State of the Knowledge of the Slave River and Slave River Delta

A Component of the Vulnerability Assessment of the Slave River and Delta

Final Report: April 2016

Prepared for the Slave River and Delta Partnership

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With input and updates by:

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Executive summary

The Slave River and Slave River Delta are unique ecosystems and important to the livelihood and culture of the Aboriginal people in the area. This report consolidates a large number of reports and articles referring to the Slave River and Delta to assess the state of the knowledge and identify areas for future research. This report is intended to be a living document, and periodically updated as more research and monitoring, from multiple knowledge perspectives, takes place[1]. Overall, we found a large volume of information on hydrology and sediment load, water quality, metals and contaminants in water, sediments and fish, and muskrats, though some of this information is dated. There was a moderate volume of information about fish community, moose, beaver and vegetation, though some of this information is dated and there are some knowledge gaps. There is little information available on benthic invertebrates and insects, mink, otter and aquatic birds, and air quality, and there are a number of knowledge gaps in understanding of function and dynamics of these ecosystem components.

Acknowledgements

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[1] Pembina Institute is the main author of this report and compiled the majority of the content. The report was provided to the SRDP in March of 2012. The SRDP highlighted the need for additional information sources related to local and traditional knowledge to be included before the report was finalized. ENR-GNWT included additional information sources and content, including on local and traditional knowledge, post-devolution updates to relevant legislation and regulatory bodies, as well as some updated water quality, sediment, air and climate and fish health information after March 2012.

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1. Introduction

1.1 Background

The Slave River and Slave River Delta make up a unique ecosystem that straddles the Alberta–Northwest Territories (NWT) border and drains into Great Slave Lake, NWT. The Slave River is part of the Great Slave sub-basin of the Mackenzie River (see Figure 1 below). The Slave River drains the Peace and Athabasca Rivers as well as a number of tributaries, a vast basin of over 600,000 km^2.

The Slave River and Slave River Delta areas are highly productive and biologically diverse. The area is known to be important for migratory birds, spawning fish and aquatic furbearing animals. The Slave River flows between two distinct geographic regions: the erosion-resistant Precambrian Shield on the eastern side covered with sparse taiga forest and numerous lakes, and the sedimentary Interior Plains on the western side covered with more dense boreal forest (Mackenzie River Basin Board, 2003). The Slave River also flows through Wood Buffalo National Park, which was established in 1922 to protect the world's last remaining known wood bison (Carbyn et al., 1993).

Water, fish and wildlife are integral in the culture, society and economy of the Aboriginal people of the area. Currently, there are three communities located along the Slave River and Slave River Delta: Fitzgerald is located along the river in Alberta, Fort Smith is located along the river on the border of Alberta and NWT, and Fort Resolution is located on the shores of Great Slave Lake near the Slave River Delta.

Residents in the Slave River and Delta area have expressed concern about cumulative environmental impacts from a number of stressors, including climate change, oil sands operations, hydroelectric development, agriculture, mining operations, pulp and paper mills and municipal discharges both locally and upstream (GNWT, 2011).

In response to these concerns, the Slave River and Delta Partnership (SRDP) was formed in 2010, to support communities developing community-based research and monitoring programs. These programs are designed to address important community concerns and questions.

The Partnership has included members of the following organizations:

- Smith's Landing First Nation
- Salt River First Nation
- Deninu K'ue First Nation
- NWT Métis Nation
- Fort Resolution Métis Council
- Fort Smith Métis Council
- Hamlet of Fort Resolution
- Town of Fort Smith
- Aurora Research Institute
- Aurora College
- Government of the Northwest Territories (GNWT), Environment and Natural Resources (ENR)
- GNWT, Municipal and Community Affairs
- Parks Canada

- Environment Canada
- Fisheries and Oceans Canada

A number of academic partners collaborate with the SRDP on various research and monitoring projects, based on community questions and priorities. Current and past academic partners include:

- Wilfrid Laurier University
- University of Waterloo
- Canadian Water Network
- University of Saskatchewan
- University of New Brunswick
- University of Alberta
- Trent University

Supporting communities to become involved in water stewardship activities and develop community-based monitoring program are key components of *Northern Voices, Northern Waters: the NWT Water Stewardship Strategy* (the Strategy). The Strategy was created in partnership by GNWT, Aboriginal Affairs and Northern Development Canada (AANDC) and an Aboriginal Steering Committee (ASC).

The vision of the Strategy is to ensure the waters of the *NWT remain clean, abundant and productive for all time* (GNWT, 2010). To achieve the vision there are a number of goals including ensuring:

- *Aquatic ecosystems are healthy and diverse.*
- *Residents are involved in and knowledgeable about water stewardship.*
- *Residents can rely on water to sustain their communities and economies.*

(GNWT, 2010)

1.2 Ecosystem Approach

The SRDP is a part of implementing the Strategy and works towards achieving its goals and vision. The SRDP uses an ecosystem-based approach when developing and implementing research and monitoring activities. This holistic approach is identified under the Strategy and involves assessing the ecosystem as a whole. The approach acknowledges and tries to understand the processes, structure, function and the interdependence of the ecosystem.

Some of the identified priorities of the SRDP were to synthesize all available information about the aquatic ecosystem in the Slave River to facilitate coordination among monitoring programs, assess the vulnerability of the Slave River and the Delta to environmental stressors and cumulative impacts, and to identify monitoring and research priorities.

This State of the Knowledge report is a literature review, attempting to collect and summarize all documented information on the aquatic and riparian ecosystem of the Slave River and Delta.

This report is the foundation for a vulnerability assessment of the Slave River and Slave River Delta and will be useful in the identification of monitoring and research priorities in the area (Pembina Institute, 2016).

The topics of this literature review are considered to be key components of the aquatic and riparian ecosystem of the Slave River and Slave River Delta. This report focuses on:

- hydrology and sediment,

- water quality,
- metals and contaminants in water, sediment and fish,
- fish and insect/benthic communities,
- terrestrial wildlife species[2] that are strongly linked to aquatic habitats and/or that are of cultural and economic importance to the Aboriginal people of the Slave River area,
- vegetation, and,
- air and climate.

The information gathered for this report was restricted spatially to the Slave River, the region immediately around the river, the Slave River Delta, and the communities of Fort Smith, Fort Resolution and Fitzgerald, with the exception of the section on sediment and contaminants. Because of the large volumes of suspended sediment deposited in Great Slave Lake by the Slave River, information with respect to sediments and contaminants from Great Slave Lake was deemed relevant to this report and was thus included. However, this report does not include a wider discussion of Great Slave Lake. A comprehensive summary of the Great Slave Lake aquatic ecosystem vulnerabilities is presented by MDA Consulting (2003).

Information for this report was gained primarily through a literature review of academic, government and consultant research that has been completed since the late 1970s. While there may be some studies completed prior to this time, most were not publicly accessible. Researchers who have applied for research permits in the Slave River area over the past 30 years were contacted to request copies of pertinent work. Data from on-line databases were also accessed, where available.

1.3 Traditional Knowledge

Traditional Knowledge (TK) can be defined as *"knowledge and values, which have been acquired through experience, observation, from the land or from spiritual teachings, and handed down from one generation to another"* (GNWT, 2005). TK is essential to capture changes in the health of the ecosystem by providing information about what the ecosystem was like and how it functioned in the past. TK illustrates the relationship between people and the land, which provides light on human health and the health of important subsistence food species. TK and western science can be thought of as "two sides of the same coin" (Sly et al., 2001). Both science and TK seek to understand the natural environment and the functions and processes that impact what we see and experience. Both generate conclusions based on observations and experiments, and information is peer-reviewed and shared. TK is also generated through experience and oral lessons (Sly et al., 2001). TK can provide critical information about the landscape and ecosystem functions. TK can also play an important role in reflecting historical conditions if there is no written record (Geonorth Consulting, 2002).

The Water Strategy clearly identifies the importance of TK in water stewardship in the NWT by stating, *"The appropriate use and consideration of all types of knowledge, including traditional, local and western scientific, are an integral part of the Strategy and related initiatives"* (GNWT, 2010). The SRDP as a whole recognizes the importance of including TK in decision making. For people in the communities along and near the Slave River and Delta, "water is very important for culture, way of life and livelihood" (Barnaby and Fresque-Baxter, 2012).

[2] As this report focuses on terrestrial species linked to aquatic habitats that are of importance to people in the region, it should not be interpreted as an inventory of all terrestrial wildlife found in the vicinity of the Slave River.

Aboriginal peoples and their representative organizations are the major holders of TK. For this report, relevant documents that include TK and local knowledge (e.g. local observations) were accessed from individual researchers, government departments, agencies and other organizations. Use of documented TK involves issues of intellectual property and ethical standards, and often the use of some of this material is restricted. Permission was requested to use available community-based TK resources but if approval was not granted, the material has not been included. TK from existing knowledge holders was shared by SRDP members as part of the development of a community-based aquatic ecosystem health monitoring program (of which this document is a key first step). Information from a TK and local knowledge focused workshop as part of the information gathering process for the transboundary negotiation of a bilateral water agreement for Slave River with Alberta has also been included (Barnaby and Fresque-Baxter, 2012). This report also summarizes some of the documented local use of resources such as fish and wildlife. Traditional and local knowledge often incorporate a holistic view of the world, with many interconnections between ecosystem components and people. As such, there are areas of crossover between the topics in this report. Many people in the Slave River area strongly feel the importance of respecting mother earth and speaking on behalf of animals, plants, trees and water that have no voice. The residents feel that it is a traditional responsibility, handed down from the creator, to protect the water (Barnaby and Fresque-Baxter, 2012).

It is important to note that TK incorporated into this report is summary information and interpreted based on available resources. As such, this report is not in any way an authoritative source of TK for the region. Community knowledge holders remain the primary authority on TK and its use for research and monitoring.

1.4 Report organization

This report was organized into the following sections:

Section 1 – Introduction

Section 2 – Way of life and geography – summarizes knowledge of current human activities in the region and the physical environment of the Slave River and Delta

Section 3 – Research and monitoring – summarizes relevant research and monitoring efforts for the Slave River region

Section 4 – Hydrology and sediment load – summarizes knowledge of hydrology and sediment load

Section 5 –Water quality – summarizes knowledge of physical and chemical water quality parameters, algae and metals

Section 6 – Metals and contaminants – summarizes knowledge of metals and contaminants in water, sediment and fish

Section 7 – Fish and insect/benthic communities – summarizes knowledge of the fish and insect/benthic communities

Section 8 – Wildlife – summarizes knowledge of aquatic birds, amphibians, moose and aquatic furbearers

Section 9 – Vegetation – summarizes knowledge of distribution of vegetation communities, berries and rare and invasive species, and the role of fire

Section 10 – Air and climate – summarizes knowledge of observed climatic changes and air quality parameters

Section 11 – Summary of state of the knowledge

Section 12 – References used in the report

Appendix A – Tables of detailed findings

Appendix B – Listing of water relevant regulations, policies and regulatory bodies

Appendix C – Common and scientific names of species listed in this report

Each section summarizes the pertinent knowledge of the topic, including discussion of traditional knowledge and local use. For topics where a number of results are available, these results are summarized in the text and presented in detail in the tables in Appendix B. When possible, the mean and median values are presented in the tables, and the range is presented where means and/or medians are not available. The type of value (mean, median or range) is identified in the table, along with the sample size when this information was available.

At the end of each section, the state of the knowledge on that topic is discussed. The current state of western science knowledge for each component was then categorized according to the following criteria:

- Good –quantitative, up-to-date information is available and uses current sampling methods
- Fair – quantitative information is available but may be out of date, and/or there are information gaps
- Limited – information is substantially limited or dated

Traditional knowledge was not categorized using these criteria. Finally, suggestions for future research to fill information gaps are discussed.

This report is intended to be a living document, and periodically updated as more research and monitoring, from multiple knowledge perspectives, takes place.

2. Way of life and geography in the Slave River and Delta

2.1 Way of life

The NWT portion of the Slave River is located within Akaitcho Territory, the Dene First Nation and NWT Métis Nation Claimant Areas. The community of Fort Smith is located along the Slave River, near the Rapids of the Drowned, while Fort Resolution resides downstream near the Slave River Delta. Aboriginal groups in the area of Fort Smith include the Fort Smith Métis Council, Salt River First Nation and Smith's Landing First Nation, which also includes Fitzgerald, Alberta. Aboriginal groups in Fort Resolution include the Deninu K'ue First Nation and Fort Resolution Métis Council.

There is a deep relationship with and respect for water and the importance of healthy ecosystems in traditional practices in Aboriginal culture. The natural resources of the Slave River and Slave River Delta are of central importance to the cultural and spiritual practices of local residents (Bodden, 1981; Bill et al., 1996; Wolfe et al., 2007a). Water is also used locally for drinking, fishing, travel, traditional activities and some local industries (at a small scale) (Bill et al., 1996). The Slave River has been described as a 'bank', as an important source of many traditional country foods (Barnaby & Fresque-Baxter, 2012).

There are a number of human impacts within the Slave, Peace and Athabasca River Basins that could potentially impact the aquatic environment (See Figure 1). Impacts include:

- Forestry/pulp and paper: Removal of forest cover can increase sedimentation, reduce fish abundance and degrade wildlife habitat. Effluent from the pulp and paper industry can increase nutrient levels and can contribute contaminants to waterways.
- Oil sands development: Oil sands operations can disturb large areas of forest resulting in the destruction of wildlife habitat and increased sedimentation/erosion, withdraw surface and groundwater for operations and produce contaminants through air emissions and potential seepage from tailings ponds. Communities are worried about impacts in the local watershed around the development as well as downstream in the NWT.
- Agriculture: Agricultural activities can contribute nutrients, pesticides and antibiotics to the water.
- Hydroelectric development: The W.A.C. Bennett Dam on the Peace River has impacts on the seasonal flow patterns in the Slave River and the geomorphology of the Delta and may change ice formation processes.
- Contaminants from municipal and industrial facilities: This includes mines (including Pine Point Mine near Fort Resolution and Uranium City in Saskatchewan) and municipal wastewater effluent and landfills.
- Climate change: Climate change can have numerous and diverse impacts on the Slave River system, including changes to hydrology and ice formation, melting of permafrost, fire frequency, vegetation and wildlife distribution, weather events and air and water temperature (Barnaby and Fresque-Baxter, 2012; GNWT and AANDC, 2012).

In addition to these anthropogenic impacts, it is recognized that deltas undergo continuous natural geomorphic change due to natural variation or shifts in hydrology and vegetation.

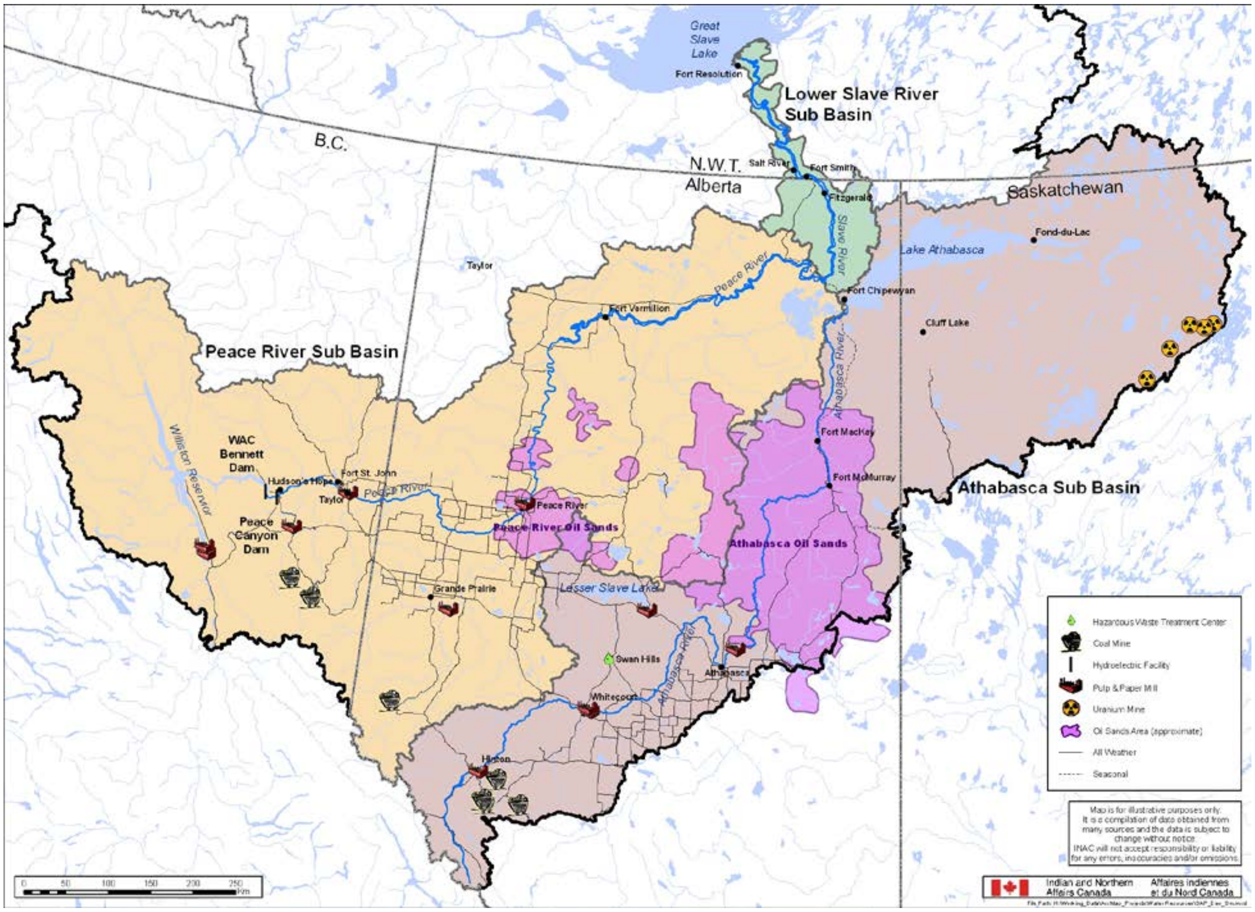

Figure 1: Map of Peace, Athabasca and Slave River Basins showing current development activities in relation to water ways and communities. Source: Sanderson et al., 2012.

Catchment maps for Fort Resolution and Fort Smith were developed by the GNWT in 2011. These maps identify the source water area for the two communities as well as industrial and municipal development and other human activities in the local watershed (See Appendix A).

Changes to water quality or quantity can, in turn, impact human activities in the Slave River and Slave River Delta including subsistence fishing, drinking water provision, harvest of aquatic mammals such as muskrat and beaver for food and furs, and use of water and ice cover for travel (Letourneau et al., 1988; Bill et al., 1996). Indirectly, changes to water quality in the Slave River and Slave River Delta may affect commercial and sport fishing on Great Slave Lake, as well as regional tourism and aesthetics, and terrestrial wildlife (Letourneau et al., 1988). Residents have noted increasing challenges and concerns with travelling on the Slave River in both winter and summer times, associated with lower water levels and changes in ice conditions including thickness, break-up and freeze-up (Barnaby & Fresque-Baxter, 2012). Residents in all of the Slave River and Delta communities have expressed concerns that future generations will not have the same opportunities to participate in travel on the land, subsistence harvesting and trapping, or cultural activities (Barnaby & Fresque-Baxter, 2012). As noted by Barnaby and Fresque-Baxter (2012, pp. 23-24), many community members have expressed "*sadness and frustration that those things which they came to know, understand and rely upon will not be there for the future. Some Elders believe that very soon there will be no water left on the Slave River, the delta and other water bodies in the area.*"

2.2 Geography of the Slave River and Delta

The most recent glaciation event in the Slave River area was the Laurentide ice-sheet which blanketed the area from approximately 18,000 to 10,000 years ago (Dyke et al., 2002). Melt water from the retreating ice-sheet formed Glacial Lake McConnell, which existed from approximately 12,000 to 8000 years ago, and covered parts of the Great Bear, Great Slave and Athabasca Lake basins (Smith, 1994). These floodwaters deposited sand over glacial mud in the modern-day Slave River lowlands. At this time, the Slave River was a southern arm of Great Slave Lake (Vanderburgh and Smith, 1988). Water and sediment flow then filled in the Slave River Delta and cut a channel in the older deltaic sediments, forming the modern Peace–Athabasca Delta (Bednarski, 1999).

Soils in the Slave River lowlands were surveyed by Day (1972), who identified 23 soil types. Alluvial deposits of sand, silt and/or clay, 1 to 10 metres in thickness, can be found in the active Delta and on the banks of the Slave River (Day, 1972). Soil in the active area of the Delta is a mix of calcareous loamy sand and silty clay loam (MRBC, 1981). Inland from the active area, soils are mostly calcareous loam with discontinuous permafrost occurring deeper than 0.8 metres (MRBC, 1981).

The Slave River is formed at the confluence of the Peace River and the Riviere des Rochers, the primary outlet of the Peace–Athabasca Delta (Figure 1). The total catchment area is approximately 600,000 km^2, nearly all of which is located in the provinces of Alberta, British Columbia and Saskatchewan (NRCan, 2009). The Peace River contributes approximately 66% of the total flow to the Slave River (English et al., 1996).

The Slave River drains to the north from its origins in Alberta. It stretches 434 km, 320 km of that is located within the NWT. The Slave River watershed is relatively small in comparison with the Peace and Athabasca watersheds, draining an area of 15,100 km^2 (NRBS, 1996). Along the upper river plain, the elevation decreases gradually at a rate of 0.65 m/km. Between Fitzgerald and Fort Smith the river drops quickly (at 1.17 m/km) as evidenced by the series of rapids in this stretch. From the base of the rapids at Fort Smith to the outer edge of the Delta, the drop becomes quite gradual, with a decrease of 0.06 m/km (straight-line distance) (Vanderburgh and Smith, 1988).

The Slave River empties into Great Slave Lake via the Slave River Delta. As it approaches Great Slave Lake, the Slave River divides into numerous distributaries with islands and bars formed by the deposition of large amounts of alluvial material. The active area of the Delta is estimated to be 400 km^2 (English, 1997).

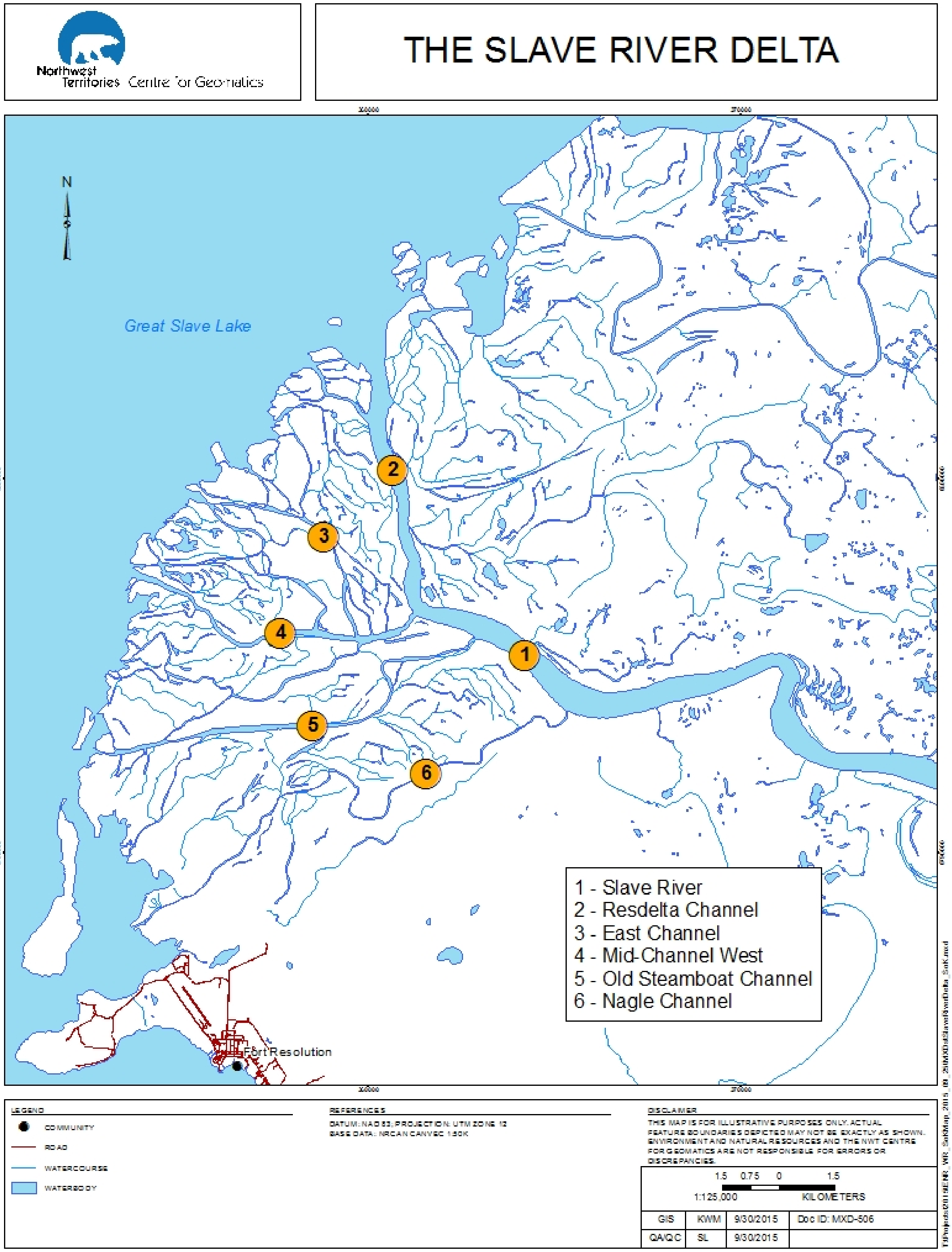

Figure 2: Slave River Delta

The Delta is divided by 27 distributaries that flow to the lake in a radial pattern at north, north-westerly, and westerly orientations. The four main channels (ResDelta, Old Steamboat Channel, Middle Channel and Eastern Channel) are 7.5–32 metres in depth, while depths in the minor channels range from 2–35 metres (Mollard, 1981). ResDelta is the largest channel in terms of volume, carrying 86% of the total flow, as measured in the summers of 1978–1980 (Mollard, 1981).

The Delta can be divided into three sections based on height of levees (sediment bars) formed by continual sediment deposition. The upstream (inactive) portion of the Delta is approximately 1 km in length and levees are high (2.3–3 metres). The outer Delta is approximately 3 km in length and levees are very close to lake level (within 0.1 metres), and consequently flooding is frequent. The mid Delta, found between the outer and upstream portions, is approximately 15 km in length with 0.5–2.5 metre levees that allow periodic flooding (English et al., 1997).

A continual process of sediment deposition and building of islands causes the Delta to prograde (expand) into Great Slave Lake (English et al., 1997). Simultaneously, lake water levels, ice, seiche and storm events work to erode the Delta (Gardner et al., 2006; Prowse et al., 2002a). The balance between progradation and erosion controls the shape and size of the Delta. The imbalance produced by this interaction (erosion being less than deposition) has resulted in slow progradation of the Delta into Great Slave Lake over the past 8,000 years (Mollard, 1981; Vanderburgh and Smith, 1988). Growth seems to occur in stages, interspersed with periods of no growth or erosion. More recently, there was strong growth in 1930–1946 (up to 0.16 km/year), but from 1946–1976 growth rate was much slower (0.03 km/year). No data exists to describe recent progradation and/or erosion in the Delta.

Wave-built shoals are also important structures as they form barriers to the erosive action of the lake and allow sedimentation (in the lee of the shoals) to take place (English, 2009). Wave-built shoals are stabilized by large pieces of driftwood. Both shoals and sediment islands are colonized by emergent vegetation and eventually become cleavage bar islands. The progradation of the outer delta is dependent on sediment load to provide structure of cleavage bars and protect from erosion (English, 2009).

3. Research and monitoring in the Slave River and Slave River Delta

This chapter summarizes relevant research and monitoring programs in the Slave River and Slave River Delta, and related research in the Peace–Athabasca Delta and the Mackenzie River Basin. These programs have generated a number of the studies and documents referenced in the body of this report. However, this is not a complete list of projects that have taken place in the Slave River and Delta area.

3.1 Research and monitoring programs

The Slave River at Fitzgerald monitoring program (1960 to present)

Environment Canada has operated the Slave River at Fitzgerald monitoring program since 1960. The water quality sampling location is located near the community of Fitzgerald in Alberta, approximately 20 km upstream from Fort Smith. During open water, surface water samples are collected just below the water's surface from a boat at mid-channel. In winter months, a hole is drilled through the ice several metres offshore to collect the water sample. Currently, sampling for nutrients, physical characteristics, 45 metals, PAHs, phenol, petroleum hydrocarbon, BTEX, cyanide and mercury occurs eight times per year.

The Slave River hydrometric program (1960 to present)

The Water Survey of Canada hydrometric gauging station is co-located with the Fitzgerald water quality sampling location and is also operated by Environment Canada as part of a national network of hydrometric stations. Water level is measured every five minutes and calculated to produce a daily mean. In open water seasons, discharge measurements are made using an acoustic profiler from a boat.

Slave River hydro study (1978–1983)

A number of studies were completed in the late 1970s and early 1980s as part of the proposed Slave River hydro project. These studies were the first comprehensive assessments of the fish and benthic communities in the Slave River (RL&L/EMA, 1985; Reid, Crowther & Partners Ltd., 1982).

The Slave River at Fort Smith (shore location) monitoring program (1982 to present)

This program, which was led by the AANDC Fort Smith District office, was transferred to the ENR South Slave Region post-devolution. This sample site is part of a larger South Slave water quality monitoring network which includes sites on the Salt, Little Buffalo, Buffalo, Kakisa, Tazin and Taltson Rivers as well as the Slave River Delta. The goal of this program is to document baseline water quality conditions in the South Slave. The Slave River sampling site is located next to the boat launch in the town of Fort Smith. Surface water samples have routinely been collected two times per year in the spring and fall (typically May and October), but this sampling frequency increased to monthly during the Slave River Environmental Quality Monitoring Program (1990–1995; Sanderson et. al., 1997). During the open water season, samples were collected from the shore just below the water's surface; during the winter, samples were collected under ice, a few feet from shore. Physical and chemical water quality parameters are collected.

The Slave River at Fort Smith (mid-river location) monitoring program (1990 to present)

This program, which was previously led by AANDC, is now led by ENR Waters post-devolution. This ongoing sampling program will provide information for the Alberta/NWT transboundary water agreement. Results from this program are summarized in the following two reports:

Slave River Environmental Quality Monitoring Program (SREQMP) (1990–1995)

The Slave River Environmental Quality Monitoring Program was a five-year water, fish and suspended sediment sampling program in the Slave River at Fort Smith. The sampling location for this program is located mid-river, below the Rapids of the Drowned at the Town of Fort Smith (Sanderson et al, 1997). This site was selected because it is downstream of the Alberta/NWT border, upstream of any major tributaries in the NWT, is well mixed, and because the rapids act as a barrier to fish. These factors were important in site selection, since the main objective of the SREQMP was to establish baseline environmental conditions for the NWT transboundary reach of the Slave River. The program was designed to identify the most likely contaminants in the most appropriate media (fish, suspended sediment or water), thus taking an ecosystem approach to monitoring. Analytical parameters were chosen based on the current knowledge of the chemical composition, fate and effects of the effluents from upstream developments and include metals and organic contaminants. The program was a cooperative effort between Aboriginal Affairs and Northern Development Canada, Government of the Northwest Territories, Department of Fisheries and Oceans and Environment Canada.

From 1990–1995, water, suspended sediment and fish samples were collected. Since 1995, water and suspended sediment samples have been collected every five years and the results from this follow-up sampling are summarized in the following report.

Water and Suspended Sediment Quality of the Transboundary Reach of the Slave River (2000–2010)

This report presents the results of the Slave River Environmental Quality Monitoring Program Follow-Up Study (2000–2010; Sanderson, et. al., 2012). The report describes water and suspended sediment quality conditions in the Slave River (at Fort Smith), as well as seasonal flow patterns and long-term temporal hydrological trends. The status and long-term trends in water quality data from the Slave River at Fitzgerald site are also examined. A summary of the geology and upstream activities in the Slave River Catchment are also provided.

Regional Fish Health Study in the Slave and Athabasca Rivers (2011-2012)

The objective of the project was to study the health of the fish from Athabasca River downstream to the Slave River and at the Slave River Delta. In 2011 and 2012, over the summer, fall, winter and spring, University of Saskatchewan researchers collected almost 1500 fish from 8 locations on the Athabasca and Slave Rivers. Samples of both healthy and unhealthy fish were collected from Fort McMurray down to

Fort Smith and Fort Resolution and included the following species: Goldeye, Lake Whitefish, Walleye, Northern Pike, Burbot and White Sucker and Inconnu. Samples were examined for overall health (gene expression and histology) and for contaminant load (metals and organic contaminants). Results have been shared with local communities and at scientific workshops. Posters presenting preliminary results are publically available[3] (Jones et al., 2012; ARI, 2011a).

NWT-Wide Community–Based Water Quality Monitoring Program (2012-present)

The NWT-wide Community-based Water Quality Monitoring Program started in 2012. Currently 21 communities and other water partners work together to monitor water quality throughout the NWT. One of the goals of this monitoring program is to give NWT residents the opportunity to do water monitoring and answer community questions about water quality. There is a site on the Slave River at Fort Smith, and one near Big Eddy in the delta near Fort Resolution. An additional site is located on Great Slave Lake in Resolution Bay.

Hydroecology of the Slave River Delta (2002-2007)

The NSERC Northern Research Chair Program in Northern Hydroecology (Brent Wolfe, Wilfrid Laurier University in collaboration with Roland Hall, University of Waterloo) studied critical water-related issues in the Slave River Delta, associated with changing water levels (see for example: Wolfe et al., 2007; Brock, Wolfe & Edwards, 2008; Brock et al., 2010). Research objectives included characterizing the hydroecology of lakes in the Delta at varying timescales (seasonal to multi-centennial) and evaluating the relative roles of multiple stressors (including river regulation and climate change) on these lakes. The research approach integrated contemporary hydroecological studies, using water isotope tracers, with long-term records of hydroecological changes derived from analyses of lake sediment cores. Seasonal lake water sampling of 40 lakes in the Delta was conducted from 2002–2005 for water isotope composition and chemistry. Several lake sediment cores were also collected. A parallel research program was conducted on the upstream Peace–Athabasca Delta (see for example: Wolfe et al., 2005; Wolfe et al., 2006).

Slave River and Delta sediment coring for assessment of contaminants (2012)

Sediment cores were retrieved in the fall of 2011 from a lake within the Slave River Delta to assess trends in contaminant (e.g. polycyclic aromatic compounds and metals) deposition over time. The analysis of the information will contribute to the overall understanding of the existing environmental stressors that might affect the aquatic ecosystem health of the Slave River Delta. Preliminary results from these studies are included in this report (Wolfe and Hall, 2012; Wolfe and Hall, 2014; ARI, 2011b).

Slave River Watershed Environmental Effects Program (SWEEP) (2013-present)

SWEEP is a program led by the SRDP and University of Saskatchewan that was established in 2013. SWEEP builds on the priority indicators and monitoring questions identified by the SRDP in this report

[3] http://nwtwaterstewardship.ca/sites/default/files/Fish%20Health%20Study%20-%20Metals-Oilsands_0.pdf
http://nwtwaterstewardship.ca/sites/default/files/Fish%20Health%20Study-PAHs%20Low%20res.pdf
http://nwtwaterstewardship.ca/sites/default/files/Fish%20Health%20Study-%20Biomarker%20Low%20res.pdf

and the accompanying vulnerability assessment report (Pembina Institute, 2016). The two-year project was funded by the Canadian Water Network to develop an Aboriginal-led, community-based cumulative effects monitoring framework for the Slave River and Slave River Delta. The framework was designed to be cost effective and to support communities interested in long-term community-based cumulative effects assessments. The program identified both traditional and local knowledge and western science indicators for fish, benthic invertebrates, wildlife and ice dynamics. It is anticipated that the framework developed through this pilot project can be adapted and rolled out to other interested NWT communities.

Mackenzie River Basin Study report (1981)

The Mackenzie River Basin Board (MRBB) report published in 1981 was one of the first large assessments of the Mackenzie River and its tributaries (Davies, 1981). This report provided an overview of water quality and hydrology in all the sub-basins of the Mackenzie River.

State of the Aquatic Environment Report for Mackenzie River Basin (2003)

This assessment of the Mackenzie River Basin included a section on the state of the Great Slave aquatic environment (including the Slave River and Slave River Delta). Parameters included water quality guideline exceedances, water quantity, seasonal flow patterns, fish populations, and the state of integration of traditional knowledge in water management (MRBB, 2003).

Northern Rivers Basin Study (1991–1996)

The Northern River Basins Study (NRBS) was a five-year research program that involved the governments of Alberta, NWT and Canada. It was launched to assess the combined impacts of industrial, agricultural, municipal and other developments on water quality and quantity in the Peace, Athabasca and Slave River basins. At the conclusion of the program a number of recommendations were made to governments to help guide future management of the rivers (NRBS, 1998).

Northern River Ecosystem Initiative (1998–2003)

To address the recommendations of the NRBS, the Northern Rivers Ecosystem Initiative (NREI) was set up in 1998 (NREI, 2003). The NREI was a collaborative research and policy program between the governments of Alberta, NWT and Canada. These studies focused on pollution prevention, hormone impacts in fish, water flows and quality, contaminants, nutrients, safe drinking water and enhanced environmental monitoring (Northern Rivers Ecosystem Initiative, 2003).

Peace–Athabasca Delta technical studies (1993–1996)

This report summarizes a series of studies on hydrology in the Peace–Athabasca Delta, and makes recommendations on water management and monitoring (PAD-TS, 1996).

Peace–Athabasca Delta Ecological Monitoring Program (ongoing)

The Peace–Athabasca Delta Ecological Monitoring Program (PADEMP) is “a collaborative approach to long-term monitoring and reporting on the health of the Peace-Athabasca Delta, using both Western Science and Traditional Knowledge, in support of effective environmental stewardship” (Peace–Athabasca Delta Ecological Monitoring Program, n.d.). The mandate of PADEMP is to “measure, evaluate and communicate the state of the Peace-Athabasca Delta ecosystem, including any changes to this ecosystem that result from cumulative regional development and climate change” (Peace–Athabasca Delta Ecological Monitoring Program, n.d.).

The program is working towards designing a comprehensive ecological monitoring program to support effective environmental stewardship. The Peace–Athabasca and Slave Rivers share many common features and issues, and thus there are opportunities to share expertise and information on areas of interest and monitoring priorities (Environment Canada, 2010).

4. Hydrology and sediment load

4.1 Water flow

Slave River

There is one active hydrometric station on the Slave River at Fitzgerald that has operated infrequently from 1921 to 1960 and continuously since 1960 (Kokelj, 2003). Between 1972 and 2002 the mean annual flow was 3411 m^3/s with a total water amount of 108 billion $m^{3/}$year (Kokelj, 2003).

In 1968 the WAC Bennett Dam was constructed, creating the Williston Reservoir which now impounds approximately 41 billion m^3 of water. From 1968 to 1971, during the filling of the reservoir, the Peace River flows were reduced by as much as 5600 m^3/ s (Peace-Athabasca Delta Technical Studies Steering Committee, 1996). Filling the reservoir led to a decline in flow downstream in the Slave River (Mackenzie River Basin Board, 2003); as well in the Smoky and Athabasca Rivers (Timoney, 2002).

In 1996 and 1997, ice jams on the Peace and Athabasca Rivers caused very high water levels (Wolfe et al., 2008). In spring 1996, when it was noted that an ice jam was underway on the Delta reach of the Peace River, BC Hydro released additional water from the reservoir to augment the flood effects in the Peace–Athabasca Delta (Prowse et al., 2002b). Additionally in 1996, BC Hydro had to implement an emergency drawdown of the reservoir to address structural problems at the dam. This release resulted in sustained high flows on the Peace and Slave Rivers, creating a summer flood event. Modelling of estimated river flow in the absence of regulation however, indicated that this high flow event was similar to conditions that would have existed if there was no flow regulation on the river (Peters and Buttle, 2009).

Other flood events in 1974 and 2005 were noted as significant by community members, and impacts included changes to wildlife habitat, flooding of infrastructure and changes to the shape of channels in the Delta (Wesche, 2009).

In 2010, record low water levels were experienced on the Slave River, on Great Slave Lake and in the upper Mackenzie River. Many of the tributaries to the Williston Lake Reservoir behind the W.A.C. Bennett Dam also experienced record lows that year. This suggests that the low water levels in the NWT that year were likely due to low snowpack and rainfall in the upper portion of the Slave River watershed (Sanderson et al, 2012).

There have been significant changes in flow in the Slave River over the past 40–50 years, as noted by both western science and from observations by residents. Observations of changes over the past 40–50 years include a decrease in summer flow, an increase in winter flow, and earlier peak flow creating a less variable annual regime (English et al., 1984; 1996; Bill et al., 1996; Prowse et al., 2002a; Prowse and Conly, 2001; MRBB, 2003; Peters and Buttle, 2009; Wesche, 2009; Barnaby and Fresque-Baxter, 2012). There has been a 20% decrease in mean peak spring flows of the Slave River and the average mean winter low flow has increased by 75% (Sanderson et al., 2012), thus reducing the variability between high and low flow. The variation in flow that still occurs is mostly due to inputs of water downstream of the Bennett Dam (Prowse et al., 2002a).

There has also been a shift in the timing and magnitude of minimum monthly flows (Prowse et al., 1996; Gibson et al., 2006a). Local residents have repeatedly observed changes to the seasonal patterns of flow (see Section 4.1. *Water Flow*) (Bill et al, 1996; Wesche, 2009; GNWT and AANDC, 2012; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). These changes have had numerous implications for fish movement and spawning, ice formation and flooding.

Both flow regulation and climatic change have been identified as drivers of hydrologic changes. Some studies have attributed significant changes seen in the flow primarily to regulation (e.g. English et al., 1996; 1997; Peters and Buttle, 2009). Other studies have found that some of the observed changes are more likely caused by climatic drivers (e.g. Mongeon, 2008; Brock et al., 2010).

In other assessments of the historical hydrology of the Slave River and Slave River Delta, it was found that both regulation and climatic effects on the river have had interactive (and sometimes opposing) effects on water level fluctuations and peak water levels (i.e., the highest water levels during a specific time period) (Prowse and Conly, 2001; Prowse et al., 2004). Gibson et al. (2006b) found similar findings for lake levels on Great Slave Lake, in that flow regulation from the Slave River and climatic effects have counterbalanced each other.

In 2011, residents of Fort Resolution described that travelling from the community to Fort Smith by boat was becoming increasingly difficult due to the emergence of sandbars throughout the main channel. Large boats and barges used to travel the Slave River to Great Slave Lake in the early 1920s. This would be nearly impossible now, and many residents noted that even small vessels have difficulties travelling in particular places. Another example illustrating the changes in the delta is that in the 1960s, larger boats with outboard motors hauled logs back and forth from a saw mill to Great Slave Lake, using the Slave River Delta and the Nagle Channel. The Nagle Channel is now no longer wide enough in many places to allow large boats to pass (Barnaby and Fresque-Baxter, 2012).

In 2011, with the declining water levels, many Elders and land users from Fort Resolution identified that it was more difficult to set nets for fish in areas in the delta. Access to specific hunting and fishing areas was also no longer possible. To be able to access and travel through some of the Delta channels, dredging had been required (Barnaby and Fresque-Baxter, 2012).

Many of the residents in Fort Resolution have observed that smaller channels off the Slave and Taltson Rivers, connecting to other rivers, the Great Slave Lake or inland lakes, are now drying out and are becoming impassable (Barnaby & Fresque-Baxter, 2012).

Slave River Delta

Significant changes in the morphology of the Slave River Delta have been documented in the past 50 years. However, deltas are environments that naturally undergo change, and the Slave River Delta is shaped by the complex interaction between flow regulation, sediment deposition, climatic change and wind and wave action.

The Slave River Delta has also experienced significant redistribution of flow among channels. An analysis of aerial photography found that the ResDelta channel flow has doubled in size and flow, while the East channel and Old Steamboat channel decreased in size by 50% and flow declined in the period between 1946 to 1995 (English et al., 1996; Prowse and Conly, 1996). This finding was substantiated by Prowse et al. (2004), who found that prior to 1960 the main flow path was through Middle channel. In 1966, drought conditions and low lake levels caused a major shift eastward to the ResDelta channel. By 1973, the shift in flow to the ResDelta channel was complete and the western and southern portions of the Delta were drying. Prowse et al. (2006) noted that since the shift commenced before the 1968–1971 filling of the Williston Reservoir, they interpreted this shift as a natural phenomenon. Thus, the Slave

River Delta has evolved from a multi-distributary delta to its current state, where water passes predominantly through the ResDelta channel.

Due to the changes in water flow, there have been changes in the sediment transport regime since the construction of Bennett Dam. At Fitzgerald on the Slave River a decrease of 33% of the annual sediment load was observed. Because of flow regulation more fine-materials and less-coarse material are deposited in the delta (English et al., 1996).

Relevant to the changed flow in the delta, local residents have observed changes to water flow rate and currents in Slave River and Taltson River. The current in these waters has slowed down. It used to be nearly impossible to paddle up the Rivers, whereas now it is possible.

Great Slave Lake

The Slave River provides about three-quarters of the total inflow to Great Slave Lake (MRBB, 2003; Gibson et al., 2006a). Rawson (1956) noted the strong connection between Slave River and Great Slave Lake, recording greater phytoplankton growth in Great Slave Lake during years with warm springs and a larger inflow from the Slave River. The Slave River provides significant sediment load to Great Slave Lake (Gardner, 2002). Declines in water levels in Great Slave Lake were noted in the mid-1990s, likely due to reduced flow from the Slave River (MBIS, 1997).

Wind seiche events (wind-driven flooding and erosion) on Great Slave Lake can penetrate the Delta and significantly alter deposition and erosion patterns. An increase in the frequency and magnitude of seiche events would cause the main sediment deposition zones to move upstream (Prowse et al., 2004; 2006). Gardner et al. (2006) found that seiche events are more common in late summer and autumn, and their effects are felt most strongly in the smaller channels and may have impacts on sediment disposition. The prevailing north-westerly winds at Great Slave Lake indicate that wind-forced water surface seiche events may be common because of the large fetch distance on the lake.

4.2 Ice

Local residents have noted concerns about ice thickness and quality, which leads to concerns about safety when crossing the Slave River and other waterbodies (Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). The predictability to safely travel on the ice is decreasing. Local residents describe the difficulty in using their traditional knowledge to “read” the ice. The known locations of weak ice are changing and the colours of the ice, indicating either thin or thick ice, have changed. Due to less safe travel conditions on the ice in the winter and the spring, access to certain areas has been limited.

Local observations indicate that spring break-up is occurring differently than before, in that the pattern and timing of break-up are no longer the same as in previous decades. Elders and other community members have identified that the break-up took longer and used to take place in mid-June; it now it is happening more quickly, as early as the middle of May (Barnaby and Fresque-Baxter, 2012).

Research on the timing of mean pre- and post-regulation break-up dates up until the mid-1990s found that there were no significant changes in overall ice duration on the Slave River (Conly and Prowse, 1998). It is likely that climate has a significant impact on breakup of ice (Prowse and Beltaos, 2002), but this has not been directly quantified in the Slave River.

4.3 Spring Flood Events

Water flow in the Slave River and Slave River Delta is naturally highly variable. Spring flood events are known to be very important to the Slave River and Delta ecosystems. Ice-jam flooding and the spring freshet (flow increase from melting snow and ice) are both extremely important phenomenon for maintaining the highly productive early successional stage vegetation, and building and maintaining delta channels and bars (MRBC, 1981; Prowse et al., 2004). Fast-flowing flood waters can also break down submerged levees at the mouths of active distributary channels. While exact effects of ice-jam flooding in the Slave River and Delta have not been quantified, modelling studies in the Peace basin suggest that reduced frequency of ice jams in recent years has affected water replenishment and retention rates (Prowse et al. 2006). Concerns have been expressed by community members about changes in flooding, including less frequent ice jam flooding in the spring (GNWT and AANDC, 2012; Fresque-Baxter and Barnaby, 2012; Pembina Institute, 2016).

One of the most important roles of flooding is rejuvenation of lakes in the Delta by spring flood waters (Brock et al., 2007; 2008; 2009). Recent research has suggested that lakes in the Delta can be divided into three categories based on their water balance characteristics (Brock et al. 2007):

> 1) evaporation-dominated lakes are located in the older non-active part of the Delta and receive snowmelt in the spring but are strongly influenced by evaporation over the remainder of the ice-free season;
>
> 2) flood-dominated lakes are located in the active Delta and are primarily influenced by Slave River floodwaters, which offset the effects of evaporation; and,
>
> 3) exchange-dominated lakes occur along the fringes of the outer Delta and adjacent to upstream reaches of the Slave River and possess variable water balances depending upon the strength of connection to Great Slave Lake seiche events or Slave River inflow.

Sokal et al. (2008, 2010) supported these findings with results that identified different limnological conditions and diatom taxa among the different types of lakes, similar to the Peace–Athabasca Delta (Wolfe et al. 2007b; Wiklund et al., 2010).

Flood waters contribute water and nutrients to isolated basins, but it appears that some lakes (those that were previously flood-prone) have higher dissolved nutrient concentrations, when isolated from flooding (Sokal et al., 2010). Similar results have been found in the Peace–Athabasca Delta (Wiklund et al., 2011). It should be noted that while overall nutrients may be higher in flooded lakes, these nutrients are in the particulate form associated with suspended sediment and thus may be less bioavailable to aquatic life.

As stated above, multiple interacting drivers control the frequency and magnitude of flooding. Climate impacts on upstream flow generation are known to be important in determining the magnitude of spring flooding in the Slave River Delta (Brock et al. 2008). This has been demonstrated through modelling of historical water flows into Great Slave Lake (Gibson et al., 2006a) and through isotope analysis of lake water to assess the magnitude of flooding in the Delta during 2003-2005 (Brock et al., 2008). Sediment records from lakes in the Delta show evidence of flood events oscillating, with a period of increased flood events starting in the 1960s and ending in the 1980s (Mongeon, 2008; Brock et al., 2010). These authors found that the current period of low flood frequency began several decades prior to the construction of the Bennett Dam, and similar patterns were found for the Peace–Athabasca Delta (Wolfe et al., 2006). Similarly, carbon isotope analysis compared against climate records showed an overall warming and drying trend since the 1950s, which became more pronounced as of the mid-1970s (Buhay et al., 2008). Sediment cores indicate that the current decline in water levels is not outside the range of natural variability experienced over the past three centuries (Mongeon, 2008). This evidence suggests that climate effects, rather than regulation, have been the primary driver in the variation in flow seen in the

Slave River (Brock et al., 2010). However, it should be noted that paleo-hydrological reconstructions of the water level record are not capable of estimating current water level conditions in the absence of flow regulation and water withdrawals.

Flow regulation may also be a driver in the reduction of spring ice jams (Prowse and Conly, 1998; Barnaby and Fresque-Baxter, 2012). Because winter flow levels have been higher since regulation, higher flow in the spring is needed to lift the ice and create an ice jam. However, due to reduced snowfall in the tributary headwaters, less flow is available in spring, reducing the probability of an ice jam (Prowse and Conly, 1998).

4.4 Sediment and travel accessibility

Sediment load is one of the primary factors that shape the unique environment of the Slave River Delta (MRBC, 1981). The Slave River has naturally high sediment loads because sedimentary rocks and glacial till found in the watershed are easily eroded and washed into rivers, as compared to the hard bedrock of the Precambrian Shield to the east and north of the Slave River catchment (MRBB, 2003). Geological composition of sediment is relatively uniform across the Slave River and Delta, and is mostly quartz, with smaller amounts of calcite, micas, montmorillonite, dolomite/ankerite and kaolinite (Mudroch, 1992; Stone and English, 1998; Milburn et al., 2000).

Sediment is composed of varying proportions of silt, sand and clay. Sanderson et al. (1997) found distinct seasonal differences in suspended sediment size; clay is the predominant particle in fall and spring while in summer, silt is the largest component by a slight margin. The percentage of sand is highest during the winter months. This may be caused by frazil ice, which forms in the nearby rapids and scours the river bed, resuspending the bottom sediment. There is significant deposition of clays and silts under ice during the winter (Milburn and Prowse, 1998a, b). Concentrations of suspended sediment vary greatly according to sample site and season (see Table 2 for list of studies and findings).

The deposition of sediment is a function of the energy in the water flow, concentration of suspended solids, the morphology of the channel, roughness of the bed and the presence of vegetation (English, 1984; Vanderburg and Smith, 1988; Milburn et al., 2000). It has been estimated that approximately 50% of suspended sediment is deposited in the Slave River Delta and 50% eventually ends up in Great Slave Lake (MRBC, 1981). Silts and clays settle more quickly in deep, relatively quiet waters than in shallow and turbulent waters where wind and waves cause sediment resuspension. Thus, clay and silt are mostly deposited in Great Slave Lake and smaller, calmer channels in the Delta, whereas sand mostly ends up in larger Delta channels (Milburn and Prowse, 1998a, b). Modelling of flow speed suggests that sediment is deposited fairly quickly after entering the Slave River Delta (within 12 hours), as compared to the Mackenzie Delta (where sediment is deposited over 1–5 days) (Fassnacht, 2000).

When sediment reaches Great Slave Lake, it is deposited in a fan-like (arcuate) pattern. The areas showing the highest rates of sedimentation are actually a significant distance (50 km) away from the mouth of the Slave River at a depth of 110 m (Mudroch, 1992; Evans et al. 1996a, b). Estimates of sedimentation in Great Slave Lake range from 340 to 3464 g/m^2/year. Refer to Table 3 for a detailed summary of findings.

The W.A.C Bennett Dam on the Peace River has had a large impact on sediment transport to the Slave River. It is estimated that sediment load has decreased by 31% (MRBB, 2004; Kokelj, 2003) to 65% (Stone and English, 1998) since the construction of the dam (late 1960s). The seasonal nature of sediment loading has also changed since the Bennett Dam began operation; it is estimated that sediment load on the Slave River at Fitzgerald has tripled during winter but has decreased by almost half during the open-water season (English et al., 1996). However, it should be noted that rates of sedimentation, building and erosion in deltas fluctuate naturally, and it is not clear how much of the observed change is associated with natural patterns.

While the above results suggest that overall sediment loads have declined, some local residents in Fort Resolution have observed increased sedimentation in Delta channels (Wesche, 2009, Barnaby and Fresque-Baxter, 2012; GNWT and AANDC, 2012; Pembina Institute, 2016). This may be caused by overall reduced flow rather than an increase in overall sediment deposition. Reduced flow could cause an increasing proportion of sediment to be deposited in the Delta rather than travelling through to Great Slave Lake. The increased sedimentation in the channels has limited the ability of residents to access traplines and hunting areas, and local residents suggest that this can also have implications for fish spawning habitats (Wesche, 2009, Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016).

4.5 Groundwater and permafrost

Little is known about groundwater movement in the Slave River area, and the connection to permafrost. One of the few studies available is by Weyer (1983) who assessed isotope concentrations to determine groundwater movement around Pine Point mine. It was found that karst geology in the region means there is a large amount of vertical movement, and that groundwater moves generally southwest to northeast from the Caribou Mountains to Slave River.

As mentioned above, permafrost is discontinuous in the Slave River area. Permafrost can act as a barrier to water infiltration, leaving more water on the surface. This can mean greater evaporation, faster runoff, and more availability for plant uptake.

Local residents have observed increased active layer depths (top layer of soil that freezes and thaws seasonally) where the permafrost has been identified as either shrinking or nonexistent in some areas around the Slave River (Pembina Institute, 2016).

4.6 State of the knowledge and potential future research

According to the categories outlined in section 1.4, the state of the knowledge about hydrology and sediment load in the Slave River and Slave River Delta can be considered Good. A long and reliable data record has been collected at the Fitzgerald hydrometric station, and a number of studies have investigated the effects of flow regulation and flooding on the Delta, including assessments of vegetation change and records from sediment cores. There is a fairly long history of measurements of suspended sediment concentrations, there have been a number of investigations of the spatial patterns of sediment distribution in the Slave River Delta and Great Slave Lake, and trends over time have been investigated up until the mid-to-late 1990s in Great Slave Lake, and until the mid-2000s for lakes in the Slave River Delta. Recent work has focused on hydrology of lakes in the Delta, and their linkages with the Slave River and Great Slave Lake.

Members of the Aboriginal groups from Fort Resolution, Fitzgerald and Fort Smith have described on numerous occasions observations related to the rate and timing of the water flows in the Slave River and the Slave River Delta. There is an overall consensus that the environment, thus the animals and the plants, are not adapted to the changes in water flows, including lower water in the spring and summer and higher during the winter, and the lack of flooding during spring break-up (GNWT and AANDC, 2012; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). There are local observations included in this report related to ice quality, and sediment quantity, but little about sediment quality.

Potential future research and monitoring

The following are based on the results from this report and the SRDP Vulnerability Assessment Workshop held in 2012.

- Modeling of historical impacts of climate, regulation and water withdrawals on water flow and sediment may help predict future impacts. The relationship between climate and water flow has been investigated in the Peace–Athabasca Delta (Wolfe et al., 2008), and similar work for the Slave River may provide insight for future water management.
- The effects of less frequent ice-jam flooding on the Slave River Delta could be further investigated beyond the existing work on hydrological and limnological consequences, by investigating impacts on vegetation and sedimentation. Local observations indicate that the Slave River ice breaks up faster in recent years and should be further monitored to look at differences in timing.
- The shape and size of the Delta is known to have changed between the 1970s–1990s (English et al., 1996). More recent changes could be assessed, and the rate of change could be determined with new aerial photography techniques to provide more continuous information, and to make comparisons at a broad scale to other large northern deltas (e.g., the Mackenzie and Peace–Athabasca Deltas) to assess any large trends.
- The observed trends in the seasonality of sediment load in the Slave River and its tributaries could be reviewed in light of the observed changes in peak flow, ice formation and breakup. This could be conducted through a mass balance study that would measure the sediment (mass and particle size) at both the entry points and the mouths of the tributaries and compare to the Slave River and Great Slave Lake. Additional sediment coring could be undertaken to assess the effects of climate on the rate of sediment deposition. Sedimentation rates in the Slave River Delta could be compared to other deltas in unregulated rivers (Pembina Institute, 2016).
- Hydrological monitoring of lakes in the Delta using isotope tracers could be used to track lake water balance changes, as outlined in Benkert (Brock) (2010).
- Biological indicators of impacts for hydrology such as muskrat, redwing blackbirds, goldeye and pelican could be included as part of an ongoing bio-monitoring program (as recommended by MacDonald, 1990a; 1995)
- Biological indicators that provide insight about the effects of changing water levels should be established (Pembina Institute, 2016).
- It was suggested by the SRDP (Pembina Institute, 2016) that ice thickness at ice crossings and bridges could be monitored by local residents (perhaps students paired with traditional knowledge holders), along with air and water temperature. This information should be provided to land users so they know when and where it is safe to cross the ice (Pembina Institute, 2016).
- There is a need to identify the critical thresholds of water volume that are required to maintain normal ecosystem functioning, and the services that the land and water provide for local people. PADEMP is moving towards developing culturally-based indicators, such as determining the minimum flow required for people to access areas to hunt and fish, seasonally and annually (Pembina Institute, 2016).
- More knowledge on movement of groundwater, including flow volume, water chemistry and identification of sites where groundwater mixes with surface water, would be helpful in determining how groundwater contributes to surface water flow (Pembina Institute, 2016).

- Studies to determine if the increasing trend in winter water flows and the decreasing trend in summer and fall winter flows in the Slave River are the result of upstream regulation or climate change.
- It was a suggested that there is a need for a better way of documenting TK. It is the only long-term knowledge that exists, and helps build the theory and argument of impacts. There was a concerted effort to have TK documented during the Northern Rivers Basins Study, but this study has not been replicated (Pembina Institute, 2016).

5. Water quality

Water quality is measured to determine how suitable water is for drinking, and for plants, bugs and fish to live in. Measuring water quality includes measuring components of what makes up water, including chemical (e.g., metal concentrations), physical (e.g., temperature) and biological (e.g., chlorophyll) parts (GNWT et al. 2012). To determine if the water quality is good or bad is sometimes complex, for example good water quality for human consumption might not be good enough for very sensitive species of fish (AANDC, 2012).

Water quality guidelines are developed to protect fish, plants and bugs living in the water, or designated uses such as drinking and recreation (AANDC, 2012). Water quality parameters are generally compared against Health Canada's Health-Based Guidelines for Canadian Drinking Water Quality, as well as the Canadian Council of Ministers of the Environment (CCME) Guidelines for the Protection of Freshwater Aquatic Life (CGPAL).

Water quality is important for residents living in the Slave River and Delta area. Concerns have been raised regarding upstream development, in particular the oil sands, local sewage lagoons (Fort Resolution), the float base (Fort Smith), and the potential effects these may have on the water quality. The local residents are worried about how the water quality can affect the animals, plants and people living in the area. It is more common to bring bottled water out on the land as some land users now consider the local water unsafe to drink. Traditional knowledge and local observation relating to water quality include the taste, smell, colour and the "look" of the water (Barnaby and Fresque-Baxter, 2012).

Water quality and hydrology are intimately related and any studies of water quality should take into account variation in flow level. Seasonal changes in flow, along with changes in climate and biological activity, lead to variations in water quality parameters. As compared to the (unregulated) Athabasca River, some water quality parameters in the Slave (and Peace) River show weaker seasonal patterns or opposite patterns to those expected for an unregulated river (Glozier et al., 2009). For example, while expected seasonal patterns were seen in particulate matter (peak in summer) and dissolved oxygen (peak in winter), concentrations of dissolved forms of nitrogen and phosphorus showed opposite than expected patterns (e.g., peak in the summer rather than winter) (Glozier et al., 2009).

5.1 Water quality

Physical characteristics

pH is a measure of acidity or alkalinity of a waterbody, or of the concentration of hydrogen ions present in solution. It is an important variable in water quality assessment as it influences many biological and chemical processes, such as the solubility and biological availability of nutrients and heavy metals (Michaud, 1991). The pH of water is determined by the geology of the watershed and is influenced by the seasonal and daily variations in photosynthesis, respiration and decomposition (CCME, 1999). Municipal, mining and agricultural activities can also affect pH (BC MOE, 1998). Values for pH range from 0 (acidic) to 14 (alkaline), with 7 being neutral.

The pH of the Slave River has been found to be slightly alkaline, ranging from 7.45 to 8.1. Refer to Table 4 for a detailed summary of findings. This is within normal range for natural waters and within the

CGPAL range of 6.5 to 9.0. The NWT-wide Community-based Monitoring (CBM) program (results from open water season in 2012 and 2013) found that pH had a range of 7.7 to 8.2 during the open water season at Big Eddy and the Slave River Rapids. Although no trend was detected in the 1972 to 2010 dataset (Sanderson et al, 2012), an increasing trend (less acidity) was detected in the 1989 to 2006 dataset, at a rate of 0.01 pH units/year (Glozier et al., 2009). The cause of this trend is not known, but it should be noted that variability in pH measurements can be derived from calibration of pH meters for on-site sampling, or due to a biological activity or changes to the equilibrium of carbonic acid during shipping if samples are sent to a laboratory for analysis (Glozier et al., 2009).

Dissolved oxygen is an important variable for aquatic life, particularly for fish. Oxygen becomes dissolved in water from mixing with air, and oxygen is produced as a by-product of photosynthesis by aquatic plants. Dissolved oxygen is temperature dependent, with higher oxygen concentrations generally found in colder water. The CGFPAL water quality guideline for dissolved oxygen is 6.5 mg/L.

In general, dissolved oxygen levels in the lower reaches of the Slave River are relatively high, ranging from 8–15 mg/L (Table 5). This is likely because the rapids at Fort Smith cause turbulence which boosts oxygen content, and because the amount of municipal effluent from the town of Fort Smith discharged into the Slave River is quite small compared to the volume of the river (Chambers and Mill, 1996). Dissolved oxygen levels were found to be increasing at a rate of 0.07 mg/L/year from 1989 to 2006 at Fitzgerald (Glozier et al., 2009). Between 1989 and 2010 the range at Fitzgerald was between 6 – 16.6 mg/L (Sanderson et.al 2012). CBM program results have shown a range of 7.85 – 9.85 at Big Eddy and 9 – 12.75 at the Slave River Rapids.

Conductivity is a measure of the ability of water to conduct an electric current and is a useful indicator of the amount of salts in a sample (such as Ca, Mg, Na, K). The conductivity of a river is determined by the geology of the watershed and may be influenced by road salt, urban runoff and industrial inputs (Lower Colorado River Authority, 2014). Conductivity is measured in microsiemens per centimetre (µS/cm).

Conductivity has been found to vary seasonally with flow and sediment volume and in the Slave River at Fitzgerald, has been found to range from 138 – 364 µS/cm (median 217 µS/cm) (Sanderson et al, 2012). This is low compared to the values found in the Peace and Athabasca Rivers, which is reflective of the location of the Peace and Athabasca in a predominantly sedimentary basin, as opposed to the Slave which is located on a combination of sedimentary rock and Canadian Shield. Conductivity values have not significantly changed over the period since 1989 (Glozier et al., 2009; Sanderson et al., 2012). See Table 6 for a detailed summary of findings. CBM program results have shown a range of 178-255 µS/cm at the Slave River Raids and 210-273 µS/cm at Big Eddy during the open water season at Big Eddy.

Turbidity measures the amount of light scattered by a sample (Michaud, 1991). Turbidity is therefore an indirect measure of the amount of suspended matter in the water, which consists of silt, clay, fine particles of organic and inorganic matter, soluble organic compounds, plankton and other microscopic organisms. Turbidity is measured most commonly in Nephelometric Turbidity Units (NTU) but sometimes in Formazin Turbidity Units (FTU), which are comparable (UNESCO/WHO/UNEP, 1996).

Turbidity varies greatly by season and with flow rate. Turbidity levels at Fort Smith and Fitzgerald tend to be the highest during open-water season (May-July) and lower during winter, however higher levels of turbidity have occurred in November and December (Sanderson et al., 2012). Mean turbidity on the Slave River (Fitzgerald) ranged from 3 to 6400 NTU (n=241; 1972-2010; Sanderson et al., 2012). See Table 7 for a detailed summary of findings. Turbidity values have not significantly changed over the period from 1972-2010 (Sanderson et al., 2012). However, some local residents have noted observations of increased turbidity (Wesche, 2009) while others have stated that in some places the water is now more clear (Barnaby and Fresque-Baxter, 2012). Results from the CBM program showed that turbidity ranged from 52 – 968 NTU within the CBM open water sampling period at Big Eddy and Slave River Rapids.

Nutrients

Phosphorus is an essential nutrient for primary productivity in water bodies. Phosphorus is most commonly measured in particulate, dissolved, and total (particulate plus dissolved) forms. There are no guidelines for phosphorus concentrations in water, as it can vary widely from natural sources.

Natural phosphorus is mostly derived from weathering of phosphorus-bearing rock. Some forms of phosphorus (mineral phosphorus) are not in a usable form (bioavailable) for organisms but can be transformed into usable forms. Human-derived additions of phosphorus (from municipal effluent discharges, septic systems, and agricultural runoff) can be significant in some regions, but are unlikely to be a large contribution to phosphorous levels in the Slave River.

The Slave River has higher total phosphorus as compared to other water bodies in the Mackenzie River basin due to the large catchment area (MRBC, 1981, Glozier et al. 2009). According to a 2004 paper by Stone, a greater proportion of the phosphorus in the Slave River Delta has been found in a form that is potentially bioavailable as compared to other rivers. Conversely, Sanderson et al. (2012) found 81% of the total phosphorus measured at Slave River (Fitzgerald) to be in particulate form and therefore less bioavailable.

Phosphorus concentrations follow the seasonal trend of water flow and sediment volume, being higher in the spring, decreasing through summer and fall, and lowest during in the winter. In the Slave River (Fitzgerald) total phosphorus ranged from 0.006 – 4.67 mg/L, dissolved phosphorus ranged from <0.002 – 0.343 mg/L and particulate phosphorus ranged from 0.01 – 0.5 mg/L. See Table 8 for detailed summary of findings.

For the CBM program, total phosphorous ranged from 0.05 – 0.42 mg/L (at Big Eddy) and 0.04 – 0.31 mg/L (at Slave River Rapids). Dissolved phosphorus ranged from <0.002 – 0.05 mg/L.

A significant trend of increasing dissolved and total phosphorus concentrations was found in the 1989–2006 data (Glozier et al. (2009), but this trend leveled off in more recent years (1997–2006) (Glozier et al. (2009). There was no change in particulate phosphorus over any time period (Glozier et al., 2009). Sanderson et al (2012) found an annual increase in total phosphorus and a seasonal increased trend of dissolved phosphorus in the spring and winter (1974-2010). These trends may be a result of increased agricultural activities within the Peace and Athabasca river basins (MRBB, 2003). More algae on rocks and in fishing nets in the Slave River and denser growth of willows has been observed around the Slave River and maybe linked to increasing phosphorus (GNWT and AANDC, 2012).

Nitrogen is essential for living organisms as an important constituent of proteins, and is found in three major dissolved forms in water (nitrate, ammonium and small amounts of nitrite) and as particulate organic nitrogen. Nitrogen from the air can be captured by certain bacteria and algae and converted into forms that are needed by plants. Nitrogen in waterways is derived largely from biota, but can be added through sewage effluent and agricultural runoff, which are unlikely to be large sources in the Slave River.

At Slave River (Fort Smith), total ammonia ranged between 0.002 – 0.52mg/L in 1982-2010 (Sanderson et al. 2012), and within the CBM sites (Big Eddy and Slave River Rapids) ranged between non-detect to 0.02mg/L. At Fitzgerald, dissolved ammonia values to < 0.001 – 0.33 mg/L and were within CCME ammonia guidelines (1993-2010; Sanderson et al, 2012). There are no guidelines for total nitrogen concentrations. Levels of nitrogen in the Slave River are similar to or slightly less than those found in the Peace and Athabasca Rivers (Glozier et al., 2009).

Deposition of nitrogen in sediment just offshore of the Slave River Delta has been increasing since the 1950s (Evans et al. 1996 a, b), but over a shorter time period, most dissolved forms of nitrogen have been decreasing (Gartner Lee, 2001; Glozier et al., 2009). See Table 9 for a detailed summary of findings related to Nitrogen.

Organic carbon is derived from living material and can enter surface waters from human inputs or from vegetation material. It is found in particulate and dissolved forms. Total organic carbon is the sum of particulate and dissolved organic carbon, with dissolved making up the majority of the total organic carbon. Organic carbon concentrations are linked to transport and bioavailability of some metals and contaminants (Evans et al., 2005), but these relationships are not fully understood.

Findings suggest that average total organic carbon concentrations range from 6.95 – 15 mg/L, average dissolved organic carbon ranges from 4.98 – 9 mg/L, and particulate organic carbon ranges from 1.85 – 4.7 mg/L (see Table 10 for a detailed summary of findings and references). MRBC (1981) found that the Slave River has relatively high organic carbon as compared to other water bodies in the Mackenzie River Basin, based on the large catchment area.

Results from the CBM program showed concentrations for total organic carbon ranged between 6.6 – 11.7 at Big Eddy and Slave River Rapids, and concentrations for dissolved organic carbon ranged from 6.8 – 11.9 mg/L.

Similar to nitrogen, there is evidence of increasing carbon deposition in Great Slave Lake just offshore of the Slave River Delta over the past 50–100 years (Evans et al. 1996a, b; Bourbonniere et al., 1997) but there has been no change in organic carbon concentrations in water more recently (1989–2006) (Glozier et al., 2009) or 1978 to 2010 (Sanderson et al, 2012). There are no guidelines for organic carbon in water.

5.2 Algae

There is very limited information available about algae communities in the Slave River. Chlorophyll concentrations, which indicate phytoplankton abundance, were found to be low (0.3 – 1.1 μg/L) in both winter and summer just offshore off the Slave River Delta (Evans et al., 1997; Evans et al., 1998a)[4]. These values are fairly low in comparison to the other areas of Great Slave Lake, which may be due to high turbidity that could limit the penetration of sunlight in the water. There is also a link between available nutrients in the water (see section above) and the algae.

The algal community is dominated by diatoms, pyrrophyta and cryptophyta (Evans et al., 1997). Sokal et al. (2010) assessed diatom communities in the Slave River and found a seasonal trend, with high levels of some taxa in the spring associated with floodwater.

Residents of both Fort Smith and Fort Resolution have observed similar increased algal growth in the past 5–10 years (Wesche, 2009; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). They have also expressed concerns about oily foam that forms on boats and in eddies (Pembina Institute, 2016).

[4] This section will be updated with available and forthcoming data from the NWT-wide Community-based Monitoring Program. Community partners in the Slave River and Delta area monitor sites on the Slave River at Fort Smith, the Slave River near Big Eddy in the Delta, and on Great Slave Lake.

5.3 State of the knowledge and potential future research

According to the categories outlined in section 1.4, the state of the knowledge about water quality in the Slave River and Slave River Delta can be considered Good. Most of the available information, however, is from sampling sites at Fitzgerald and Fort Smith, where data sets go back to 1960 for some parameters.

There is very little information available about plankton and algal communities, either historically or recently.

Potential future research and monitoring

- Multiple stressor impacts (where more than one factor combines to create an unexpected or higher-than-expected impact) are known to be important in determining overall stress on the aquatic ecosystem. Some multiple stressor impacts have been investigated in the Athabasca River (i.e., Culp et al., 2000a), but not yet in the Slave River. For example, the productivity of Great Slave Lake may have increased (Evans et al., 1998a), which may result in the increased bioavailability of metals (e.g., mercury) through various transformations (Evans et al., 2005). Future investigations of the combined impacts of multiple stressors could improve the understanding of the cumulative effects of human activity (Culp et al., 2000b).
- Despite local observations of increased algal growth in the Slave River, there does not appear to be any research documenting algal communities from recent years, or assessing trends in productivity over time. This is especially pertinent given that recent results from Carrie et al. (2010) show increased algal growth in lakes in the Mackenzie Basin due to warming temperatures, and that there is a link between algal growth and bioavailability of mercury. In particular, research could investigate the possibility of algal growth on biofilms or in oxbow lakes which do not receive regular inputs of river water.
- Further work could be pursued on changes in concentrations of dissolved organic carbon over time. Worldwide, trends of increasing dissolved organic carbon in rivers have been observed (Bourbonniere, 2009). While this trend has not been seen in the Slave River, future monitoring could confirm this finding. Considering the large spatial area of peatlands and bogs (known to be a large source of dissolved organic carbon) in the Slave River catchment, research could investigate the role of dissolved organic carbon in aquatic food webs, particularly microbial components.
- A number of the recommendations that have been presented by Glozier et al. (2009) for water quality monitoring within Wood Buffalo National Park are relevant to the Slave River and Delta, including:
    - Assessment and reporting of water quality data on a set schedule (for example, every five years) could be considered.
    - Site-specific objectives for nutrients could be established for routine reporting.
    - Biota density and community composition of algae could be determined at sites of interest, at a frequency of every three years.
- Community members have expressed concerns related to *Ecoli bacteria* and potential effects on human health (Pembina Institute, 2016). MACA tests raw and treated water on a regular basis and information can be accessed through an online drinking water database (MACA, n.d.).
- Water quality sampling needs to capture the full profile of the river. It may be worthwhile to collect samples at different depths at each site. Testing should be sporadic and across time to better determine water quality at multiple monitoring stations.

- It was stated by the SRDP (Pembina Institute, 2016) that water quality should be sampled during extreme high (when turbidity is high), and extreme low (when dilution is low) water level events. If information could be communicated by Environment Canada (weather related) or by the government of British Columbia (if the water levels are caused by a release from the Bennett Dam), people along the river could collect samples as the pulse moves down. Methodology and data sharing would need to be coordinated. Sampling after large rain events could also be useful. The foam that appears on boats in the river and in eddies should be sampled to determine its composition (Pembina Institute, 2016)
- Bioindicators such as pelicans and beavers may be useful in assessing water quality and impacts of changes to water quality (Pembina Institute, 2016).
- Work with the jurisdictions of the Mackenzie River Basin to develop a consistent approach to assessing water quality and quantity conditions so that regional comparisons can be made. This will allow for a common understanding of potential changes to water quality throughout the watershed, and specifically in the Slave River.
- The development of site specific water quality objectives for the Slave River based on historical data would provide a more accurate context for the review and assessment of the water quality results.
- Undergo studies to understand the causes and impacts of the long-term trends identified in the water quality of the Slave River.
- Studies to determine if the increasing trend in winter water flows and the decreasing trend in summer and fall winter flows are having an impact on water quality and biological receptors of the Slave River.

6. Metals and contaminants

Metals in water, sediment and fish

Metals have both natural and anthropogenic origins and are often strongly associated with sediments in the Slave River. Metals undergo a complex series of transformations: weathering in rocks, dissolution and precipitation, forming complexes, and changing from oxidized to reduced forms. Human activity can result in increased metal concentrations both locally and through long-range transport. Metals are mostly derived from the underlying bedrock and generally associated with sediments (see section 4.4). Trace concentrations of some metals are required for plant and animal nutrition; however, high concentrations of metals can be harmful or toxic to aquatic organisms.

Concentrations of metals on or in sediment can be compared to the Interim Freshwater Bottom Sediment Quality Guidelines, which determines a threshold effect level (TEL), below which adverse effects would be expected to rarely occur, and the probable effect level (PEL), above which adverse effects are predicted to occur frequently. Another set of guidelines, the Ontario Sediment Quality Guidelines, uses a Lowest Effect Levels (LEL) and Severe Effect Levels (SEL). It should be noted that there are currently no guidelines for suspended sediments.

In fish, concentrations of metals vary between fish species and within species (i.e., by age, length and weight), trophic position, lipid (fat) content of tissue, and sample site.

Guidelines for human consumption of metals are fish are determined by Health Canada and the Government of Northwest Territories (Environment Canada, 2012).

It is important to note that improved analytical technologies have decreased the detection limit (below which no concentration can be confirmed) for metals over the last 40 years. Currently, metals can be detected at much lower levels than was previously possible. Thus, comparisons of earlier results to more recent results are not always possible, and any comparison of temporal trends from data generated with different methodologies must be viewed with caution.

Results from the Water and Suspended Quality of the Transboundary Reach of the Slave River, Northwest Territories 2012 report include metals and contaminants in water and suspended sediment from 2000–2010 and are included in this report. Since 2012, NWT communities, water partners and ENR have worked together to monitor water quality as part of the NWT-Wide Community-based Water Quality Monitoring Program to help answer community questions about water. Grab water samples were analyzed for both dissolved and particulate metals. In addition, *Diffusion Gradients in Thin-Films passive samplers* are analyzed for dissolved aluminum, iron, manganese, cobalt, nickel, copper, zinc, cadmium, lead, vanadium and methyl mercury. The results from these samplers are compared with guidelines developed by the *United States Environmental Protection Agency (USEPA)* as there are no CCME Guidelines available for dissolved metals in water, just for the total amount of metals in the water (GNWT 2014)

Metals in water

In the Slave River, metals are thought to be mostly of natural origin and adapted to by biota (McCarthy et al., 1997a). Although levels of some total metals in the Slave River did exceed guidelines, most of the metal was in the particulate form and therefore potentially less biologically available (Sanderson et al., 2012). However, for cadmium and copper, the dissolved fraction accounted for a large percentage of the total metal concentration. 12 out of 24 dissolved cadmium values and almost all (99%) of the total cadmium values (when the detection limit was above the guideline) exceeded the total cadmium guideline. 13 out of 28 dissolved copper values and 154 out of 211 total copper values exceeded the total copper guideline. There are no guidelines for dissolved metals. This highlights the need for site specific water quality objectives to be developed for both total and dissolved metals, to be better able to determine the potential impacts, if any, of metals concentrations in the Slave River. Of all metals assessed, iron concentrations most commonly exceeded guidelines, followed by copper. See Table 11 for a detailed summary of findings.

In an assessment of trends in measurements at Fitzgerald, Glozier et al. (2009) found that metal concentrations were generally stable or decreasing over the late 1990s to early 2000s. Sanderson et al. (2012) found decreasing trends in total aluminum, chromium and molybdenum levels in water samples from Fitzgerald.

Metals in suspended sediments

Contaminant concentrations in suspended sediments have been found to be higher than in water or bottom sediments (Swanson et al., 1993; Crosley, 1996; Carey et al., 1997). This is due to the finer silt and clay content of the suspended sediment, which provides a greater surface area for compounds to adhere to (Swanson et al., 1993). Suspended sediment can therefore serve as an early warning of environmental degradation. As sediments remain suspended in the water column for a long period in the Slave River, they can be transported great distances.

Overall, Sanderson et al. (2012) found some metals above TEL or LEL (arsenic 15/23 samples, cadmium 7/27, chromium 6/27, copper 2/27, manganese9/25, nickel 26/27 and zinc 5/27), and only one sample above the SEL (manganese). Refer to Table 12 for a detailed summary of findings. Exceedances of guidelines were found to be highly correlated with high levels of suspended sediment (Glozier et al., 2009), thus metals are likely either naturally derived from sediments or absorbed onto the organic film that covers small particles (e.g., clay). It should be noted that values were compared to the Canadian Draft Interim Freshwater Bottom Sediment Quality Guidelines because suspended sediment guidelines do not exist.

Significant differences were not observed between 1990-1995 and 2000-2010 suspended sediment metal concentrations (Sanderson et al., 2012). A positive correlation was found between metal concentrations, percentage of clay particles, and organic carbon levels of the suspended sediment. Three different seasonal patterns were observed for the individual metals. Most metals, including aluminum, barium, lead, mercury, strontium, vanadium and zinc had higher concentrations during summer and fall than winter. This was similar to the pattern observed with organic carbon and percent clay content. Another common pattern that emerged for chromium, cobalt, copper, iron and manganese, was that highest concentrations were observed in fall with lower levels occurring in the summer and lowest levels in the winter. Nickel showed higher concentrations during the fall than in the summer and winter (Sanderson et al., 2012).

Metals in bottom sediments

As stated above, metals associated with sediments in the Slave River and Slave River Delta are likely natural in origin (Evans et al., 1996a, b; Evans et al., 1998a). In an investigation to determine whether the decommissioned Pine Point Mine could be contributing to metals in water, sediments and fish, Evans et al. (1998a) found no evidence of contamination, and a review of mine operations did not reveal any mechanism that could cause contamination. Refer to Table 13 for a detailed summary of findings.

Over the last century, there has been a small increase in arsenic (Mudroch et al., 1992), copper and lead which can be attributed to atmospheric deposition (Evans et al., 1998a). Preliminary results from a sediment coring research project indicated that concentrations of most metals in the Slave River Delta lake were within natural variation (Wolfe and Hall, 2014). Metals were analyzed in sediment cores representing 87 years of sedimentation to compare values pre-oil sands development (pre-1967) to post-development (post-1967). Some metals however, such as arsenic, strontium and calcium exceeded guidelines during pre-oil sands development and could potentially be related to the air emissions from the gold mine Giant Mine (Yellowknife, NWT).

Metals in fish

From 1990–1995, walleye, northern pike, lake whitefish and burbot were collected from both the Slave River and control sites and analyzed for metals (Sanderson et al., 1997). Many of the elements (calcium, copper, iron, magnesium, manganese, mercury, phosphorus, potassium, sodium, strontium and zinc) were detected in most muscle and liver samples from both sites. Some metals were present in a greater percentage of muscle samples while tin and cadmium were found in a greater percentage of liver samples. The percentages of detection and the range of values were generally comparable between the Slave River and the control lakes, which suggests similar sources of metals, either geological or airborne. Evans et al. (1998a) sampled burbot, walleye and pike muscle in the Slave River and found elevated arsenic in some samples, but this may have been related to changes in analysis methodology over time. Arsenic and other metals (excluding mercury) in fish in Resolution Bay were found to be generally low by Lafontaine (1997) and Evans et al. (1998b).

Although mercury occurs naturally in the environment, human activities, such as hydroelectric, mining, and pulp and paper industries, have increased its concentration (Lafontaine, 1994). Methylmercury is the primary form of mercury in the environment due to conversion by anaerobic organisms (Sorensen, 1991). Mercury biomagnifies through the food chain and consequently fish at higher trophic levels have great body burdens of mercury (Lafontaine, 1994). Mercury concentrations in Slave River fish range from 0 to 0.54 µg/g, depending on species, tissue sampled and sample site. Refer to Table 14 for a detailed summary of findings. Similar concentrations of mercury in the Slave River, control lakes and other NWT sites suggest that mercury is of atmospheric or geologic origin (Grey et al., 1995; Sanderson et al., 1997). Lafontaine (1997) did not find elevated mercury concentrations in fish sampled in Resolution Bay.

Sanderson et al. (1997) and Evans et al. (1998b) found that some individual fish had mercury concentrations higher than 0.2 µg/g which is the guidance provided by Health Canada for subsistence users. Mean values for pike and walleye were above the guideline of 0.2 µg/g for subsistence consumption but the average value of samples was below 0.5 µg/g which is the guideline for commercial consumption. Please see Table 14 for a detailed summary of findings.

Evans et al. (2005) looked at trends in mercury concentration in sport fish in the Slave River between 1990 and 2000 but found no conclusive results and instead suggested that results are reflective of the individual fish sampled.

Metallothionein is a metal-binding protein that is thought to be induced by exposure to selected heavy metals (Macdonald, 1990a). Klaverkamp and Baron (1996) found levels of metallothionein in burbot kidney and gill tissue to be 7 to 26 times higher in the Slave River Delta than sites in the Peace and Athabasca Rivers. However, Evans et al. (1998a) repeated the metallothionein study in burbot but did not find elevated concentrations.

Preliminary results from the Regional Fish Health Study in the Slave River and Athabasca River show that the majority of the metals that were analysed in fish samples showed little or no variability between the different sites. Concentrations of four metals (Thallium, Vanadium, Selenium and Mercury) did show location associated variability (Tendler et al., 2012). Vanadium, Thallium and Selenium were greater at sites sampled on the Slave River than sites on the Athabasca River (Tendler et. al., 2012). Vanadium can occur in higher concentrations due to natural hydrocarbon sources (e.g., bitumen seeps) and from industrial development such as exploration of oil sands. Tendler et al. (2012) note that "selenium concentrations varied little among sites in summer, but in the fall were greater on the Slave River…A steady increase in the concentration of thallium in fish muscle was noted at sites proceeding down the Athabasca/Slave system". Thallium was higher in higher level trophic species (jackfish and whitefish) (Tendler et. al., 2012). The concentrations are still low and not a concern for human health. The preliminary results show no evidence of health impacts on the fish itself (Jones, 2013).

Contaminants in water, sediment and fish

Environmental contaminants can enter aquatic ecosystems through effluent from industrial activities, application of chemicals for land use activities, and atmospheric deposition (Barrie et al., 1997). In aquatic systems, contaminants are distributed among sediment, water and biota.

Similar to metals, concentrations of some contaminants can be compared to the Interim Freshwater Bottom Sediment Quality Guidelines (threshold effect level (TEL) and the probable effect level (PEL)), or the Ontario Sediment Quality Guidelines (Lowest Effect Levels (LEL) and Severe Effect Levels (SEL)). Guidelines for all contaminants do not exist currently as knowledge of toxicity is evolving.

As with metals, the ability to detect many contaminants has changed over time and caution must be used when comparing historical results to more modern results. Results that are below detection limits must also be viewed with some caution, as contaminants may still have unknown effects or may act synergistically with other compounds to produce effects.

Below are listed some of the potential contaminants of concern in the Slave River:

- **Polycyclic aromatic hydrocarbons (PAHs)** can be of geologic origin associated with petroleum deposits or can be created during combustion (Bobak, 2010). A small portion of PAHs are also made by biosynthesis (Neff, 1979). Natural sources of PAHs can include natural oil seeps, bituminous outcrops, and forest fires, while anthropogenic sources of PAHs can include industrial production, refining and transport of petroleum, spills and leaks from tailings ponds and waste sites, and incomplete combustion of fossil fuels (Bobak, 2010; AANDC, 2012; Environment Canada, 2013). Some types of PAHs are highly toxic to aquatic organisms and are carcinogenic (Hawkins et al., 1988; Burgess, 2009). PAHs are known to be associated with organic material in aquatic environments (CCME, 1999a). This relationship has not necessarily been seen in the Slave River (McCarthy et al., 1997a) though it appears there is a highly specific relationship between size and type of sediment molecule and species of PAH (Ahangar, 2010). Generally, low molecular weight PAHs are more soluble and volatile than high molecular weight PAHs (CCME, 2010).
- **Dioxins and furans** are a family of structurally and chemically similar compounds. Dioxins are also known as polychlorinated dibenzo-*para*-dioxins (PCDDs), and furans are also known as polychlorinated dibenzofurans (PCDFs). Of the 210 types of dioxins and furans, 2,3,7,8-tetrachloro-p-dibenzo-dioxin (2,3,7,8-TCDD) is considered the most toxic and is a probable carcinogen (EPA, 2000). Dioxins and furans are known to bioconcentrate and cause toxic effects (WHO, 2010). Dioxins and furans are by-products of a number of industrial processes including chemical, pulp and paper, metallurgical and dry-cleaning industries. They are found in the effluent of bleached kraft pulp and paper mills (Swanson et al., 1993). They can be transported in water in association with sediments and can also be transported through the atmosphere over long distances (Commoner et al., 2000).

- **Pesticides** such as DDT, toxaphene, dieldrin, mirex, chlordane and lindane are highly toxic and tend to bioaccumulate. Some of these compounds are now prohibited in Canada, but may still be used globally, and have been widely used in the past (CCREM, 1987). Toxaphene (also known as camphechlor) is a broad spectrum pesticide and is a prominent contaminant in fish. It was banned in Canada in 1982 but has been shown to be transported atmospherically to areas where it has never been used (Bidleman and Olney, 1975). Lindane is an organochlorine insecticide that was used to control a broad spectrum of insect pests. Most uses of lindane were discontinued in Canada by 2002; however it remains in the environment due to its persistence. Lindane enters aquatic systems mainly as surface runoff from treated lands, treated lumber and livestock, and deposition following volatilization and aerial transport. (CCME, 1999b).
- **Polychlorinated biphenyls (PCBs)** are chlorinated aromatic hydrocarbons that are highly persistent in the environment and known to bioconcentrate in fatty tissue (CCREM, 1987). PCBs were used widely as coolants in electrical and mechanical systems and in paints, adhesives and sealants. Sources of PCBs entering the environment include incomplete combustion of PCB wastes, and sewage and leaching from dumps and landfills (EPA, 2002). Exposure to PCBs may result in toxicity, reproductive impairment and cancer (EPA, 1996). Use of PCBs has been banned in Canada since 1980 (Environment Canada, 1980).
- **Chlorophenols** are a family of organic chemicals in which one or more of the hydrogen atoms in the phenol group are replaced by one or more atoms of chlorine. Chlorophenols are most commonly used in pesticides, but can also be formed though degradation of other chemicals (e.g., phenoxyalkanoic acids) or as a result of the chlorination of humic matter or carboxylic acids during the treatment of municipal drinking water. They are no longer manufactured in Canada, but continue to be imported and used (Health Canada, 1987).

Local residents have expressed concerns about the potential health impacts of contamination in water and fish. They are concerned that rates of cancer and diseases in Fort Smith and Fort Resolution are higher than in the past, and higher than average (Wesche, 2009; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). Cancers of the kidney and liver as well as cancers in young children were highlighted as major concerns (Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016).

Contaminants in water

Few organic contaminants have been detected in Slave River waters, and of those, most are associated with suspended sediment. In general, very low levels of chlorinated phenols and pesticides were found in a few samples; these detected values were below guidelines and PCBs were not detected. Refer to Table 15 for a detailed summary of findings. PAHs have been detected using the PMDs as part of the NWT-wide Community-based Monitoring Program. Most of the total hydrocarbon concentrations were below the background levels for northern rivers (15 ng/L: Yunker et al., 2002). All of the dissolved hydrocarbon results were well below concentrations that can affect aquatic life (400 ng/L: Carls et al., 1992).

Contaminants in suspended sediment

Contaminants tend to adsorb to fine grain suspended sediment, and thus sediments often have much higher levels of contaminants than the surrounding water (Schindler et al., 1995; Evans et al., 1996a, b).

Sediment grain size is an important factor in sediment adsorption and deposition as contaminant levels are higher in small particles (clay and silt) as compared to sand (McCarthy et al., 1997a). Consequently, spatial distribution of contaminants is strongly connected to spatial distribution of clay and silt (Milburn et al., 1998). Some contaminants may also be strongly associated with organic matter in sediment (McCarthy et al., 1997a) and toxicity may be modified by the presence of organic matter (Barrie et al., 1997).

In the Slave River Delta, deposition of large amounts of clay and silt in distributary channels create higher concentrations of contaminants in the river bed as compared to upstream in the Slave River (Milburn and Prowse, 1997a). Within the Delta, the smallest channels have higher concentrations of contaminants due to high levels of deposition of clay and silt under ice (Milburn and Prowse, 1997; 1998a, b). Additionally, the mid-Delta exhibits higher levels of the contamination as opposed to the outer or upstream areas because the mid-Delta experiences high levels of sediment deposition but little erosive activity, as rooted vegetation acts as a trap for finer sediments (Milburn et al., 2000).

As mentioned above, a large portion of sediments and contaminants from the Slave River are ultimately deposited in Great Slave Lake. Because the Slave River is fast flowing, fine grain sediments (and contaminants adsorbed onto them) can be transported great distances into Great Slave Lake (MacDonald and Smith, 1993). Sediments can also be re-suspended numerous times due to wave action. While the Slave River could be a significant source of contaminants to Great Slave Lake, concentrations in the lake are still low and comparable to other subarctic and arctic lakes (Evans et al. 1996a, b).

PAHs: PAHs are associated with suspended sediments, with peak concentrations in open water seasons corresponding with peak suspended sediment concentrations (Sanderson et al., 1997). Sanderson et al. (1997) found all but one of the PAHs tested for in sediment samples from 1991-1995. Some concentrations found were above the TEL and/or LEL but all results were well below the PEL. Therefore it was concluded that PAH levels detected in the Slave River sediments would not adversely impact the aquatic biota (McCarthy et al., 1997a). As compared to southern lakes, levels of PAHs in Great Slave Lake are quite low (Evans et al., 1996a). From 1990 to 1995, no change in PAH concentrations in suspended sediment was observed (Gartner Lee, 2001).

Results from the follow-up study of the SREQMP (2000-2010) detected 26 out of 28 PAH compounds The ranges of values above detection tended to be lower in the follow-up study and all of the detected PAH compounds were below CCME CPFAL guidelines.

Preliminary results from a sediment coring research project indicated no increase of PAHs in the sampled delta lake after the industrial mining of oil sands started along the Athabasca River (Wolfe and Hall, 2012). This study indicated that the contaminants from the oil sands mining are carried by the Athabasca River and deposited in the Peace-Athabasca Delta and Lake Athabasca and are not carried further downstream to the Slave River Delta.

Organchlorine Pesticides and PCBs: No detectable levels of PCBs were found in suspended sediment samples in the Slave River at Fort Smith (Sanderson et al., 1997; Sanderson et al., 2012). A few organic pesticides were detected in surface water samples at Fitzgerald.

Dioxins and furans: Sanderson et al. (1997) found five of 17 dioxin and furan isomers in the suspended sediment samples at Fort Smith. These concentrations were quite low (near detection limits). In the follow-up study (2000-2010), six of 17 dioxin and furan isomers were detected, also at low levels (Sanderson et al., 2012). The most toxic compound, 2,3,7,8-TCDD was never detected. The apparent decrease in in detection of the 2,3,7,8 TDCF, a marker for bleached kraft pulp mills, may be attributed to changes in the pulp mill bleaching process. All values were below guidelines (1990-2010).

Chlorophenols: Of the 44 chlorophenols tested for**,** 21 were detected by Sanderson et al. (1997) at Fort Smith. No guidelines for chlorophenols were available to compare these findings against; however, the authors suggest that the concentrations and frequency of findings were low and therefore adverse impacts on the environment were unlikely. Results suggest that the Slave River may be a source of chlorophenols to Great Slave Lake (Gartner Lee, 2001). Chlorophenols were not detected in 2000-2010 suspended sediment samples, but detection limits were not always comparable. Refer to Table 16 for a detailed summary of findings.

Contaminants in bottom sediment

PAHs: PAHs have been found in bottom sediments in the Slave River and Great Slave Lake (Evans et al., 1997). Concentrations range from 60 – 837 ng/g, depending on sample site. Temporal analysis of core samples suggested that there has been increasing deposition of PAHs over the past 40-50 years; however this trend was not uniform for all cores and all compounds (Evans et al., 1996a, b).

Dioxins and furans: Dioxins and furans have been found at low concentrations in sediment samples from near the mouth of the Slave River (Evans et al. 1996a, b). The concentration of dioxins and furans in sediment has been increasing since the 1950-1960s, but overall, levels of these compounds are considered to be low (Evans et al., 1996a).

Pesticides: Mudroch et al. (1992) found seven pesticides in all sediment samples taken from the mouth of the Slave River Delta. Concentrations of pesticides ranged from 0.1 to 1.1 ng/g, and were much lower than those in other large lakes in more industrialized areas. Evans et al. (1996a, b) found low levels of a number of pesticides in bottom sediment samples collected from Great Slave Lake. HCH concentrations appeared to be increasing over time (Evans et al., 1996a).

PCBs: Concentrations range from 1.5 – 300 ng/g, depending on sample site, with highest concentrations in small distributary channels. The low molecular weight of the PCBs suggests atmospheric deposition as the route of transport. Evans et al. (1996a) found a trend of increasing PCB deposition since the 1950-1960s.

Chlorophenols were found to be higher in bottom sediment than suspended sediment (Gartner Lee, 2001). Concentrations in bottom sediments in various channels of the Slave River Delta ranged from 19.7 – 62.5 ng/g (Milburn and Prowese, 1998b).

Refer to Table 17 for a detailed summary of findings of contaminants in bottom sediment.

Contaminants in fish

Because many contaminants resist degradation and accumulate in lipids (for organics) and muscle and other tissue (for metals), and because fish in cold-climate regions grow slowly, there is considerable potential for accumulation of environmental contaminants in the Slave River and Delta. Contaminant concentrations are strongly influenced by trophic position of the species, fat content (for organics) and the age, length and weight of the fish. Burbot in particular are prone to high concentrations of contaminants due to their high trophic position (Tallman et al., 1996c) and high lipid content in muscle and liver. Burbot liver in particular is very high in fat (12 to 48% lipid) and the liver is the deposition site within the body for many toxic compounds (Voss and Yunker, 1983; Sanderson et al., 1997).

PAHs: Sanderson et al. (1997) showed very low levels of PAHs have been found in fish.

Preliminary results of a regional fish health study looking at the bile in fish to indicate exposure to PAHs, in particular for 5-ring PAHS, indicated that fish from sites closer to the oil sands activities along the Athabasca River exhibited the greatest exposure. This method of measuring PAHs only indicates recent exposure to PAHs and the concentrations from the bile are not a reflection of the concentrations of the edible fish tissues. Further investigations to identify a profile of the PAHs (the source of the contaminants) will take place as part of the regional fish health study (Ohiozebau et. al, 2012).

Dioxins and furans: Monenco Consultants Ltd. (1991) found no detectable dioxins and furans in goldeye and pike muscle in the Slave River. With regards to dioxins, Sanderson et al. (1997) found that dioxins were present in burbot livers and wholefish samples of all species studied. Burbot livers showed the highest concentrations for both dioxins and furans, because "their high lipid content (12 – 48%) make them attractive to lipophilic chlorinated organic contaminants" (Sanderson et al., 1997, p. 5-54). Fish from both the Slave River and control sites contained the compounds. The most toxic form, 2,3,7,8-TCDD, was found in all species except northern pike, but at values substantially below the Health Canada guidelines (Sanderson et al., 1997). It should be noted that values decreased after 1990 and that the higher values detected in earlier years may have been a result of less accurate laboratory analytical methods.

Pesticides: Toxaphene has been detected in burbot liver from the Slave River (Sanderson et al., 1997) and in Great Slave Lake burbot (Evans, 1996a, b, c). An increase in the level of toxaphene found between samples collected in 1990-91 as compared to 1991-92 prompted Health Canada to recommend that people limit the consumption of burbot livers from the site (GNWT, 1992) to no more than 20 grams of burbot liver per day. It was later determined that the analytical methods used in these tests led to overly high results (Sanderson et al., 1997) and subsequent studies revealed lower values (Evans et al., 1998b). Toxaphene concentrations have remained steady in the west basin of Great Slave Lake as compared to declining concentrations in the east arm during the 1990s (Evans and Muir, 2001). Muir and Fraikin (2004) hypothesized that Great Slave Lake may act as a sink for toxaphene because of its cold temperatures and long water residence times.

Other pesticides, such as chlordane and lindane, were found at levels close to detection limits in burbot livers (Pastershank and Muir, 1996; Sanderson et al., 1997; Muir and Fraikin, 2004).

PCBs: PCBs are another contaminant of concern in fish. PCBs in burbot livers range from 0.0001 to 0.8 μg/g (Pastershank and Muir, 1996; Sanderson et al., 1997; Evans et al., 1998b). The presence of PCBs in fish in the Slave River was similar to control sites, which suggests an atmospheric source of PCBs (Sanderson et al., 1997).

Chlorophenols: Monenco Consultants Ltd. (1991) sampled goldeye and pike muscle in summer 1990 in the Slave River, and found very low levels of chlorinated phenols. Sanderson et al. (1997) found chlorophenols in the fish samples from both the Slave River and control sites, suggesting an atmospheric source. However, levels in the Slave River were higher, suggesting additional sources associated with upstream activities.

Williams et al. (1997) assessed MFO, an enzyme in fish that indicates the presence of contaminants, in walleye, northern pike, lake whitefish and burbot. They found few significant differences between the Slave River and the nearby control site, and that overall concentrations of the enzyme were low.

Refer to Table 18 for a detailed summary of findings.

6.1 State of the knowledge and potential future research

According to the categories outlined in section 1.4, the state of the knowledge about metals and contaminants in the Slave River and Slave River Delta can be considered Good. There have been a number of investigations of metals and contaminants, with most of this information generated in the mid-to-late 1990s. There have been a number of investigations into fish contaminant loads, some of which are from the early 2000s. Research efforts have been focused on species and contaminants that are known to be of concern and/or of importance to local residents.

Potential future research and monitoring

- Ongoing monitoring of contaminants in water and sediments is needed to collect up-to-date information and build a database that will allow assessment of temporal trends. The sample frequency should be determined based on a risk assessment while including the precautionary principle and estimated increases in contaminants.
- Contaminant deposition over time has been sampled in Great Slave Lake a number of times, but has not been investigated in the Slave River Delta recently. An assessment of sediment and contaminant deposition over time in the Slave River Delta would be helpful to compare to the Great Slave Lake results, to better understand how patterns of sediment deposition may be changing with changing water level, and the implications of these changes for contaminant loading.
- While it is likely that fish, benthic organisms and aquatic plants are adapted to metals that are associated with sediment, it has been shown that toxicity of combinations of metals can be more than additive (Reeder et al., 1979). Therefore, follow-up studies on the toxicity and natural variability of the metals in the suspended sediments in the Slave River at Fort Smith could be warranted.
- Further investigation is warranted into the effects of nutrient concentrations on the bioavailability and toxicity of organochlorines, as has been investigated in the Peace River (e.g., Culp et al., 2000a).
- Research in other regions suggests that analytical analysis can indicate the source of PAHs (e.g., Wang et al., 1999). Similar research could be undertaken on the Slave River to assess the contribution to PAHs from natural and human sources. Sampling bitumen seeps along the Slave River for PAHs, metals and naphthenic acids could also help to differentiate between sources.
- Core sampling has shown that the Slave River is a source of PAHs to Great Slave Lake and that deposition is increasing over time (Evans et al., 1996a, b). These compounds could be monitored on an ongoing basis in order to assess rates of contamination.
- Spatial patterns in sediment deposition indicate that atmospheric transport is the source of a number of organic compounds. Continental trends of contaminant distribution could be compared against sediment cores to further investigate how cycling and re-suspension of sediments contributes to overall bioavailability of contaminants in Great Slave Lake (Evans et al., 2005).
- The natural range and variation in metal distribution based on geology for the Slave River region (e.g., Painter et al., 1994) could be assessed to determine how natural sources of metals are contributing to observed concentrations.
- Increases in mercury loading can be a result of melting permafrost (Rydberg et al., 2010). The Slave River catchment could be assessed for mercury flux to determine how increases in natural load are linked to observations of mercury concentrations in sediments, in light of declining atmospheric concentrations.
- As suggested by Tallman et al. (1996a, b), differences in life history in fish could potentially explain different amounts of contaminants in inconnu and burbot, two fish that are found at a similar place in the trophic chain. Other comparisons of contaminant levels between fish with similar feeding habitats could identify key differences in life history, which could inform future work.

- There is evidence that some organochlorines are at lower concentrations and/or declining in burbot livers in the Slave River while higher concentrations were observed in Great Slave Lake. This trend may be due to analytical methods or decreases in organochlorine inputs from the Peace and Athabasca Rivers (Muir and Fraikin, 2004; Evans et al., 2005). Further contaminant trend monitoring could be set up to complement the existing research under the Northern Contaminants Program.
- The higher levels of contaminants seen in burbot in the Slave River Delta as compared to those in the Athabasca and Wapiti Rivers may indicate a higher quality food source found in the Slave River Delta, leading to greater lipid content and higher contaminant concentrations (Pastershank and Muir, 1996). This hypothesis could be investigated further.
- The effect of water temperature on metabolic function and lipid content of fish could be further investigated. Since the storage of lipids directly impacts contaminant concentrations, increased metabolic activity under higher temperature conditions may lead to reduced contaminant storage.
- Ongoing studies on human contaminant exposure for residents could be undertaken, using an approach that accounts for all sources of exposure and metabolic pathways.
- Boag (1993) noted that flathead chub are a non-migratory, abundant species found throughout the Slave River. As they could provide information about site-specific contaminants in the Slave River, further investigation is warranted in this area.
- Given the observed contaminant loading in burbot liver and their importance to local people, future contaminants research should continue to monitor this species.
- Generally, it has been expressed that there is a need to ensure that monitoring programs are capturing the full range of contaminants in the system, that interactive effects between contaminants and other water quality parameters are understood and factored into the water quality standards, and that baseline data is needed to pinpoint stressors and impacts (Pembina Institute, 2016).
- Reintroduce toxicological tests on Slave River suspended sediment samples. These tests measure the toxicity of the sediment samples to lower trophic levels of the aquatic environment and are considered standard protocols for toxicity testing by Environment Canada.
- Consider archiving suspended sediment samples. Archival of these samples will allow for re-analysis should new contaminants emerge or if lower detection limits can be obtained.

7. Fish and insect/benthic communities

7.1 Fish population

A wide variety of fish species are known to inhabit the Slave River and Slave River Delta, including anadromous, resident and migratory species. Studies of the fish community in the Slave River have identified between 18 and 23 fish species. Species diversity of major fish species does not appear to have changed to any recognizable degree from the late 1970s to the late 1990s (Tallman et al., 1996c; Stewart, 1999). Refer to Table 19 for a detailed summary of findings.

Fish species composition varies seasonally due to spawning migrations (Tallman et al., 1996c). Migratory species such as inconnu and lake whitefish spawn in the Slave River in the fall and return to Great Slave Lake for most of the year. Spring spawners such as goldeye, flathead chub and walleye dominate shortly after ice break-up. Other species remain constantly abundant through the open water season, such as pike, flathead chub and goldeye. Small fish are found in greatest abundance during the late spring and summer while large fish are most abundant during spawning in early spring and late fall (Tripp et al., 1981).

The lower part of the Slave River (below the rapids at Fort Smith) is higher in abundance and diversity than the upper part, as the rapids act as a barrier to fish movement and the Delta provides diverse habitat (Tripp et al., 1981; Boag, 1993). Small, well-vegetated channels are gathering places for minnow fish species such as lake chub, emerald shiner and pearl dace (MRBC, 1981). Larger channels, such as ResDelta, East, Middle, and Steamboat, are known to provide critical spawning habitat for burbot and cisco, and rearing habitat for juvenile goldeye, lake whitefish, juvenile burbot, flathead chub, longnose sucker, and northern pike (Stewart, 1999). In the main river, lake whitefish, inconnu, and chum salmon are known to spawn just below the Rapids of the Drowned in fall, and goldeye and walleye spawn in the spring in upstream parts of the Slave (RL & L/EMA, 1985).

Trophic relationships and life history of fish communities were assessed in the mid-1990s. The trophic structure is dependent on the invertebrate community, which is consumed by invertebrate-eaters (such as lake whitefish, goldeye, flathead chub, longnose sucker and white sucker). These fish are consumed by piscivorous species (such as burbot, pike, walleye and inconnu) (Tallman et al., 1996c). Predator-prey circularities likely exist, where one species preys upon juveniles of another, while also being the prey to the adults. Little et al. (1998) found that there was significant overlap between piscivorous species and invertebrate-eaters, especially in spring when high turbidity reduces visibility. At this time, most fish tended to be generalist, consuming both other fish and invertebrates. Stable isotope analysis of sulphur in the Slave River shows evidence of two distinct sources of food for fish: one from Great Slave Lake and another upstream in the Peace and Athabasca Rivers (McCarthy et al., 1997c; Hesslein and Ramlal, 1992).

Because lake whitefish, burbot and inconnu are very popular species for human consumption, there has been a larger research focus on these species.

Lake whitefish are mostly migratory and return to the Delta from Great Slave Lake to spawn in October. However there is evidence of a resident population as well (RL&L/EMA, 1985). The rapids below Fort Smith are likely an important spawning area (Stewart, 1999) but spawning has also been noted as far downstream as Mile 379 below Grand Detour (RL&L/EMA, 1985. Little et al. (1998) identified three groups of whitefish: migratory whitefish that return in the fall to spawn, immature whitefish that were present and feeding, and a small peak of mature whitefish found in the spring that likely overwintered at their spawning grounds.

Burbot return to the Delta in the fall right before freeze-up, and some burbot may move under ice, as a small population remains around Fort Smith until early to mid-December. Spawning likely occurs near the Slave River Delta and in the Cunningham Landing/Salt River areas in late December to February (Tallman et al., 1996a, b). Jacobson and Boag (1995) found that burbot preferred shallow areas with cobble, gravel, and sand substrate. In a comparison between burbot from the Slave River and from the Peace and Athabasca Rivers, burbot in the Slave River Delta were bigger and in better condition but showed lower fecundity, with a relatively high age-at-maturity and slow growth rates (Cash et al., 2000). Tallman et al. (1996c) noted that burbot appeared to be relatively sedentary as compared to other inconnu, another migratory species.

Inconnu are an important species in the area (Sly, 2001). Inconnu feed and overwinter in Great Slave Lake but spawn in the fall around Fort Smith (Howland et al., 2000, 2001). Inconnu populations have declined in the early 1970s, and according to a report by Kavik-AXYS (2009), inconnu are currently considered as ‘may be at risk’. Tallman et al. (1996a, b) sampled inconnu over the open water season of 1994 and radio-tagged fish to track movement over fall of 1994 to spring of 1995. They found that inconnu moved into the Slave River during end of summer with peak abundance in early September; spawning occurred in early and mid-October. Spawning takes place at the rapids below Fort Smith, as burbot are not found upstream of this point (Stewart, 1999). Abundance of inconnu in the river is negatively correlated with temperature. Low temperatures may reduce the metabolic stress on the inconnu when they are spawning, and there may be upper temperature limits for successful rearing of their eggs (Tallman et al., 1996b). Inconnu in the lower Slave River show a low age-at-maturity and rapid growth, with females maturing later and reaching a larger size at maturity than males. The Slave River population shows relatively narrow and young age structure (Tallman et al., 1996b). Declining catch of inconnu in the early 1990s led to the decision to close the fishery to non-Aboriginal domestic fishing licences in the fall from 1995–1998. This restriction was removed in 1999 as it was determined that the stock was stable (Stewart, 1999).

7.2 Fish health

The Slave River and Slave River Delta continues to be major fishing areas for residents of Fitzgerald, Fort Smith and Fort Resolution. Fish are consumed frequently by humans and are the preferred food for feeding the large number of sled dogs (Lutra and Associates, 1989). In the 1980s, the large majority (74 – 81%) of households reported participating in spring or fall fishing (Lutra and Associates, 1989) and fish was consumed approximately 50 times a year in Fort Smith (Wein et al., 1991). MRBC (1981) stated that fish at one time made up approximately 40% of total food supply for Fort Resolution residents. Lutra and Associates (1989) reported that 29% of households noted a decline in fishing activity in the late 1980s as compared to the previous decade, because of fewer domestic dogs.

In the mid-1980s, inconnu was the most abundant species caught by weight, though whitefish catch was highest in individual fish caught (RL&L/EMA, 1985; Stewart, 1999). Lake whitefish are reported as the most frequently consumed species by residents of Deninu K’ue (Kim et al., 1998; Bodden, 1981; MRBB, 2003). Other important species for consumption include inconnu, burbot, walleye and pike (Bodden, 1981; RL&L/EMA, 1985; Evans et al., 1998a) and pickerel (Lutra and Associates, 1989). Northern pike, suckers and goldeye are the most accessible species in the spring, but the more preferred species such as inconnu, lake whitefish and burbot appear in the fall, making the fall the most important period for local fishing (Kennedy, 1999).

It was also noted that 20% of households reported observations of a decline in fish stocks in the 1980s, and that up to 27% noted observations of fish abnormalities (Lutra and Associates, 1989). Elders reported in Bill et al. (1996) that whitefish used to be found all summer long, but no longer return to the Delta until mid-September. The same study noted observations that some fish were thin and unhealthy.

Indication of declining fish health in the Slave River and Delta area relates to a number of factors observed by local harvesters, including the texture of the fish (softer tissue), increased amounts of black spots on the liver, more parasites, and physical abnormalities and red stress marks on the fish (Barnaby and Fresque-Baxter, 2012).

Wesche (2009) recorded observations from Fort Resolution residents about changes in fish populations, including lake fish moving out farther to colder water, variation in spawning timing, decline of some species, changes to consistency of meat, and increased frequency of abnormalities such as tumours or lesions. Contamination in burbot, especially livers, has implications for human health because livers are especially valued as a food source (MacDonald and Smith, 1993, Boag and Westworth, 1993; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016).

Preliminary results from a Regional Fish Health study suggest that currently conditions of fishes are relatively stable at sites along the Athabasca and Slave Rivers. As Jones et al. (2012) note: "while some statistically significant differences in morphometrics were observed these tended to be relatively small in magnitude and were not consistent for all species from the same location”. Further analysis on sensitive biochemical indicators of fish health and stress is currently underway (Jones et. al., 2012).

7.3 Insects and benthic invertebrate communities

Benthic invertebrates live in or near the sediments in an aquatic ecosystem and can be used as indicators of health of the aquatic ecosystem. Because they live in the sediment, which can be associated with a number of contaminants, monitoring benthic organisms can provide information about toxins in the ecosystem. Benthic organisms do not move around very much, which means the health of their population is a reflection of the health of a particular area. They also have fairly short lives, which means that changes in population because of a change in the environment will be noticed quickly (Reece and Richardson 2000).

Stoneflies, mayflies and caddisflies are known to be sensitive to environmental stress caused by pollutants because they require relatively high dissolved oxygen concentrations and clear water. A lack of these species and a concurrent abundance of worms and non-biting midges indicate that the aquatic environment is under reduced oxygen conditions (Cash et al., 1996).

While two surveys of benthic invertebrates have been completed, with very similar findings, there is little recent information or detailed knowledge on habitat and seasonal patterns in abundance or distribution. Work on benthic invertebrates in currently underway through SWEEP to address this gap.

Tripp et al. (1981) assessed benthic communities in the Delta in the fall and spring of 1978 and 1980. They found that samples were dominated by tolerant invertebrate species such as worms and non-biting midges, which composed up to 93% of the fall sample. They found an average density of 1272 organisms/m^2. Fall samples were almost 4 times as large as spring, but spring was more diverse. The more intolerant taxa such as mayfly, stoneflies and caddisflies were mostly found in the fall at depths greater than 3 metres.

McCarthy et al. (1997c) found extremely similar results in sampling in 1990–1991. Again, they found 91% of the sample was aquatic worms and midges, and density averaged 1247 organisms/m^2. Thus

McCarthy et al. (1997c) concluded that there had been no substantial changes in community composition or abundance in the intervening decade since Tripp et al. (1981).

McCarthy et al. (1997c) compared the Slave River to other waterbodies and found that benthic productivity is low but that this is likely due to natural oligotrophy (low nutrient levels). Using the same data as McCarthy et al. (1997c), Paterson et al. (1991; 1992) looked at relationships between benthic communities and the aquatic environment and found that substrate material, water depth and organic content were the strongest variables to explain distributions, but that these relationships were different between sampling seasons.

Local residents have observed a decline in mosquitoes, bees and yellowjackets, and noted some insects emerge earlier in the spring (Pembina Institute, 2016).

Refer to Table 21 for scientific and common names of benthic invertebrate species in the Slave River area.

7.4 State of the knowledge and potential future research

Fish community

According to the categories outlined in section 1.4, the state of the knowledge about fish community in the Slave River and Slave River Delta can be considered Fair. There have been a number of assessments of fish diversity in the Slave River and Slave River Delta and they show remarkably little change from the early 1980s to the late 1990s. However, there have been limited new assessments in the last decade.

Potential future research and monitoring

- Spawning areas, particularly for whitefish, burbot and inconnu, could be more precisely located, which would help to gain a better understanding of preferred substrate characteristics of spawning. In particular, the base of the rapids in Fort Smith and some of the smaller channels in the Delta could be assessed.
- It has been suggested that spawning habitat may be a limiting factor on fish productivity in the Slave River (Macdonald 1990a). This could be investigated more fully (Pembina Institute, 2016).
- Boag (1993) noted that flathead chub are an abundant forage species distributed throughout the Slave River and are likely important to aquatic food chains but that their biology and life history is not well understood.
- Considering that it is suspected that inconnu are negatively affected by high water temperatures, the effect of the predicted increase in water temperatures with climate change could be investigated more thoroughly.
- The relationship between fish population abundance and diversity with suspended sediment and turbidity does not appear to be fully investigated. Turbidity can affect feeding behaviour of certain species. Considering the increase in turbidity noted by local residents, the investigation of changes in relative abundance of species with different feeding behaviour could be warranted.
- Analysis of fecundity and life history seems to be limited to species such as inconnu and burbot. A more comprehensive analysis of these variables could be undertaken for other important species such as goldeye, northern pike, and walleye.
- There is little information on the differences in survival between juveniles and adult fish. Impacts from environmental degradation will probably affect juvenile stages first (Tallman et al., 1996c) and thus further information on causes of mortality of juvenile fish would be helpful.

- There is little knowledge of movement, behaviour and distribution of fish under ice (Tallman et al., 1996c). As the Slave River provides over-wintering habitat for a number of species, further studies could pursue this.
- While there have been incidental catches of arctic lamprey in the Slave River (RL&L/EMA, 1985), further work is warranted to assess the abundance and distribution of this species, and what effect, if any, their parasitic behaviour is having on resident fish populations.
- The influence of climate variability on ecosystems processes in the Delta and river could be further explored. For example, the link between temperature and spawning and survival success, and how warmer water temperatures and reduced flow are linked to reduced oxygen levels under ice, could be explored (Pembina Institute, 2016).
- It would be good to link data from the commercial fishery on Great Slave Lake with observations on the Slave River, as this is obviously important spawning ground for many lake fish.
- A study could identify preferred fishing sites of local residents and monitor changes in populations, species and behaviour at these sites as well as gathering traditional knowledge on fish population, species, behavior patterns, abundance and changes from local residents (Pembina Institute, 2016).
- An assessment of the lamprey population could indicate the level of stress that the parasitic behaviour is applying on other fish species (Pembina Institute, 2016).

Insect/ benthic communities

According to the categories outlined in section 1.4, the state of the knowledge about insect/benthic communities in the Slave River and Slave River Delta can be considered Limited. While results from two previous surveys (Tripp et al., 1981; McCarthy et al., 1997b) were similar, an updated assessment would provide valuable information and contribute to a longer term monitoring program. In addition, these studies do not take into account interannual differences in benthic population, differences in habitat requirements, or the importance of benthic distribution with respect to fish feeding.

Potential future research and monitoring

- An updated assessment of invertebrate species diversity and habitat requirements from the Slave River and from the various Slave River Delta channels could be undertaken. Work on benthic invertebrates in currently underway through SWEEP to address this gap. Detailed substrate information could be collected to further identify habitat requirements (Paterson et al., 1991; 1992).
- Benthic populations could be further assessed under ice and in spring high water, as very little is known about the distribution of benthos during these seasons. This would provide knowledge about food availability for fish in these seasons.
- Benthic species are known to be a potential conduit of contaminants from sediments to fish (Meysman et al., 2006). However, they have not been assessed for contaminants in the Slave River. The potential for biotransformation and bioaccumulation of contaminants in benthos could be examined more closely.
- Certain benthic invertebrates are known to be indicators of environmental conditions or have been identified as possible ecological maintenance indicators for the Slave River (Macdonald, 1995). Ongoing monitoring of certain benthic taxa could provide insight into water quality and aquatic health.
- Observations of reduced mosquitoes, bees and yellowjackets should be investigated as these species play important role in ecosystem functioning (Pembina Institute, 2016).

8. Wildlife

8.1 Aquatic birds

The Slave River Delta provides critical habitat for staging waterfowl in the spring and fall and is recognized by Canadian Wildlife Service as a key migratory bird terrestrial habitat site (Alexander et al., 1991; Dickson et al., 2002; Latour et al., 2008). This key site is designated as an Important Bird Area in Canada (Bird Studies Canada, 2004). 113 bird species have been observed in the Slave River Delta and estimates based on migratory patterns indicate an additional 61 species may use the Delta (Kavik–AXYS 2009).

Aquatic birds are an important source of food for local residents. Hunting of waterfowl is a ritual activity, and loss and/or decline of many species can impact traditional diet. Local residents have noted a decline in ducks and geese migrating to the delta in recent years (Bill et al., 1996; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). Migration patterns and bird behaviour appear to be changing in recent years, with earlier arrival of birds in the spring (Wesche, 2009; Pembina Institute, 2016) according to observations from Fort Resolution residents. Drying of the Delta and loss of preferred vegetation habitat has been linked to the decline in birds (GNWT and AANDC, 2012; Pembina Institute, 2016). Local residents have also noted a decline in duck and goose health, noting that they are thinner and sometimes have worms (GNWT and AANDC, 2012; Pembina Institute, 2016). It should be noted that duck and geese populations are reported as declining throughout their migratory range (GNWT, 2011). Major causes of population decline are thought to be habitat loss on the wintering/staging areas, insect controls leading to declines in insect populations and earlier springs due to climate change, which may cause earlier insect emergence and offset of timing between maximum food availability and hatching of chicks (GNWT, 2012). The limited available recorded observations from locals seem to indicate a decline in aquatic birds in recent years.

The large majority of species use the Delta in spring or fall for staging or breeding. In spring of 1979 21,000 aquatic birds were seen (Thompson et al., 1979). In spring of 1983, approximately 80,000 aquatic birds were seen (Dickson et al., 2002). Geese are a prominent species in spring (Environmental Management Associates, 1985). Fall migration can be equally large, with 17,080 waterfowl recorded in the Delta in 1979 (Thompson et al., 1979) and 73,200 waterfowl recorded in 1983 (Dickson et al., 2002).

The Slave River Delta wetlands are also important to nesting birds. In 1978, about 5,200 pairs of ducks were recorded on the Slave River Delta with 47 successful broods (Thompson et al., 1979). An assessment of several sites near the Slave River in 1984 by UMA noted the presence of diving ducks, particularly Lesser Scaup and Goldeneye as well as Canada Geese but these observations were not quantified. More recently, ECG (2008) reported the presence of Common Loons, Horned Grebes, Piedbilled Grebes, Red-necked Grebes, Mallards, Gadwalls, Northern Pintails, American Widgeons, Northern Shovelers, Green-winged Teals, Blue-winged Teals, Ring-necked Ducks, Greater Scaup, Lesser Scaup, Canvasbacks, Redheads, Whitewinged Scoters, Surf Scoters, Buffleheads, Common Mergansers, and Red-breasted Mergansers (refer to Table 23 for scientific names of these species).

A number of shorebirds pass through this region in their migratory journeys to nesting grounds farther north. Common migrants include Sandhill Cranes, Sora Rails, American Coots, American Bittern, White-rumped Sandpipers and Upland Sandpipers. Other shorebirds that breed in the area include Semipalmated Plovers, Killdeer, Lesser Yellowlegs, Spotted Sandpipers, Least Sandpipers, Common Snipe and Red-necked Phalaropes. Mew Gulls, California Gulls, Herring Gulls, Common, Black and Arctic Terns and Bonaparte's Gulls (ECG, 2008).

Data from the Christmas Bird Count in Fort Smith from 2007 to 2010 shows observations of 540 – 796 birds, with approximately 15 species (Audubon Society, 2011).

The Slave River is known for the colonies of American White Pelican that nest below the rapids near Fort Smith. Vermeer (1970) found about 50 nests in this area from 1967 – 1969, and noted that this group of pelicans is unique among the Canadian population because they nest near a fast-flowing waterbody. Since 1974, the pelican colony on the Slave River has been monitored annually. The Pelican Advisory Circle undergoes three aerial surveys of nests and chicks each summer. Since the early 1980s, there has been a gradual increasing trend in numbers of chicks and nests (The Pelican Advisory Circle, 2010) with a few dramatic drops. In 2013, 362 chicks were counted by the Pelican Advisory Circle , and was the fifth highest number since 1974 (Northern Journal 2013, accessed June 19, 2014) .

Another distinctive species in the Slave River area is the Whooping Crane. The primary natural breeding site for the Whooping Crane lies within the drainage of the Slave River on the Nyarling, Sass, and Little Buffalo rivers. This site has been identified as a Wetland of International Importance (Ramsar, 2005), a UNESCO World Heritage Site (UNESCO, 2005) and an Important Bird Area in Canada (IBA Canada, 2004). The population reached an all-time low of 14 adults in 1938 (COSEWIC, 2010) but as of winter 2008, the population has recovered to 270 birds, growing by 40% in the previous 10 (COSEWIC, 2010). The Whooping Crane is protected under the federal Species at Risk Act. Other aquatic birds that are found in the Slave River Delta that are listed by COSEWIC include the Caspian tern and the Red Knot (Kavik–AXYS, 2009).

8.2 Amphibians

Wood frogs are common in the NWT, including in South Slave communities. Boreal chorus frogs are less common in the NWT but have a distribution that ranges up at least to Yellowknife. In the South Slave, they have been located occasionally in the Fort Smith area and northeast-ward toward Tsu Lake. In the NWT, Canadian toads are known only from the Fort Smith area (Ecology North, 1998).

Local residents have noted a decline in frogs and the silence of the forest in spring due to the lack of frog songs (Pembina Institute, 2016).

Amphibian surveys in 2009 and 2010 found a number of malformed frogs. Possible causes of physical abnormalities include cold temperatures during embryo development (as might occur during cold springs), infection by trematode parasites, and/or toxicity effects of various substances in the environment (personal communication, Danna Schock, 2012). Schock et.al. (2009) investigated the geographic distribution of amphibian chytrid fungus and ranaviruses in the Taiga Plains in the NWT. These two diseases can impact frogs very negatively and is the suspected cause to the global decline in frog populations. The study showed that both diseases were detected in the region. Ranaviruses were found in a geographically greater area, but found only in wood frogs. The chytrid fungus was found at a single site, but was detected in all 3 species of amphibians in the study area (wood frogs, boreal chorus frogs, and western toads) (Schock et al., 2009).

8.3 Moose

Moose are used extensively as a food source by people in Fort Resolution (Treseder and Graf, 1985; Sly et al., 2001; Nakano et al., 2005) and in Fort Smith (Wein et al., 1991; Bill et al., 1996), and have been for generations. Early published documents stated that moose were common in the Slave River area (Soper, 1942; Kelsall, 1972; Jacobson 1979; UMA Engineers, 1985).

Hawley and Toniak (1983) completed the first quantitative assessment of moose population. They surveyed the Slave River and Slave River Delta and estimated the average density to be 0.05 moose/km^2. They raised concerns about the hunting pressure in the area, with estimated annual harvest of 250 animals around Fort Resolution. Moose populations were surveyed in the southern Slave River lowlands around Fort Smith in 1986 (Graf and Case, 1991). Average population density in the south was 0.05 moose/km^2. Harvest of moose in the 1990s was noted to be significantly larger than the harvests of the 1980s and 1970s (Case and Graf, 1992). Bradley and Kearney (1998) assessed the South Slave River Lowlands again in 1996, and found a density of 0.11 moose/km^2. The authors concluded that these are low densities as compared to more southern regions, but that the population of moose around the Slave River was stable. In the northern Slave River lowlands around Fort Resolution, moose populations were assessed in 1987 and 1988 (Graf and Case, 1992) and average population density was estimated as 0.13 moose/km^2. An updated assessment in 1995 found a density of 0.15 moose/km^2 and the population was deemed to be stable (Bradley et al., 1996). Preferred moose habitat is areas along river valleys and other riparian areas where willows are abundant (Kelsall, 1972). Bradley et al. (1996) and Bradley and Kearey (1998) found that moose preferred deciduous shrub habitat. Anthrax infection, while most common in bison, has also occurred in moose (Gates et al, 1995).

Residents have noted a local decrease in the number of moose harvested and a decrease in observable moose signs (i.e., browsing, tracks, physical sightings, etc.) (Barnaby and Fresque-Baxter, 2012). Many residents have stated that the moose have not declined but moved northward towards the treeline (Pembina Institute, 2016). Hunting pressure and changes to hydrology and water quality have all been identified as possible reasons for the shift in distribution and/or decline in moose population (Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016). In 2011, ENR conducted a moose survey in the South Slave region. Compared to previous survey conducted in mid-1990s there were fewer moose in 2011. The moose densities in the Slave River and Delta region corresponds with other surveyed areas in southern NWT (areas surveyed between 2003-2011) (ENR, 2011)

8.4 Aquatic furbearers

Muskrat

Muskrat has traditionally been the most important fur bearing mammal and source of trapping income for the people of the Delta (Townsend, 1984), as well as a traditional food source. (Geddes, 1981; Bill et al., 1996). Bodden (1981) noted that in the high-population years of 1975-1976, sales from muskrat fur and from calculated food value combined to represent 65% of the total value obtained from wildlife resources in the Slave River Delta. Still today muskrat is described as “good eating” and is a food source for people in the Slave River and Delta area (Barnaby and Fresque-Baxter, 2012). UMA Engineers (1985) reported that harvests of muskrats in the 1930s could be up to 1000 animals per trapper but that trapping was no longer as profitable as it had been in the past.

Muskrat are known to have a cyclic population (MRBC, 1981). Numerous studies and local observations have reported that muskrat population declined in the late 1970s-early 1980s (Geddes, 1981; MRBC, 1981; Environmental Management Associates, 1984; UMA Engineers, 1985; GNWT and AANDC, 2012; Barnaby and Fresque-Baxter, 2012). Community members note that populations have declined and it is not possible to catch as many muskrats as in the past (Barnaby and Fresque-Baxter, 2012).

Various studies, and traditional and local knowledge, have noted the presence of muskrat throughout the Delta. Most studies note that muskrats (as evidenced by trapping success or number of houses/pushups) are found in greatest concentrations on small tributaries in the Delta where there is abundant vegetation (Soper, 1942; Law, 1950; Geddes, 1981; UMA Engineers; 1985; Environmental Management Associates, 1984). Several studies noted the importance of adequately deep water in the channels to allow the muskrats to access vegetation under the ice in the winter (Law, 1950; UMA Engineers, 1985). UMA Engineers (1985) hypothesized that advanced encroachment of terrestrial vegetation from lack of flooding was reducing the availability of this habitat, and low water levels in winter reduced the ability of the muskrats to access vegetation under ice and created the low population observed in the mid-1980s. Local residents have expressed concerns that water being released from the Bennett Dam after the beavers and muskrats have built their winter homes causes a layer of water on top of existing ice, which then freezes, creating a double layer. This double layer causes the muskrats to drown as they are unable to escape from their river bank homes as the water rises (GNWT and AANDC, 2012; Barnaby and Fresque-Baxter, 2012).

Muskrats in the Slave River Delta use three types of shelters: houses; bank burrows and pushups (UMA Engineers, 1984). Houses are usually built in the fall in deeper water and are found on the lakes and outer Delta. It was noted that it was often difficult to obtain accurate population estimates in areas where houses are being utilized because they are more difficult to identify than other types of shelter (MRBC, 1981). Bank burrows are normally located at steep sloping shorelines and are used when water levels are low (MRBC, 1981). Pushups are piles of submerged plant material and pieces of emergent vegetation debris that are built after wetlands become covered in ice (UMA Engineers, 1985). Contrary to UMA Engineers (1985), who reported observations of trappers around Fort Smith who said that bank burrow habitats were less important than pushups, Geddes (1981) reported that bank burrows are more commonly utilized by muskrats, especially in those areas that are along active distributaries with moderately sloping levees which often allowed an air space under the ice in the winter. This is similar to Law (1950) who noted that muskrat in the Delta tended to occupy bank burrows along active channels. It is likely that these different results and observations of utilization of house types are linked to changing water levels. Muskrats in the Slave River Delta have been noted to be more adaptable in their construction of shelter as compared to populations in other regions, such as muskrats in Peace-Athabasca Delta which use almost solely pushups, and those in the Mackenzie Delta which use almost solely bank burrows (MRBC, 1981).

In the late 1970s, in general, muskrats seemed to be in good physical condition, with few signs of disease or parasites, a high reproductive potential and large litter size of 16 young per female (Geddes, 1981; MRBC, 1981). However they did find juvenile survival to be low and determined that trapping and predation were the main reasons for mortality. In the early 1980s, populations seemed to have declined, with low litter size and low female reproductive potential (UMA Engineers, 1985). UMA Engineers (1985) stated that areas that had been identified as good trapping areas for muskrat by the Fort Smith Hunters and Trappers Association were no longer as productive. Reasons put forward by local trappers for the decline in population included early snow melt followed by a cold snap, which can lead to water flowing into pushups and freezing inside, preventing entry, and a rapid, early freeze-up when shallow pools would freeze solid, preventing access to vegetation under the ice. The main cause of the muskrat decline was identified by community members as linked to the overall decline in water levels and less frequent flooding in the previous decade due to flow regulation (Wesche, 2009; Barnaby and Fresque-Baxter, 2012).

Muskrat are known to be carriers of contaminants. While they occupy a low place on the trophic chain, it is hypothesized that they consume large amounts of cattails and other vegetation species that are known to take up metals and contaminants (Halbrook et al., 1993). However, testing of muskrat muscle and livers in 1998, found that PCBs, DDT, organochlorines and cadmium levels were very low or below detection limits (Kennedy, 1999) and are similar to other terrestrial wildlife (Gamberg et al., 2006).

Beaver

Beavers (*Castor canadensis*) are known to be distributed all along the Slave River and Slave River Delta (Soper, 1942). Beaver is noted to be an important food source for local people and predators (Bill et al., 1996). Since the 1600s, beaver fur has been in demand for hats and clothing, and high prices for pelts created heavy trapping pressure on the Slave River population (Novakowski, 1965). Observations from local resource users suggest that the beaver population has been increasing since the 1950s and are higher than when the harvesting quotas were put in place (Novakowski, 1965; Bill et al., 1996; Wesche, 2009), except for an observed decline in the early 1970s to 1984, which may have been due to low water levels during this time period (UMA Engineers, 1985). Howerver, concerns about declining populations have also been noted (Barnaby and Fresque-Baxter, 2012). There appear to be no recent assessments of population abundance or dynamics for the regional population.

Beavers tend to prefer areas with abundant supplies of aspen, balsam poplar, and alder (Environmental Management Associates, 1984; MacDonald, 1995). Novakowski (1965) reported that willow was the most important food for beaver in the Slave River area.

Beaver activity has important implications for hydrology, vegetation and other species. Beaver dams slow the flow of water on the landscape and create pond habitat. A declining beaver population changes the flow of the water, which affects muskrats and mink that rely on these water sources (Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016).

Beavers are also known to be carriers of contaminants, but it appears that contaminants are at very low levels in beavers in this area. Testing of beaver muscle and livers from the Slave River Delta in 1998 found that PCBs, DDT and organochlorine levels were very low and well below available guideline levels or below detection limits, which is consistent with their herbivorous diet (Kennedy et al., 1999). Beaver livers contained an average of 6.6µ g/g of cadmium (Kennedy et al., 1999) which is lower than levels found in other regions (Gamberg et al., 2006).

Otter

There is little documented information about otter in the Slave River or Slave River Delta. There appears to be no up-to-date assessments of population abundance or dynamics for the regional population, and no publicly accessible documented information from local trappers.

There are few documented observations about otters within the Slave River and Slave River Delta (Soper, 1942; UMA Engineers, 1985). More recently, residents have noted that otter populations are linked to beaver populations (Pembina Institute, 2016). Otter distribution in the Slave River area is restricted to fast-flowing, fish-bearing streams that remain open throughout winter (ECG, 2008).

Mink

There is little documented information about mink in the Slave River or Slave River Delta. There appear to be no assessments of population abundance or dynamics for the regional population and no publicly accessible documented information from local trappers.

Some studies assessing contaminants in mink have been completed, as they are a higher trophic level species and often bioaccumulate contaminants. Organs from mink collected in Fort Smith during the winters of 1991-1992 and 1992-1993 showed an average PCB concentration of 27.67 ng/g, the highest of the four NWT communities assessed (Poole et al., 1995). However, in a second, larger study that included organs from mink collected in Fort Resolution and Fort Smith during winters 1991-1992 to 1994-1995, average PCB concentrations for Fort Resolution mink was 41.07 ng/g, but higher concentrations were detected in other communities. Concentrations of metals and organochlorines in the Slave River and Slave River Delta mink were low in comparison to other regions (except for mercury, which showed slightly elevated levels). All concentrations of contaminants were found to be at least an order of magnitude below that which would impair reproduction or survival (Poole et al., 1998). The authors suggest that long-range atmospheric transport is likely the main source of the observed organochlorine contaminants.

Refer to Table 22 for common and scientific names of wildlife species in the Slave River area.

8.5 State of the knowledge and potential future research

Aquatic birds

According to the categories outlined in section 1.4 the state of the knowledge about aquatic birds in the Slave River and Slave River Delta can be considered Poor. While comprehensive surveys have been done in the past, they are out of date, and there is very little information about feeding, habitat or fecundity of either migratory or resident species.

Potential information gaps

- Considering the observations from locals that migration timing and patterns have been changing, the significant number of bird species in the Slave River, as well as the presence of a number of species that are identified as being at risk, an updated bird survey is warranted. This survey could also further our understanding of the relationship between water levels and food availability (benthos and vegetation) for aquatic birds in the Slave River Delta.
- Migratory birds are an important food source for people in Fort Resolution, and are known to be carriers of contaminants (Ohlendorf and Fleming, 1988). Future work could assess contaminant burdens among migratory species that pass through the Slave River area, and assess if and how contaminants are transferred through predation or hunting. Resident birds may also be exposed to contaminants from the local area, thus a comparison between migratory and resident birds may highlight differences in contaminant exposure.
- Local residents have suggested that other species of bird should also be monitored, including songbirds, ptarmigans, and peregrine falcon (Pembina Institute, 2016).

Amphibians

According to the categories outlined in section 1.4 the state of the knowledge about amphibians in the Slave River and Slave River Delta can be considered Fair. There is up-to-date population and health information available, however the causes of the observed decline in frog and toad populations should be further investigated.

Moose

According to the categories outlined in section 1.4 the state of the knowledge about moose in the Slave River and Slave River Delta can be considered Fair. There have been a number of moose population and habitat surveys. However, these surveys could be updated, and there appears to be little research on contaminants in organs, which are known to be elevated in moose in other regions.

Potential future research and monitoring

- There is a need to investigate concerns raised by community members about changes in moose populations (e.g., communities have indicated concerns about declines in population in the Slave River area and/or that moose may be moving northward). Possible drivers of this change may include vegetation changes (potentially a decline in aquatic species that moose use as a food source), an increase in predation of moose calves by bears and wolves, and an increase in the distribution and severity of ticks on moose (Pembina Institute, 2016).
- Future research could include assessment of contaminants (particularly cadmium) in moose liver, as moose liver is an important dietary source for local residents. Baseline information on the health status of moose in the South Slave region and diseases, contaminants and parasites has been collected since 2009 (personal communication, Allicia Kelly, 2011). Future work could complement baseline and ongoing research and monitoring.

Aquatic furbearers

According to the categories outlined in section 1.4 the state of the knowledge about aquatic furbearers in the Slave River and Slave River Delta can be considered Good for muskrat, Fair for beaver and Poor for mink and otter. Systematic population surveys have been completed only for muskrat, and these are now out of date.

Potential future research and monitoring

- Population estimates, fecundity and life history information, and fine scale wildlife habitat evaluations for muskrat, otter, beaver and mink could be conducted, given the value of these species for local trappers.
- Contaminants are known to accumulate in cattails, an important food species for many aquatic furbearers, and this may be the primary source of contaminant load in organs of furbearers (Erikson and Lindzey, 1983). This relationship could be examined in detail in the Slave River vegetation and furbearer population.
- There are known relationships between the price of furs, harvest levels and population dynamics of aquatic furbearing species in some regions (e.g., Bailey, 1981; Robert and Crimmons, 2010). This relationship could be investigated for aquatic furbearing species for the Slave River area.
- Historical river flow data could be compared to populations of aquatic furbearers to better elucidate the relationship between population and flood frequency.

9. Vegetation

9.1 Vegetation shift

At a landscape scale, Zoltai and Pollett (1983) classified the area around the Slave River as High Boreal Wetland. ECG (2008) classified the land east of the Slave River as being part of the Slave Plain Mid-Boreal Ecoregion.

At a regional scale, vegetation has been classified a number of ways. The Northern Research Group (1978) described four groups of vegetation in the Slave River lowlands: prairie, dry sedge meadow, wet sedge meadow and saline meadow. Porsild and Cody (1980) assessed and identified vegetation including rare plants around the Slave River and Slave River Delta. LGL (1986) identified 11 habitat types in the Slave River and Slave River Delta area. They found that shrubland made up 63% of the area, with emergent aquatic habitats and forested habitats both covering approximately 16% and open water habitats covering the remainder. The flood regime and deposition of alluvial material are critical factors that determine vegetative distribution and succession in the Slave River Delta (English, 1979; Prowse et al., 2002a).

The upstream portion of the Slave River Delta and along the Slave River banks is a mixed boreal forest (English, 1984; English et al., 1997). Tripp et al. (1981) described a mixed poplar-aspen and spruce forest with a dense growth of alders. MRBC (1981) recorded balsam poplar, alder and spruce in dry areas. UMA Engineers (1985) described the forest as balsam poplar/aspen birch forest. Prowse et al. (2002a) described the upland vegetation as a mature white spruce forest with a bryophyte floor. ECG (2008) described terrestrial vegetation as being a vigorous mixed-wood, white spruce and aspen forest in drier areas, with jack pine and black spruce woodlands on rock outcrops, with stands of aspens and paper birch (refer to Table 23 for the scientific names of these species).

The mid-Delta is a mesic zone with riparian vegetation and has been noted to be dominated by willows (MRBC, 1981; UMA Engineers, 1985), or as dominated by poplar with a mix of alder and willow (Prowse et al., 2002a).

The most common emergent vegetation is sedge found in the fens that are widespread throughout the Slave River Delta area (Zoltai and Pollett, 1983; UMA Engineers, 1985). UMA Engineers (1985) noted the presence of “rooted” sedge fens which are raised above the water levels of lakes and streams and thus are virtually dry during most of the summer. Horsetail and cattails have also been described as important (Tripp et al., 1981; English, 1984; Prowse et al., 2002a). Pondweed species (including grassy pondweed and Richarson’s pondweed) are important submerged aquatic plants along the outer Delta and along the major channels (Tripp et al., 1981).

One of the few assessments of macrophyte biomass from six lakes in the Delta was undertaken by Sokal et al. (2010) over 2003-2005. Mean aboveground macrophyte biomass was 192 g/m^2, with significant year-to-year variability.

A number of studies have noted changes in vegetation over the past 50 years. UMA Engineers (1985) noted the changes in vegetation in areas around the Slave River with reduced flooding, where smaller lakes and marshes have disappeared under the encroaching vegetation or have been reduced to shallow ponds or marshy sloughs. English et al. (1997) assessed aerial photographs that spanned 1946 to 1994 and found a shift in vegetation community in the outer Delta to a drier, less productive environment with loss of horsetail communities and replacement with willow/alder (English et al., 1997). This shift may have significant impacts on wildlife species like aquatic birds that depend on macrophytes as a food source.

This shift has also been noted by numerous local residents. They stated that areas that were formerly prairies, fens and wetlands are now dry terrestrial vegetation (mostly willows). This growth restricts access to the land for hunting, fishing and travel.

Refer to Table 24 for common and scientific names of vegetation species in the Slave River area.

9.2 Berries

Residents within the Slave River and Slave River Delta collect a number of different berries, including the small cranberry, low bush cranberry (Bodden, 1981), high bush cranberry/mooseberry (Kim et. al., 1998), and likely blueberry and cloudberry (Kavik-AXYS, 2009).

Local residents have noted a decline in the abundance and quality of berries in the last 10 years, even in areas where berry harvest has been dependable in the past (Wesche, 2009; Pembina Institute, 2016). Many residents have correlated this decline to drying of the ecosystem.

9.3 Forest infestation

Environment Canada and ENR (2009) stated that there are eleven alien species of insects in the NWT, but the extent of the distribution of these species through the Slave Region is not clear. Two of the identified alien species are invasive and can change the natural habitat, Larch Sawfly and Birch Leafminer.

Spruce budworm, although a native species, can cause significant damage. Spruce budworm caused extensive damage to forest around the Slave River in the 1960s (Moody and Amirault, 1992) and again in 2002-2003. Local residents have also noted impacts on aspen, willow and pine trees (Pembina Institute, 2016).

9.4 Rare and invasive plant species

Kavik-AXYS (2009) estimated that 386 species of plants and trees can be found in the Slave River and Slave River Delta area. There are no vegetation species with protected status under COSEWIC or under the Species at Risk Act, but there are some rare aquatic/riparian species including northern water plantain, marsh marigold, crawford sedge, and slender naiad. Porsild and Cody (1980) documented the presence of some rare Great Plains species in the saline and alkaline habitats near the Slave River west of Fort Smith.

A number of invasive or alien species have been noted in the Slave River and Fort Smith area, such as sweet clover (personal communication, Jeff Shatford, 2011), black medick, common buttercup, tall baby's breath, yellow goatsbeard and Canada horseweed (Porsild and Cody, 1980).

Fire is an important process in the Slave River area for regeneration of vegetation, nutrient cycling, and to control anthrax. Human-caused fires are common historically, through both prescribed burning and accidental fire (Pembina Institute, 2016). Prescribed burns in spring have been shown to have only a small effect on willows but may reduce the abundance of primary bison forage plants (Quinlan et al., 2003).

Fire frequency and severity is highly variable from year to year. Significant historical fires include a 6,748,840 km^2 fire in 1971 and two very large fires in 1979 (1,1825,658 km^2) and 1981 (16,329,708 km^2) that burned areas directly adjacent to the Slave River (NWT Centre for Geomatics). More recently, there was a 190 km^2 fire near the Slave River in 2007 (NWT Centre for Geomatics).

An increased number of fires and a longer fire season are predicted in many climate change scenarios for the NWT with increased lightning activity (Kochtubajda et al., 2006). Local residents have noted that fires in the spring have been more frequent in the past few years, and that the fire season begins earlier (Pembina Institute, 2016).

9.5 State of the knowledge and potential future research

According to the categories outlined in section 1.4, the state of the knowledge about vegetation in the Slave River and Slave River Delta can be considered Fair. There have been a number of vegetation surveys, and while somewhat dated, they are still likely accurate, with the exception of the active areas of the Delta and riparian zones.

Potential future research and monitoring

- As stated above, an updated vegetation survey is needed in active areas of the Delta and riparian zones. Comparing this information to historical data (such as the vegetation distribution in 1977 as assessed by English (1979)) would allow examination of the trend of willow encroachment into fens in the Delta that was identified in the mid-1990s.
- It appears that there have been no formal aquatic plant studies. Certain aquatic plants have been identified as ecological maintenance indicators for the Slave River (MacDonald, 1995), and invasive or alien species are often transported in waterways. A survey of biodiversity and productivity of aquatic plant species may also give an indication of ecosystem health.
- There is a need for a systematic survey of invasive species (Pembina Institute, 2016).
- The forest ecosystem should be modelled to try to predict future vegetation cover while considering the effects of reduced water flow. There is a need to make the linkage between what is happening in the water and on the land, and also expand research focus beyond the river and delta into an integrated ecosystem model (Pembina Institute, 2016).
- Fire frequency information could be compared with snowpack data to look at the relationship between fire frequency and snow (Pembina Institute, 2016).
- The forest ecosystem should be modeled to try to predict future vegetation cover while considering the effects of reduced water flow. There is a need to make the linkage between what's happening in the water and on the land, and also expand research focus beyond the river and delta into an integrated ecosystem model (Pembina Institute, 2016).
- Slumping associated with permafrost melt could be assessed through looking at old aerial photos in comparison to satellite imaging, and the connection to tree growth (Pembina Institute, 2016).
- The combined effect of drought and insect infestation on trees should be assessed (Pembina Institute, 2016).

10. Air and climate

10.1 Temperature

The Slave River area is characterized by a climate that fluctuates seasonally, with long, cold winters and short, warm summers. Temperature information is not available for Fort Resolution, but is available for Hay River (which is located 150 km from Fort Resolution) and for the Fort Smith airport. Many local residents have reported changes in temperature, in particular that winters are warmer and shorter now than in the 1950s (Wesche, 2009; Barnaby and Fresque-Baxter, 2012; Pembina Institute, 2016).

10.2 Moisture in the air

A number of local residents have noted that the air seems to contain more moisture now than in the past, which affects visibility and transportation (Pembina Institute, 2016). Residents have also noted that moisture patterns of the seasons are changing — summers are now wetter and winters are drier, which is inverse of past patterns.

10.3 Rain, storms and wind

Local residents have noted that storms are more frequent and violent and occur earlier in the spring, and that hailstorms, more dramatic rainfalls and freezing rain are becoming more common. Concerns have also been noted that the wind is stronger and seems to be coming more frequently from the south (Pembina Institute, 2016). They also noted warm and fast winds that rapidly melt snow and evaporate water. One of the effects of the wind is to push the ice up against the shore on Great Slave Lake (Pembina Institute, 2016).

10.4 Snow

Local residents have stated that the volume of snow in the Slave River area has decreased in the last 50 years (Wesche, 2009; Pembina Institute, 2016). While snow measurements from the 1950s are not available, more recent Snow Water Equivalent data (which is the amount of water contained within the snowpack) from 1982-2010 presented in Figure 4 does not suggest any major trends.

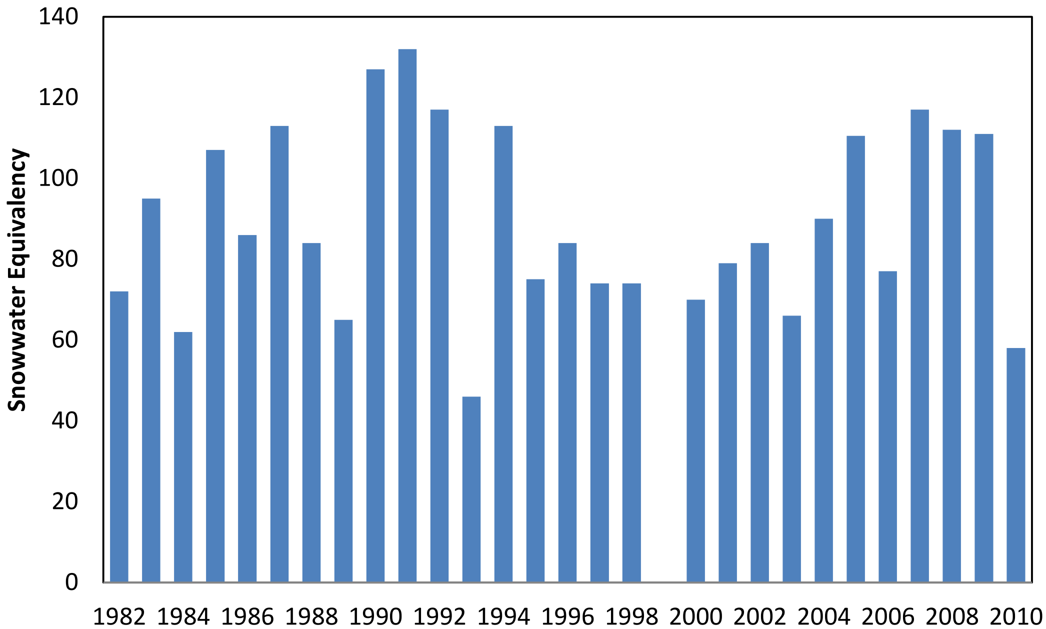

Figure 3: Snow-water equivalency data for Fort Smith, 1982 to 2010

Source: AANDC, Water Resources Division

Local residents have commented that the texture and quantity of snow has changed in the past 30 years (Pembina Institute, 2016). Snow volume is reduced and there are some observations that snow texture is fluffier, but other observations have indicated that the snow is harder and has a crust that makes it difficult for browsing animals to feed (Pembina Institute, 2016).

10.5 Air quality

A monitoring site and deposition station operated by Environment Canada is located in Wood Buffalo National Park along Highway 5. This station is part of the Canadian Air and Precipitation Monitoring Network (CAPMoN) (Environment Canada, 2015) and was established in 2014. Before 2014, the nearest ambient air quality monitoring site in NWT was Yellowknife (GNWT, 2010) and the nearest site in Alberta was Fort Chipewyan (CASA website, 2011). The nearest deposition station was approximately 200 km north of Fort McMurray in Alberta (Fenn and Ross, 2010).

Air quality is determined by the concentrations of pollutants in the atmosphere resulting from the dispersion of pollutants from emission sources. Pollutants can be emitted from point sources (e.g., a smoke stack), or non-point/area sources (e.g., flux emissions from tailings ponds or smoke from forest fires).

Locally, there is little industrial activity in the immediate vicinity of the Slave River to create air pollutants, with the exception of the Fort Smith power plant which is a small source of some greenhouse gases and air pollutants (AECOM, 2010). Smoke from forest fires can be a source of a considerable amount of air pollutants, but in 2010 these did not exceed air quality standards anywhere in NWT (GNWT, 2010).

At a regional level, it is unlikely that there is significant deposition of hydrocarbon particulates from the oil sands in the Slave River region as it has been found that polycyclic aromatic compound deposition exponentially declined with distance from sites within the oil sands region as compared to sites 50 km away (Kelly et al., 2009). There is evidence from modeling of infrequent mass air transport up to 200 km north of the oil sands region (Weins et al., 2004). AECOM (2010) summarized trends in air quality parameters from Fort Chipewyan from the last decade and found that concentrations of the parameters of concern are generally low (below the Alberta Ambient Air Quality Objectives) and are stable over time. Lakes along the Athabasca River did not show evidence of acidification in an assessment of diatom communities, despite sulphur emissions from oil sands (Hazewinkle et al., 2008).

At a wider spatial scale, patterns in contaminants in biota and sediment from the Slave River and Great Slave Lake indicate that there is at least some long-range transport and deposition of pollutants in this area (e.g., Mudroch et al., 1992; 1998; Grey et al., 1995; Evans et al., 1996a,b; Carey et al., 1997; Sanderson et al., 2012).

10.6 State of the knowledge and potential future research

According to the categories outlined in section 1.4, the state of the knowledge about air quality in the Slave River and Slave River Delta can be considered Limited. There appears to be no information available about local air quality around the Slave River, and limited studies in the peripheral areas from which to extrapolate or make inferences on air quality.

Potential future research and monitoring

- Limited local sources of air pollution are present in the Slave River area; however, considering the downstream location of the Slave River to industrial activity and the evidence of potential long-range transport of emissions from the oil sands, air quality monitoring is recommended to determine the quantity and spatial distribution of contaminants.
- An inventory and dispersion model of suspected emission sources would be a valuable undertaking to collaborate with existing monitoring data. This could be used to investigate local observations of decreased air quality associated with southerly winds (Pembina Institute, 2016).

11. Summary of state of the knowledge

Table 1 summarizes the state of the knowledge as determined in this report and outlines areas for potential future research. This state of the knowledge determination is based on the documents available to the author, and thus cannot take into account any information that may be recorded but not accessible, or unrecorded.

Table 1. Summary of state of the knowledge

Topic	State of the Knowledge	Summary
Hydrology and sediment load	Good	There is a large body of work from the mid-to-late 1990s, and some work on lakes in the late 2000s. Future research could focus on historical and current effects of climate on water flow, sediment loading and ice jam formation.
Water quality	Good	There are a number of studies from the mid-to-late 1990s, one from late 2000s, upcoming research results and ongoing community-based monitoring. Future work could focus on plankton and algal communities and a better assessment of multiple stressors and factors affecting productivity.
Metals and contaminants	Good	Studies from the mid-to-late 1990s assessed sediment contaminants in the Slave River Delta and Great Slave Lake. Future work could allow more accurate assessment of trends over time, and those contaminants that appear to be increasing could be monitored on an ongoing basis, and compared against trends in atmospheric deposition. In fish, future work could focus on long-term trends in contaminants levels, and investigation of other factors (temperature, food source) on contaminant loading.
Fish and insect/benthic communities	Fish - Fair	Fish community studies are now dated, and detailed information on behaviour and habitat is available for only a few species. Future work could include detailed investigations of spawning areas and feeding behaviour, food web pathways, factors affecting fish growth rates and year class strengths.

Topic	State of the Knowledge	Summary
	Insect/Benthic - Limited	There is little up-to-date or detailed information available on the insect/benthic community. SWEEP results will contribute to this. Future work could include an updated inventory, investigations into habitat requirements and the relationship between insect productivity, overall aquatic health and contaminant movement.
Wildlife	Aquatic birds - Limited	Comprehensive surveys of aquatic birds have been completed, however these are now out of date, and there is little information available about habitat and feeding. Future work could include an updated assessment of resident and migratory species and an assessment of contaminant loads.
	Amphibians - Fair	Up-to-date information about frog population and health is available, but causes of the decline in population should be further pursued.
	Moose - Fair	Detailed population and habitat surveys were carried out in the late 1990s. Future work could include an updated population assessment and investigation of contaminants in organs.
	Aquatic furbearers: Muskrat - Good Beaver - Fair Mink, Otter - Limited	There is a large amount of information available on muskrat, some information on beaver but little on mink and otter. Future work could include updated population, reproductive and habitat data for all species.
Vegetation	Fair	A number of older surveys have investigated vegetation in the Slave River region. Future work could include an updated assessment of vegetation distribution in the active areas of the Delta, and a thorough survey of aquatic species and invasive species.
Air and Climate	Limited	There is limited air quality data available for the immediate Slave River Area, with the exception of the new station in Wood Buffalo National Park. There is a long record of climate and snow data for Fort Smith. Future work could include an assessment of air quality, and modeling of wind direction and associated contaminant loading.

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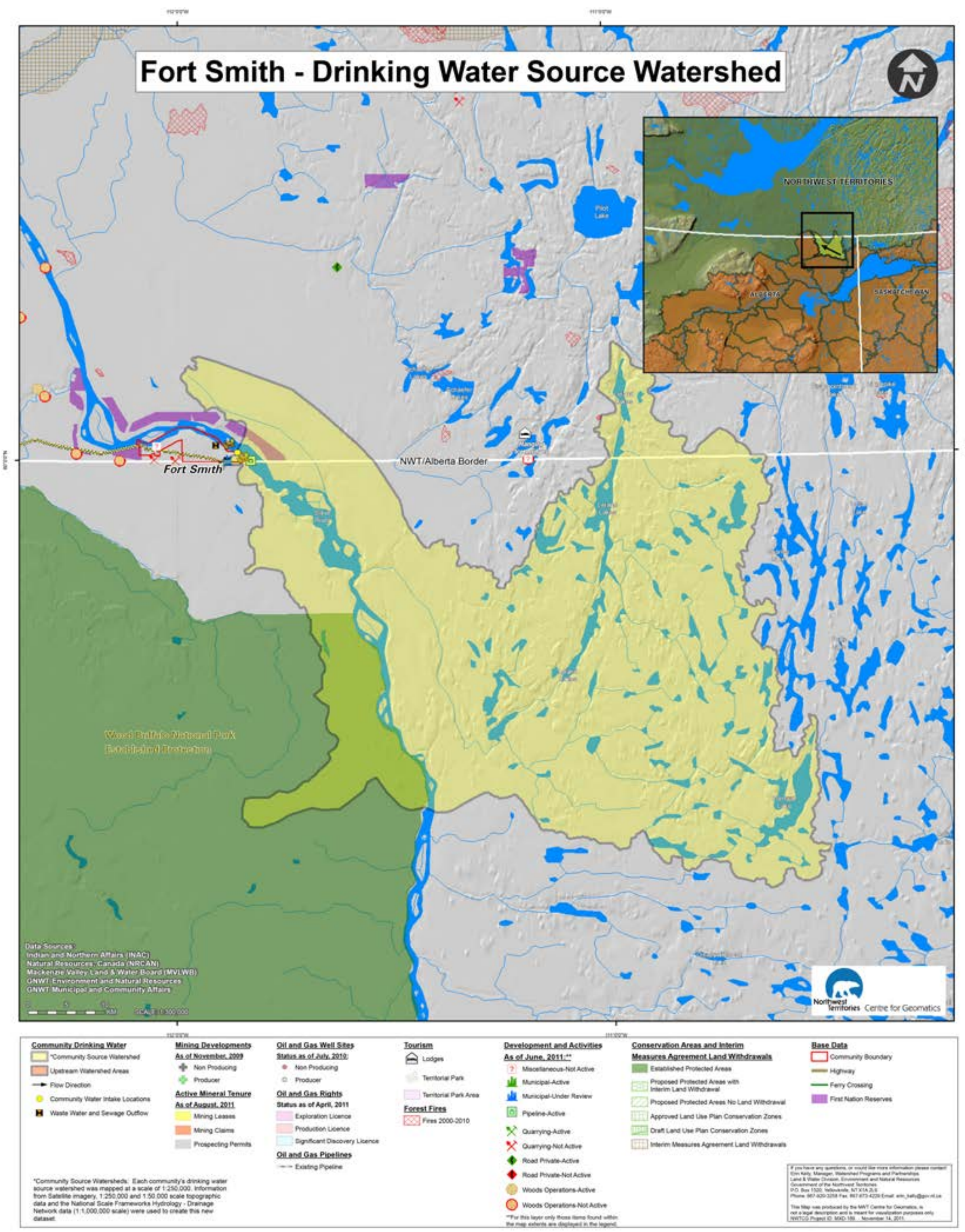
Appendix A: Detailed summaries of findings

Source Water Catchment Maps

Fort Smith



Fort Resolution

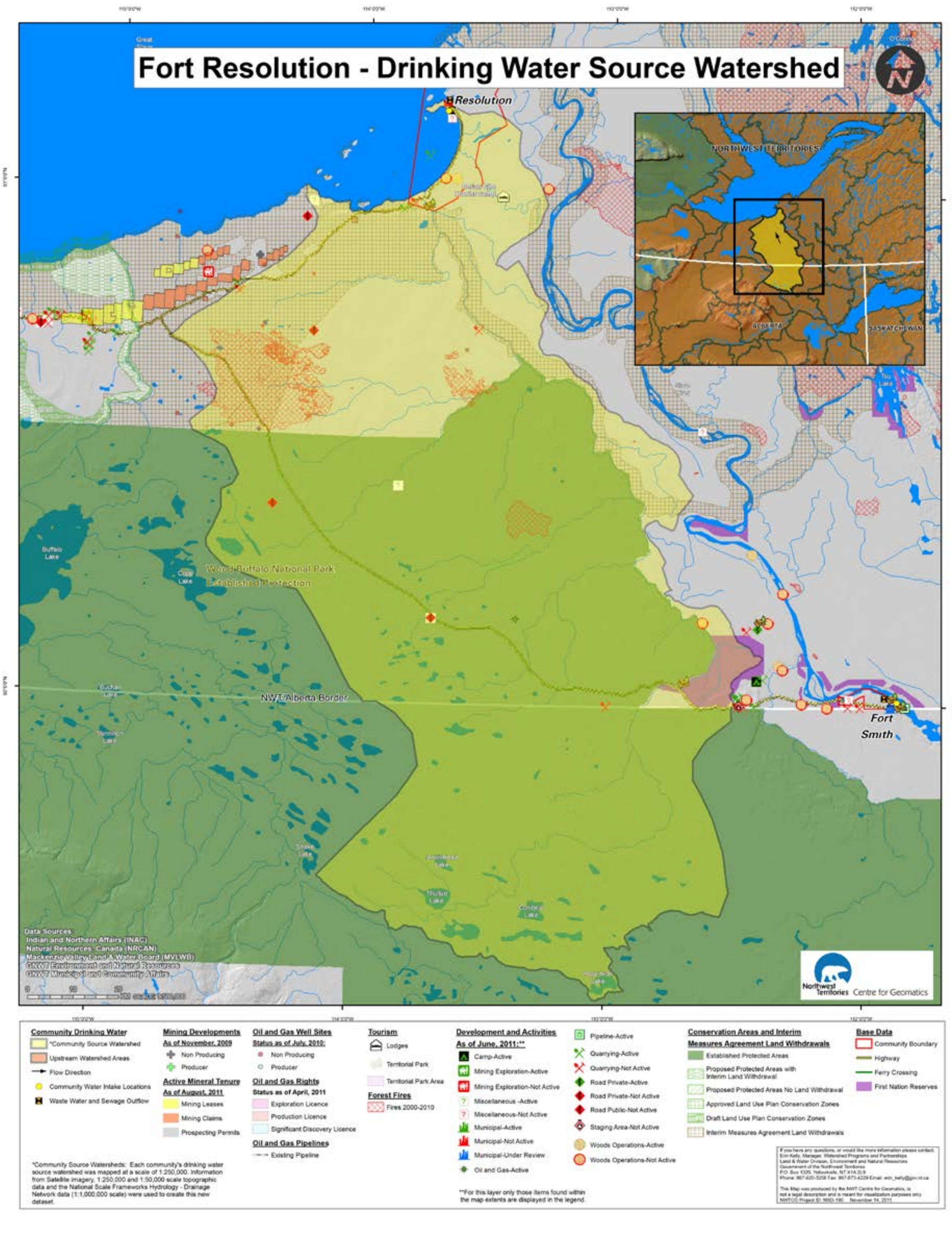


Table 2: Summary of suspended sediment concentration research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
250 mg/L (mean), with peak of 1000–2000 mg/L	Summer, 1978-1980	Slave River Delta	Davies (1981)	Assessed hydrology and sediment data in the Slave River Delta.
3-5600 mg/L (range) (n=105)	1960 to 1992	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
<3-586 mg/L (range) (n=45)	1990–1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
25-8900 mg/L (range) 300 mg/L (mean during open water season	1970-1990	Fort Smith	Carson and Hudson (1997)	Summary and trends of suspended sediment data
27-84 mg/L	spring and fall, 1997	Channels in Slave River Delta	Milburn and Prowse (1998b)	Assess seasonal patterns in of sediment and contaminant deposition in the Slave River Delta.

Table 3: Summary of rates of sedimentation in Great Slave Lake research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
46.6 g/m^2/year	Summer, 1987	In Great Slave Lake near Slave River Delta (and other locations across Great Slave lake, results not presented here)	Mudroch et al. (1992)	Assessment of geochemistry and sediment contaminants in Great Slave Lake and historical trends in contaminant deposition.
3464 g/m^2/year	1960–1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
340-700 g/m^2/year, up to a maximum of 1082 g/m^2/year	August 1993, March 1994	Just offshore of the Slave River Delta	Evans et al. (1996a, b)	Assessed spatial and temporal patterns of sediment and contaminant deposition in Great Slave Lake.

Table 4: Summary of pH research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
7.8 (mean) (n=40)	1978-1980	Mid-channel in the Slave River, just upstream of Nagle Channel	Tripp et al. (1981)	An assessment of water quality and fish population in the Slave River.
7.8 (median) (n=102)	1960 to 1992	Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
7.45 (mean) (n=8)	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta.	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
7.9 (median)	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
7.7 (mean) (n=unknown)	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
7.92 (median) (n=115)	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.
8.1 (median) (n=51)	Open water seasons of 2003-2005	Slave River and several Delta channels	Sokal et al. (2010)	Assessed the role of flooding in chemistry and biota in lakes on the Slave River Delta.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
7.91 (median) (n=241)	1972-2010	Slave River at Fitzgerald	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; Determine if water quality and flows have changed over time.
7.99 (median) (n= 105)	1982-2010	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; Determine if water quality and flows have changed over time.

Table 5: Summary of dissolved oxygen/biological oxygen demand research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
10.4 mg/L (mean) (n=40)	1978-1980	Mid-channel in the Slave River, just upstream of Nagle Channel	Tripp et al. (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
11.9 mg/L (median)	1960 to 1992	Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
10.5 and 15.2 mg/L (range) (n=9)	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
12.9 mg/L (mean) (n=7)	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
8.7 mg/L (mean) (n=unknown)	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
11.7 mg/L (median) (n=105)	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.
11.8 mg/L	2000-2010	Slave River at Fitzgerald	Sanderson et al. (2012)	Provide a general overview of the current state of water quality,

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
				suspended sediment quality and flows in the transboundary reach of the Slave River; Determine if water quality and flows have changed over time.

Table 6: Summary of conductivity research and monitoring results[5]

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
218 µS/cm (mean), n=107	1960-1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
199 µS/cm (median), n=102	1960 to 1992	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
190-250 µS/cm, n=9	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta.	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
190 µS/cm, n= unknown	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
170 – 262 µS/cm, n=50	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
219 µS/cm (median), n=115	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized

[5] Other sources of data for conductivity include Tripp et al. 1981

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
				trends over time.
169-340 µS/cm Mean 213, median 210 (n=107)	1982-2010	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; Determine if water quality and flows have changed over time.
138-364 µS/cm Mean 218, median 217 (n= 241)	1972-2010	Slave River at Fitzgerald	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 7: Summary of turbidity research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
91 NTU (mean) (n=107)	1960-1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
140 FTU (mean) (N=40)	1978-1980	Mid-channel in the Slave River, just upstream of Nagle Channel	Tripp et al. (1981)	An assessment of water quality and fish population in the Slave River.
35 NTU (median), 5.3 to 700 (range) (n=102)	1960 to 1992	Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
7 NTU (mean) (n=2) (at depths of 1m and 6m)	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta.	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
4.1 to 464 NTU (range) (n=50)	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
183 NTU (mean) (n= unknown)	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here).	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
55 NTU (median) (n=120)	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
54 NTU (median) (n= 241)	1972-2010	Slave River at Fitzgerald	Sanderson et al (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.
61 NTU (median) (n= 104)	1982-2010	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 8: Summary of phosphorus research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Total:0.065 mg/L (n=31) Dissolved: *not available* Particulate: *not available*	1960-1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
Total: *not available* Dissolved: 0.140 mg/L (mean) (n=13) Particulate: *not available*	Summer 1979	Mid-channel in the Slave River, just upstream of Nagle Channel	Tripp et al. (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
total: 0.092 (mg/L) (median) (n=48) dissolved: 0.007 (mg/L) (median) (n=48) particulate: 0.084 (mg/L) (median) (n=48)	1960 to 1992	Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
total: 0.02mg/L (median) (n=2) Dissolved: 0.01mg/L (median) (n=2) Particulate: 0.01mg/L (median) (n=2)	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta.	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
total: 0.02-0.612 mg/L (range) (n=28) dissolved: *not available* particulate: : *not available*	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
Total: 0.146 mg/L (mean)	August-	Slave River (sampling	Evans et al. (1998a)	Investigation of the possibility of metal

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
(n= unknown) Dissolved: *not available* Particulate: *not available*	September 1994	also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)		contamination of water and sediment from the decommissioned Pine Point mine.
Total: 0.078 mg/L (median) (n=121) Dissolved: 0.011 mg/L (median) (n=122) Particulate: 0.070 (median) (n=120)	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.
Total: 0.2 mg/L (n=51) Dissolved: 0.03 mg/L (n=51) Particulate: *not available*	Open water seasons of 2003-2005	Slave River and several Delta channels	Sokal et al. (2010)	Assessed the role of flooding in chemistry and biota in lakes on the Slave River Delta.
Total 0.006mg/L to 4.67 mg/L(n=223), dissolved <0.002mg/L to 0.343 mg/L (n=215)	1974-2010 1978-2010	Slave River at Fitzgerald	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.
Total 0.014 – 4.4 mg/L (n=82) Dissolved 0.008- 0.02mg/L (n=6)	1982-2010 2000-2007	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 9: Summary of nitrogen research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Total: 0.7 mg/L (mean) (n=11)	1960-1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
Total: *not available* Dissolved: 0.60 mg/L (mean) (n=13 Particulate: *not available*	Summer 1979	Mid-channel in the Slave River, just upstream of Nagle Channel	Tripp et al. (1981)	An assessment of water quality and fish population in the Slave River.
Total: 0.38 mg/L (median) Dissolved: 0.19 mg/L (median) Particulate: 0.18 mg/L (median)	1960 to 1992	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters 1960 to 1992 using data collected by Environment Canada
Total: *not available* Dissolved: *not presented* Particulate: 0.01 (mean) (n=2)	March 1994	Numerous sites in Great Slave Lake. Data presented here are for site 20, just offshore of the Slave River Delta.	Evans et al. (1997)	Assessed the effect of the Slave River on the limnology of Great Slave Lake.
Total: 0.3 mg/L (mean) (n= unknown) Dissolved: *not available* Particulate: 0.5 mg/L (mean) (n= unknown)	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here).	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
Total: 0.36 mg/L (median) (n=114) Dissolved: 0.2 mg/L	1989-2006	Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
(median) (n=118) Particulate: 0.16 mg/L (n=116)				trends over time.
Total: 0.6 mg/L (n=51) Dissolved: *not available* Particulate: *not available*	Open water seasons of 2003-2005	Slave River and several Delta channels	Sokal et al. (2010)	Assessed the role of flooding in chemistry and biota in lakes on the Slave River Delta.
Ammonia nitrogen NH_3 total 0.002-0.52 mg/L (n=83)	1982-2010	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.
Ammonia nitrogen NH3 dissolved < 0.001-0.33 mg/L (n=99)	1993-2010	Slave River at Fort Fitzgerald	Sanderson et al. 2012	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; Determine if water quality and flows have changed over time.

Table 10: Summary of organic carbon research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Total:15 mg/L (n=12) Dissolved: *not available* Particulate: *not available*	1960-1980	Slave River at Fitzgerald	MRBC (1981)	A multi-disciplinary research project to establish baseline information on the Mackenzie River Basin.
Total: 6.95 mg/L (median) (n=48) Dissolved: 4.98 mg/L (median) (n=48) Particulate: 1.85 mg/L (median) (n=48)	1960 to 1992	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada.
Total: *not available* Dissolved: *not available* Particulate:4.735 mg/L (mean) (n= unknown)	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
Total: 12 mg/L (median) (n=114) Dissolved: 8 mg/L (median) (n=119) Particulate: *not available*	1989-2006	Slave River at Fort Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.
Total: *not available* Dissolved: 9 mg/L (median) (n=51) Particulate *not available*	Open water seasons of 2003-2005	Slave River and several Delta channels	Sokal et al. (2010)	Assessed the role of flooding in chemistry and biota in lakes on the Slave River Delta.
Dissolved 1.5- 40.4. mg / L	1978-2010	Slave River at Fitzgerald	Sanderson et al.	Provide a general overview of the current

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
(n=213) Particulate 0.13-84.0 mg/L (n=211)			(2012)	state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.
Dissolved 2.8 – 14.6 mg/L (n=6) Particulate not available	2000-2007	Slave River at Fort Smith	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 11: Summary of metals in water research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Copper, iron and lead exceeded the CCME Water Quality Guidelines in about 70% of samples, and cadmium and zinc exceeded guidelines about 15% of the time, out of 14 metals assessed.	1980-1992	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada
Chromium, copper, iron, lead, manganese, and zinc sometimes exceeded CGPFAL out of 11 metals tested for.	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
Iron exceeded CCME guidelines for drinking water, out of 13 metals tested for.	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here)	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
Aluminum, iron, copper and cadmium exceeded the CGPAL in more than 50% of samples. Lead and zinc exceeded CGPAL in less than 36% of samples.	1989-2006	Slave River at Fitzgerald	Glozier et al. (2009)	Assessed and compared the status of water quality from three rivers in Wood Buffalo National Park, and summarized trends over time.
Total Cadmium, Chromium, Copper, Iron, Lead and	varies for each metal;	Slave River at Fitzgerald	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Mercury exceeded CGPAL in more than 25% of the samples. Most were in particulate form and less bioavailable. Dissolved fraction of cadmium and copper however made up a large percentage of the total concentration. Total metals that exceeded CGPAL in less than 25% of the samples were arsenic, barium, manganese, nickel, selenium, silver, vanadium and zinc.	1980-2010			sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 12: Summary of metals in suspended sediment research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
A few samples contained concentrations of arsenic, cadmium, chromium, copper, manganese, nickel and zinc above the TEL or LEL, and all but one sample (of manganese) was below the SEL, out of 29 metals sampled for.	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
Significant differences were not observed between 1990-1995 and 2000-2010 suspended sediment metal concentrations. Positive correlation found between metal concentrations, percentage of clay particles, and TOC of the suspended sediment. Different seasonal patterns were observed for the individual metals.	1990-2010 (n=27)	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Table 13: Summary of metals in bottom sediment research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Elevated arsenic (14 µg/g) near Slave River Delta as compared to rest of the lake (6 µg/g) out of 6 metals tested for.	Summer 1987	In Great Slave Lake near Slave river delta (and other locations across Great Slave lake, results not presented here)	Mudroch et al. (1992)	Assessment of geochemistry and sediment contaminants in Great Slave Lake and historical trends in contaminant deposition.
Aluminum and iron were the primary metals found; cadmium, mercury and selenium occurred in low concentrations.	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here).	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
Chromium, mercury, arsenic and cadmium exceed the PEL for CGPAL	*not available*	Slave River Delta (various sites)	Milburn et al. (2000)	Assessed sediment chemistry and spatial distribution of metals across the Delta.

Table 14: Summary of metals in fish research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Mercury Walleye muscle- 0.13 to 0.80 µg/g Pike muscle – range of 0.17 to 0.54 µg/g, Whitefish muscle -0.08 µg/g (mean)	1988 to 1990	Slave River	Grey et al. (1995)	Determine level of contaminants in the Slave and Hay Rivers, and Leland Lake (control site)
Other metals Tested for 28 metals in pike, burbot, whitefish, walleye, and longnose sucker and found low or undetectable levels of all.	Fall 1992 and Fall 1993	Resolution Bay, Great Slave Lake	Lafontaine (1997)	Assess metals in fish in Resolution Bay to address community concerns about fish health.
Mercury Walleye muscle 0.28 µg/g (mean) (n=72) Pike muscle 0.25 µg/g (mean) (n=66) Whitefish muscle 0.04 µg/g (mean) (n=76) Burbot muscle 0.12 µg/g (mean) (n=36) **Other metals** Tested for 9 metals on whitefish, pike, burbot and walleye muscle, and burbot liver.	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Arsenic Pike muscle- 0.09 µg/g (mean) Pike kidney, liver- below detection limits Burbot muscle -0.18 µg/g (mean) Burbot liver- 0.73 µg/g (mean) Burbot kidney -3.18–19.29 µg/g (mean) (above consumption guidelines) Inconnu muscle- 0.27 µg/g (mean) **Other metals** Tests were very low or below detection limits	August-September 1994	Slave River (sampling also took place on the East side of Resolution Bay and in the Little Buffalo River, data not presented here).	Evans et al. (1998a)	Investigation of the possibility of metal contamination of water and sediment from the decommissioned Pine Point mine.
Mercury at or above 0.2 µg/g in large pike and walleye- approached or exceed Health Canada's fish consumption guidelines **Other metals** Assessed muscle liver and bile of pike, walleye, burbot, and inconnu and found all other metals to be low.	Summer 1996	Resolution Bay, Great Slave Lake	Evans et al. (1998b)	Assess metals and organic contaminants in fish in Resolution Bay to address community concerns about fish health.

Table 15: Summary of contaminants in water research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Most samples were under the detection limit. Six pesticides had a single value above the detection limit. The only detectable compounds were α-BHC which had a median value of 0.003 mg/L, out of 29 pesticides and PCBs tested for.	1979-1986	Slave River at Fitzgerald	WER Agra (1993)	Assessment of water quality parameters using data collected by Environment Canada.
Low levels of chlorinated phenols in water were found, and PCBs and pesticides were below the detection limit.	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.

Table 16: Summary of contaminants in suspended sediment research and monitoring

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
PAH - Found 16 out of 17 PAHs tested for in at least one sample, with concentrations varying between 4 to 580 ng/g **Dioxins and furans -** five of 17 dioxin and furan isomers were detected. No 2,3,7,8-TCDD was detected. **Pesticides** - below detection limits **PCBs** - below detection limits **Chlorophenol** - 21 out of 44 chlorophenols were detected at low levels.	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	To characterize baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.
PAHs – values similar but lower than those detected in 1990-1995 Alkylated PAHs and naphthenic acids added to parameter list **Chlorophenols -** were not detected in 2000-2010 suspended sediment samples, but detection limits were not always		Fort Smith, below Rapids of the Drowned.	Sanderson et al. (2012)	Provide a general overview of the current state of water quality, suspended sediment quality and flows in the transboundary reach of the Slave River; determine if water quality and flows have changed over time.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
comparable. **Pesticides** - below detection limits **PCBs** - below detection limits **Dioxins and furans -** six of 17 dioxin and furan isomers were detected. No 2,3,7,8-TCDD was detected. All values below guidelines				

Table 17: Summary of contaminants in bottom sediment research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
PCB-1.5-6.4 ng/g **Pesticides** - out of 16 compounds tested for, 7 (pentachlorobenzene, 1,2,3,4-tetrachlorobenzene, hexachlorobenzene, A-HCH pentachloroanisol, hexachlorobutadiene, and A-chlordane) were present in every sample. Concentrations ranged from 0.1 to 1.1 ng/g.	Summer 1987	In Great Slave Lake near Slave River delta (and other locations across Great Slave lake, results not presented here)	Mudroch et al. (1992)	Assessment of geochemistry and sediment contaminants in Great Slave Lake and historical trends in contaminant deposition.
PAHs - 60–224.2 ng/g **Dixons and furans** – 4.1–26.9 ng/g **PCBs** - 109-309 ng/g **Chlorophenols -** 19.7-62.5 ng/g	April and October 1997	Slave River Delta, Old Steamboat and Middle Channel West	Milburn & Prowse (1998b)	Assessed spatial distribution of contaminants in the Delta.
PAH - mean of 553.6 ng/g, maximum of 832.7 ng/g **Dioxins and furans -** present at low levels **Pesticides -** found low levels of a number of compounds. The most common compounds were DDT, HCH and dieldrin.	August 1993 and March 1994	Great Slave Lake near the mouth of the Slave River	Evans et al. (1996a, b)	Assessed spatial distribution and historical patterns of contaminant distribution in Great Slave Lake.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
PCBs - mean 9.8 ng/g				

Table 18: Summary of contaminants in fish research and monitoring results

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Dioxins and furans Pike and goldeye muscle-below detection limit **Chlorophenols** Pike and goldeye muscle-below detection limit	Summer 1990	Slave River at Hay Camp, Slave River at Fort Smith	Monenco Consultants Ltd. (1991)	Summarized water quality and sediment and fish contaminants on the Peace, Smoky and Slave Rivers.
PAHs - detected in only 3 muscle samples **Dixons and furans** Walleye muscle 1-3 pg/g Burbot liver- 0–20 pg/g **Pesticides** *Toxaphene* Walleye muscle-0.002-0.137 µg/g (range) (n=44) Pike muscle-0.03-0.035 (range) µg/g (n=30) Whitefish muscle- <0.03-0.063 µg/g (range) (n=20) Burbot liver-0.061–1.97 µg/g (range) (n=100)	1990-1995	Fort Smith, below Rapids of the Drowned.	Sanderson et al. (1997)	Characterized baseline conditions of the aquatic ecosystem and determine contaminant levels in the Slave River, and provide information for transboundary negotiations.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Chlordane Burbot liver: <0 .002 to 0.016 ug/g **PCBs** Burbot liver-0.013 to 0.8 µg/g **Chlorophenols** Muscle samples –0.0007-0.007 µg/g Walleye and whitefish bile-0.074-0.860 µg/g				
Pesticides *Toxaphene* Walleye liver- 0.0415 ng/g Pike liver 0.0557 Burbot: 0.348 ng/g **PCBs** Burbot muscle-0.0029 µg/g (mean) Inconnu muscle 0.0115 µg/g (mean) Walleye liver: 0.0278 µg/g (mean) Pike liver: 0.0351 µg/g	Summer 1996	Resolution Bay, Great Slave Lake	Evans et al. (1998b)	Assess metals and organic contaminants in fish in Resolution Bay to address community concerns about fish health.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
(mean) Burbot liver: 0.0961 µg/g (mean)				

Table 19: Summary of fish community assemblage research and monitoring results

See Appendix C for scientific names of species.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
23 species, 14 of which were rare or incidental. Most common species were: northern pike, lake chub, emerald Shiner, flathead chub, trout-perch and white sucker. Rare species were: Arctic grayling, slimy sculpins, pearl dace, ninespine stickleback, spottail shiners, white suckers, chum salmon, round whitefish, rainbow trout, lake char, lake cisco, Arctic cisco, least cisco, and yellow perch.	Fall and Spring of 1978-1980 in the Delta, Fall of 1979 at Fort Smith	Slave River Delta and Fort Smith	Tripp et al. 1981	Discussion of life history, seasonal movement, distribution and abundance of fish in the Slave River, along with associated aquatic vegetation, water quality and benthic information.
Found 16 fish species. Goldeye were the most abundant, followed by small-bodied cisco, lake whitefish and inconnu.	Fall 1983 and Winter 1985	Slave River below Rapids of the Drowned	RL&L/EMA (1985)	Assessed fish communities and habitat for the Slave River Hydro Study.
Found 16 species. Most abundant species were northern pike, goldeye, walleye and burbot.	1990-1992	Alberta portion of the Slave River	Boag (1993)	Assessed fish communities of the Peace and Slave river as part of the Northern River Basin study.
Found 18 species	Spring/Summer of 1994 and 1995	Slave River Delta	Tallman et al. (1996c)	Assessed diet and trophic relationships within fish communities.

Findings	Sampling date(s)	Sampling location	Reference	Purpose of study
Found 23 species in the area, with pike, walleye, goldeye, whitefish and white suckers as the most common.	Spring/Summer of 1994 and 1995	Slave River Delta and Slave River below Rapids of the Drowned	Little et al. (1998)	Assessed diet and trophic relationships within fish communities

Appendix B: Water Governance and Regulatory Bodies

This appendix summarizes relevant acts and agreements and regulatory bodies and their responsibilities in the Slave River and Slave River Delta, and reflects post-devolution changes to water management in the NWT.

Relevant legislation

Waters Act (2014)

The *Waters Act* and Regulations mirror the former federal *Northwest Territories Waters Act* and Regulations. This territorial act governs the use of water and the deposit of waste (GNWT, 2014). The Act also outlines the two types of water licences that may be issued (subject to the amount of water used or waste discharged). It is the water licence that set out the terms and conditions for water use, waste disposal, construction, operations, security deposits and final closure and reclamation of the site.

Mackenzie Valley Resource Management Act (1998, c. 25)

This federal Act creates an integrated co-management structure for the regulation of public and private lands and waters in the Slave River and Slave River Delta regions, with the exception of Wood Buffalo National Park (Government of Canada, 1998). This Act establishes boards for regional land use planning, regional water and land management boards, and an environmental impact review board.

Under the Devolution Agreement, the GNWT has delegated authorities under the Act for non-federal areas including: approval of Type A water licences and Type B water licences where a public hearing is held, approval of securities, cumulative impact monitoring, environmental audits and an approval function associated with the environmental assessment process (GNWT, n.d .). The minister of Indigenous and Northern Affairs Canada (INAC) maintains these functions for any federal areas in the NWT.

Akaitcho Dene First Nation Interim Measures Agreement (2000)

This Agreement acknowledges the Akaitcho Dene First Nation processes for determining the use of lands and water. It establishes a process for screening proposed development projects, issuing land use permits and water licenses, disposition of federal and territorial land, and forest management (Akaitcho Dene First Nation, 2001).

South Slave Metis Tribal Council Interim Measures Agreement (2002)

This Agreement outlines the “process whereby the South Slave Metis Tribal Council will pre-screen applications for activities described in Section 4 of the Agreement (“Activity” or “Activities”), including licenses, permits and leases relating to the occupation, use and disposition of lands and resources provided for by statutes and regulations of Canada and the GNWT, pending the negotiations of these matters under the South Slave Metis Process” (South Slave Metis Tribal Council Interim Measures Agreement, 2002, p. 3).

Canada National Parks Act (S.C. 2000, c. 32)

This federal act has provisions for the establishment and management of national parks (Government of Canada, 2000). Because a large proportion of the Slave River flows through Wood Buffalo National Park, this act is relevant to the use and protection of the Slave River.

Relevant policy

Transboundary Waters Master Agreement (1997)

This agreement was signed by the governments of Canada, British Columbia, Alberta, Saskatchewan, the Northwest Territories and Yukon. Under this agreement, each jurisdiction is committed to use water in a sustainable manner; protect the ecological integrity of aquatic ecosystems in the whole basin; and consult with other jurisdictions on any developments that would affect the integrity of aquatic ecosystems in another jurisdiction. The agreement also established the Mackenzie River Basin Board, which is a "cooperative forum to inform about and advocate for the maintenance of the ecological integrity of the entire Mackenzie watershed" (Mackenzie River Basin Board website, 2011). Currently, there are three bilateral agreements under the Master Agreement: Yukon and Northwest Territories (Governments of Northwest Territories and Yukon, 1997), Alberta and Northwest Territories (Governments of Alberta and Northwest Territories, 2015) and British Columbia and Northwest Territories (Governments of British Columbia and Northwest Territories, 2015).

Alberta – NWT Bilateral Water Management Agreement (2015)

This Bilateral Water Management Agreement (BWMA) was signed in March 2015. The BWMA establishes a framework for cooperation between NWT and Alberta for managing shared waters in a manner that maintains the ecological integrity of the aquatic ecosystem.

Northern Voices, Northern Waters: NWT Water Stewardship Strategy (2010)

The NWT Water Stewardship Strategy was created by the Government of Northwest Territories and Aboriginal Affairs and Northern Development Canada in partnership with Aboriginal governments and outlines the vision, guiding principles, goals and approaches to water management and stewardship in the NWT (Government of Northwest Territories, 2010). The strategy's vision is to ensure the waters of the NWT remain clean, abundant and productive and to promote an ecosystem-based approached within watersheds. This strategy contains a number of unique components including source water protection, watershed-based planning and a priority for sufficient water for ecosystem functioning (Government of Northwest Territories, 2010).

The Convention on Wetlands (Ramsar Convention) (1971)

The Convention on Wetlands, known as the Ramsar Convention, is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance. The Whooping Crane Summer Range was established as a Ramsar site in 1982. This area is partly contained within Wood Buffalo National Park and partly on NWT crown lands (Ramsar, 2005).

Regulatory bodies and responsibilities

Government of the Northwest Territories

The Government of Northwest Territories is responsible for water management in the NWT and administering the *Waters Act* ***and*** *Regulations.* This authority resides over non-federal areas in the NWT. For these areas, the Minister of Environment and Natural Resources provides approval of all Type A water licences and Type B water licences in which a public hearing is held, enforcement of water licence conditions, collection of water quantity and water quality data and planning for future water use and management. The Department of Environment and Natural Resources is also responsible for implementing the Northern Voices, Northern Waters: NWT Water Stewardship Strategy.

Department of Fisheries and Oceans

In the Slave River and Slave River Delta, the Department of Fisheries and Oceans administers the Aboriginal Aquatic Resource and Oceans Management Program. This program provides funding for projects that support either capacity building or collaborative management of water resources (DFO website, 2011).

Environment Canada

Environment Canada works with Aboriginal Affairs and Northern Development Canada to monitor water quantity and water quality at a number of sites around the Northwest Territories. The department is also responsible for collecting water quality and quantity data at Fitzgerald on the Slave River (Kokelj, 2003).

Mackenzie River Basin Board

The Mackenzie River Basin Board was created in 1997 by the Transboundary Waters Master Agreement. The board does not have regulatory authority or legal basis to manage resource use in any of the signatory jurisdictions but instead works to increase government communication and public engagement concerning water management of the Mackenzie River Basin. It may make recommendations for objectives and guidelines for water quality and monitoring and for incorporation of traditional knowledge and values into water management. It also monitors the implementation of bilateral water management agreements (Mackenzie River Basin Board website, 2011).

Mackenzie Valley Environmental Impact Review Board

The Mackenzie Valley Environmental Impact Review Board is responsible for conducting environmental impact assessments across the entire Mackenzie Valley. The Board performs an environmental assessment or environmental impact review for any development proposal referred to the Board. Following assessment, the Board makes a recommendation to the federal Minister and responsible ministers for approval. The responsible ministers are federal or territorial ministers having jurisdiction related to the development. On non-federal lands the federal Minister is the Minister of Lands, GNWT, and for federal lands it is the Minister of Indigenous and Northern Affairs Canada.

Mackenzie Valley Land and Water Board

The Mackenzie Valley Land and Water Board is responsible for regulating the use of land and water and the deposit of waste in the Slave River and Slave River Delta. The Board performs preliminary screenings of development proposals, and makes recommendations on whether a proposed project requires further review, based on the potential for adverse environmental and social impacts or public concern. The Mackenzie Valley Land and Water Board is responsible for issuing land use permits and water licences in areas of the NWT that are not yet settled under land claims (south Mackenzie Valley), processing transboundary land and water use applications in the Mackenzie Valley, and ensuring consistency in the application of the legislation between the regional boards.

Parks Canada-Wood Buffalo National Park

Parks Canada's mandate includes "protection to ensure the perpetuation of natural environments essentially unaltered by human activity" in National Park areas. Activities of Parks Canada include maintaining ecological integrity through management planning, prohibiting activities within a national park that threaten the integrity of park ecosystems, preventing new sources of pollution and minimizing existing sources of pollution, promoting research, collecting data and maintaining research databases (Parks Canada, 1994).

Appendix C: Scientific names of species

Table 20: Common and scientific names of fish species in the Slave River and Slave River Delta

Common name	Scientific name
Northern pike	*Esox lucius*
Lake chub	*Couesius plumbeus*
Emerald shiner	*Notropis atherinoides*
Flathead chub	*Platygobio gracilis*
Trout-perch	*Percopsis omiscomaycus*
Goldeye	*Hiodon alosoides*
Spoonhead sculpin	*Cottus ricei*
Arctic grayling	*Thymallus arcticus*
Slimy sculpins	*Cottus cognatus*
Pearl dace	*Margariscus margarita*
Ninespine stickleback	*Pungitius pungitius*
Spottail shiners	*Notropis hudsonius*
Chum salmon	*Oncorhynchus keta*
Round whitefish	*Prosopium cylindraceum*
Rainbow trout	*Oncorhynchus mykiss*
Lake char	*Salvelinus namaycush*
Lake cisco	*Coregonus artedi*
Arctic cisco	*Coregonus autumnalis*
Least cisco	*Coregonus sardinella*
Yellow perch	*Perca flavescens*
Burbot	*Lota lota*
Emerald shiner	*Notropis atherinoides*
Walleye	*Sander vitreu*

Table 21: Common and scientific names of benthic invertebrate species in the Slave River and Slave River Delta

Common name	Scientific name
Non-biting midges	*Chironomidae*
Worms	*Oligochaeta*
Mayfly	*Ephemeroptera*
Stoneflies	*Plecoptera*
Caddisflies	*Trichoptera*

Table 22: Common and scientific names of wildlife species in the Slave River and Slave River Delta

Common name	Scientific name
Moose	*Alces alces*
Muskrat	*Ondatra zibethicus*
Beaver	*Castor canadensis*
Otter	*Lontra canadensis*
Mink	*Neovison vison*

Table 23: Common and scientific names of aquatic bird species in the Slave River and Slave River Delta

Common name	Scientific name
American Bittern	*Botaurus lentiginosus*
American Coots	*Fulica americana*
American White Pelican	*Pelecanus erythrorhychos*
American Widgeons	*Anas americana*
Blue-winged Teals	*Anas discors*
Bonaparte's Gulls	*Chroicocephalus philadelphia*
Buffleheads	*Bucephala albeola*
California Gulls	*Larus californicus*
Canada Goose	*Branta canadensis*
Canvasbacks	*Aythya valisineria*
Caspian Tern	*Hydroprogne caspia*
Common Loons	*Gavia immer*
Common Mergansers	*Mergus merganser*
Common Snipe	*Gallinago gallinago*
Common, Black Arctic Terns	*Sterna paradisaea*
Gadwalls	*Anas strepera*
Greater Scaup	*Aythya marila*
Green-winged Teals	*Anas carolinensis*
Herring Gulls	*Larus smithsonianus*
Horned Grebes	*Podiceps auritus*
Killdeer	*Charadrius vociferus*
Least Sandpipers	*Calidris minutilla*
Lesser Scaup	*Aythya affinis*
Lesser Yellowlegs	*Tringa flavipes*
Mallards	*Anas platyrhynchos*
Mew Gulls	*Larus canus*
Northern Pintails	*Anas acuta*
Northern Shovelers	*Anas clypeata*
Piedbilled Grebes	*Podilymbus podiceps*

Common name	Scientific name
Red Knot	*Calidris canutus*
Red-breasted Mergansers	*Mergus serrator*
Redheads	*Aythya americana*
Red-necked Grebes	*Podiceps grisegena*
Red-necked Phalaropes	*Phalaropus lobatus*
Ring-necked Ducks	*Aythya collaris*
Sandhill Cranes	*Grus canadensis*
Semi-palmated Plovers	*Charadrius semipalmatus*
Sora Rails	*Porzana carolina*

Table 24: Common and scientific names of vegetation species in the Slave River and Slave River Delta

Common name	Scientific name
Alders	*Alnus spp*
Black medick	*Medicago lupulina*
Paper birch	*Betula papyrifera*
Blueberry	*Vaccinium uliginosum*
Canada horseweed	*Conya canadensis*
Cattails	*Typha latifolia*
Cloudberry	*Rubus chamaemorus*
Common buttercup	*Ranunculus acris*
Cranberry	*Vaccinium vitis-idaea*
Crawford sedge	*Carex crawfordii*
Grassy pondweed	*Potamogeton gramineus*
Mooseberry	*Viburnum edule*
Horsetail	*Equisetum spp.*
Jack pine	*Pinus banksiana*
Lowbush cranberry	*Vaccinium oxycoccus*
Marsh marigold	*Caltha palustris var.palustris*
Northern water plantain	*Alisma triviale*
Paper birch	*Betula papyrifera*
Poplar	*Populus spp.*
Richardson’s pondweed	*Potamogeton richardsonii*
Slender naiad	*Najas flexilis americanum*
Spruce	*Picea glauca*
Sweet clover	*Melilotus officinalis*
Tall baby's breath	*Gypsophila paniculata*
Willows	*Salix spp.*
Yellow goatsbeard	*Tragopogon dubius*