State of the Aquatic Knowledge of Great Bear Watershed

Prepared for:

Water Resources Division
Indian and Northern Affairs Canada
P.O. Box 1500
3rd Floor, Bellanca Building
Yellowknife, Northwest Territories X1A 2R3

Prepared – January 2004 – by:

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ENVIRONMENTAL SCIENCES LTD.

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List of Acronyms

µg/kg	-	micrograms per kilogram
BOD_5	-	biological oxygen demand
CCME	-	Canadian Council of Ministers of the Environment
CDUT	-	Canada-Déline Uranium Table
CFU	-	colony forming units
DFO	-	Department of Fisheries and Oceans
DW	-	dry weight
INAC	-	Indian and Northern Affairs Canada
LRTAP	-	long range transport of atmospheric pollutants
MAC	-	maximum acceptable concentrations
m	-	metres
m asl	-	metres above sea level
MDLs	-	method detection limits
mg/kg	-	milligrams per kilogram
mg/L	-	milligrams per litre
mL	-	millilitres
MW	-	megawatts
NTU	-	nephelometric turbidity units
NWT	-	Northwest Territories
PAHs	-	polycyclic aromatic hydrocarbons
PCBs	-	polychlorinated biphenyls
pCi/l	-	picocuries per litre
PELs	-	probable effect levels
SNP	-	Surveillance Network Program
SQGs	-	sediment quality guidelines
SSA	-	Sahtu Settlement Area
TAC	-	total allowable catch
TDS	-	total dissolved solids
TSS	-	total suspended solids
WQG	-	water quality guideline
WSC	-	Water Survey of Canada
WW	-	wet weight

Executive Summary

The state of the aquatic knowledge report for Great Bear Lake was commissioned by Indian and Northern Affairs Canada as one of the precursors for developing a Great Bear Lake Management Plan. This document summarizes and reviews what is presently known about aquatic resources and aquatic conditions in the Great Bear watershed, based on available reports and published scientific studies. Sequential sections of this report review ambient limnology of Great Bear Lake, hydrological conditions in its tributaries, and ambient environmental quality conditions throughout the watershed. The structure of the Great Bear Lake ecosystem is described, as are existing water uses and existing and potential disturbance activities. This report concludes by identifying a series of data gaps that will need to be addressed in the future in order to improve the knowledge base and further extend our understanding of the Great Bear Lake ecosystem.

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Chapter 1 Introduction

1.0 Background

The Great Bear watershed comprises an area of approximately 146,000 km^2 in the Western Arctic (Environment Canada 2002). For the purposes of this report, the Great Bear watershed includes the Great Bear Lake, the Great Bear River and their respective watersheds. Great Bear Lake represents the dominant physiographic feature within the watershed. With a surface area of 31,000 km^2, Great Bear Lake is the largest lake wholly contained within the borders of Canada (Johnson 1975a). The lake straddles the boundary of the Precambrian Shield to the north and east, and the Interior Plains to the south and west. The major tributaries to the lake include the Camsell, Johnny Hoe, Dease, Haldane, Whitefish, and Sloan rivers (Figure 1.1). With a population of less than 1000 residents, Déline (formerly Fort Franklin) is the largest community within the basin. Gameti is also located within the watershed.

Prior to contact with the first Europeans, the area served as part of the traditional territories of several First Nation groups, including the Dogrib, Hare, Slavey, Yellowknives, and Inuit. In the centre of this region, the Sahtu Dene people (who were known as the "people of the lake") practised traditional lifestyles by hunting caribou, trapping fur-bearing animals, and catching fish around the perimeter of Great Bear Lake (Johnson 1975c). Not surprisingly, the Sahtu Dene were, and remain today, strongly connected to the Great Bear Lake ecosystem.

Following the appearance of fur traders, explorers, and missionaries during the 19th Century, there were substantial changes to the culture, economy, and social structure of the region. By the early 19th Century, Fort Franklin had been established on the southern shore of the lake near the Great Bear River (Morris 1973). Subsequently, the formerly semi-nomadic existence of the Sahtu Dene was replaced by a settlement existence.

In the 1920s, radium, pitchblende, and silver were discovered in the vicinity of Port Radium. Soon thereafter (i.e., early 1930s), mining operations were developed at this location to extract uranium ore, which was processed into radioactive material for the atomic bombs used during the second World War (Falk *et al.* 1973a). Other mines were also developed in the watershed, primarily to extract silver ore from the Camsell River drainage basin (EBA 1993). None of these mines are currently in operation.

During the 1950s, interest in tourism and sportfishing increased within the watershed. To meet the expanding demand for services, a total of five fishing lodges were established on Great Bear Lake. With the increased fishing pressure on large, trophy-sized lake trout, fisheries management agencies and stakeholders took steps to limit fishing pressure due to the sensitivity of the lake trout population to over-harvesting (including catch-and-release fishing on trophy-sized fish).

A significant event in recent years was the 1993 Comprehensive Land Claim Agreement that sets the terms and conditions for the negotiation of self-government agreements to be legislated in the future by Canada and the Northwest Territories (NWT). Importantly, the agreement established the institutional structure for co-management of the natural resources of the Great Bear watershed.

1.1 Environmental Issues and Concerns

While much of the Great Bear watershed is currently in a relatively pristine state, concerns have been raised about the potential effects of past, present, and possible future developments. More specifically, there is a great deal of concern about residual contamination associated with historical mining activities at Port Radium and within the Camsell River drainage. In addition, environmental contaminants can be released into aquatic ecosystems from other point sources (e.g., sewage treatment plants, solid waste facilities) and from diffuse sources (i.e., long-range atmospheric transport from southern areas). Contaminants originating from these sources have the potential to adversely affect human health or the environment. Furthermore, aquatic resources in the Great Bear watershed could also be affected by other local disturbance activities (e.g., expanding recreation and sportfishing, development of hydroelectric facilities on the Great Bear River) or by those that occur at a global level (i.e., through releases of greenhouse gases and associated climate change). Evaluation of these environmental issues and concerns necessitates implementation of a well-designed monitoring program that can detect subtle changes in the structure and/or function of the aquatic ecosystem. The results of such a monitoring program can then be used to support management initiatives that can address these concerns and promote sustainable development in the watershed.

1.2 Purpose of Report

The Great Bear Lake Working Group was established in 2002 to initiate the development of a management plan for Great Bear Lake and its watershed. Preparation of such a long-term management plan requires a detailed understanding of the study area, of the limnological and hydrological characteristics of the subject water bodies, of existing environmental quality conditions in the watershed, of the structure and function of the aquatic ecosystem, of designated water uses, and of existing and potential disturbance activities in the drainage basin. Both contemporary scientific information and traditional knowledge is needed to gain such a detailed understanding of the Great Bear watershed.

Recognizing the importance of acquiring and compiling the existing information and traditional knowledge on the Great Bear watershed, Indian and Northern Affairs Canada (INAC) and its partners have undertaken several important initiatives in recent years. First, INAC has agreed to take the lead in the preparation of a state of the knowledge report on the aquatic ecosystem. This process was initiated in 2000 when a literature survey was conducted on the natural history of Great Bear Lake (Sirois 2001). This report summarizes the scientific information that was acquired in the literature survey, as well as additional information on Great Bear Lake fisheries resources (compiled by Pamela Taylor, a contractor with Fisheries and Oceans Canada, Hay River, Northwest Territories). This state of the aquatic knowledge report highlights what is known about aquatic resources in the Great Bear watershed and includes:

- An Introduction (Chapter 1);
- A description of the Environmental Setting (Chapter 2);

- An overview of Ambient Limnological and Hydrological Conditions (Chapter 3);
- A discussion on Ambient Environmental Conditions (Chapter 4);
- A description of the Structure of the Aquatic Ecosystem (Chapter 5);
- A listing of Water Uses (Chapter 6);
- A description of Existing and Potential Disturbance Activities (Chapter 7); and,
- A discussion of Data Gaps (Chapter 8).

In addition, a bibliography on the Great Bear watershed is provided in Appendix 1, while a discussion of the environmental assessment and remediation activities that have been conducted at abandoned mine sites is presented in Appendix 2. Second, the Déline Uranium Team has taken the lead on the acquisition of traditional knowledge on the Great Bear watershed. Third, INAC has provided funding to the Sahtu Renewable Resources Board to develop a state of the terrestrial knowledge for the Great Bear watershed (Macdonald 2004). It is anticipated that the state of the knowledge reports, when used together with the available traditional knowledge, will provide valuable information for designing a long-term aquatic monitoring program for the Great Bear watershed (Figure 1.2).

Chapter 2 Environmental Setting

2.0 Introduction

This section of the report describes the environmental setting of Great Bear Lake to provide context for the subsequent analysis of the state of knowledge of the aquatic ecosystem. Included in this section are descriptions of the location, geomorphology, geology, climate, vegetation, and history of the study area.

2.1 Location and Physical Features

The Great Bear watershed is part of the Mackenzie River drainage basin, which drains into the Beaufort Sea. The study area is located in the northeastern portion of the NWT and lies approximately between 65° and 67° N latitude. Great Bear Lake is located about 250 km south of the Arctic Ocean. The total area of the watershed (which includes its lakes and streams) is approximately 145,000 km^2 (Environment Canada 2002).

The Great Bear watershed spans two major physiographic regions, the erosion-resistant Precambrian Shield to the north and southeast and the Mackenzie Lowlands to the south and west (Morris 1972). The Precambrian shorelines are generally steep, rocky and irregular with sparse soil, while the Plains tend to be sloped, sandy and regular. These two physiographic regions are visible on satellite images (Figure 2.1).

Great Bear Lake is unique because of its northerly location, its large size, and its pristine natural environment. The lake covers approximately 31,000 km^2 and has five major arms, including the Keith, McVicar, McTavish, Dease, and Smith arms. The most northerly, the Dease Arm, intersects the Arctic Circle (Figure 1.1 and 2.2). Great Bear Lake is the largest lake within the borders of Canada and one of the largest freshwater bodies in the world.

Great Bear Lake has two main inflows, the Camsell River and the Johnny Hoe River. These rivers contribute approximately 21% and 12% of the flow into the lake, respectively. The only other rivers with significant inflow are the Dease and Haldane Rivers (Dease Arm), the Whitefish River (Smith Arm), and the Sloan River (McTavish Arm; Figure 1.1). Along the northern shoreline, there are a large number of small streams draining the tundra, but for the most part they have virtually no flow in either later summer or winter. The outlet stream, the Great Bear River, is located close to Déline and flows into the Mackenzie River at Tulita (Figure 2.3).

2.2 Geomorphology and Geology

Great Bear Lake was formed by the scouring action of the Laurentide ice-sheet during the Pleistocene Epoch (1.8 million to 11,000 years ago). At the height of the most recent glaciation, the majority of the land to the east of the MacKenzie River was covered by the Laurentide ice-sheet, but an unglaciated region occurred to the west of Great Bear Lake along the front dividing the Laurentide from the Cordilleran ice-sheets (Johnson 1975a). About 10,000 years ago, the ice-margin coincided with the Shield boundary. The ice-sheet crossed the northward slope of the land blocking drainage thus giving rise to a very large proglacial lake, Glacial Lake McConnell, which covered the area now occupied by Great Bear Lake, Great Slave Lake, Lake Athabasca and the land between them. This immense lake drained to the southeast towards the Gulf of Mexico.

Following retreat of the ice, drainage developed to the northwest around the edge of the Shield, resulting in the drainage pattern which we see today. With the retreat of the ice, the land rebounded unequally causing a noticeable tilt to the strand-lines and the formation of an outlet at the western end of the lake (i.e., Smith Arm; Johnson 1975a). As the land surface continued to change, the outlet switched from this region to its present location at the western end of Keith Arm. Archaeological evidence suggests that this outlet was established by about 4000 years ago, at 12 m above the present lake level (Johnson 1975a). The present lake level was initially established about 2600 years ago.

The soils in the Great Bear watershed differ between the two major physiographic regions. In the Precambrian Shield region, soils are sparse and rocky outcrops abound. Thin layers of weathered sedimentary rock, glacial till, and alluvium can be found in small areas of lower elevation. In contrast, the soils of the Interior Plains region are far more substantial and occur over thick glacial till (Johnson 1975a). Alluvial and lacustrine deposits (i.e., soils deposited from flowing waters and those associated with lake sediments) occur at lower altitudes (Johnson 1975a).

The underlying rocks of the Precambrian Shield region are comprised of sedimentary and metamorphic deposits, with igneous intrusions forming dykes and sills (Johnson 1975a). These rocks can be classified into four main groups, including: complex sedimentary and volcanic rocks of the Echo Bay group; intrusions of diorite, grandiorite, and granite; relatively undisturbed conglomerate, sandstone, and quartzite of the Hornby Bay group; and mafic dykes and sills (Kidd 1933). By comparison, the Great Bear Plain is largely underlain with Mezozoic strata of undivided limestone that are rarely exposed (Bostock 1970).

An ecozone is an area where organisms and their physical environment interact as a system. Great Bear Lake lies adjacent to the three terrestrial ecozones, the Southern Arctic ecozone along its northern shore, the Taiga Plains to the west and south, and the Taiga Shield to the east. The Southern Arctic ecozone includes sprawling shrublands, wet sedge, meadows, and cold, clear lakes. The Taiga Plains ecozone is an area of low-lying plains centred on the Mackenzie River and its tributaries. The Taiga Shield is an ecological crossroads (i.e., transitional area) where climate, soil, flora and fauna of the Arctic meet those of the northern temperate zone.

2.3 Climate

The Great Bear watershed is characterized by a northern continental climatic regime (i.e., cool and sub-humid). The main climatic features are long and cold winters, short and cool summers, large annual ranges in temperature, and little precipitation (Johnson 1975a). In winter, the region is dominated by the Arctic air mass, while in summer, incursions of Pacific air are common.

Climatic data were collected initially at Port Radium and more recently, at Déline. From the data collected at these sites (1950 to 1974), it is apparent that annual precipitation is low (i.e., ranging between 250 and 350 mm). More than half of this precipitation falls as rain during the summer months (Figure 2.4; Johnson 1975a). Close to half of the total precipitation is lost by evaporation or evapotranspiration. While southeast winds predominate in this region, summer storms lasting one to two days may arise from any direction.

Air temperatures and incident solar radiation vary substantially on a seasonal basis. Maximum temperatures are typically recorded in July, with the highest reading on record being 29^{o}C (Johnson 1975a). The mean air temperature at Port Radium in July is 12^{o}C. The lowest air temperatures occur in January, when the mean air temperature is -27^{o}C and the extreme low is -52^{o}C (Johnson 1975a). In summer, the sun is above the horizon for 24 hours per day between June 12-20; but, in December, the days are short with the sun barely appearing (Johnson 1975a). Figure 2.4 shows mean monthly solar radiation and mean daily air temperature for Norman Wells and Port Radium, respectively. There are only 60 frost free days per annum in the study area (Johnson 1975a).

2.4 Vegetation

Great Bear Lake occupies a position close to the northern limit of trees. To the south and west are forests, largely of black and white spruce interspersed with muskeg in the lower-lying poorly drained regions. To the north, the forest thins giving way to tundra with trees in the more sheltered areas only. Johnson (1975a) summarized the effects of climate on vegetation adjacent to Great Bear Lake as follows:

> "The short summers and severe winters, combined with the low precipitation, poor soil formation and perennially frozen subsoil, result in stunted forest on the south side of the lake diminishing to tundra with occasional stunted trees along the northern shore. The forest on the southern shore is interspersed with extensive areas of muskeg where drainage is impeded. The best growth of timber is on Grizzly Bear Mountain, where stands of black and white spruce exist interspersed with occasional tamarack."

The most comprehensive description of vegetation in the NWT is provided by Porsild and Cody (1980). The report is largely a systematic account of the vascular plants that occur in the region (over 1000 species), together with distribution maps for 978 plant species. Great Bear Lake lies in a phytogeographical province of low relief which comprises the wooded western portion of the Precambrian Shield and the Mackenzie lowlands.

Arctic plants are remarkably adapted to the harsh environmental conditions, such as those adjacent to Great Bear Lake. Porsild (1930) described some of the features of arctic and sub-arctic flora. These include the remarkably short time that these plants require to waken from a dormant state at the end of the winter, bloom, reproduce and prepare for the next winter. As a consequence of the short growing season, all true Arctic plants are perennial, as the summer is too short for annual species to complete their life cycle (Porsild 1930).

The plants utilizing habitats adjacent to Great Bear Lake are also adapted to low levels of water supply. In the autumn, enough water must be stored up in the plant to withstand loss of water during the winter, when no water can be absorbed from the soil. In addition, the plant must still have enough water left over to start growth in the spring and develop new leaves and flowers. Most Arctic plants are “xerophytes”, plants highly specialized to withstand prolonged drought by having rather small leather-like leaves or dense hair-like structures which provide a felt-like covering.

Woody trees and shrubs tend to grow as dwarf trees adjacent to Great Bear Lake. For example, Richardson’s Willow, *Salix richardsonii*, is one of the hardiest of Canada’s Arctic dwarf trees. With shelter, this plant grows to be a bush 10-12 feet high. However, along the windswept shores of Great Bear Lake, the trunk and branches hug the ground and the leaves are only a few inches above ground. Likewise, spruce trees adjacent to Great Bear Lake can often be stunted, reaching only a few feet tall.

During 2000, a biological inventory was undertaken by Rescan (2000) to document the flora and plant communities of Sahyoue/Edacho, also known as the Grizzly Bear Mountain/Scented Grass Hills National Historic Site. These areas form two of the prominent peninsulas in Great Bear Lake. A total of 152 vascular plant species were documented as occurring on Edacho, representing 33 families. Six dominant plant families accounted for almost 60% of the species total, including sedge (Cyperaceae), willow (Salicaceae), grass (Graminae), pea (Leguminosea), heath (Ericaceae), and sunflower (Compositae).

2.5 History

Great Bear Lake is situated in a region that was previously inhabited by four First Nations, including the Dogribs, Yellowknives, Hares, and Slaveys (Osgood 1932). In the centre of this region is a fifth First Nation, the Sahtu Dene or Great Bear Lake people. It is uncertain whether the Sahtu Dene were always an independent group or whether they became one during the 19th Century owing to conditions created by European contact. Osgood (1932) concluded that the Sahtu Dene are probably more closely related to the Hares than to any other tribe and may have at one time been one of a number of Hare bands. By the 20th Century, the Sahtu Dene were politically, socially, and linguistically differentiated from the Hares, and were more often associated (e.g., through intermarriage) with the Dogribs.

A historical demographic analysis was undertaken by Morris for the period prior to European contact (Morris 1972) and following European contact (Morris 1973). Prior to European contact, the Sahtu Dene were largely a nomadic people, pursuing barren ground caribou, and subsisting on fish, hares, and other animals that were in abundant supply. With the establishment of Fort Franklin (previous name for Déline), these people went from a quasi-nomadic lifestyle and eventually became settlement-oriented.

Morris (1973) identified three distinct phases of European influence on the Sahtu Dene including: prior to 1799, when a North West Company outpost was erected at Great Bear Lake; 1799 - 1851 when traders and explorers occupied the North West Company outpost; and, after 1851 following the arrival of a sequence of missionaries. After the transformation of the North West Company into the Hudson's Bay Company in 1821, the camp was re-built at Fort Franklin to serve as a base for Arctic exploration owing to its dependable food supply. Following six years of exploration, the explorers departed in 1827, leaving the Sahtu Dene to their own devices for much of the next 30 to 40 years.

Between 1799 - 1851, repeated incursions of the explorers and traders introduced a new way of life and a new material culture to the area, but the transient and sporadic visits were not sufficient to establish a new economic and cultural framework for the Sahtu Dene. Subsequently, missionaries visited occasionally, but it wasn't until the 1900s before there was a large influx of traders, scientists, and white trappers into the area. By the end of the 1920s, there was a small Indian settlement at Fort Franklin with 18 log houses and only a few Sahtu Dene lived a nomadic existence. The traditional hunting economy was replaced by a combination of hunting and trapping, neither of which was very successful (Morris 1973).

With the discovery of pitchblende, silver, and other minerals at Port Radium and petroleum at Norman Wells during the 1920s, Great Bear Lake and the Great Bear River became important as a commercial transportation route. Oil, food, and equipment were barged upstream, while silver-copper concentrates were transported downstream by barge to Fort McMurray and then by rail to a smelter at Tacoma, Washington. Later, radium was sent to Port Hope, Ontario, for refining. Following the establishment of a permanent Roman Catholic Mission, Federal Day School, and Hudson's Bay Company post in 1949-50, many Sahtu Dene settled permanently in Fort Franklin.

During the late 1950s, interest in tourism and sportfishing increased in the Great Bear watershed. This interest catalysed the establishment of five fishing lodges along the shores of Great Bear Lake. These lodges now cater to anglers who fish for trophy lake trout (up to 30 kg).

One of the most important events in recent years, with regards to the management of Great Bear Lake, was the 1993 signing of the Comprehensive Land Claim Agreement between Canada and the Dene of Colville Lake, Déline, Fort Good Hope, and Fort Norman and the Metis of Fort Good Hope, Fort Norman, and Norman Wells. This agreement confirms hunting and fishing rights of the Sahtu Dene and Metis throughout the Sahtu Settlement Area (SSA), and establishes their exclusive trapping rights. The agreement guarantees the Sahtu Dene and Metis participation in institutions of public government for renewable resource management, land use planning and land and water use in the SSA, and participation in environmental impact assessment and review in the Mackenzie Valley. The agreement also provides for negotiation of self-government agreements that will be brought into effect through federal and/or territorial legislation. (For information on this agreement visit: http://www.ainc-inac.gc.ca/pr/agr/sahtu/sahmet_e.html.)

Chapter 3 Ambient Limnological and Hydrological Conditions

3.0 Introduction

Great Bear Lake, with a surface area of 31,000 km^2 and a watershed area of 145,000 km^2, represents one of the major sub-basins of the Mackenzie River system. This section of the report summarizes what is known about the physical limnology of Great Bear Lake and the hydrology of its tributaries.

3.1 Physical Limnology of Great Bear Lake

Limnology is the scientific study of lakes. Great Bear Lake captures the curiosity of limnologists because of its many distinctive features, including:

- It is the largest lake within the borders of Canada;
- It is the 9th largest lake in the world in terms of water volume;
- It is the 19th deepest lake in the world, with a maximum depth of 446 m;
- It is the world's largest mass of cold fresh water;
- It has slow water turnover, with a water residence time of 124 years;
- It has clear water, with a maximum recorded Secchi depth of 30 m; and,
- It has a simple food web.

A summary of physical limnological data for Great Bear Lake is provided in Table 3.1.

The total volume of water in Great Bear Lake is close to 2200 km^3. The ratio of the drainage basin area to the area of the lake itself is five, a relatively small number compared to other lakes around the world. The relatively small drainage basin of Great Bear Lake, coupled with low precipitation of 300 mm per year, produce a very small flow through the lake. There is a complete change of all of the water in Great Bear Lake once every 124 years, a relatively long turnover time. Great Bear Lake is a deep lake, with a maximum recorded depth of 446 m and an average depth of 72 m. A three-dimensional graphic of Great Bear Lake is shown in Figure 3.1.

Lake circulation is strongly influenced by temperature, which directly affects water density. In turn, water density affects a lake's mixing properties. To understand a lake, it is necessary to measure temperature at all depths from surface to bottom. Temperature data are usually plotted against depth in a graph called a temperature profile. A previous climate change impact study for the Mackenzie Basin (1997) compared lake temperature profiles for Great Bear Lake, Great Slave Lake, and Athabasca Lake. Temperatures shown in Figure 3.2 are the warmest measurements available for the offshore regions in the years indicated (Melville 1997).

In Great Bear Lake, with the exception of shallow bays and waters that can reach 17^{o}C at the height of summer, most lake water is in the vicinity of 4-6^{o}C (summer). When a lake is ice-covered, the water temperatures are between 0-4^{o}C. Great Bear Lake is an isothermal, unstratified lake, which means that temperatures are similar top-to-bottom, even in the deepest areas of Great Bear Lake. The lack of temperature stratification (i.e., when warmer waters sit on top of colder waters) means that Great Bear Lake is well-mixed. During summer wind storms, water from shallow zones of Great Bear Lake circulates and exchanges with water from deeper areas. On average, Great Bear Lake "turns-over" once every three years (i.e., mixes completely from the surface to the bottom; Johnson 1975a). Turn-over events are important because they re-oxygenate the lower levels of the water column (if depleted) and they mobilize nutrients which are associated with bottom sediments.

Light transparency in lakes can be measured with a black-and-white disk called a Secchi disk (Figure 3.3). Secchi depth data are very useful for understanding lake transparency. Transparency is the ability of the water to transmit light. Lakes with high transparency tend to have low productivity (i.e., the density of plants and animals in the water column is low). In murky (cloudy) water, small Secchi depths are observed, while in clear, transparent water, like Great Bear Lake, large Secchi depths are common. Previously recorded Secchi depths in Great Bear Lake range between 10 to 30 m, depending on location within the lake

(Johnson 1975b). In selected lakes in British Columbia, Secchi depths of between 1.2 and 11 m have been previously measured (Figure 3.4; Levy 1989). Lake Baikal in Russia, the largest and clearest lake in the world, has Secchi depths as great as 40 m (Figure 3.4; T.G. Northcote. Summerland, British Columbia. Personal communication).

Great Bear Lake is ice-covered between December and May, although sheltered bays begin to freeze in September and can be completely frozen as early as November. Ice formation continues until April, when it reaches a thickness of 2.6 m inshore and 1.5 m offshore. Melting or ice break-up begins in the spring and the ice is not completely off the lake until July.

Figure 3.5 presents an example of the process of ice break-up over Great Bear Lake as determined by satellite observations. On the images the dark blue areas represent open water, while the red areas represent the ice cover. The first sign of ice break-up can be seen on the satellite image for June 29, where a small area of open water is apparent in McVicar Arm. The decay of the ice cover progresses over the lake during the following 2 weeks, and the lake is essentially clear of ice on July 15.

3.2 Hydrological Conditions

The drainage area of Great Bear Lake is very small compared to the total area of the lake, which limits the influence of inflows from contributing basins. In all, there are six major inflow streams to the lake, including the Johnny Hoe, Camsell, Sloan, Dease, Haldane, and Whitefish rivers (Figure 1.1). The Camsell River is the largest tributary, occupying 21% of the total drainage area and having a mean total annual flow of 3083 $10^6 m^3$/yr (Kokelj 2001). The second largest tributary is the Johnny Hoe River, occupying 12% of the Great Bear watershed and having a mean annual flow of 1287 $10^6 m^3$/yr (Kokelj 2001).

The flow regimes of the Camsell and Johnny Hoe rivers at the site of their hydrometric gauges are very different. Figure 3.6 shows the annual hydrograph of the Johnny Hoe River, a typical subarctic nival flow regime, common to the Great Bear watershed (note: the x-axis is numbered in Julian days rather than the months of the year). The term 'nival' refers to the response of the river system and the timing of peak flow. Nival streams typically have peak flows that are the direct result of snow melt and runoff. The mean annual flow diagram indicates that peaks usually occur in mid- to late-May. Soon after the peak, flow begins to subside to low levels for the rest of the year. This type of river provides a sudden influx of water to Great Bear Lake during peak discharge and provides very little input following the melt event.

The Camsell River (Figure 3.7) illustrates how lakes delay peak discharge and prolong flow over the entire year. A number of lakes within the Camsell River system store runoff water each year. Large snowmelt peaks do not occur on the Camsell River because of the lake storage effects. Maximum discharge usually does not occur until sometime between mid-June and mid-July. The Camsell River is the only basin within the Great Bear watershed with such a strong lake influence.

The same process occurs in Great Bear Lake only at a much larger scale. The annual hydrograph of the Great Bear River (Figure 3.8) illustrates how the influx of water from the various tributaries is stored by the lake. The seasonal peak discharges that are seen in the Johnny Hoe River, and to a lesser extent the Camsell River are attenuated and less apparent in the outflow from Great Bear Lake. Mean annual discharge only increases by about 100 m^3/s each year.

The dynamics of Great Bear Lake can be summarized with a simple water balance equation. The lake water balance is the difference between all inputs and all outputs.

$$\text{Inputs} - \text{Outputs} = \text{Change in Storage Volume}$$

There are two main inputs, river inflow and precipitation, and two main outputs, lake outflow and evaporation. Variations in the inputs and outputs result in lake level changes. Fluctuations in water levels are the direct result of daily, weekly and annual changes in lake volume.

Figure 3.9 illustrates how average lake levels change over the year. Lake level data have been collected by the Water Survey of Canada (WSC) since 1938; however, continuous recording was not initiated until 1963 (Johnson 1975a). The influx of water from the numerous drainage basins increases water levels in summer and fall (Julian Day 152 - 304); then water levels decline as lake outflow continues while winter ice encompasses the lake. The lake water that was collected is slowly released and lake levels begin to fall. This trend continues until the melt season occurs the following year.

Water level data collected at Port Radium and Hornby Bay indicate that the extreme range in lake surface elevations is one metre. The lowest mean daily lake level elevation was 155.57 metres above sea level (m asl), while the highest was 156.59 m asl, recorded on April 30, 1948 and August 17, 1961, respectively. The difference in lake volume between these extreme events is approximately 32 km^3 or 1.4 % of the total. Figure 3.10 illustrates the extreme years in respect to maximum, minimum and mean daily lake levels.

Lake water levels vary in part due to regional climatic conditions. During a series of dry years, water levels drop. Conversely, during wet years water levels increase as the lake recharges. Usually there is a cyclical pattern between wet and dry years. Figure 3.11 illustrates the cyclical nature of high and low lake levels and their corresponding wet and dry years. The driest years on record occurred in the late 1940s where water levels reached an all-time low, with another low recorded in the mid 1990s. The wettest years on record occurred in the early to mid 1960s, with other peaks occurring in the mid 1940s and early 1970s.

The majority of surface water levels fall between 155.8 m asl and 156.4 m asl (Figure 3.11). Other observations indicate a quick recharge that occurred between the mid to late 1950s, especially between 1955 and 1956. Given this large rise in water level it is likely that a heavy snow accumulation occurred during the winter months in 1955 and that precipitation was above average in 1956.

Water levels may also be affected in the very short term by what is referred to as “seiche”, the effect of a strong wind over several days in pushing water towards the leeward side of a lake. Changes in barometric pressure may also temporarily influence water levels (Johnson 1975a).

Chapter 4 Ambient Environmental Quality Conditions

4.0 Introduction

Ambient environmental quality monitoring data have been collected in the Great Bear watershed for more than 40 years (Table 4.1). Routine water quality monitoring has been conducted at various locations in Great Bear Lake and in the Great Bear River between 1960 and present (Environment Canada 1981; Unpublished data). Routine monitoring of the water quality characteristics of the Camsell River was conducted between 1969 and 1999 (Environment Canada Unpublished data). In addition, a number of specific surveys have been conducted to assess water quality conditions in portions of Great Bear Lake and/or its tributaries (Johnson 1975a; Gartner Lee Limited 2000). However, the majority of the sampling effort has been expended to assess contaminant levels in water, sediment, and biota in the vicinity of Port Radium (Falk 1972; Roy and Vezina 1973; Moore and Sutherland 1981; Environment Canada 1981; DIAND 1982; Myers 1982; Kalin 1982; 1983; 1984; Hatfield Consultants Ltd. 1985; Swanson 1995). Collectively, these monitoring data provide useful information on the status and trends of environmental quality conditions in the Great Bear watershed. For further information on environmental quality conditions in the watershed (Gartner Lee Limited 2000) the reader is directed to a review of the available literature on radionuclide, metal, and organochlorine concentrations in the water and fish of Great Bear Lake.

The available information on environmental quality conditions in the Great Bear watershed was compared to the Canadian water quality guidelines (WQGs; Table 4.2a and 4.2b) to determine if existing water uses are being adequately protected. The Canadian Council of Ministers of the Environment (CCME 1999) Water Quality Guidelines are used by provincial, territorial and federal agencies to assess water quality conditions. Guidelines exist for the protection of aquatic life, drinking water quality, agricultural water uses, recreation and aesthetics, and industrial water uses.

The guidelines for the protection of freshwater aquatic life are not site-specific. They are meant to be applied to freshwater and to protect all forms of aquatic life, including the most sensitive life stage of the most sensitive species. The guidelines are a tool, a reference for the analysis of water quality data to allow some interpretation of what the values mean.

The guidelines for Canadian drinking water quality lists the maximum acceptable concentration (MAC) values for various substances that are of health concern, as well as aesthetic objectives that ensure water is of good quality (appearance, smell, and taste). Health Canada maintains that adherence to these guidelines will result in provision of drinking water that is safe, palatable, and protective of public health. The guidelines are not intended to assess raw source waters; they are to be used to assess drinking water that has been processed through some type of treatment system (CCME 1999).

4.1 Water Quality Conditions in Great Bear Lake Tributaries

The majority of the water that enters Great Bear Lake is transported by small streams many of which have significant flow only during the period of snow melt (Johnson 1975a). The two main rivers supplying the lake are the Camsell River and the Johnny Hoe River, which together drain 30% of the total basin (Johnson 1975a). The only two other rivers that drain appreciable land areas are the Haldane River and the Whitefish River. Some of the other smaller tributaries to the lake include the Dease River, the Bloody River, and the Sloan River.

Information on water quality conditions in the tributaries to Great Bear Lake was obtained from several sources. Environment Canada has operated a routine water quality monitoring station on the Camsell River at the outlet of Clut Lake (65º35'N/117º45'W; Figure 4.1) between 1969 and 1999. This station was established to collect baseline water quality information against which future conditions could be compared. In addition, special studies have been conducted to evaluate water quality conditions on several other Great Bear Lake tributaries (e.g., Johnson 1975b).

4.1.1 Camsell River

The Camsell River is the largest tributary to Great Bear Lake, encompassing a watershed area of more than 31,100 km^2. From its headwaters in the vicinity of Sarah Lake, the Camsell River flows in a southerly and then a northwesterly direction some 300 km to its mouth in Conjuror Bay of McTavish Arm of Great Bear Lake. Over this distance, the Camsell River connects a series of large lakes, including Clut, Grouard, Hottah, Hardisty, Rae, Faber, and Sarah lakes.

The water quality conditions of the Camsell River are influenced by the series of lakes through which it drains. Because streamflows in the Camsell River do not exhibit a great deal of variability during the open water season, the levels of total suspended solids (TSS; range of 1 to 76 mg/L; n=48) and turbidity (range of 0.1 to 6.0 NTU; n=48) tend to be relatively low at the outlet of Clut Lake (Table 4.3). Based on the results of long-term monitoring, the average water hardness and alkalinity of the Camsell River are 58 mg/L and 51 mg/L, respectively. The levels of major ions that were reported for this site are consistent with the relatively low water hardnesses that have been reported (Table 4.3). The pH ranged from 7.3 to 8.0 at this site.

The levels of nutrients in the Camsell River tend to be quite low relative to other rivers in northern Canada. For example, total phosphorus levels ranged from 0.002 to 0.018 mg/L and averaged 0.007 mg/L at the outlet of Clut Lake between 1985 and 1999. By comparison, total phosphorus concentrations as high as 0.57 mg/L have been recorded in the Coppermine River (MacDonald *et al.* 1999). The levels of nitrogen compounds in this system are also relatively low, ranging from 0.002 to 0.070 mg/L for total ammonia and 0.008 to 0.080 mg/L for total nitrate plus nitrite (Table 4.3). By comparison, total ammonia and nitrate plus nitrite levels as high as 0.150 and 0.340, respectively, have been observed in the Coppermine River (MacDonald *et al.* 1999). The lower levels of nutrients that are typically observed in this system are typical for rivers on the Canadian Shield.

Although the levels of metals in the Camsell River tend to be quite low throughout much of the year (i.e., as evidenced by the low median values for total metals), higher levels have been observed during elevated flow periods (Table 4.3). For example, the concentrations of total cadmium, copper, chromium, lead, selenium, and silver ranged to levels that exceeded the Canadian WQGs for the protection of aquatic life (CCME 1999; Table 4.2a). As these metals are most likely associated with fine inorganic sediment (i.e., elevated levels of TSS), it is unlikely that elevated metal levels pose a significant hazard to aquatic organisms in the Camsell River system. No data were located on the levels of organic contaminants in water from this river system.

The effects of five abandoned mines located in the Camsell River watershed were evaluated by INAC (2003). These mines included the Terra mine, the Northrim mine, the Norex mine, the Smallwood Lake mine, and the Contact Lake mine. All of these mines focussed on silver production, except the Contact Lake mine, which was a uranium mine. The results of the INAC (2003) study showed that the levels of arsenic, copper, iron, lead, and/or zinc exceeded the Canadian WQGs in water collected at several of these sites, particularly at Terra, Norex, Northrim, and Contact Lake (Appendix 2). However, metal leaching from various locations does not seem to be affecting downstream water bodies. Of the areas studied, the highest levels of metals in surface waters were observed in Moose Bay (near the Terra mine).

4.1.2 Johnny Hoe River

The Johnny Hoe River is located on the south side of Great Bear Lake. From its headwaters, located north of the Willowlake River, the Johnny Hoe River flows more than 150 km to its mouth at the head of McVicar Arm of Great Bear Lake. Keller Lake, Lac Ste. Thérèse, Lac Taché, and Tseepantee Lake are the largest lakes in the system.

Data on the water quality in the Johnny Hoe River are limited. However, data collected in 1963 (Johnson 1975a) and between 1969 and 1976 (Environment Canada Unpublished data) provide a basis for conducting a preliminary evaluation of water quality conditions. These data show that the Johnny Hoe River above Lac Ste. Thérèse is harder and more coloured than the Camsell River. Over the period of record, water hardness has ranged between 92 and 224 mg/L and alkalinity has ranged from 61 to 147 mg/L. Water colour ranged from 5 to 100 total colour units between 1969 and 1976. In addition, major ion concentrations were substantially higher than those that have been reported for the Camsell River. The pH at this site was between 7.6 and 8.2 units (Table 4.4).

The levels of nutrients in the Johnny Hoe River are similar to, or higher than those that have been recorded in the Camsell River. For example, total phosphorus concentrations ranged from 0.003 to 0.006 mg/L (averaging 0.005 mg/L; Table 4.4). In contrast, the levels of total ammonia in this river are quite high, ranging from 0.2 to 0.3 mg/L. Nitrate plus nitrite concentrations are also elevated relative to those in the Camsell River, ranging from 0.001 to 0.190 mg/L. Total organic carbon ranged from 9.0 to 89 mg/L at the site above Lac Ste. Thérèse between 1969 and 1976 (Table 4.4). These characteristics are probably due to the fact that the Johnny Hoe River has its headwaters in an area of extensive muskeg and flows through the Great Bear Plains (Johnson 1975a).

Insufficient information is available to fully evaluate the levels of metals and organic contaminants in the Johnny Hoe drainage basin. However, the limited data indicate that the concentrations of extractable arsenic, cadmium, and copper range to or above the Canadian WQGs. No data were located on the concentrations of organic contaminants in water from this river.

In 1992 and 1993, Stephens (1997) collected surface water samples from the four largest lakes within the Johnny Hoe watershed (i.e., Lac Ste. Thérèse, Keller Lake, Tseepantee Lake, and Lac Taché; Table 4.5). The results of chemical analyses of these samples indicate that the four largest lakes tend to be slightly alkaline (pH ranged from 7.1 to 8.5), moderately soft (mean hardness ranged from 69 to 163 mg/L), and have moderate levels of major ions. Total mercury concentrations varied among the four lakes that were sampled, with the highest levels occurring in Lac Ste. Thérèse (i.e., to 1.64 µg/L). Few data were located on the levels of other metals or organic contaminants in water from these lakes.

4.1.3 Dease River

The Dease River is located on the north side of Great Bear Lake. From its headwaters, located some 30 km south of Dismal Lake in the Great Bear watershed, the Dease River flows in a southwesterly direction roughly 75 km to its mouth at the head of Dease Arm of Great Bear Lake. The Dease River basin is relatively small, draining an area of roughly 3000 km^2 of highly insoluble Proterozoic rocks (Johnson 1975a).

As would be expected based on the underlying geology, the Dease River tends to have only low levels of dissolved solids (i.e., 32 mg/L; n=1; Table 4.6). Accordingly, water hardness, alkalinity, and major ion levels are low (Table 4.6). While the levels of total phosphorus are also low, nitrate levels were the highest among the various tributaries that were sampled in 1963 (Johnson 1975a). Although the levels of aluminum, manganese, and zinc were all below the Canadian WQGs (CCME 1999; Table 4.2a), concentrations of copper exceeded the guideline for the protection of aquatic life on the date that it was sampled (Table 4.6). As TSS levels were not reported, it is not possible to determine if the elevated levels of copper were likely to be biologically available. No data were located on the levels of organic contaminants in water from this river system.

4.2 Water Quality Conditions of Great Bear Lake

4.2.1 Great Bear River at the Outlet of Great Bear Lake

Routine water quality monitoring data have been collected on the Great Bear River at the outlet of Great Bear Lake (65º08'N/123º30'W; Figure 4.2) since 1969. This station, which is located on the north shore of the Keith Arm near Déline, is strategically located at the outlet of Great Bear Lake. Accordingly, this station provides relevant baseline information on water quality conditions within this portion of the lake, against which future conditions can be compared.

Based on the results of long-term monitoring activities, it is apparent that Great Bear Lake has relatively low levels of total dissolved solids (TDS; i.e., ranging from 77 to 150 mg/L; Table 4.7). However, these levels are not as low as those that have been reported for lakes that are located entirely within the Canadian Shield (Armstrong and Schindler 1971; MacDonald *et al.* 1999). As would be expected in a lake with low levels of TDS, hardness (mean of 70.3 mg/L), alkalinity (mean of 56.9 mg/L), and major ion levels (Table 4.7) are also relatively low. The concentrations of calcium, magnesium, and sulphate averaged 16.7 mg/L, 7.1 mg/L, and 14.5 mg/L, respectively. The water collected at this location tended to be slightly alkaline, with pH ranging from 7.3 to 8.2 (median value of 7.9).

While the levels of aquatic plant nutrients were relatively low in Great Bear Lake, they tended to be higher than other Canadian Shield lakes. For example, the concentrations of total ammonia at the outlet of Great Bear Lake averaged 0.018 mg/L and ranged from 0.002 to 0.095 mg/L (Table 4.7). By comparison, total ammonia levels were generally below 0.01

mg/L in Lac de Gras during 1994 and 1995 (Diavik 1998). Nitrate plus nitrite concentrations were also higher in Great Bear Lake (i.e., mean of 0.146 mg/L) than was the case for Las de Gras (i.e., typically less than 0.006 mg/L; Diavik 1998). In terms of total phosphorus, concentrations ranged from 0.002 to 0.363 mg/L in Great Bear Lake between 1969 and 2001; mean and median values of 0.013 and 0.006 mg/L, respectively, were calculated from these data. It is likely that peak levels of phosphorus are associated with elevated levels of suspended solids, perhaps due to wave-driven or ice-driven erosion of lake bed materials upstream of the sampling site. If sampling had been conducted in the main body of the lake instead of at the outlet, it is likely that phosphorus levels would have been much lower, supporting classification of the lake as ultraoligotrophic to oligotrophic (i.e., extremely low to low productivity). In general, the levels of nutrients measured at the outlet of Great Bear Lake were higher than those that have been reported for the Camsell River and Johnny Hoe River (Johnson 1975a). No obvious temporal trends in nutrient levels were noted in the data collected between 1980 and 2001 (Table 4.8).

The concentrations of metals that have been measured in the Great Bear River at the outlet of Great Bear Lake indicate that water quality conditions are generally sufficient to support the designated uses of this lake. Nevertheless, the maximum levels of aluminum, cadmium, chromium, copper, iron, lead, manganese, and silver all exceeded the Canadian WQGs for the protection of aquatic life. In addition, the maximum level of iron exceeded the Canadian WQG for drinking water supplies. Because maximum levels of TSS were relatively high (i.e., 183 mg/L), it is likely that the elevated metal levels were associated with fine inorganic sediments. As such, elevated metal levels probably do not pose a hazard to aquatic life at this location. No data were located on the levels of organic contaminants in water samples from this site.

4.2.2 Great Bear Lake in the Vicinity of Port Radium

The Eldorado mine was situated on the eastern shore of Great Bear Lake in the vicinity of Port Radium on McTavish Arm. This mine operated during the period 1932 to 1960, producing radium, uranium, silver, copper, cobalt, nickel, and polonium over that period. The Echo Bay mine, which was located at the same site, commenced operations in 1964 and operated for a period of 18 years before being decommissioned in 1982. Ore containing silver, copper, lead, and zinc was mined and milled at the site during this period. The mine tailings from both of these operations were deposited directly into Great Bear Lake for much of the period between 1932 and 1975, primarily in the vicinity of Cobalt Channel (north of Cobalt Island). Due to the nature of the operations and the methods used to dispose of mine wastes, numerous studies have been conducted in the vicinity of Port Radium to evaluate the effects of discharges from these mines on Great Bear Lake.

The results of the various water quality assessments that have been conducted in the vicinity of Port Radium were compiled by Gartner Lee Limited (2000; see Figure 4.3 for a description of landmarks). These results indicate that water quality in the vicinity of Port Radium has been impaired by historic mining activities. For example, Redshaw (1974) reported elevated levels of arsenic (0.022 mg/L in 1969), copper (mean value of 0.16 mg/L in 1970), and lead (to a maximum of 0.016 mg/L in 1971) in Labine Bay (which is located inshore of Cobalt Island). These levels exceeded the Canadian WQGs for the protection of aquatic life (CCME 1999). Even higher levels of arsenic (mean value of 0.13 mg/L) and lead (mean value of 0.03 mg/L) were reported for the Labine Bay site in 1982 (Kalin 1983). Elevated levels of arsenic, copper, and lead were also observed in Cobalt Channel during various years between 1969 and 1982 (Falk 1972; Redshaw 1974; Kalin 1983). However, lower levels of these metals were reported in 1978 (Moore and Sutherland 1981).

Swanson (1995) compiled water quality data collected in the vicinity of Port Radium between 1969 and 1994. These results suggest that the waters near Port Radium were still impaired after mining activities had ceased at the site. These data showed that the levels of arsenic, cadmium, copper, lead, zinc, and/or uranium exceeded the Canadian WQGs for the protection of aquatic life at the following sites in 1984: Bear Bay; Labine Bay; Murphy Bay; and, Silver Point. By 1994, the levels of these metals in surface waters had dropped substantially; however, the levels of copper, lead, and zinc still exceeded the aquatic life guidelines at several locations (Swanson 1995).

4.3 Bed Sediment Quality Conditions

The particulate materials that lie below the water in ponds, lakes, springs, streams, rivers, and other aquatic systems are called sediments (ASTM 2003). Sediments represent essential elements of aquatic ecosystems because they support both autotrophic and heterotrophic organisms. Autotrophic (which means self-nourishing) organisms are those that are able to synthesize food from simple inorganic substances (e.g., carbon dioxide, nitrogen, and phosphorus) and the sun's energy. Green plants, such as algae, bryophytes (e.g., mosses and liverworts), and aquatic macrophytes (e.g., sedges, reeds, and pond weed), are the main autotrophic organisms in freshwater ecosystems. In contrast, heterotrophic (which means other-nourishing) organisms utilize, transform, and decompose the materials that are synthesized by autotrophic organisms (i.e., by consuming or decomposing autotrophic and other heterotrophic organisms). Some of the important heterotrophic organisms that can be present in aquatic ecosystems include bacteria, epibenthic, and infaunal invertebrates, fish, amphibians, and reptiles. Birds and mammals can also represent important heterotrophic components of aquatic and aquatic-dependent food webs (i.e., through the consumption of aquatic organisms).

Contaminated sediments represent an important environmental concern for several reasons. First, contaminated sediments have been demonstrated to be toxic to sediment-dwelling organisms and fish (Ingersoll *et al.* 1997). As such, exposure to contaminated sediments can result in decreased survival, reduced growth and/or impaired reproduction in benthic invertebrates and fish. Additionally, some contaminants in the sediments are taken up by benthic organisms through a process called bioaccumulation (Ingersoll *et al.* 1997). When larger animals feed on these contaminated prey species, the pollutants are taken into their bodies and are passed along to other animals in the food web in a process called biomagnification. As a result of the effects of toxic and bioaccumulative substances, benthic organisms, fish, birds, and mammals can be adversely affected by contaminated sediments (MacDonald *et al.* 2002a; 2002b). Contaminated sediments can also adversely affect human health and the human uses of aquatic ecosystems.

4.3.1 Sediment Quality Conditions in the Vicinity of Port Radium

Four studies were located that provide information on sediment quality conditions in the Great Bear watershed. In the first of these studies, sediment chemistry data were collected at two sites in the vicinity of Port Radium in 1971 and four sites in 1972 (Falk *et al.* 1973b; Table 4.9; Figure 4.4). In 1971, average concentrations of copper (3320 mg/kg dry weight; DW), lead (278 mg/kg DW), and zinc (813 mg/kg DW) at the two stations located adjacent to Cobalt Channel exceeded the Canadian sediment quality guidelines (SQGs) for the protection of aquatic life (Table 4.10; CCME 1999). The probable effect levels (PELs) for these metals were also exceeded, suggesting that these sediments would be toxic to sediment-dwelling organisms. A broader suite of analytes (i.e., variables) was measured in 1972 at the same two stations plus several others located in Labine Bay. Although the mean concentrations of zinc were lower (389 mg/kg DW) than the value that was calculated in 1971, the average concentrations of copper (7788 mg/kg DW) and lead (937 mg/kg DW) were substantially higher than the values that were calculated in 1971. In addition, arsenic (3525 mg/kg DW), cadmium (913 mg/kg DW) and nickel (481 mg/kg DW) were also measured at elevated concentrations, typically exceeding the PELs. Uranium was measured at nine stations in this study, with concentrations ranging from 2.0 to 1820 mg/kg DW (Figure 4.4). As no SQG is available for uranium, the biological significance of these concentrations can not be determined.

In 1978, Moore and Sutherland (1981) collected whole-sediment samples from 37 stations in the vicinity of Port Radium (Figure 4.5). The results of this study showed that mercury concentrations were elevated at the majority of the stations sampled, with concentrations as high as 3.0 mg/kg DW reported in sediments from Cobalt Channel. Similarly, sediments from this location also had the highest concentrations of lead (to 1800 mg/kg DW), manganese (to 31,500 mg/kg DW), and nickel (to 590 mg/kg DW). By comparison the levels of arsenic (to 3700 mg/kg DW) and copper (to nearly 10,000 mg/kg DW) peaked at the stations that were within Labine Bay and further offshore. The Canadian SQGs for all of the metals measured were exceeded in the majority of the whole-sediment samples collected in this study, suggesting that sediment-associated metals pose a hazard to benthic organisms utilizing habitats in the vicinity of Port Radium. As the underlying data were not presented in the report, it was not possible to tabulate these data.

Sediment quality conditions in the vicinity of Port Radium were also evaluated in 1982 and 1983 (Kalin 1983). The results of this study indicated that the levels of uranium in bed sediments varied substantially on a spatial basis. The highest levels of uranium (mean of 443 mg/kg DW; n=6) were observed in Cobalt Channel. Relatively lower levels were observed in Outer Labine Bay (270 mg/kg DW; n=1), Murphy Bay (163 mg/kg DW; n=1), and Inner Labine Bay (48 mg/kg DW; n=1). The Environmental Protection Service reported somewhat higher levels of uranium in Cobalt Channel and Outer Labine Bay (Kalin 1983). Canadian

SQGs are not available for uranium; therefore, it is not possible to determine if the levels measured pose a hazard to sediment-dwelling organisms.

Macdonald (1998) collected whole-sediment samples from four stations in the vicinity of Port Radium to evaluate the influence of mining operations on sediment quality conditions (Figure 4.6). The results of this study indicated that the levels of the majority of the metals measured were elevated relative to background concentrations (with the exception of beryllium, tin, and thallium; i.e., based on samples collected elsewhere in the lake). Importantly, the concentrations of arsenic, cadmium, chromium, copper, lead, mercury, and zinc exceeded toxicity thresholds (i.e., PELs; Table 4.10) at all or most of the stations sampled, often by a factor of 10 or more (Table 4.11). These data confirm that sediments in the vicinity of Port Radium are still highly contaminated and pose a serious hazard to the benthic invertebrate community.

4.3.2 Sediment Quality Conditions Elsewhere in Great Bear Lake

Based on the results of sampling conducted in 1995, it appears that the levels of mercury in Great Bear Lake have increased over time (Evans *et al.* 2003). Coring results showed that, in the early 1800s, mercury concentrations in bed sediments from McVicar Arm were in the order of 40 to 50 µg/kg DW. Over the past 200 years, these levels have increased to roughly 80 µg/kg DW (Figure 4.7). As there are no known point sources of mercury in this area of the lake, atmospheric deposition represents the most likely source of this substance.

In 1998, Macdonald (1998) collected sediments from six locations in Great Bear Lake to establish background levels of metals. The results of this study indicated that the levels of most metals occurred at concentrations below the Canadian SQGs; however, both arsenic and copper exceeded the SQGs by a small margin at several locations (Table 4.11). Because background concentrations of metals are so variable in this watershed, it would be useful to explore the use of a reference element approach to develop a tool for detecting anthropogenic enrichment of lake sediments with metals (e.g., Carvalho *et al.* 2002). This approach involves the development of linear regressions between metal concentrations and the concentrations of a reference element (e.g., lithium, aluminum). Anthropogenic enrichment is suspected when metal concentrations fall outside the upper 95% prediction limit for the regression.

4.3.3 Sediment Quality Conditions in the Johnny Hoe River Basin

Stephens (1997) collected whole-sediment samples from four lakes in the Johnny Hoe River basin. The concentrations of total mercury were determined in each sample. The results of this study indicated that mercury levels were similar in three of the lakes (Lac Ste. Thérèse, Keller Lake, and Lac Taché; Table 4.12). Higher mercury levels were observed in Tseepantee Lake (mean of 64 µg/kg DW); however, the Canadian SQGs were never exceeded.

4.3.4. Sediment Quality Conditions Elsewhere in the Great Bear Watershed

In 1993 and 1994, Puznicki (1997) collected whole-sediment samples from 292 randomly selected sampling stations in lakes located in the Slave Structural Province. Of these, 41 samples were located in the Great Bear watershed. The results of this study showed that levels of metals in lake sediments within the Great Bear watershed are highly variable. For example, arsenic concentrations ranged from 0.760 to 31.5 mg/kg DW at the stations that were sampled in this study, with one sample having sufficient arsenic to adversely affect sediment-dwelling organisms (i.e., > PEL; Table 4.13). Similarly, cadmium, chromium, copper, and lead concentrations typically varied by a factor of 10 to 100 among the stations that were sampled; however, the levels of these metals never exceeded the PELs. For mercury, concentrations ranged from 0.004 to 1.04 mg/kg DW, with the highest level measured exceeding the PEL by more than a factor of two. The highest frequency of exceedance of the PEL (i.e., 3 of 41 samples) was observed for zinc; the concentrations of this metal ranged from 47.2 to 494 mg/kg DW.

4.4 Contaminant Residues in Aquatic Resources

Environmental contaminants, including metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, and other substances, can be released into the Great Bear Lake ecosystem from local or distant sources. Because mining has represented an important land use in this watershed over the past seventy years, it is likely that much of the anthropogenic metal loading to the lake and its tributaries is associated with releases from historic mine sites. However, atmospheric transport and subsequent deposition within the watershed is probably occurring to a significant extent for several metals (e.g., cadmium and mercury). For the organic pollutants, long-range atmospheric transport from the more southerly portions of North America probably represents the most important process contributing to loadings to the lake and its tributaries.

Releases of contaminants into aquatic ecosystems within the Great Bear watershed represent a significant environmental concern when these substances enter the aquatic food web. Substances that occur at only low levels in water can concentrate in the tissues of aquatic organisms (i.e., algae) and subsequently biomagnify in the food web. In addition, certain contaminants (metals, PAHs, PCBs, and organochlorines) can accumulate in bed sediments and, subsequently, accumulate in the tissues of sediment-dwelling organisms. These contaminants can then magnify in the food web when sediment-dwelling organisms are consumed by fish, other aquatic organisms, or wildlife. Elevated levels of contaminants in fish and other aquatic organisms represent a significant environmental concern because they can pose a hazard to piscivorus wildlife and to human health. However, Canadian tissue residue guidelines are available for only a limited number of the chemicals of potential concern in the Great Bear watershed (CCME 1999).

4.4.1 Contaminants in Fish Tissues Collected in the Vicinity of Port Radium

Several studies have been conducted to evaluate the levels of contaminants in the tissues of fish from the Great Bear watershed. In 1971, Falk collected lake cisco (*Coregonus artedii*) and lake trout (*Salvelinus namaycush*) from Cobalt Channel to evaluate the levels of metals in muscle and liver tissues (Falk 1972; Table 4.14). The results of this study indicated that the levels of copper, lead, and zinc in cisco muscle ranged from 0.05 to 0.42 mg/kg wet weight (WW; n=9), 0.08 to 0.28 mg/kg WW (n=9), and 4.85 to 10.5 mg/kg WW (n=9), respectively. The levels of these metals were up to a factor of 10 higher in lake cisco liver (n=2) than the average concentration in muscle tissue. The levels of copper, lead, and zinc in lake trout muscle (mean of 0.18, 0.21, and 4.99 mg/kg WW, respectively; n=5) and liver tissues (1.76, 0.24, and 37.2 mg/kg WW, respectively; n=5) were generally comparable or lower than those that were observed in lake cisco tissue. The lack of Canadian tissue residue guidelines makes it difficult to interpret these data relative to the potential for adverse effects on aquatic-dependent wildlife or human health.

Sampling conducted by Falk in 1972 provided additional information on the levels of metals in tissues of fish collected from the vicinity of Port Radium (Falk *et al.* 1973a; Table 4.14). The results of this follow-up study indicated that the levels of copper, lead, and zinc in cisco muscle (mean of 0.38, 0.18, and 8.2 mg/kg WW, respectively; n=18) and liver (mean of 4.0, 0.64, and 143 mg/kg WW, respectively; n=18) were similar to the 1971 results. However, the levels of these metals in lake trout muscle were up to a factor of three higher than they were in the samples collected in 1971 (Table 4.14). While the levels of lead (mean of 0.52 mg/kg WW) and zinc (mean of 31.9 mg/kg WW) in lake trout liver were comparable in 1971 and 1972, the concentrations of copper were much higher in 1972 (mean of 11.2 mg/kg WW). In general, the levels of arsenic, cadmium, nickel, and selenium in lake trout tissues were comparable to the levels in lake cisco tissues (Table 4.14). Canadian tissue residue guidelines are not available for any of these metals, so it was not possible to evaluate the hazards that they pose to human health or aquatic-dependent wildlife. Nevertheless, it is clear that both lake trout and lake cisco had elevated levels of various metals.

In 1984, Hatfield Consultants Ltd. (1985) collected fish tissues from several sampling stations located in the vicinity of Port Radium. The samples represented composites of the tissues from lake cisco and lake trout, and included several individuals of each species. This unique approach to creating composite samples makes it difficult to interpret the results. Accordingly, the results are not presented in this document.

Nearly ten years later (1993), fish tissue samples were collected at two locations in Great Bear Lake, including Port Radium and Deerpass Bay (which is located in the Keith Arm, north of Déline; Lafontaine 1994). Fourteen lake trout were collected in the vicinity of Port Radium, while 10 lake trout, four lake whitefish (*Coregonus clupeaformis*), and one arctic grayling (*Prosopium cylindraceum*) were captured in Deerpass Bay. Both muscle and liver tissues were analysed for each fish that was collected. The results of this study showed that the levels of cadmium, copper, zinc, and selenium were substantially higher in liver than they were in muscle tissues of all species at both locations (Table 4.15). Importantly, the levels of arsenic, cadmium, copper, and zinc were at least a factor of two higher in the samples taken from the Port Radium site than they were in fish from Deerpass Bay. These results confirm that the metals in environmental media near Port Radium are bioavailable and are being accumulated in the aquatic food web.

4.4.2 Contaminants in Fish Tissues Collected from Locations Elsewhere in Great Bear Lake

In 1978, Fisheries and Oceans Canada collected lake trout and northern pike (*Esox lucius*) from Great Bear Lake to determine the concentrations of selected metals in their muscle tissues (Wong 1985). As the sampling station was believed to be well-removed from point sources of metals, the results provide an estimate of background concentrations in the lake. In general, the levels of arsenic, cadmium, copper, and lead were low in lake trout muscle, averaging 0.14, 0.01, 0.3, and 0.08 mg/kg WW, respectively (Table 4.16). In northern pike, the levels of arsenic, cadmium, copper, and lead averaged 0.07, 0.01, 0.22, and 0.5 mg/kg WW, respectively.

In 1978 and 1979, Fisheries and Oceans Canada collected tissue samples at several locations in Great Bear Lake that were removed from point source discharges of metals (i.e., Port Radium, Camsell River; Evans *et al.* 2002). The three fish species that were sampled included cisco, northern pike, and lake trout. The results of this study showed that muscle tissues from cisco generally had low levels of mercury (i.e., <0.05 mg/kg WW). By comparison, northern pike had mercury concentrations ranging from <0.05 to >0.5 mg/kg WW in muscle tissues. The largest specimens (i.e., in terms of length) tended to have the highest concentrations in their tissues. In lake trout muscle, mercury levels ranged from 0.2 to 0.65 mg/kg WW, again with larger fish tending to have higher concentrations of mercury in their tissues. These results emphasize the need to consider both trophic status and fish length when comparisons of the levels of mercury between locations are being made. In addition, these results showed that the levels of mercury in lake trout and northern pike samples often exceeded the levels recommended for humans who frequently consume fish tissues (i.e., 0.2 mg/kg WW; Health and Welfare Canada 1990).

In addition to mercury, Evans (2003) compared levels of other contaminants in lake trout taken from Great Bear Lake and Lac Ste. Thérèse during 2002. The additional contaminants measured include PCBs, toxaphene, DDT, chlordane and dieldrin. The results of this study showed that lake trout from Lac Ste. Thérèse had the highest levels of mercury in their tissues (averaging roughly 0.7 mg/kg WW); consumption advisories have been issued by Health Canada for walleye, lake trout, and pike from this lake (Evans 2003). The levels of mercury in lake trout were substantially lower in Great Bear Lake, averaging roughly 0.35 mg/kg WW in muscle tissue. In contrast, the levels of PCBs, toxaphene, DDTs, chlordane, and dieldrin were all higher in Great Bear Lake than was the case for Lac Ste. Thérèse (Figure 4.8). None of these organic contaminants approached levels of concern with respect to the protection of human health (CCME 1999).

4.4.3 Contaminants in Fish Tissues Collected from the Johnny Hoe River Basin

While much of the fish tissue sampling that has been conducted in the Great Bear watershed has been focussed in the vicinity of Port Radium, some effort has also been directed at the Johnny Hoe River basin. More specifically, Stephens (1997) compiled the historical data on the levels of mercury in fish tissues from several lakes in the watershed, including Lac Ste. Thérèse, Keller Lake, Tseepantee Lake, and Lac Taché. In addition, the results of the 1992 and 1993 sampling program were also reported. The results of this study showed that the average concentrations of mercury in the muscle tissues of walleye, lake trout, northern pike, and longnose sucker always exceeded the recommended limit for frequent consumers of fish tissues (0.2 mg/kg WW), with the highest average levels observed in walleye (Table 4.17). Lower levels of mercury were observed in lake whitefish and burbot muscle tissues. Mercury concentrations tended to be similar or lower in the liver and kidney of the fish that were collected from these four lakes. The lack of anthropogenic sources of mercury in this watershed suggests that mercury is being released into the system from natural sources and that this mercury is accumulating to levels of concern in fish tissues.

Chapter 5 Structure of the Aquatic Ecosystem

5.0 Introduction

Information on the structure and function of aquatic ecosystems within the Great Bear watershed is available from a number of sources. A number of focussed studies have been conducted to collect basic scientific data on the aquatic organisms that utilize habitats within the watershed. In addition, several broad surveys of fish and other aquatic resources have been undertaken in the central portion of the NWT and Great Bear Lake and its tributaries were frequently included in these investigations. Furthermore, a great deal of traditional knowledge of aquatic resources in the Great Bear watershed exists among the indigenous peoples that reside within the basin or utilize portions of the area on a seasonal basis. Miscellaneous smaller scale studies also contribute to the knowledge base on the river system. Together, these data sources provide sufficient information to construct an overview of the structure of aquatic ecosystems within the drainage basin.

One of the distinguishing characteristics of aquatic ecosystems in the north is their low productivity. These systems tend to be oligotrophic due to the low levels of nutrients that exist in the water column and the cold water temperatures that are prevalent throughout much of the year. Hence, the fish and other aquatic organisms that utilize these systems tend to have relatively low growth rates and low densities. In addition to low productivity, northern ecosystems also tend to have relatively simple food webs. This latter characteristic simplifies the process of establishing the linkages between stressors and receptors in these systems. The simplicity of the food webs makes these ecosystems vulnerable to disturbance activities.

As is the case for most ecosystems, photosynthetic-based primary productivity (i.e., green plants) represents the fundamental basis of the aquatic food web. However, limitations on the influx of nutrients to the aquatic system from terrestrial areas make nutrient cycling extremely important in northern ecosystems (MacDonald *et al.* 1999). While secondary production (i.e., aquatic invertebrates) occurs both in the water column and in benthic habitats, it is likely that benthic production represents a particularly important source of energy flow to the fish that utilize these systems. The importance of benthic production is related to the availability of nutrients in bottom sediments (i.e., due to the deposition of plankton post-die off) and high water clarity [which increases the depth of the euphotic zone (i.e., from the lake surface to the depth to which sufficient light penetrates to support active photosynthesis) and, hence, the area that can support primary production] that occur in northern lakes and rivers.

5.1 Aquatic Plants

Aquatic plants represent the fundamental elements of aquatic food webs in northern ecosystems. The aquatic plants that occur within the Great Bear Lake and associated tributaries fall into three general categories, including phytoplankton, periphyton, and aquatic macrophytes. Phytoplankton is a general term that is used to describe a wide variety of free-living algae that occur in lakes (i.e., the microscopic plants that live in the water column). In contrast, the term periphyton is used to describe the algal species that are attached to the bottom substrate in aquatic systems. Finally, aquatic macrophytes are vascular plants that occur in aquatic systems, usually in association with soft bottom substrates.

Although a number of studies have been conducted within the study area, only one (Moore 1980) provides detailed information on the structure of phytoplankton communities in Great Bear Lake. This investigator sampled three areas within the lake, including Echo Bay, Conjuror Bay, and Fort Franklin during the period June, 1976 to August, 1978. The results of this investigation showed that the standing crop of phytoplankton in Great Bear Lake was among the lowest found in freshwater systems, ranging from 20 to 91 mg/m^3 (Moore 1980). The average densities for the three areas sampled were 51 mg/m^3 for Echo Bay, 76 mg/m^3 for Conjuror Bay, and 41 mg/m^3 for Déline. By comparison, algal biomasses in the lower Great Lakes generally exceed 1000 mg/m^3 (Moore 1980). In total, 48 species of phytoplankton were recorded in this study. Of these, diatoms (Bacillariophyta) and chrysophytes (Chrysophyta) comprised the majority of the species encountered (i.e., 13 and 21, respectively). The dominant species were similar among the three areas sampled and included *Dinobryon bavaricum*, *Dinobryon sociale*, *Dinobryon boreale*, *Rhodomonas minuta*, *Synedra acus* var. *radians* (Moore 1980; Table 5.1).

As was the case for phytoplankton communities, little information was located on the periphyton communities that occur within Great Bear Lake or its tributaries. Nevertheless, the limited data which were available suggest that periphyton communities contribute substantially to total primary productivity of the lake (Duthie and Hart 1987). Benthic productivity would be even more important in the tributaries, where phytoplankton exists at only low levels. The periphyton communities of Great Bear Lake tended to be more diverse than the associated phytoplankton communities. Overall, 101 species of periphyton were recorded at the three sites that were sampled in Great Bear Lake (Moore 1980). The dominant species observed in these communities tended to consist primarily of diatoms and chlorophytes (Chlorophyta), including *Achnanthes spp.*, *Amphora ovalis*, *Gomphonema spp.*, *Ulothrix zonata*, *Eunotia curvata*, *Cymbella angustata*, and *Cymbella microcephala* (Moore 1980; Table 5.2). No information was located on the periphyton communities that occur in the tributaries to Great Bear Lake.

Little information was located on macrophyte communities in Great Bear Lake or in its tributaries. However, Johnson (1975b) reported that *Equisetum sp.* beds occur in certain areas within the lake, typically where water is less than one metre deep.

5.2 Zooplankton

A number of studies have been conducted to evaluate zooplankton communities in Great Bear Lake. While several of these studies were designed to provide information on one or more components of the zooplankton community (i.e., Miller 1947; Larkin 1948; Johnson 1964; Patalas 1975), others were intended to provide a more comprehensive understanding of the structure of the community (Johnson 1975b; Moore 1981). The results of the latter studies were considered to be more relevant for describing the characteristics of the zooplankton community in this water body.

The results of several studies suggest that Great Bear Lake has among the lowest diversity and density of zooplankton of any mainland lake in North America, with offshore areas generally less productive than nearshore areas (Table 5.3; Patalas 1975; Johnson 1975b). Johnson (1975b) reported that only five invertebrate species were captured in the offshore waters of Great Bear Lake, including four species of copepods (*Limnocalcanus macrurus*, *Senecella calanoides*, *Diaptomus sicilis*, and *Cyclops scutifer*) and one cladoceran species (*Daphnia middendorfiana*). *Diaptomus sicilis* was always the most abundant species. In this investigation, the densities of zooplankton ranged from 38,000 to 142,000 individuals/m^2 among the four locations sampled in 1964 and 1965. The offshore waters that were studied included McTavish Arm, Smith Arm, McVicar Arm, and Dease Arm (Table 5.3). In addition to the species identified by Johnson (1975b), the mysid, *Mysis relicta*, is also known to occur in Great Bear Lake (Larkin 1948).

Both the diversity and abundance of zooplankton tends to be higher in nearshore areas, as compared to offshore areas. Based on the results of sampling conducted in 1964, between four and eight species were recorded at the four inshore waters that were investigated (i.e., Northeast Dease Arm, South Keith Arm, Good Hope Bay, and South McVicar Arm; Johnson 1975b; Table 5.4). The species that were collected at these locations included seven species of copepods (*Limnocalcanus macrurus*, *Senecella calanoides*, *Epischura nevadensis*, *Diaptomus sicilis*, *Cyclops scutifer*, *Cyclops vernalis*, *Cyclops sp.*) and four cladoceran species (*Daphnia middendorfiana*, *Daphnia longispina*, *Bosmina longirostris*, and *Leptodora kindtii*). The densities of zooplankton ranged from 268,000 to 471,000 individuals/m^2 among the locations sampled, with *Diaptomus sicilis* always being the most abundant species (Johnson 1975b). The results of a study conducted more recently (1978) suggest that inshore zooplankton communities may be more diverse than the results of previous investigations had suggested (Moore 1981). These results indicated that seven species of copepods, three species of cladocerans, seven species of rotifers, and three species of protozoa occurred at the two locations that were sampled (Echo Bay and Conjuror Bay; Moore 1981). The most abundant species included *Diaptomus sicilis*, *Cyclops scutifer*, *Bosmina coregoni*, and *Limnocalcanus macrurus* (Table 5.5).

5.3 Benthic Macroinvertebrates

Benthic invertebrates inhabit the bottom substrates in lakes and rivers. Benthic invertebrates play an important role in maintaining the energy flow in aquatic ecosystems, both through the consumption of primary producers (i.e., by consuming phytoplankton in the case of filter feeders and periphyton in the case of grazers) and by processing detritus (i.e., detritivores). The larger benthic organisms (i.e., benthic macroinvertebrates) also represent essential fish food organisms. Therefore, benthic invertebrates represent fundamental components of aquatic food webs, particularly in the north where zooplankton communities tend to be less important (i.e., due to cold water conditions and low levels of nutrients).

While no information was located on benthic invertebrate communities in the riverine components of the watershed, the available data indicate that relatively diverse communities of benthic invertebrates occur in Great Bear Lake. Johnson (1975b) reported that a variety of benthic macroinvertebrates occurred in shallow water areas (i.e., <5 m deep), including amphipods (*Hyalella azteca* and *Gammarus lacustris*), gastropods (*Valvata cincera*, *Gyraulus deflectus*, and *Lymnaea elodes*), caddisfly (Tricoptera) larvae, mayfly (Ephemeroptera) larvae, beetle (Coleoptera) larvae, and water boatmen (Corixidae). Stonefly (Plecoptera) larvae were commonly observed in shallow waters with bouldery substrates. The biota that were associated with soft substrates and distributed over a wider range of water depths included amphipods, mysids, clams, oligochaetes, and midges (Johnson 1975b).

The densities of benthic invertebrates differed substantially among the various water depths sampled in Great Bear Lake, with appreciable densities of benthic invertebrates occurring only in waters less than 20 m deep (Johnson 1975b). The highest densities (i.e., 400/m^2, all species combined) were found in waters between one and five metres deep, either associated with beds of algae or *Equisetum sp.* Lower densities were observed in waters five to 10 m deep (350/m^2), six to 15 m deep (200/m^2), and 16 to 20 m deep (125/m^2; Johnson 1975b). Larkin (1948) also reported that the densities of the amphipod, *Diporeia affinis,* were highest in waters of less than 17 m deep (1600 to 1800/m^2), with densities dropping to 400/m^2 below this depth. Among the various species of benthic invertebrates encountered by Johnson (1975b), chironomids were the most abundant organisms in Great Bear Lake (Johnson 1975b). While midges occurred at all water depths down to 110 m, they were most abundant between 0 and 32 m. By comparison, oligochaetes tended to be most abundant at water depths of less than six metres.

5.4 Fish

Great Bear Lake and its tributaries support a variety of fish species. These fish exhibit a number of life history strategies and occupy a range of aquatic habitats within the watershed. The following sections provide an overview of the available information on the diversity, distribution, and abundance of fish in the Great Bear watershed. Due to their importance in Great Bear Lake, additional information is provided on the biology of lake trout.

5.4.1 Diversity

As documented by Johnson (1975b), at least 15 fish species utilize habitats within Great Bear Lake during at least a portion of their life history. These include lake trout *(Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), lake cisco (*Coregonus artedii*), northern pike (*Esox lucius*), Arctic grayling *(Thymallus arcticus*), round whitefish (*Prosopium cylindraceum*), yellow walleye (*Stizostedion vitreum*), burbot (*Lota lota*), slimy sculpin (*Cottus cognatus*), ninespine stickleback *(Pungitius pungitius*), longnose sucker (*Catostomus catostomus*), trout-perch (*Percopsis omiscomaycus*), inconnu (*Stenodus leucichthys;* rare), chum salmon, (*Oncorhynchus keta*; rare), and fourhorn sculpin (*Myoxocephalus quadricornis*).

Additional fish species captured in the Great Bear River by Chang-Kue and Cameron (1980) include Arctic cisco (*Coregonus autumnalis*), least cisco (*Coregonus sardinella*), broad whitefish (*Coregonus nasus*), mountain whitefish (*Prosopium williamsoni*), white sucker (*Catostomus commersoni*), flathead chub (*Platyogobio gracilis*), lake chub (*Couesius plumbeus*), longnose dace (*Rhinichthys cataractae*), spottail shiner (*Notropis hudsonius*), goldeye (*Hiodon alosoides*), Arctic lamprey (*Lampetra japonica*), and Dolly Varden (*Salvelinus malma*). This latter species may have been misidentified (Reist *et al.* 2002) and is presently believed to be bull trout (*Salvelinus confluentis*). A fish survey by McCart (1982) in the Great Bear River also identified the presence of emerald shiner (*Notropis atherinoides*), and brook stickleback (*Culaea inconstans*).

To date a total of 29 fish species have been identified within the Great Bear watershed. This species list may be expanded in future when additional fish collections are undertaken in Great Bear Lake and its tributary streams.

5.4.2 Abundance

Insufficient information is currently available to determine the abundance of fish species utilizing habitats in Great Bear Lake. Nevertheless, studies conducted in the 1970s provide information on the relative abundance of various fish species. More specifically, gillnet catches obtained by Johnson (1975b) indicated that lake trout and lake whitefish are the most abundant fish species in the pelagic zone (i.e., water column) of Great Bear Lake. Between 1963-1965, 236 gillnet sets were made using 10,856 m of net. Lake trout and lake whitefish were captured in 78% and 34% of the gillnet sets, respectively. Seventeen percent of sets failed to capture any fish. The following species also occurred in gillnet catches: walleye (4.1%); northern pike (3.1%); longnose sucker (1.8%); Arctic grayling (0.7%); lake cisco (0.3%); and, round whitefish (0.1%). Data collected more recently using multimesh gillnets confirmed that lake trout is the most abundant species in Keith Arm, followed by cisco (K. Howland. Department of Fisheries and Oceans, Winnipeg, Manitoba. Personal communication). While lake trout are evidently the most abundant fish species in Great Bear Lake, most lake trout captured during sampling were between 450 - 800 mm and juvenile size lake trout were absent from the catch. Although these data provide an indication of the relative abundance of the various fish species, they do not facilitate the development of population estimates.

5.4.3 Distribution

Johnson (1975b) has undertaken the most detailed fish sampling in Great Bear Lake to date, utilizing gangs of graded mesh gillnets (5 mesh sizes ranging from 38 mm to 140 mm) of 230 m total length. During this study, gillnet catch data from the different lake arms were pooled for analysis, precluding comparison of fish distribution in the different arms of Great Bear Lake.

Between mid-July to mid-August, before any definitive spawning congregation took place, lake trout were widely distributed according to depth, ranging between shallow surface waters to as deep as 400 m. Most fish were captured in depths less than 24 m. There was evidence for temperature preference in lake trout, with most captures occurring at water temperatures between 4^{o} and 9^{o}C. Nevertheless, lake trout tolerated warmer temperatures of 15.5^{o}C close to the mouth of the Johnny Hoe River. Spawning concentrations of lake trout occurred only within a narrow range of temperatures (4.5^{o} - 6^{o}C) and depths (5-13 m) between August 18 - September 4. Tagging data for lake trout indicated that only localized migrations occurred in most tagged animals; however, it is likely that longer migrations occur occasionally. Some animals were recaptured at their tagging locations five and six years following release. Juvenile lake trout from Great Bear Lake were absent from the catch, suggesting that these fish largely utilize rocky shorelines and/or inflowing streams on the periphery of the zone utilized by adults (Miller and Kennedy 1948). Juveniles have also been captured at depths greater than 50 feet (Johnson 1975b).

Although an ecological study of cisco populations in Great Bear Lake has not been completed, it is clear that lake ciscoes are one of the most abundant fish species in the lake. Falk and Dahlke (1974) deployed gillnets at various locations throughout the lake, and captured ciscoes at Port Radium, in Smith Arm, in Cameron Bay, in Neiland Bay, and Dease Arm. These data suggest that ciscoes are broadly distributed throughout the lake.

Lake whitefish have a discontinuous distribution in Great Bear Lake. The results of sampling conducted throughout the lake indicate that they were confined to bays and generally absent from open waters, even in the shallowest reaches. During October, large spawning concentrations of whitefish occurred at the mouth of the Johnny Hoe River, where they have been traditionally fished by the Sahtu Dene (Johnson 1975b).

Fourhorn sculpin were sampled in Great Bear Lake by Johnson (1975b) by means of beam trawling and otter trawling. Fourhorn sculpin were distributed at depths ranging from 3 to >200 m. Densities of fourhorn sculpin, ranged between 0.008 per m^2 to 0.5 per m^2, with no evident trends with respect to depth. Slimy sculpin were largely restricted to depths less than 3 m, so there was very little spatial overlap between fourhorn sculpin and slimy sculpin in Great Bear Lake.

Walleye in Great Bear Lake are near to the most northerly boundary of their geographical distribution. In Great Bear Lake, walleye are restricted exclusively to the circular basin at the southern end of McVicar Arm, which has a maximum depth of 35 m. This shallow basin forms the largest mass of warm water within Great Bear Lake, with summer temperatures ranging between 13ºC (surface) and 11ºC (bottom). There is no evidence that walleye exist elsewhere in Great Bear Lake. Walleye are also abundant in Keller Lake and Lac Ste. Thérèse, two lakes within the Johnny Hoe River system.

Burbot were encountered infrequently within Great Bear Lake, but appear to be widely distributed throughout the lake. Burbot in Great Bear Lake are typically less than 200 mm long. In contrast, burbot in the Great Bear River are large-bodied animals, frequently reaching lengths of over 500 mm (Chang-Kue and Cameron 1980).

Arctic grayling in the Great Bear watershed are concentrated in the upper reaches of the Great Bear River. Grayling are also found in lower concentrations in the mouths of the rivers originating on the Precambrian Shield and along exposed shorelines where water temperatures are generally below 10^{o}C.

In Great Bear Lake, both northern pike and ninespine stickleback are common in the warm shallow extremities of the bays in the vicinity of emergent or submerged aquatic vegetation.

5.4.4 Lake Trout Biology in Great Bear Lake

Miller and Kennedy (1948) were the first to report basic biological data for lake trout in Great Bear Lake. Fish ages and growth rate were determined by microscopic analysis of fish scales. Lake trout in Great Bear Lake grow very slowly, reaching a weight of 0.03 kg after 3 years. Such juvenile lake trout spend their first four summers in shallow water close to shore. Lake trout reach average weights of 0.45 and 0.9 kg at ages 9 and 14, respectively, indicating very slow growth compared to lake trout in more southerly lakes. Maturation is reached between age 13 and 17, with mature fish spawning only every second or third year. Lake trout spawning in Great Bear Lake occurs in mid-August.

Miller and Kennedy (1948) observed that adult lake trout feed on different food sources in Great Bear Lake, including plankton, bottom organisms, fish and insects. Differences in fish tissue colouration were observed to be associated with spawning: fish preparing to spawn were 90% pale-fleshed (white or yellow), while those which were not preparing to spawn were 60% orange- or red-fleshed, and only 40% pale-fleshed.

Johnson (1975b) analysed the stomach contents of lake trout captured between 1963-1965. The most frequent item in the diet of lake trout was lake cisco. Other fish species that occurred in lake trout gut contents included fourhorn sculpin, juvenile lake trout, slimy sculpin and several other fish species in small quantities. Lake trout also fed heavily on

Mysis relicta and several other invertebrates in smaller quantities, including *Gammarus lacustris*, *Diporeia affinis*, and sphaeriid clams. Insects were also consumed in smaller quantities, including chironomid nymphs, ants, beetles, and insect larvae.

Johnson (1976) compared arctic populations of lake trout and lake whitefish in 35 lakes throughout the NWT. Although primary and secondary productivity in arctic lakes is low (i.e., the abundance of fish food organisms is low), lake trout standing crops are large, and mean body size is also large. These characteristics can give the wrong impression that large arctic lakes, including Great Bear Lake, have considerable potential to support increased fisheries harvests. In reality, the low primary productivity implies that harvest mortality rates must be kept at low-moderate levels in order to avoid negative impacts of over-fishing on the lake trout population.

During the 1970s Fisheries and Oceans Canada actively monitored angler catches of lake trout in Great Bear Lake and collected biological data on lake trout growth rates, mortality rates, and other supporting data for fisheries management (Falk *et al.* 1973a; 1974a; 1974b; 1975; 1981; Gillman and Roberge 1982; Moshenko and Gillman 1978a; 1978b; 1983). Yaremchuk (1986) analysed these data to develop fisheries management recommendations for Great Bear Lake. Of primary importance for management, tagging studies indicated that lake trout moved very little between tagging and recapture sites, with 65% of the trout moving less than 5 km over a nine-month period. This implies that lake trout in different areas of Great Bear Lake should be considered as separate stocks. Total allowable harvest of lake trout by management area were also recommended by Roberge and Dunn (1988).

Healey (1978) compared lake trout population dynamics in a cross-section of lake trout lakes ranging from the Laurentian Great Lakes in Ontario to five lakes north of 60ºN. The variables that were measured and compared include mortality, growth, reproduction, and potential yield of lake trout. In Great Bear Lake, growth rates for lake trout are among the lowest recorded across their geographic range. Among lake trout populations north of 60ºN, average ages at first (i.e., first spawning), 50%, and 90% maturity were 12, 16.8, and 19 years, respectively, compared to 7.7, 9.4, and 11.5 years for southern populations.

Melville (1997) analysed climate change implications for lake trout in the Mackenzie Great Lakes (Great Bear Lake, Great Slave Lake, and Lake Athabasca) as a component of the

Mackenzie Basin Impact Study. Great Bear Lake sits in a zone where the average winter temperature increased by 1.5-2 ^{o}C between 1959-73 and again between 1974-88 due to global warming. Melville concluded that, at the present time, the potential effects of climate change on the yields of lake trout in Great Bear Lake or in other lakes in the Mackenzie River basin cannot be forecasted.

Recently, Tallman *et al.* (2000) collected baseline biological data as part of an ongoing Fisheries and Oceans Canada - Sahtu Renewable Resources Board research project (2000-2005). As part of this study, size, age structure, fecundity (number of eggs per female), growth, mortality, and migrations of lake trout in Keith Arm of Great Bear Lake are being determined. As such, the results of this investigation will further expand our understanding of lake trout biology in Great Bear Lake.

5.5 Aquatic-Dependent Wildlife

A wide variety of aquatic dependent wildlife species utilize habitats in the Great Bear watershed, either on a seasonal or continuous basis. While a compilation of information on terrestrial wildlife is beyond the scope of the present report, data collected by Rescan (2000) for Edacho on the periphery of Great Bear Lake indicate that numerous mammalian (14 species) and avian (42 species) species utilize habitats within the watershed; many of which can be classified as aquatic-dependent species. Deerpass Bay, for example, supports large numbers of aquatic-dependent waterfowl, including loons. Other areas around Great Bear Lake also support ducks and other waterfowl species.

Using funding provided by INAC, the Sahtu Renewable Resources Board commissioned Colin Macdonald (Northern Environmental Consulting) to prepare the Great Bear Watershed State of Terrestrial Knowledge report. Completion of this report in 2004 will facilitate access to a great deal of information on wildlife within the watershed.

Chapter 6 Water Uses

6.0 Introduction

The Great Bear watershed supports a variety of water uses. Of these, the provision of municipal and domestic water supplies is one of the most important to northern residents. In terms of water quality requirements, however, the protection of fish and aquatic life tends to be the most sensitive. The other existing and potential water uses in the basin include wildlife watering, recreation and aesthetics, hydroelectric power generation, and industrial water supplies. Each of these water uses are discussed briefly in the following sections of this document.

6.1 Municipal and Domestic Water Supplies

Surface waters represent the only source of potable water that is being utilized by residents of Déline, Gameti, the various lodges, exploration camps, and recreational water users in the Great Bear watershed. Tulita residents also rely on water from Great Bear Lake as a potable source, which is filtered and trucked to houses in the community. For this reason, maintenance of the exceptional water quality that currently exists throughout most of the system is of critical importance to basin residents and those who utilize the system on a seasonal basis. In addition, it is important to address the concerns that have been expressed by Déline residents regarding water quality conditions in the vicinity of Port Radium.

The community of Déline obtains all of its potable water from Great Bear Lake. Water is gravity fed into a concrete wet well (located in the water treatment plant) through a 250 m screened, polyethylene intake line that extends out into Great Bear Lake near the community dock. The water is treated (chlorinated) and pumped into water trucks designed for hauling potable water. The water trucks distribute the water throughout the community of Déline.

Based on the 1999 NWT Bureau of Statistics Community Population Projections, the current population of Déline is estimated to be roughly 625 and is projected to grow at a rate of roughly 1% per year over the next two decades. Using information on the current rates of water consumption by the community (i.e., roughly 105 L/person/day) and the above population projections, it is possible to estimate water consumption for the community to 2020 (Table 6.1). These calculations indicate that annual water usage will increase from roughly 23,100 m^3 in 1999 to 25,800 m^3 in 2010 to 28,500 m^3 in 2020. The current water licence (S00L3-002), a municipal Type "B" licence, was issued in January 2001 and expires in December 2010. The licence allows for a maximum of 26,000 m^3 of water to be removed from Great Bear Lake for domestic purposes.

The municipality of Gameti obtains its domestic water supply from Rae Lake. Similar to Déline, chlorinated water is pumped into trucks for distribution of potable water to households. The total quantity of water used by the community in 2000 was 8,146 m^3 (Puznicki 2001).

6.2 Fish and Aquatic Life

Great Bear Lake and its tributaries support relatively abundant and diverse communities of fish and other aquatic organisms (i.e., relative to other northern river basins). At least 29 fish species have been observed in the lakes and streams that comprise this river system (Johnson 1975b; Chang-Kue and Cameron 1980; McCart 1982). Collectively, more than 40 species of benthic macroinvertebrates and zooplankton have been recorded in the system (Johnson 1975b). The diversity, distribution, and abundance of aquatic organisms in the Great Bear watershed are described in Section 5.0 of this document.

The Great Bear watershed provides essential habitats for a variety of aquatic organisms and life stages. For example, most of the fish species that occur in the basin use habitats within the system for egg deposition and incubation. Riverine and lacustrine habitats also support the rearing activities of most fish species. While the timing of each life stage varies for individual fish species, sensitive life stages (i.e., eggs, alevins, and emergent fry) are present throughout much of the year. Therefore, it is likely that protection of fish and aquatic life will be the most stringent water use for most chemicals of potential concern in the watershed.

6.3 Wildlife Watering

The Great Bear watershed supports a wide range of wildlife species, many of which are hunted for food or trapped for their pelts. These wildlife species include a number of mammals, including large ungulates (such as caribou and muskox), carnivores (such as mink, marten, fishers, otters, lynx, fox, wolves, wolverines, and grizzly bear), lagomophs (such as hares), and rodents (such as beaver, muskrats, and lemmings). A variety of avian species also utilize the basin on either a seasonal or continuous basis, including waterfowl (e.g., ducks and geese), shorebirds (e.g., sandpipers, plovers, and dowitchers), songbirds (e.g., blackbirds), gamebirds (e.g., ptarmigan), and raptors (e.g., eagles and hawks). All of these wildlife species rely on surface water sources located throughout the drainage basin for drinking water.

6.4 Recreation and Aesthetics

The Great Bear watershed offers a diverse array of recreational opportunities that are significant both from a local (i.e., Déline, Gameti) and a regional perspective (western Arctic). From an economic perspective, the most important recreational activities in the basin are ecotourism, fishing, and hunting. While environmental aesthetics are important wherever ecotourism is promoted and practised, it is even more important in the north because the ‘pristine wilderness’ is a major attraction to these areas. Real or perceived impairments to the wilderness experience that are associated with resource developments could significantly affect future tourism and economic growth in the basin. As recreational and aesthetic water uses are critically important in the watershed, water management activities should be focussed on making sure that these water uses are protected and conserved.

6.5 Hydroelectric Power Generation

Currently, there are no hydroelectric power generation projects in the Great Bear watershed. However, three locations on the Great Bear River have been identified as potential hydro sites, including Wolverine Creek, St. Charles Rapids, and Lower Bracket. The need for power to supply compressor stations for the proposed Mackenzie Valley gas pipeline has sparked interest in developing the hydroelectric power potential that exists within the watershed. Therefore, hydroelectric power generation remains a potential water use in the Great Bear watershed that may be pursued in the coming years.

6.6 Industrial Water Supplies

Most industrial operations require adequate supplies of water to support their production and manufacturing activities. Certain operations, such as those in the food and beverage industry, require water of exceptional quality to maintain product integrity. In other industries, water quality requirements are less stringent, with concerns focussed on the potential for equipment damage through corrosion or scaling and for reduction in plant efficiency through tuberculation, sludge formation, scale formation, foaming, or biological growths (CCREM 1987). Complex industrial operations may have a number of specific water uses (e.g., cooling water, process water, etc.), each of which has specific water quality requirements. Currently, there are no industrial water users in the Great Bear watershed. There have been industrial water uses in the past at several mining operations, including the Port Radium/Echo Bay mines and the Silverbear mines, for process water and waste disposal.

Chapter 7 Existing and Potential Disturbance Activities

7.0 Introduction

Protection of the health and integrity of northern river systems has been identified as a high priority water management goal in the north. However, the need for economic growth in the region has increased pressure to develop mineral and other natural resources. While much of the Arctic remains in a relatively pristine state, certain areas have been significantly affected by human activities. For example, the availability of abundant mineral deposits has resulted in the development of a number of metal mines in the watershed, both in the Camsell River basin and in the vicinity of Port Radium. While mineral development has been the most significant human activity in the basin, there are other ongoing and potential disturbance activities (i.e., stressors) that have the potential to adversely affect water uses in the Great Bear watershed.

Environmental stressors can be classified into two categories: regional stressors (within the Great Bear watershed); and, global stressors. Regional stressors include activities such as production and disposal of community wastes, fisheries exploitation, contamination from historic mining activity, and proposed hydropower development for the Great Bear River. Global stressors include impacts that occur over large spatial scales such as climate change and long range transport of atmospheric pollutants. Both types of stressors and their potential effects on aquatic resources in the Great Bear watershed are described in this chapter.

7.1 Mineral Exploration and Historic Mining Activities

Great Bear Lake lies on the boundary of two major physiographic regions, including the Canadian Shield and the Interior Plains region (Bostock 1970). The Precambrian rocks of the shield are comprised of sedimentary and metamorphic deposits that are supplemented by igneous intrusions forming dykes and sills (Johnson 1975a). The host rocks in this region are characterized by deposits of uranium, pitchblende, silver, cobalt, nickel, copper, and gold. These metals have been targeted by exploration activities and metal mining for more than six decades in the Great Bear watershed (Figure 7.1).

7.1.1 Exploration Activities

Based on the information contained in the Northern Minerals Database (NORMIN; www.nwtgeoscience.ca/normin), there is little or no active mineral exploration in the Great Bear watershed. The location of active mineral claims, pending mineral claims, mineral leases, and prospecting permits are shown in Figure 7.1.

7.1.2 Historic Mining Activities

No mining activities are currently being conducted in the Great Bear watershed. However, mining activities have been conducted at several locations within the watershed over the past 60 years, including Port Radium and the Camsell River basin (Figure 7.1).

7.1.2.1 Port Radium

Port Radium, which is situated on a peninsula adjacent to McTavish Arm (66º05'N; 118º02'W), was the site of Canada's first uranium mine (Figure 7.2). Mining and milling of uranium took place at the Eldorado Mine at Port Radium almost continuously from 1930 to 1982. From 1942 to 1960, the mine and mill were operated by a Crown-owned mining company. The Port Radium town site was closed in 1960 and subsequently reopened in 1964 for a silver operation, the Echo Bay Mine. When the silver mine was decommissioned in 1982, the mine surface openings were sealed and the buildings were demolished.

During the various mining operations, tailings were deposited directly in Great Bear Lake, as well as in a number of on-land lakes and depressions. It is estimated that approximately 100,000 m^3 of tailings were deposited on land in depressions around the site, mostly covered by waste rock. The remaining tailings were deposited in Great Bear Lake and McDonough Lake (Garbage Lake). A previous Environment Canada study concluded (Falk *et al.* 1973a):

> "Uranium contamination of the lake sediments is believed to primarily have resulted from the past mining operations by Eldorado Nuclear Ltd. Prior to 1960 this mine was a major producer of uranium oxide. Despite the fact that a different ore body is currently being mined, the proximity of the two lead us to believe that radioactive contamination may result. To this end Echo Bay mill effluent and minewater and water from the nearby Camsell River were analysed for radioactive content. The results revealed total alpha and beta counts above background. In addition, radioactive thorium, radium, and potassium were identified. Counts are below the maximum permissible concentration in water of 100 pCi/l set by the International Commission on Radiological Protection. Of concern to the present study is that through continued discharge of these wastes, concentration of radioactive wastes in aquatic organisms may occur. Further study is necessary to define the nature and magnitude of this phenomenon."

The results of several more recent studies confirm that aquatic and terrestrial systems in the vicinity of Port Radium have been seriously contaminated by wastes from mine operations. More specifically, Moore and Sutherland (1981) reported elevated levels of heavy metals and radionuclides in the sediments immediately adjacent to the Echo Bay Mine discharge in the area of tailings deposition. In addition, INAC undertook a technical review of contamination issues at Port Radium (Swanson 1995). The most contaminated sites in terms of both radionuclides and metals were the Silver Point tailings area, the West Adit tailings area, and Garbage Lake. Ponded water in the area of the West Adit waste rock is also contaminated. Based on the results of the previous studies examined by Swanson (1995), the contaminants that exceeded Canadian drinking water guidelines at this site were uranium, radium-226, arsenic, cadmium, iron, and lead. Most exceedances occurred in ponded water at Silver Point tailings and the West Adit tailings. Additional exceedances occurred in Cobalt Channel and Inner Labine Bay (uranium, arsenic, lead), Garbage Lake (uranium, arsenic, iron and lead), Bear Creek (iron) and Bear Bay (lead).

Based on the data compiled by Swanson (1995), the contaminants that exceeded the Canadian WQGs for the protection of aquatic life were uranium, arsenic, copper, lead, mercury, nickel, and zinc. Most exceedances occurred in ponded water at the Silver Point tailings, the West Adit tailings and/or waste rock and Garbage Lake. Additional exceedances occurred at Cobalt Channel and Inner Labine Bay (uranium, arsenic, copper, mercury, zinc), Bear Creek (arsenic), Bear Bay (copper, zinc), and the control area to the north of Port Radium (mercury, copper, zinc). By comparison, the contaminants that exceeded Canadian background concentrations were uranium, arsenic, copper, lead, mercury, nickel, and zinc (Swanson 1995). Most exceedances were in Garbage Lake and in ponded water at the Silver Point tailings and West Adit tailings. Other water bodies with exceedances were Cobalt Channel and Inner Labine Bay (uranium, arsenic), Bear Bay (arsenic), and Bear Creek (arsenic and iron).

In 1999, the Canada-Déline Uranium Table (CDUT) was formed by the federal government and the community of Déline in response to community concerns about contamination at the mine site. At present, the CDUT is undertaking human health and ecological risk assessments in the vicinity of Port Radium to determine the full impacts of contamination at the site, and on the surrounding environment and ecosystems. An inventory of hazardous waste at the site has been conducted, and bioavailability of contaminants will be predicted using a methodology of pathways analysis, sampling (air, water, soil, vegetation, fish, and wildlife) and computer modelling. The results of these investigations will provide a basis for better characterizing the risks on and off-site, and allow the CDUT to develop remedial action plans that will effectively mitigate those risks.

7.1.2.2 Abandoned Mine Sites in or Near the Camsell River Basin

Besides Port Radium, there are other abandoned uranium and silver mines located near the southeast corner of the Great Bear watershed (Figure 7.3). These mines have been identified as potential sources of environmental contamination (EBA 1993) and have been included in the Federal Contaminated Sites inventory (R. Fielding. Indian and Northern Affairs Canada, Yellowknife, Northwest Territories. Personal communication). A contaminated site is defined as a site at which substances occur at concentrations: (1) above background levels and pose, or are likely to pose, an immediate or long-term hazard to human health and the environment; or, (2) exceed levels specified in policies or regulations (INAC 2002). The mines include: Terra; Northrim; Norex; and, Smallwood Lake mines (collectively known as Silver Bear Mines), as well as: the Contact Lake mine; and, Indore Gold Mine. The Silver Bear mine, as well as Indore

Gold Mine lie within the Camsell River watershed, which drains an area of approximately 31,100 km^2 (Environment Canada 2002). Contact Lake mine is located further north, on Contact Lake, roughly 50 km upstream from Great Bear Lake. The Indore Gold mine is located in the vicinity of Hottah Lake. The individual mine sites are described below, together with an evaluation of their existing and potential impacts. These descriptions were taken directly from INAC (2003). The mine sites are the focus of ongoing assessment and remediation studies, which are described further in Appendix 2.

Terra Mine Site

The Terra mine site (Figure 7.4) is located approximately 290 km northwest of Yellowknife, located at 65º37'N and 118º07'W. The mine is situated on the south shore of Rainy Lake (Camsell River) and also borders the north shore of Ho-Hum Lake, which served as the tailings pond/containment area throughout the operation of the mill. Originally staked in the 1940s, the Terra silver mine began operations in 1969 and continued until 1985 when the site was put into care-and-maintenance. Ore from Norex and Smallwood mines was also milled and processed at the Terra facility. The Terra mine produced primarily silver, but significant concentrations of sulphide ores rich in iron, copper, lead, and zinc were also present.

All mine facilities at the time of closure in 1985 were simply abandoned and are, therefore, still present and intact, although significant deterioration is evident. A substantial quantity of heavy mining equipment, mining supplies and support materials are also found on site. The mine portals/adits are not sealed and most buildings and machinery are accessible.

Most of the mine infrastructure is located north and up-gradient of Ho-Hum Lake. Drainage is to the northwest, with Little Ho-Hum Lake draining into Ho-Hum Lake which eventually empties into the Camsell River (i.e., at Moose Bay on Rainy Lake).
There are submerged tailings in Ho-Hum Lake, as well as land-based tailings strewn along its shore. The quantity of tailings are unknown but are thought to be significant. The coarse-grained waste rock is distributed over a large area around the mine site. Waste rock was apparently used as road base as well as for airstrip construction. It is

estimated that there are 200,000 m^3 (500,000 tonnes) of waste rock at the Terra mine site (EBA 1993).

Previous studies (Appendix 2) indicate that the Terra Mine site has high excess acidity potential, but that it is unlikely that acid rock drainage would significantly impact surface waters at the mine site due to the buffering capacity in the receiving waters. Arsenic is the primary toxic element of environmental concern at this facility (EBA 1993).

Norex Mine Site

The Norex mine site is located approximately 270 km northwest of Yellowknife (65º36'N and 117º58'W) and 600 m south of the Camsell River (Figure 7.5). The mine includes the Graham Vein area which is located approximately 460 m east of the main Norex site. Originally staked in the 1950s, the silver mine was developed as a satellite mine in the 1970s to Terra operations. The mine ceased productions in 1983 and was allowed to flood in 1984 (Dillon and EBA 1999)

There is one machine shop building, a generating/processing building and a small tank farm remaining on site. There are two mine adits, one of which is blocked by ice throughout the year, while the other has steel doors that are not secured.

It is estimated that there are 51,000 m^3 (107,400 tonnes) of coarse-grained waste rock present at the Graham Vein and Norex mine site, most of which is located up-gradient from the Camsell River, approximately 600 m (Dillon and EBA 1999). Some waste rock was used as a road base to connect Norex, Graham Vein, and Smallwood Mines to Terra Mine. No tailings exist at the Norex sites, as all ore was trucked over a 17 km all-weather road to Terra for processing. However, tailings from early mine site production at the Graham Vein were deposited into Xeron Pond (Dillon and EBA 1999). Xeron Pond is located 200 m northeast of the Graham Vein mine site. The facilities at the Graham Vein are still intact.

Previous studies (Appendix 2) indicate that the Norex Mine site has moderate excess acidity potential, but that it is unlikely that acid rock drainage would significantly impact surface waters at the mine site due to the buffering capacity in the receiving waters. Arsenic is the primary toxic element of environmental concern at this site.

Smallwood Lake Mine Site

The Smallwood mine site, situated on Smallwood Lake, is located at 65º34'N and 117º56'W, approximately 900 m south of the Camsell River. Also developed as a satellite mine to Terra, exploration, development and production took place in the 1970s and 1980s. The mine was closed in 1984 and allowed to flood. There has been no development on the site since that time (Dillon and EBA 1999).

There is little that remains on site other than a few service buildings, a fuel tank, and the waste rock. The estimated 53,000 m^3 (111,300 tonnes) of waste rock were disposed of or dispersed over a large area down-slope of the main mine portal and immediately up-slope of Smallwood Lake (EBA 1993). No tailings were produced at Smallwood mine, as the ore was trucked to Terra for milling. The ore contained silver, lead, zinc and copper (Thurber Environmental 1993).

Previous studies (Appendix 2) indicate that the Smallwood Lake Mine site has high excess acidity potential, but that it is unlikely that acid rock drainage would significantly impact surface waters at the mine site due to the buffering capacity in the receiving waters. Arsenic is the primary toxic element of environmental concern at the site (EBA 1993).

Northrim Mine Site

The Northrim mine site is located approximately 270 km northwest of Yellowknife (65º36'N and 117º58'W) on the north shore of the Camsell River. The silver mine was originally staked in 1932 and operated intermittently until abandonment in 1977 (Vista Engineering and Deton'Cho 1996). There has not been any further development since.

Although Northrim mine was a relatively small mine, a significant amount of waste was generated during its operation, the majority of which is still on site along with much of the mining equipment. The three mine portals at Northrim are open and accessible (Vista Engineering and Deton'Cho 1996).

There are conflicting views as to the disposal location of the tailings. Some assessments report that tailings were deposited directly into the Camsell River; however, others indicate that the tailings were pumped from the mill to Hermandy Lake via a tailings pipe. Hermandy Lake is up-gradient from the mill workings and drains into Jason Bay (Camsell River) through a small creek at the southeast corner of the lake. At the time of sampling, exposed tailings were observed in the muskeg area located south and adjacent to Hermandy Lake. The outlet of Hermandy Lake flows through this muskeg area and through two connected, leachate ponds.

There are approximately 21,500 m^3 (45,100 tonnes) of waste rock at Northrim (EBA 1993) much of which was used for road construction, building pads, construction of a berm around fuel storage tanks, and to build the dock on the Camsell River (EBA 1993). There are two waste rock piles, the larger contains approximately 5,000 m^3 and the smaller pile, located on the shore of the Camsell River, is estimated at 1,500 m^3 (Dillon and EBA 1999).

Previous studies (Appendix 2) indicate that the Northrim Mine site has high excess acidity potential, but that it is unlikely that acid rock drainage would significantly impact surface waters at the mine site due to the buffering capacity in the receiving waters. Arsenic is the primary toxic element of environmental concern (EBA 1993).

Contact Lake Mine Site

The Contact Lake mine site (Figure 7.6) is located 330 km northwest of Yellowknife at 65º59'N and 117º48'W, approximately 500 m north of Contact Lake (1196 ha). Contact Lake flows into Moody Lake which drains into the northwest arm of Conjuror Bay of Great Bear Lake. Originally staked as a silver mine in the 1930s, the property became important following World War II when uranium became the focus. Actual uranium production took place from 1949-1950. Mining operations were conducted intermittently until the site was abandoned in 1980 (EBA 1993). It has been reported that ore and/or tailings were transported to the Echo Bay mill at Port Radium in 1979 (EBA 1993).

There are five buildings at the main mine site in various stages of deterioration including a head frame, the remnant mill structure, the portal entrance building, and support buildings. An estimated 29,100 m^3 (61,100 tonnes) of coarse-grained waste rock and 1450 m^3 (3050 tonnes) of uncontained tailings exist on site (Thurber Environmental 1993), both of which are downslope of the mine site and upslope of Contact Lake (EBA 1993).

Previous studies (Appendix 2) indicate that the Contact Lake Mine site has high excess acidity potential, but that it is unlikely that acid rock drainage would significantly impact surface waters at the mine site due to the buffering capacity in the receiving waters. Arsenic, copper, uranium and zinc are the primary toxic elements of environmental concern. There are also high levels of radionuclides (radium-226 and uranium-235) in the tailings water; however, radionuclides were undetectable in water at Contact Lake.

Indore Gold Mine

The Indore Gold Mine is located at the southern end of Hottah Lake within the Camsell River watershed (64º48'N and 118º26'W; Figure 7.3). The original mineral claims for this facility were staked in 1950 and put into operation in 1952 (EBA 1993). The name of this mine was changed to Consolidated Indore Uranium Mines Ltd. in 1953 to reflect the change in the focus of the mine (i.e., from gold to uranium; EBA 1993). The assets of the site were acquired by United Uranium Corp. in 1955 (EBA 1993). There are no records of operation of the facility after 1955.

Currently, there are few structures that remain at the Indore mine site. As of 1993, only one building remained at the site, which may have been used as living quarters or a service building for a boat. The mine adit and mine shaft represent the only buried structures at the site (EBA 1993).

There are two waste rock piles at the Indore site, including one located north of the mine shaft and one located near the shore of Hottah Lake. The volumes of these waste rock piles are estimated at 3100 m^3 and 1300 m^3, respectively (EBA 1993). A small volume of land-based tailings were also identified at the mine site, near the shore of Hottah Lake.

Based on an analysis of four tailings and six waste rock samples, EBA (1993) concluded that it is unlikely that acid rock drainage would be problematic at this site. In addition, the results of analyses of leachates from these materials suggested that metal concentrations were not elevated to levels that would be toxic to aquatic organisms. The levels of radioactivity at the site were considered to pose little risk to site personnel.

7.1.2.3 Waste Sites in the Great Bear Watershed

Waste sites are defined as sites where materials have been deposited (e.g., garbage sites, vehicles, hazardous materials) or where hazards exist (opening to a mine). A waste site may or may not be a contaminated site (INAC 2002). Fourteen waste sites have been identified in the Great Bear watershed (Figure 7.1). INAC is responsible for the classification, assessment and remediation of those sites on Crown Land. One such site is the abandoned Hottah Lake Mine.

The Hottah Lake uranium mine is located on Beaverlodge Lake, which drains into Hottah Lake in the vicinity of the Indore Gold Mine. Because a full engineering report has not been completed, there is little information available on site history, on remaining structures, on quantities of waste rock and tailings, or on the hazards that these materials pose to human health or the environment. Nevertheless, INAC personnel recently visited the site and collected water and sediment samples. The results of associated chemical analyses should provide some insight into the potential effects of historic mining activities on water resources in the vicinity of the site (J. Ward. Indian and Northern Affairs Canada, Yellowknife, Northwest Territories. Personal communication).

7.2 Municipal Developments

Although municipal developments can adversely affect aquatic ecosystems in a variety of ways, discharges of liquid wastes and releases of contaminants from solid waste facilities represent two of the most important. The relevant information on both types of contaminant sources are described below.

7.2.1 Déline

7.2.1.1 Liquid Wastes

Municipal wastewater is a complex mixture of human waste, suspended solids, debris and a variety of chemicals derived from residential and commercial sources. As a result, municipal wastewaters can be a source of nutrients, suspended solids, and contaminants to receiving water bodies.

Sewage treatment for Déline consists of a primary and secondary lagoon (two-cell) system that relies on bacteria to degrade the incoming raw sewage prior to release into the environment (Bayha 2000). In the primary cell, the solids settle out and microbiological action completes the first treatment phase. The sewage is then pumped from the primary cell to the secondary cell where further microbial degradation reduces the sewage strength. Following acceptable effluent test results, the sewage is discharged into a wetland area where further filtration and decomposition occurs as the effluent travels through wetlands and/or marshy areas. Ultimately, the effluent reaches Little Lake which then drains into Great Bear Lake.

In accordance with the community water licence (Sahtu Land and Water Board 2001), there are water quality sampling sites (i.e., as part of the Surveillance Network Program; SNP) located at: the raw water intake from Great Bear Lake at the water treatment plant; at the outflow of the primary and secondary lagoons; and, at the point of entry of seepage to Little Lake. Monthly and annual quantities of wastes discharged to the primary cell, to the secondary cell, and to Little Lake are also estimated through calculation. In general, the SNP is intended to ensure that appropriate monitoring and assessment is conducted and that the effluent meets acceptable discharge standards. All facilities are inspected, at minimum, once per year and improvements are made where appropriate. The effluent quality criteria for this facility are expressed as maximum average concentrations and are as follows: faecal coliforms <10,000 CFU/100 mL; BOD_5 <80 mg/L; and, suspended solids <100 mg/L.

Relatively minor, localized impacts from the discharge of treated sewage effluent could be expected in Little Lake and, possibly, in the Great Bear River immediately downstream from the discharge point. However, no surveys have been undertaken to determine whether such impacts have occurred. The amount of sewage effluent from the Déline lagoon system is insignificant compared to the volume of Great Bear Lake

7.2.1.2 Solid Waste

The solid waste facility is located northeast of the sewage lagoon, approximately 2 km from Déline. The materials that have been deposited in this facility include domestic garbage, wood waste, bulk metal waste (such as old appliances and vehicles), and certain hazardous wastes (such as old batteries and waste oil). Like many communities in the north, proper Solid Waste Management is difficult and is attributed to logistics and available personnel. For many northern communities, including Déline, some of the main issues/concerns include: proper segregation of wastes; signage designating waste disposal areas (i.e., domestic garbage, bulky wastes, hazardous waste, etc.); proper management and responsible disposal of hazardous wastes (paints, oils, batteries, etc.); detailed inventories of waste being deposited; proper water sampling (SNP) stations; and, development and continual implementation of Operation and Maintenance Plans. Even though, Déline does possess some of the above issues they are working hard to ensure their Solid Waste Management Plan meets acceptable sanitation standards. INAC will continue to work with the community as much as possible to achieve proper Solid Waste Management.

The Déline solid waste facility requires attention because waste is not properly segregated or adequately contained and because the domestic garbage needs to be compacted and covered with fill (Bayha 2000). Segregation of wastes as well as proper containment will ultimately contribute to the overall improvement and maintenance of the facility. Runoff from the solid waste disposal site is monitored under the SNP to ensure that any contaminants including metals and hydrocarbons can be detected and that the leachate meets acceptable standards.

7.2.2 Gameti

The only other community in the Great Bear watershed is Gameti, formerly known as Rae Lake. Gameti is located in the southeast portion of the basin, at 64º09'N and 177º20'W. It is situated on Rae Lake, one of many lakes making up the Camsell river system. The shores of Rae Lake were historically used as a hunting camp by the Dogrib Dene until the early 1970s when Gameti became a permanent settlement with the establishment of a community hall, school, general store and an airstrip. According to the 2001 census, there are 274 residents in the community. Source water is from Rae Lake (Puznicki 2001).

7.2.2.1 Liquid Wastes

The sewage waste disposal facilities consist of an unlined sand pit for trucked sewage and a trench for bagged toilet waste. Approximately 20 households are on the bagged system which are being converted to the pump-out system at a rate of about three per year. There have not been any reported environmental concerns with the sewage disposal site or disposal practices.

Presently the community of Gameti is not licensed for water use and waste water disposal. However, according to the NWT Waters Act, a Type “B” water licence is required for the use of water, and for the deposit of waste by means of sewage collection or treatment system, for a community with a population of between 50 and 2,000. Nevertheless, the amount of sewage effluent form the Déline lagoon system is insignificant compared to the volume of Great Bear Lake.

7.2.2.2 Solid Waste

The solid waste facility is located approximately 1.5 km from town. Efforts are made to segregate the domestic waste from the bulk material. The community would like to see the waste facilities located further away from the townsite. The main concerns are the proximity to the community, the odours and attraction of wildlife.

7.3 Fisheries Exploitation

Sportfishing is one of the most important recreational activities in the Great Bear watershed and, as such, has the potential to adversely affect fish populations. There are a total of five fishing lodges and two outpost camps that have been built adjacent to Great Bear Lake; a sixth lodge was built on Hottah Lake (Figure 7.7). The number of lake trout harvested by sportfishers has greatly decreased over time, from a peak harvest of 20,000 fish in the early 1970s to a 1990 level of 3840 (Figure 7.8; Fisheries and Oceans Canada Unpublished data). The reduction in lake trout harvests can be attributed to fisheries co-management efforts to reduce harvests by promoting live release fishing, placement of a moratorium on lodge development, and reductions in catch and possession limits. No sportfishing harvest data are available past 1990.

Lake trout stocks appear to be recovering from extensive sportfishing harvests that occurred during the 1960s and 1970s. Falk *et al.* (1973b) reported that the trophy-sized lake trout in McTavish Arm (south) were exhausted by 1972. Roberge and Dunn (1988) reported declining or stabilizing lake trout stocks in the mid-1980s. By 1990 all lodges were harvesting below the recommended total allowable catch (TAC) for their area and harvests decreased further to very low levels in the McTavish and McVicor arms with the closing of three lodges in the 1990s. Great Bear Lake should be managed for the availability of large trophy-sized lake trout, not just for sustainability of stocks. The key fisheries management concern is whether the trophy status of lake trout stocks can be maintained at current harvest levels which are assumed to be below recommended harvest levels for each of the lodge areas. In the Keith Arm, sports harvest levels will need to be set with consideration of the food fishery harvest in this multi-use area.

During the period of active investigation of lake trout harvest by sportfishers (i.e., 1970s to 1990), there were no data collected on the Sahtu Dene fishery harvest. However, the Sahtu Renewable Resources Board recently estimated the catch at 8000, 3248, and 2725 fish during 1999, 2000, and 2001, respectively. Therefore, total fishing mortality could be in the order of 6700 to 12,000 fish per year, with most of the domestic fishing occurring in Keith Arm and the sportfishing occurring in the vicinity of the various lodges.

It is not possible at the present time to accurately determine whether current fish catch levels are adversely affecting the Great Bear Lake fish population. Present catch levels are not monitored, and it is not known what present catches represent in terms of exploitation rate. In view of the observation that historic lake trout catches were much higher than those at present, it is unlikely that the fishery is presently causing depletion of the fish population.

However, the trophy status of the fishery is vulnerable. And, it is possible that specific lake trout stocks are being depleted of trophy-sized fish in areas with high fishing pressure.

7.4 Hydroelectric Power Development

The NWT Power Corporation is presently undertaking pre-feasibility studies to develop hydropower in the Great Bear River to supply power to future Mackenzie Valley gas pipeline compressor stations. Each compressor station has an electricity demand of 30 MW and compressor stations are to be located near Norman Wells, Wrigley, Fort Simpson, and Inuvik. The hydropower project, if developed, would require about 1000 km of transmission lines and would also provide power for the communities of Déline, Tulita, Fort Good Hope, Norman Wells, Wrigley and Fort Simpson (total community demand is about 4 MW).

Three potential hydro sites have been identified, including Wolverine Creek (200 MW), St. Charles Rapids (125 MW), and Lower Bracket (275 MW). Most attention is being directed towards the St. Charles Rapids site (construction costs would be about $600 million). At this site, the dam across the Great Bear River would be about 300 m wide, and 25 to 27 m high. While water would be backed up about 6 km, water levels in the lake would not be affected. The powerhouse would initially have two turbines, but be capable of handling a third. The upper (Wolverine Creek) and lower (Lower Bracket) sites could be developed in future as additional electricity markets become available. To date, detailed environmental, economic or engineering studies have not been undertaken for any of the prospective sites. However, it is possible that this project could move forward quickly in the event that the Mackenzie Valley Gas Project proceeds in a timely fashion.

Hydroelectric power development can cause a number of effects on aquatic ecosystems. Modification of natural streamflows is one of the most prevalent disturbances of lotic (i.e., flowing water) ecosystems. Flow regimes in regulated systems can be highly variable and unpredictable, with flow variations typical of seasonal changes occurring on weekly or even daily bases. These large variations in streamflow result in changes of dilution capacity, depth, and velocity in downstream areas. Rapid changes in any of these variables can result in changes in water quality conditions and direct effects on instream and other water uses.

Effects of hydroelectric developments on downstream water quality can occur during the construction or operational stages of development (MacDonald *et al.* 1999). During construction, the extensive use of fill materials to build dams can lead to increased downstream transport of fine grained, inorganic sediment, with subsequent deposition in low velocity stream reaches. After completion of construction, reservoir filling can cause severe flow depletion in downstream areas. Water quality degradation is likely to occur if contaminant inputs to the system are not reduced during this period. Water uses, such as those associated with fish and aquatic life, that have rather stringent water quality requirements can, therefore, be adversely affected during these periods. Similar effects can be inferred during the operational stage of development if extreme low flows occur. However, operational flows from hydroelectric projects are usually characterized by increased low flows and reduced high flows, relative to background conditions.

Large short-term variations in stream depth and velocity can have numerous direct effects on instream water uses. Perry and Perry (1986) investigated the effects of flow regulation on stream invertebrates in the Flathead and Kootenai Rivers in Montana. The results of this study suggest that invertebrate drift is highly correlated with discharge, with increased drift observed during both increasing and decreasing discharges. Large daily fluctuations in stream discharge could, therefore, result in impoverishment of downstream reaches with respect to benthic invertebrate populations. Short-term variations in stream depth tend to cause dewatering of shallow shoreline areas (Corrarino and Brusven 1983), and stranding of macroinvertebrates and fish utilizing these areas. In large systems, these nearshore areas are the most productive, so repeated dewatering of these areas can cause severe effects on aquatic biota. Detailed information on specific development proposals would be required to identify the nature and extent of effects that could occur in the Great Bear watershed.

7.5 Other Land Uses

Apart from historic mining activity, there are no large-scale industrial activities in the Great Bear watershed that could affect the Great Bear Lake ecosystem. There are no all-weather roads in the vicinity of the lake, and the winter ice road that connects Déline, Tulita, and Norman Wells is likely relatively benign in terms of environmental impact. This road is maintained by a grader, but there are no chemicals utilized to maintain the road surface through the winter. However, the potential for fuel spills or other materials remains a concern.

7.6 Long-Range Transport of Atmospheric Pollutants

The results of environmental monitoring programs that have been conducted over the past several decades have demonstrated that a variety of contaminants occur at elevated levels in northern ecosystems. These contaminants are known to include certain PAHs [e.g., benzo(a)pyrene], PCBs, certain heavy metals (e.g., mercury), organochlorine pesticides (e.g., toxaphene, DDTs, etc.), and radionuclides. While some of this contamination has resulted from natural sources (e.g., for mercury), anthropogenic sources outside the north account for much of the contamination. Virtually all media types (i.e., water, sediment, and biota) have been affected; however, these contaminants tend to accumulate in sediments and biological tissues. Localised land-based sources (e.g., DEW line sites, mines, etc.) are known to be important point sources of these contaminants; however, atmospheric inputs have been identified as the major source of these contaminants to aquatic ecosystems in areas that are spatially removed from point sources (MacDonald *et al.* 1999).

Long-range transport of atmospheric pollutants is the term that is commonly used to describe the process whereby pollutants are transported in the atmosphere from a release site to another site located some distance away. The contaminants that are most likely to be transported via this process are persistent and semi-volatile substances. Following their initial release, these chemicals are deposited from the atmosphere as wet and/or dry precipitation and subsequently re-volatilized from land and water surfaces. This repeated deposition and volatilization results in a slow northerly movement over time (Swyripa *et al.* 1995). In this way, both historic and ongoing (e.g., from countries where the use of such chemicals has not been banned) releases can represent important sources of these contaminants to the atmosphere and, subsequently, aquatic ecosystems in northern regions (Woodwell *et al.* 1971; Ostromogil'skii *et al.* 1987; Oehme 1991; ATSDR 1994). The Arctic represents the ultimate repository for such pollutants in the northern hemisphere.

A wide variety of contaminants have been measured in the atmosphere and in other environmental compartments in northern regions. For example, Barrie *et al.* (1995) reported that air samples collected at Alert, NWT contained elevated levels of chlordane, dieldrin, endosulfan, lindane (gamma-HCH), and PCBs. Schroeder *et al.* (1995) indicated that air samples from this location also contained elevated levels of gaseous mercury. In addition to chlordane, dieldrin, endosulfan, and lindane, air samples collected from a ship stationed in the Bering-Chukchi seas also contained nonachlor and toxaphene (Bidleman *et al.* 1995). That these contaminants have been deposited from the atmosphere into aquatic ecosystems was confirmed by measurements of these and other substances (e.g., DDTs, hexachlorobenzene) in snow (Swyripa *et al.* 1995) and seawater (Bidleman *et al.* 1995). The results of monitoring activities conducted under the Arctic Environmental Strategy suggest that the rivers draining into the Arctic Ocean have relatively low levels of these contaminants in water and sediment (Jefferies *et al.* 1995). However, Evans (2003; Figure 4.8) reported that PCBs, toxaphene, DDTs, chlordane, and endrin occurred at elevated levels in the tissues of lake trout from both Great Bear Lake and Lac Ste. Thérèse. Therefore, long-range transport of atmospheric pollutants is a disturbance activity that needs to be considered in cumulative effects assessments in northern river basins.

In addition to long-range transport of atmospheric pollutants, the potential for aerial transport of contaminants from regional sources cannot be discounted. For this reason, future air quality monitoring programs should be designed to evaluate loadings of contaminants from both distant and local sources.

7.7 Climate Change

The earth's atmosphere contains a number of gases, including water vapour, carbon dioxide, methane, and nitrous oxide, that trap the sun's energy and prevent heat from quickly dissipating into space. Because these gases help to regulate the earth's temperature, they are often referred to as greenhouse gases. Without the effects of these naturally-occurring gases, the average temperature on earth would be -18^{o} instead of the current 15^{o}C (Environment Canada 1999).

The presence of greenhouse gases in the atmosphere makes life on earth possible. Although there are numerous natural sources of these gases (e.g., forest fires, volcanoes, evaporation, etc.), anthropogenic activities have substantially increased the levels of these greenhouse gases in the atmosphere over the past two hundred years. The burning of fossil fuels represents the major source of greenhouse gas emissions from anthropogenic sources, accounting for the release of 5.0 to 5.5 billion tonnes of carbon dioxide per annum. Another 1 to 1.5 billion tonnes of carbon dioxide are released into the atmosphere as a result of deforestation (Environment Canada 1999).

The concentrations of greenhouse gases in the atmosphere are now increasing at an unprecedented rate. The current levels are 30% higher than the concentrations that were present prior to the industrial revolution (Environment Canada 1999). Alarmingly, roughly 50% of the total associated with anthropogenic enrichment has been released during the last 30 years (Environment Canada 1999). Over that period, average global temperatures have increased by roughly 0.5°C. At current rates of greenhouse gas emissions, carbon dioxide levels in the atmosphere will double over the next 50 years, compared to pre-industrial levels (IPCC 1990). Global climate models predict that such an increase in greenhouse gases will raise global temperatures by 3 ± 1.5°C by the year 2050 (IPCC 1990). However there is great uncertainty with respect to the level and timing of warming, primarily because the effects of climate change on cloud formation and the role of oceans in cycling and re-absorbing radiative gases are not well understood.

Notwithstanding the uncertainties associated with predicting the magnitude of global climate change, there is ample evidence available to demonstrate that mean air temperatures have recently increased in Canada. From the 1959-1973 period to the 1974-1988 period, air temperatures have increased in the central and western parts of Canada by as much as 1.5°C and 2.5°C during spring and winter, respectively (Hengeveld 1991). Doubling of CO_2 is predicted to produce further temperature increases up to 4°C during winter along the western part of the continent (Hengeveld 1991). Increased water run-off at high latitudes and increased summer dryness are expected in association with such temperature increases. Wind, storm, precipitation, and ocean circulation patterns will also be altered, and the ocean level is expected to rise.

Changes in climatic conditions will most certainly influence environmental conditions in the Great Bear watershed. One likely effect of climate change on Great Bear Lake will be to shift the shape of the temperature profile of the lake so that it will more closely resemble the thermal profiles of Great Slave Lake and Lake Athabasca (Figure 3.2), two large lakes located at more southerly latitudes than Great Bear Lake. Another likely effect will be to reduce the duration of winter ice cover on the lake. The duration of the ice-free period in tributaries will also increase, as will the temperature of tributary streams. Valued aquatic ecosystem components are likely to be affected by changes in stream hydrology, water quality, and habitat availability. However, it is not possible to determine if such changes in aquatic habitats will be positive or negative for the fish and other aquatic organisms that reside in the lake and the tributary streams.

Chapter 8 Data Gaps

8.0 Introduction

This report provides an overview of the state of the knowledge on the aquatic ecosystem in the Great Bear watershed. The report was prepared using the results of studies that were conducted for many different purposes and over a protracted time interval. Some of the underlying studies were broad surveys designed to describe aquatic resources on a regional basis, while others were detailed investigations implemented to characterize baseline conditions or evaluate the impacts of developmental activities on a site-specific basis. While these studies provide a great deal of valuable information, there are a number of important gaps in the available knowledge base. The existence of such data gaps is currently limiting our ability to fully assess environmental conditions in the watershed and evaluate temporal trends. The following list of data gaps is not intended to be exhaustive. Rather, it is intended to identify the types of information that should be collected preferentially to better define baseline conditions in the watershed and, hence, provide a basis for assessing the current status of aquatic resources and for evaluating trends over time.

8.1 Climatic Conditions

While long-term climate monitoring has been conducted at Port Radium and, to a lesser extent, Déline, certain data gaps remain. More specifically:

- Data from additional monitoring locations are needed to support characterization of spatial variability in climatic conditions and to support an evaluation of the water balance of Great Bear Lake. One of the best indices of climate change is the duration of ice-free conditions on Great Bear Lake.

8.2 Limnological and Hydrological Conditions

A substantial amount of information is available on the limnology of Great Bear Lake. Nevertheless, there are a number of data gaps that limit our understanding of the processes that influence the physical, chemical, and biological characteristics of the lake. More specifically, the limnological information that is lacking includes:

- Seasonal current patterns in Great Bear Lake;
- Detailed temperature profiles to adequately characterize the physical limnology of the lake; and,
- Variability of water clarity in Great Bear Lake to better characterize spatial variability in lake productivity.

Hydrometric data are currently available from seven locations within the Great Bear watershed, of which two are active (Figure 8.1). While these data were generally sufficient to provide an overview of existing hydrological conditions within the watershed, the data set is limited in several important respects, including:

- The data available from the hydrometric stations are insufficient to fully describe existing and historic hydrological conditions (i.e., to determine mean monthly discharge, mean annual discharge, average peak flow, average low flow, and basin yield) for the Sloan River sub-basin, Haldane River sub-basin, and Whitefish River sub-basin. No hydrometric data are available for several of the tributaries to Great Bear Lake. Such information is needed to evaluate the effects of climate change on the hydrology of the tributaries to Great Bear Lake;
- The hydrometric data that have been collected at various locations in the basin are difficult to compare due to differences in the timing and duration of monitoring;
- The water balance for Great Bear Lake has not been fully evaluated;
- Additional information on ice break-up and freeze-up conditions is needed to evaluate the effects of climate change on Great Bear Lake; and,

- Little or no limnological information currently exists for other lakes in the Great Bear watershed.

8.3 Environmental Quality Conditions

Information on the characteristics of surface water, sediment, and biological tissues is required to evaluate baseline environmental conditions in the Great Bear watershed. Water chemistry data have been collected at various locations in the study area for more than 40 years. While these data are invaluable for describing the existing conditions in the watershed, they have some important limitations that should be addressed in future monitoring initiatives, including:

- Routine monitoring has been conducted on the Camsell River (1985 to present) and the Great Bear River (1960 to present). However, only limited data are available on the Johnny Hoe River and Dease River. No data are available on the Sloan, Haldane, and Whitefish rivers. Therefore, it is difficult to evaluate the large-scale spatial variability in water quality conditions within the watershed;
- No data have been collected to assess cross-sectional or longitudinal variability in water quality conditions in any tributary to Great Bear Lake or in the Great Bear River;
- Very little sampling has been conducted in Great Bear Lake, except in the vicinity of Port Radium. Therefore, it is difficult to assess spatial and temporal variability in water quality conditions in the lake;
- Incomplete data are available to evaluate the relationships between the total and dissolved forms of metals and metalloids in the lake or in the various tributaries. It may be necessary to derive site-specific water quality objectives for the substances that naturally exceed the Canadian WQGs (e.g., cadmium, copper, chromium, and silver); and,
- In some cases, the analytical detection limits that were achieved in various studies were insufficient to determine if important water uses are being

adequately protected [i.e., method detection limits (MDLs) were greater than the WQGs].

Data on ambient sediment quality conditions in the watershed were obtained from several investigations. The majority of these data were collected in the vicinity of Port Radium, at a number of randomly selected sites in the watershed, and in the Johnny Hoe River basin. While these data provide valuable information for assessing sediment quality conditions in the eastern portion of the watershed, they are limited in several important respects, including:

- Insufficient sampling has been conducted in Great Bear Lake to assess spatial variability, temporal trends, or the importance of non-point sources of contaminants to the lake (i.e., through long range transport of atmospheric pollutants);
- The data on the lakes in the Camsell River basin include metals only; no information has been collected on the concentrations of several classes of organic contaminants (i.e., PAHs, PCBs, and organochlorine pesticides);
- The data on lakes in the Johnny Hoe River basin include total mercury only; no information has been collected on the concentrations of several classes of other metals or organic contaminants (i.e., PAHs, PCBs, and organochlorine pesticides);
- No data were available on the Sloan, Haldane, Dease, and Whitefish rivers. Therefore, it is difficult to evaluate the large-scale spatial variability in sediment quality conditions;
- Data on the variables that are thought to influence the toxicity of sediment-associated contaminants were generally not available (i.e., total organic carbon, acid volatile sulphides, grain size, etc.);
- No data were located on pore-water chemistry or on the toxicity of bulk sediments or pore water in this watershed. Such information is particularly important for evaluating sediment quality conditions in areas that are known to have substantial metal enrichment in the sediments; and,
- Tools for identifying the presence of metal enrichment of sediments have not been developed for the study area (e.g., reference element approach).

Currently, few data are available on contaminant residues in the tissues of any of the resident aquatic organisms in the watershed. The following data gaps were identified following evaluation of the existing data:

- While data on the levels of mercury in fish tissues are available for certain locations in the study area, sufficient information to evaluate the temporal and spatial variability of contaminant residues in aquatic organisms is not available;
- Few data were located on the levels of PAHs, PCBs, pesticides, and other persistent organic pollutants in fish tissues;
- No data were located on the levels of environmental contaminants in aquatic plants or aquatic invertebrates from Great Bear Lake or its tributaries; and,
- Little information was located on mercury bioaccumulation pathways for fish in the Johnny Hoe River basin.

8.4 Aquatic Ecosystem Structure

Information on the structure of aquatic communities, including microbial communities, aquatic plant communities, aquatic invertebrate communities, and fish communities, is essential for characterizing background conditions in the Great Bear watershed. Although several investigations have been conducted in the watershed to acquire information on the structure of aquatic communities, several important data gaps remain, including:

- No information was located on the microbial community of Great Bear Lake or its tributaries;
- The available information on phytoplankton communities in Great Bear Lake is insufficient to evaluate spatial or temporal variability in community structure or biomass. No data were available on phytoplankton communities in the smaller lakes within the Great Bear watershed;
- The available information on periphyton communities in Great Bear Lake is insufficient to evaluate spatial or temporal variability in community structure or

biomass. No data were available on periphyton communities elsewhere in the watershed;

- Virtually no information was available on aquatic macrophytes anywhere in the watershed.
- The available information on zooplankton communities in the watershed was limited to Great Bear Lake. While these data provide some information for assessing spatial variability in community structure and biomass, they are generally insufficient to evaluate temporal variability, either seasonally or annually. No data were located on zooplankton community structure, biomass, or succession for any of the smaller lakes in the basin;
- The available information was generally insufficient to evaluate the structure, distribution, or abundance of benthic invertebrate communities in Great Bear Lake. No data were located on the structure of benthic invertebrate communities that utilize habitats in the tributaries to Great Bear Lake or the Great Bear River;
- Little information was available on the basic life history patterns of any fish species other than lake trout. Fish species for which life history information is required on a priority basis include arctic grayling, cisco, lake whitefish, northern pike, bull trout, and walleye;
- Few data were located that describe the biology and movements of lake trout in Keith and North McVicar Arms;
- Incomplete information is available on the productivity, mortality, biomass, and abundance of trophy lake trout; and,
- Insufficient information was located to assess the status of other fish stocks (i.e., species other than lake trout), including those utilized by the Sahtu Dene and Metis for food (e.g., those utilizing habitats in the Johnny Hoe and Whitefish rivers). Additional information is also needed on the utilization of various fish species by the Sahtu Dene and Metis.

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Tables

Table 3.1. Limnological data for Great Bear Lake (Source: Johnson 1975a).

Location	**65° - 67° N and 118° - 125° W**
Altitude (range; metres above sea level)	118 - 119
Drainage basin (km^2)	145 000
Total lake area (km^2)	31 000
Shoreline length (km)	2720
Length (km)	350
Breadth (km)	174
Volume (km^3)	2240
Maximum depth (m; Figure 3.1)	446
Mean depth (m)	72
Water residence time (yr)	124
Date lake becomes ice-free	June 15 – July 15
Date lake becomes frozen	October 15 – November 15
Total dissolved solids (mg/L)	82[1]
Dissolved oxygen (mg/L)	12 – 14
Conductivity (µmho/cm)	156[1]
Total phosphorus (µg/l)	<100[1]
pH	7.8 - 7.9
Amount of bright sunshine (hr/yr)	1854
Maximum Secchi depth (m)	30
Lake physical turnover	Once per 3 years

[1]Represents an average of 4 samples collected at various locations in the lake in 1963 and 1964.

Table 4.1. Summary of environmental studies conducted on Great Bear Lake and tributaries.

Water Body	Reach	Sampling Date	Media Sampled	Analytes Measured	Reference
Great Bear Lake	Labine Bay	1972	SW	Metals	Roy and Vezina 1973
Great Bear Lake	Cobalt Channel	?	SW, WS, FT	Metals	Falk 1972
Great Bear Lake	Various	1963	SW	Conventionals, Metals, Nutrients	Johnson 1975a
Great Bear Lake	Port Radium	1977	SW, WS, FT	Metals, Radionuclides	Moore and Sutherland 1981
Great Bear Lake	Port Radium	1982	SW	Radionucludes	DIAND 1982
Great Bear Lake	Port Radium	1982	SW	Conventionals, Metals	Kalin 1982
Great Bear Lake	Port Radium	1983	SW	Conventionals, Metals, Radionuclides	Kalin 1983
Great Bear Lake	Various	1960-1979	SW	Conventionals, Metals	Environment Canada 1981; Unpublished data
Great Bear Lake	Various	1960-1979	SW	Conventionals, Metals	Environment Canada 1981; Unpublished data
Great Bear Lake	Port Radium	1978	SW	Metals	Myers 1982
Great Bear Lake	Port Radium	1984	SW, FT	Metals, Radionuclides	Hatfield Consultants Ltd. 1985
Great Bear Lake	Deline	1983-1999	SW	Metals	NWT Water Board 1999
Great Bear Lake	Deline	1992	SW	Metals	ANON 1992
Great Bear Lake	Port Radium	1995	SW	Metals, Radionuclides	Swanson 1995
Camsell River	Outlet of Clut Lake	1969-1999	SW	Conventionals, Metals	Environment Canada 1981; Unpublished data
Johnny Hoe River	Four Lakes	1992-1993	SW, FT	Conventionals, Mercury	Stephens 1997

SW = saltwater; WS = whole sediment; FT = flow-through.

Table 4.2a. Summary of the Canadian water quality guidelines for drinking water supplies, recreation and aesthetics, and fish and aquatic life (CCME 1999)

Parameter	Units	Canadian Water Quality Guidelines		
		Drinking Water	Recreation and Aestetics	Fish and Aquatic Life
pH	pH units	6.5 - 8.5 (AO)	5.0 - 9.0	6.5 - 9.0
Colour	TCU	15 (AO)		Narrative
Turbidity	NTU	1 (5 AO)	Narrative	Narrative
Suspended Sediments	µg/L			Narrative
Sodium Dissolved	mg/L	200 (AO)		
Chloride Dissolved	mg/L	250 (AO)		
Sulphate Dissolved	mg/L	500 (AO)		
Ammonia Total	mg/L			see Table 4.2b
Cyanide Total	µg/L	200.0		5.00
Arsenic Total	µg/L	25 (IMAC)		5.0
Cadmium Total	µg/L	5.0		0.017
Chromium Total	µg/L	50.0		
Trivalent chromium (Cr (III))	µg/L			8.90
Hexavalent chromium (Cr (IV))	µg/L			1.00
Copper Total	µg/L	1000 (AO)		2 - 4
Iron Total	µg/L	300 (AO)		300.00
Lead Total	µg/L	10.00		1 - 7
Manganese Total	µg/L	50 (AO)		
Mercury Total	µg/L	1.00		0.10
Nickel Total	µg/L			25 - 150
Uranium Total	µg/L	20 (IMAC)		
Zinc Total	µg/L	5000 (AO)		30.00

IMAC = interim maximum acceptable concentration; AO = aesthetic objective
TCU = True Colour Units; NTU = nephelometric turbidity units; NA = not available.

Table 4.2b. Summary of the Canadian water quality guidelines for total ammonia for fish and aquatic life (CCME 1999).

Temperature (^oC)	pH							
	6	6.5	7	7.5	8	8.5	9	9.5
0	231	73	23.1	7.32	2.33	0.749	0.25	0.042
5	153	48.3	15.3	4.84	1.54	0.502	0.172	0.034
10	102	32.4	10.3	3.26	1.04	0.343	0.121	0.029
15	69.7	22	6.98	2.22	0.715	0.239	0.089	0.026
20	48	15.2	4.82	1.54	0.499	0.171	0.067	0.024
25	33.5	10.6	3.37	1.08	0.354	0.125	0.053	0.022
30	23.7	7.5	2.39	0.767	0.256	0.094	0.043	0.021

Table 4.3. Summary of the water quality data collected on the Camsell River at Outlet of Clut Lake (1985-1999).

Parameter	Units	Detection Limits	n	ndets	Mean	Minimum	Median	Maximum
pH	pH units		48	0	NA	7.33	7.65	8.01
Conductivity	µS/cm		48	0	132.5	94.6	131.5	161.0
Colour	TCU		48	21	5.74	5.00	5.00	10.00
Turbidity	NTU		48	0	0.7	0.1	0.4	6.0
Total Suspended Solids	mg/L		48	28	4.4	1.0	3.0	76.0
Total Dissolved Solids	mg/L		28	2	77.8	3.0	79.0	100.0
Hardness	mg/L		48	0	58.1	42.8	57.1	68.7
Alkalinity	mg/L		47	0	51.1	38.5	49.9	73.1
Calcium Dissolved	mg/L		45	0	13.7	10.4	13.5	16.8
Magnesium Dissolved	mg/L		48	0	5.81	4.10	5.94	6.80
Sodium Dissolved	mg/L		48	0	2.06	1.46	2.04	2.70
Potassium Dissolved	mg/L		48	0	0.97	0.77	0.96	1.58
Chloride	mg/L		48	0	2.1	0.4	2.1	3.2
Sulphate	mg/L		48	3	11.0	2.0	11.1	22.9
Ammonia	mg/L		28	13	0.008	0.002	0.005	0.070
Nitrate + Nitrite	mg/L		48	11	0.032	0.008	0.037	0.080
Dissolved Phosphorous	mg/L		22	10	0.003	0.002	0.003	0.007
Ortho Phosphorous	mg/L		18	15	0.002	0.001	0.002	0.005
Total Phosphorous	mg/L		31	4	0.007	0.002	0.006	0.018
Aluminum Total	µg/L	0.5-30	5	2	17.6	3.1	13.3	30.0
Arsenic Total	µg/L	0.1 - 0.3	33	28	0.3	0.1	0.3	0.3
Barium Total	µg/L	1.0 - 100.0	19	14	66.7	7.6	80.0	100.0
Beryllium Total	µg/L	0.1 - 2.0	8	8	0.3	0.1	0.1	2.0
Bismuth Total	µg/L	0.1 - 0.4	8	8	0.1	0.1	0.1	0.4
Cadmium Total	µg/L	0.1 - 1.0	46	30	0.4	0.1	0.1	5.0
Cesium Total	µg/L	0.1 - 0.4	8	8	0.1	0.1	0.1	0.4
Chromium Total	µg/L	0.2 - 3.0	26	7	1.2	0.2	1.0	4.6
Cobalt Total	µg/L	0.5 - 1.0	46	43	0.5	0.1	0.5	1.0
Copper Total	µg/L	0.5 - 1.0	46	5	1.1	0.4	0.9	5.0
Cyanide Total	mg/L	0.001 - 0.004	35	24	0.002	0.001	0.001	0.006
Iron Total	µg/L	1.0 - 30.0	26	4	37.5	4.0	20.0	161.0
Lead Total	µg/L	0.2 - 1.0	46	25	1.0	0.2	0.7	9.3
Lithium Total	µg/L	0.1 - 3.0	8	1	2.0	1.6	1.8	3.0
Manganese Total	µg/L	1.0 - 6.0	23	5	1.6	0.3	0.7	6.0
Mercury Total	µg/L	0.01 - 0.02	11	9	0.02	0.01	0.02	0.05
Molybdenum Total	µg/L	0.1 - 1.0	8	1	0.3	0.1	0.2	1.0
Nickel Total	µg/L	0.1 - 1.0	45	23	0.7	0.1	0.6	4.1
Selenium Total	µg/L	1.0 - 10.0	5	4	4.7	1.0	1.3	10.0
Silver Total	µg/L	0.1 - 0.3	8	8	0.1	0.1	0.1	0.3
Strontium Total	µg/L	0.1 - 1.0	8	0	49.5	34.4	50.6	57.6
Thallium Total	µg/L	0.1 - 0.4	8	8	0.1	0.1	0.1	0.4
Uranium Total	µg/L	0.1 - 0.3	6	0	0.4	0.3	0.4	0.4

Table 4.3. Summary of the water quality data collected on the Camsell River at Outlet of Clut Lake (1985-1999).

Parameter	Units	Detection Limits	n	ndets	Mean	Minimum	Median	Maximum
Vanadium Total	µg/L	0.1 - 1.0	27	19	0.5	0.1	0.5	1.2
Zinc Total	µg/L	0.4 - 5.0	46	17	2.4	0.4	1.0	12.1

* ndets = number of values less than the detection limit.
* TCU = True Colour Units; NTU = nephelometric turbidity units; NA = not applicable.

Table 4.4. Summary of water quality data collected on the Johnny Hoe River above Lac Ste. Thérèse (1969-1976).

Parameter	Units	Detection Limits	n	ndets	Mean	Median	Min	Max
pH	pH units		13	0	7.94	8	7.6	8.2
Conductivity	µS/cm		12	0	303.3	272.5	164	492
Colour	TCU		12	0	38.00	40	5	100
Turbidity	JTU		12	0	5.19	2.4	0.8	30
Total Dissolved Solids	mg/L		1	0	207	207	207	207
Total Suspended Solids	mg/L		2	1	2.5	2.5	1	4
Alkalinity	mg/L		12	0	100.7	91.45	61	147
Hardness	mg/L		11	0	146.3	132	92.3	224
Calcium Dissolved	mg/L		9	0	40.62	33.9	26.1	70.5
Sodium Dissolved	mg/L		13	0	8.00	6.1	3.7	19.7
Potassium Dissolved	mg/L		13	0	0.935	0.8	0.5	1.6
Chloride Dissolved	mg/L		13	0	7.58	5.5	3.4	21.1
Sulphate Dissolved	mg/L		12	0	35.41	28.45	14.3	76.3
Fluoride Dissolved	mg/L		10	1	0.110	0.09	0.025	0.26
Ammonia	mg/L		3	0	0.233	0.2	0.2	0.3
Nitrate and Nitrite	mg/L		9	4	0.057	0.0025	0.0005	0.19
Ortho Phosphate	mg/L		7	5	0.003	0.001	0.001	0.01
Total Phosphorous	mg/L		3	1	0.005	0.006	0.0025	0.006
Total Inorganic Carbon	mg/L		5	0	14.8	15	12	17
Total Organic Carbon	mg/L		5	0	28.4	17	9	89
Arsenic Dissolved	mg/L	0.005	2	2	0.005	0.005	0.005	0.005
Aluminum Extractable	mg/L	0.1	1	1	0.1	0.1	0.1	0.1
Barium Extractable	mg/L	0.1	1	1	0.1	0.1	0.1	0.1
Boron Dissolved	mg/L	0.02	2	1	0.035	0.035	0.02	0.06
Cadmium Extractable	mg/L	0.001	4	3	0.0009	0.0005	0.001	0.002
Chromium Extractable	mg/L	0.01	1	1	0.005	0.005	0.005	0.005
Cobalt Extractable	mg/L	0.001	4	2	0.001	0.00075	0.001	0.002
Copper Dissolved	mg/L	0.001	3	1	0.002	0.001	0.001	0.004
Copper Extractable	mg/L	0.001	6	3	0.08	0.009	0.001	0.012
Iron Dissolved	mg/L	0.001	6	0	0.057	0.065	0.02	0.09
Iron Extractable	mg/L	0.02	4	0	0.148	0.155	0.05	0.23
Lead Dissolved	mg/L	0.001	3	3	0.001	0.001	0.001	0.001
Lead Extractable	mg/L	0.001	6	5	0.005	0.005	0.001	0.005
Lithium Extractable	mg/L	0.005	2	1	0.0065	0.0065	0.005	0.008
Manganese Extractable	mg/L	0.01	6	4	0.01	0.01	0.01	0.02
Manganese Dissolved	mg/L	0.01	4	4	0.01	0.01	0.01	0.01
Molybdenum Extractable	mg/L	0.05	2	2	0.05	0.05	0.05	0.05
Nickel Extractable	mg/L	0.004	4	2	0.0065	0.005	0.004	0.012
Strontium Extractable	mg/L	0.02	1	0	0.16	0.16	0.16	0.16
Vanadium Extractable	mg/L	0.05	1	1	0.05	0.05	0.05	0.05
Zinc Dissolved	mg/L	0.001	3	0	0.0023	0.001	0.001	0.005
Zinc Extractable	mg/L	0.01	5	2	0.0108	0.01	0.01	0.019

* ndets = number of values less than the detection limit.
* TCU = True Colour Units; NTU = nephelometric turbidity units; NA = not available.

Table 4.5. Summary of water quality data collected from lakes within the Johnny Hoe River Basin, 1992 and 1993 (Stephens 1997).

Parameter	Units	Lac Ste. Thérèse			Keller Lake			Tseepantee Lake			Lac Taché		
		n	Mean	Range	n	Mean	Range	n	Mean	Range	n	Mean	Range
pH	pH units	14	7.70	7.12-7.94	7	7.84	7.75-8.00	8	8.01	7.77-8.27	7	8.35	8.20-8.48
Conductivity	µmho/cm	14	219	200-246	7	155	154-156	8	253	236-324	7	340	324-369
Turbidity	NTU	14	1.3	0.7-2.3	7	0.4	0.4-0.5	8	1.7	1.1-3.7	7	0.9	0.7-1.1
Colour		9	39	35-45	7	5	5-6	8	32	25-42	7	8	7-12
Calcium	mg/L	14	26.3	23.8-28.6	7	16.3	16.0-16.8	8	5.3	25.1-33.9	7	4.6	38.3-46.3
Magnesium	mg/L	14	9.7	9-10.4	7	7.0	6.9-7.0	8	10.1	9.3-12.8	7	15.0	14.6-15.6
Hardness	mg/L	9	110	107-112	7	69	68-71	8	108	101-137	7	163	156-180
Alkalinity	mg/L	4	86.0	85.5-87.1	2	66.9	66.8-67.0	1	105.0	105.0	2	124.0	123-125
Sodium	mg/L	14	4.7	4.4-5.3	7	2.8	2.8-2.9	8	8.6	6.8-11.9	7	4.3	4.0-5.0
Potassium	mg/L	13	0.88	0.80-1.00	7	0.71	0.69-0.80	8	0.73	0.5-0.9	7	1.21	1.0-1.4
Chloride	mg/L	14	4.40	4.00-4.13	7	1.69	1.62-1.71	8	9.35	7.23-13.1	7	1.48	1.34-1.82
Sulfate	mg/L	14	20	16.1-29.0	7	8	7.6	8	5	4.0-10.0	7	54	42-75
Iron	µg/L	17	72	35-109	7	13	6.0-10.0	8	85	34-205	7	13	20-21
Mercury	ng/L	4	1.49	1.34-1.64	2	0.55	0.43-0.66	1	0.77	0.77	2	0.34	0.28-0.40

n = number of samples; NTU = nephelometric turbidity units.

Table 4.6. Chemical composition of water from Great Bear Lake and tributary streams (1963 - 1964; n=1 for each location).

Parameter	Units	McTavish Arm	Smith Arm	McVicar Arm	Conjuror Bay	Camsell River	Dease River	Johnny Hoe River
pH	pH units	7.8	7.9	8.1	7.5	7.7	7.5	8.2
Colour	hazen units	0	15	15	5	5	20	45
Total Alkalinity ($CaCO_3$)	mg/L	55.8	54.4	66.3	46.5	43.6	29.4	99.3
Conductivity (at 25^oC)	mho/cm^2	155	152	191	125.6	115.4	60	269.3
Hardness ($CaCO_3$)								
Total	mg/L	66.6	68	87.3	57	52	31.5	131
Noncarbonate	mg/L	13.9	13.6	21	10.5	8.7	2.1	31.5
Calcium	mg/L	16.2	16.1	19.9	12.8	1.4	6.7	31.4
Magnesium	mg/L	6.9	6.8	9.1	6.1	5.7	3.6	12.7
Iron Dissolved	mg/L	0.13	<0.01	0.01	0.19	0.01	0.03	0.03
Aluminum	mg/L						0.06	
Manganese	mg/L						0.015	
Copper	mg/L						0.004	
Zinc	mg/L		0.003				0.013	
Sodium	mg/L	4.2	4	4.5	2.2	1.7	0.6	4.9
Potassium	mg/L	0.8	0.8	0.8	0.7	0.9	0.5	0.9
Nitrate (NO_3)	mg/L	0.49	0.37	0.3	<0.01	Trace	0.5	0.2
Phosphate (PO_4) Total	mg/L	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1
Carbonate	mg/L	0	0	0	0	0	0	0
Bicarbonate	mg/L	68	66.3	80.8	56.7	57.8	35.8	121
Sulphate	mg/L	14.8	14.1	21.9	10.9	9.3	1.6	31.5
Chloride	mg/L	4.8	4.4	5.3	2.3	1.5	0.6	4.4
Fluoride	mg/L	0.11	0.13	0.17	0.16	0.17	0.06	0.23
Silica (SiO_2)	mg/L	2.2	2	2	1.3	0.9	0.6	3.2
Total Dissolved Solids	mg/L	78.4	81.3	104	62.7	57.6	32.3	149

Table 4.7. Summary of the water quality data collected on the Great Bear River at Outlet of Great Bear Lake (1969-2001).

Parameter	Units	Detection Limits	n	ndets	Mean	Minimum	Median	Maximum
pH	pH units		133	0	NA	7.30	7.90	8.20
Conductivity	µS/cm		135	0	164.1	52.4	164.0	494.0
Colour	TCU		99	64	5.82	5.00	5.00	30.00
Turbidity	NTU		135	1	2.6	0.1	0.4	82.9
Total Suspended Solids	mg/L		122	79	7.4	1.0	1.5	183.0
Total Dissolved Solids	mg/L		36	0	95.6	77.0	91.2	150.0
Hardness	mg/L		139	0	70.8	30.4	70.3	160.4
Alkalinity	mg/L		126	0	56.5	23.0	56.9	90.0
Calcium Dissolved	mg/L		139	0	16.9	8.4	16.7	35.4
Magnesium Dissolved	mg/L		118	0	7.17	5.47	7.10	17.50
Sodium Dissolved	mg/L		139	0	4.06	0.90	4.10	6.60
Potassium Dissolved	mg/L		138	0	0.74	0.20	0.72	2.14
Chloride	mg/L		138	0	4.9	1.1	5.0	7.3
Sulphate	mg/L		139	0	14.8	2.3	14.5	44.9
Fluoride	mg/L		120	5	0.090	0.020	0.090	0.150
Ammonia	mg/L		36	9	0.018	0.002	0.010	0.095
Nitrate + Nitrite	mg/L		128	0	0.146	0.015	0.153	0.250
Dissolved Phosphorous	mg/L		128	69	0.007	0.001	0.004	0.187
Total Phosphorous	mg/L		98	24	0.013	0.002	0.006	0.363
Dissolved Organic Carbon	mg/L		111	0	2.296	0.200	1.910	21.000
Particulate Organic Carbon	mg/L		110	0	0.29	0.01	0.10	4.96
Particulate Organic Nitrogen	mg/L		111	24	0.0	0.0	0.0	0.7
Aluminum Total	µg/L	0.1 - 2.0	35	2	98.2	2.0	6.0	2120.0
Arsenic Dissolved	µg/L	0.1-5.0	119	37	1.4	0.1	0.2	5.0
Barium Total	µg/L	0.05 - 200	87	36	71.3	17.7	40.0	200.0
Beryllium Total	µg/L	0.002 - 50.0	35	32	50.9	0.0	50.0	130.0
Cadmium Total	µg/L	0.005 - 1.0	89	66	0.3	0.0	0.1	1.0
Chromium Total	µg/L	0.02 - 0.2	35	19	0.4	0.2	0.2	3.0
Cobalt Total	µg/L	0.002 - 1.0	89	69	0.4	0.1	0.5	1.8
Copper Total	µg/L	0.02 - 1.0	89	30	1.1	0.2	0.6	8.0
Iron Total	µg/L	0.2 - 1.0	36	1	204.9	0.2	17.5	4260.0
Lead Total	µg/L	0.005 - 1.0	89	52	0.6	0.1	0.7	2.5
Lithium Total	µg/L	0.02	35	0	3.9	2.7	3.7	7.6
Manganese Total	µg/L	0.01	36	0	5.9	0.3	0.9	72.4
Molybdenum Total	µg/L	0.01	35	0	0.3	0.2	0.3	0.8
Nickel Total	µg/L	0.05 - 1.0	89	32	0.7	0.2	0.5	5.7
Selenium Dissolved	µg/L	0.1 - 0.5	113	76	0.2	0.1	0.1	0.6
Silver Total	µg/L	0.005 - 0.1	15	8	0.1	0.0	0.1	0.5
Strontium Total	µg/L	0.05	35	0	99.4	16.0	101.0	118.0
Vanadium Total	µg/L	0.01 - 0.5	78	44	0.4	0.1	0.5	5.3
Zinc Total	µg/L	0.05 - 1.0	89	12	1.7	0.1	1.0	17.6

* ndets = number of values less than the detection limit.
* TCU = True Colour Units; NTU = nephelometric turbidity units; NA = not available.

Table 4.8. Time series of the annual mean values for the Great Bear River at Outlet of Great Bear Lake.

Parameter	Units	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Number of Samples		8	6	4	3	5	7	5	7	6	6	4	5	7	7	7	6
pH	pH units	7.80	7.85	7.80	7.80	7.90	7.90	7.92	7.80	7.89	7.93	7.90	7.95	7.63	7.89	7.77	7.93
Conductivity	µS/cm	168.50	172.67	152.75	168.00	150.40	163.29	163.60	166.71	163.50	155.67	140.60	167.40	163.00	167.17	165.02	169.53
Colour	TCU		7.00	7.50	6.67	5.00	5.00	5.00	5.00	5.00	5.83	5.00	5.00	5.00	5.00	6.43	5.00
Turbidity	NTU	4.65	0.83	0.33	0.30	5.26	1.25	0.38	0.53	0.58	0.47	0.51	0.35	1.15	0.48	2.60	1.36
Total Suspended Solids	mg/L	30.14	2.67	1.00	1.00	11.80	8.29	1.00	1.29	2.37	1.90	1.00	1.20	1.97	2.71	7.76	6.56
Total Dissolved Solids	mg/L														86.67	109.39	93.67
Hardness	mg/L	70.87	72.83	75.63	75.13	84.02	69.95	67.00	71.71	69.65	68.13	73.70	72.16	72.16	71.09	70.06	71.26
Alkalinity	mg/L	55.50	56.17	57.00	59.67	55.60	57.23	58.72	58.67	55.67	55.47	58.65	56.86	57.14	57.60	57.39	56.41
Calcium Dissolved	mg/L	16.55	16.97	17.68	17.67	19.24	16.47	15.88	17.04	16.52	16.27	17.33	16.96	16.92	16.80	16.48	16.80
Magnesium Dissolved	mg/L	7.18	7.40	7.65	7.53	8.74	7.00	6.64	7.09	6.90	6.68	7.40	7.24	7.26	7.08	7.02	7.12
Sodium Dissolved	mg/L	3.71	4.17	3.75	4.27	3.88	4.20	4.08	4.29	4.11	4.04	4.36	4.26	4.26	3.93	3.99	4.22
Potassium Dissolved	mg/L	0.73	0.80	0.85	0.85	0.72	0.75	0.71	0.77	0.73	0.73	0.72	0.71	0.72	0.91	0.71	0.73
Chloride	mg/L	4.31	5.17	5.20	5.37	2.96	5.22	4.70	5.13	4.88	4.73	5.08	4.86	5.21	5.11	4.84	5.21
Sulphate	mg/L	13.50	14.33	14.50	16.30	19.78	13.87	13.96	15.06	14.05	13.63	14.40	13.94	14.04	15.24	15.29	15.79
Fluoride	mg/L	0.09	0.07	0.09	0.07	0.09	0.10	0.09	0.10	0.09	0.10	0.10	0.10		0.09	0.09	0.09
Ammonia	mg/L														0.01	0.01	0.03
Nitrate + Nitrite	mg/L	0.13	0.15	0.16	0.17	0.14	0.16	0.16	0.15	0.15	0.12	0.17	0.16	0.16	0.18	0.12	0.16
Dissolved Phosphorous	mg/L	0.004	0.008	0.012	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.004
Total Phosphorous	mg/L	0.014	0.013	0.026	0.008	0.023	0.009	0.004					0.012	0.004	0.003	0.006	0.006
Dissolved Organic Carbon	mg/L	2.625	1.700	2.475	1.733	5.360	1.571	1.760	2.229	1.758	2.022	1.878	1.984	1.922	1.648	2.710	2.075
Particulate Organic Carbon	mg/L	0.283	0.198	0.088	0.063	0.566	0.399	0.098	0.137	0.149	0.110	0.054	0.081	0.093	0.509	0.253	0.226
Particulate Organic Nitrogen	mg/L	0.073	0.026	0.020	0.020	0.050	0.034	0.016	0.020	0.015	0.019	0.015	0.011	0.010	0.134	0.029	0.023
Aluminum Total	µg/L														14.87	41.19	43.28
Arsenic Dissolved	µg/L	5.00	5.00	5.00	3.83	0.40	0.23	0.16	0.16	0.22	0.17	0.20	0.16	0.14	0.16	0.13	0.10
Barium Total	µg/L				200.00	200.00	200.00	140.00	83.71	83.67	80.33	80.00	48.00	40.00	27.20	23.50	23.63
Beryllium Total	µg/L														50.00	50.00	50.00
Cadmium Total	µg/L				1.00	1.00	1.00	0.55	0.20	0.12	0.12	0.13	0.12	0.17	0.10	0.23	0.15
Chromium Total	µg/L														0.26	0.26	0.22
Cobalt Total	µg/L				1.00	1.00	1.00	0.75	0.50	0.50	0.53	0.50	0.18	0.39	0.10	0.12	0.12
Copper Total	µg/L				7.00	2.80	1.00	0.78	1.40	0.52	0.63	0.63	0.72	0.40	0.72	1.01	0.44
Iron Total	µg/L														58.11	86.92	70.48
Lead Total	µg/L				1.00	1.00	1.00	0.85	0.94	0.70	0.78	0.70	0.88	0.68	0.41	0.26	0.20
Lithium Total	µg/L														4.13	4.26	4.20
Manganese Total	µg/L														3.11	3.53	3.24

Table 4.8. Time series of the annual mean values for the Great Bear River at Outlet of Great Bear Lake.

Parameter	Units	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Molybdenum Total	µg/L														0.32	0.29	0.32
Nickel Total	µg/L				1.00	1.60	1.00	0.75	0.61	0.67	0.77	0.70	0.84	0.88	0.44	0.31	0.29
Selenium Dissolved	µg/L	0.50	0.50	0.50	0.37	0.10	0.13	0.10	0.11	0.12	0.10	0.15	0.14	0.11	0.10	0.10	0.10
Silver Total	µg/L																
Strontium Total	µg/L														103.15	99.40	105.04
Vanadium Total	µg/L				0.50	0.56	0.51	0.60	0.50	0.50	0.52	0.58	0.33		0.10	0.16	0.10
Zinc Total	µg/L				5.00	3.80	1.86	0.85	2.04	0.75	1.58	2.00	1.14	1.07	1.70	1.85	0.56

* TCU: True Colour Units; NTU: nephelometric turbidity units

Table 4.8. Time series of the annual mean values for the Great Bear River at Outlet of Great Bear Lake.

Parameter	Units	1996	1997	1998	1999	2000	2001
Number of Samples		5	3	2	3	2	3
pH	pH units	7.96	7.89	7.96	7.97	7.84	7.90
Conductivity	uS/cm	179.40	279.67	150.00	165.00	150.17	151.00
Colour	TCU	10.00	6.67	5.00	5.00	7.50	7.22
Turbidity	NTU	21.65	0.43	0.63	1.02	0.95	1.48
Total Suspended Solids	mg/L	45.20	3.00	9.83	4.11	3.00	4.33
Total Dissolved Solids	mg/L	102.87	95.00	98.00	88.11	83.50	85.67
Hardness	mg/L	77.18	72.62	72.57	69.25	67.47	66.70
Alkalinity	mg/L	65.37		58.80		54.47	53.67
Calcium Dissolved	mg/L	18.80	16.90	17.25	16.19	15.95	15.67
Magnesium Dissolved	mg/L	7.34	7.39	7.17	7.00	6.71	6.70
Sodium Dissolved	mg/L	4.63	4.24	4.27	4.18	3.87	3.71
Potassium Dissolved	mg/L	0.93	0.73	0.69	0.75	0.75	0.64
Chloride	mg/L	5.78	5.17	5.47	5.04	4.82	3.85
Sulphate	mg/L	18.49	15.43	14.85	14.81	14.42	9.92
Fluoride	mg/L	0.10	0.10	0.08	0.09	0.10	0.09
Ammonia	mg/L	0.01	0.04	0.02	0.01	0.04	0.01
Nitrate + Nitrite	mg/L	0.14	0.15	0.14	0.15	0.14	0.10
Dissolved Phosphorous	mg/L	0.041	0.008	0.007	0.004	0.007	0.009
Total Phosphorous	mg/L	0.085	0.014	0.007	0.005	0.005	0.019
Dissolved Organic Carbon	mg/L	4.133	3.133	2.100	2.189	3.583	2.833
Particulate Organic Carbon	mg/L	2.113	0.241	0.202	0.160	0.143	0.274
Particulate Organic Nitrogen	mg/L	0.182	0.047	0.028	0.070	0.023	0.037
Aluminum Total	µg/L	524.93	4.33	2.00	6.67	3.67	49.18
Arsenic Dissolved	µg/L	0.10	0.17	0.30	0.10	0.10	0.10
Barium Total	µg/L	39.59	23.20	23.70	44.11	22.03	23.79
Beryllium Total	µg/L	66.00	50.00	50.00	50.00	50.00	33.34
Cadmium Total	µg/L	0.16	0.10	0.10	0.10	0.10	0.07
Chromium Total	µg/L	0.92	0.20	0.80	0.37	0.60	0.27
Cobalt Total	µg/L	0.54	0.10	0.10	0.10	0.10	0.13
Copper Total	µg/L	1.84	4.20	4.00	0.51	0.45	0.44
Iron Total	µg/L	1110.50	11.67	10.60	10.93	15.22	107.66
Lead Total	µg/L	0.72	0.20	0.30	0.20	0.40	0.17
Lithium Total	µg/L	4.73	3.50	3.60	3.01	2.92	2.88
Manganese Total	µg/L	25.50	1.57	0.50	0.64	1.75	4.04

Table 4.8. Time series of the annual mean values for the Great Bear River at Outlet of Great Bear Lake.

Parameter	Units	1996	1997	1998	1999	2000	2001
Molybdenum Total	µg/L	0.37	0.27	0.30	0.34	0.38	0.32
Nickel Total	µg/L	1.59	0.37	0.30	0.27	0.28	0.31
Selenium Dissolved	µg/L	0.10	0.10	0.10	0.10	0.10	0.10
Silver Total	µg/L	0.10	0.10	0.20	0.10	0.10	0.20
Strontium Total	µg/L	90.20	103.30	104.00	100.61	94.60	93.76
Vanadium Total	µg/L	1.44	0.10	0.10	0.10	0.10	0.17
Zinc Total	µg/L	4.86	1.23	1.10	0.60	0.25	0.35

* TCU: True Colour Units; NTU: nephelometric turbidity units

Table 4.9. Summary of sediment chemistry data (in mg/kg DW) collected in the vicinity of Port Radium in 1971 and 1972 (Falk *et al.* 1973b).

Substance[1]	**Station**									
	1	**3**	**4**	**5**	**5A**	**6**	**8**	**9**	**11**	**15**
Arsenic	>2000	>4000	3100	NR	NR	3100	4700	3200	NR	16
Cadmium	>750	>700	450	NR	NR	970	700	1530	NR	<100
Copper[2]	<1000	11 800	1650	NR	NR	8600	NR	9100	NR	<1000
Lead	2800	>550	1800	NR	NR	>700	NR	>600	NR	<100
Nickel	1340	>200	1050	NR	NR	300	190	385	>400	26
Uranium	2	4	230	260	30	1620	1820	4	90	4
Zinc	>450	>300	>800	NR	NR	>300	330	300	NR	143

NR = not reported; DW = dry weight.

[1]Note: In some cases concentrations were estimated from histogram presentation of data.

[2] Reference site located off Mystery Island.

Table 4.10. Canadian sediment quality guidelines (SQGs) and associated probable effect levels (PELs; CCME 1999).

Substance	Interim SQG	PEL
Metals (in mg/kg DW)		
Arsenic	5.9	17
Cadmium	0.596	3.53
Chromium	37.3	90
Copper	35.7	197
Lead	35	91.3
Mercury	0.174	0.486
Zinc	123	315
Polycyclic Aromatic Hydrocarbons (PAHs; in µg/kg DW)		
Acenaphthene	6.71[1]	88.9[2]
Acenaphthylene	5.87[1]	128[2]
Anthracene	46.9[1]	245[2]
Fluorene	21.2[1]	144[2]
2-Methylnaphthalene	20.2[1]	201[2]
Naphthalene	34.6[1]	391[2]
Phenanthrene	41.9	515
Benz[a]anthracene	31.7	385
Benzo(a)pyrene	31.9	782
Chrysene	57.1	862
Dibenz[a,h]anthracene	6.22[1]	135[2]
Fluoranthene	111	2355
Pyrene	53	875
Polychlorinated Biphenyls (PCBs; in µg/kg DW)		
Aroclor 1254	60[3]	340[4]
Total PCBs	34.1	277
Dioxins and Furans (ng TEQ/kg)		
Polychlorinated dibenzo-*p*- dioxins	0.85[5]	21.5[5]
Polychlorinated dibenzofurans	0.85[5]	21.5[5]
Organochlorine Pesticides (in µg/kg DW)		
Chlordane	4.5	8.87
Dieldrin	2.85	6.67
Sum DDD	3.54	8.51

Table 4.10. Canadian sediment quality guidelines (SQGs) and associated probable effect levels (PELs; CCME 1999).

Substance	Interim SQG	PEL
Organochlorine Pesticides (in µg/kg DW; cont.)		
Sum DDE	1.42	6.75
Sum DDT	1.19[1]	4.77[2]
Endrin	2.67	62.4
Heptachlor epoxide	0.6	2.74
Lindane (gamma-BHC)	0.94	1.38
Toxaphene	0.1[6]	-

DW = dry weight.

[1]Provisional; adoption of marine interim sediment quality guidelines.
[2]Provisional; adoption of marine probable effect level.
[3]Provisional; adoption of lowest effect level from Ontario (Persaud *et al.* 1993).
[4]Provisional; 1% total organic carbon (TOC); adoption of severe effect level of 34 mg/kg TOC from Ontario (Persaud *et al.* 1993).
[5]Values are expressed as toxic equivalency (TEQ) units based on WHO 1999 TEF values for fish.
[5]Provisional; 1% TOC; adoption of chronic sediment quality criterion of 0.01 mg/kg TOC of the NYSDEC (1994).

Table 4.11. Metal concentrations in Great Bear Lake and Port Radium sediments (in mg/kg DW; Macdonald 1998).

Parameter	Great Bear Lake (Background)								Port Radium					
	SED 1	SED 2	SED 3	SED 5	SED 6	SED 7	Average	Standard Deviation	PR 1	PR 2	PR 3	PR 4	Average	Standard Deviation
Arsenic	2.8	13.8	33.6	13.6	10.6	14.4	14.9	10.2	668	2880	3630	2100	1797	1265.9
Barium	64.6	565	181	355	1310	386	495.1	443.3	288	304	94.2	265	282.4	97.1
Beryllium	<1	<1	<1	<1	<1	<1	<1		<1	>1	<1	<1	<1	
Cadmium	>0.5	<0.5	<0.5	<0.5	<0.5	1.4	<0.5		1.7	1.8	<0.5	0.6	1.8	0.7
Chromium	3.9	33.8	19.7	44.8	50.1	20.4	30.5	17.4	55.8	118	20.3	60.4	52.9	40.4
Cobalt	2	14	12	17	16	14	12.2	5.4	242	500	1550	469	574.4	584.6
Copper	5	50	54	72	45	42	45.2	22.1	2540	3100	3290	4240	2238	707.4
Lead	<5	19	39	21	20	15	15	9.3	1340	2870	398	719	1154.3	1097.5
Mercury	0.04	0.1	0.12	0.07	0.07	0.1	0.1	0.03	1.44	7.81	0.25	2.45	2.4	3.3
Molybdenum	<1	<1	<1	<1	<1	2	<1		27	7	74	10	36	30.9
Nickel	5	30	27	38	39	57	27.8	17.1	186	964	426	195	398.3	364.8
Silver	<1	<1	<1	5	1	<1	<1		42	136	8	41	62	55.1
Strontium	12	62	36	57	59	59	45.2	19.8	23	18	14	20	18.7	3.8
Thallium	<1	<1	<1	<1	<1	<1	<1		<1	<1	<1	<1	<1	
Tin	<5	<5	<5	<5	<5	<5	<5		<5	<5	<5	<5	<5	
Uranium	0.55	4.08	4.77	5.41	2.88	5.31	3.5	1.9	129	275	1670	216	519	734.1
Vanadium	11	49	31	60	58	41	41.8	18.5	170	161	369	279	179.6	98.7
Zinc	30	120	73.7	126	119	114	93.7	37.9	863	1030	187	306	529.5	412.7

Table 4.12. Mercury levels (µg/kg DW) in sediment samples from four lakes in the Johnny Hoe River basin (1992-1993; Stephens 1997).

Lake	n	Mean	Standard Deviation	Minimum	Median	Maximum
Lac Ste. Thérèse	43	30.4	21.1	2.0	31	64.0
Keller Lake	11	26.0	17.1	7.0	25	56.0
Tseepantee Lake	16	64.1	48.5	10.0	50.5	160
Lac Taché	14	29.1	18.4	1.0	26.5	54

DW = dry weight; n = number of samples.

Table 4.13. Summary of sediment quality data collected at selected lakes in the Great Bear watershed in 1993 and 1994 (Puznicki 1997).

SAMPLE_NUM	Arsenic (mg/kg DW)	Cadmium (mg/kg DW)	Chromium (mg/kg DW)	Copper (mg/kg DW)	Mercury (µg/kg DW)	Zinc (mg/kg DW)
CA85N14CS1	6.67	0.28	67.67	44.9	14	94.99
CA86C10DS1	8.2	0.36	46.81	31.27	56	104.71
CA86C11CS1	4.25	0.09	58.6	29.12	7	73.7
CA86C12AS1-1T	3.75	0	55.78	29.54	28	66.35
CA86C6BS1	6.91	0.09	69.05	44.24	24	87.19
CA86C6DS1	6.53	0.21	65.43	33.87	17	81
CA86C7AS1	5.05	0.04	70.42	36.11	14	92.08
CA86C7BS1-1T	5.03	0.22	66.9	45.08	13	98.67
CA86C9BS1	5.7	0.09	68.65	31.68	11	86.73
CA86E8AS1	4.8	0.13	58.49	36.22	255	93.8
CA86E8CS1	3.58	0.21	49.41	34.4	38	104.14
CA86E8DS1	3.74	0.14	51.85	34.93	305	89.69
CA86E9AS1	9.47	0.1	52.71	40.3	200	105.9
CA86E9AS2-1D	5.72	0.11	49.66	30.64	367	106.62
CA86F10CS1-1H	1.15	0.34	20.1	37.23	68	139.51
CA86F10CS1-2H	31.49	0.55	22.1	50.6	61	207.78
CA86F11BS1	4.49	0.12	30.77	62.85	1041	164.35
CA86F11DS1-3H	0.76	0.05	13.24	15.17		70.81
CA86F15CS1-1T	9.57	1.35	26.04	65.67	32	263.26
CA86F2CS1	3.63	0.48	25.33	50.62	28	123.87
CA86F5CS1-1H	3.65	0.19	37.32	27.81	4	65.69
CA86F5CS1-2H	7.83	0.45	38.1	29.64	7	63.43
CA86F5CS1-3H	6.46	0.11	59.2	32.78		88.3
CA86F6CS1	1.35	0.05	6.78	5.61		33.56
CA86F7BS1	3.67	0.86	26.48	69.09	62	166.05
CA86F8AS1	11.57	1.31	26.59	67.39	76	494.3
CA86F9BS1	2.46	0.43	23.86	45.3	85	128.09
CA86G14DS1	13.03	0.18	20.33	20.04	21	69.6
CA86G3AS1	1.38	0.1	25.05	32.83	52	67.06
CA86G4BS1	0.8	0.18	43.86	48.77	137	80.29
CA86G4BS2	4.69	0.47	30.22	47.89	13	76.18
CA86G6AS1	3.89	0	24.2	23.17	63	47.27
CA86J12AS1	8.2	0.43	14.79	73.71	109	98.4
CA86J4BS1-2H	13.77	0.99	36.86	101.52	113	317.63
CA86J4CS1-1H	8.84	0.66	34.47	90.16	134	304.12
CA86J4CS2-3H	2.67	0.16	28.54	48.09	46	121.13
CA86K11AS1	4.62	0.13	14.29	76.01	125	259.88
CA86K11CS1	2.28	0	27.22	49.73	127	135.17

Table 4.13. Summary of sediment quality data collected at selected lakes in the Great Bear watershed in 1993 and 1994 (Puznicki 1997).

SAMPLE_NUM	Arsenic (mg/kg DW)	Cadmium (mg/kg DW)	Chromium (mg/kg DW)	Copper (mg/kg DW)	Mercury (µg/kg DW)	Zinc (mg/kg DW)
CA86K15BS1	2.46	0.46	19.51	61.32	285	243.34
CA86K6BS1	5.57	0	40.42	41.78	76	125.2
CA86K8DS1	4.66	0.38	30.46	48.74	73	361.07
Number of samples	*41*	*41*	*41*	*41*	*38*	*41*
Mean	*5.96*	*0.305*	*38.5*	*44.5*	*110*	*137*
Median	*4.69*	*0.180*	*34.5*	*41.8*	*61.5*	*98.7*
Minimum	*0.760*	*0*	*6.78*	*5.61*	*4.00*	*33.6*
Maximum	*31.5*	*1.35*	*70.4*	*102*	*1041*	*494*
Standard deviation	*5.15*	*0.328*	*18.2*	*19.5*	*179*	*96.5*
Variance	*26.5*	*0.107*	*331*	*381*	*31999*	*9309*
10th percentile	*1.38*	*0.0400*	*19.5*	*27.8*	*12.4*	*66.4*
90th percentile	*9.57*	*0.660*	*66.9*	*69.1*	*264*	*263*

Table 4.14. Mean concentrations of metals in fish tissues collected from Great Bear Lake in the vicinity of Port Radium (Falk *et al.* 1973b).

Species	Tissue	Year	n	Metal Concentration (mg/kg)						
				Zinc	Copper	Lead	Cadmuim	Arsenic	Nickel	Selenium
Lake cisco	Muscle	1971	9	8.07	0.23	0.16	NR	NR	NR	NR
Lake cisco	Liver	1971	1	977	1.06	0.36	NR	NR	NR	NR
Lake cisco	Liver	1971	3	377	2.50	1.55	NR	NR	NR	NR
Lake trout	Muscle	1971	5	4.99	0.18	0.21	NR	NR	NR	NR
Lake trout	Liver	1971	3	37.2	1.76	0.24	NR	NR	NR	NR
Lake trout	Muscle	1972	15	15.7	0.59	0.31	0.05	ND	0.19	ND
Lake trout	Liver	1972	15	31.9	11.2	0.52	0.16	ND	0.21	ND
Lake cisco	Muscle	1972	18	8.20	0.38	0.18	0.05	ND	0.07	0.23
Lake cisco	Liver	1972	18	143.3	4.00	0.64	0.13	0.23	0.27	ND

NR = not reported; ND = not detected; n = number of samples.

Table 4.15. Biological characteristics and heavy metal concentrations in the muscle (m) and liver (l) of lake trout, lake whitefish, and arctic grayling from Port Radium and Deerpass Bay, 1993 (Lafontaine 1994).

Species	Metal Concentration (mg/kg wet weight) in muscle (m) and liver (l)											
	Cadmium (m)	Cadmium (l)	Copper (m)	Copper (l)	Zinc (m)	Zinc (l)	Lead (m)	Lead (l)	Silver (m)	Silver (l)	Arsenic (m)	Arsenic (l)
Port Radium												
Lake trout	0.0008	0.176	0.32	7.77	2.94	56.93	<0.03	<0.03	0.132	0.149	0.22	0.38
Lake trout	0.0003	0.218	0.33	23.61	2.81	46.25	<0.03	<0.03	0.134	0.157	0.14	0.37
Lake trout	0.0002	0.018	0.45	7.32	2.92	26.11	<0.03	<0.03	0.145	0.147	0.09	0.17
Lake trout	0.0004	0.290	0.23	9.26	3.69	34.72	<0.03	0.04	0.044	0.037	<0.05	0.11
Lake trout	0.0003	0.462	0.24	23.07	3.16	42.88	<0.03	<0.03	0.194	0.181	0.20	0.34
Lake trout	0.0007	0.738	0.29	38.28	2.88	51.88	<0.03	<0.03	0.080	0.083	0.20	0.37
Lake trout	0.0003	0.215	0.30	5.04	3.29	30.06	<0.03	<0.03	0.096	0.075	0.07	0.16
Lake trout	0.0003	0.209	0.30	14.78	4.33	34.04	<0.03	<0.03	0.114	0.062	0.05	0.13
Lake trout	0.0011	0.960	0.41	39.2	3.22	51.45	<0.03	<0.03	0.147	0.263	0.06	0.23
Lake trout	0.0008	0.387	0.28	71.93	3.15	128.39	<0.03	<0.03	0.197	0.193	0.07	0.23
Lake trout	0.0003	0.031	0.29	26.6	3.13	46.52	<0.03	0.09	0.147	0.168	0.13	0.24
Lake trout	0.0007	0.031	0.37	10.81	3.52	33.84	<0.03	0.03	0.051	0.072	0.07	0.38
Lake trout	0.0004	0.067	0.26	11.03	3.15	33.81	<0.03	<0.03	0.027	0.028	0.06	0.33
Lake trout	0.0004	0.200	0.25	23.6	3.79	34.84	<0.03	<0.03	0.094	0.077	0.07	0.20
Deerpass Bay												
Grayling	0.0004	0.073	0.37	2.28	4.09	24.98	<0.03	<0.03	0.100	0.119	<0.05	0.05
Lake whitefish	0.0009	0.073	0.27	19.24	3.06	28.41	<0.03	<0.03	0.112	0.341	0.39	0.14
Lake whitefish	0.0002	0.030	0.20	13.51	3.33	45.48	<0.03	<0.03	0.047	0.102	0.19	0.17
Lake whitefish	0.0002	0.047	0.24	6.17	3.78	30.05	<0.03	<0.03	0.009	0.070	0.12	0.19
Lake whitefish	0.0003	0.030	0.22	3.2	2.95	27.16	<0.03	<0.03	0.055	0.039	0.10	0.13
Lake trout	0.0003	0.033	0.24	9.94	2.73	26.81	<0.03	<0.03	0.178	0.146	0.05	0.06
Lake trout	0.0002	0.034	0.24	7.37	2.69	28.32	<0.03	<0.03	0.166	0.117	0.17	0.22
Lake trout	0.0002	0.038	0.28	6.69	2.68	23.98	<0.03	<0.03	0.147	0.159	0.21	0.20
Lake trout	0.0003	0.188	0.27	13.45	2.73	33.46	<0.03	<0.03	0.173	0.095	0.14	0.20
Lake trout	0.0001	0.060	0.24	6.97	2.72	29.01	<0.03	<0.03	0.188	0.158	0.26	0.19
Lake trout	0.0003	0.032	0.23	5.75	2.97	22.36	<0.03	<0.03	0.239	0.273	0.30	0.10

Table 4.15. Biological characteristics and heavy metal concentrations in the muscle (m) and liver (l) of lake trout, lake whitefish, and arctic grayling from Port Radium and Deerpass Bay, 1993 (Lafontaine 1994).

Species	Metal Concentration (mg/kg wet weight) in muscle (m) and liver (l)											
	Cadmium (m)	Cadmium (l)	Copper (m)	Copper (l)	Zinc (m)	Zinc (l)	Lead (m)	Lead (l)	Silver (m)	Silver (l)	Arsenic (m)	Arsenic (l)
Deerpass Bay (cont.)												
Lake trout	0.0002	0.043	0.26	12.63	2.89	42.34	<0.03	<0.03	0.130	0.183	0.12	0.18
Lake trout	<0.0001	0.047	0.28	9.13	2.90	27.52	<0.03	<0.03	0.235	0.309	0.18	0.14
Lake trout	0.0002	0.031	0.33	17.53	3.10	34.86	<0.03	<0.03	0.119	0.130	0.06	0.12
Lake trout	0.0002	0.052	0.24	8.47	2.95	28.41	<0.03	<0.03	0.228	0.151	0.12	0.12

Table 4.16. Levels of metals in muscle tissue of lake trout and northern pike from Great Bear Lake in 1978 (Wong 1985).

Fish Species	Parameters	n	Mean (mg/kg WW)	Minimum (mg/kg WW)	Maximum (mg/kg WW)
Lake trout	Cadmium	29	0.01	0.01	0.02
	Arsenic	30	0.14	0.03	1.1
	Lead	29	0.08	0.05	0.9
	Copper	29	0.3	0.16	0.44
Northern pike	Cadmium	25	0.01	0.01	0.01
	Arsenic	25	0.07	0.04	0.12
	Lead	25	0.5	0.05	2.6
	Copper	25	0.22	0.15	0.33

WW = wet weight.

Table 4.17. Total mercury concentrations in fish caught from lakes within the Johnny Hoe River basin (Stephens 1997).

Location	Species	Year	n	Muscle (mg/kg WW)		Liver (mg/kg WW)		Kidney (mg/kg WW)	
				Mean	Range	Mean	Range	Mean	Range
Lake Ste. Thérèse	Walleye	1975	8	1.00	0.59-1.43	-	-	-	-
Lake Ste. Thérèse	Walleye	1980	12	1.39	1.09-1.82	-	-	-	-
Lake Ste. Thérèse	Walleye	1992	30	1.338	0.706-2.313	1.242	0.393-2.535	0.545	0.124-1.705
Lake Ste. Thérèse	Walleye	1993	30	1.488	0.292-1.985	1.398	0.386-2.398	-	-
Lake Ste. Thérèse	Lake trout	1980	12	1.25	0.80-2.52	-	-	-	-
Lake Ste. Thérèse	Lake trout	1992	4	0.949	0.675-1.401	3.138	1.766-5.581	2.128	1.11-3.626
Lake Ste. Thérèse	Lake trout	1993	2	1.338	1.337-1.338	3.865	3.814-3.916	-	-
Lake Ste. Thérèse	Northern pike	1980	9	1.45	0.62-2.51	-	-	-	-
Lake Ste. Thérèse	Northern pike	1992	12	0.914	0.370-1.776	1.010	0.273-2.314	0.941	0.385-2.504
Lake Ste. Thérèse	Northern pike	1993	4	0.735	0.247-1.086	0.660	0.148-1.143	-	-
Lake Ste. Thérèse	Lake whitefish	1992	23	0.132	0.044-0.502	0.374	0.033-2.046	0.275	0.059-1.798
Lake Ste. Thérèse	Lake whitefish	1993	15	0.273	0.079-1.365	0.447	0.052-2.191	-	-
Lake Ste. Thérèse	Long nose sucker	1992	7	0.225	0.124-0.362	0.114	0.070-0.229	0.124	0.070-0.370
Lake Ste. Thérèse	Long nose sucker	1993	4	0.259	0.164-0.356	0.096	0.052-0.139	-	-
Keller Lake	Lake trout	1993	15	0.412	0.222-1.051	0.492	0.158-1.987	-	-
Keller Lake	Northern pike	1993	1	0.445	0.445	0.189	0.189	-	-
Keller Lake	Lake whitefish	1993	15	0.064	0.036-0.123	0.114	0.050-0.267	-	-
Keller Lake	Burbot	1993	1	0.133	0.133	0.031	0.031	-	-
Tseepantsee Lake	Walleye	1993	15	0.926	0.247-1.422	0.560	0.095-1.132	-	-
Tseepantsee Lake	Northern pike	1993	6	0.475	0.392-0.711	0.0227	0.129-0.433	-	-
Tseepantsee Lake	Lake whitefish	1993	15	0.102	0.037-0.160	0.212	0.075-0.368	-	-
Tseepantsee Lake	Long nose sucker	1993	1	0.284	0.284	0.173	0.173	-	-
Lac Taché	Lake trout	1993	5	0.345	0.134-0.586	0.746	0.271-1.306	-	-
Lac Taché	Northern pike	1993	10	0.347	0.129-0.696	0.155	0.058-0.351	-	-
Lac Taché	Lake whitefish	1993	15	0.068	0.025-0.139	0.118	0.041-0.238	-	-

n = number of samples; WW = wet weight.

Table 5.1. List of phytoplankton collected from three different areas of Great Bear Lake (from Moore 1980).

Species	Echo Bay	Conjuror Bay	Fort Franklin
Division, Bacillariophyta			
Asterionella formosa Hass.	+	+	+
Cyclotella glomerata Bach.	+	+	+
Cyclotella ocellata Pant.	+ +	+ +	+ +
Diatoma tenue Ag.	+	+	+
Diatoma tenue var. *subsalsum* A. Cl.	+		
Rhizosolenia eriensis H. L. Smith	+	+	+
Stephanodiscus astraea (Ehr.) Grun.	+	+	+
Stephanodiscus astraea var. *minutula* (Kütz.) Grun.	+	+	+
Synedra acus var. *angustissima* (Grun.) V.H.	+		+
Synedra acus var. *radians* (Kütz.) Hust.	+ +	+	+ +
Synedra tenera W. Sm.	+		
Tabellaria fenestrata (Lyngb.) Kütz.	+	+	+
Tabellaria flocculosa (Roth) Kütz.	+ +	+	+
Division, Chlorophyta			
Ankistrodesmus convolutus Corda	+	+	+
Ankistrodesmus falcatus (Corda) Ralfs	+ +	+	+ +
Chlamydomonas species (unidentified)	+	+	+
Chlorella vulgaris Beyer.	+	+	+
Oocystis solitaria Wittrock	+	+	
Pediastrum boryanum (Turp.) Meneg.	+		
Division, Chrysophyta			
Bicoeca exillis Penard		+	
Bicoeca lacustris Clarke		+	
Bicoeca multiannulata Skuja		+	
Chromulina glacialis Lund	+		
Chrysochromulina parva Lackey	+	+	+
Chrysococcus rufescens Klebs	+	+	+
Chrysolykos gracilis Skuja	+	+	+
Chrysolykos planktonicus Mack	+	+	+
Dinobryon bavaricum Imhof	+ +	+ +	+ +
Dinobryon borgei Lemm.	+	+	+
Dinobryon cylindricum Imhof	+ +	+	+
Dinobryon divergens Imhof	+	+	+
Dinobryon elegantissimum Bour.	+	+	+
Dinobryon sociale Ehr.	+ +	+ +	+ +
Kephyrion boreale Skuja	+ +	+	+ +
Kephyriopsis entzii Skuja	+		
Ochromonas species (unidentified)	+	+	+
Ochromonas aspera Playfair	+		
Ochromonas nana Dolf.	+	+	
Ochromonas sphaerella Skuja	+	+	+

Table 5.1. List of phytoplankton collected from three different areas of Great Bear Lake (from Moore 1980).

Species	Echo Bay	Conjuror Bay	Fort Franklin
Division, Chrysophyta (cont.)			
Pseudokephyrion attenuatum Hilliard	+	+	+ +
Pseudokephyrion undulatissimum Scherf.	+	+	+
Division, Cryptophyta			
Cryptomonas erosa Ehr.	+	+	+
Cryptomonas ovata Ehr.	+	+	+
Rhodomonas minuta Skuja	+	+	+
Rhodomonas minuta var. *nannoplanktonica* Skuja	+	+ +	+
Division, Cyanophyta			
Oscillartoria limnetica Lemm.	+	+	+ +
Division, Pyrrophyta			
Ceratium hirundinella (O. F. Müll.) Duj.	+	+	+
Peridinium aciculiferum Lemm.	+	+	+

+ + indicates that the species represented >10% by weight of the assemblage in at least one collection.
+ indicates that it represented <10% in all collections.

Table 5.2. List of periphytic algae collected from different areas of Great Bear Lake (from Moore 1980).

Species	Epilithon Echo Bay	Epilithon Conjuror Bay	Epipelon Echo Bay	Epipelon Fort Franklin
Division, Bacillariophyta				
Achnanthes flexella (Kütz.) Brun.			+	
Achnanthes hauckiana Grun.	+	+	+	+
Achnanthes hauckiana var. *rostrata* Schulz		+	+	
Achnanthes lanceolata (Bréb.) Grun.	++	++	+	++
Achnanthes lanceolata var. *elliptica* Cl.	+		+	+
Achnanthes linearis (W. Sm.) Grun	++	++	+	+
Achnanthes minutissima Kütz.	++	++	+	++
Amphora species (unidentified)			+	
Amphora ovalis (Kütz.) Kütz.	+	++	++	++
Amphora ovalis var. *libyca* (Ehr.) Cl.	+	+		+
Amphora ovalis var. *pediculus* (Kütz.) V.H.	++	+	++	++
Anomoeoneis vitrea (Grun.) Ross			++	+
Cocconeis placentula Ehr.	++	+	++	++
Cocconeis placentula var. *euglypta* (Ehr.) Cl.	+		+	+
Cymatopleura solea (Bréb.) W. Sm.			++	+
Cymbella affinis Kütz.	+		+	+
Cymbella angustata (W. Sm.) Cl.		+		
Cymbella cesatii (Rabh.) Grun.	+		+	+
Cymbella microcephala Grun.		+		
Cymbella turgida (Greg.) Cl.			+	++
Cymbella ventricosa Kütz.	+	+	+	+
Denticula tenuis Kütz.		+		
Diatoma tenue Ag.	+	+	+	+
Diploneis puella (Schum.) Cl.			++	+
Diploneis oblongella (Naeg. ex Kütz.) Ross				+
Eunotia curvata (Kütz.) Lagerst.		+		
Fragilaria construens (Ehr.) Grun.	++	+		+
Fragilaria leptostauron (Ehr.) Hust.	+	+	+	+
Fragilaria pinnata Ehr.	++	+	+	+
Fragilaria pinnata var. *lancettula* (Schum.) Hust.	+		+	++
Fragilaria vaucheriae (Kütz.) Peters	++	+	+	++
Frustulia rhomboides (Ehr.) DeT.		+		
Gomphonema angustatum (Kütz.) Rabh.	+			+
Gomphonema intricatum Kütz.	+	++	++	+
Gomphonema intricatum var. *pumilum* Grun.	+	++	++	
Gomphonema parvulum May	+	+		+
Gyrosigma acuminatum (Kütz.) Rabh.			+	+
Gyrosigma attenuatum (Kütz.) Rabh.				+
Gyrosigma spenceri (Quek.) Griff. & Henfr.	+		++	+
Melosira distans (Ehr.) Kütz.			+	+
Navicula bacillum Ehr.			+	+

Table 5.2. List of periphytic algae collected from different areas of Great Bear Lake (from Moore 1980).

Species	Epilithon		Epipelon	
	Echo Bay	Conjuror Bay	Echo Bay	Fort Franklin
Division, Bacillariophyta (cont.)				
Navicula elginersis (Greg.) Ralfs	+	+	++	+
Navicula exigua Greg. ex Grun.			+	+
Navicula gastrum (Ehr.) Kütz.			+	
Navicula lanceolata (Ag.) Kütz.		+	+	+
Navicula cf. *minuscula* Grun.			+	
Navicula mutica Kütz.				+
Navicula pseudoscutiformis Hust.			++	
Navicula pupula Hust.	+	+	+	+
Navicula radiosa Kütz.			+	
Navicula radiosa var. *tenella (* Bréb. ex Kütz.) Grun.		+		+
Navicula viridula (Kütz.) Kütz.			++	+
Neidum affine (Ehr.) Pfitz.			+	+
Neidum productum (W. Sm.) Cl.			++	
Nitzschia acicularis W. Sm.			++	+
Nitzschia amphibia Grun.		+	+	+
Nitzschia angustata var. *acuta* Grun.	+	+	++	
Nitzschia dissipata (Kütz.) Grun.	+		++	+
Nitzschia frustulum (Kütz.) W. Sm.			+	+
Nitzschia linearis W. Sm.			+	+
Nitzschia obtusa W. Sm.			++	+
Nitzschia palea (Kütz.) W. Sm.	+	+	++	++
Nitzschia paleacea Grun.			++	+
Pinnularia biceps Greg.			+	+
Pinnularia borealis Ehr.			+	
Pinnularia microstauron (Ehr.) Cl.				+
Pinnularia nodosa (Ehr.) W. Sm.	+	+	++	+
Rhopalodia gibba (Ehr.) O.F. Mull.		+		
Stauroneis anceps Ehr.		+	++	+
Stauroneis phoenicenteron (Nitz.) Ehr.				+
Surirella angustata Kütz.			++	+
Surirella ovalis Bréb.			+	
Tabellaria fenestrata (Lyngb.) Kütz.	+	+	+	+
Tabellaria flocculosa (Roth) Kütz.	++	++	+	+
Division, Chlorophyta				
Ankistrodesmus falcatus (Corda) Ralfs			+	+
Bulbochaete species (unidentified)	++	+		
Cosmarium species (unidentified)	+		+	+
Mougeotia species (unidentified)	++	++	+	++
Spirogyra species (unidentified)	++	++	+	
Scenedesmus bijuga (Turp.) Lag.			+	

Table 5.2. List of periphytic algae collected from different areas of Great Bear Lake (from Moore 1980).

Species	Epilithon		Epipelon	
	Echo Bay	Conjuror Bay	Echo Bay	Fort Franklin
Division, Cyanophyta (cont.)				
Scenedesmus quadricauda (Turp.) Bréb.			+	+
Ulothrix zonata (Weber & Mohr) Kütz.	++	+	+	+
Zygnema species (unidentified)	+	+	+	+
Chroococcus dispersus var. *minor* G. M. Smith			+	
Lyngbya species (unidentified)	++	++	+	+
Merismopedia glauca (Ehr.) Kütz.	+		+	+
Merismopedia punctata Meyen	++		+	+
Oscillatoria species (unidentified)		+	+	
Oscillatoria limosa (Roth) Ag.		+	+	
Oscillatoria tenuis Ag.			+	

+ + indicates that the species represented >10% by weight of the assemblage in at least one collection.
+ indicates that it represented <10% in all collections.

Table 5.3. Percentage occurrence of zooplankton in offshore waters of Great Bear Lake (from Johnson 1975b).

Species	McTavish Arm August 2, 1965 0 - 350 m (%)	Smith Arm August 28, 1965 0 - 40 m (%)	McVicar Arm August 26, 1965 0 - 97 m (%)	Dease Arm July 30, 1964 0 - 50 m (%)
Limnocalanus macrurus				
Adults	0.5	4.5	9.3	5.7
Copepods	6.3			
Nauplii	2.1			
Senecella calanoides	2.0	0.03	1.1	0.4
Diaptomus sicilis				
Adults and copepodids	84.3	95.0	85.8	90.5
Nauplii	2.5	0.4		
Cyclops scutifer				
Adults and copepodids	1.9		4.6	3.4
Nauplii	0.04			
Daphnia middendorfiana		0.07		
Total no. individuals/m^2 (x 10^3)	40	142	43	38

Table 5.4. Percentage occurrence of zooplankton in inshore waters of Great Bear Lake (from Johnson 1975b).

Species	Northeast Dease August 4, 1964 (%)	South Keith August 15, 1964 (%)	Good Hope Bay September 1, 1964 (%)	South McVicar August 24, 1964 (%)
Limnocalanus macrurus	6.5	3.2	0.3	0.4
Senecella calanoides		0.1		
Epischura nevadensis		0.6		
Diaptomus sicilis	68.1	93.6	97.4	51.0
Cyclops scutifer	3.6	2.5		
Cyclops vernalis	21.8			3.1
Cyclops sp. (copepodids)			2.3	16.6
Daphnia longispina hyalina var. *microcephala*				0.1
Bosmia longirostris			0	21.5
Daphnia sp. *(?middendorffiana)*			0.03	1.9
Total no. individuals/m^2 (x 10^3)		268	471	

Table 5.5. List of zooplankton species collected from two different areas of Great Bear Lake (from Moore 1981).

Species	Echo Bay	Conjuror Bay
Division, Copepoda		
Cyclops scutifer Sars	X	X
Diaptomus ashlandi Marsh	X	X
Diaptomus pribilofensis Juday and Mutt.	X	X
Diaptomus sicilis Forbes	X	X
Heterocope septentrionalis Juday and Mutt.	X	
Limnocalanus macrurus Sars	X	X
Senecella calanoides Juday	X	X
Division, Cladocera		
Bosmina coregoni (Baird)	X	X
Daphnia middendorfiana Fischer	X	X
Holopedium gibberum Zaddach	X	X
Division, Rotifers		
Asplanchna priodonta Gosse	X	X
Brachionus calyciforus Rhrb.	X	
Conochilus unicornis (Rousselet)		X
Kellicottia longispina (Kellicott)	X	X
Keratella cochlearis (Gosse)	X	X
Keratella quadrata (O.F. Müller)	X	X
Trichocera cylindrica (Imhof)		X
Division, Protozoa		
Ceratium hirundinella O.F. Müller	X	X
Codonella cratera (Leidy)	X	X
Unidentified ciliates	X	X

Table 6.1. Projected water consumptions for Déline (2000-2020; NWT Bureau of Statistics 1999).

Year	Population	Projected/Capita Consumption (105Led)	Total Projected Consumption (m^3/yr)
1999	600		
2000	605	105	23,187
2001	612	105	23,455
2002	620	105	23,762
2003	626	105	23,991
2004	632	105	24,221
2005	641	105	24,566
2006	646	105	24,758
2007	652	105	24,988
2008	659	105	25,256
2009	666	105	25,524
2010	673	105	25,793
2011	679	105	26,023
2012	687	105	26,329
2013	695	105	26,636
2014	703	105	26,942
2015	710	105	27,211
2016	718	105	27,517
2017	724	105	27,747
2018	730	105	27,977
2019	735	105	28,169
2020	743	105	28,475

Figures

Appendices

Appendix 1. Bibliography of Information on the Aquatic Resources of the Great Bear Watershed

Subject Listing Includes:

History, Ethnography, Earth Sciences, Limnology, Water Quality, Plants, Invertebrates, Fish, Large Mammals, Birds, and Management and Research

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Appendix 2. Environmental Assessment and Remediation of Abandoned Mine Sites in the Camsell River Basin

A2.0 Introduction

The Camsell River is a major tributary to Great Bear Lake. The river originates in the north central portion of the Northwest Territories at Faber Lake and drains an area of approximately 31,000 km^2. Mining activities were initiated at five locations in the basin between 1930 and 1970, primarily targeting ores rich in silver. While mining activities have ceased at all of these sites, the mines were never decommissioned. As such, these mine pose potential risks to human health and ecological receptors. To address concerns relative to human health and the environment, the Canadian Government commissioned a series of investigations at the abandoned mine sites. Due to the importance of these studies for developing future reclamation plans, the key results are briefly summarized in this Appendix.

A2.1 Site Characterization and Environmental Assessment of Abandoned Mine Sites in the Northwest Territories

As part of the Arctic Environmental Strategy – Action on Waste, EBA Engineering Consultants Ltd. (EBA) was retained by Public Works Canada in 1992 to conduct site characterizations and environmental assessments at seven mine sites, of which six are in the Camsell River Basin. These mines included Contact Lake, Northrim, Smallwood Lake, Norex, Terra, and Indore Gold. The scope of work for these investigations included:

- Site reconnaissance to identify the general layout and apparent health or safety hazards;
- Radioactivity survey;
- Survey of mine/mill waste deposits;

- Sampling of waste rock;
- Sampling of tailings (land-based and/or submerged), where applicable;
- Sampling of other soils and sediments;
- Sampling of surface water (streams, ponds, lakes);
- Sampling of stream bed sediments, where applicable;
- Conducting environmental site audits;
- Sampling tailings pond sediments;
- Collecting lake bottom sediments, if possible; and,
- Inventory of industrial buildings, equipment, chemicals and materials.

The results of these investigations indicated each of the abandoned mine sites presented specific environmental issues and concerns that require individual responses. Importantly, significant quantities of uranium-enriched process residue were identified at the Contact Lake mine site. Uranium is present in waste rock as localized hot spots and is uniformly enriched in a land-based tailings deposit. The other sites did not respond to radiation monitoring surveys (EBA 1993).

Acid rock drainage (ARD) was identified as a potential environmental concern at a number of the mine sites. At the Smallwood Lake, Northrim and Terra mine sites, high excess acidity potential was identified. Excess acidity potential was classified as moderate at the Norex mine site, however. EBA (1993)concluded that any ARD that developed would be generated slowly due to the cold climate and the low precipitation. In addition, any acid produced would be naturally buffered by the waste materials and by surface waters. EBA (1993) stated that it is unlikely that ARD would significantly impact surface waters at the mine sites.

Heavy metal contamination has been identified in the waste rock and tailings at all mine sites. Laboratory simulated leachate analyses inferred that arsenic is the prime element of environmental concern. Arsenic is documented as both a hazardous and toxic element. Other heavy metals that responded to laboratory acid leachate analysis include zinc and copper, and occasionally lead. The analyses inferred that the mobility of other metals from waste materials is low or absent.

There are numerous physical and structural safety concerns at each mine site including unrestricted mine entrances, mine buildings in various stage of deterioration and open or partially open mine ventilation shafts. Hazardous or toxic materials have been tentatively identified at Northrim and Terra.

At the time of the study, the NWT Water Board classification for abandoned mine sites ranked Terra, Contact Lake, Northrim and Smallwood Lake as high impact sites, based on the relative potentials for contamination, acid generation, hazardous or toxic leachates and combinations thereof. Norex mine site was classified as a medium impact site.

A2.2 Northrim, Norex, Smallwood Lake and Terra Mine Sites, Abandonment and Restoration Plan

In 1999, Dillon Consulting Ltd. and EBA Engineering Consultants Ltd. were retained by Public Works and Government Services Canada on behalf of the Department of Indian Affairs and Northern Development to produce:

- Mine site reclamation options for the physical and environmental hazards;
- A determination of assets; and,
- Specifications for the removal of hazardous materials from the Northrim, Norex, Smallwood Lake and Terra mine sites (Dillon and EBA 1999).

The remediation plans provide a series of possible reclamation options ranging from the bare minimum (addresses physical hazards only) to a complete site restoration program which addresses the physical and environmental hazards, as well as site aesthetics, and public perception. The "DO NOTHING" approach was not considered as a reclamation option for any of the sites because the physical hazards on site (blast holes, ventilation shafts, and abandoned buildings) would remain as potential threats to public health and safety. The maximum reclamation option would involve calculating the cost for the "ultimate" site cleanup. This would involve shipping everything out of the area to appropriate landfill sites and capping mine openings with engineered cement barriers.

Reclamation options proposed by Dillon and EBA Consultants for individual mine sites were developed based on review of various reports including:

- EBA (1993). Site Characterization and Environmental Assessment of Seven Abandoned Mine Sites in the Northwest Territories;
- Thurber Environmental (1993). Review and Summary of Assessment and Remediation Options for 18 Mine sites, Northwest Territories, Volume 1; and,
- Vista Engineering and Deton'Cho (1996). AES Abandoned Mine Assessments. Final Report, Volume II.

A2.3 Water Quality Assessment at Five Abandoned Mine Sites in the Great Bear Watershed, NWT

Recently, the Department of Indian and Northern Affairs made site visits to Terra, Northrim, Norex, Smallwood Lake and Contact Lake mines (INAC 2003). The main objectives of the September, 2002 water quality sampling program were to collect water samples at each mine site to determine potential impacts from these abandoned mines to the aquatic environment. The main focus was to determine metal concentrations at various locations at each mine site including:

- Tailings containment areas/ponds;
- Seepage from waste rock piles;
- Drainage from mine adits and portals;
- Surface runoff and streams; and,
- Nearby downstream bodies of water where contamination might be occurring.

The sampling program was designed to build upon monitoring completed during previous site assessments. The sampling results will contribute to the abandonment and restoration plans at each mine site and help identify reclamation priorities.

Generally, it was determined that Camsell River water quality is good. Levels of metals in the Camsell River mainstem, Contact Lake, and Smallwood Lake are low. However, there is localized contamination at each mine site. The concentrations of various metals in samples collected from tailings ponds, mine adit drainages, seeps from waste rock piles, and runoff streams exceed certain drinking water guidelines, as well as certain water quality guidelines for the Protection of Aquatic Life (CCME 1999).

The potential for contamination at Contact Lake exists as a result of the 3,000 tonnes of uncontained tailings, as well as the 50,000 tonnes of coarse tailings on site. The data show high levels of arsenic, copper, uranium, and zinc. The levels of radionuclides are also high in the tailings sample. Radium-226 and uranium-235 levels at Contact Lake are similar to those at Port Radium. All radionuclides measured in water at Contact Lake were undetectable.

INAC staff, with assistance from Déline community members, conducted another round of water quality sampling in June 2003. Additional tailing soil samples were also collected at Terra, Northrim and Contact Lake. Results have not yet been received or reviewed.

It was recommended that an INAC geologist or an experienced mine site environmental engineer familiar with northern ARD issues visually assess the waste rock piles according to their acid rock drainage potential and collect samples for further investigation. INAC has recommended continued monitoring and has applied for 5 years of funding for remediation work at all 5 mine sites.