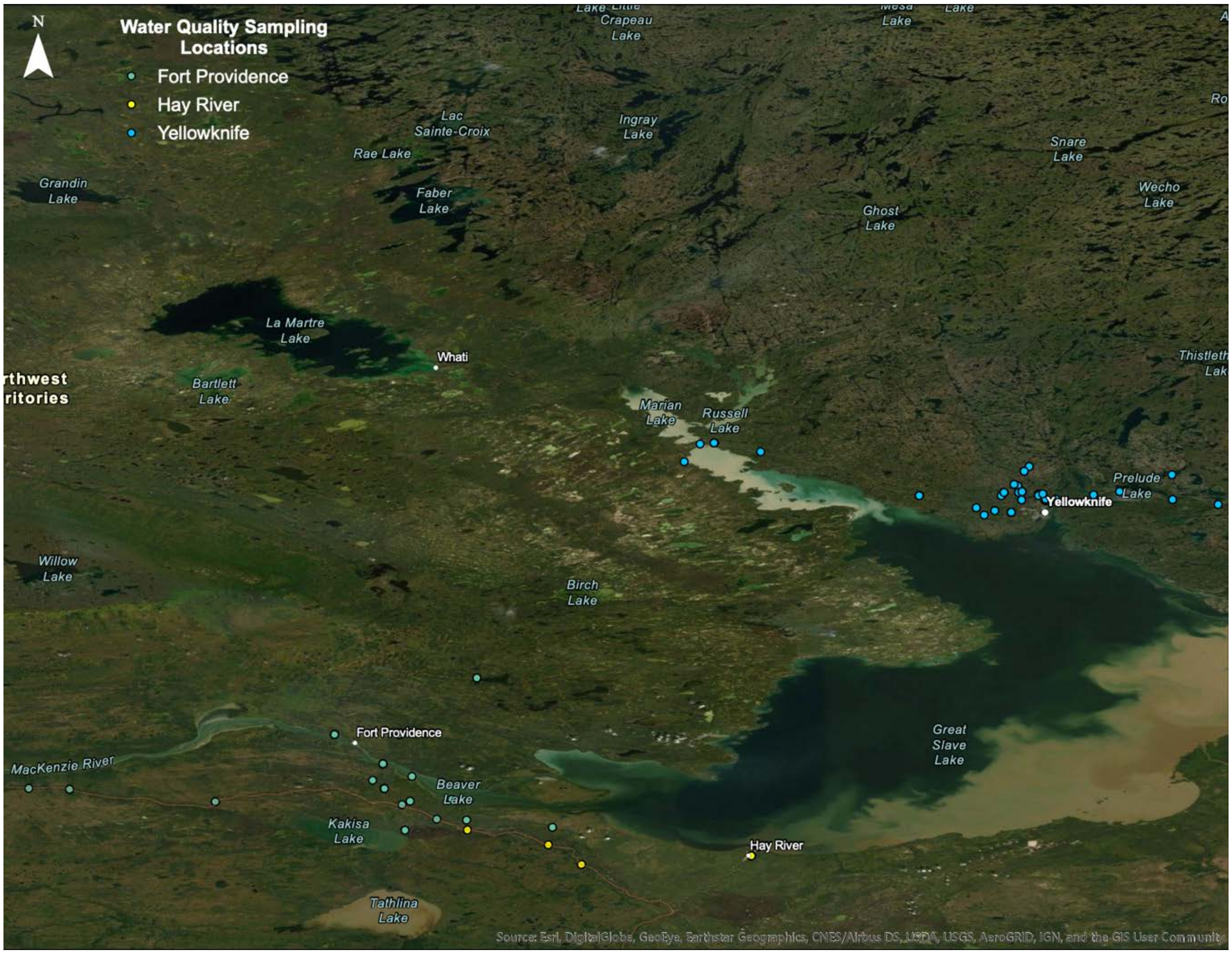

Figure 6 Point map of water quality sampling locations of ambient mined water quality data in the Northwest Territories. Water quality point samples are divided into applicable locations.

4 Results

Overall, six of eight heavy metal concentrations were found to be significantly different between locations. Cu and Zn concentrations were significantly different between environment types ($p<0.05$), while As showed no significant differences between location or environment type (Appendix B). The CEQGs for long-term exposure of inorganic compounds in the environment were identified to determine which samples exceeded federal guidelines (Table 1). Further detailed results of individual metals and comparisons to CCME’s CEQG are summarized in the following sections.

Table 1 Long-term exposure guidelines for inorganic parameters of Canadian Environmental Quality Guidelines (CEQGs) for the Protection of Aquatic Life. Data obtained from CCME (2007).

Inorganic Parameter	**CEQG for the Protection of Aquatic Life (µg/L)**
Arsenic	5
Cadmium	0.09*
Chromium total	9.9
Copper	2
Lead	1
Molybdenum	73
Nickel	25
Zinc	30

* Cadmium guideline is based on a hardness of 50 mg/L

4.1 Arsenic (total)

Total As in Yellowknife's lagoon and wetland environments had concentrations higher than all other environment types and locations, but these differences were not statistically significant ($p>0.05$) (Fig. 7). For visual purposes, the ambient Yellowknife samples of 159 µg/L and 218 µg/L were removed from the range of samples based on previous box plot analysis (Fig. 7). In the Yellowknife wastewater treatment system, 100% of samples from both lagoon and wetland environment types exceeded CCME guidelines (5 µg/L) for total arsenic in freshwater environments. The ambient samples exceeded CCME guidelines 5.17% of the time, whereas samples from Hay River and Fort Providence did not exceed the CCME guidelines for total arsenic (Fig. 8).

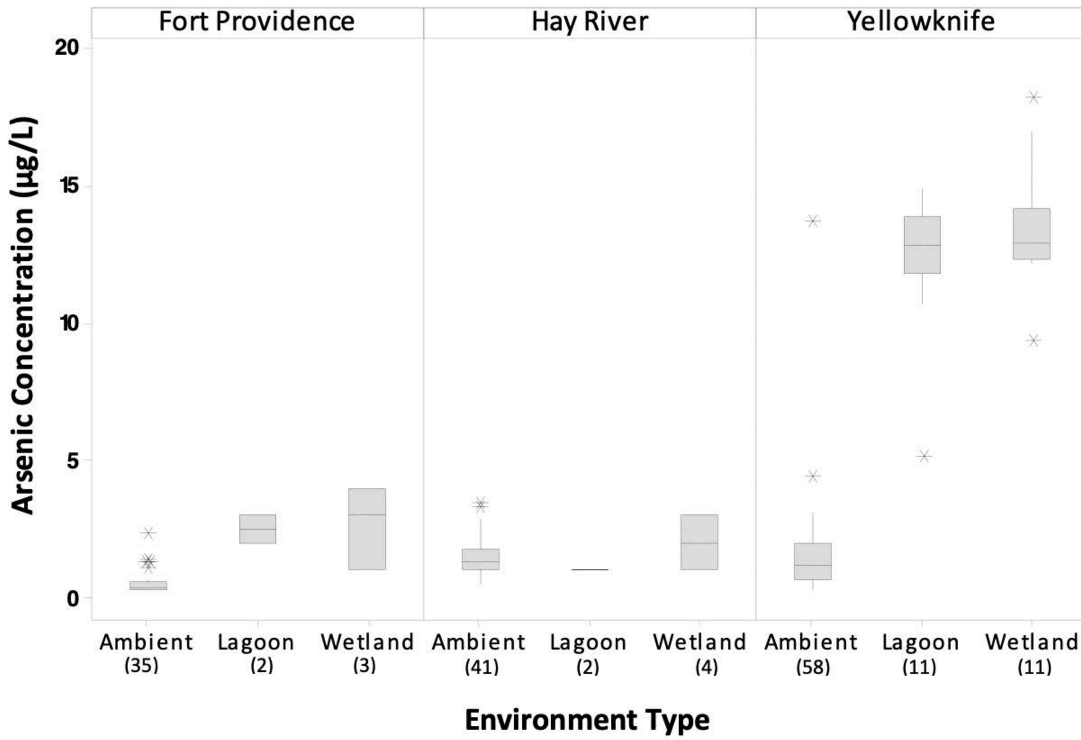

Figure 7 Interquartile range boxes demonstrating total arsenic concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers. Samples 159 µg/L and 218 µg/L from the Yellowknife Ambient environment type were removed from range for visual purposes based on previous box plot analysis.

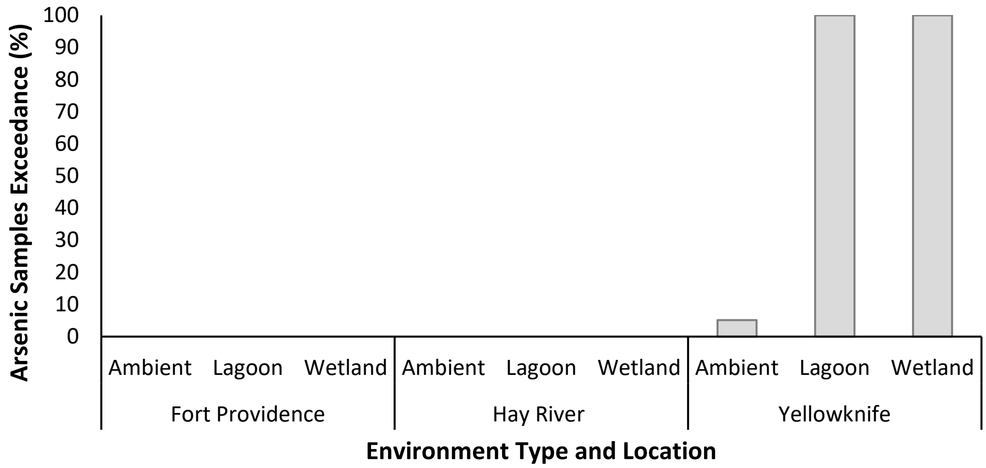

Figure 8 Total arsenic samples frequency (%) exceeding CCME guidelines (Canadian Environmental Quality Guidelines for the protection of aquatic life) of 5 µg/L by environment type (lagoon, wetland, and ambient) in three locations (Yellowknife, Hay River, and Fort Providence, NWT).

4.2 Cadmium (total)

Total Cd in Fort Providence's lagoon environment was elevated but not significantly different (P>0.05) compared to its ambient and wetland environment types. In Hay River and Yellowknife, ambient concentrations of Cd were higher but not significantly different (P>0.05) compared to lagoon and wetland samples (Fig. 9). Total Cd in Fort Providence was significantly higher than both Yellowknife and Hay River (p<0.05). All locations demonstrated ambient samples exceeding the CEQGs (Yellowknife = 5%, Hay River = 39%, and Fort Providence = 15%). Fort Providence's lagoon environment type reported 50% of samples exceeding the CEQG of 0.09 µg/L for total Cd (Fig. 10).

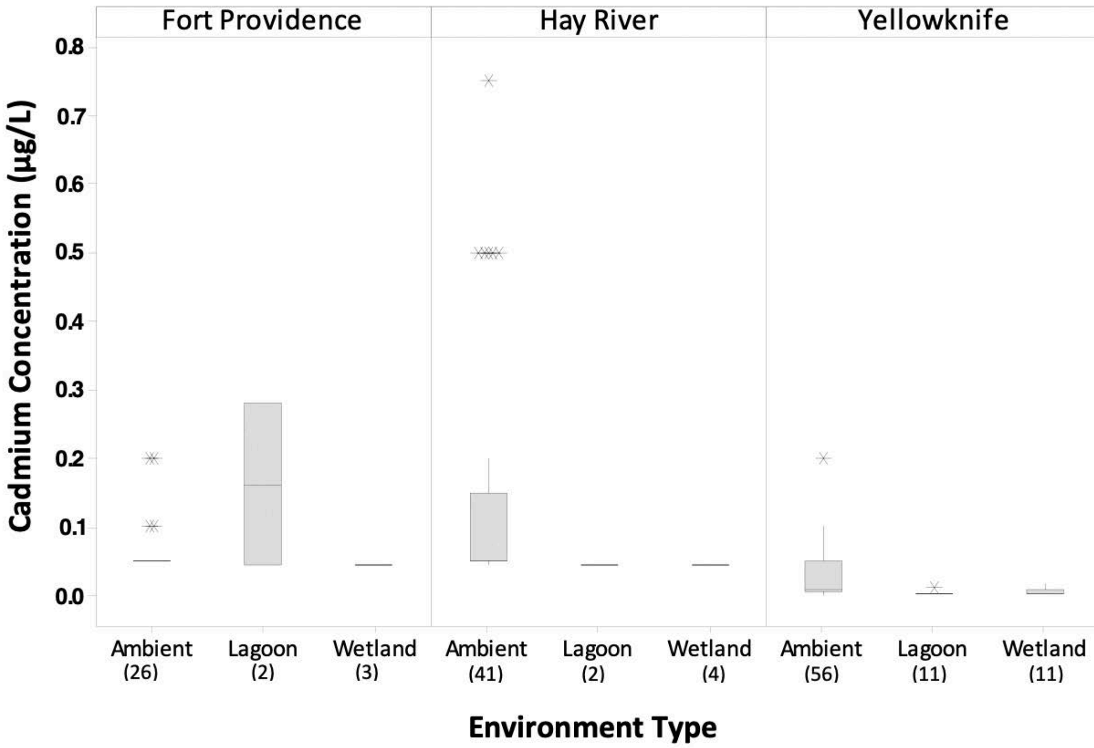

Figure 9 Interquartile range boxes demonstrating total cadmium concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

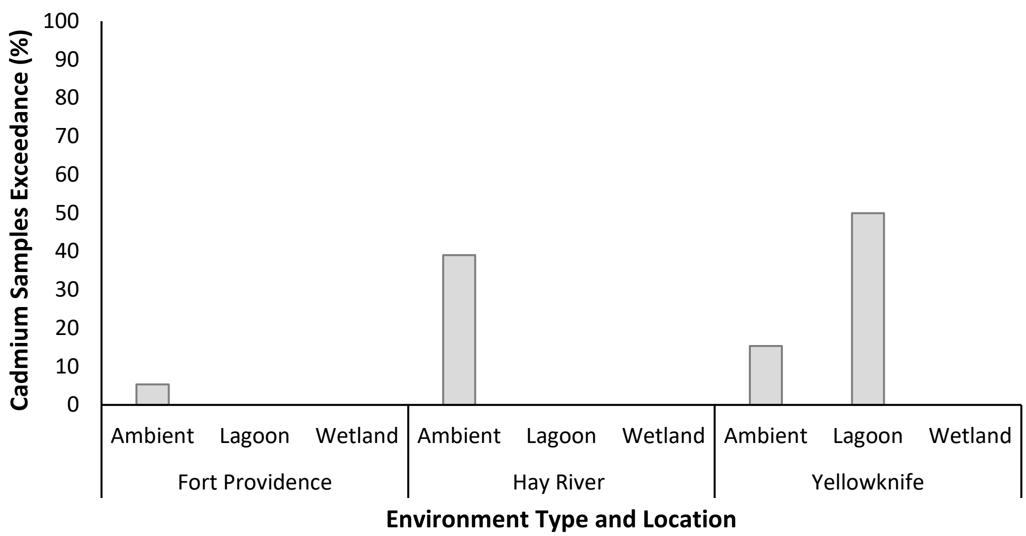

Figure 10 Percent total cadmium samples exceedance of CCME guidelines (Canadian Environmental Quality Guidelines for the protection of aquatic life) of 0.09 µg/L by environment type (lagoon, wetland, and ambient) in three locations (Yellowknife, Hay River, and Fort Providence, NWT).

4.3 Chromium (total)

Total Cr concentrations in Fort Providence and Hay River were elevated in lagoon and wetland environment types compared to ambient levels but did not show significant differences ($p>0.05$). In Yellowknife, Cr was higher in the ambient environment type and lowest in the lagoon wastewater system (Fig. 11). Significant differences were detected between Yellowknife and Fort providence ($p<0.05$). Total Cr exceeded the CEQGs of 9.9 μg/L in Yellowknife ambient samples 10% of the time. All other samples in varying locations and environments did not exceed the CEQG for total chromium.

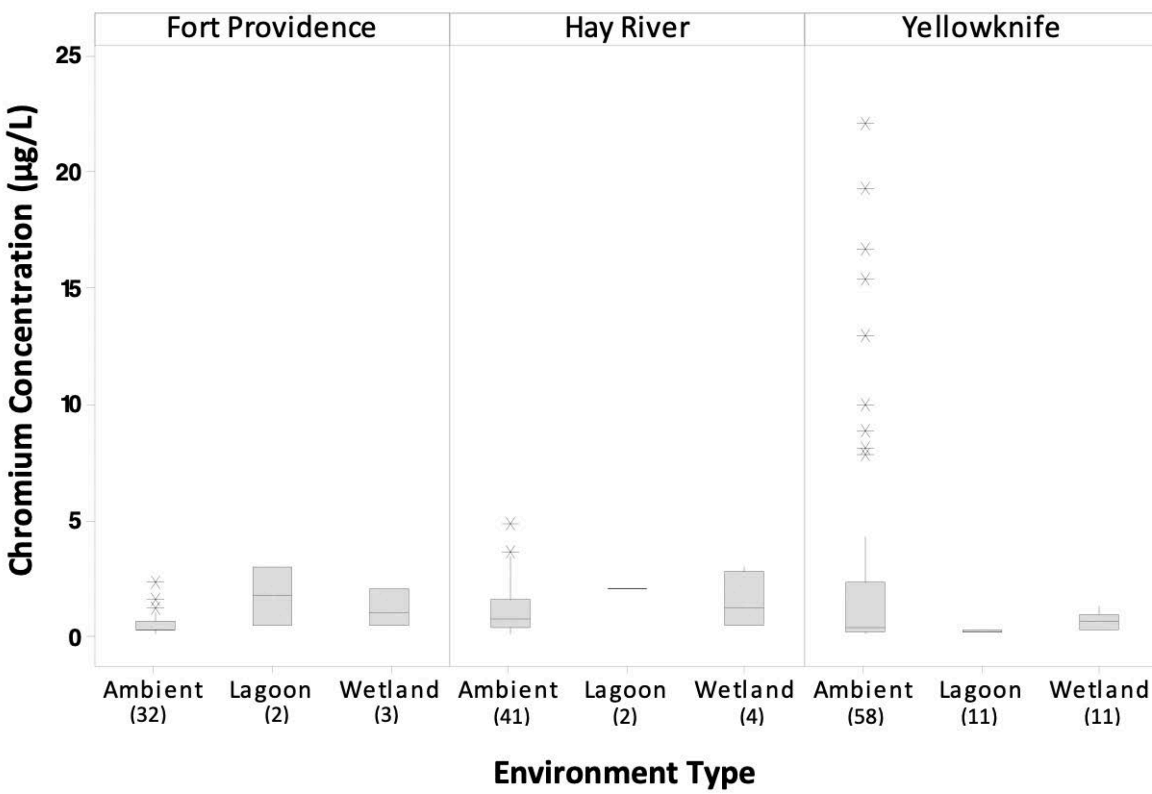

Figure 11 Interquartile range boxes demonstrating total chromium concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

4.4 Copper (total)

Total Cu in Fort Providence's lagoon environment was elevated and quite variable compared to its ambient and wetland environment (Fig. 12). Similarly, Hay River's lagoon concentration of Cu was highest followed by wetland and ambient environment types. Lagoon environment types demonstrated significantly higher concentrations compared to wetland and ambient environment types ($p<0.05$). Significant differences were detected between Hay River compared to Yellowknife ($p< 0.05$) where Cu concentration were higher in Hay River (Fig. 12). All environments in Hay River demonstrated samples exceeding the CEQG of 2 μg/L for total Cu (Fig. 13). Specifically, 100% of lagoon, 50% of wetland, and 78% of ambient samples exceeded CEQGs. In Yellowknife, 9% of lagoon and 33% of ambient samples exceeded federal guidelines. Fort Providence demonstrated 50% of lagoon and 8% of ambient samples exceeding the CEQGs for Cu (Fig. 13).

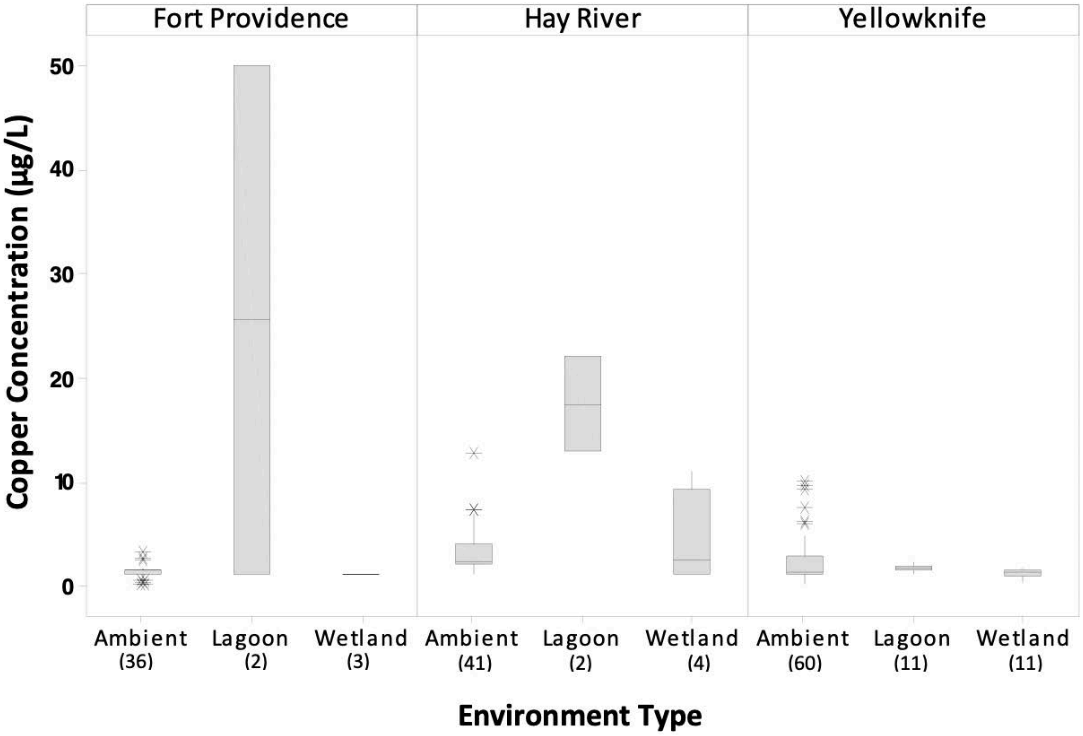

Figure 12 Interquartile range boxes demonstrating total copper concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

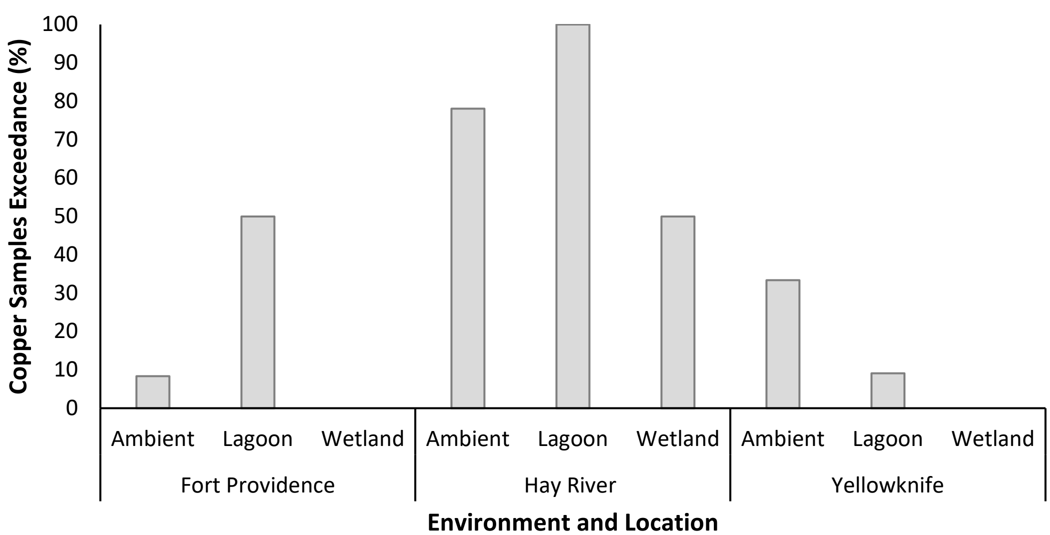

Figure 13 Percent total copper samples exceedance of CCME guidelines (Canadian Environmental Quality Guidelines for the protection of aquatic life) of 2 µg/L by environment type (lagoon, wetland, and ambient) in three locations (Yellowknife, Hay River, and Fort Providence, NWT).

4.5 Lead (total)

Total Pb in Yellowknife and Hay River demonstrated higher concentrations in the ambient environment compared to their lagoons and wetlands; however, no significant differences between environment types were detected ($p>0.05$). In Fort Providence, lagoon and wetland environment types contained greater Pb concentrations compared to ambient levels (Fig. 14). Significant differences between Hay River and Fort Providence were detected ($p<0.05$) as Pb concentrations were higher in Hay River (Fig. 14). Total Pb demonstrated samples exceeding the CEQG of 1 μg/L in 18% of Yellowknife ambient samples, 50% in Fort Providence lagoon samples, and 25% and 29% in Hay River's wetland and ambient samples respectively (Fig. 15).

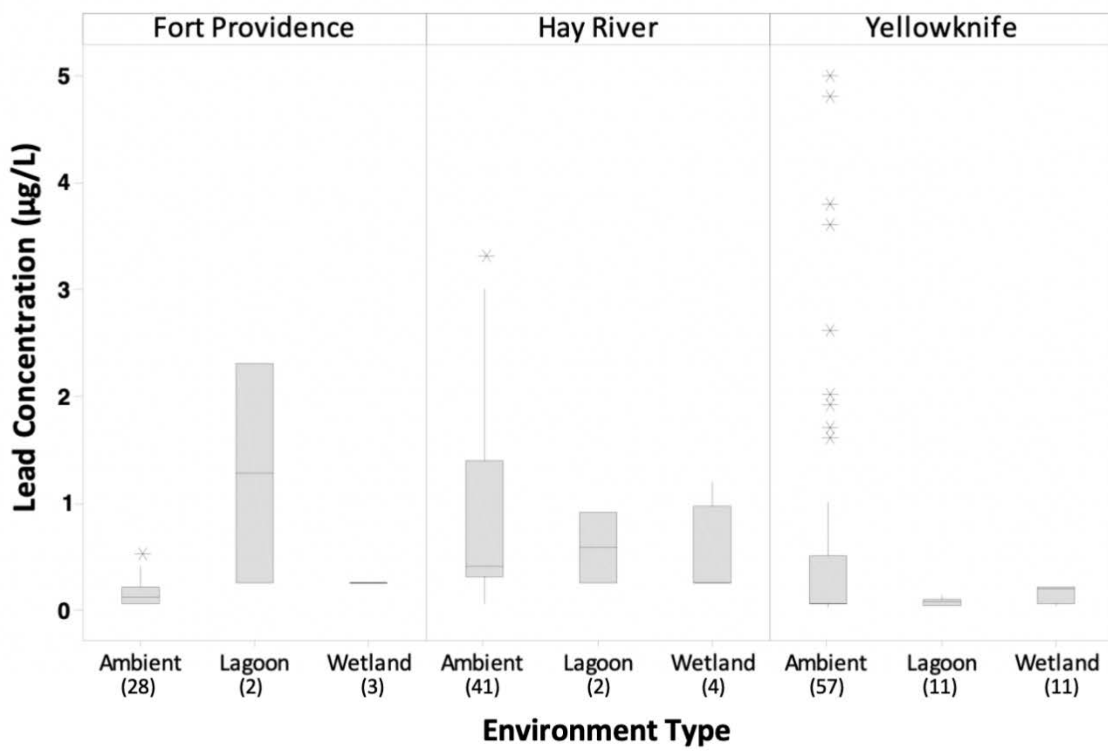

Figure 14 Interquartile range boxes demonstrating total lead concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

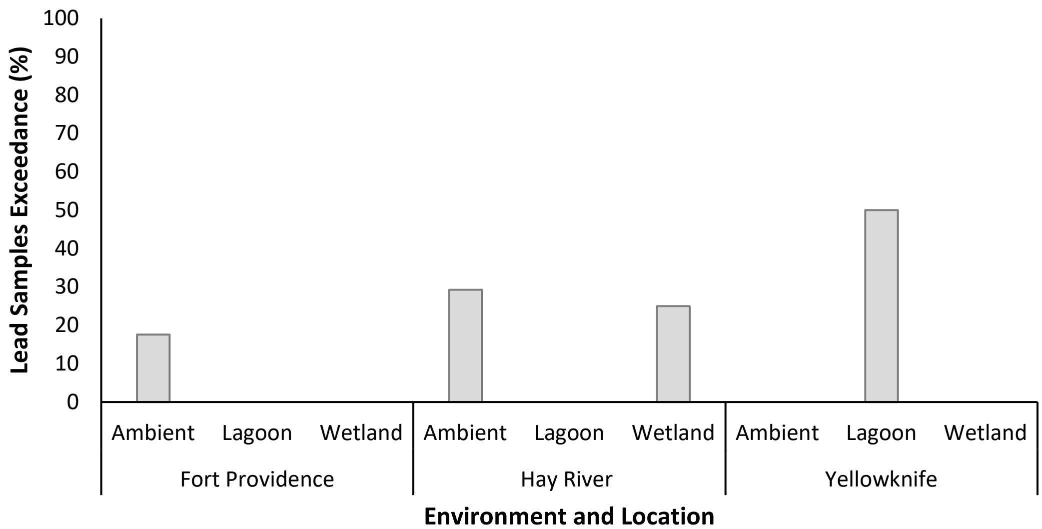

Figure 15 Percent total lead samples exceedance of CCME guidelines (Canadian Environmental Quality Guidelines for the protection of aquatic life) of 1 μg/L by environment type (lagoon, wetland, and ambient) in three locations (Yellowknife, Hay River, and Fort Providence, NWT).

4.6 Molybdenum (total)

Total Mo was higher in Fort Providence's lagoon environment compared to all other environments and locations which demonstrated relatively low concentration, but significant differences were not detected between environment types ($p>0.05$) (Fig.16). Significant differences between Yellowknife and Hay River locations were detected ($p< 0.05$) as Hay River's Mo concentrations were higher than Yellowknife's (Fig. 17). Overall, no Mo samples exceeded the CEQG of 73 μg/L.

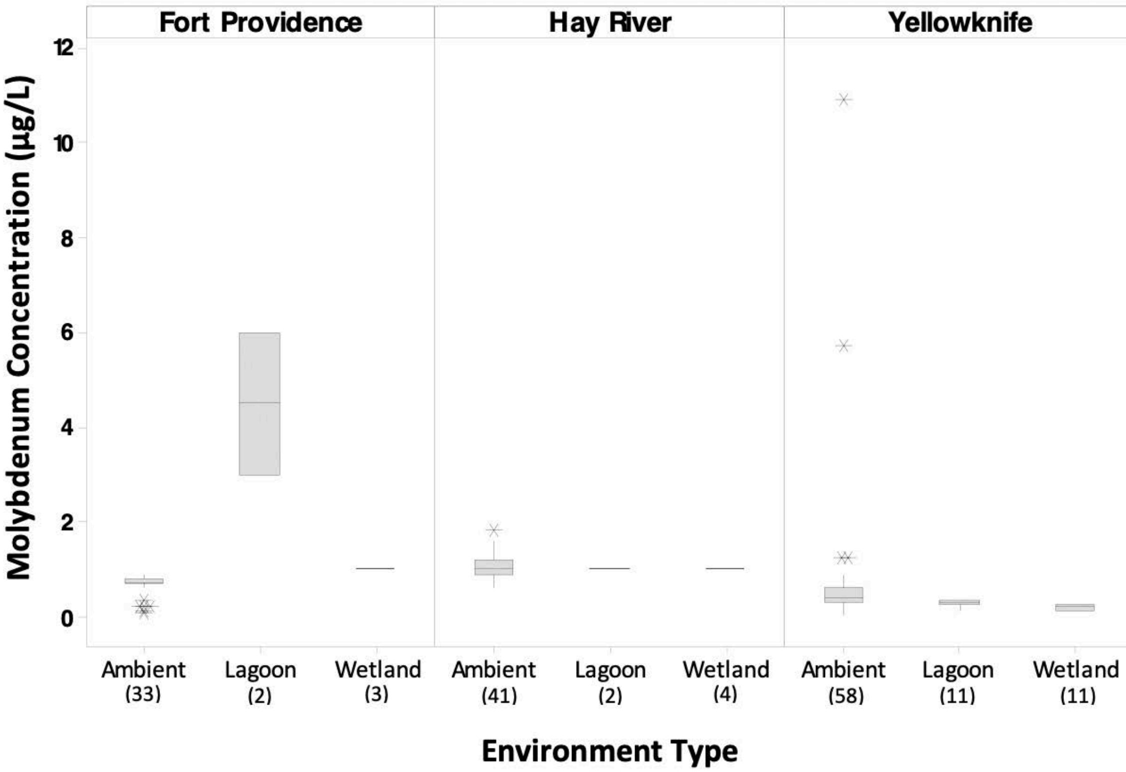

Figure 16 Interquartile range boxes demonstrating total molybdenum concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

4.7 Nickel (total)

Total Ni in Fort Providence and Hay River's lagoon and wetland environments were elevated compared to its ambient environment, but no significant differences between environment types were detected ($p>0.05$). In Yellowknife, ambient concentrations of Ni had a greater range and was higher in concentration compared to lagoon and wetland environments (Fig. 17). Significant differences between Yellowknife and Hay River and Hay River and Fort Providence were detected ($p<0.05$) as Fort Providence demonstrated higher Ni concentrations. Overall, no Ni samples exceeded the CEQG of 25 μg/L.

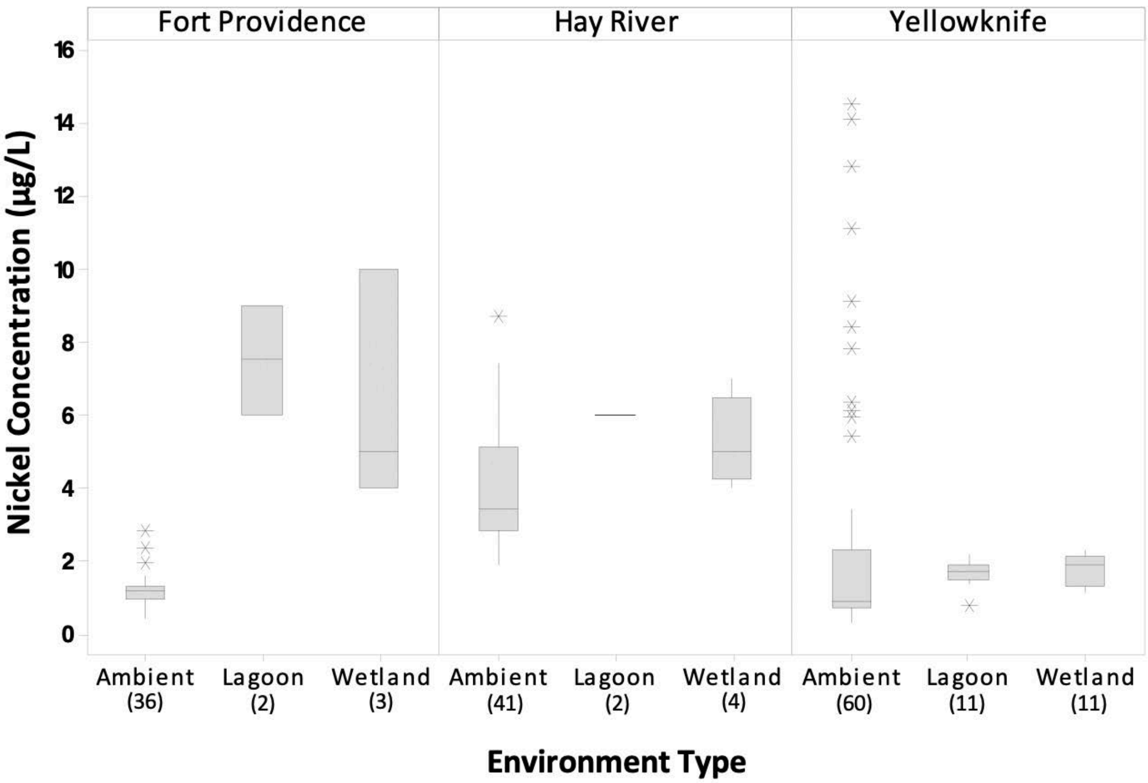

Figure 17 Interquartile range boxes demonstrating total nickel concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

4.8 Zinc (total)

The range and concentration of total Zn in Fort Providence's lagoon environment was elevated compared to its ambient and wetland environment. In Hay River, lagoon and wetland concentrations of Zn were generally greater than ambient levels (Fig. 18). Significant differences were detected between lagoon and ambient environment types ($p<0.05$). No significant differences were detected between locations ($p>0.05$). Fort Providence's lagoon environment reported 50% of samples exceeding the CEQG of 0.09 µg/L for total Zn while 12% of Hay River's ambient samples exceeded federal guidelines (Fig. 19).

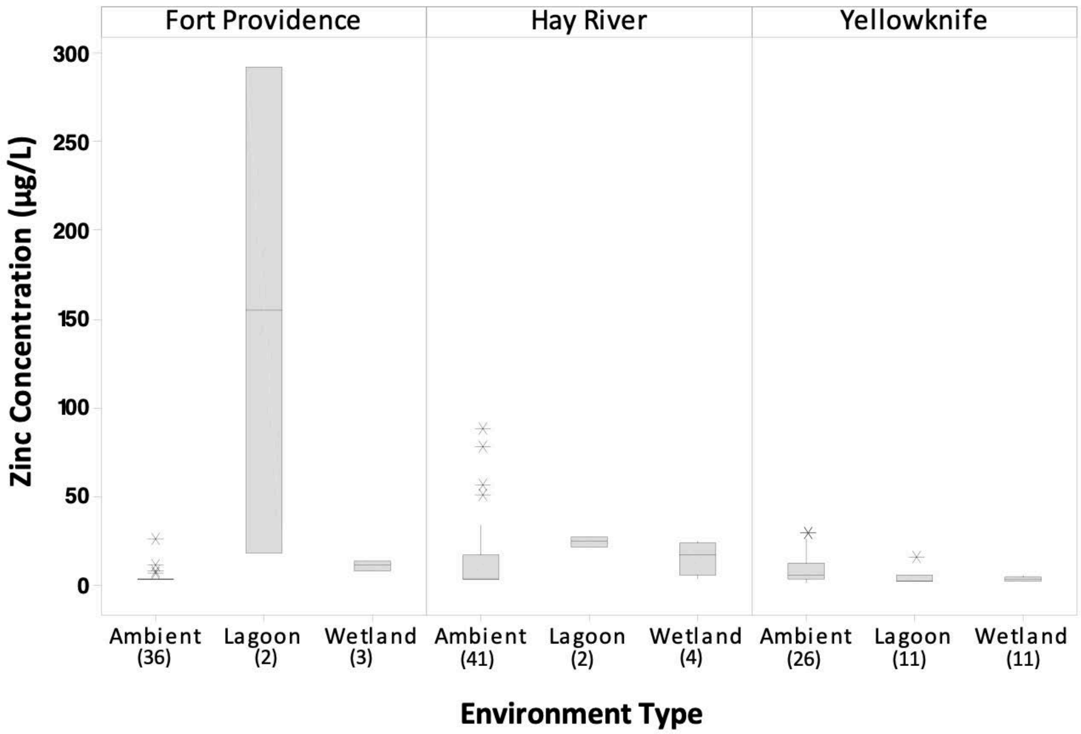

Figure 18 Interquartile range boxes demonstrating total zinc concentration in varying environment types (ambient, lagoon, and wetland) in Fort Providence, Hay River, and Yellowknife, NT. Whiskers indicate maximum and minimum ranges, black lines indicate sample median, and asterisks indicate outliers.

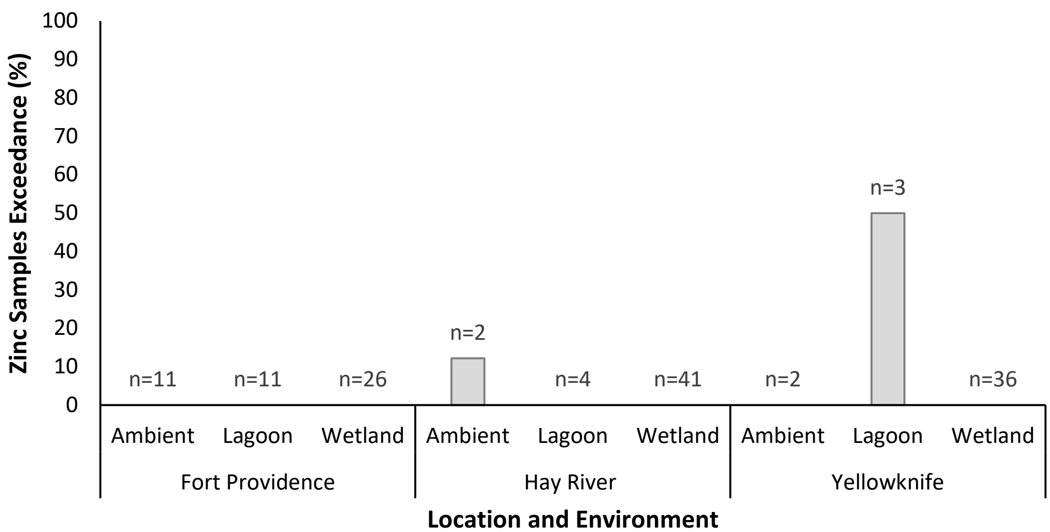

Figure 19 Percent total zinc samples exceedance of CCME guidelines (Canadian Environmental Quality Guidelines for the protection of aquatic life) of 0.09 µg/L by environment type (lagoon, wetland, and ambient) in three locations (Yellowknife, Hay River, and Fort Providence, NWT).

5 Discussion

The current study hypothesized that levels of heavy metals would exhibit significant differences between locations and environment types due to distinct underlying geology of locations and biogeochemical differences between environment types. The results determined locational significance between six of eight heavy metals (Appendix B). This could be explained by differences in baseline effects of the geochemistry and geology in the region. Yellowknife is located in the southwestern Slave geological province whereas Fort Providence and Hay River are located in the Western Interior Platform geological province (Galloway et al., 2015; NWT Geologic Survey, n.d.) (Fig. 20). Differences in geochemistry of surficial materials between these two geological provinces could potentially explain the differences between locations; however, further research is needed as no surveys currently exist related to geochemistry of bedrock or superficial materials in the Slave Geological Province or the Western Interior Platform (Galloway et al., 2015). When considering implementation of new regulations and standards in these regions, geographic distribution of communities should be considered a factor as significant differences exist between the studied communities and should be reflected in the new regulations and standards. Baseline monitoring data should also be used to help establish realistic effluent quality objectives for municipal wastewater treatment systems.

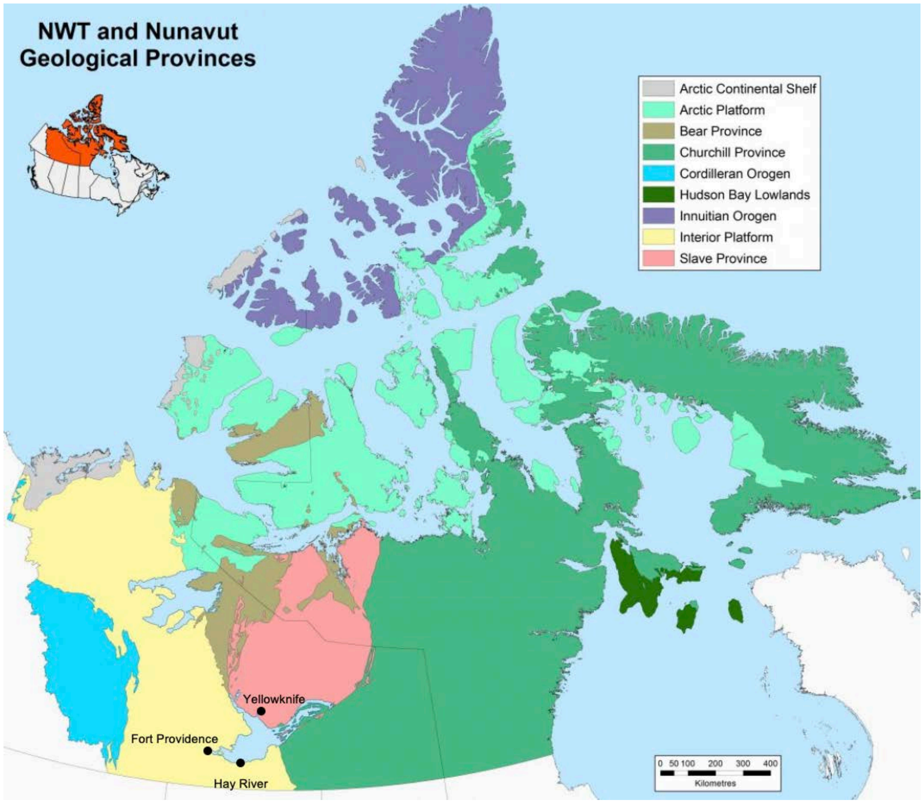

Figure 20 NWT and NU divided into 9 geologic provinces based on geologic ages, history, and mineral potential. Retrieved from NWT Geological Survey.

These results demonstrate that treatment mechanisms between lagoon and wetlands, and lagoon and ambient environments are significantly reducing contaminants between environment types of the wastewater treatment system. Two of eight heavy metals were significantly different between environment types (Appendix B). Cu was higher in lagoons compared to ambient environments as well as wetland and lagoon environment types, while Zn was higher in lagoon environment types compared to ambient environment types. The lack of significance between environment types for the remaining six metals could potentially signify wastewater systems as not significantly reducing heavy metal concentration for the remaining 6 metals (As, Cd, Cr, Pb, Mo, Ni) or that other confounding factors are affecting the results. If treatment wetlands are not significantly reducing heavy metal concentrations, these wetland systems may eventually become saturated with heavy metals and their performance may decrease. However, as demonstrated by comparisons to CEQGs, treatment wetlands were reducing lagoon concentrations of heavy metals below guidelines and appeared to be lower than ambient levels of heavy metals. This result suggests that wetlands were acting as sinks to heavy metals as ambient concentrations tended to exceed that of wetlands. Wetlands are demonstrating the ability to reduce heavy metal in surface water concentrations below ambient levels despite an influx of wastewater contaminants. Although concentrations between environments did not differ significantly, comparisons of samples exceeding federal guidelines determined that wetlands are acting as sinks to heavy metals by reducing lagoon concentration below ambient metal levels.

The present study hypothesized there would be higher concentrations of heavy metals found in passive wastewater systems compared to their ambient environment type due to the nature of the system affected by wastewater inputs. The results found trends of wetlands demonstrating lower overall concentrations of heavy metals in comparison to both lagoon and ambient environment types. This suggests that heavy metals in wastewater discharged from lagoons into wetlands are being reduced through treatment wetlands. Exact treatment mechanisms cannot be determined through this study; however, it is evident that heavy metal concentrations are being reduced within wetland systems as no wetland samples analyzed surpassed CEQGs (except arsenic samples in Yellowknife). Additionally, the levels of heavy metals being reduced in samples taken from wetlands were at times lower than environments unaffected by wastewater treatment. Specifically, heavy metal concentrations found in wetlands were generally lower than those in ambient environment types. This finding supports the finding that wetlands are acting as sinks to heavy metals. In nature, wetlands tend to prevent further wastewater pollution from land sources as they exist as the boundaries between land and open water bodies, otherwise known as ecotones (Matagi et al., 1998).

5.1 Geologic and Anthropogenic Sources of Heavy Metals

Heavy metals derived from municipal sewage and industrial waste ultimately end up in wastewaters, causing water and soil pollution. The build-up of heavy metals is dependent on local factors such as industry types and the degree of proper waste disposal (Chipasa, 2003). The Yellowknife area is situated on geology that might produce naturally elevated levels of some heavy metals. Allan (1979) found that regional-scale bedrock geochemistry influences the distribution of heavy metal concentration. For the NWT, it was determined that "gold, base metal deposits, mineralized greenstone belts and sedimentary bedrock, and uriniferous granites" are likely sources of heavy metal concentrations near Great Slave Lake (Allan, 1979, p.49). Specifically, the Archean greenstone belt contains mesothermal gold deposits rich with As, Cu, Pb, and Zn (Galloway et al., 2015). Overall, natural large-scale sources of heavy metals can influence heavy metal concentrations in a local area.

In the current study, Yellowknife demonstrated elevated concentrations of total arsenic in lagoon and wetland environment types. In fact, 100% of samples in both environment types exceeded the CEQG of 5 μg/L. High As values could be a result of As loading from anthropogenic activities including land-use changes in these rich geologic environments. Regions near Yellowknife demonstrated As and Zn concentrations in receiving environments of surrounding lakes as elevated. Anthropogenic factors such as prolonged mining activities might have also contributed to elevated levels of heavy metals to the ambient environment. For example, the gold mining operations of Giant Mine, Con Mine, Tahera and Salmita have been active since the late 1930s with As runoff contributing to major ecological contamination in this region (Galloway et al., 2015; Mudroch et al., 1989). In Galloway et al. (2015), concentrations of As from lake sediments closer to Yellowknife were elevated likely due to past land-use activities and from surface materials of the region's bedrock. Andrade et al. (2010) outlined three pathways in which gold mining activating could have increased the levels of As in the Yellowknife Bay of Great Slave Lake, including tailings discharged from a tributary to the bay, erosion of submerged tailings, and atmospheric dispersion of stack emissions. Overall, it is evident that the background geology in the NWT demonstrates environments of heavy metal-rich geology; however, with increased anthropogenic stressors, heavy metals are becoming bioavailable to the receiving aquatic environment.

5.2 Study Limitations and Recommendations for Future Research

Heavy metals do not necessarily behave the same as organic compounds, which have been studied more greatly (Hsu-Kim et al., 2018). Due to the toxic nature of heavy metals and potential intensification of long-term consequences, it is vital to study their effects. Heavy metals are persistent in aquatic environments and can mix and transport, causing increased ecological effects (Hsu-Kim et al., 2018). Heavy metal solubility, mobility, and speciation are dependent on factors such as pH, ORP, and DO (Chuan et al., 1996). Additionally, Chuan et al. (1996) stated that acidic and low oxidation conditions were most favourable for solubilizing heavy metals, while the effects of decreased pH were more significant than that of redox potential. Jakubus & Czekala (2001) investigated the residual matter (sewage sludge) from wastewater treatment and found differences in chemical composition between heavy metal in their stable state and sewage sludge samples. Overall, determining only the heavy metal concentration in a sample cannot help in identifying the bioavailability and mobility potential of heavy metals (Jakubus & Czekala, 2001; Kunito et al., 2001; Liu et al., 2007). Assessing heavy metal speciation allows for better estimates of bioavailability to the environment (Liu et al., 2007; Amir et al., 2005). Ultimately, heavy metals demonstrate various methods of transport, mixing, and exchange processes that can potentially increase environmental degradation or create additional human exposure pathways. The next steps in research should investigate the bioavailability of heavy metals that were at high concentrations above federal guidelines and how mobility and transport mechanisms may influence bioavailability.

Overall, the main limitation of the sampling methodology was the inaccessibility to particular sites within the passive treatment system, limiting the study spatially. Additionally, with only a single sampling event in Hay River and Fort Providence during the summer of 2019, the temporal scope of these locations is limited to a single sampling season. As a result, Hay River and Fort Providence lagoon and wetland environment types had a sample size of two to three samples. More samples need to be taken within these environments with consistent annual sampling events and for better representation of the surrounding water quality. In terms of the data mining phase, a limitation includes a reduced amount of open data available to researchers. For example, many open-source water quality datasets in the NWT are narrow in spatial scope and limited to community accessible areas. Therefore, representation of the ambient environment can be incomplete; however, a potential mitigation for this includes making direct contact with government and land and resource boards to gain access to their non-open-source databases.

Limitations related to the study can be mitigated for the next phase of sampling and reporting in the grand scheme of the heavy metal cumulative effects monitoring program. Ultimately, this first sampling event was exploratory and will inform next year’s sampling scheme. Likewise, the limitations occurring this year will facilitate mitigation measures in the future. For these reasons, treatment mechanisms related to heavy metals as sinks in wetlands should be studied in a northern framework. Other areas of research the current study could not access were biological factors such as northern vegetation as a proxy for metal uptake and climate/temporal effects of heavy metals in northern environments. Water quality transport mechanisms should also be investigated in future study in order to understand heavy metal mobility in treatment wetland systems. These new areas of research should be considered in future studies related to passive wastewater treatment in northern regions.

6 Conclusion

This study produced novel results related to wastewater management in the NWT where unique environmental and socio-economic conditions warrant the use of passive wastewater treatment systems. It was determined that heavy metal concentrations vary amongst geographic locations due to geologic, and anthropogenic stressors. Additionally, the current study demonstrated that wetlands act as sinks for heavy metals as lagoon and ambient samples generally contained higher concentrations of heavy metals compared to treatment wetlands. This research can act as a steppingstone to advise the creation of new regulations and standards in northern passive wastewater treatment system. It is recommended that regulations and standards are set with the knowledge that differences between locations/communities do exist and can be impacted by naturally occurring levels of heavy metals. Further research related to treatment mechanisms of heavy metals in treatment wetlands should be studied to further understand the fate of these metals and the long-term performance of these systems.

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Appendix A: CCME – Protocols Manual for Water Quality Sampling in Canada

Protocols manual for water quality sampling in Canada is from CCME (2011). Please follow the attached link for the protocol manual. Relevant sections and page numbers are outlined below.

https://www.ccme.ca/files/Resources/water/water_quality/protocols_document_e_final_101.pdf

i. Protocol for Surface Water Grab Samples (Section 1.3)

ii. Protocol for Field Filtration (Section 5.0)

iii. QAQC Standard Procedures (Section 1.3)

iv. COC Standard Procedures (Section 4.1)

Appendix B: Summary of 2-Way ANOVA Results

Summary of 2-Way ANOVA results demonstrating p-value significance by location (FP=Fort Providence, HR=Hay River, and YK=Yellowknife) and environment type (ambient, lagoon, and wetland) factors for metals. Subsequent significant Tukey pairwise comparisons of location and environment factors are displayed. All significant p-values are bolded.

Metal (total)	**2-Way ANOVA: Location (p-value)**	**2-Way ANOVA: Environment (p-value)**	**Tukey Test: Location (p-value)**	**Tukey Test: Environment (p-value)**
Arsenic	0.066	0.694	NA	NA
Cadmium	**0.000**	0.275	HR – FP: **0.022**; YK – HR: **0.000**	NA
Chromium	**0.026**	0.165	YK – FP: **0.030**	NA
Copper	**0.018**	**0.000**	YK – HR: **0.013**	Lagoon – Ambient: **0.000**; Wetland – Lagoon: **0.001**
Lead	**0.021**	0.235	HR – FP: **0.016**	NA
Molybdenum	**0.042**	0.415	YK – HR: **0.040**	NA
Nickel	**0.000**	0.332	HR – FP: **0.000**; YK – HR: **0.000**	NA
Zinc	0.079	**0.014**	NA	Lagoon – Ambient: **0.010**

Appendix C: Total Metals Data

i. Arsenic (total)

Location	Environment	Arsenic Concentration (µg/L)
Yellowknife	Ambient	218
Yellowknife	Ambient	159
Yellowknife	Wetland	18.2
Yellowknife	Wetland	17
Yellowknife	Lagoon	14.9
Yellowknife	Lagoon	14.7
Yellowknife	Wetland	14.2
Yellowknife	Wetland	14.1
Yellowknife	Wetland	14
Yellowknife	Lagoon	13.9
Yellowknife	Lagoon	13.9
Yellowknife	Ambient	13.7
Yellowknife	Lagoon	13.5
Yellowknife	Wetland	12.9
Yellowknife	Lagoon	12.8
Yellowknife	Wetland	12.8
Yellowknife	Wetland	12.8
Yellowknife	Lagoon	12.6
Yellowknife	Wetland	12.3
Yellowknife	Wetland	12.2
Yellowknife	Lagoon	12.1
Yellowknife	Lagoon	11.8
Yellowknife	Lagoon	10.7
Yellowknife	Wetland	9.33
Yellowknife	Lagoon	5.14
Yellowknife	Ambient	4.4
Yellowknife	Ambient	3.1
Yellowknife	Ambient	2.6
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.4
Yellowknife	Ambient	2.3
Yellowknife	Ambient	2.3
Yellowknife	Ambient	2.2
Yellowknife	Ambient	2.1
Yellowknife	Ambient	2.1
Yellowknife	Ambient	2.1
Yellowknife	Ambient	2
Yellowknife	Ambient	2
Yellowknife	Ambient	1.9
Yellowknife	Ambient	1.9
Yellowknife	Ambient	1.9
Yellowknife	Ambient	1.8
Yellowknife	Ambient	1.8
Yellowknife	Ambient	1.7
Yellowknife	Ambient	1.7
Yellowknife	Ambient	1.5
Yellowknife	Ambient	1.4
Yellowknife	Ambient	1.4
Yellowknife	Ambient	1.3
Yellowknife	Ambient	1.3
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4

Location	Environment	Arsenic Concentration (µg/L)
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Hay River	Ambient	3.4
Hay River	Ambient	3.3
Hay River	Wetland	3
Hay River	Wetland	3
Hay River	Ambient	2.9
Hay River	Ambient	2.6
Hay River	Ambient	2.4
Hay River	Ambient	2.2
Hay River	Ambient	2.2
Hay River	Ambient	2.1
Hay River	Ambient	2
Hay River	Ambient	1.8
Hay River	Ambient	1.8
Hay River	Ambient	1.7
Hay River	Ambient	1.7
Hay River	Ambient	1.6
Hay River	Ambient	1.6
Hay River	Ambient	1.5
Hay River	Ambient	1.5
Hay River	Ambient	1.5
Hay River	Ambient	1.4
Hay River	Ambient	1.3
Hay River	Ambient	1.3
Hay River	Ambient	1.3
Hay River	Ambient	1.3
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Lagoon	1
Hay River	Lagoon	1
Hay River	Wetland	1
Hay River	Wetland	1
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Hay River	Ambient	0.7
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Fort Providence	Wetland	4
Fort Providence	Lagoon	3
Fort Providence	Wetland	3
Fort Providence	Ambient	2.3
Fort Providence	Lagoon	2
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.1
Fort Providence	Wetland	1
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.5
Fort Providence	Ambient	0.5
Fort Providence	Ambient	0.5

Location	Environment	Arsenic Concentration (µg/L)
Fort Providence	Ambient	0.5
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3

ii. Cadmium (total)

Location	Environment	Cadmium Concentration (µg/L)
Hay River	Ambient	0.75
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Fort Providence	Lagoon	0.28
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Hay River	Ambient	0.2
Hay River	Ambient	0.2
Hay River	Ambient	0.2
Hay River	Ambient	0.2
Yellowknife	Ambient	0.2
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Hay River	Ambient	0.1
Hay River	Ambient	0.1
Hay River	Ambient	0.1
Hay River	Ambient	0.1
Hay River	Ambient	0.1
Hay River	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.062
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05

Location	Environment	Cadmium Concentration (µg/L)
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Fort Providence	Lagoon	0.045
Fort Providence	Wetland	0.045
Fort Providence	Wetland	0.045
Fort Providence	Wetland	0.045
Hay River	Ambient	0.045
Hay River	Ambient	0.045
Hay River	Lagoon	0.045
Hay River	Lagoon	0.045
Hay River	Wetland	0.045
Hay River	Wetland	0.045
Hay River	Wetland	0.045
Hay River	Wetland	0.045
Yellowknife	Ambient	0.031
Yellowknife	Wetland	0.0164
Yellowknife	Wetland	0.013
Yellowknife	Lagoon	0.01
Yellowknife	Wetland	0.0092
Yellowknife	Ambient	0.009
Yellowknife	Wetland	0.0089
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.008
Yellowknife	Ambient	0.007
Yellowknife	Ambient	0.007
Yellowknife	Ambient	0.007
Yellowknife	Wetland	0.0068
Yellowknife	Ambient	0.006
Yellowknife	Ambient	0.005
Yellowknife	Ambient	0.005
Yellowknife	Ambient	0.005
Yellowknife	Ambient	0.005
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.004
Yellowknife	Ambient	0.003
Yellowknife	Ambient	0.003
Yellowknife	Ambient	0.003
Yellowknife	Ambient	0.003
Yellowknife	Ambient	0.003
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Lagoon	0.0025
Yellowknife	Wetland	0.0025
Yellowknife	Wetland	0.0025
Yellowknife	Wetland	0.0025

Location	Environment	Cadmium Concentration (µg/L)
Yellowknife	Wetland	0.0025
Yellowknife	Wetland	0.0025
Yellowknife	Ambient	0.002
Yellowknife	Ambient	0.002
Yellowknife	Ambient	0.002
Yellowknife	Ambient	0.0005
Yellowknife	Ambient	0.0005
Yellowknife	Ambient	0.0005
Yellowknife	Ambient	0.0005

iii. Chromium (total)

Location	Environment	Chromium Concentration (µg/L)
Yellowknife	Ambient	22
Yellowknife	Ambient	19.2
Yellowknife	Ambient	16.6
Yellowknife	Ambient	15.3
Yellowknife	Ambient	12.9
Yellowknife	Ambient	9.9
Yellowknife	Ambient	8.8
Yellowknife	Ambient	8.1
Yellowknife	Ambient	7.8
Hay River	Ambient	4.8
Yellowknife	Ambient	4.3
Yellowknife	Ambient	3.9
Hay River	Ambient	3.6
Yellowknife	Ambient	3.6
Yellowknife	Ambient	3.6
Hay River	Ambient	3.4
Hay River	Ambient	3.2
Hay River	Wetland	3
Fort Providence	Lagoon	3
Yellowknife	Ambient	2.8
Hay River	Ambient	2.5
Hay River	Ambient	2.4
Hay River	Ambient	2.3
Fort Providence	Ambient	2.3
Hay River	Ambient	2.2
Yellowknife	Ambient	2.2
Yellowknife	Ambient	2.1
Hay River	Lagoon	2
Hay River	Lagoon	2
Hay River	Wetland	2
Fort Providence	Wetland	2
Yellowknife	Ambient	1.8
Hay River	Ambient	1.7
Yellowknife	Ambient	1.7
Hay River	Ambient	1.6
Hay River	Ambient	1.6
Hay River	Ambient	1.5
Fort Providence	Ambient	1.5
Yellowknife	Wetland	1.28
Hay River	Ambient	1.2
Fort Providence	Ambient	1.2
Hay River	Ambient	1.1
Fort Providence	Ambient	1
Fort Providence	Wetland	1
Yellowknife	Wetland	0.94
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Fort Providence	Ambient	0.9
Yellowknife	Wetland	0.89
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Yellowknife	Wetland	0.77
Yellowknife	Wetland	0.76
Hay River	Ambient	0.7
Hay River	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Yellowknife	Wetland	0.69
Yellowknife	Wetland	0.62
Hay River	Ambient	0.6
Hay River	Ambient	0.6
Hay River	Ambient	0.6
Fort Providence	Ambient	0.6
Fort Providence	Ambient	0.6
Yellowknife	Ambient	0.6
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Fort Providence	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5

Location	Environment	Chromium Concentration (µg/L)
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Hay River	Ambient	0.5
Hay River	Ambient	0.5
Hay River	Wetland	0.5
Hay River	Wetland	0.5
Fort Providence	Lagoon	0.5
Fort Providence	Wetland	0.5
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Wetland	0.37
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Lagoon	0.27
Yellowknife	Lagoon	0.26
Yellowknife	Lagoon	0.26
Yellowknife	Wetland	0.26
Yellowknife	Lagoon	0.25
Yellowknife	Wetland	0.22
Yellowknife	Lagoon	0.21
Yellowknife	Lagoon	0.21
Hay River	Ambient	0.2
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Lagoon	0.19
Yellowknife	Lagoon	0.19
Yellowknife	Lagoon	0.17

Location	Environment	Chromium Concentration (µg/L)
Yellowknife	Lagoon	0.17
Yellowknife	Lagoon	0.16
Hay River	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Hay River	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Yellowknife	Ambient	0.05

iv. Copper (total)

Location	Environment	Copper Concentration (µg/L)
Fort Providence	Lagoon	50
Hay River	Lagoon	22
Hay River	Lagoon	13
Hay River	Ambient	12.6
Hay River	Wetland	11
Yellowknife	Ambient	9.9
Yellowknife	Ambient	9.5
Yellowknife	Ambient	9.1
Yellowknife	Ambient	7.4
Hay River	Ambient	7.3
Hay River	Ambient	7.2
Hay River	Ambient	7
Yellowknife	Ambient	6
Hay River	Ambient	5.8
Yellowknife	Ambient	5.8
Hay River	Ambient	4.9
Hay River	Ambient	4.8
Yellowknife	Ambient	4.8
Yellowknife	Ambient	4.7
Yellowknife	Ambient	4.6
Hay River	Ambient	4.4
Yellowknife	Ambient	4.4
Hay River	Ambient	4.3
Hay River	Ambient	4.3
Yellowknife	Ambient	4.2
Hay River	Wetland	4
Hay River	Ambient	3.7
Hay River	Ambient	3.2
Fort Providence	Ambient	3.1
Hay River	Ambient	3
Yellowknife	Ambient	3
Yellowknife	Ambient	3
Hay River	Ambient	2.9
Yellowknife	Ambient	2.9
Hay River	Ambient	2.8
Yellowknife	Ambient	2.8
Hay River	Ambient	2.7
Hay River	Ambient	2.7
Yellowknife	Ambient	2.7
Fort Providence	Ambient	2.6
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.4
Hay River	Ambient	2.3
Hay River	Ambient	2.3
Fort Providence	Ambient	2.3
Yellowknife	Lagoon	2.22
Hay River	Ambient	2.2
Hay River	Ambient	2.2
Hay River	Ambient	2.2
Hay River	Ambient	2.1
Hay River	Ambient	2.1
Hay River	Ambient	2.1
Hay River	Ambient	2.1
Yellowknife	Ambient	2.1
Yellowknife	Ambient	2.1
Hay River	Ambient	2
Hay River	Ambient	2
Hay River	Ambient	2
Hay River	Ambient	2
Hay River	Ambient	1.9
Hay River	Ambient	1.9
Yellowknife	Ambient	1.9
Yellowknife	Lagoon	1.88
Yellowknife	Lagoon	1.86
Hay River	Ambient	1.8
Hay River	Ambient	1.8
Yellowknife	Ambient	1.8
Yellowknife	Lagoon	1.79
Yellowknife	Lagoon	1.75
Yellowknife	Lagoon	1.72
Yellowknife	Lagoon	1.71
Hay River	Ambient	1.7
Fort Providence	Ambient	1.7
Fort Providence	Ambient	1.7
Yellowknife	Ambient	1.7

Location	Environment	Copper Concentration (µg/L)
Fort Providence	Ambient	1.6
Fort Providence	Ambient	1.6
Yellowknife	Ambient	1.6
Yellowknife	Lagoon	1.54
Yellowknife	Wetland	1.52
Hay River	Ambient	1.5
Fort Providence	Ambient	1.5
Fort Providence	Ambient	1.5
Fort Providence	Ambient	1.5
Fort Providence	Ambient	1.5
Fort Providence	Ambient	1.5
Yellowknife	Wetland	1.5
Yellowknife	Lagoon	1.44
Yellowknife	Wetland	1.44
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Yellowknife	Wetland	1.4
Yellowknife	Wetland	1.35
Yellowknife	Wetland	1.35
Yellowknife	Lagoon	1.31
Hay River	Ambient	1.3
Fort Providence	Ambient	1.3
Yellowknife	Ambient	1.3
Yellowknife	Ambient	1.3
Yellowknife	Ambient	1.3
Yellowknife	Ambient	1.3
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Lagoon	1.15
Fort Providence	Ambient	1.1
Fort Providence	Ambient	1.1
Fort Providence	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Fort Providence	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Hay River	Ambient	1
Hay River	Ambient	1
Fort Providence	Lagoon	1

Location	Environment	Copper Concentration (µg/L)
Hay River	Wetland	1
Fort Providence	Wetland	1
Fort Providence	Wetland	1
Fort Providence	Wetland	1
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Wetland	0.87
Yellowknife	Ambient	0.8
Yellowknife	Wetland	0.8
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.6
Yellowknife	Wetland	0.57
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Yellowknife	Ambient	0.3
Yellowknife	Wetland	0.25
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Yellowknife	Ambient	0.1

v. Lead (total)

Location	Environment	Lead Concentration (µg/L)
Yellowknife	Ambient	5
Yellowknife	Ambient	4.8
Yellowknife	Ambient	3.8
Yellowknife	Ambient	3.6
Yellowknife	Ambient	2.6
Yellowknife	Ambient	2
Yellowknife	Ambient	1.9
Yellowknife	Ambient	1.7
Yellowknife	Ambient	1.6
Yellowknife	Ambient	1
Hay River	Ambient	3.3
Hay River	Ambient	3
Hay River	Ambient	2.9
Hay River	Ambient	2.3
Hay River	Ambient	1.9
Hay River	Ambient	1.8
Hay River	Ambient	1.7
Hay River	Ambient	1.7
Hay River	Ambient	1.5
Hay River	Ambient	1.4
Hay River	Ambient	1.4
Hay River	Ambient	1.3
Hay River	Wetland	1.2
Fort Providence	Lagoon	2.3
Hay River	Lagoon	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.7
Hay River	Ambient	0.6
Hay River	Ambient	0.6
Hay River	Ambient	0.6
Yellowknife	Ambient	0.6
Fort Providence	Ambient	0.5
Hay River	Ambient	0.5
Fort Providence	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Hay River	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Fort Providence	Ambient	0.3
Fort Providence	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Hay River	Ambient	0.3
Fort Providence	Wetland	0.25
Fort Providence	Wetland	0.25
Fort Providence	Wetland	0.25
Fort Providence	Lagoon	0.25
Hay River	Ambient	0.25
Hay River	Ambient	0.25
Hay River	Wetland	0.25
Hay River	Wetland	0.25
Hay River	Wetland	0.25
Hay River	Lagoon	0.25
Yellowknife	Wetland	0.227
Yellowknife	Wetland	0.22
Yellowknife	Wetland	0.213
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2

Location	Environment	Lead Concentration (µg/L)
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Hay River	Ambient	0.2
Hay River	Ambient	0.2
Hay River	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Wetland	0.19
Yellowknife	Wetland	0.189
Yellowknife	Wetland	0.184
Yellowknife	Wetland	0.173
Yellowknife	Lagoon	0.122
Yellowknife	Lagoon	0.116
Yellowknife	Ambient	0.11
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Fort Providence	Ambient	0.1
Yellowknife	Lagoon	0.093
Yellowknife	Lagoon	0.072
Yellowknife	Wetland	0.07
Yellowknife	Lagoon	0.062
Yellowknife	Lagoon	0.062
Yellowknife	Lagoon	0.06
Yellowknife	Wetland	0.055
Yellowknife	Lagoon	0.055
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Fort Providence	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Hay River	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.03
Yellowknife	Ambient	0.03
Yellowknife	Ambient	0.03

Location	Environment	Lead Concentration (µg/L)
Yellowknife	Ambient	0.03
Yellowknife	Wetland	0.025
Yellowknife	Wetland	0.025
Yellowknife	Lagoon	0.025
Yellowknife	Lagoon	0.025
Yellowknife	Lagoon	0.025
Yellowknife	Ambient	0.02
Yellowknife	Ambient	0.01
Yellowknife	Ambient	0.01
Yellowknife	Ambient	0.01
Yellowknife	Ambient	0.01
Yellowknife	Ambient	0.01

vi. Molybdenum (total)

Location	Environment	Molybdenum Concentration (µg/L)
Yellowknife	Ambient	10.9
Fort Providence	Lagoon	6
Yellowknife	Ambient	5.7
Fort Providence	Lagoon	3
Hay River	Ambient	1.8
Hay River	Ambient	1.6
Hay River	Ambient	1.4
Hay River	Ambient	1.4
Hay River	Ambient	1.4
Hay River	Ambient	1.4
Hay River	Ambient	1.3
Hay River	Ambient	1.3
Hay River	Ambient	1.3
Hay River	Ambient	1.2
Hay River	Ambient	1.2
Yellowknife	Ambient	1.2
Yellowknife	Ambient	1.2
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1.1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Lagoon	1
Hay River	Lagoon	1
Hay River	Ambient	1
Hay River	Ambient	1
Hay River	Wetland	1
Hay River	Wetland	1
Hay River	Wetland	1
Hay River	Wetland	1
Fort Providence	Wetland	1
Fort Providence	Wetland	1
Fort Providence	Wetland	1
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Hay River	Ambient	0.9
Fort Providence	Ambient	0.9
Yellowknife	Ambient	0.9
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Hay River	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8
Fort Providence	Ambient	0.8

Location	Environment	Molybdenum Concentration (µg/L)
Fort Providence	Ambient	0.8
Hay River	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Fort Providence	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Hay River	Ambient	0.6
Fort Providence	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.5
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Lagoon	0.36
Yellowknife	Lagoon	0.333
Yellowknife	Lagoon	0.331
Yellowknife	Lagoon	0.308
Fort Providence	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Ambient	0.3
Yellowknife	Lagoon	0.298
Yellowknife	Lagoon	0.289
Yellowknife	Lagoon	0.27
Yellowknife	Wetland	0.252
Yellowknife	Lagoon	0.249
Yellowknife	Wetland	0.237
Yellowknife	Lagoon	0.234
Yellowknife	Wetland	0.231
Yellowknife	Lagoon	0.224
Yellowknife	Wetland	0.212
Yellowknife	Wetland	0.211
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Fort Providence	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2

Location	Environment	Molybdenum Concentration (µg/L)
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Ambient	0.2
Yellowknife	Wetland	0.189
Yellowknife	Wetland	0.184
Yellowknife	Wetland	0.15
Yellowknife	Wetland	0.124
Yellowknife	Wetland	0.113
Yellowknife	Lagoon	0.102
Fort Providence	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Ambient	0.1
Yellowknife	Wetland	0.097
Fort Providence	Ambient	0.05
Yellowknife	Ambient	0.05
Yellowknife	Ambient	0.03

vii. Nickel (total)

Location	Environment	Nickel Concentration (µg/L)
Yellowknife	Ambient	14.5
Yellowknife	Ambient	14.1
Yellowknife	Ambient	12.8
Yellowknife	Ambient	11.1
Fort Providence	Wetland	10
Yellowknife	Ambient	9.1
Fort Providence	Lagoon	9
Hay River	Ambient	8.7
Yellowknife	Ambient	8.4
Yellowknife	Ambient	7.8
Hay River	Ambient	7.4
Hay River	Ambient	7
Hay River	Wetland	7
Hay River	Ambient	6.9
Hay River	Ambient	6.8
Yellowknife	Ambient	6.3
Hay River	Ambient	6.2
Hay River	Ambient	6.1
Yellowknife	Ambient	6.1
Hay River	Ambient	6
Hay River	Lagoon	6
Hay River	Lagoon	6
Fort Providence	Lagoon	6
Yellowknife	Ambient	5.9
Hay River	Ambient	5.6
Hay River	Ambient	5.4
Yellowknife	Ambient	5.4
Hay River	Wetland	5
Hay River	Wetland	5
Fort Providence	Wetland	5
Hay River	Ambient	4.8
Hay River	Ambient	4.5
Hay River	Ambient	4.3
Hay River	Wetland	4
Fort Providence	Wetland	4
Hay River	Ambient	3.7
Hay River	Ambient	3.7
Hay River	Ambient	3.6
Hay River	Ambient	3.6
Hay River	Ambient	3.5
Hay River	Ambient	3.5
Hay River	Ambient	3.5
Hay River	Ambient	3.4
Yellowknife	Ambient	3.4
Hay River	Ambient	3.2
Hay River	Ambient	3.1
Hay River	Ambient	3
Hay River	Ambient	3
Hay River	Ambient	3
Hay River	Ambient	3
Hay River	Ambient	2.9
Hay River	Ambient	2.9
Yellowknife	Ambient	2.9
Yellowknife	Ambient	2.9
Hay River	Ambient	2.8
Hay River	Ambient	2.8
Hay River	Ambient	2.8
Fort Providence	Ambient	2.8
Hay River	Ambient	2.6
Hay River	Ambient	2.6
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.4
Yellowknife	Wetland	2.32
Hay River	Ambient	2.3
Fort Providence	Ambient	2.3
Yellowknife	Ambient	2.3
Yellowknife	Wetland	2.23
Hay River	Ambient	2.2
Yellowknife	Ambient	2.2
Yellowknife	Lagoon	2.16
Yellowknife	Wetland	2.13
Yellowknife	Wetland	2.12
Hay River	Ambient	2
Yellowknife	Wetland	2
Hay River	Ambient	1.9

Location	Environment	Nickel Concentration (µg/L)
Yellowknife	Wetland	1.9
Yellowknife	Lagoon	1.88
Yellowknife	Lagoon	1.86
Yellowknife	Lagoon	1.83
Yellowknife	Ambient	1.8
Yellowknife	Ambient	1.8
Yellowknife	Lagoon	1.77
Yellowknife	Ambient	1.7
Yellowknife	Lagoon	1.7
Yellowknife	Lagoon	1.67
Fort Providence	Ambient	1.6
Yellowknife	Wetland	1.59
Yellowknife	Lagoon	1.53
Yellowknife	Ambient	1.5
Yellowknife	Lagoon	1.5
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Fort Providence	Ambient	1.4
Yellowknife	Lagoon	1.33
Yellowknife	Wetland	1.31
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Fort Providence	Ambient	1.3
Yellowknife	Ambient	1.3
Yellowknife	Wetland	1.29
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Fort Providence	Ambient	1.2
Yellowknife	Wetland	1.17
Yellowknife	Wetland	1.14
Yellowknife	Ambient	1.1
Yellowknife	Ambient	1.1
Fort Providence	Ambient	1
Fort Providence	Ambient	1
Fort Providence	Ambient	1
Fort Providence	Ambient	1
Fort Providence	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Yellowknife	Ambient	1
Fort Providence	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Yellowknife	Ambient	0.9
Fort Providence	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.8

Location	Environment	Nickel Concentration (µg/L)
Yellowknife	Lagoon	0.73
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Yellowknife	Ambient	0.7
Fort Providence	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Yellowknife	Ambient	0.6
Fort Providence	Ambient	0.5
Fort Providence	Ambient	0.5
Yellowknife	Ambient	0.5
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Fort Providence	Ambient	0.4
Yellowknife	Ambient	0.4
Yellowknife	Ambient	0.3

viii. Zinc (total)

Location	Environment	Zinc Concentration (µg/L)
Fort Providence	Lagoon	292
Hay River	Ambient	87
Hay River	Ambient	77.5
Hay River	Ambient	55.7
Hay River	Ambient	49.8
Hay River	Ambient	34
Yellowknife	Ambient	29
Yellowknife	Ambient	28.8
Hay River	Ambient	27.3
Hay River	Lagoon	27
Yellowknife	Ambient	25.3
Hay River	Wetland	25
Fort Providence	Ambient	24.6
Hay River	Ambient	22.1
Yellowknife	Ambient	22
Hay River	Lagoon	21
Hay River	Ambient	20
Yellowknife	Ambient	19.8
Hay River	Wetland	18
Fort Providence	Lagoon	18
Hay River	Ambient	17.8
Hay River	Ambient	17.3
Hay River	Ambient	16.7
Hay River	Ambient	16.3
Yellowknife	Lagoon	15.1
Hay River	Ambient	15.1
Hay River	Ambient	15
Hay River	Ambient	14.2
Hay River	Wetland	14
Hay River	Ambient	13.2
Fort Providence	Wetland	13
Yellowknife	Ambient	12.2
Yellowknife	Ambient	11.5
Hay River	Ambient	11.4
Yellowknife	Ambient	11.4
Fort Providence	Wetland	11
Yellowknife	Ambient	10.3
Fort Providence	Ambient	10.2
Yellowknife	Ambient	7.5
Hay River	Ambient	7
Fort Providence	Wetland	7
Hay River	Ambient	6.9
Fort Providence	Ambient	6.9
Yellowknife	Ambient	6.2
Fort Providence	Ambient	6
Yellowknife	Lagoon	6
Hay River	Ambient	5.8
Yellowknife	Wetland	5.6
Yellowknife	Ambient	5.3
Yellowknife	Ambient	5.3
Yellowknife	Lagoon	5.1
Yellowknife	Ambient	5
Yellowknife	Wetland	5
Yellowknife	Lagoon	5
Yellowknife	Ambient	3.9
Yellowknife	Wetland	3.9
Yellowknife	Wetland	3.7
Yellowknife	Wetland	3.4
Yellowknife	Wetland	3.3
Yellowknife	Wetland	3.1
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5

Location	Environment	Zinc Concentration (µg/L)
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Hay River	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Fort Providence	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Yellowknife	Ambient	2.5
Hay River	Wetland	2.5
Yellowknife	Wetland	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Wetland	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Wetland	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Wetland	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Lagoon	1.5
Yellowknife	Ambient	1.1
Yellowknife	Ambient	0.8
Yellowknife	Ambient	0.5