CUMBERLAND
RESOURCES LTD.

MEADOWBANK GOLD PROJECT

BASELINE AQUATIC ECOSYSTEM REPORT

OCTOBER 2005

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DESCRIPTION OF SUPPORTING DOCUMENTATION

Cumberland Resources Ltd. (Cumberland) is proposing to develop a mine on the Meadowbank property. The property is located in the Kivalliq region approximately 70 km north of the Hamlet of Baker Lake on Inuit-owned surface lands. Cumberland has been actively exploring the Meadowbank area since 1995. Engineering, environmental baseline studies, and community consultations have paralleled these exploration programs and have been integrated to form the basis of current project design.

The Meadowbank project is subject to the environmental review and related licensing and permitting processes established by Part 5 of the Nunavut Land Claims Agreement. To complete an environmental impact assessment (EIA) for the Meadowbank Gold project, Cumberland followed the steps listed below:

1. Determined the VECs (air quality, noise, water quality, surface water quantity and distribution, permafrost, fish populations, fish habitat, ungulates, predatory mammals, small mammals, raptors, waterbirds, and other breeding birds) and VSECs (employment, training and business opportunities; traditional ways of life; individual and community wellness; infrastructure and social services; and sites of heritage significance) based on discussions with stakeholders, public meetings, traditional knowledge, and the experience of other mines in the north.

2. Conducted baseline studies for each VEC and compared / contrasted the results with the information gained through traditional knowledge studies (see Columns 1 and 2 on the following page for a list of baseline reports).

3. Used the baseline and traditional knowledge studies to determine the key potential project interactions and impacts for each VEC (see Column 3 for a list of EIA reports).

4. Developed preliminary mitigation strategies for key potential interactions and proposed contingency plans to mitigate unforeseen impacts by applying the precautionary principle (see Columns 4 and 5 for a list of management plans).

5. Developed long-term monitoring programs to identify residual effects and areas in which mitigation measures are non-compliant and require further refinement. These mitigation and monitoring procedures will be integrated into all stages of project development and will assist in identifying how natural changes in the environment can be distinguished from project-related impacts (monitoring plans are also included in Columns 4 and 5).

6. Produced and submitted an EIS report to NIRB.

As shown on the following page, this report is part of the documentation series that has been produced during this six-stage EIA process.

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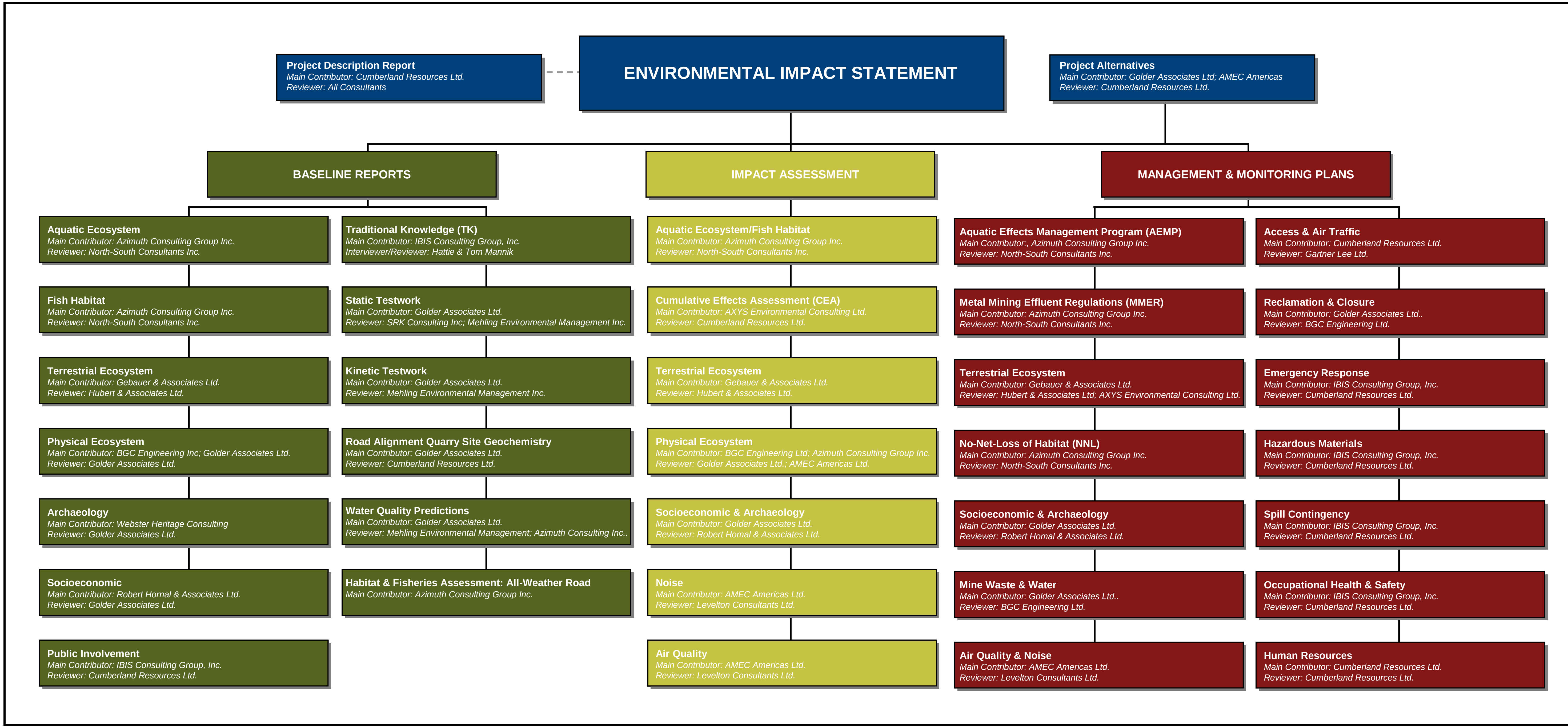
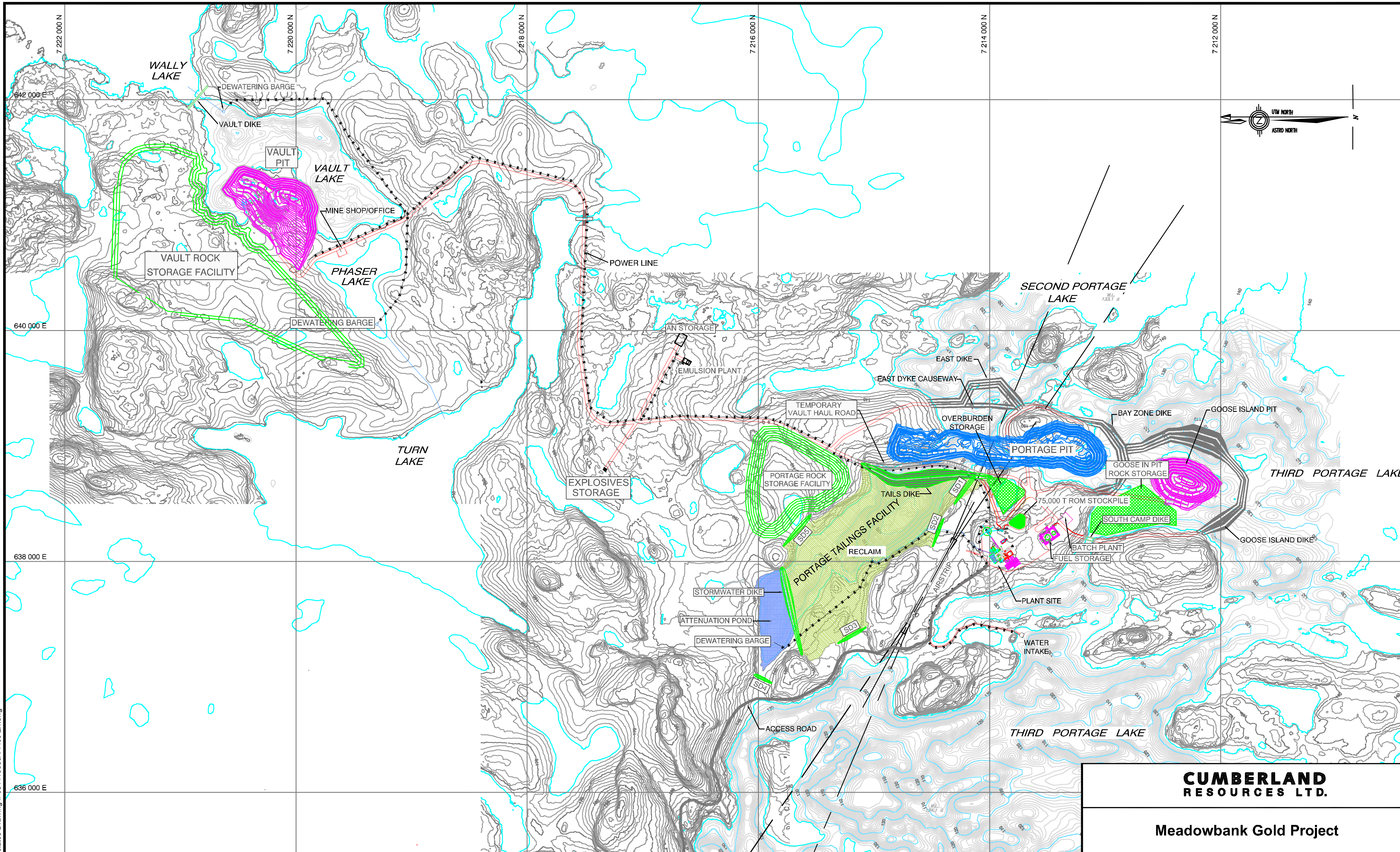
EIA DOCUMENTATION ORGANIZATION CHART



Date: October 2005

PROJECT LOCATION MAP



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Meadowbank Gold Project

General Site Plan

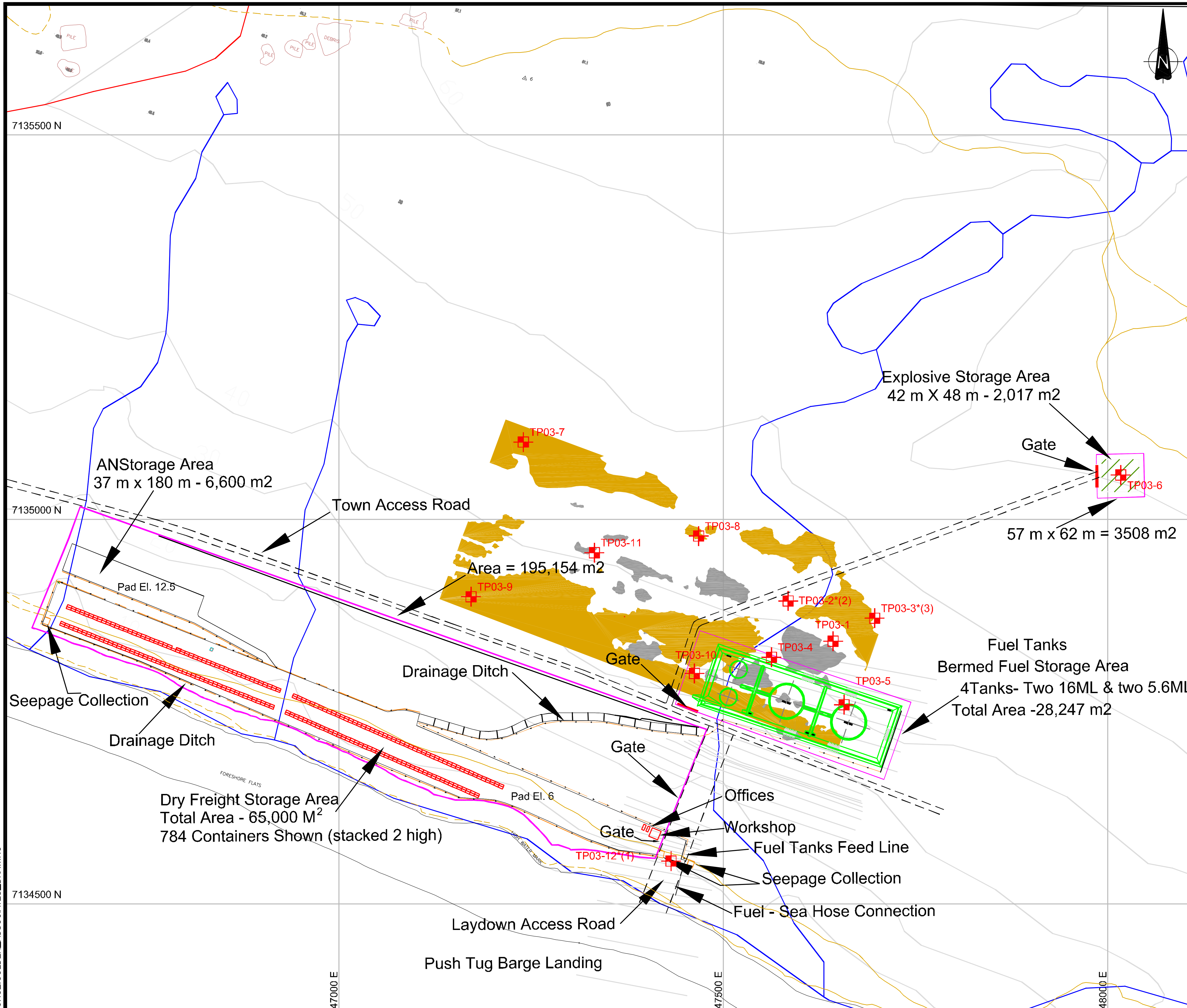
NOTES

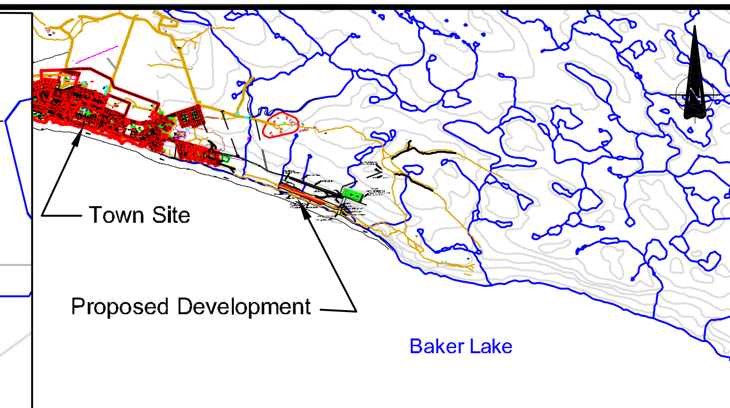
1) Topographic contour interval 2m.
2) Bathymetric contour interval 1m.
3) Scale As shown.

LEGEND

SD: SADDLE DAM

Source:Golder Associates Drawing # 051413036A-1400-2.1.dwg





LOCATION MAP

LEGEND

- Test Pit Location (Approximate)
- Property Limit
- Contour Interval
- Bedrock Outcrop (Approximate)
- Interpreted Frost-susceptible Ground

NOTES

1) Northing and eastings are in metres referenced to UTM Zone 14, NAD83.

2) Elevations are in metres referenced to geodetic datum.

3) Testpit, bedrock outcrop, seismic line and EM31 survey boundary locations were determined using GPS equipment and are considered approximate.

0 50 100 150 200 250
Scale in Meters

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Meadowbank Gold Project

Baker Lake Storage & Marshalling Area

SECTION 1 • EXECUTIVE SUMMARY

Cumberland commissioned Azimuth Consulting Group Inc. of Vancouver (Azimuth) to prepare this "Baseline Aquatic Environment Assessment Report" (BAEAR) as part of the environmental assessment component of the Meadowbank project. The BAEAR serves to document the physical, chemical, and ecological features of the aquatic environment in the vicinity of the project prior to mine development and place it into local and regional context.

This BAEAR summarizes aquatic baseline studies conducted from 1996 to 1999 and from 2002 through 2005. Key aquatic features of the study area and reference lakes are examined, including limnology, water and sediment chemistry, and all levels of the aquatic food web, including phytoplankton, zooplankton, benthic invertebrates, and fish. In addition, this report describes habitat and migratory fish populations within all streams crossed by the proposed all-weather road between Baker Lake and the mine site, a distance of 102 km.

The overall goal of the BAEAR is to assemble and interpret existing information on the aquatic environment of Meadowbank project area lakes and streams crossed by the proposed all-weather road. The information used to generate this document serves as the foundation for a quantitative assessment of impacts of mine development and operational activities on the aquatic environment as part of the Environmental Impact Assessment (EIA). Predicting potential impacts of mine development on aquatic life and developing appropriate mitigation strategies can only be accomplished if there is a good understanding of the physical, chemical, and biological features of the local and regional aquatic environment. Central to this understanding is a thorough characterization of spatial, seasonal, and inter-annual variability in key aquatic features. Specifically, the objectives of the BAEAR report are to:

- document seasonal and inter-annual physical, chemical, and ecological features of Meadowbank project area lakes prior to mine development
- document spatial, seasonal, and inter-annual physical, chemical, and ecological features of the reference lakes (Third Portage South Basin, Inuggugayualik Lake)
- describe habitat and determine fish movements within streams crossed by the proposed all-weather road between the Meadowbank project area and Baker Lake
- compare and contrast key features of project and reference lakes to provide a baseline context against which future data can be compared
- compare and contrast key features of Meadowbank project area lakes with published data from regional lakes in Nunavut and the Northwest Territories to place the Meadowbank data into a broad, regional context.

The Meadowbank project area lakes share similar physical, limnological, and chemical features that are consistent with soft-water, ultra-oligotrophic lakes found elsewhere in Nunavut and the Northwest Territories.

The primary and secondary productivity of the project and reference lakes was similar among years. In general, biomass and/or density of lower trophic level groups (e.g., benthos, zooplankton) were similar to values from regional Arctic lakes. Differences in key features among lakes or years can be partly explained by differences in sampling methods, seasonal effects, and the heterogeneity of natural populations that overwhelm subtle trends or differences that might be evident among project area lakes. In general, abundance and biomass of lower trophic level biota appeared to be similar among lakes, or slightly lower in Third Portage Lake than in other lakes.

Fish species composition, mean size, and condition factor were similar for most lakes. Lake trout (*Salvelinus namaycush*) dominated all project, reference, and regional lakes and were characterized as being large, old, climax community populations, typical of oligotrophic, Arctic lakes. Round whitefish (*Prosopium cylindraceum*) and Arctic char (*S. alpinus*) were the next most abundant species in all lakes, with very small numbers of burbot (*Lota lota*), ninespine stickleback (*Pungitius pungitius*), and sculpins (*Cottus* sp.). There are no spring spawning species such as suckers (*Catostomus* sp.) or Arctic grayling (*Thymallus arcticus*) within the regional study area. Metals concentrations of lake trout, round whitefish, and Arctic char were very low and similar among species in all lakes. Mercury concentration in tissue of lake trout and round whitefish was relatively low and typical of concentrations of fish from pristine lakes.

The magnitude of fish movement among project lakes is very small and opportunistic. Movement between lakes is constrained by the small, ephemeral channels that connect these headwater lakes that have relatively low discharge for their size. Fish movement between Third Portage and Second Portage lakes is especially difficult and is only possible during a short duration during spring freshet. Fish movement between Tehek Lake and Second Portage Lake is also very low, despite the excellent hydraulic connection between these lakes throughout the open water season. The absence of fish movement between lakes, despite suitable conditions demonstrates that there are no defined migrations by fish between lakes, due to the absence of anadromous fish (e.g., Arctic char, lake cisco) and spring spawning species such as Arctic grayling.

Arctic char are present in all the study lakes. Based on hydrological information, life history characteristics, and strontium concentrations in body hard parts (fins and otoliths), local populations are landlocked. There is an impassable falls on the lower reaches of the Quoich River (St. Clair Falls) that prevents anadromous char from accessing this system.

Habitat features associated with greater productivity are more abundant in Second Portage Lake than Third Portage Lake. Much of Third Portage consists of large, deep, cold basins with a lower abundance of shallow, littoral habitat. Second Portage Lake has a higher relative proportion of boulder/cobble shoal and platform habitat and a greater proportion of high value habitat (27%) than Third Portage Lake (12%).

Based on catch-per-unit-effort statistics, Second Portage Lake appeared to contain a higher density of fish than the other lakes, and especially more than Third Portage Lake. Third Portage Lake also contained fewer Arctic char than the other project lakes. These data suggest that Third Portage Lake might be less productive per unit area than the other lakes, because of its large, cold basins and ultimately has fewer nutrients or productivity to support the same density of fish as the other project lakes. Overall, the Meadowbank project area lakes support healthy communities of plankton, benthos, and fish that are characteristic of oligotrophic Arctic lakes.

SECTION 2 • INTRODUCTION

2.1 BACKGROUND

The Meadowbank project area is located approximately 75 km north of the hamlet of Baker Lake, Nunavut. A group of lakes, hereafter referred to as "project lakes," are located directly within the boundaries of the mineral zones being explored on the Meadowbank property (65° N, 96° W) and may be subject to direct or indirect environmental impacts related to mine development (see Figure 2.1). These lakes include Second Portage and Third Portage lakes, the Vault Lake, Wally Lake, Drilltrail Lake, and Turn Lake. These headwater lakes of the Quoich River system drain into Tehek Lake and eventually flow into the western end of Chesterfield Inlet downstream of Baker Lake, before entering Hudson Bay. To the north, the project lakes lie immediately south of the Meadowbank River, which is part of the Back River system that drains to the Arctic Ocean. The surrounding terrain is typically barren-ground subarctic with little relief, and is dominated by many small lakes with indistinct and complex drainage patterns. These headwater lakes have no large streams associated with them, so there is a paucity of stream habitat in the area as well as organisms that typically inhabit streams.

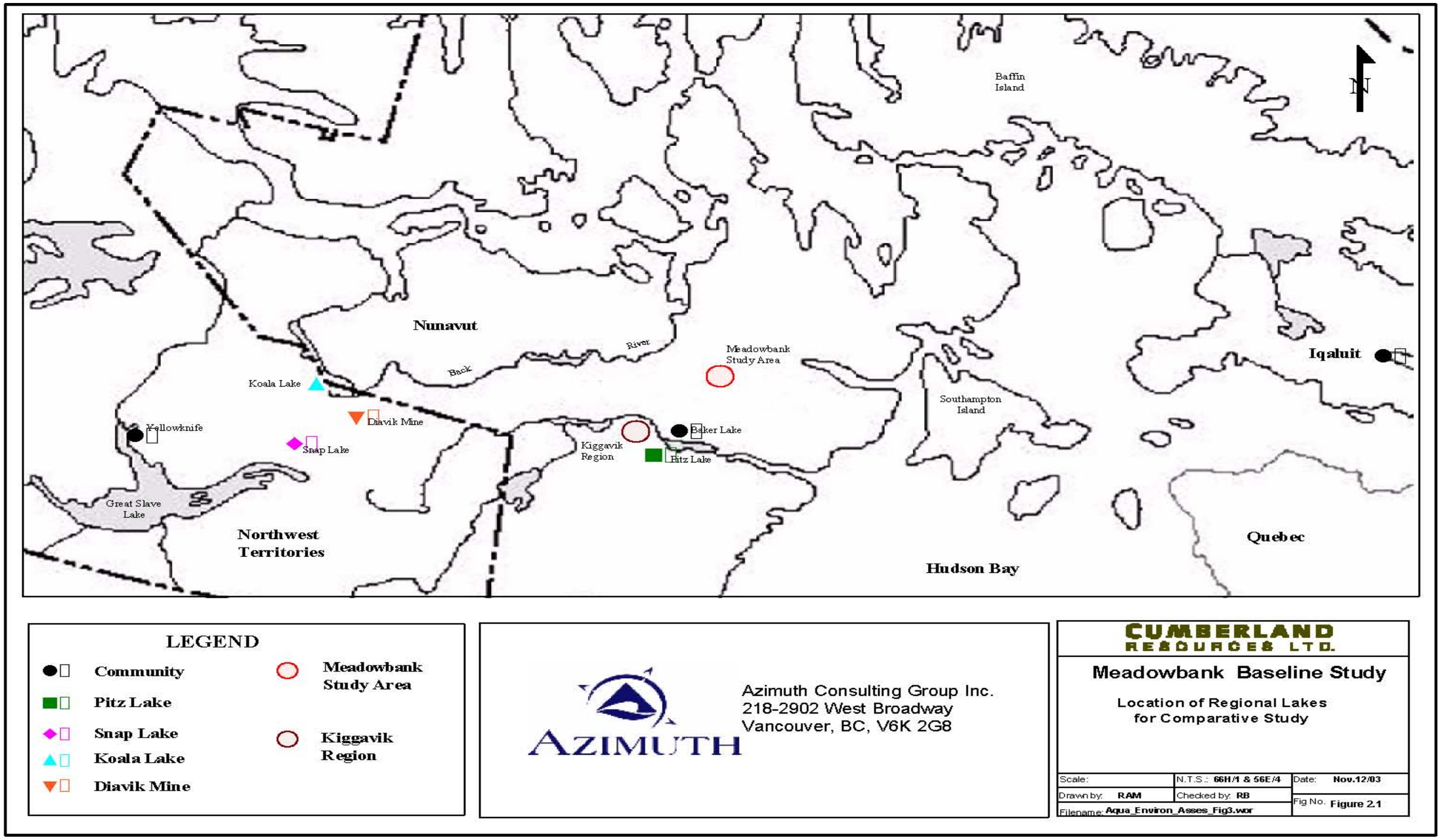
Studies targeting the physical (e.g., water depth, temperature, and substrate type), chemical (e.g., metals concentrations in water, sediment, and fish tissue) and/or ecological (e.g., phytoplankton, zooplankton, periphyton, benthic invertebrates, and fish) characteristics of the aquatic environment in the vicinity of the Meadowbank project have been conducted since 1991. The objective of these studies has been to describe the baseline environmental conditions of these pristine lakes prior to any disturbances as a result of mine-related development and operational activities.

An important component of the baseline data is to provide a means of discriminating between mine-related impacts and natural changes. Data collection from reference lakes near the mine, as well as from other lakes within the region, is important in understanding wider-scale changes. Compiling all historic regional data from the Meadowbank study area within a single baseline aquatic environmental assessment report (BAEAR) provides one of the cornerstones for detecting long-term changes in aquatic environment features.

It is recognized that more detailed studies are required in order to detect subtle changes in the aquatic environment as a result of project activities. If a decision is made to proceed with the mine, examination of specific study components such as water quality and the benthic invertebrate community within spatially discrete areas will be undertaken in response to the construction- and operation-related effects of dikes, blasting, effluent discharge, and so on.

Long-term aquatic effects monitoring programs will be described as part of the Aquatic Environmental Management Plan (AEMP, 2005). This plan will be harmonized with Environmental Effects Monitoring (EEM, 2005) requirements under the Metal Mining and Effluent Regulations (MMER) to ensure that adverse environmental effects are detected early and appropriate mitigation efforts can be implemented.

Figure 2.1: Location of Regional Lakes for Comparative Study



2.2 OVERVIEW OF HISTORIC ENVIRONMENTAL STUDIES

Following is a brief, annotated bibliography of aquatic environmental studies conducted since monitoring began in 1991.

Water samples were collected from four stations in Meadowbank project area lakes (presumably Second and Third Portage) in 1991 and analyzed for conventional parameters, nutrients, and total and dissolved metals. Results showed the lakes to be soft-water, nutrient-poor lakes with very low metals concentrations, and no differences among locations. According to the letter report, similar data were found for samples collected in 1990 from the same lakes.

In August 1996, EVS Environment Consultants undertook the first reconnaissance level studies of Second and Third Portage lakes. Preliminary examinations of water and sediment chemistry were undertaken, with limited qualitative examinations of zooplankton and benthic invertebrate communities. No fish were collected. This study provided basic information on physical and biological features and provided the basis for more detailed studies in subsequent years.

Water, sediment, periphyton, phytoplankton, zooplankton, and benthos were collected from four stations in Third Portage Lake and from and individual stations in Second Portage, Tehek, and Vault Lake during late August 1997. Conventional water chemistry parameters (hardness, alkalinity, dissolved solids, etc.) and total and dissolved metals concentrations were low and typical of soft-water, nutrient-poor Arctic lakes. There were few differences in water quality between study lakes. Sediment metals concentrations were also low, although the concentrations of some metals (e.g., arsenic, chromium, copper, nickel, zinc) exceeded federal sediment quality criteria (CCME, 2001), indicating naturally high sediment mineralization. Abundance and diversity of lower trophic level organisms were also low and typical of Arctic lakes.

Baseline data collection of water and sediment chemistry and lower trophic level biota was continued by Golder in 1998 in much the same fashion as in 1997, except that fewer stations were sampled in project area lakes in favour of additional sampling at two candidate reference area lakes (Inuggugayualik Lake and Amarulik Lake, based on 1998 fisheries studies), outside of the potential influence of the mine development. Sampling was conducted in late August (fall). Basic conclusions of 1998 investigations were similar to those of the 1997 investigation, although sampling gear differed somewhat between years. Three years of baseline data collections confirmed the ultra-oligotrophic status of the lakes with mineralized sediments and healthy zooplankton and benthic invertebrate communities characterized by limited productivity and species diversity.

The first detailed, quantitative investigation of the fisheries resource and population biology of Third Portage, Second Portage, and Tehek lakes was conducted in summer 1997. Short-set multi-mesh gill nets were used to capture fish to document the catch-per-unit-effort, species composition, distribution, and abundance of fish at different geographic locations. Biological data including length, weight, age, maturity, diet, and parasites of individual fish were collected from each study lake. Fish populations of the study lakes were dominated by large, healthy, relatively old lake trout (*Salvelinus namaycush*), followed by Arctic char (*Salvelinus alpinus*) and round whitefish (*Prosopium cylindraceum*). Movements of fish between Second Portage Lake and Tehek Lake monitored with hoop nets during the fall revealed that there was very little movement of fish between the lakes, with only a few lake trout captured, primarily moving in a downstream direction.

The geographic scope of the 1997 fisheries investigation was expanded in 1998 to include six potential candidate reference lakes, against which fish population biology statistics were compared with data from study lakes in 1997. Abundance of fish was again dominated by lake trout, with round whitefish being of secondary importance, followed by lake cisco (*Coregonus artedii*), Arctic char, and burbot (*Lota lota*). There were no large differences in life history parameters of the fish populations among the study lakes that obviated the selection of one lake over another for the best candidate as a reference lake. Therefore, based on a suite of parameters including lower trophic level characteristics, Inuggugayualik Lake was selected as the best candidate as an external reference lake. This lake had the greatest similarity in water and sediment chemistry, lower trophic level biota and fish populations as the project area lakes. The south basin of Third Portage Lake was selected as an internal reference lake. The south basin upstream and far removed from the possible influence of the mine. The use of internal and external reference lakes is of critical importance in helping to determine if observed changes in fish communities or population statistics are due to natural changes or are the result of the effects of mine development and operation.

Gill nets, hoop nets, and minnow traps were used to capture fish shortly after ice-off in spring 1999 from Second and Third Portage lakes, Tehek Lake, Turn Lake, and Inuggugayualik Lake. Floy or spaghetti tags were applied to a large number of fish captured alive and released, with the objective of determining fish movements within or between lakes based on recapture data. Consistent with the results of the 1997 and 1998 surveys, lake trout was the dominant species in all lakes (67%), followed by round whitefish (26%) and Arctic char (4%). Ninespine stickleback (*Pungitius pungitius*) were captured in minnow traps from Second Portage Lake, Tehek Lake, and Inuggugayualik Lake. A single burbot was captured in a minnow trap from Tehek Lake. All fish appeared to be very healthy with high condition factor. Monitoring of fish movements between Third Portage Lake and Second Portage Lake and between Drilltrail Lake and Second Portage Lake was conducted during spring using hoop nets. Results showed very limited movement of lake trout between Third Portage Lake and Second Portage Lake, and no fish movement between Drilltrail Lake and Second Portage Lake.

Aquatic environment studies conducted in July (spring) and August (late summer/fall) 2002 focussed on synoptic collections of water and sediment chemistry and lower trophic level studies (periphyton, phytoplankton, benthos, zooplankton) from multiple near- and far-field stations within the project area and regional lakes. This was a comprehensive study of ecological components on a seasonal basis to determine local and regional spatial and temporal trends.

Results indicated that lower trophic level biota had a similar taxonomic composition among study lakes, although density and abundance varied between lakes and seasons and was typical of oligotrophic lakes. Zooplankton had low species diversity and abundance, and was dominated by calanoid copepods with lower density in spring than in fall. Zooplankton density was three times higher in Second Portage Lake than in Third Portage Lake.

Aquatic larvae of chironomid insects dominated the benthic community, both in terms of diversity and abundance. Other less abundant and diverse taxa were identified including bivalve clams, oligochaetes, Notostraca, amphipods (*Gammarus lacustris*), and mites. Mean density of benthic invertebrates varied among lakes and seasons according to hatching synchrony of chironomid species; mean density was lowest in Third Portage Lake and highest in Vault and Drilltrail lakes.

Helicopter and ground surveys of terrestrial and riparian zones traversed by the winter ice road between Baker Lake and the Meadowbank camp showed there was no significant disturbance of shoreline integrity and no erosion or exposure of permafrost at any crossing points. No evidence of impacts to fish habitat was observed at any crossing along the entire route.

Several small ponds between Second Portage Lake and Turn Lake were surveyed in August 2003 to define limnological conditions (water and sediment chemistry, bathymetry), zooplankton communities, and benthic communities and to determine whether or not the lakes contained fish populations. Six ponds were first surveyed by helicopter to determine whether the lakes were deep enough to support fish. Three ponds were deemed to be too shallow (<3 m) to contain fish because maximum ice thickness is typically 2 to 2.5 m. These same ponds were surveyed by helicopter in 2005 and were frozen to the bottom. Three other lakes, Dogleg Lake (NP-1), NP-2, and NP-3 are small, isolated ponds and appear to be isolated from the larger, adjacent lakes. None of the ponds have a defined stream channel connection to either Second Portage or Tern Lake. Flow is low, ephemeral, and is probably sub-subsurface except during the brief freshet. Thus, there is no opportunity for fish to move into or out of these ponds and the resident populations have been contained here for many decades, if not hundreds of years. These ponds were relatively deep (>8 m), isothermal, and well mixed, and contained healthy zooplankton and benthic communities with similar species composition and abundance as the other study lakes. Each of these ponds also contained fish consisting of either lake trout or lake trout/round whitefish combinations.

Quantitative mapping and assessment of fish habitat features of the Meadowbank project lakes was also conducted in 2003. To determine the lake-wide distribution of habitat, stereoscopic aerial photographs (1:10,000 scale) with excellent resolution were used to quantify and map the majority of Third Portage and all of Second Portage and Vault/Wally lakes. To groundtruth and quantify the different habitat types identified from the aerial photographs, an underwater video survey was carried out. Habitat attributes (substrate type and composition, depth, and complexity) were defined within major morphological units, specifically platforms (habitat attached to shorelines), aprons (transition habitat to deeper water), shoals (habitat that is unattached to shorelines) and sediment basin habitat (habitat that is deep (> 8m) and consists of fine grain sediment). Underwater video imagery of representative habitat types was used to describe and quantifying habitat throughout the project area lakes to achieve our objective of determining and quantifying the relative abundance and distribution of high, medium, or low value fish habitat, based on a ranking and weighting system. Habitat value was ranked as high, medium, or low according to the degree to which particular habitats were suitable for spawning, nursery, shelter, foraging, and overwintering of important fish species, especially lake trout, Arctic char and round whitefish. Results of this assessment were used to determine the No Net Loss (NNL, 2005) plan for the Meadowbank project and satisfy the overall objective of the DFO policy on fish habitat.

In 2004 additional efforts were expended to determine the magnitude and seasonality of fish movements between project area lakes. Hoop nets set to capture fish moving between Second Portage and Third Portage lakes, between Vault and Wally lakes, and between Second Portage and Tehek lakes confirmed results of previous studies. Fish movement between these lakes is very small and opportunistic. There are no defined migrations by fish between any of the lakes.

A limited gill net survey of Phaser and Vault lakes in 2004 by Cumberland Resources local Inuit environmental staff revealed that lake trout and round whitefish were present in both lakes. A single burbot was captured in Vault Lake.

Environmental studies in 2005 focused on the all-weather road. A 102 km all-weather road is being proposed to provide access between the mine site and the Hamlet of Baker Lake. This road will cross approximately 25 ephemeral drainage channels and streams that will require the installation of either culverts or bridges. Bridges are planned for five crossings where there are known, defined migrations of Arctic grayling (*Thymallus arcticus*). One additional, small channel for which a culverted crossing is planned, is also used by Arctic grayling. In addition, there are small, random, undefined movements by lake trout (*Salvelinus namaycush*) and round whitefish (*Prosopium cylindraceum*) within these streams. Only six of the 25 stream channels crossed by the all-weather road are used opportunistically by trout and whitefish and by Arctic grayling to access spawning habitat from either upstream or downstream overwintering lakes during early spring, prior to break-up of the stream. Stream habitat consisted of large cobble and boulders and riffle/run sequences and a few pools. All the streams freeze solid to the bottom during winter. Peak upstream movements by grayling occurred during mid to late June, prior to ice break-up on the lakes. Fish eggs and larvae were captured from drift traps set in the streams in the vicinity of the planned crossings.

All other stream channel crossings were relatively small channels with low flow that typically flowed over grassy areas in undefined channels over inundated tundra. These channels typically connected very small, shallow lakes or ponds, most of which are frozen or nearly frozen to the bottom during winter. The absence of fish populations upstream or downstream and the unsuitability of the habitat for spawning or nursery habitat means that most of the channels crossed by culverts do not support important fish species such as Arctic grayling or lake trout. A few ninespine stickleback were captured using minnow traps set in two of the larger channels, but no other species.

In 2005 a greater effort was expended to verify that spring spawning species were not present in the study area lakes (under separate cover). Hoop nets were set between the major lakes in connecting channels in early July, two to three weeks before ice-off came off of the lakes (see Section 7.10). Nets were left in place until late August. Hoopnets set to capture fish moving upstream of downstream between Tehek Lake and Second Portage Lake (the bottleneck between the local and regional environment) captured small numbers of lake trout, round whitefish and Arctic char. No grayling or other spring spawning species was captured. Hoop nets set between Third Portage Lake and Second Portage Lake also captured very few fish, with lake trout being most common. The stream channels habitat separating major lakes are boulder strewn, shallow and difficult for fish to move through, even during freshet. Lake trout and whitefish are not normally migratory and any movements of fish between lakes are simply opportunistic and there is no biological imperative for fish to migrate. Movements by fish within lakes are limited to foraging and seeking spawning habitat during fall. The headwater nature, small drainage area and cold climatic conditions with a short open water season are not conducive to spring spawning species.

2.3 REPORT OBJECTIVES

The overall goal of this BAEAR is to assemble and interpret the existing information on the aquatic environment in the vicinity of the Meadowbank project to serve as a foundation for subsequent environment impact assessment (EIA) and environmental effects monitoring (EEM) activities.

Predicting potential impacts of mine development on aquatic life and developing appropriate mitigation strategies can only be accomplished based on a good understanding of the physical, chemical, and ecological features of the receiving environment.

The specific objectives of this BAEAR for the Meadowbank project were as follows:

- document the physical, chemical, and ecological characteristics, including spatial, seasonal, and inter-annual variability, of project lakes (i.e., those potentially affected if the mine is developed) prior to mine development
- document habitat utilization and fish movements between lakes within streams crossed by the proposed all-weather road between Baker Lake and the mine site
- document the physical, chemical, and ecological characteristics, including spatial and seasonal variability, of local reference lakes (i.e., lakes similar to project lakes but outside the zone of potential impacts of the mine development). Note that both internal (i.e., within the watershed but up gradient) and external (i.e., nearby, but in a separate watershed) reference lakes are included.
- compare and contrast the existing data between project and local reference lakes to provide a baseline context against which future data can be compared
- compare and contrast the existing data between project and reference lakes with published data from lakes elsewhere in Nunavut and the Northwest Territories to place the Meadowbank results into a broad, regional context.

2.4 APPROACH

The intent of this BAEAR is to serve as a foundation for information required to address potential impacts of project-related activities as part of an EIA document. With this in mind, the review and interpretation of available data was conducted at a level considered to inform and facilitate the EIA process. Examining the general patterns from multiple stations collected within several lakes over a number of seasons and years provides a “big picture” perspective of the physical, chemical, and ecological features of the Meadowbank project area lakes.

This BAEAR considers environmental data from numerous previous studies (see Section 2.2) conducted by different companies and individuals. An overview of the methods used to collect and interpret the data is provided as a preface to each section to provide important context for the reader. Differences in sampling or analytical methods (e.g., mesh size and depth of sample) among studies, where important to data interpretation, are discussed herein.

An important component of the big picture is to put Meadowbank area data in perspective with similar data acquired from regional studies conducted in the past and with recent studies conducted elsewhere over a much broader geographic area. To accomplish this, historic data from other lakes within the Baker Lake region of Nunavut Territory have been gathered to determine long-term temporal patterns in physical, chemical, and biological features. As well, more recently collected baseline data from similar studies conducted at mining properties elsewhere within Nunavut and the Northwest Territories have been gathered and have been compared and contrasted with Meadowbank project area data. Differences in methods and data analysis between the current studies and other baseline studies (i.e., conducted at other mine developments in the territories) make direct comparisons to Meadowbank project area data difficult. Nevertheless, general comparisons are possible, provided that differences in specific methodologies are discussed in proper context.

The document has been structured with a bottom-up approach to presenting information. Section 3 describes the physical setting of the study lakes so the reader gains an understanding of the important climatic and physical parameters that influence the distribution and abundance of biota. Section 4 describes the general approach that was used to gather limnological, chemical, and ecological data on the lakes with respect to study design and sample station location. This section provides an overview of why, where, and what was collected within each lake and how the sample design was influenced by the location of mineral deposits and the general mine plan. Quality assurance/quality control (QA/QC) procedures employed during this program are also discussed in a general sense in this section.

Section 5 describes the intra- and inter-annual trends in limnological (temperature, oxygen, depth, morphometry) and chemical (nutrients, pH, metals) features of project lakes. Together, the physical and chemical parameters comprising “water quality” of the study area are strong influences on the species composition, relative abundance, and diversity of organisms that exist at each trophic level of the food web. Section 6 describes each of the major lower trophic levels beginning with periphyton (algae attached to rocks, Subsection 6.1), phytoplankton (planktonic algae, Subsection 6.2), zooplankton (small planktonic animal species, Subsection 6.3), and benthos (small animals living in or on the sediment, Subsection 6.4). Finally, the most recognizable aquatic organisms—fish—are discussed in Section 7. Each section or subsection is structured in a similar fashion, as follows:

- The distinguishing characteristics of each group and its role in the food web are explained.
- The methods used to collect, identify, enumerate, and quantify the organisms are discussed in detail.
- The seasonal, spatial, and inter-annual trends in species composition and density or biomass of organisms are summarized for each study lake from 1996 to 2005.
- Results from near-field and far-field stations are contrasted and compared with results from internal (a remote area of Third Portage Lake) and external (Inuggugayualik Lake) reference areas. It is important to compare data from areas of potential direct impact by the mine with data from areas away from the mine to distinguish between mine-related and natural changes in ecological parameters.
- Finally, data from project lakes are compared with data acquired elsewhere in the Northwest Territories and Nunavut, from both a regional perspective (the Baker Lake region) and a broader scale (other recently developed mines such as Ekati). These data help to put local data from the project lakes in a larger perspective to determine if there are any unique or unusual features about the lakes.

Finally, Section 8 examines all of the data together to provide an overview, or big picture, of the physical, chemical, and ecological features of the project lakes from a spatial and temporal perspective, as well as from a larger-scale perspective, in order to compare and contrast local conditions with broad-scale conditions in a regional sense.

2.5 SCOPE OF WORK

This report summarizes all data on water and sediment chemistry, lower trophic levels, and fish collected between 1996 and 2005 for each of the project lakes (Second Portage, Third Portage and Vault lakes), nearby lakes (e.g., Turn, Drilltrail, and Tehek lakes), and reference areas (Third Portage South Basin) and lakes (Inuggugayualik Lake). Note that the information contained herein constitutes Azimuth's and Cumberland's current understanding of the physical, chemical, and ecological features of the lakes. Results could change pending collection of further data in future studies.

Provided that the mine proceeds, monitoring programs will be developed and tailored to allow detection of specific mine-related activities (e.g., use of explosives, effluent discharge, sediment introductions) during construction and operation phases. Monitoring requirements of the Metal Mining Effluent Regulations (MMER) will be implemented and will include routine acute and sublethal toxicity testing, weekly and monthly effluent testing, and benthic and fish surveys. These will be described as part of the EIA and under separate cover (MMER, 2005).

An overview of the frequency, timing, and location from which various environmental media (e.g., water, sediment, fish) were sampled within the study and reference lakes is provided in Table 2.1. Table 2.2 provides similar information from a number of other lakes in the Northwest Territories and Nunavut that were used to contrast with study area lakes. Examining results over several years and over a larger geographic area to view differences in spatial and temporal trends in physical, chemical, and biological parameters provides a better understand the true nature of the aquatic environment of Meadowbank project lakes. Having a good understanding of the local aquatic environment will allow for more accurate, realistic predictions regarding the nature and magnitude of project-related impacts.

Outside of the project area, a number of previous studies have been conducted on relatively nearby lakes, including Baker Lake (1975 and 1989; McLeod et al, 1976; McKee et al, 1989) and a number of small lakes in the Kiggavik area between 1979 and 1989 (Urangesellschaft Ltd., 1981; McKee et al, 1989). The Kiggavik area lies due west of Baker Lake and Whitehills Lake, less than 50 km from the Meadowbank study area. The Kiggavik area lakes are situated in the headwaters of the Aniguq River, a small watershed that drains directly into Baker Lake, between the Thelon River to the north and the Kazan River to the south. Baseline environmental studies were conducted in and around these lakes for a period of more than 10 years as part of a potential uranium mine, hereafter referred to as the Kiggavik uranium project. The mine was never developed.

Data from regional lakes provide a temporal perspective to baseline environmental conditions of Meadowbank project lakes. As well, baseline environmental data have recently been collected during monitoring studies of several diamond mine developments in western Nunavut and eastern Northwest Territories (Snap Lake, Diavik, Ekati). Contrasting Meadowbank area data with data from lakes elsewhere in the territories puts project area lakes in a broader spatial perspective. As described above, this report begins with a description of the physical setting of the general study area, followed by discussions for each major study component (e.g., water chemistry, zooplankton, etc.). Each of these sections is structured such that dominant characteristics of the project lakes are first discussed, followed by comparisons with local reference areas, then with other lakes elsewhere in the Northwest Territories and Nunavut. This will provide a weight-of-evidence approach to describing various limnological, chemical, and biological data to put the aquatic environment of Meadowbank project lakes in context with lakes elsewhere in the Arctic.

Table 2.1: Aquatic Data Collected from Project, Regional & Reference Area Lakes (1996 to 2005)

Lake/Station	Station ID	Year[1]	Water Chemistry	Sediment Chemistry	Periphyton Biomass	Phytoplankton Biomass	Zooplankton Density	Benthic Density	Fish Abundance /Habitat Mapping	Fish Movements
PROJECT LAKES										
Third Portage Lake										
North Basin, Dike West	TP-N, TPD-W	1996 (A)	+	+	-	-	-	-	-	-
		1997 (A)	+	+	-	-	+	+	+	-
		1998 (A)	-	-	-	-	-	-	-	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (M)	+	-	-	-	-	-	-	-
		2003 (A)	+	-	+	+	+	+	+	-
		2005 (J A)	-	+	-	-	-	-	+	+
East Basin, Dike East, Dike South	TP-E, TPD-E, TPD-S	1997 (A)	+	+	-	-	+	+	+	+
		1998 (A)	+	+	+	+	+	+	-	+
		1999 (A)	-	-	-	-	-	-	-	+
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	-	+	+	+	+	-
		2003 (M)	+	-	-	-	-	-	-	-
		2003 (A)	-	-	-	-	-	-	+	+
		2004 (J A)	-	-	-	-	-	-	-	+
		2005 (J A)	+	+	-	-	-	-	-	+
Second Portage Lake										
North	SP-N	1996 (A)	+	+	-	-	-	-	-	-
		1997 (A)	-	-	-	-	-	-	+	-
		1998 (A)	+	+	-	+	+	+	-	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-
		2005 (A)	-	+	-	-	-	-	-	-
Middle	SP-M	1997 (A)	-	-	-	-	-	-	+	-
		1998 (A)	-	-	-	-	-	-	-	+
		1999 (J A)	-	-	-	-	-	-	-	+
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-

Table 2.1 – Continued

Lake/Station	Station ID	Year[1]	Water Chemistry	Sediment Chemistry	Periphyton Biomass	Phytoplankton Biomass	Zooplankton Density	Benthic Density	Fish Abundance /Habitat Mapping	Fish Movements
		2003 (A)	+	-	-	-	-	-	-	-
		2004 (J A)	-	-	-	-	-	-	-	+
		2005 (A)	-	+	-	-	-	-	-	+
South	SP-S	1996 (A)	+	+	-	-	-	-	-	-
		1997 (A)	+	+	-	-	+	+	+	+
		1998 (A)	+	+	-	+	+	+	-	+
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-
		2005 (J A)	-	-	-	-	-	-	-	+
Tehek Lake										
North	TE-N	1997 (A)	+	+	-	-	+	+	+	+
		1998 (A)	+	+	+	-	+	+	-	+
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-
		2005 (J A)	-	-	-	-	-	-	-	+
Middle/East	TE-M	2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
South	TE-S	1998 (A)	+	+	+	-	+	+	-	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	-	+	+	+	-	-
Turn Lake										
Station 1	Tern-1	1998 (A)	-	-	-	-	-	-	+	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-
Station 2	Tern-2	1998 (A)	-	-	-	-	-	-	+	-
		2002 (J)	-	+	-	-	+	+	-	-
		2002 (A)	-	-	+	-	+	+	-	-
Vault Lakes										
Vault Lake	V-1	2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-

Table 2.1 – Continued

Lake/Station	Station ID	Year[1]	Water Chemistry	Sediment Chemistry	Periphyton Biomass	Phytoplankton Biomass	Zooplankton Density	Benthic Density	Fish Abundance /Habitat Mapping	Fish Movements
		2003 (M)	+	-	-	-	-	-	-	-
		2005 (A)	-	+	-	-	-	-	+	-
Wally Lake	V2-1, V2-2	2002 (J)	+	+	-	+	+	+	+	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-
Drilltrail Lake	V3-1, V3-2	1997 (A)	+	+	-	-	+	+	-	-
		1999 (J A)	-	-	-	-	-	-	-	+
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	-	+	+	+	-	-
		2003 (M A)	+	-	-	-	-	-	+	-
Farside Lake										
West	FL-W	1998 (A)	-	-	-	-	-	-	+	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	-	-	-	-	-	+	-	-
East	FL-E	1998 (A)	-	-	-	-	-	-	+	-
		2002 (J)	-	-	-	-	-	+	-	-
		2002 (A)	+	-	-	+	+	+	-	-
North Portage Lakes										
North Portage 1 (Dogleg)	NP-1	2003(A)	+	+	-	-	+	+	+	-
North Portage 2	NP-2	2003(A)	+	+	-	-	+	+	+	-
North Portage 3	NP-3	2003(A)	+	+	-	-	+	+	+	-
REFERENCE LAKES										
Third Portage Lake										
South Basin	TP-S	1997 (A)	+	+	-	-	+	+	+	-
		2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	-	-
		2003 (M)	+	-	-	-	-	-	+	-
Inuggugayualik Lake										
North	IL-N	2002 (J)	+	+	-	+	+	+	-	-
		2002 (A)	+	-	+	+	+	+	+	-
South	IL-S	1998 (A)	+	+	+	+	+	+	+	-
		2002 (J)	-	+	-	-	-	+	-	-
		2003 (M)	+	-	-	-	-	-	-	-

Table 2.1 – Continued

Lake/Station	Station ID	Year[1]	Water Chemistry	Sediment Chemistry	Periphyton Biomass	Phytoplankton Biomass	Zooplankton Density	Benthic Density	Fish Abundance /Habitat Mapping	Fish Movements
CANDIDATE REFERENCE LAKES										
Amarulik Lake		1998 (A)	+	+	+	+	+	+	+	-
Pipedream Lake		1998 (A)	-	-	-	-	-	-	+	-
Tahiryuaraaqyuk Lake		1998 (A)	-	-	-	-	-	-	+	-
Ihipqiituk Lake		1998 (A)	-	-	-	-	-	-	+	-

Notes: 1. J=July, A=August, M=May.

Table 2.2: Aquatic Monitoring Studies from Regional Arctic Lakes

Regional Arctic Lakes	Year	Water Chemistry	Sediment Chemistry	Periphyton Biomass	Phytoplankton Biomass	Zooplankton Density	Benthic Invertebrate Density	Fish Abundance	Fish Biological Parameters	Fish Tissue Metals	Reference
Snap Lake	1998	+	-	-	-	-	-	+	-	-	De Beers, 2002
	1999	+	+	-	+	+	+	+	+	+	De Beers, 2002
	2001	+	-	-	-	-	-	-	-	-	De Beers, 2002
Snap Reference Lake	1999	-	+	-	-	-	-	-	+	+	De Beers, 2002
Baker Lake	1975	+	-	-	-	-	+	-	+	-	McLeod et al, 1976
	1989	+	-	-	+	+	+	-	-	-	McKee et al, 1989
Kiggavik Area Lakes[1]	1979	-	+	-	-	+	+	-	+	-	Urangesellschaft, 1981
	1980	+	-	-	-	-	+	+	-	+	Urangesellschaft, 1981
	1986	+	+	-	-	-	-	-	-	-	McKee et al, 1989
	1988	+	+	-	-	-	-	-	-	+	McKee et al, 1989
	1989	+	-	-	+	+	-	-	-	-	McKee et al, 1989
Koala Area Lakes[2]	1993	-	-	-	-	-	+	+	-	-	Rescan, 1994
	1994	-	-	-	-	+	+	+	+	text	Rescan, 1994
Lac de Gras	1994	+	-	-	-	-	-	-	-	-	Diavik & Aber, 1998
	1995	+	-	-	-	-	+	-	+	-	Diavik & Aber, 1998
	1996	+	+	-	-	+	+	+	+	-	Diavik, 1998; Diavik & Aber, 1998
Lac du Sauvage	1994	+	-	-	-	-	-	-	-	-	Diavik & Aber, 1998
	1995	+	-	-	-	-	-	-	-	-	Diavik & Aber, 1998
	1996	+	+	-	-	+	+	-	+	-	Diavik, 1998; Diavik & Aber, 1998
Pitz Lake	1976	-	-	-	-	-	-	+	+	-	Lawrence et al, 1977
Great Slave Lake & Region[3]	1983	-	-	-	+	-	-	-	-	-	Fee et al, 1985
Baker Lake Inland Region[4]	1959-1968	-	-	-	-	-	-	-	+	-	Moshenko, 1980

Notes: **1.** Lakes include: Pointer, Sissons, Jaegar, Scotch, Squiggly, Skinny, Caribou, Boulder, Kavisilik. **2.** Lakes include: Koala, Kodiak, Long, Little, Fox3, and others. **3.** Lakes include: Great Slave, Gordon, Prosperous, Chitty. **4.** Lakes include: Baker, Lockhart, Macdougall, Meliadine, Meridian, Pointer.

SECTION 3 • PHYSICAL & LIMNOLOGICAL SETTING

The Meadowbank project lakes are situated in the barren-ground central sub-Arctic region of Nunavut at approximately 65^{o} north latitude, within an area of continuous permafrost. The study lakes are headwater lakes of the Quoich River system that flows south, through Tehek Lake into Chesterfield Inlet and eventually, Hudson Bay. St. Clair Falls is about 50 km upstream from Chesterfield Inlet on the Quoich Rive. This falls is believed to be impassable to fish and is a barrier to any fish wishing to move upstream, including Arctic char (*Salvelinus alpinus*). Lake whitefish (*Coregonus clupeaformis*) are not known to occur in the Quoich River system above St. Clair Falls (Lawrence and Davies, 1978; MacDonald and Stewart, 1980). Arctic grayling (*Thymallus arcticus*) are known from the Quoich River, but have not been recorded from Tehek Lake or from the project area lakes and tributary streams.

This region became ice-free approximately 6,000 years ago, after the last glaciation period, which was responsible for sculpting of the landscape to form the myriad of lakes and streams with their indistinct and complex drainages.

Lakes in this region of the Arctic are cold, oligotrophic (i.e., low in nutrients and having low productivity), and isothermal (i.e., uniform temperature from top to bottom) during summer and winter. Diversity and abundance of plants and animals is also low because of the paucity of nutrients and severity of the climate.

The ice-free season on these lakes is very short. Ice break-up usually occurs during mid to late-June; ice begins to form again on the lakes beginning in late September or early October, with complete ice cover by late October. Maximum ice thickness is at least 2 m by March/April. Because the lakes are ice covered for most of the year, gas exchange with the atmosphere is limited, although oxygen concentrations usually remain high under the ice because of the low rates of biological activity and decomposition of organic material (processes that consume oxygen from the water).

Lake shorelines are covered predominantly with a complex mixture of boulders and large cobble with some gravel to a depth of between 4 to 6 m below the surface. These substrates are very stable and not subject to erosion except by ice scouring and ice rafting. Below a depth of about 6 m, there is a transition to fines, with the bottom consisting predominantly of silt/clay. The organic carbon content of the fine sediment provides a food source for burrowing invertebrate worms and chironomid larvae. The majority of the lakes are shallow, averaging 6 to 12 m maximum depth. In larger lakes, such as Second and Third Portage lakes, maximum depth in certain areas can exceed 40 m.

The project lakes are headwater lakes, situated on the watershed boundary that separates Hudson Bay and Arctic drainage lakes. Only a few hundred metres to the north of Second and Third Portage lakes (e.g., Pipedream, Inuggugayualik lakes), water flows north to the Arctic Ocean via the Meadowbank and the Back River system. The headwater nature of the project area lakes means that there are no large streams entering or leaving the watershed. Therefore, there are no external sources of nutrients or sediment that would contribute to nutrient enrichment or productivity of the system. Sedimentation rates are typically very low, which partly explains why water clarity is so high and why nutrient concentrations are so low.

The headwater nature of the streams, their great distance from marine waters of Hudson Bay, the paucity of stream habitat, and an impassable falls also helps to explain why certain fish species are found in great abundance and why others are absent. For example, the high latitude, cold climate, and near absence of stream habitat explains the lack of Arctic grayling (*Thymallus arcticus*). Grayling require stream habitat for spawning during spring as well as for feeding. Their absence from the project area is due in great part to the lack of suitable habitat, but also because the project lakes are situated near the maximum northern range of their distribution (McPhail and Lindsay, 1970). The lack of snow cover and brief freshet in spring does not provide sufficient water flow nor water temperature for successful incubation of eggs by grayling.

Lake cisco are also absent from the study lakes and are not known to occur in this watershed (Lawrence and Davies, 1978; MacDonald and Stewart, 1980). Arctic cisco are relatively abundant in lakes near Hudson Bay, where they have easier access to the ocean. Cisco, like Arctic char, often travel back and forth between the lake and marine environment, where they spend the short summer months foraging near shore in the brackish water, returning to lakes to overwinter.

Lake trout and round whitefish dominate abundance in project area lakes and are typically the two most common species in Arctic headwater lakes in Nunavut and the Northwest Territories (Scott and Crossman, 1979). Lake whitefish are also known to be present from other watersheds in this region, but are absent from the Quoich River system (Lawrence et al, 1978; MacDonald and Stewart, 1980). This species is near the edge of its northerly distribution, which may also explain its absence in project lakes.

Landlocked (i.e., non-anadromous) Arctic char are present in all of the project lakes, although relative abundance differs among lakes. Char generally tend to be relatively more abundant in downstream lakes than upstream lakes. South of Tehek Lake, anadromous char are known to migrate up the Prince River to Whitehills Lake, which is used by Arctic char to overwinter (MacDonald and Stewart, 1980).

Other fish species that comprise a very minor abundance (<1% combined) include burbot (*Lota lota*), ninespine stickleback (*Pungitius pungitius*) and slimy sculpin (*Cottus cognatus*). Burbot typically occur in deep water portions of lakes, and, given the lack of stream habitat are limited to lake basins. Unlike other species, they during mid-winter under the ice over sand, gravel, and rubble substrates in shallow depths (Scott and Crossman, 1979; Richardson et al. 2001). Juveniles and adults inhabit rocky shorelines at margins of deeper areas of lakes, as well as in deeper areas away from shorelines and shoals. Sculpin are spring spawners and spawn over sand, gravel and rock substrates in shallow water. Seasonal movements within lakes are restricted and this species is often favoured as a sentinel species. Ninespine stickleback are widespread in lakes and streams and inhabit shallow bays, ponds, and stream channels. Although stickleback prefer areas with macrophytes and vegetation, given the absence of aquatic plants in the project lakes, stickleback were associated with coarse substrates with good shelter nearshore associated with rocky, cobble shorelines.

The major project area lakes, Third Portage and Second Portage, have small drainage areas relative to the surface area of the lakes themselves, a common feature of headwater lakes. Third Portage Lake is relatively large, with a surface area of 39.5 km^2 and a drainage area of 89 km^2, resulting in a low drainage area to surface area of 2.2. Second Portage Lake is much smaller with a surface area of 4.8 km^2 (4,800 hectares; ha) and a drainage area of 14.6 km^2 (ratio of 3.1). Including the additional lakes that drain into the south end of Second Portage Lake (Turn Lake, Vault Lakes), the lake surface area to drainage area ratio is similar (3.2). Local inflow from surrounding terrain is the predominant influence on water movement within the system.

The physical and climatic setting of the study lakes strongly influences the chemical and biological features of the project area lakes. The headwater nature, climate, lack of nutrients, shallow depth, and similarity in limnological properties of the project lakes helps to explain similarities observed among the lakes as well as possible differences in chemical or biological features between project lakes, reference lakes, and regional Arctic lakes. The low nutrient concentration in the water column, deep depth and cold water temperature of Second and Third Portage lakes severely constrains productivity and biomass of fish populations that are limited by nutrients and not by abundance of critical habitat types, which is typical of the vast majority of Arctic lakes.

SECTION 4 • STUDY DESIGN, STATION LOCATION & QA/QC

This section provides a rationale for the sampling design strategy, including a near-field/far-field approach within the project lakes, and the use of internal and external Reference lakes to contrast with near-field data. Sampling stations have been strategically located within the project lakes to establish a network of monitoring points to allow detection of possible deleterious, mine-related effects early in the mine development/operation stages. Stations have been situated at increasing distances from specific locations of study lakes areas that are targeted (e.g., from dikes and open pits) for development to ensure that the spatial bounds of potential effects can be detected. This information will be important in planning and conducting future EEM programs.

It is important to put the local aquatic environment in context from a broader perspective and to understand how local limnological and ecological features compare with similar features from other regional Arctic lakes. To facilitate this, the approach and major findings of previous studies conducted within the Baker Lake region are summarized, along with results form several, more-recent studies conducted at other mine developments in the Northwest Territories. This annotated bibliography provides an overview of the scope and level of understanding of aquatic environments elsewhere in the Arctic that assist in interpretation of data from the Meadowbank region.

Finally, this section presents an overview of the quality assurance/quality control (QA/QC) methods used in the various baseline studies carried out at Meadowbank since 1996. The intent of this subsection is not to provide an exhaustive description of all details, which can be found in the original documents, but rather to give the reader the necessary context within which to follow subsequent data interpretations.

4.1 STUDY DESIGN & STATION LOCATION

The Meadowbank project area contains a large number of lakes of various sizes. Early baseline studies were limited in spatial extent, sampling intensity, and range of parameters considered. These investigations started with aquatic environments in core areas of the potential mine (e.g., Second Portage Lake and the east basin of Third Portage Lake). As project plans solidified, baseline studies were expanded to cover a broader range of parameters and wider spatial coverage. Lakes targeted in the baseline studies can essentially be divided into two categories:

1. Project Lakes – Lakes (or portions thereof) potentially vulnerable to the effects of the proposed development. Greater effort and spatial coverage was dedicated to lakes directly affected by open-pit mining activities relative to other lakes (e.g., those potentially affected by road development). Project lakes include:

- Third Portage Lake (North Basin)
- Third Portage Lake (East Basin)
- Second Portage Lake
- North Portage Ponds

- Turn Lake
- Vault Lake
- Wally Lake
- Drilltrail Lake
- Tehek Lake (North Basin).

2. Reference Lakes – Lakes (or portions thereof) outside the range of potential mining-related impacts. These lakes will serve to document non-project related changes over time. A number of candidate lakes were evaluated, with two being selected. Reference lakes include:

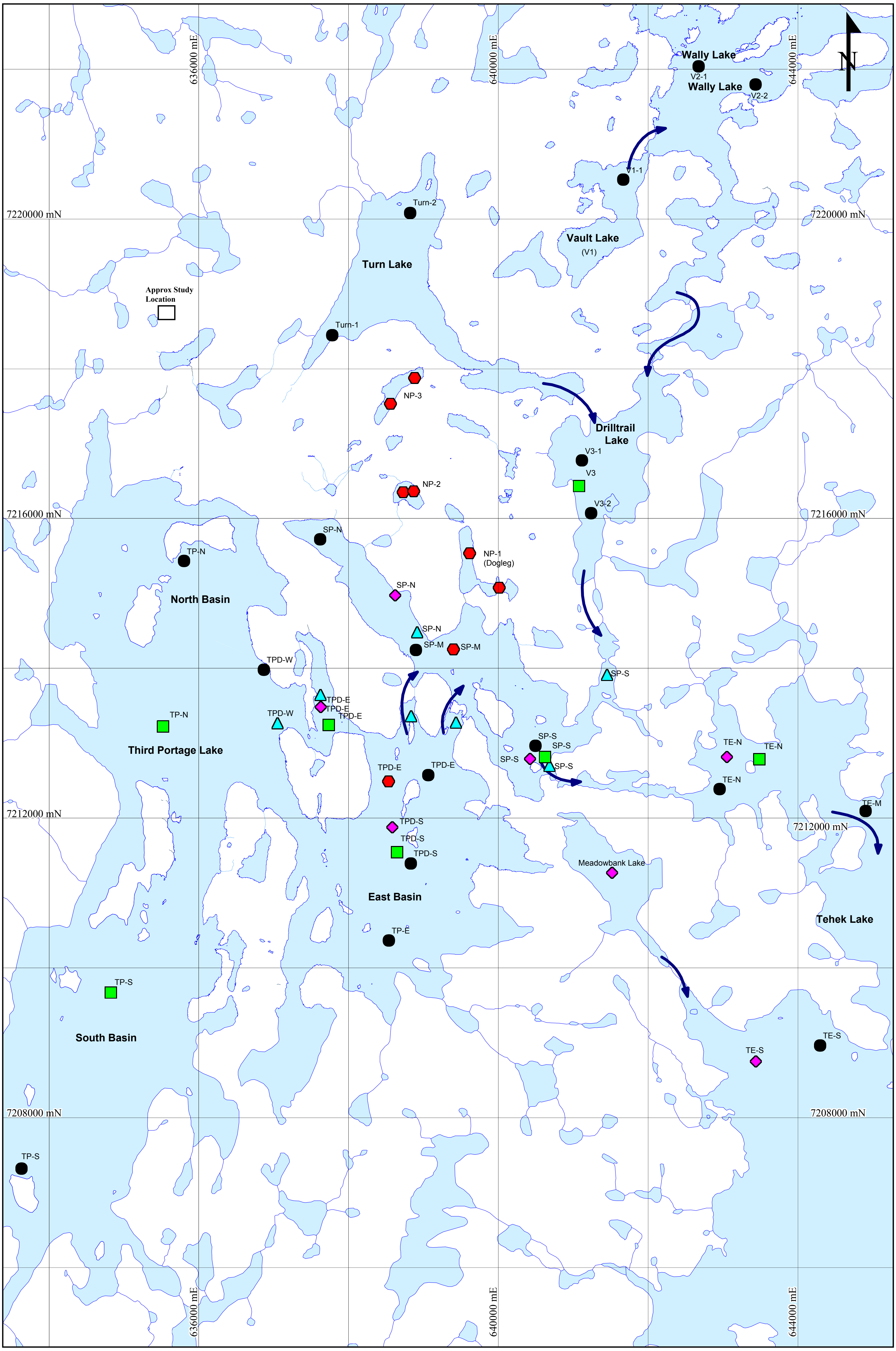
- Third Portage Lake (South Basin) as an internal (i.e., up-current in the same watershed) reference lake.
- Inuggugayualik Lake as an external (i.e., different watershed) reference lake. Note that several other lakes in the general region were surveyed for water chemistry, lower trophic level biota, and fish. Inuggugayualik Lake was chosen as the reference because it had the greatest overall similarity to the project lakes.

The project lakes and reference lakes from the baseline studies are collectively referred to as the Meadowbank project area lakes. To meet the objective of placing the baseline study results into perspective, data from other lakes in Nunavut or the Northwest Territories have also been compiled. These lakes are collectively referred to as regional Arctic lakes.

To provide an overview of the location and kinds of sample collections made within lakes and stations, a matrix depicting the kinds of environmental media (e.g., water, periphyton) that were collected from each of the Meadowbank project area lakes between 1996 and 2003 is compiled in Table 2.1. The locations of individual sampling locations over this time period are depicted in Figure 4.1 for water, sediment, and lower trophic level biota. Note that synoptic collections of water and sediment chemistry and phytoplankton, zooplankton and benthos were made at each station with only a few exceptions. Figure 4.2 shows the locations of baseline fishing efforts.

4.1.1 Project Lakes

The Meadowbank study area includes Third Portage Lake (TP), Second Portage Lake (SP), Tehek Lake (TE), Turn Lake (TURN), and the Vault Lake system—Vault 1 (V1), Wally Lake (V2), and Drilltrail Lake (V3). Vault Lake drains north into the main basin of Wally Lake before draining into Drilltrail Lake, where Turn Lake enters the drainage system. The entire Vault/Wally/Drilltrail system drains into the lower basin of Second Portage Lake, before discharging to Tehek Lake. Farside Lake was also sampled in 2002 to acquire synoptic data for a nearby lake with an Arctic drainage. The general locations of sampling stations from study lakes between 1996 and 2003 have been harmonized to facilitate ease of comparison and interpretation among years. For example, stations sampled in different years, but in relatively close proximity to one another, were grouped. That is, all stations in the north basin of Third Portage (TP) Lake have the prefix TP-N. All near-field stations in Third Portage Lake in the vicinity of the proposed dike have the prefix TPD, followed by west (-W), east (-E), or south (-S) depending on the direction of the station from the proposed dike location.



LEGEND

- Flow Direction
- 2003 Sampling Station
- 2002 Sampling Station
- 1998 Sampling Station
- 1997 Sampling Station
- 1996 Sampling Station

Scale: 1:50,000

0 1,000 2,000

metres

CUMBERLAND RESOURCES LTD.

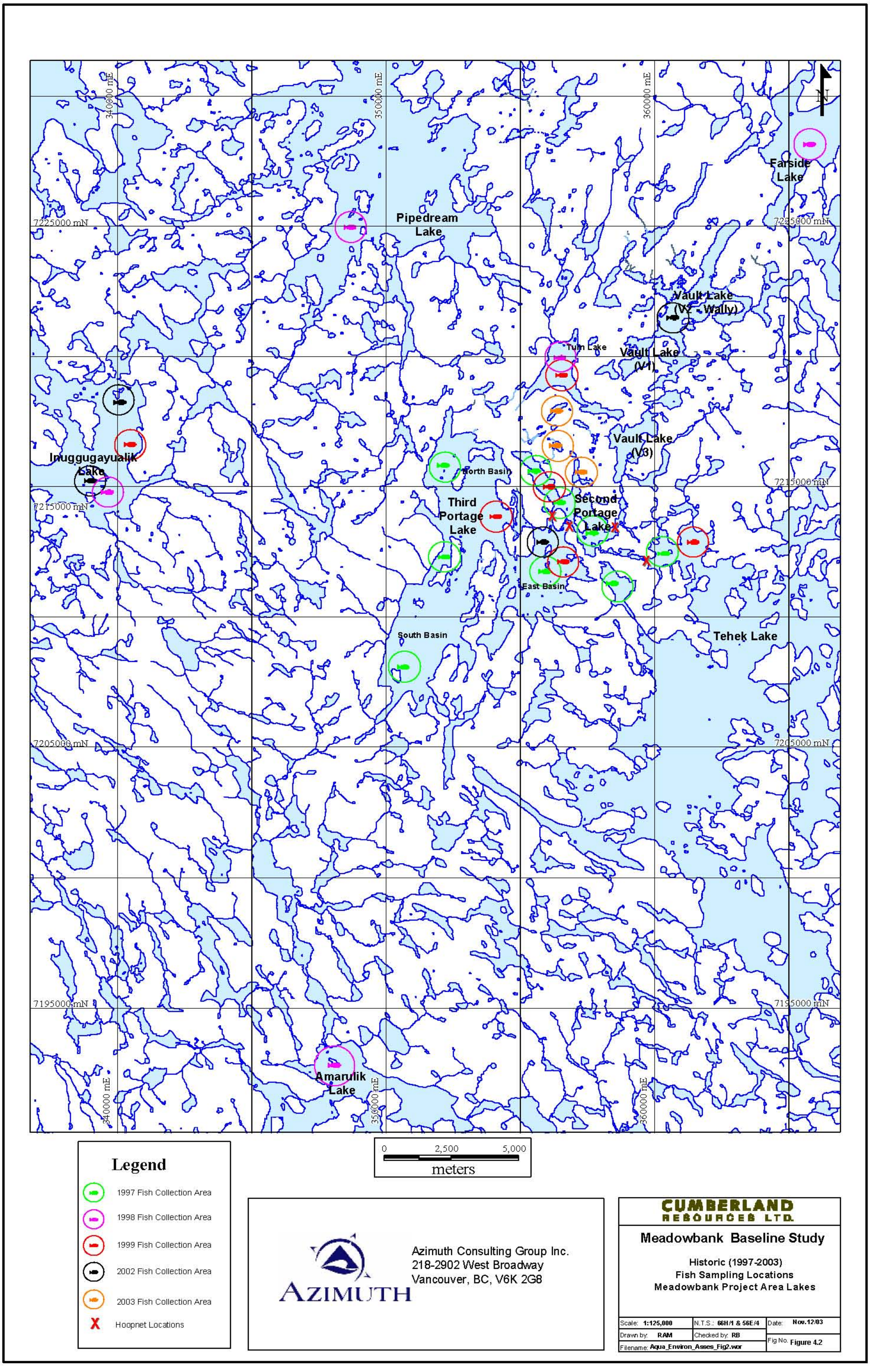
Meadowbank Baseline Study

Historic (1996-2003)
Sampling Stations
Meadowbank Project Area Lakes

(Water and Sediment Chemistry; Lower Trohpic Level Biota)

Scale: 1:50,000	N.T.S.: 66H/1 & 56E/4	Date: Oct. /05
Drawn by: RAM	Checked by: RB	Fig No. Figure 4.1
Filename: Aqua_Environ_Asses_Fig1.wor		

Figure 4.2: Historic (1997-2003) Fish Sampling Locations in Meadowbank Project Area Lakes



There are also several small ponds north of Second Portage Lake between Second Portage and Turn lakes that are isolated with no surface drainage. These ponds, called NP-1 (Dogleg Lake), NP-2, and NP-3, were investigated in 2003 for limnology, water and sediment chemistry, and lower trophic level biota, and to determine whether fish were present or absent.

Sampling stations in Second and Third Portage lakes were strategically located to establish a monitoring strategy such that possible deleterious, mine-related effects can be detected early in the mine development/operation stages. This was accomplished by incorporating a “near-field/far-field” study design for the study area. Near-field (i.e., dike stations) sampling stations were selected within Second and Third Portage lakes in proximity to the proposed mine-development areas and dike structures to establish baseline conditions that will serve as “early warning” stations to detect possible changes in water and sediment chemistry and benthic invertebrate community structure. These stations surround the proposed dike and/or dam structures that are designed to encompass open pit mine areas proposed for construction within the project area lakes.

Far-field stations were established outside of the near-field perimeter to allow detection of wider-scale effects in the major basins of Second Portage Lake and Third Portage Lake in particular. Sampling was conducted on Vault 1 Lake as well as progressively further downstream within the drainage basin in Vault 2 Lake (Wally Lake) and Vault 3 Lake (Drill Trail Lake), before this system enters Second Portage Lake.

Sampling stations were established progressively downstream of the mine development areas in Third Portage Lake (at Goose Island) and in Second Portage Lake, near the middle of the lake where Third Portage drains into Second Portage and within the ultimate receiving environment, Tehek Lake. This ensures that the spatial bounds of all mine-related effects are assessed and quantified to provide assurance that monitoring and mitigation measures implemented during mine construction and operation are effective. This concept is embedded in the Aquatic Environment Management System (AEMP, 2005) document, which describes in detail the monitoring program for the mine throughout its life.

4.1.2 Reference Lakes

Internal and external control, or reference, lakes were selected for the purposes of making comparisons with project lakes. By definition, references lakes are sufficiently removed from the mine that they should be unaffected by any infrastructure (roads, dikes, runways), and effluent streams (aerial and aquatic) associated with mine development. Monitoring of reference lakes is important in order to distinguish between mine-related changes and natural changes in physical, chemical, or ecological parameters of project lakes.

In 1999, Turn Lake was selected as an internal watershed reference lake. However, since 1999, discovery of the Vault Deposit may result in potential impacts to Turn Lake via road access to the Vault deposit. Thus, Turn Lake is no longer suitable as an internal reference lake. However, Turn Lake may now serve as near-field lake to detect effects of road construction and operation.

Given this change, the southern basin of Third Portage Lake was selected as the internal reference lake for the following reasons:

- The southern basin is upstream and at the extreme headwaters of Third Portage Lake and far removed from the mine and potential effects of mine discharge.
- The prevailing wind direction is from the north, which will prevent any movement of water or sediment from the mine site in this direction.
- The outlet of Third Portage Lake is also towards the proposed mine site location from the south basin, so there is no likelihood that sediment could be transported by currents into the south basin.
- Movement by fish between the basins is possible; however, lake trout and round whitefish are not migratory, nor do they undertake concerted, regular movements over large distances.

Inuggugayualik Lake, about 16 km west of the mine site, was chosen as an external reference lake based on a 1999 synoptic study of six candidate reference lakes on water and sediment chemistry, zooplankton, benthos, and fish. The selection of external reference lakes is based on a number of criteria, including: the amenability of the selected lakes to quantitative assessment techniques, proximity of the lakes to the mine development area, and a favourable combination of physical and biological features. Although Inuggugayualik Lake is also a headwater lake, it drains north to the Arctic Ocean as part of the Meadowbank River, which is part of the Back River system. Despite the different drainage basin, Inuggugayualik Lake satisfies the requirements of an external reference lake from a physical/chemical perspective because it is at the same latitude, has similar geology, relief and climate, does not have any significant inflows, and is a headwater lake with similar limnological parameters and water chemistry as the project lakes. From a biological perspective, there were no large or meaningful differences in life history parameters of fish among the various lakes surveyed that either eliminated or obviated the selection of one candidate reference lake from another for use as a reference.

Two of the other candidate reference lakes, Ihipqiituq Lake and Amarulik Lake, were rejected as possible external reference lakes because of greater species diversity, greater abundance of lake cisco (*Coregonus artedii*), and high catch-per-unit-effort (CPUE) relative to the study lakes. Inuggugayualik Lake was eventually chosen as the external reference lake because the composition of its fish species was similar to that in the project lakes; mean size, condition factor, and abundance of lake trout were similar; and CPUE data were intermediate to project lakes; Although a small number of Arctic char in Inuggugayualik Lake may be anadromous, the relative abundance of anadromous char is very low (1%) and does not contribute significantly to the biomass or productivity of this lake.

4.1.3 Regional Arctic Lakes

Aquatic monitoring studies have been conducted in Nunavut and the Northwest Territories that are external to the Meadowbank project area lakes. Data from these studies have been compiled and used in this BAEAR to provide broad geographic-scale comparisons between Meadowbank project area lakes and other regional Arctic lakes. Following is a brief annotated bibliography of the major aquatic environmental studies discussed here.

4.1.3.1 Diavik Area Lakes

[Diavik and Aber] Diavik Diamond Mines Inc. and Aber Resources Ltd. 1998 (March). Diavik Diamonds project Integrated Environmental and Socio-Economic Baseline Report. Volume I.

An aquatic environmental effects assessment was conducted in conjunction with the Diavik Diamond Mines project in the Northwest Territories, near the Nunavut border (Figure 2.1). Data were collected for Lac de Gras (study lake) and Lac du Sauvage (reference lake) between 1994 and 1997. Information reported included water and sediment chemistry, zooplankton abundance, benthic invertebrate abundance, and fish abundance and biological parameters. Results indicated that Lac de Gras and Lac du Sauvage are ultra-oligotrophic lakes with relatively low metals concentrations. Abundance of zooplankton and benthos was low and species composition was typical for Arctic lakes. Lake trout, lake cisco, and round whitefish were the dominant fish species.

4.1.3.2 Kiggavik Area Lakes

McKee, P., R. Watters, D.L. Lush (Beak Consultants Ltd.). 1989 (December). Supporting Document No.4. Aquatic Baseline Conditions – Kiggavik Project Area, District of Keewatin, NWT.

[Urangesellschaft] Urangesellschaft Canada Ltd. 1981 (February). Environmental Studies Report – 1980 (Baker Lake Region).

Aquatic baseline studies were conducted in the Kiggavik region lakes between 1979 and 1989 in conjunction with the Urangesellschaft uranium mine project. Results from these studies in 1989 and 1981 are summarized in the above reports. The Kiggavik study area is situated near Baker Lake, Nunavut (Figure 2.1). Data were collected from more than 20 lakes, including Baker Lake, and included information on water and sediment chemistry, phytoplankton biomass, zooplankton, benthos, and fish abundance. Data on fish biological parameters and metals concentrations are also presented. Water and sediment chemistry data were typical of Arctic, oligotrophic lakes, with high sediment mineralization. Biomass of phytoplankton and abundance of zooplankton and benthic invertebrates were all low. Consistent with other Arctic lakes, chrysophytes dominated the plankton biomass, calanoid and cyclopoid copepods were the most abundant zooplankton groups, and chironomids were the dominant benthic invertebrate taxa. Lake trout, round whitefish, and lake cisco were the predominant species in the Kiggavik lakes.

4.1.3.3 Koala Area Lakes

Rescan. 1994. NWT Diamonds Project Environmental Impact Assessment.

The Koala region lakes are located near Lac de Gras and the NWT-Nunavut border (Figure 2.1). Aquatic environmental studies were conducted on several lakes in the area by Rescan on behalf of BHP Environmental in 1993 and 1994 for the environmental assessment of the BHP Ekati Diamonds Mine project. Abundance of lower trophic organisms was low, and species composition was consistent with other Arctic lakes. Dominant fish species in the Koala lakes were lake trout and round whitefish.

4.1.3.4 Snap Lake Project

[De Beers] De Beers Canada Mining Inc. 2002 (February). Snap Lake Diamond Project Environmental Impact Assessment. Chapter 9, Aquatic Resources + App.; p 9-1 – 9-416.

Snap Lake is located near the Diavik and Koala area lakes, NWT, between Great Slave Lake and the Nunavut border (Figure 2.1). An extensive environmental impact assessment was conducted between 1998 and 2001 as part of the De Beers Snap Lake Diamond Mine project. Data on water and sediment chemistry, phytoplankton biomass, zooplankton and benthos densities, and fish abundance, biological parameters, and metals concentrations are included in the assessment. Diatoms dominated phytoplankton biomass. Abundance of zooplankton and benthos was low, and species composition was comparable to other Arctic lakes. Lake trout, round whitefish, Arctic grayling, longnose sucker (*Catostomus catostomus*), and lake chub (*Couesius plumbeus*) were common in Snap Lake over the 1998 and 1999 sampling years.

4.2 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

The objective of QA/QC is to assure that the chemical and biological data collected are representative of the material or populations being sampled, are of known quality, are properly documented, and are scientifically defensible. A high standard of QA/QC was maintained throughout the course of the studies by following accepted, well-known protocols and standards for collection and analysis of environmental media.

The QA/QC steps were as follows:

- staff the program with experienced samplers
- employ laboratories that have been certified for all applicable methods
- employ the same taxonomist used in previous work and who is familiar with taxonomic identification of lower trophic level biota from Canadian Arctic lakes
- employ the same analytical laboratory for all chemical parameters over all years
- follow strict laboratory QA/QC procedures, including analysis of blind field replicate samples, laboratory duplicate samples, matrix spike duplicates, and certified reference materials (CRM).

In addition, standard sampling procedures were used from year to year to maximize comparability among years and with other locations. This was not always possible because different companies were sometimes involved in collecting biological samples at different times. For example, different mesh sizes were used between years in the collection of zooplankton. However, steps have been taken in this report to account for these limitations in a defensible manner where appropriate. These include re-analysis and double-checking of data, peer review, consistent treatment of data from a taxonomic perspective (e.g., only including organisms that are reliably captured by the mesh size used), and using data analysis and presentation techniques that are consistent with other investigations.

Results that were made uncertain due to missed hold times, improper calibration, contamination of analytical blanks, or poor calibration verification results were deemed invalid. Results that were flagged due to matrix effects (low spike recoveries) or imprecision were also considered invalid.

The general data quality objectives (DQOs) for this project were as follows:

- Analytical Precision = 25% Relative Percent Difference (RPD) calculations for concentrations that exceed 10x the method detection limit.
- Analytical Accuracy = 80% to 120% recovery of matrix spikes and CRMs.
- Completeness = 95% valid data obtained.

Complete descriptions of QA/QC procedures followed for collection, transport, and analysis of water and sediment chemistry and lower trophic level biota are described in greater detail within individual study reports.

SECTION 5 • PHYSICAL/CHEMICAL PARAMETERS

5.1 LIMNOLOGY

Vertical temperature (^{o}C), oxygen (mg/L), and conductivity (µS/cm) depth profiles in all Meadowbank project area lakes were acquired using a Yellow Springs Instruments (YSI) temperature-oxygen meter or a Hydrolab^{TM} multi-probe meter. Water depth (m) was acquired using a hand-held digital depth meter or weighted line. Temperature/oxygen profiles were acquired periodically from most field stations within each lake during the course of seasonal surveys to track changes in stratification of oxygen and temperature profiles (Figures 5.1a to 5.1f). Limnological data were used to determine at which depth water chemistry samples should be collected and to understand how lake stratification might influence the distribution of water column biota (i.e., phytoplankton and zooplankton).

5.1.1 Project Lake Data

All of the lakes in the Meadowbank project area can be described as ultra-oligotrophic, nutrient poor and isothermal with neutral pH and high oxygen concentrations year round. Water clarity is extremely high with Secchi depth typically of 10 m or more, suggesting very low suspended solids concentrations. Shoreline complexity (i.e., the degree to which a shoreline does not resemble a smooth, circular shape of equal circumference) of all project lakes is relatively high. There are no macrophytes (i.e., plants that are rooted in the bottom and emerge into the water column, such as grasses or weeds) along shorelines or rooted in shoals. Substrate along shorelines and shallow shoals consists of a heterogeneous mixture of large boulder and cobble, areas of sloping, fractured bedrock shelves, and occasional patches of cobble and coarse gravel. There are no fine substrates, such as sand; in shallow water at depths of less than 4 m. Very coarse substrates predominate to depths of at least 3 m, at which point there is a transition to finer substrates to about 6 m. At depths greater than 6 to 8 m, substrate is predominantly silt/clay with a few partially buried individual boulders or cobble patches. This shallow, coarse material provides abundant habitat for spawning, rearing and foraging by fish. There is also a great deal of offshore, shoal habitat that may also be suitable for spawning and rearing by fish.

Vertical temperature (°C) and oxygen (mg/L) profiles measured from all stations from each lake, regardless of season or year, showed very little difference in temperature or oxygen concentration between surface and bottom water (Figures 5.1a to 5.1f). Any vertical stratification observed was very ephemeral and easily broken down and mixed by wind, which is locally frequent and strong. Vertical temperature and oxygen profiles from Third Portage Lake are provided in Figure 5.1a for spring/summer data from 2002. Oxygen concentrations ranged between 10.3 and 13.7 mg/L, depending on water temperature and was nearly always completely saturated. Water temperature was lowest (4.3°C) in early spring (July) in the large basins of Third Portage Lake shortly after ice-off. Water temperature increased through July reaching 8°C. By mid to late August 2002, water temperature had reached nearly 12°C before declining to 9°C. Some minor stratification (2 to 3°C) was observed after two or three calm, windless days, although this was quickly broken down during the first wind event. Water temperatures gradually decline through the fall until ice begins to form on the lake surfaces, once water temperatures approach 0°C.

Figure 5.1a: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Third Portage Lake, July & August 2002

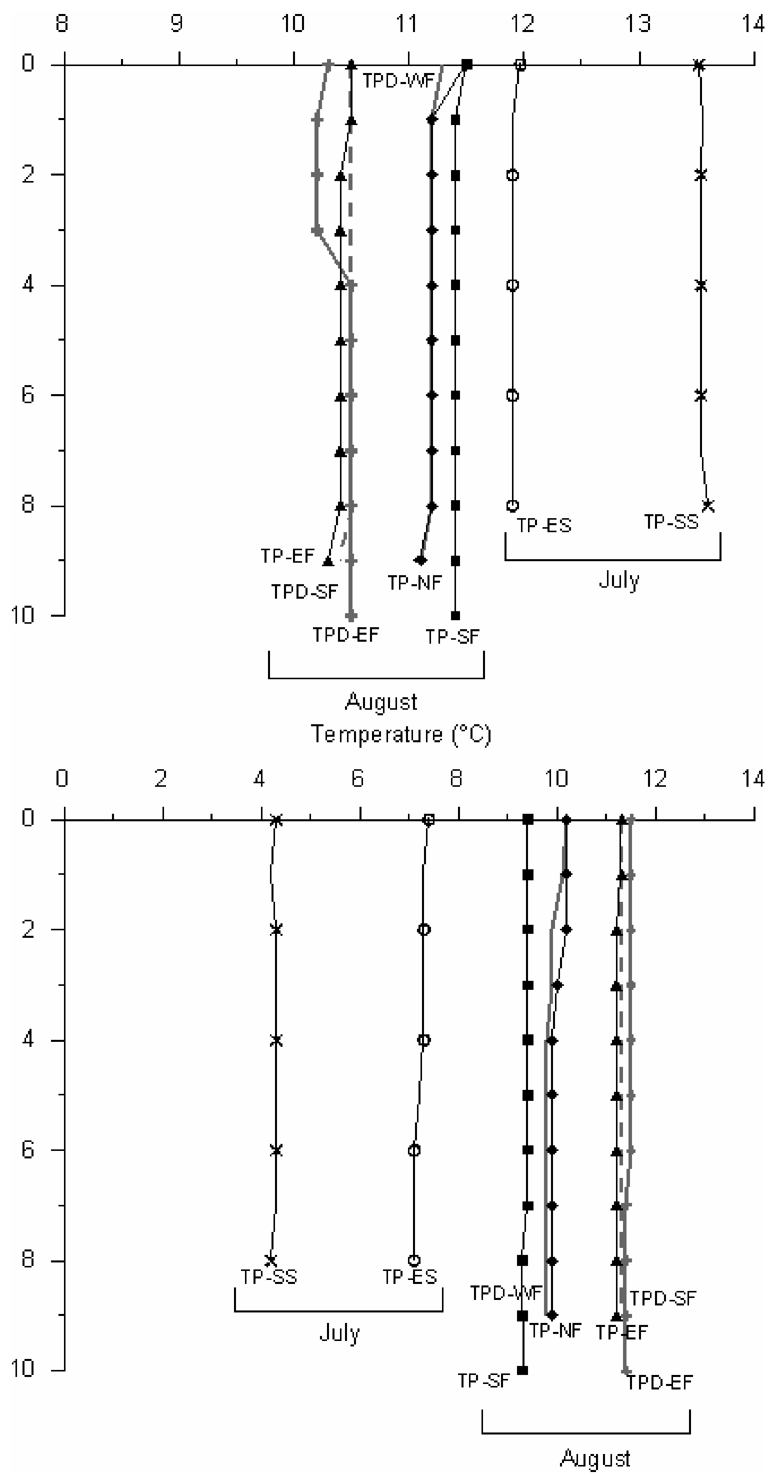


Figure 5.1b: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Third Portage Lake, May (Winter) 2003

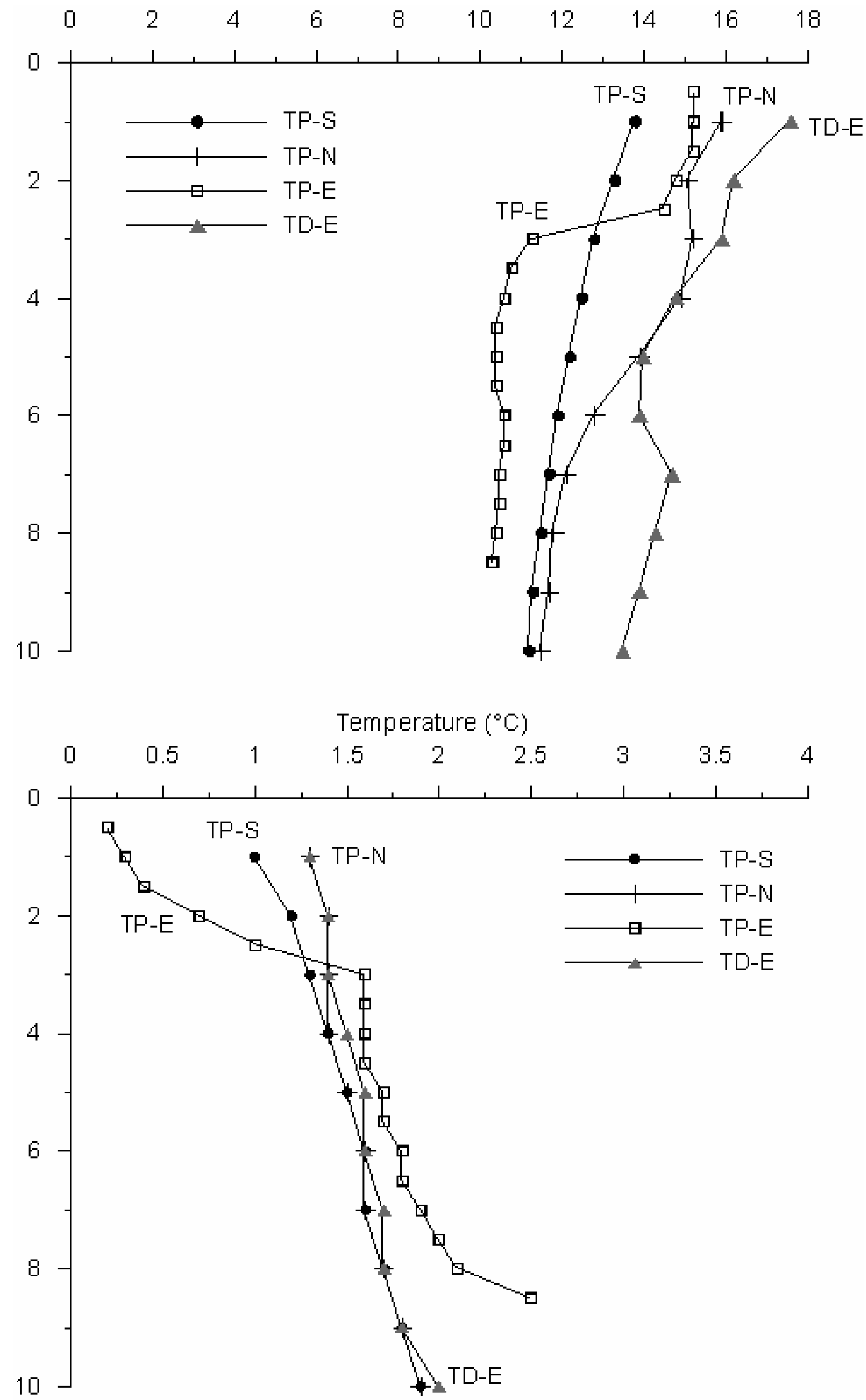


Figure 5.1c: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Second Portage Lake, July & August 2002

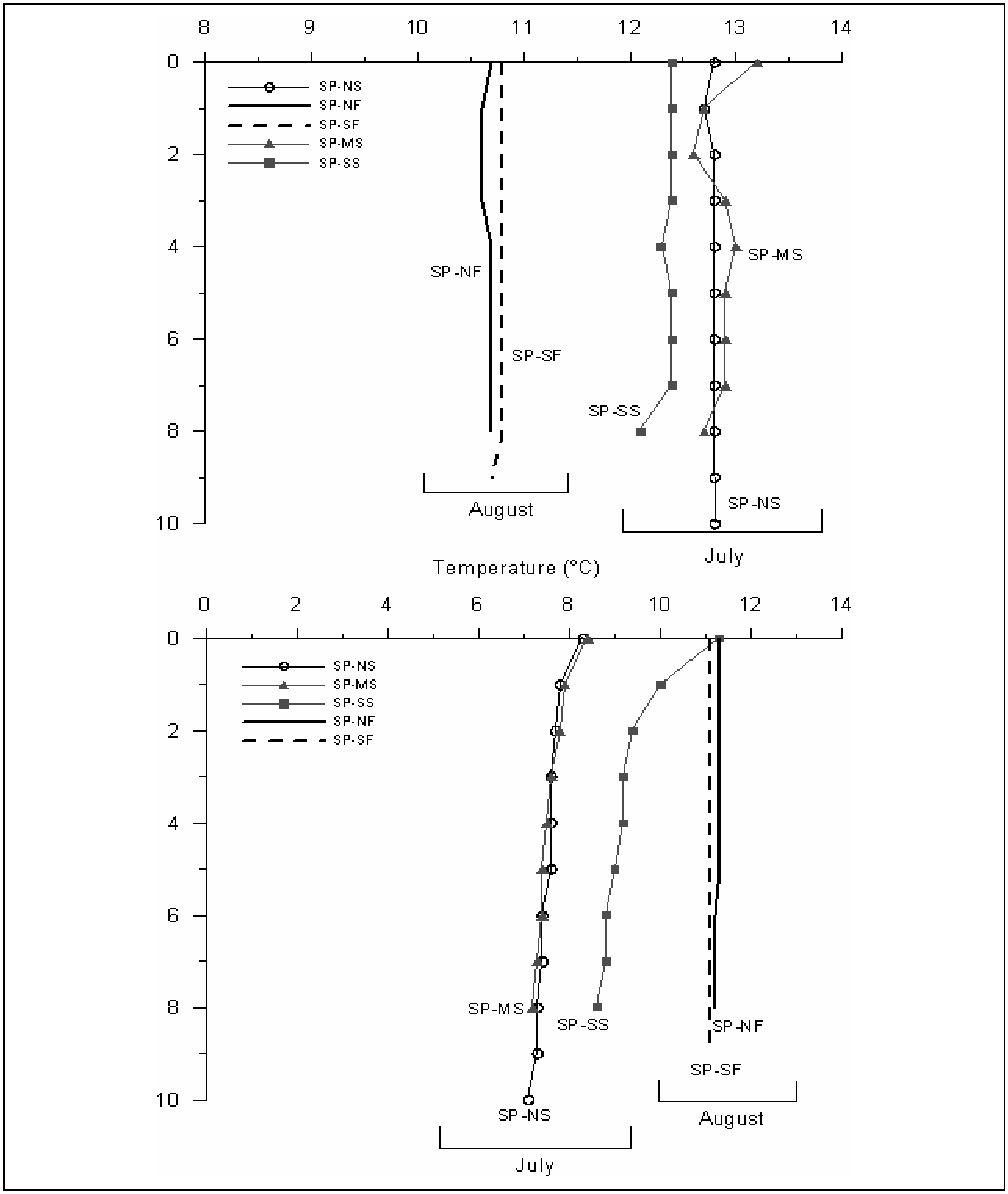


Figure 5.1d: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Second Portage Lake, May (Winter) 2003

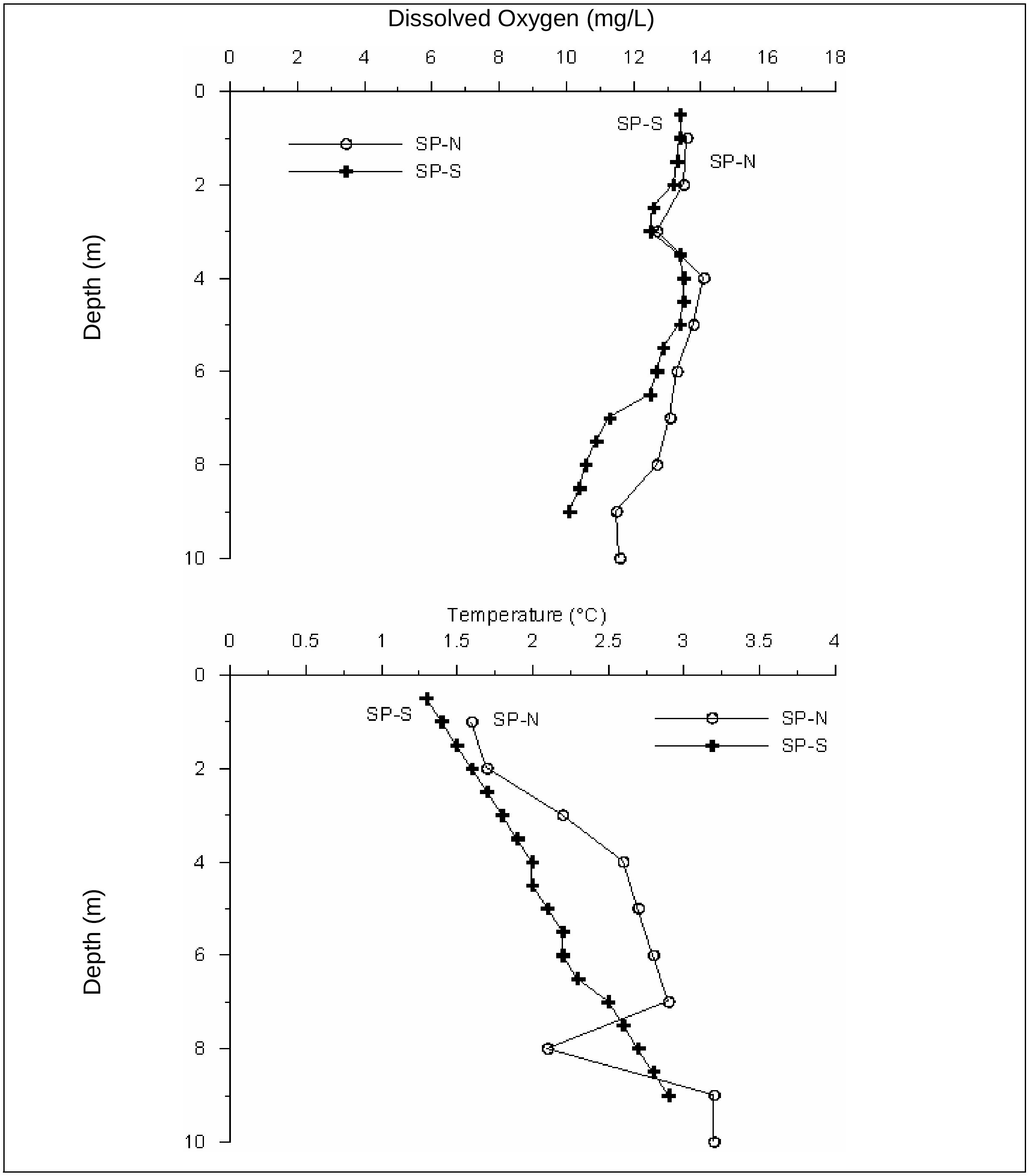


Figure 5.1e: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Tehek & Wally (V3) Lakes, July & August 2002

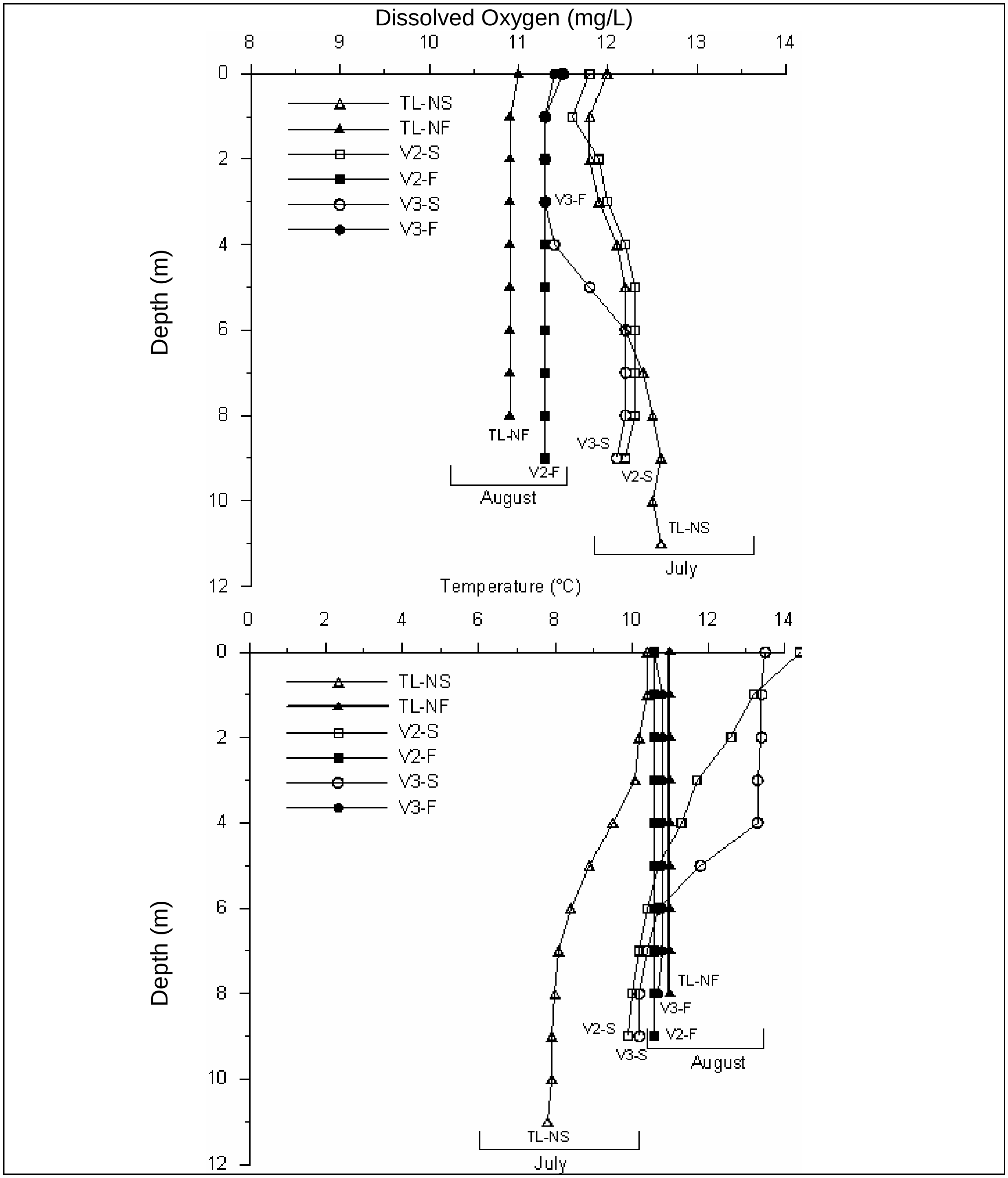
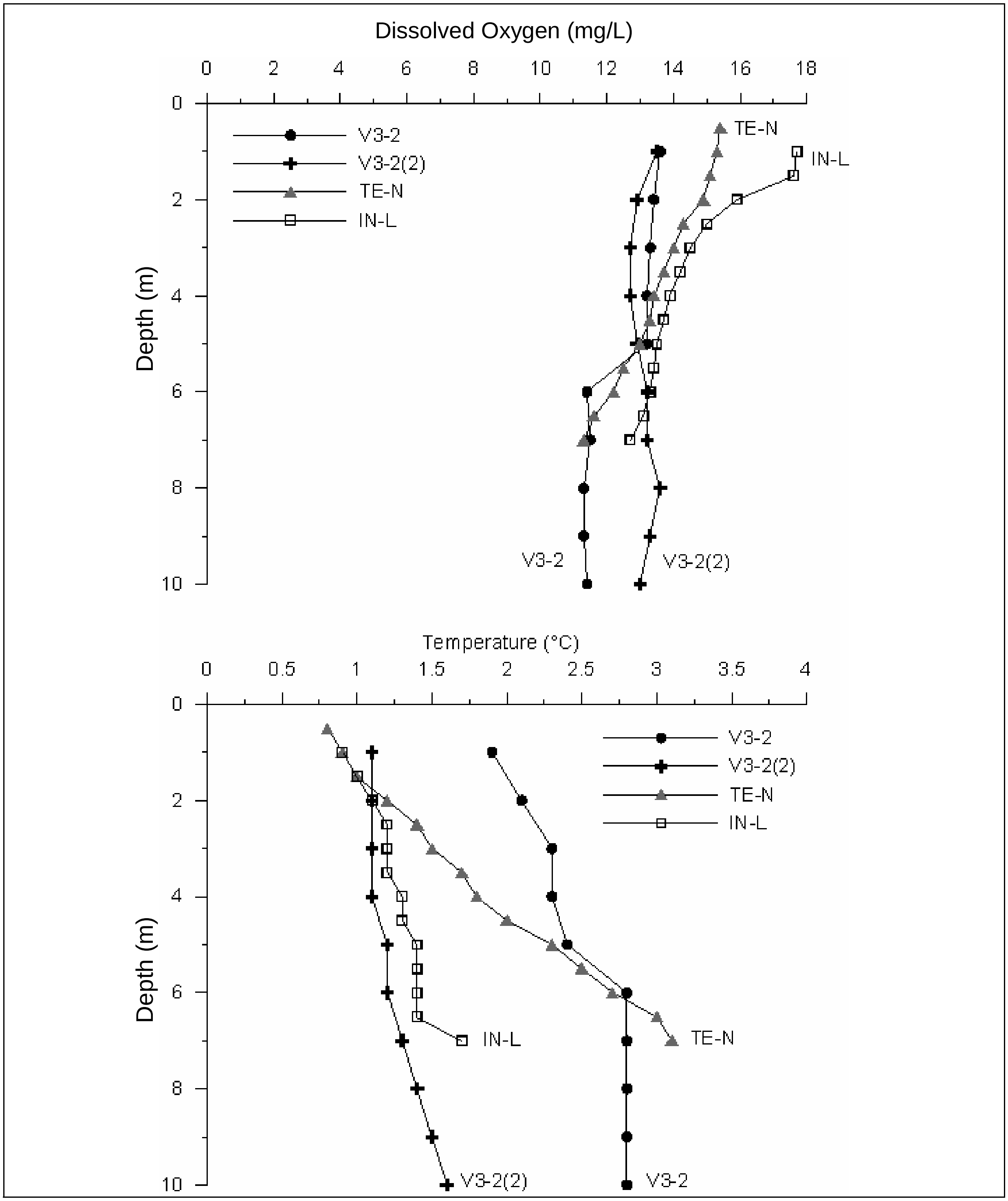


Figure 5.1f: Vertical Dissolved Oxygen (mg/L) & Temperature (°C) Profiles in Tehek, Wally (V3) & Inuggugayualik Lakes, May (Winter) 2003



Very similar profiles were observed in Second Portage Lake in July and August, with uniform temperature and oxygen concentrations from surface to 10 m depth (Figure 5.1c). Very little if any stratification was observed at any station and oxygen concentrations were always high and completely saturated. This same trend was also observed in the Vault lakes and downstream in Tehek Lake (Figure 5.1e). Some minor thermal stratification (2 to 3°C) was observed in August; however, this condition was ephemeral and water became well mixed on windy days. Note that oxygen concentration was slightly inverse at the same stations where there was some vertical thermal stratification because of the lower saturation of oxygen in warmer surface water.

Water temperature and oxygen profiles collected from project lakes (Figures 5.1b, 5.1d) and reference lakes (Figure 5.1f) in late winter/early spring (May 2002) showed that temperature and oxygen were reasonably uniform from surface to bottom, with some inverse stratification. Higher oxygen concentrations just below the ice surface are likely due to photosynthesis by algae living at the ice-water interface. Although there is a thick ice and snow layer above the water, sufficient light penetrates in late winter/early spring to stimulate algal growth, thus increasing oxygen concentrations near the bottom of the ice surface.

Ice thickness ranged from 1.7 to 2.1 m at sampling stations in May 2002. Temperatures ranged from between 0.2 and 1.6°C at the ice-water interface. Just below the ice-water interface, water temperature increased gradually with increasing depth, to reach 2.5 to 3.1°C in Third Portage and Second Portage lakes and 1.6 to 2.2°C in Vault/Wally lakes. A similar profile was also observed in Inuggugayualik Lake. Because the density of water is at 4°C, water temperature is naturally higher at deeper depths than at the surface. This kind of profile is typical of freshwater lakes in winter, in both temperate and Arctic environments.

Oxygen concentrations were high and ranged between 11.2 and 15.5 mg/L throughout the water column in all lakes and were at least 80% saturated at all depths (Figures 5.1b, 5.1d, 5.1f). Oxygen concentrations were slightly lower in deep water (>10 m) than surface water, and did not show any signs of anoxic conditions, being consistently greater than 10 mg/L. These data confirm that oxygen concentrations remained high in all project and reference lakes throughout the water column, even during early spring at maximum ice thickness. Decomposition rates in bottom sediments are probably very low and are not sufficient to cause reductions in oxygen concentration that would pose a risk to resident biota.

The headwater nature of the lakes, lack of tributary streams, and small drainage area strongly influence limnology of the project lakes. Given the absence of streams and low sediment and nutrient additions into the lakes, limnological conditions tend to be very stable, with uniform vertical temperature, oxygen, and nutrient distributions. Biological productivity of the lakes, reflected in growth and biomass of plankton and fish, is limited by nutrient availability and not by lack of availability or abundance of physical habitat features. Results of habitat mapping and quantification of project lakes (Fish Habitat Assessment Report, 2005) indicates that all lakes have complex shoreline and shoal features. There appears to be sufficient and abundant habitats for all fish species to accomplish all major life history functions including spawning, nursery, rearing, foraging, and overwintering.

5.1.2 Reference Lakes

Limnological parameters of the south basin of Third Portage and Inuggugayualik lakes were very similar to project area lakes. In early July 2002 (Figure 5.1a), water temperature of Third Portage south basin (TP-SS; i.e., Third Portage south [S] basin, spring [S]) was several degrees colder than the other basins and project lakes. This was presumably due to the great depth (>30 m) and large volume of the south basin, which requires more energy to heat. Maximum summer water temperatures of the south basin are also slightly lower than in the north (TP-N) and east (TP-E) basins, which have a shallower mean depth (<12 m).

During May 2002, water temperature below the ice-water interface was 1.9°C in Third Portage south basin (internal reference lake; Figure 5.1a) and 1.7°C in Inuggugayualik Lake (external reference lake; Figure 5.1f). Oxygen concentration was particularly high in late winter just under the ice in Inuggugayualik Lake (17 mg/L), reflecting the early oxygen contribution by photosynthetic algae.

Temperature profiles were very similar among all Meadowbank project area and reference lakes with isothermal temperature and oxygen profiles during nearly all sampling episodes, reflecting the near-continuous turnover of the lakes. Oxygen concentrations were high (> 10 mg/L) in deep water in all lakes, confirming that winter oxygen depletion is not occurring.

5.1.3 Regional Lakes

Other lakes examined by the BAEAR include Snap Lake (De Beers, 2002), Baker Lake and Kiggavik area lakes (McLeod et al, 1976; Urangesellshaft, 1981; McKee et al, 1989), Koala area lakes (Rescan, 1994), Lac de Gras and Lac du Sauvage (Diavik and Aber, 1998), and lakes from the Great Slave Lake region (Fee et al, 1985). These Arctic lakes have similar limnological characteristics as Meadowbank project lakes.

Snap Lake is a shallow (mean depth of 5.2 m), clear, soft-water lake, with moderate to low nutrient concentration and neutral to slightly acidic pH (De Beers, 2002) and is not as oligotrophic in nature as the project lakes. Nevertheless, Snap Lake has similar physical properties, as it is well mixed in the summer, with only minor vertical stratification observed in July (2 to 3°C), and none in August (fall). Water temperatures ranged from a maximum of 14.7°C at the surface to 11.5°C at 6 m depth. Dissolved oxygen concentration was high and fully saturated, even in winter.

Baker Lake is a large lake with an area of about 1,700 km^2, approximately 280 km west of Hudson Bay at the head of Chesterfield inlet (McLeod, 1976) and 70 km south of the project lakes. Information from this lake is presented because of its proximity to the project lakes, in spite of some limnological differences (e.g., large size, marine influence on bottom). The range in water temperatures observed in summer in Baker Lake was similar in magnitude and pattern as observed in the study lakes, with a maximum of 15.5°C in mid-August and high dissolved oxygen concentration. Some vertical stratification in temperature was observed because of the deep depth of the lake and higher salinity in bottom water (McLeod et al, 1976).

Lakes monitored in the Kiggavik area as part of baseline studies for the proposed Kiggavik uranium project included several lakes with similar limnological characteristics as the Meadowbank study lakes, except that they are smaller and probably have a shallower mean depth. The lakes from which data were gathered for comparative purposes include Kavisilik (564 ha), Squiggly (638 ha), Caribou

(341 ha), Judge Sissons (9,550 ha), Skinny (197 ha), Scotch (195 ha), Pointer (374 ha), and Jaeger (McKee et al, 1989). All of these lakes share similar limnological characteristics in that they become ice-covered from September to June (small lakes) or July (large lakes). During summer the lakes are cold, clear, and isothermal, with neutral to slightly acidic pH values. Secchi depth values ranged up to 8.5 m in Judge Sissons Lake. Temperature and dissolved oxygen profiles from Judge Sissons Lake (1980) showed slight, ephemeral stratification of the water column during brief periods during the ice-free months. Oxygen concentrations were high and fully saturated at all times (Urangesellshaft, 1981; McKee et al, 1989).

Data from lakes in the Koala region (Rescan, 1994; Figure 2.1) include Koala, Kodiak, Long, Little, Fox3, and others. These lakes are also cold, clear, and oligotrophic. Surface water temperatures in summer months ranged from 9.4°C to 15.4°C while Secchi depth ranges to 8.0 m (Rescan, 1994).

Lac de Gras is a large headwater lake with high transparency (Secchi depths of 8 to 10 m), low dissolved solids, and hardness. It is nutrient poor and therefore ultra-oligotrophic. Like the other lakes, Lac de Gras is also isothermal with a similar ice-free season and temperature range (Diavik and Aber, 1998).

These data from widely different geographic areas of the Arctic indicate that project and reference lakes are typical, sharing similar limnological features. There do not appear to be major differences in important limnological parameters within lakes, among seasons, between lakes, or by geographic location.

5.2 WATER CHEMISTRY

In general, the methods used to collect water between 1996 and 2003 were similar among years. Water samples were collected either by pumping water from depth using weighted C-flex (food-grade silicone) tubing and a diaphragm pump, or from the surface by hand. Ultraclean techniques (USEPA, 1996) were employed to minimize contamination. Water samples were always collected first, before the collection of other environmental media, such as sediment or benthos, to eliminate contamination of the water column. In advance of water sample collection, a Global Positioning System (GPS) (NAD 83) position was recorded, in addition to total depth (m). Then, vertical temperature and oxygen profiles were acquired to determine the depth at which water samples would be taken. Water samples were pumped from either discrete depths (e.g., 3 m) or integrated over the top 8 to 10 m, depending on whether there was any observed difference in vertical temperature profiles. On some occasions, when lake water was very well mixed, surface water samples were simply collected by hand-submerging sampling vessels 30 cm below the water surface. Water samples for nutrients and metals analysis were preserved with appropriate acids and held on ice prior to analysis.

Water samples for determination of dissolved constituents (e.g., solids, dissolved organic carbon (DOC), metals) were obtained by filtering the pumped water with an inline filter unit (Gelman 0.45 µm pore size) that was discharged directly into the appropriate vessel. Alternatively, filtration was carried out in the laboratory prior to analysis. All water samples were analyzed for conventional parameters (hardness, anions, pH), nutrients (nitrate, nitrite, ammonia, phosphorus), dissolved organic carbon, total dissolved solids (TDS), and total and dissolved metals concentrations (mg/L). Total (i.e., from a non-filtered sample) and dissolved solids concentrations and/or turbidity (NTU) data were collected periodically. Water was also measured for cyanide speciation in 1997, 1998, and 2002. ALS Laboratories, Vancouver conducted all water chemistry analyses between 1996 and 2003.

Metals concentrations were compared against each other, as well as to the federal Canadian Council of Ministers of the Environment (CCME, 2001) surface water quality guidelines. These guidelines are intended to protect aquatic life from chronic exposure to anthropogenic contaminants or physical stressors (suspended solids, temperature). CCME guidelines are, by nature, conservative and have been developed to protect the most sensitive life history stages (e.g., eggs and larvae). The CCME values are guideline concentrations and, by definition, are not meant to imply that adverse effects will necessarily be seen in the event that a single parameter exceeds a threshold concentration.

Water samples were collected at different locations (Figure 4.1) and depths within each of the lakes among years. However, given that the water column is generally very well mixed, notable differences in water quality parameters with differences in depth or geographic location were not expected and were not detected. The great similarity in nearly all water quality parameters regardless of depth, location, season, or year is a reflection of the considerable homogeneity in water quality parameters.

5.2.1 Conventional Parameters

5.2.1.1 Project Lakes

Conventional water quality parameters measured in project, reference, and regional lakes include pH, hardness, anions, total and dissolved solids concentrations, and nutrients, including dissolved organic carbon (DOC), nitrogen nutrients (ammonia, nitrate, and nitrite), and phosphorus (total phosphorus, dissolved phosphorus). Conventional chemistry of all lakes, including reference areas (i.e., Third Portage Lake south basin, internal reference; and Inuggugayualik Lake, external reference) between 1996 and 2002 was remarkably similar (Table 5.1) and typical of oligotrophic, Arctic lakes (Wetzel, 1983). There were no meaningful differences in any parameter related to season or among lakes and years. In fact, surface water quality of the study lakes closely resembled distilled water, with many parameters at or below detection limits.

Total and dissolved solids in surface waters were also low, typically below laboratory detection (<1 mg/L and <10 mg/L, respectively), as was turbidity (<1.1 NTU). Hardness (4.4 to 9.5 mg/L) and dissolved anions (chloride, fluoride, sulphate) were also very low (<0.05 to 0.06 mg/L) and near detection limits. Surface water had circum-neutral pH (6.6 to 7.7) and low conductivity (5 to 77 µS/cm). Secchi depth of all project lakes frequently exceeded 6 m and on calm days, exceeded 10 m depth.

Table 5.1: Mean Conventional Water Chemistry Parameters & Selected Total Metals Concentrations in Project, Reference & Regional Arctic Lakes

	CCME Drinking Water Quality Guidelines	CCME (2002) Aquatic Life Guidelines	PROJECT LAKES																				REFERENCE LAKES								
			Third Portage Lake							Second Portage Lake							Other Project Lakes*						Third Portage South Basin				Inuggugayualik Lake				Amarulik
			1996	1997	1998	2002(J)	2002(A)	2003(M)	2003(A)	1996	1997	1998	2002(J)	2002(A)	2003(M)	2003(A)	1997	1998	2002(J)	2002(A)	2003(M)	2003(A)	1997	2002(J)	2002(A)	2003(M)	1998	2002(J)	2002(A)	2003(M)	1998
			(n=1)	(n=2)	(n=1)	(n=5)	(n=5)	(n=3)	(n=1)	(n=1)	(n=1)	(n=2)	(n=3)	(n=4)	(n=2)	(n=1)	2 Lakes (n=2)	1 Lakes (n=3)	6 Lakes (n=7)	6 Lakes (n=7)	5 Lakes (n=5)	3 Lakes (n=3)	(n=1)	(n=1)	(n=1)	(n=1)	(n=1)	(n=1)	(n=1)	(n=1)	(n=1)
CONVENTIONAL PARAMETERS																															
PH	6.5 – 8.5	6.5 - 9.0	6.92	6.85	6.52	6.62	6.93	6.84	7.34	7.14	6.50	6.79	7.86	7.29	7.19	7.26	6.60	–	6.96	7.25	7.29	7.61	6.70	6.64	6.92	6.61	7.2	6.82	7.07	6.67	6.61
Total Dissolved Solids (mg/L)			<10	<10	<10	–	10	12	13	11	<10	17	–	12	14	11	11	–	–	18	26	27	12	–	<10	<10	12	–	<10	13	10
Total Suspended Solids (mg/L)			<1	<1	<1	–	<3	<3	<3	<1	<1	<1	–	3	<3	<3	1	–	–	<3	3	3	<1	–	<3	<3	<1	–	<3	<3	<1
Hardness (mg/L)			4.57	4.71	4.41	4.7	4.6	6.4	4.8	6.94	5.19	7.61	7.9	8.5	10.7	8.7	8.63	4.90	10.61	10.18	17.38	19.90	4.38	4.9	4.7	5.1	4.5	5.3	5.3	6.2	5.66
Nutrients (mg/L)																															
Ammonia Nitrogen			<0.005	0.03	<0.02	0.02	0.02	0.005	<0.02	<0.005	0.03	<0.02	0.02	0.036	0.005	<0.02	0.02	<0.02	0.03	0.03	0.01	0.02	0.03	<0.02	<0.02	0.006	<0.02	<0.02	0.03	0.015	<0.02
Nitrate Nitrogen			<0.005	<0.005	<0.005	<0.005	<0.005	0.008	<0.005	<0.005	<0.005	<0.005	<0.005	0.012	0.005	<0.005	<0.005	<0.005	0.04	<0.005	0.02	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.009	<0.005
Total Phosphorus			0.002	0.002	0.002	0.002	0.003	0.002	<0.002	0.001	0.005	0.002	0.003	0.002	0.002	0.002	0.002	0.004	0.003	0.003	0.003	0.003	0.002	0.002	0.003	<0.002	<0.001	0.002	0.003	0.002	0.004
Total Dissolved Phosphorus			<0.001	0.003	0.001	–	–	<0.002		<0.001	0.001	0.002	–	–	<0.002		0.001	0.002	–	–	<0.002	-	0.002	–	–	<0.002	<0.001	–	–	<0.002	0.001
Organic Parameters (mg/L)																															
Dissolved Organic Carbon			2.3	2.2	1.8	1.2	1.4	1.8	0.8	2.1	1.9	2.2	1.5	1.7	1.8	-	2.3	1.8	1.8	1.9	2.5	2.0	1.9	1.2	1.3	1.5	2.4	1.9	2.2	2.1	3.1
TOTAL METALS (mg/L)																															
Aluminum	NG	0.1	0.011	0.008	0.012	0.006	0.006	<0.005	0.008	0.020	0.008	0.010	0.007	0.008	<0.005	0.005	0.011	0.016	0.010	0.005	0.006	0.009	0.006	<0.005	<0.005	<0.005	0.012	0.01	0.007	<0.005	0.013
Antimony	0.006	NG[A]	<0.0001	<0.00005	<0.00005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	<0.00005	<0.00005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00005	<0.00005	<0.0005	<0.0005	<0.0005	<0.0005	<0.00005	<0.0005	<0.0005	<0.0005	<0.00005	<0.0005	<0.0005	<0.0005	<0.00005
Arsenic	0.025	0.005	<0.0001	<0.0001	<0.0001	<0.0005	<0.0005	<0.0005	<0.0005	<0.0001	<0.0001	0.0001	<0.0005	<0.0005	<0.0005	<0.0005	0.00015	<0.0001	<0.0005	<0.0005	<0.0005	0.000633	<0.0001	<0.0005	<0.0005	<0.0005	<0.0001	<0.0005	<0.0005	<0.0005	<0.0001
Cadmium[B]	0.005	0.000026	<0.0002	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.0002	<0.00005	<0.00005	<0.00005	0.00005	<0.00005	<0.00005	<0.00005	0.00005	0.00005	0.00019	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.0001	<0.00005	<0.00005	<0.00005	<0.00005
Chromium[C]	0.05	0.001	<0.001	<0.0005	<0.0005	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0005	<0.0005	<0.001	<0.001	<0.001	<0.001	<0.0005	<0.0005	<0.001	<0.001	<0.001	<0.001	<0.0005	<0.001	<0.001	<0.001	<0.0005	<0.001	<0.001	<0.001	<0.0005
Copper	<1.0	0.002	<0.001	0.0004	0.0004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0005	0.0005	<0.001	<0.001	<0.001	<0.001	0.0008	0.0004	<0.001	<0.001	0.0015	<0.001	0.0004	<0.001	<0.001	<0.001	0.0004	<0.001	<0.001	<0.001	0.0010
Lead	0.01	0.001	<0.001	0.0001	<0.00005	<0.0005	0.0005	<0.0005	<0.0005	<0.001	0.0001	<0.00005	<0.0005	0.0012	0.0006	<0.0005	0.0001	0.0001	0.0013	0.0007	0.0010	<0.0005	<0.00005	<0.0005	<0.0005	<0.0005	0.00005	<0.0005	<0.0006	<0.0005	<0.00005
Mercury	0.001	0.0001	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005
Nickel	NG	0.025	<0.001	0.0004	0.0003	<0.001	<0.001	<0.001	<0.001	<0.001	0.0002	0.0003	<0.001	<0.001	<0.001	<0.001	0.0006	0.0002	<0.001	<0.001	0.0015	0.0017	0.0004	<0.001	<0.001	0.0020	0.0003	<0.001	<0.001	<0.001	0.0005
Zinc	<5.0	0.03	<0.005	0.004	0.001	<0.005	<0.005	<0.005	<0.005	<0.005	0.019	<0.001	<0.005	<0.005	<0.005	<0.005	0.005	0.001	0.010	<0.005	0.009	<0.005	0.002	<0.005	<0.005	<0.005	0.002	<0.005	<0.005	<0.005	0.001

Notes: A. NG = no guideline. **B.** Cadmium guideline developed using the lowest hardness value. **C.** Chromium guideline is for Cr VI. **B** and **C** give the most conservative guidelines. **D.** Candidate Reference Lake. Shaded concentrations exceed CCME guideline.

* **1997**: Tehek, Vault 3. **1998**: Tehek. **2002(J):** Tehek, Tern, Vault 1,2,3, Farside. **2002(A):** Tehek, Tern, Vault 1, 2, 3, Farside. **2003(M):** Tehek, Tern, Vault 1, 2, 3. **2003(A):** North Port1, North Port2, North Port3.

References: 1. Urangesellschaft, 1981. **2.** McKee et al, 1989. **3.** McLeod et al, 1976. **4.** Diavik and Aber, 1998. **5.** De Beers, 2002.

Table 5.1 – Continued

	CCME Drinking Water Guidelines	CCME (2002) Aquatic Life Guidelines	REGIONAL LAKES															
			Kiggavik Region**				Baker Lake		Lac de Gras[4]			Lac du Sauvage[4]			Snap Lake[5]		
			1980 [1]	1986 [2]	1988 [2]	1989 [2]	1975 [3]	1989 [2]	Sep-94	Aug-95	Aug-96	Sep-94	Aug-95	Aug-96	1998	1999	2001
			6 Lakes (n=6)	5 Lakes (n=5)	5 Lakes (n=8)	4 Lakes (n=6)	(n=13)	(n=3)	(n=8)	(n=23)	(n=9)	(n=1)	(n=2)	(n=3)	(n=8)	(n=16)	(n=9)
CONVENTIONAL PARAMETERS																	
PH	6.5 – 8.50	6.5 – 9.0	5.92	6.10	6.67	6.66	6.86	7.17	5.84	6.22	6.06	5.86	6.11	6.03	6.8	6.5	6.7
Total Dissolved Solids (mg/L)			-	23	<10	24	77	73	6	8	7	10	9	6	13	15	30
Total Suspended Solids (mg/L)			-	-	2	4	1.3	4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<3	<3	<3
Hardness (mg/L)			-	-	5.4	5.3	25	18.8	-	-	4.5	-	-	4.4	4	6	6
Nutrients (mg/L)																	
Ammonia Nitrogen			-	-	0.052	0.041	-	0.034	<0.01	<0.01	0.05	<0.01	<0.01	0.05	0.004	0.028	<0.005
Nitrate Nitrogen			-	0.009	0.14	0.01	-	0.03	<0.003	<0.003	-	<0.003	<0.003	-	-	-	0.02
Total Phosphorus			-	0.002	0.007	0.003	0.06	0.007	0.003	0.004	<0.003	0.003	0.011	<0.003	0.004	0.011	0.003
Total Dissolved Phosphorus															-	0.009	<0.001
Organic Parameters (mg/L)																	
Dissolved Organic Carbon			-	-	4.98	2.69	-	2.6	2.2	2	2.1	2.3	2.4	2.5	-	3	4
TOTAL METALS (mg/L)																	
Aluminum	NG	0.1	-	0.024	0.038	0.021	-	0.015	0.040	<0.01	0.044	0.090	0.010	0.042	0.0069	<0.0300	0.0095
Antimony	0.006	NG[A]	-	-	-	-	-	-	-	-	-	-	-	-	0.001	0.001	<0.00003
Arsenic	0.025	0.005	<0.0002	<0.001	<0.001	<0.001	-	<0.001	<0.0002	-	<0.0002	0.0002	-	<0.0002	-	<0.0002	<0.00003
Cadmium[B]	0.005	0.000026	0.00200	<0.01	0.00030	0.00080	-	0.00030	<0.003	<0.003	<0.0002	<0.003	<0.003	<0.0002	<0.0001	<0.0001	<0.0001
Chromium[C]	0.05	0.001	<0.5	<0.01	0.003	0.001	-	<0.001	0.003	<0.002	0.007	0.016	<0.002	0.007	0.0003	<0.002	<0.00006
Copper	<1.0	0.002	0.0010	0.0050	0.0013	0.0008	-	<0.0005	<0.001	<0.001	0.0015	<0.001	0.0030	0.0010	0.0014	0.0010	0.0006
Lead	0.01	0.001	0.0020	<0.05	0.0008	0.0008	-	<0.0005	<0.02	<0.02	<0.0003	<0.02	<0.02	<0.0003	0.0003	0.0008	0.0002
Mercury	0.001	0.0001	0.00002	0.00003	<0.00005	0.00005	-	<0.00005	<0.00005	-	<0.00005	<0.00005	-	<0.00005	<0.00001	<0.00001	<0.00002
Nickel	NG	0.25	-	<0.01	0.0018	<0.001	-	<0.001	0.0060	<0.005	0.0038	0.0250	<0.005	0.0025	0.0002	0.0004	0.0002
Zinc	<5.0	0.03	0.003	<0.01	<0.005	<0.005	-	<0.005	0.005	0.007	<0.0006	0.006	0.013	0.001	0.0024	<0.010	0.0013

Notes: A. NG = no guideline. **B.** Cadmium guideline developed using the lowest hardness value. **C.** Chromium guideline is for Cr VI. **B** and **C** give the most conservative guidelines. **D.** Candidate Reference Lake. Shaded concentrations exceed CCME guideline.

** **1980**: Jaeger, Kavisilik, Pointer, Scotch, Sissons, Squiggly. **1986**: Caribou, Pointer, Scotch, Sissons, Skinny. **1988**: Jaeger, Pointer, Scotch, Sissons, Skinny. **1989**: Jaeger, Pointer, Sissons, Skinny.

References: 1. Urangesellschaft, 1981. **2.** McKee et al, 1989. **3.** McLeod et al, 1976. **4.** Diavik and Aber, 1998. **5.** De Beers, 2002.

Nutrient concentrations (nitrogen, carbon, phosphorus) in the study lakes were very low (Table 5.1) and equivalent to values typical of oligotrophic lakes (Wetzel, 1983). Nutrient concentrations did not differ appreciably within or between lakes and seasons, and most values only slightly exceeded laboratory detection limits. Nitrogen nutrients (nitrate, nitrite, ammonia, dissolved phosphate) seldom exceeded 0.001 mg/L, while dissolved phosphate ranged from <0.001 to 0.003 mg/L. Dissolved organic carbon (DOC) values ranged from 1.4 to 2.3 mg/L over all lakes between 1996 and 2002.

5.2.1.2 Reference Lakes

Conventional chemistry (anions, pH, hardness, turbidity, solids concentrations) parameters in reference lakes (i.e., Third Portage south basin, internal reference; and Inuggugayualik Lake, external reference) between 1997 and 2002 were similar to conventional data from project lakes (Table 5.1). Values were typical of oligotrophic Arctic lakes. Nutrient concentrations were also below or slightly above detection limits, and were similar to project lakes.

5.2.1.3 Regional Lakes

Conventional water chemistry values from other lakes, including Snap Lake, Kiggavik lakes, Lac de Gras, and Lac du Sauvage, were similar in magnitude to study lakes (Table 5.1). For example, hardness (6 to 30 mg/L) and total suspended solids (<0.4 to 4 mg/L) concentration in regional lakes was equivalent to or slightly higher than values from project lake values (Table 5.1). Water pH values were similar for most lakes; however, some lakes were more acidic (Lac de Gras, Lac du Sauvage, some Kiggavik lakes) exhibiting pH values of <6.5.

Nutrient concentrations from regional lakes were similar to or slightly higher than project lakes. For example, maximum ammonia and nitrate concentrations of project area lakes were 0.034 mg/L and 0.030 mg/L, respectively, which is lower than values found in lakes from other regions (0.052 mg/L and 0.140 mg/L, respectively). Maximum total phosphorus was 0.005 mg/L in project lakes, which is also lower than the maximum value (0.011 mg/L) for regional lakes. Total phosphorus concentration in Lac de Gras was also less than 0.005 µg/L, indicating that it is ultra-oligotrophic and very nutrient poor, similar to Meadowbank project lakes. Similarly, DOC concentration ranged from 1.2 to 2.4 mg/L in the Meadowbank project lakes and was comparable to but slightly lower than levels found in regional lakes (2.0 to 5.0 mg/L).

These data corroborate the limnological data in confirming that water quality of the project lakes is extremely high and characteristic of pristine waters unaffected by development activities of any kind. Project lakes generally have lower conventional chemistry and nutrient values than regional lakes, reflecting their highly oligotrophic status, which is to be expected of headwater lakes in remote locations in Nunavut Territory.

5.2.2 Metals

5.2.2.1 Project Lakes

Total and dissolved metals concentrations in surface waters from project lakes from multiple stations, seasons, lakes, and years showed remarkable similarity (Table 5.1). A limited suite of metals is presented in this report, focussing on metals for which there are CCME (2001) guideline concentrations. Also, only total metal concentrations are provided, as dissolved concentrations are always lower and comprise the vast majority of metals in the water column because of the very low suspended solids concentrations.

Mean total antimony, arsenic, chromium, copper, mercury, and nickel concentrations from Third Portage, Second Portage, and the other project lakes were all below laboratory detection limits and, with the exception of cadmium, were well below CCME (2001) water quality guidelines for the protection of aquatic life. The only metals to exceed detection limits were aluminum (0.006 to 0.014 mg/L), lead (up to 0.0012 mg/L), and zinc (0.001 to 0.019 mg/L). Lead marginally exceeded surface water quality guidelines (Table 5.1) from a few stations in 2002. The cadmium concentration, although non-detectable, is above the extremely low CCME hardness adjusted guideline concentration. This concentration is more than 100 times lower than the concentration that caused minimal toxicity to the most sensitive test organism (CCME, 2002). Thus, although the detection limit for cadmium exceeds the purported guideline value, there result has no relevance. These data indicate that metal concentrations in surface water of all project lakes are extremely low and do not differ geographically within or between lakes or temporally, between seasons and years.

Other metals and metalloids that were measured, but not presented here, include barium, beryllium, boron, calcium, cobalt, iron, lithium, magnesium, manganese, molybdenum, potassium, selenium, silver, sodium thallium, tin, uranium, and vanadium. Nearly all of these parameters were below their appropriate detection limits (ranging from <0.01 to <0.0005 mg/L) for total and dissolved parameters at all stations during all seasons and years. The only exceptions to this were common ions calcium and magnesium.

Water was also measured for cyanide speciation including total cyanide (<0.005 mg/L), cyanate (<0.5 mg/L), thiocyanate (<0.5 mg/L), and weak acid digestible (WAD) cyanide (<0.005 mg/L) from select locations in 1997 and at all project lake water quality sampling stations in 2002. All cyanide species concentrations were below laboratory detection limits for all lakes in all years.

Dissolved metals concentrations comprised the vast majority of total metals concentrations where results exceeded detection limits, indicating that nearly all metals are dissolved and not associated with particulates. This trend is supported by the empirical data on total suspended solids and turbidity (Table 5.1).

None of the parameters measured in water (conventional parameters and metals) from any lake at any time exceeded any of the interim maximum allowable or aesthetic drinking water quality guideline.

5.2.2.2 Reference Lakes

Metal concentrations in Third Portage Lake south basin were very similar to concentrations found elsewhere in Third Portage Lake and the other project lakes. Because of frequent, strong winds in the study area, all of the lakes are very well mixed both vertically and over broad spatial scales, so the uniformity in parameters is to be expected. Metal concentrations in water in Inuggugayualik Lake were also very low and below detection for most metals. Although Inuggugayualik is within a different watershed (i.e., an Arctic watershed), there was no difference in metal concentrations in water between the external reference lake and the project lakes. The similarity in regional geology, headwater nature, latitude, and climatic conditions is responsible for this similarity.

Water metals concentrations indicate that water quality of the study and reference lakes is high, as would be expected given the remote location and absence of anthropogenic activities. Given that the project lakes are situated in the uppermost reaches of the Quoich River system, they do not receive inputs from upstream lakes or streams that might carry suspended and dissolved solids into the study lakes. Therefore, all inputs into the lakes are restricted to the immediate vicinity of the lakes within very small watersheds and help to explain why the lakes are so oligotrophic, nutrient poor, and relatively unproductive.

5.2.2.3 Regional Lakes

Mean total metals concentrations from Snap Lake, Baker Lake, Kiggavik region lakes, Lac de Gras, and Lac du Sauvage were all comparable to or slightly higher than levels observed from Meadowbank project area lakes. Concentrations of arsenic, mercury, nickel, and zinc were below or near laboratory detection limits and did not exceed CCME (2001) water quality guidelines. Only aluminum (<0.010 to 0.044 mg/L) and cadmium (up to 0.002 mg/L) exceeded detection limits. There were minor exceedences of CCME guidelines at a few stations for chromium in Kiggavik, Lac de Gras, and Lac du Sauvage; for cadmium (because of high detection limit relative to guideline), copper in Kiggavik and Lac du Sauvage; and for lead in Kiggavik Lake (Table 5.1). This was also the case in the Doris North lakes (Nunavut), where concentrations of aluminum, iron, copper, cadmium, chromium, lead, and manganese exceeded water quality guidelines on a seasonal basis (AMEC, 2003).

These data indicate that water-borne metals concentrations in Meadowbank project area lakes are generally low and comparable to metals concentrations in lakes elsewhere in the territories and are consistent over broad temporal and spatial scales (Table 5.1). Marginal exceedences of CCME water quality guidelines for a few metals from Meadowbank and regional lakes reflect regional geochemistry and the highly mineralized nature of the sediments and underlying bedrock.

5.3 SEDIMENT CHEMISTRY

Sediment is an important sink for most contaminants, including metals. Contaminants entering aquatic systems via tributary streams or directly from local sources are often associated with suspended particulate matter in the water column. Particulates eventually settle in depositional areas as sediment, especially in deeper areas of lakes. Measuring water for the presence of contaminants, such as metals, is not necessarily as indicative as measuring sediments, because sediments provide a long-term, temporal record of deposition, integrating concentrations over time and provide more than just snapshots of water quality. Low concentrations of water-borne contaminants that may meet relevant water quality criteria can be associated with elevated concentrations in sediments that exceed sediment quality guidelines. Sediments, therefore, act as accumulators of contaminants over time in aquatic systems and can become a sink as well as potential source of contaminants within a system. The degree to which sediments function this way depends on the contaminant and physical condition of the environment (temperature, redox, pH, grain size, etc.).

Sediment samples were acquired using available, proven sample collection and handling techniques (Environment Canada, 1984; PSEP, 1997) and QA/QC procedures. Sediment was collected from all stations using a petite ponar grab (sampling area of 0.026 m^2). Typically, at least three grabs were composited from each station to account for variability by reducing heterogeneity within stations. Sediments were collected after collections of benthic invertebrates were made to avoid possible disturbance of biota.

Only those grab samples that met the following acceptability criteria were retained for analysis: did not contain large foreign objects; adequate penetration depth (i.e., >10 cm); not overfilled (sediment surface not touching the top of sampler); did not leak (there was overlying water present and no visible leaks); and was undisturbed (sediment surface was relatively flat). Grabs that did not satisfy these conditions were discarded.

Overlying water was removed from acceptable grabs and a description of the sediment was recorded, including: colour, odour, grain size, and the presence of other materials (e.g., organic debris, vegetation, biota). The upper 5 cm of sediment was removed from the surface of acceptable grab samples with a pre-cleaned stainless steel spoon and homogenized in a stainless steel bowl until the sediments had a uniform consistency.

Pre-cleaned stainless steel utensils were used to completely fill (i.e., no head space) 250 mL glass sample jars. Jars were sealed and placed in a cooler with ice packs. Jars were kept on ice and transported to ALS in Vancouver for analysis.

Sediments were analyzed for total metals concentration (mg/kg dw), moisture content, total organic carbon (TOC), and grain size (% gravel, sand, silt, and clay). A subset of stations within Third Portage and Second Portage lakes was also examined for acid volatile sulphides (AVS) and simultaneously extractable metals (SEM) concentrations (µmoles/g). The difference between AVS and SEM has been used to determine the potential or capacity for sediments to chemically bind available metals (such as cadmium, lead, and zinc) and render them less available to biota.

Similar to water parameters, sediment quality guideline (SQG) concentrations for metals have also been developed by CCME (2001); these guideline concentrations were compared against values from project and reference lakes. SQG concentrations have been divided into two categories: Interim Sediment Quality Guidelines (ISQG) and Probable Effects Level (PEL) concentrations. ISQGs are conservative values that have been derived from available toxicological information and a weight-of-evidence approach to determine the minimum concentration at which adverse effects have been observed in the literature. The PEL is less conservative and represents a concentration at which adverse effects are frequently observed, based on laboratory studies. However, exceedences of the ISQG or the PEL concentration do not necessarily mean that adverse effects will be observed, as many factors can influence this such as adaptation by animals to naturally high background concentrations (that exceed the PEL), and other substances in the sediments that may bind and make metals less bioavailable (e.g., sulphides, iron hydroxides, TOC). At Meadowbank, all sediment metals concentrations observed can be regarded as background because of the near absence of anthropogenic activities.

5.3.1 Project Lakes

Grain size of project lake sediment at water depths greater than 8 m was reasonably consistent between lakes and years and was dominated by fine sediments (clay 50% to 70%; silt 25% to 40%), with some sand (2% to 14%), and no gravel (Table 5.2). The consistency in grain size within the project lakes is, in part, because sediment was acquired from consistent depths, especially in 2002 (i.e., between 8 and 10 m) and because of similar hydrodynamic regimes (i.e., low energy) among lakes. At shallower depths, sediment grain size increased and was comprised of boulder and cobble at depths less than 5 m and often had a layer of fine sediment draped over coarse materials. Because of the absence of sediment input from tributary streams, it is expected that grain size would be very fine because of the lack of hydraulic energy needed to transport and deposit larger grain material.

Mean total organic carbon (TOC) content of the sediment ranged between approximately 2.5% to 5.2% in the Meadowbank project lakes. These levels are reasonably high for such an oligotrophic system and illustrate the small amount of inorganic contributions to the lakes that might dilute organic materials if sedimentation rates were higher. Again, the low sedimentation rate is primarily because the study lakes are headwater lakes, with no stream sources of sediments.

Total metals concentration in project lake sediment was very consistent within and between project lakes and among years (Table 5.2). This result indicates that the erosional and geochemical processes within each lake are similar and that sediment of one particular lake is not significantly more or less mineralized than another lake. When metals concentrations were compared against CCME (2001) ISQG and PEL guidelines for arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc, several guideline concentrations were exceeded, despite the pristine nature of the lakes. Exceedences of these guideline values does not necessarily imply that adverse effects have occurred or are expect to occur. The ISQG and PEL guidelines are relatively conservative and do not reflect site-specific conditions that may limit metals availability to biota. In addition, the guidelines do not consider regional geochemistry or acclimatization by benthic organisms to regional characteristics.

Arsenic, chromium, and nickel in project lakes exceeded PEL concentrations in nearly all lakes over all years that sediment was collected, while cadmium, copper and zinc concentrations exceeded ISQG values at the majority of lakes in most years (Table 5.2). These data indicate that metals concentrations are generally similar across the area, and reflect the natural, mineralized nature of the sediments.

Similar to water chemistry data, this document focuses on metals for which there are guideline criteria. In addition to the sediment metals data presented in Table 5.2, metals concentration data were measured for several metals for which there are no federal guideline values. Concentrations of barium (102 to 382 g/kg), beryllium (1 to 2.4 mg/kg), cobalt (11 to 24 mg/kg), molybdenum (4 to 22 mg/kg), selenium (<2 mg/kg), silver (<2 mg/kg), thallium (<1 mg/kg), tin (<5 mg/kg), and vanadium (40 to 63 mg/kg) were also measured from across the project lakes.

5.3.2 Reference Lakes

Sediment grain size in the reference lakes—Third Portage south basin and Inuggugayualik Lake—was dominated by fine grain (clay/silt) material, comprising >90%, with only small fractions of sand,

Table 5.2: Mean Conventional & Total Metals Concentrations in Sediments from Project, Reference & Regional Arctic Lakes

	Sediment Quality Guidelines		PROJECT LAKES												REFERENCE LAKES					REGIONAL LAKES						
			Third Portage Lake				Second Portage Lake				Other Project Lakes*				Third Portage South Basin		Inuggugayualik		Amarulik[B]	Kiggavik Study Area[1]**			Lac de Gras[2]	Lac du Sauvage[2]	Snap Lake[3]	Snap Ref. Lake[3]
			1996	**1997**	**1998**	**2002**	**1996**	**1997**	**1998**	**2002**	**1997**	**1998**	**2002**	**2003**	**1997**	**2002**	**1998**	**2002**	**1998**	**1979**	**1986**	**1988**	**Sep-96**	**Sep-96**	**1999**	**1999**
	ISQG	**PEL**									**2 Lakes**	**1 Lakes**	**5 Lakes**	**3 Lakes**						**4 Lakes**	**4 Lakes**	**2 Lakes**	Range	Range		
	(CCME, 2001)		(n=1)	(n=2)	(n=1)	(n=5)	(n=1)	(n=1)	(n=2)	(n=3)	(n=2)	(n=2)	(n=11)	(n=3)	(n=1)	(n=1)	(n=1)	(n=2)	(n=1)	(n=4)	(n=4)	(n=5)	(n=6)	(n=3)	(n=4)	(n=4)
CONVENTIONAL PARAMETERS																										
Organic Parameters																										
Total Organic Carbon (% dw)	NA	NA	2.59	2.62	3.28	2.87	0.79	2.88	2.50	5.19	3.56	3.56	4.64	7.97	2.13	0.96	2.37	3.79	1.63	-	7.53	13.8	0.38 -2.05	0.95 - 1.47	12.5	16.0
Particle Size																										
Gravel (>2.00 mm) (%)	NA	NA	-	-	<0.1	0.1	-	<0.1	<0.1	<0.1	<0.1	<0.1	0.73	<0.1	<0.1	0.8	<0.1	0.1	<0.1	-	-	-		-	-	-
Sand (2.00 mm - 0.063 mm) (%)	NA	NA	-	3.1	4.1	6.1	-	6.5	14.2	5.5	3.3	9.1	7.2	4.0	2.1	42.6	9.9	6.2	46.9	-	-	46.9		-	77.5	76.5
Silt (0.063 mm - 4 µm) (%)	NA	NA	-	28.2	25.9	31.1	-	26.0	34.4	35.8	30.9	40.6	38.5	39.5	26.7	24.9	50.6	36.3	27.1	-	-	41.6		-	21.5	22.5
Clay (<4 µm) (%)	NA	NA	-	68.8	70.0	62.8	-	67.5	49.9	58.7	65.9	50.4	53.9	56.5	71.2	31.7	39.5	57.6	26.0	-	-	11.5		-	1.0	1.0
TOTAL METALS (mg/kg dw)																										
Aluminum	NG[A]	NG	-	-	-	-	-	-	-	-	-	-	-	-						-	9,550	12,975	5,627 - 14,500	9,562 - 16,533	12,500	12,000
Antimony	NG	NG	0.39	<40	<40	<10	0.21	<40	<40	<20	<40	<40	<20	<20	<20	<10	<40	<10	<40	2.32	3	3.4	<0.02 - 0.03	<0.02 - <0.02	<0.2	<0.2
Arsenic	5.9	17	27	103.9	21	26.6	**11.2**	53.5	28	68	30.8	**12.9**	39.3	72.7	31.0	20.0	18.0	24.0	**10.0**	-	187.3	234.9	**8.1 -** 99.6	3.5 - 85.9	1.4	0.75
Cadmium	0.6	3.5	0.12	<0.2	0.35	<0.5	0.10	<0.2	**1.10**	**0.77**	0.30	1.80	**<1**	**<1**	<0.1	<0.5	0.27	<0.5	0.20	<0.5	**<1**	0.2	0.03 - 0.16	0.06 - 0.22	**0.7**	0.3
Chromium	37.3	90	158	136	113	120	**84**	101	**90**	98	105	**80**	96	117	157	97	111	125	**64**	**88**	29	34	23 - **61.0**	**44.3 - 69.0**	29.7	25.3
Copper	35.7	197	**96.0**	**89.0**	**74.0**	**70.0**	**45.8**	**121**	**73.5**	**94.7**	**91.5**	**98.0**	**87.0**	**115.7**	**91.0**	**56.0**	**42.0**	**55.5**	**51.0**	17	17	25	11.3 - **54.8**	19.4 - **37.5**	**69.6**	35.6
Lead	35.0	91.3	22.7	<100	24.0	30.2	16.3	<100	21.5	<30	<100	29.5	49.5	<60	**<50**	0.0	14.0	<30	15.0	<5.0	10	11.9	2.29 - 5.24	2.48 - 4.6	4.9	4.7
Mercury	0.17	0.49	-	0.015	0.023	0.020	-	0.015	0.023	0.047	0.036	0.029	0.035	0.081	0.015	0.009	0.023	0.023	0.015	0.02	0.04	0.05	<0.02 - 0.03	<0.02 - 0.02	0.050	0.060
Nickel	18	36	86	82	76	90	51	66	63	93	71	119	64	167	80	49	70	87	41	-	17	**22**	0.05 **-23.5**	4.8 - **33.53**	38	**20**
Zinc	123	315	**128**	**128**	**135**	115	107	**176**	**136**	**133**	**140**	**197**	114	**133**	**127**	74	89	99	84	-	48	59	30.5 - 79.0	48.6 - 86.1	**176**	99

Note: A. NG = no guideline. **B.** Candidate Reference Lake. **Bold:** Concentrations exceed ISQG. Shaded concentrations exceed PEL.

* **1997**: Tehek, Vault. **1998**: Tehek. **2002**: Tehek, Turn, Vault, Farside. **2003**: North Port1, North Port2, North Port3. ** **1979**: Jaeger, Pointer, Scotch, Sissons. **1986**: Boulder, Caribou, Sissons, Skinny. **1988**: Jaeger, Pointer.

References: 1. McKee et al, 1989. **2.** Diavik, 1998; **3.** De Beers, 2002.

which is similar to project lake sediments at similar depths. As well, total metals concentrations in sediment of reference lakes, was also similar to metals concentrations in project lakes. As in the other lakes, certain metals, specifically arsenic, chromium, and nickel, exceeded the CCME (2001) PEL values by a similar magnitude. Sediment metals for which there are no federal guidelines (e.g., barium, selenium, tin, thallium) from the reference lakes had a similar range of concentrations as was observed in project lake sediments.

5.3.3 Regional Lakes

Sediment grain size, TOC, and metals concentration are a function of local geochemical conditions, hydraulic influences, water depth, and natural heterogeneity in sediment characteristics. Thus, it is difficult to make direct comparisons in sediment features between widely different geographic areas. For example, grain size of Snap Lake (1999) and Kiggavik area (1988) lake sediment had a predominance of sand (77% and 47%, respectively) rather than fine grain (i.e., clay and silt fractions) sediment (23% and 53%, respectively). It is not known if sediments were collected from shallower depths than at Meadowbank, or if this is a true reflection of grain size in profundal sediment. Because of the larger grain size, it is expected that sediment metals concentrations would also be lower.

With respect to sediment metals, with the exception of arsenic in Kiggavik region lakes, concentrations of all sediment metals from regional lakes were similar to or lower than the concentrations in Meadowbank project lakes (Table 5.2).

Results from Meadowbank are similar to those reported for two recently completed environmental impact assessments. In the Jericho region lakes (Tahera Corporation, 2003), ISQG or PEL thresholds were exceeded for arsenic (PEL), nickel (PEL), chromium (ISQG), and copper (ISQG) in nearly all sediment samples. This was also the case for the Doris North project area in Nunavut, where ISQGs were exceeded for chromium, copper, arsenic, and cadmium (AMEC, 2003). At regional lakes reported in Table 5.2, arsenic and chromium exceeded the ISQG and/or PEL guidelines in Kiggavik, Lac de Gras, and Lac du Sauvage, copper exceeded the ISQG in Snap Lake, Lac de Gras, and Lac du Sauvage, while zinc exceeded the ISQG in Snap Lake.

These data further support the conclusion that sediment metals concentrations are naturally elevated above guideline values in areas with mineralized bedrock. It is worthwhile re-emphasizing that exceedence of guideline values does not imply that there are adverse effects on the resident benthic community. Resident biota can be well acclimatized to these local conditions and suffer no ill effects as a result to exposure of metals concentrations that are typical for this region.

At least 70 sediment samples have been collected from the project area lakes between 1996 and 2005 (sediment cores were collected in 2005) from a variety of depths and geographic locations throughout the lakes. Sediment grain size and total metals concentrations are extremely uniform regardless of geographic location and over time. Certain metals (e.g., arsenic, chromium, nickel) consistently exceeded CCME (2001) guideline concentrations among all lakes and locations. Concentrations of metals for which there are no guidelines (e.g., aluminum, barium, cobalt, thallium, etc.) were also consistent over space and time and values were within the expected range considering natural variability and heterogeneity.

SECTION 6 • BIOLOGICAL PARAMETERS OF LOWER TROPHIC LEVELS

This section summarizes data collected on lower trophic levels including periphyton (6.1), phytoplankton (6.2), zooplankton (6.3), and benthic invertebrates (6.4) from Meadowbank project lakes between 1996 and 2003. This report harmonizes the approach, data analysis, presentation, and discussion of data that have been collected from numerous locations and at different times to facilitate understanding of ecological features of project lakes (Table 2.1, Figure 4.1). Although the methods used to gather data from lower trophic level groups during baseline studies were generally similar among different years, there were some minor differences in mesh size, sample depth, and so on. To account for these factors, for example, organisms that were too small to be reliably retained by the mesh size used (e.g., nematodes from benthic samples, small zooplankton copepodites stages from plankton hauls) were excluded from estimates of density and abundance among years. Thus, differences in methodologies and analytical procedures among years have been accounted for to the extent possible in this BAEAR, and data presented have been analyzed and presented using consistent methods.

6.1 PERIPHYTON

Periphyton are unicellular and colonial aquatic algae species that attach to and coat rocks and other hard substrates beneath the water surface. Periphyton provide an important food source for certain benthic invertebrate species and, together with phytoplankton (unicellular plants suspended in the water column), form the base of the food web. Periphyton typically increase in biomass during the course of the open water season, reaching maximum abundance during late summer, and declining during late fall and winter. Periphyton are most abundant in the upper several metres of water. Ice scouring can limit periphyton abundance in the upper metre or two, depending on exposure to ice and ice thickness.

Species composition and biomass of periphyton are indirect indicators of lake productivity, reflecting nutrient concentrations in the lake, and are sometimes used as indicators of the presence of contaminants. Because some periphyton species are sensitive to the presence of metals, reductions in periphyton communities over time can indicate the presence of dissolved metals in the water column.

Periphyton were collected by scraping a known surface area of a rock, and biomass of individual genera or species was estimated as $\mu g/cm^2$. Species composition and biomass is sometimes used to roughly estimate lake productivity. Most periphyton samples were collected using a quantitative approach and sampling method. To obtain unbiased results (e.g., to avoid variations in sun exposure or water depth), periphyton sampling stations were chosen to meet the following criteria: south-facing exposure; depth of 0.5 m below the surface; large, flat rock surface; uniform algal coverage; and coverage by periphyton not unusually dense or sparse. This improved data quality by minimizing natural variability in periphyton abundance associated with differences in each of the above parameters. Care must be taken when collecting periphyton because of the large natural variability in biomass data, and because of the confounding effects of differences in collection methodologies among studies. For example, the differences in collection method, care taken by collectors, the decisions of the taxonomist, the laboratory procedures, and other factors contribute to variability of results.

No detailed comparisons of periphyton biomass data between Meadowbank lakes and other Nunavut lakes has been attempted because of the above-mentioned difficulties, and because few periphyton biomass data could be found in the published literature. Given the large natural variability in biomass, and the potential for sampling bias, it is not useful to make detailed comparisons in biomass among lakes, or over time.

Periphyton density (cells/cm^2) and biomass (µg/cm^2) were determined from periphyton samples collected in August 1998 and in 2002, near the height of the growing season for plants from all project lakes (Table 6.1). Three major taxonomic groups—blue-green algae (cyanophytes), green algae (chlorophytes), and diatoms—typically dominate the periphyton community. Golden-brown algae (chrysophytes) sometimes compose a minor component of the biomass. Biomass is the most meaningful measure used to quantify and compare periphyton communities among lakes because it is ecologically relevant (i.e., it expresses the quantity of food available to grazing benthic invertebrates).

The periphyton community of Meadowbank project lakes in 2002 was dominated, in terms of density, by blue-green algae (*Tabellaria flocculsa* and *Achnanthes minutissima*), cyanobacteria (*Lyngbya* sp., *Petalonema alatum* and *Rivularia* sp. [Cyanophyta]), followed by diatoms and green algae (*Mougeotia* sp). *Mougeotia* is a filamentous green algae, and a true benthic genus with numerous species that were abundant at specific locations. This genus has a wide ecological distribution, and occurs under extreme conditions such as low pH, excessive nutrients, and Arctic lakes with short growing seasons. These species occur in lakes of a broad spectrum of trophic levels, from oligotrophic to eutrophic (Prescott, 1962). *Tabellaria* and *Achnanthes* (diatoms) are cosmopolitan genera and have been documented in temperate (Findlay et al, 1999) and Arctic lakes (Welch et al, 1989). Ecologically, *Tabellaria fenestrate* prefers lakes and ponds that are oligo-mesotrophic, in which they attach to rocks in shallow water (Patrick and Reimer, 1966). This species also occurs in planktonic form. *Achnanthes minutissima* also is widely distributed, generally occurring in oligotrophic lakes and having a preference for circumneutral environments (pH >7.1) (Findlay and Shearer, 1992).

Among the remaining, common periphyton species, *Rivularia* sp., and *Petalonema alatum* dominated biomass. These genera prefer submerged habitats on calcareous substrata within the splash zone (water surface to 0.7 m) and form large attached colonies. *Rivularia* sp. and *P. alatum* are heterocystous species (i.e., capable of fixing nitrogen from the water). Their dominance could suggest nitrogen limitation in these lakes, a contention supported by the nutrient-poor chemistry of the study lakes. These species are present in temperate lakes, but also occur in extreme environments such as coastal lakes in the eastern Arctic (Komarek et al, 2002) and the Antarctic (Vincent, 2000).

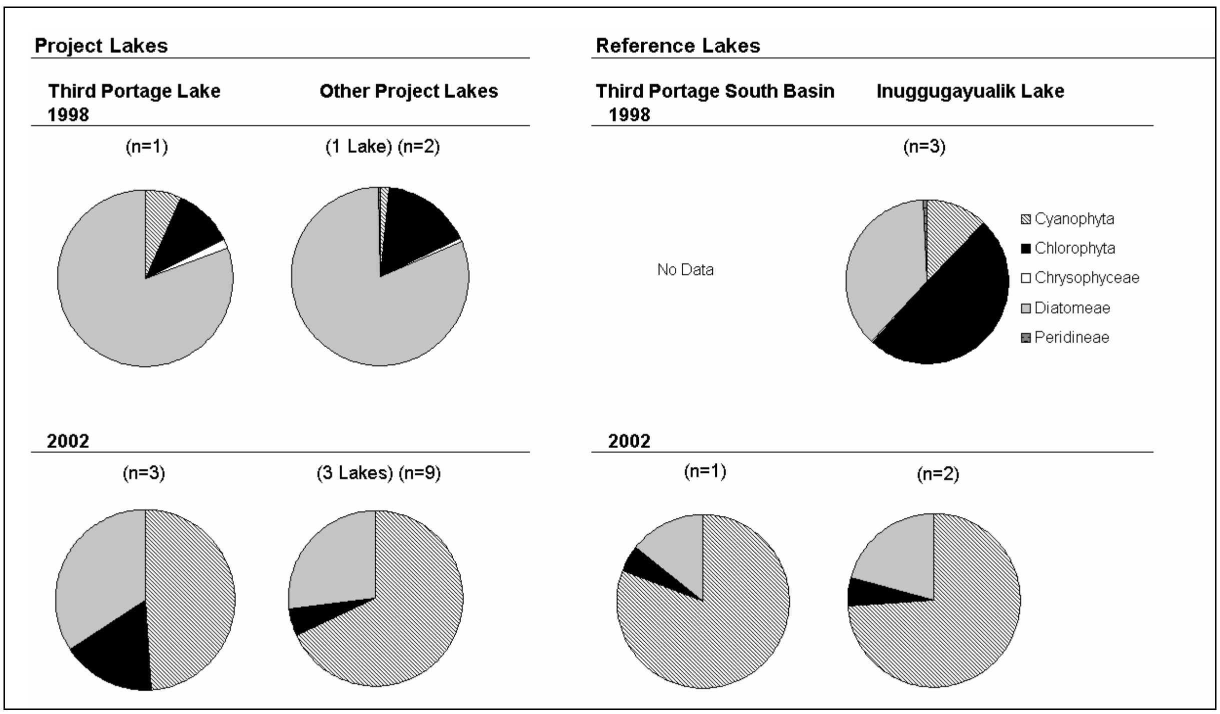
Mean periphyton biomass (µg/cm^2), presented for each study lake in 1998 and 2002 (Table 6.1), illustrates the kind of variability in biomass and species composition that is typically seen among studies and between years. For example, there was very little relationship among biomass estimates within lakes between years. Furthermore, while diatoms dominated biomass in all lakes in 1998, blue-green algae dominated biomass in all lakes in 2002. To illustrate this, relative biomass (%) of major taxonomic groups from study lakes for 1998 and 2002 are presented (Figure 6.1). This figure clearly

Table 6.1: Mean Periphyton Biomass by Major Taxa in Project & Reference Lakes, August 1998 & 2002

Year/Lake	No. Sample Stations	Biomass (µg/cm²)					
		Cyanophyta	Chlorophyta	Chrysophyceae	Diatomeae	Dinoflagellate	Total
August 1998							
Project Lakes							
Third Portage Lake	1	79.1	129.2	18.6	947.5	-	1,174
Tehek Lake	2	9.3	97.8	2.4	480.3	1.7	592
Reference Lakes							
Innugugayualik Lake	3	40.5	162.0	0.8	121.9	2.7	328
Amarulik Lake[1]	1	8.0	37.1	5.4	180.0	-	231
August 2002							
Project Lakes							
Third Portage Lake	3	210.0	73.0	-	147.4	-	430
Second Portage Lake	3	583.8	11.2	-	208.6	-	804
Tehek Lake	2	567.5	15.8	-	188.8	-	772
Turn Lake	2	232.8	107.1	-	346.6	-	686
Vault Lakes	2	1089.9	9.9	-	87.6	-	1,187
Reference Lakes							
Third Portage South Basin	1	2761.8	170.6	-	487.1	-	3,420
Inuggugayualik Lake	2	718.5	53.0	-	202.6	-	974

Notes: 1. Candidate Reference Lake.

Figure 6.1: Relative Biomass (%) of Periphyton Taxa in Project & Reference Lakes (August 1988 & 2002)



demonstrates the magnitude of difference in community composition between study years, which is consistent across lakes.

In 2002, blue-green algae contributed the most to the total biomass in nearly all lakes, accounting for 68% of the biomass, with diatoms (26%) and chlorophytes (6%) contributing smaller portions of total biomass (Figure 6.1). In 1998, diatoms (69%) were the dominant group, followed by chlorophytes (23%) and cyanophytes (6%). There were virtually no chrysophytes in either 1998 or 2002.

Periphyton species composition and density is subject to great variability due to: differences in sun exposure and aspect (i.e., angle towards the sun), nutrient availability, water depth and clarity, grazing by zooplankton, and sampler bias. Efforts were made in the 2002 sampling program to minimize the influence of these factors by using a specialized sampler and sampling rocks from similar depths, aspects, and density of coverage by periphyton to acquire samples that were representative of algal coverage. Consequently, it is difficult to determine whether inter-annual differences described previously were due to real annual variability or to improvements to the sampling program. Nevertheless, the variable nature of periphyton data means that they are only useful for monitoring gross effects on the community.

Comparisons of periphyton abundance and biomass between near-field and far-field locations or between project lakes and reference lakes can only be made on a gross, community-level basis (Figure 6.1). Cyanophytes dominated abundance in both project and reference lakes in 2002, and roughly similar proportions of each major taxonomic group (cyanophyte, chlorophyte, and diatom) were represented in each area. In 1998, however, diatoms were more abundant in project lakes compared to Inuggugayualik Lake, where chlorophytes were more abundant. Because of the large natural variability in periphyton biomass, both spatially and temporally, and the small sample sizes, no meaningful comparison between project and reference lakes is possible.

Given the relatively low intensity of sampling efforts to date, this tool is not likely to be useful in long-term monitoring. It could, however, be employed in a gradient-based (i.e., exposure gradient) study specifically targeting mining-related activities (e.g., effluent discharge, acid rock drainage), and to monitor or measure periphyton growth on rock substrates surrounding the dike structures.

6.2 PHYTOPLANKTON

Phytoplankton are microscopic, unicellular, or colonial plant species that are suspended in the water column and contribute to the base of the food web. These organisms use chlorophyll to convert the sun's energy to plant tissue. Phytoplankton are primary producers and are grazed on by herbivorous zooplankton (i.e., free-swimming invertebrates) species throughout the year, especially during the open water season when primary production within the lake is greatest. Some production occurs in spring, utilizing sunlight that penetrates the snow and ice. Maximum production usually occurs within the upper 10 m of water, where there is the greatest amount of light. Annual production can vary widely depending on water temperature, mixing, nutrient concentration, amount of sunlight, water clarity, and predation by zooplankton. Estimates of phytoplankton biomass are used as gross indicators of productivity from a "snap-shot" perspective, depending on frequency of sampling. They are only useful to detect long-term trends or gross changes in lake production, such as eutrophication as a result of nutrient additions (e.g., from sewage disposal) or addition of nitrites as a result of the use of explosives.

There are six major groups of phytoplankton present in lakes: chlorophytes (green algae), cyanophytes (blue green algae), cryptophytes, dinoflagellates, chrysophytes (golden-brown algae), and diatoms. Diatoms are unique because they have a crystalline structure composed of silica. The diversity in types and sizes of phytoplankton is very large and their abundance is very great, typically exceeding 1 million individuals per litre with a total biomass of approximately 100 mg/m^3. Comparative biomass of these groups is a useful measure to determine the relative importance of each group as a food source for zooplankton.

Phytoplankton were collected by subsampling a small volume of water (about 15 mL), from which individual phytoplankton species were identified and their densities estimated. Biomass (mg/m^3) was estimated based on species composition and cell density of individual taxa (number of cells/mL). Species composition and biomass data are used as rough indicators of lake productivity and trophic status (e.g., oligotrophic, eutrophic).

Phytoplankton studies of Meadowbank project lakes examined species composition and cell density in 1996 to 1998 and in 2002, but biomass was only determined in 1998 and 2002. Comparisons of cell density are of little use because of the differing cell sizes among species. Biomass comparisons are therefore made between project and reference lakes and regional Arctic lakes for 1998 and 2002 only.

6.2.1 Project Lakes

Phytoplankton density (cells/L) and biomass (mg/m^3) were determined from all water chemistry stations in 1998 and 2002. Phytoplankton cell abundance was determined in 1997, but biomass was not, so these data are not discussed further. At least 40 species of phytoplankters, represented by six major classes of algae (chrysophytes, diatoms, chlorophytes, dinoflagellates, cryptophytes, and cyanophytes), were identified in the Meadowbank project lakes. Chrysophytes (golden-brown algae) are small, usually unicellular phytoplankton, and are very numerous in lake water samples, frequently having the greatest biomass due to their large numbers. This group composed 76% to 86% of total phytoplankton biomass over all stations in July and August 2002, respectively, from all study lakes (Table 6.2). Major chrysophyte species were *Dinobryon sociale*, *Chrysococcus* sp., and *Uroglena volvox*. Chrysophytes were also the most abundant phytoplankton group from 1998 samples, although for unknown reasons, overall phytoplankton biomass was much lower in 1998 than in 2002.

The major phytoplankton species found in Meadowbank project lakes are consistent with dominant and commonly occurring phytoplankton species usually found in oligotrophic lakes with circum-neutral pH and low nutrient concentrations (Wetzel, 1983).

Diatoms (10% of biomass) and dinoflagellates (12% of biomass) were the next most abundant groups in 2002. Diatoms are a diverse and important group, although the majority of species are sessile and associated with littoral substrates such as rocks and attached vegetation (Wetzel, 1983). Because of this limitation in habitat, the abundance of diatoms in the water column is reduced relative to other groups. Dinoflagellates are unicellular, flagellated motile algae that are common in fresh water. Dinoflagellates are useful for biomonitoring purposes because particular species are very sensitive to changes in certain water chemistry variables such pH, dissolved organic matter, and temperature.

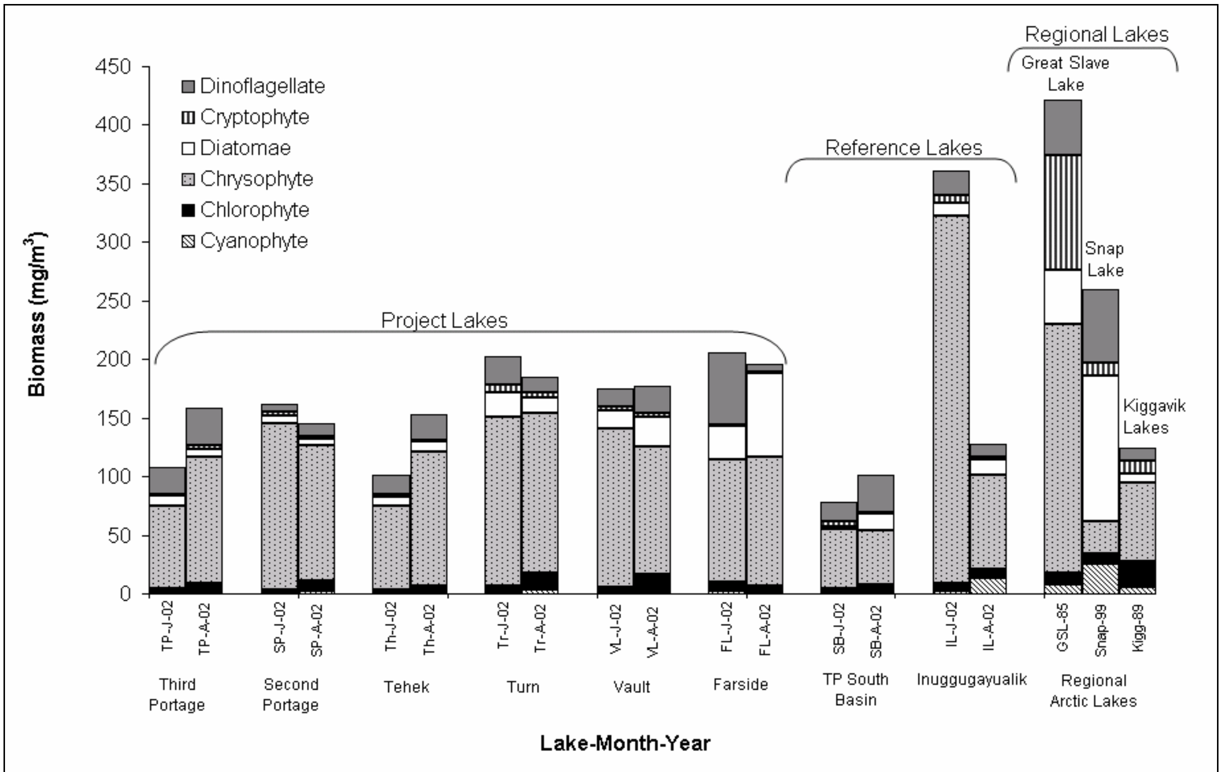
Overall, mean phytoplankton biomass was very consistent among all project lakes and seasons, ranging from 101 to 174 mg/m^3 and from 145 to 177 mg/m^3 in July and August 2002, respectively (Table 6.2, Figure 6.2).

Table 6.2: Mean Phytoplankton Biomass by Major Taxa in Project & Reference Lakes, August 1998, July 2002 & August 2002

Year/Lake	No. Sample Stations	Phytoplankton Biomass (mg/m^3)						
		Cyanophyte	Chlorophyte	Chrysophyte	Diatomae	Cryptophyte	Dinoflagellate	Total
August 1998								
Project Lakes								
Third Portage Lake	1	1.1	1.2	11.1	0.3	-	0.6	14.4
Second Portage Lake	1	0.2	4.3	3.9	0.3	0.4	5.4	14.3
Tailings Pond Camp Island	1	-	36.3	28.4	1.6	1.6	14.5	82.5
Reference Lakes								
Inuggugayualik Lake	1	0.8	0.9	2.2	0.3	0.5	0.3	5.1
Amarulik Lake[1]	1	7.3	21.0	31.1	0.9	1.1	1.3	62.6
July 2002								
Project Lakes								
Third Portage Lake	5	-	4.0	70.3	9.8	1.1	22.8	108.0
Second Portage Lake	3	0.9	2.6	141.8	6.7	3.1	6.6	161.8
Tehek Lake	3	0.2	2.6	71.8	7.5	2.2	17.0	101.3
Turn Lake	1	-	6.7	144.1	20.3	7.4	23.9	202.4
Vault Lake	3	0.5	4.7	135.1	16.3	3.0	14.8	174.4
Farside Lake	1	2.7	7.5	104.1	29.1	0.2	61.8	205.4
Reference Lakes								
Third Portage South Basin	1	0.5	3.9	50.2	2.7	3.8	16.5	77.7
Inuggugayualik Lake	1	1.8	7.0	313.4	11.6	6.5	20.7	360.8
August 2002								
Project Lakes								
Third Portage Lake	5	1.3	7.4	108.3	6.7	2.5	32.0	158.1
Second Portage Lake	3	2.5	8.8	115.7	5.1	1.9	11.6	145.6
Tehek Lake	3	1.6	4.6	114.5	9.6	1.1	21.6	153.0
Turn Lake	1	3.1	14.9	136.0	13.5	4.6	12.6	184.7
Vault Lake	3	1.1	15.3	109.0	25.8	2.4	23.7	177.5
Farside Lake	1	-	6.9	110.1	70.8	1.8	6.3	195.9
Reference Lakes								
Third Portage South Basin	1	-	7.4	47.0	13.6	1.4	31.8	101.3
Inuggugayualik Lake	1	13.4	7.9	80.0	13.1	1.9	10.8	127.1

Notes: 1. Candidate Reference Lake.

Figure 6.2: Comparison of Mean Phytoplankton Biomass (mg/m³) by Major Taxa in Project, Reference & Regional Arctic Lakes



6.2.2 Reference Lakes

Mean biomass of major phytoplankton taxa from Inuggugayualik Lake (Table 6.2, Figure 6.2) in July and August 2002 (361 and 127 mg/m³, respectively) was higher in spring and slightly lower in fall compared to biomass in project lakes. Overall biomass for Inuggugayualik Lake, averaged over both seasons, was similar to mean biomass values for the project lakes, which illustrates the range in natural variability in this factor.

Phytoplankton biomass in Third Portage south basin was also slightly lower than biomass from the remaining stations in Third Portage Lake during July and August. This is likely because of the overall colder water temperatures in the basin, which might limit productivity, and because of its great depth and large volume, which might dilute cell density due to mixing by wind.

The relative biomass of major phytoplankton taxa was also similar between project and reference lakes (Figure 6.2). Abundance of dinoflagellates, cryptophytes, chlorophytes, diatoms, and cyanophytes was similar across all lakes and major differences in overall biomass was usually due to higher or lower densities of golden brown algae (chrysophytes). It is noteworthy that the species composition and biomass of phytoplankton from the external reference lake was similar to that of project lakes, even though Inuggugayualik Lake is within a separate drainage basin that flows towards the Arctic rather than Hudson Bay.

6.2.3 Regional Lakes

The magnitude of biomass estimates from the study lakes is typical for oligotrophic lakes and is similar to what has been observed from other regional Arctic lakes (Table 6.3) such as Snap Lake (266 mg/m^3; De Beers, 2002), Kiggavik lakes (125 mg/m^3; McKee et al, 1989), Great Slave Lake (421 mg/m^3; Fee et al, 1985), Char Lake (Kalff et al, 1975), and Spring Lake near Saqvaqjuac, not far from Baker Lake (Welch et al, 1989). For example, the range in phytoplankton biomass for Great Slave (McLeod Bay) in July and August was 105 to 164 mg/m^3 (Fee et al, 1985), which is very similar to the range observed in August 2002 (129 to 194 mg/m^3) at Meadowbank. Seasonal biomass in Spring Lake (Saqvaqjuac) ranged from 10 to 120 mg/m^3 (Welch et al, 1989). Seasonal biomass in Char Lake ranged from 30 to 166 µg/cm^3 (note that the units µg/cm^3 and mg/m^3 are equivalent) between May 1969 and March 1971 (Kalff et al, 1975). Holmgren (1983) observed similar densities and assemblages of phytoplankton species in oligotrophic Scandinavian lakes at similar latitudes.

The relative biomass estimates of major phytoplankton groups from Snap Lake, Kiggavik region lakes, and small regional lakes in the Great Slave Lake area were compared to project lakes (Figure 6.3). As expected, relative biomass estimates of major groups differed somewhat among lakes, but the magnitude of difference between study lakes and regional lakes was no greater than the magnitude of difference within study lakes between years (i.e., 1998 and 2002). These data illustrate the natural spatial and temporal variability in phytoplankton community composition and biomass.

Chrysophytes dominated biomass in Kiggavik and Great Slave region lakes (54% and 50%, respectively), and this group was proportionally similar in biomass to other Meadowbank project lakes. Some of the dominant chrysophyte species in the Kiggavik lakes were similar to Meadowbank project lakes and included *Uroglena americana*, *Ochromonas* sp., and *Dinobryon bavaricum*. In Kiggavik region lakes, other major groups were also present at comparable levels to project lakes, accounting for between 18% (chlorophytes) and 4% (cyanophytes) of total biomass. In small lakes in the Great Slave Lake region, cryptophytes (23%), dinoflagellates (11%), and diatoms (11%) were the other important phytoplankton groups. The phytoplankton community of Snap Lake (1999) differed from other regional lakes in that Snap Lake had a greater proportion of diatoms (47%) and dinoflagellates (24%), with smaller proportions of chrysophytes (10%) and cyanophytes (10%). These data illustrate the large, natural differences in taxonomic composition of phytoplankton among lakes, regions, and over time.

6.3 ZOOPLANKTON

Zooplankton are small, free-swimming animal species that feed on phytoplankton, bacteria, detritus, and smaller zooplankton. Zooplankton are a key food chain species for fish, especially young-of-the-year lake trout, round whitefish, lake cisco, and minnow species. Zooplankton are also the main food source for adults of some species, particularly round whitefish and Arctic char.

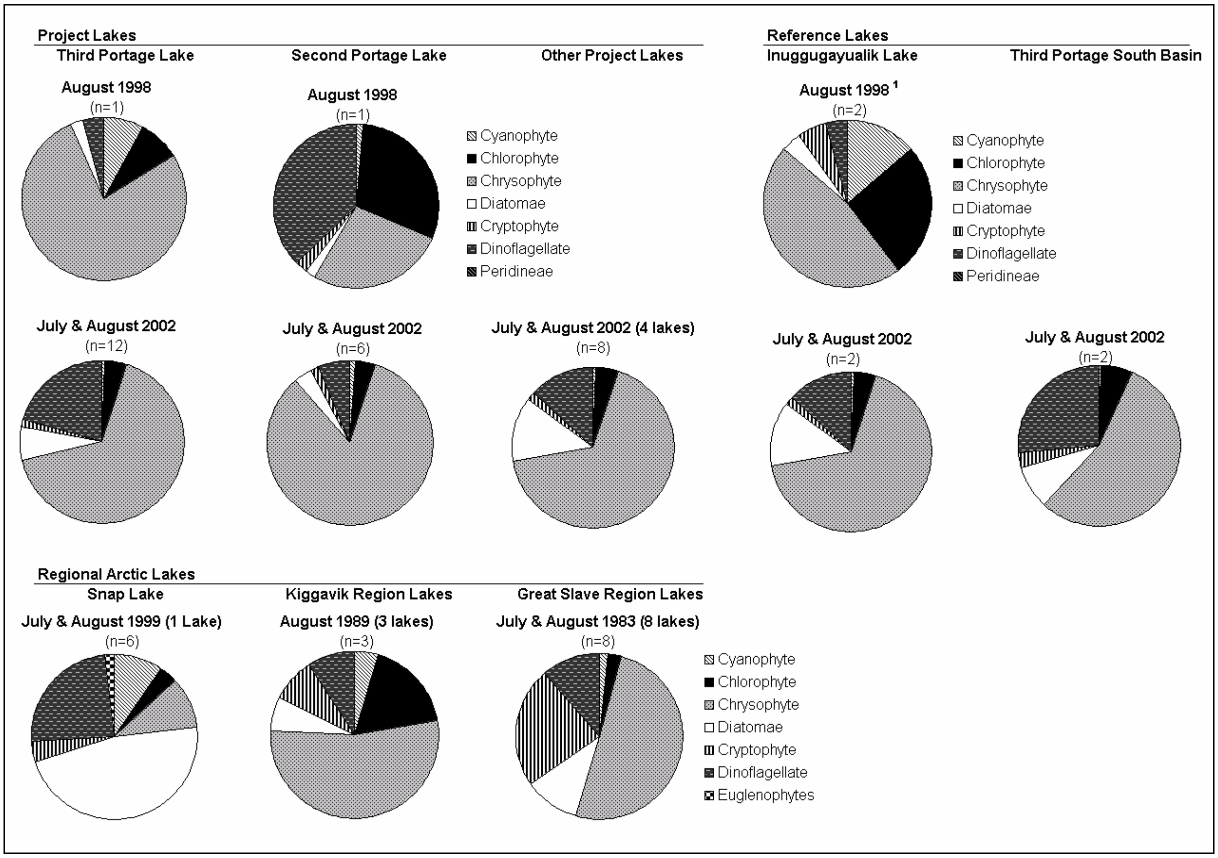
Three major groups of zooplankton typically dominate the plankton community in freshwater lakes. These are rotifers, and two subclasses of the Crustacea, Cladocera and Copepoda (within which there are two major orders, calanoid and cyclopoid copepods) (Wetzel, 1983).

Table 6.3: Relative Abundance & Mean Biomass of Major Phytoplankton Taxa in Regional Arctic Lakes

Lake/Year	Parameter	Sample Size	Phytoplankton Relative Abundance (%)							Mean Biomass (mg/m^3)
			Cyanophyte	Chlorophyte	Chrysophyte	Diatomae	Cryptophyte	Dinoflagellate	Euglenophyte	
G. Slave Lake[1]	Mean	5 lakes	1.8	2.5	50.3	11.0	23.3	11.4	0.1	421
Jul/Aug 1983	Range	(n=8)	0 - 11	0 - 5	11 - 64	1 - 48	7 - 40	3 - 20	0 - 1	135 - 656
Kiggavik Area[2]	Mean	3 lakes	4.3	17.8	53.7	6.4	8.5	9.3	-	125
Aug 1989	Range	(n=3)	0 - 10	11 - 24	35 - 70	4 - 10	2 - 13	1 - 25	-	118 - 138
Snap Lake[3]	Mean	1 lake	9.5	3.5	10.2	46.8	4.2	23.8	1.9	266
Jul/Aug 1999	Range	(n=6)	2 - 21	2 - 5	5 - 22	10 - 70	0 - 10	2 - 51	0 - 6	165 - 392

References: **1.** Fee et al, 1985. **2.** McKee et al, 1989. **3.** De Beers, 2002.

Figure 6.3: Relative Biomass (%) of Major Phytoplankton Taxa in Project, Reference & Regional Arctic Lakes



Rotifers are a large and diverse group that are often sessile and associated with littoral substrates, although planktonic species can form a significant component of the zooplankton community. Rotifers tend to be quite small and feed mostly on phytoplankton and other organic matter. Some species are predatory and feed on protozoans and other rotifers. Rotifers are preyed upon by copepods and cladocerans and perhaps by very small larval fish. Individual rotifers tend to be quite small and most species can only reliably be captured in fine mesh nets, less than 50 µm in size. Also, the seasonal distribution and abundance of rotifers is complex and variable (Wetzel, 1983), making it difficult to generalize. Thus, most rotifer species are usually excluded from density (# organisms/m^3) calculations to avoid the confounding factor of catch efficiency when larger mesh sizes are used. There are, however, a few species (e.g., *Asplanchna* sp. and *Conochilus* sp.) that are large enough to be reliably captured in a 250 µm net, and so these can be included in density calculations.

Cladocerans and copepods dominate zooplankton community species composition and biomass because they are relatively large in size (0.2 to 3.0 mm), and are the major source of food for several Arctic fish species including adult Arctic char, round whitefish, lake cisco, stickleback, sculpins, as well as juvenile stages of these species and lake trout. Other notable zooplankton groups include tadpole shrimp (Branchiopoda) and larvae of some aquatic insects such as *Chaoborus*. The vast majority of zooplankton identified from Meadowbank project lakes, however, consisted of copepods and cladocerans.

Zooplankton are sampled by lowering a fine mesh (250 µm) net into the water column and towing it vertically to the surface, filtering zooplankters from a known volume of water. Individuals are identified to species (or lowest practical taxa), enumerated, and the data are presented in terms of relative abundance (# organisms/m^3) in the water column. Abundance estimates and species composition determinations of zooplankton are influenced by the mesh size of the net and water column depth from which zooplankton are collected. Generally, more zooplankters are found in shallow water (<5 m) than in deeper water (>5 m) (Wetzel, 1983).

Quantitative collections of zooplankton were made in 1997, 1998, and 2002. Direct inter-annual comparisons of results reported in the various baseline reports were complicated by differences in depth range sampled and differences in mesh size. Nevertheless, although different mesh sizes were used in 1998 (64 µm) and 1997/2002 (250 µm), raw data from the1998 study data were adjusted, based on organism size, to develop a data set comparable to those based on the larger mesh size. No corrections could be made to account for differences in depth of tow. To ensure consistency in the density (#/m^3) estimates among years, very small organisms, which are not reliably captured by a 250 µm net, were excluded from density calculations in this study, although they are reported in the raw data. The taxa excluded were the rotifer *Kellicottia longispina* and the copepod *Leptodiaptomus* sp. stage I and II copepodites. *Heterocope septentrionalis* were included in density calculations, even the stage I copepodites, because they are quite large and so are easily captured by the 250 µm net. All other taxa and *Leptodiaptomus* copepodites stage III and higher are large enough to be reliably captured by the net.

Applied Technical Services Ltd. (Sidney, BC) was employed for taxonomic identification of all zooplankton species between 1996 and 2002, so there is consistency in species composition and richness across years. Also, Applied Technical Services determined zooplankton taxonomy for several other mine developments, including BHP's Ekati project and the Diavik project, so there is good comparability between Meadowbank project area lakes and regional lakes.

6.3.1 Project Lakes

Zooplankton were quantitatively sampled from many areas within Meadowbank project lakes in 1997, 1998, 2002, and 2003 (Figure 4.1). Diversity and abundance of the zooplankton community of the Meadowbank project lakes is low (Table 6.4), but typical of oligotrophic Arctic lakes. All of the zooplankton taxa identified from study lakes are common, widespread species that are well known from this region of the Arctic (Patalas et al., 1994). There were no unusual or uncommon species identified from any of the lakes.

Mean density (Table 6.4), taxa richness (Table 6.4), taxa presence/absence (Table 6.5), and relative major taxa abundance (Figure 6.4) are provided for each study year. Calanoid copepods dominated abundance (55% of all enumerated organisms) of zooplankton in all lakes over all years, except for small ponds (2003 data). Cyclopoid copepods were the next most abundant group (40%), followed by Cladocera (5%). *Leptodiaptomus ashlandi*, a calanoid copepod, was the most abundant species in most lakes in 1997, 1998, and 2002 zooplankton samples, followed by *L. sicilis* and *L. priblofensis*. The other dominant calanoid species, *Heterocope septentrionalis*, was present in all lakes.

Table 6.4: Mean Density & Richness of Major Zooplankton Taxa from Project & Reference Lakes, 1997 to 2003

Year/Lake	No. of Sample Stations	Mean Sample Depth (m)	Density (# organisms/m^3)				Mean Richness (# taxa) Total
			Cladocera	Calanoida	Cyclopoida	Total	
August 1997 (250 µm)							
Project Lakes							
Third Portage Lake	(n=2)	14 - 20	1,034	4,119	4,036	9,188	8
Second Portage Lake	(n=1)	9	18	4,662	1,429	6,109	8
Tehek Lake	(n=1)	6	285	1,455	1,122	2,862	6
Vault Lakes	(n=1)	18	41	650	1,201	1,892	8
Reference Lake							
Third Portage South Basin	(n=1)	22	338	2,524	4,395	7,258	8
August 1998 (64 µm adjusted)*							
Project Lakes							
Third Portage Lake	(n=1)	14	242	7,335	3,834	11,411	9
Second Portage Lake	(n=1)	4	46	11,010	1,133	12,189	6
Reference Lakes							
Inuggugayualik Lake	(n=1)	11	254	4,078	6,401	10,733	10
Amarulik Lake	(n=1)	3	75	9,544	1,109	10,728	9
July 2002 (250 µm)							
Project Lakes							
Third Portage Lake	(n=5)	8	48	837	318	1,203	7
Second Portage Lake	(n=3)	8	241	1,055	812	2,108	10
Tehek Lake	(n=3)	7 - 8	176	381	644	1,202	8
Turn Lake	(n=2)	6 - 8	571	566	1,098	2,235	9
Vault Lakes	(n=3)	7 - 8	853	1,875	4,190	6,917	9
Farside Lake	(n=1)	8	710	106	2,905	3,720	9
Reference Lakes							
Third Portage South Basin	(n=1)	7	4	830	471	1,305	5
Inuggugayualik Lake	(n=1)	7	473	1,763	1,968	4,204	11
August 2002 (250 µm)							
Project Lakes							
Third Portage Lake	(n=5)	7 - 8	55	1,839	1,304	3,198	7
Second Portage Lake	(n=3)	8	416	6,729	1,718	8,863	10
Tehek Lake	(n=3)	7 - 8	119	5,147	642	5,907	10
Turn Lake	(n=2)	8	410	2,018	2,245	4,673	7
Vault Lakes	(n=4)	6 - 8	312	8,017	3,330	11,659	9
Farside Lake	(n=1)	8	1,276	1,270	17,156	19,702	10
Reference Lakes							
Third Portage South Basin	(n=1)	7	85	992	976	2,053	9
Inuggugayualik Lake	(n=1)	5	164	7,815	1,286	9,265	9
August 2003 (250 µm)							
Project Lakes							
North Portage 1 (Dogleg)	(n=1)	6	5,272	2,041	1,573	8,886	7
North Portage 2	(n=1)	4	291	1,031	1,254	2,577	7
North Portage 3	(n=1)	5	5	1,607	13,393	15,005	5

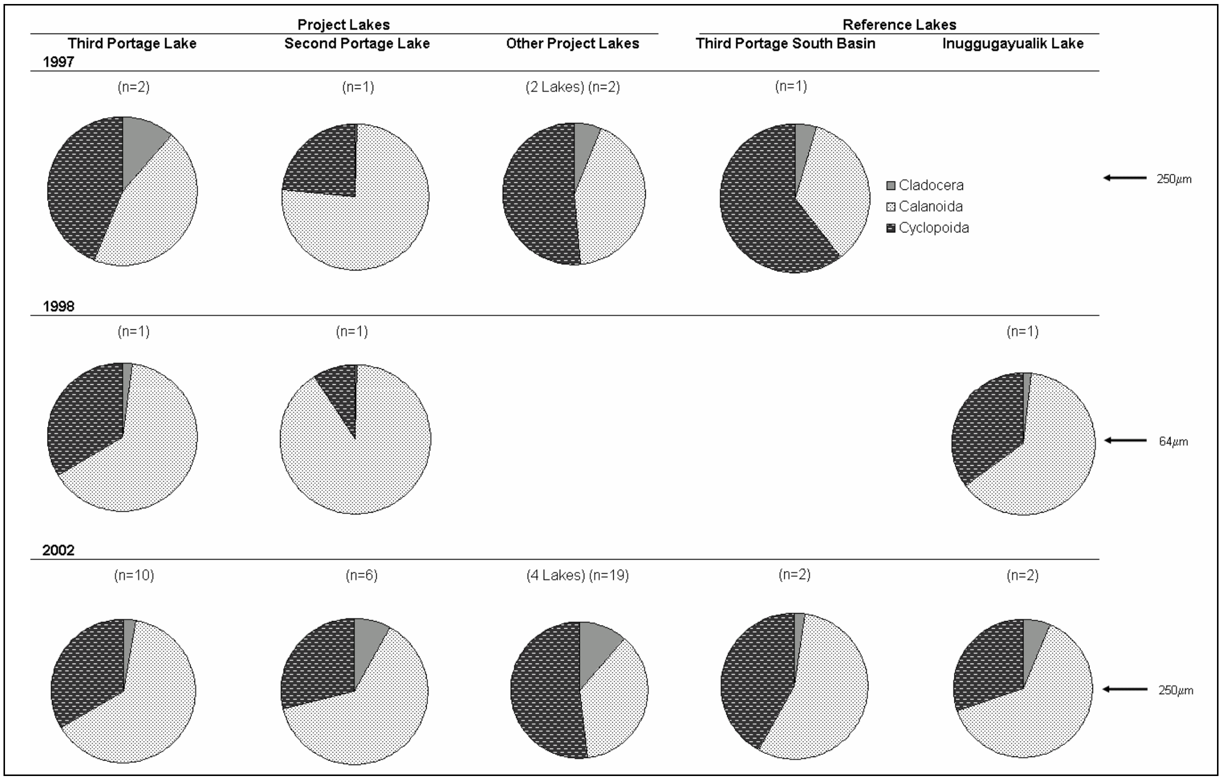
Note: * 64 µm tows were adjusted to include only those groups reliably captured by a 250 µm net to ensure comparability.

Table 6.5: Presence (+) / Absence (-) Matrix of Zooplankton Species in Project, Reference & Regional Arctic Lakes

	Project Lakes				Reference Lake				Regional Lakes			
	Third Portage Lake		Second Portage Lake		Innugugayualik Lake		Kiggavik Region Lakes[1]		Lac de Gras[2]		Snap Lake[3]	
Taxa/Group	**1997**	**1998**	**2002**	**1997**	**1998**	**2002**	**1998**	**2002**	**1979**	**1989**	**1995**	**1999**
CLADOCERA	+	+	+	+	+	+	+	+	+	+	-	+
Holopedium gibberum	+	+	+	+	+	+	+	+	+	+	-	+
Daphnia longiremis	+	+	+	+	-	+	-	+	+	+	-	+
Daphnia middendorffiana	+	-	+	+	-	+	+	+	-	-	+	-
Bosmina longirostris	+	+	+	+	+	+	+	+	+	+	+	+
Chydorus sphaericus	-	+	+	-	+	+	+	+	+	+	-	-
Triops longicaudatus	-	-	-	-	-	+	-	+	-	-	-	-
Eurcerus glacialis	-	-	-	-	-	-	-	-	-	+	-	-
COPEPODA	+	+	+	+	+	+	+	+	+	-	-	-
Calanoida	+	+	+	+	+	+	+	+	+	-	-	-
Leptodiaptomus pribilofensis	+	+	+	+	+	+	+	+	+	-	-	-
Leptodiaptomus ashlandi	+	+	-	-	+	+	+	+	-	-	+	-
Leptodiaptomus sicilis	-	-	+	+	-	+	+	+	-	-	-	+
Heterocope septentrionalis	+	+	+	+	-	+	+	+	+	+	+	+
Epischura lacustris	+	+	+	-	-	+	+	+	+	+	-	+
Epischura nevadensis	-	-	-	-	-	-	-	-	+	-	-	-
Diaptomus minutus	-	-	-	-	-	-	-	-	+	+	-	+
Cyclopoida			+	-	-	+	-	+		-	-	-
Cyclops bicuspidatus thomasi	-	-	+	-	-	+	-	+	-	-	-	-
Cyclops scutifer	+	+	+	+	+	+	+	+	+	-	+	-
Cyclops capillatus	-	-	-	-	-	+	-	-	-	-	-	-
Macrocyclops fuscus	-	-	-	-	-	-	-	-	-	+	-	-
Mesocyclops sp.	-	-	-	-	-	-	-	-	-	-	+	-
Diacyclops bicuspidatus	-	-	-	-	-	-	-	-	-	-	-	+
Total	**9**	**9**	**11**	**8**	**6**	**14**	**10**	**13**	**10**	**9**	**6**	**8**

References: 1. McKee et al, 1989. **2.** Diavik and Aber, 1998. **3.** De Beers, 2002.

Figure 6.4: Relative Abundance (%) of Major Zooplankton Taxa (adjusted for mesh size) in Project & Reference Lakes, 1997– 2002



In 2003, three small, fish-bearing ponds between Second Portage and Turn lakes were sampled. Zooplankton taxonomic composition of the ponds was significantly different than the lakes, as well as from each other. For example, in Dogleg Lake (NP-1), three Cladocera species (*Daphnia longiremis*, *Bosmina longirostris*, and *Holopedium gibberum*) were numerically the most abundant species, and collectively composed 60% of the community, followed by calanoid (23%) and cyclopoid copepods (17%) (Table 6.4). On the other hand, in NP-2 and NP-3, Cladocera contributed a very small proportion of the zooplankton community (<2%). In NP-3 a single genus (*Cyclops* sp.) composed 89% of all individuals enumerated, contributing to the very high density of zooplankters in this pond (15,005/m^3). It may be that the isolated nature and small fish population, consisting almost exclusively of lake trout, may be responsible for the differences observed in community structure and density between the ponds and the larger lake system.

As expected, there were also differences in relative abundance of different species among lakes and years, aside from the differences observed in the small ponds in 2003. For example, although *L. ashlandi* was the most abundant zooplankten in all study lakes in 2002, it was absent from Third Portage Lake. This is unusual, because this species was present in Third Portage Lake in previous years, although in lower abundance than the other lakes. Because Third Portage Lake is a large, headwater lake, it is possible that it has evolved a naturally different zooplankton community (i.e., because movement of zooplankters from downstream lakes, such as Second Portage and Tehek lakes, is not possible). This illustrates the value of having collected baseline data over multiple years, such that temporal variability can be considered in defining “true” baseline conditions. Given the potentially confounding influence of sampling zooplankton from different depths and, to a lesser extent, mesh size in this study, future monitoring programs will improve the understanding of inter-annual differences in abundance and diversity of the zooplankton community over time. This will also improve the ability to distinguish between natural changes in community structure and possible changes due to mine-related activities. Because zooplankton are water-column dwellers, however, their abundance naturally varies according to time of day, wind speed and direction, predation by fish, and other factors, so abundance estimates are naturally more variable than those for benthos, for example, which are sessile.

There were significant seasonal differences in abundance and size of zooplankters, evident from the 2002 data. For example, abundance of small (stage I to III) copepodites was greatest in spring, while in August 2002 stage IV and V and adults were most abundant, illustrating the growth of zooplankton over the course of the summer. This is also reflected in the abundance of zooplankters over the course of the summer as mean density increased from 2,898 zooplankers/m^3 in July to 9,000 zooplankters/m^3 in August, simply because more organisms reach sufficient size to be retained by the net (Table 6.4). Thus, temporal factors such as season influence measurable community composition and density of zooplankton in the water column. Mean density of zooplankton collected from project lakes in August 1997 (5,013/m^3) was lower than in 1998 (11,800/m^3) and in 2002 (9,000/m^3), which were similar. It is likely that inter-annual differences are explained by differences in depth from which zooplankton were collected.

Taxa richness was consistent between lakes and years, with similar numbers of taxa in each lake. The percent similarity of taxa was evaluated by determining the number of taxa that each lake had in common, relative to the number of unique taxa found in one lake and not another (Table 6.5). Although some species were not identified in some lakes in some years, taxonomic composition was very similar between Third Portage and Second Portage lakes and Inuggugayualik Lake, the external reference lake.

6.3.2 Reference Lakes

Zooplankton density in Third Portage Lake south basin was very similar to other Third Portage Lake stations in July and August 2002 (Figure 6.4). Relative abundance of cladocerans and of calanoid and cyclopoid copepods was similar among major basins in Third Portage Lake, which illustrates that the zooplankton community is similar in terms of density and taxonomic composition throughout the lake. Zooplankton density in Third Portage Lake overall was lower than densities observed in other project lakes, and the south basin of the lake was no exception. This is presumably because Third Portage Lake is deeper and colder, especially in the south basin, than the other project lakes. Zooplankton density in Inuggugayualik Lake in July (4,204/m^3) and August (9,265/m^3) 2002 was similar to mean zooplankton densities observed across the project lakes during these same months (2,898/m^3 and 9,000/m^3, respectively; Table 6.4).

To assess the degree of similarity in taxonomic composition of zooplankton species within study lakes and between project lakes and reference lakes, presence/absence of individual taxa were compared among all lakes (Table 6.5). Of the 13 zooplankton taxa documented from Second Portage and Third Portage lakes, and the reference Inuggugayualik Lake, only one species was present in Second Portage and Inuggugayualik lakes that was not present in Third Portage, for an overall similarity of 92% among study lakes. These data demonstrate the similarity in abundance and community structure of zooplankton between the project and reference lakes, from a local regional perspective, as well as from across a larger geographic region, notwithstanding differences in watershed basin drainage patterns (i.e., Hudson Bay vs. Arctic Ocean).

6.3.3 Regional Lakes

Density and richness of zooplankton taxa from Meadowbank project lakes are reasonably similar to lakes elsewhere in the Northwest Territories and Nunavut (Table 6.6, Figure 6.5). Differences in mesh size, sample depth, and time of year of sample collection are partly responsible for variation in results among studies (Urangesellshaft, 1981; McKee et al, 1989; Rescan, 1994; Diavik and Aber, 1998; De Beers, 2002). The predominance of calanoid and cyclopoid copepods from project lakes in all years is evident (Figure 6.4) and is similar to Snap Lake and Kiggavik area lakes (Figure 6.5), although the proportion of cyclopoid copepods relative to calanoid copepods in some Kiggavik lakes and Koala area lakes (Rescan, 1994) was higher. The proportion of cladocerans was similarly low in all Meadowbank and regional lakes.

Zooplankton richness ranged from 6 to 11 taxa in project lakes over the four sampling seasons. This was comparable to the number of non-rotifer zooplankton taxa observed in Snap Lake (1999), Judge Sissons Lake (1979, 1989), and other Kiggavik area lakes (1979), which ranged from 8 to 14 species. Thus, species diversity is naturally low in oligotrophic Arctic lakes.

Taxonomic composition between project and reference lakes, Kiggavik lakes, and Snap Lake was very similar. For example, 56% of zooplankton taxa were found in all lakes, which is relatively high considering the geographic scope. All of the widespread, common zooplankton species (Patalas et al, 1994), including *Holopedium gibberum*, *Daphnia longiremis*, *D. middendorffiana*, *Leptodiaptomus sicilis*, and *Cyclops scutifer*, were present in all study and regional lakes (Table 6.5).

Density (#/m^3) of major taxonomic groups from Kiggavik area lakes (1979) and Koala lakes (Table 6.6) differed considerably from one another in some cases, and were different from project and reference lakes (Table 6.4). Mean zooplankton density of Meadowbank project lakes ranged from 3,000 to 9,000/m^3, and is similar to densities observed in Kiggavik study area lakes (3,000 to 7,600/m^3) in 1979 (Urangesellshaft, 1981). Density estimates from the same area were, however, an order of magnitude lower in 1989 because different collection methods were used between years (hence, the data are not presented). Zooplankton density from Snap Lake was somewhat higher at 14,300/m^3, probably because a 76 µm net was used, which will capture more and smaller zooplankters. Maximum density of Koala Lake zooplankton (164 µm net) in 1994 (Rescan, 1994) was much higher than all other lakes.

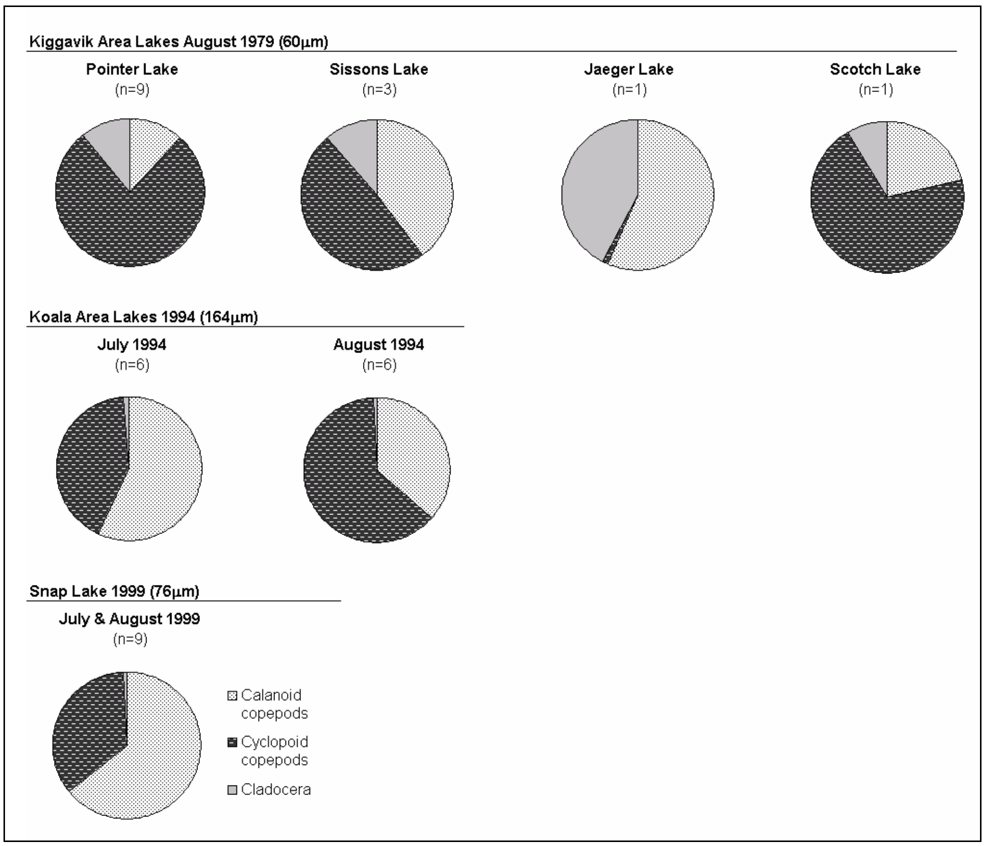
These data simply indicate the substantial variability in zooplankton density within different lakes, during different seasons and years. Natural inter-annual, seasonal, and/or spatial variability in zooplankton species composition and abundance can occur as a result of differences in water temperature, nutrient availability, phytoplankton abundance, and grazing by fish. In addition, differences in sampling methods, including mesh size, depth of water column sampled, net clogging, sampling methodology, collection location within the lake, season, and time of day, can also affect density estimates. Thus, it is difficult to make direct comparisons over large geographic areas and over time. Notwithstanding these difficulties, the taxonomic composition of project lakes was very similar among the lakes and fairly similar to regional lakes. Also, zooplankton density in project lakes was within the same range as most regional lakes.

Table 6.6: Mean Density & Richness of Major Zooplankton Taxa from Regional Arctic Lakes

Region/Lake/Year	Sample Size	Net Mesh Size	Relative Abundance (%) Calanoid Copepods	Relative Abundance (%) Cyclopoid Copepods	Relative Abundance (%) Cladocera	Total Density (#/m^3)	Mean Richness (# taxa)
Kiggavik Study Area 1979[1]							
Judge Sissons	(n=3)	60 µm	36.0	44.1	10.3	7,620	10
Pointer	(n=9)	60 µm	11.7	77.6	10.8	2,249	10
Jaeger	(n=1)	60 µm	55.3	1.3	41.6	2,871	14
Scotch	(n=1)	60 µm	21.4	70.0	8.5	3,839	13
Mean[A]	(n=11)	60 µm				2,986	12
Koala Area Lakes 1994[2B]							
6 lakes Jul 1994	(n=6)	164 µm	56.9	41.8	1.3	*11,713 - 173,974 (range)*	*7 – 15 (range)*
6 lakes Aug 1994	(n=6)	164 µm	36.4	62.8	0.7	-	-
Lac de Gras 1997[3,C]	(n=12)	NR	75.7	(calanoid+	24.3	n/r	*19*
Lac du Sauvage 1997[3,C]	(n=6)	NR	27.5	cyclopoid)	72.5	n/r	*16*
Snap Lake 1999[4]	(n=9)	76 µm	64.2	34.9	0.9	20,477 (July)	9 (July)
						14,297 (August)	10 (August)

Notes: A. Mean of Pointer, Jaeger, and Scotch lakes. **B.** Density and richness include rotifers. **C.** Richness includes rotifers.
References: 1. Urangesellschaft, 1981. **2.** Rescan, 1994. **3.** Diavik and Aber, 1998. **4.** De Beers, 2002.

Figure 6.5: Relative Abundance (%) of Major Zooplankton Taxa in Regional Arctic Lakes



6.4 BENTHIC INVERTEBRATES

Benthic invertebrates (collectively referred to as “benthos”) are relatively small animals that live on or in the bottom sediments. Benthic invertebrates provide an important food source for most fish species, especially young-of-the-year and juvenile lake trout, round whitefish, lake whitefish, sculpins, and stickleback (Machniak, 1975; Scott and Crossman, 1979). As lake trout get larger, they gradually shift from a diet dominated by invertebrates to one dominated by fish (Scott and Crossman, 1979).

The abundance and species composition of benthic invertebrates is strongly affected by water depth, sediment grain size, and organic carbon content of the sediment. Benthic invertebrates are typically most abundant at depths between approximately 3 m and 12 m. Benthos are not abundant at shallower depths because of ice scouring and coarse grain size. Below a depth of about 12 m, light penetration is much reduced and algal productivity is lower, so abundance and diversity of benthos is similarly reduced. The vast majority of benthic invertebrates in deeper sediments consist of oligochaete worms (true worms) and chironomid (midge) larvae, which live primarily in the sediment (i.e., infauna), as opposed to organisms that live on top of the sediment (epifauna). In shallower sediments (<12 m), the major invertebrate groups consist of aquatic larvae of insects (Class Insecta), especially chironomids (Order Diptera), caddisflies (O. Trichoptera), mayflies (O. Ephemeroptera), and stoneflies (O. Plecoptera). Other major taxa include amphipods (Crustacea; O. Amphipoda), mites (O. Acarina), fingernail clams (Class Bivalvia; *Pisidium* or Sphaeridae), harpacticoid copepods (Crustacea; O. Harpacticoida), and tadpole shrimp (O. Notostraca).

The amount of organic carbon, a food source, in the sediment will also influence abundance of benthic infauna that feed on the organic particles. Generally, sediment with a high proportion of organic material (>5%) will have greater abundance and diversity of benthos than sediments with small amounts (<1%) of organic carbon.

In addition to physical factors, abundance and composition of benthic communities are also influenced by biological factors, such as foraging by fish and timing of hatch of insect larvae. Because sampling cannot be conducted on all lakes at the same time, significant hatches of chironomids may occur during the course of sampling (a period of days or weeks). This may result in a particular species being very abundant in one lake, and much less abundant in another, because of hatching of larvae into the terrestrial adult. This can be partly overcome by sampling during late fall, after the emergence of most groups.

Benthic invertebrate samples were obtained by deploying a standard size Ekman or Ponar clamshell grab sampler from a boat to acquire a known area of bottom sediment. Two or three independent grabs from a small area were collected and composited to increase the surface area of the bottom sampled, and thus reduce heterogeneity between sampling stations. Sample depths for benthic invertebrates ranged from approximately 6 to 20 m during benthic sampling conducted between 1996 and 2002. Sediment grain size at all depths greater than 6 m is extremely consistent and fine and is comprised of 70% clay, 25% silt, and 5% sand. During the comprehensive survey of 2002, all benthic invertebrates were collected from depths ranging from 7 to 9 m to minimize the effect of depth and grain size on abundance and species composition. Sediment grain size, total organic carbon, and total metals were measured at all benthic sampling stations.

Only those grab samples that met the following acceptability criteria were retained for analysis: did not contain large foreign objects; adequate penetration depth (i.e., >10 cm); not overfilled (sediment surface not touching the top of sampler); did not leak (there was overlying water present and no visible leaks); and was undisturbed (sediment surface was relatively flat). Grabs that did not satisfy these conditions were discarded. Because of the soft nature of the sediment, care was taken not to overfill the grab sampler. Grab samples typically penetrated to at least the top 10 cm of sediment. To ensure consistency, the entire grab sample was processed, as per Environmental Effects Monitoring (EEM) protocols. The majority of benthic invertebrates are found within the top 5 cm.

Once on-board, the sediment was sieved through a fine-mesh screen to filter out the sediment and retain the organisms, which were then preserved with a formalin solution and transported to a taxonomic laboratory. At the laboratory, all organisms were removed from the sample, identified taxonomically, and enumerated. Density of benthic organisms was calculated by determining the number of each taxa present in standard units of # organisms/m^2, based on the surface area of bottom sediment sampled at each station. In all benthic studies conducted between 1996 and 2002, a 250 µm mesh screen was used to sieve benthos. As for the zooplankton taxonomy, Applied Technical Services Ltd. of Victoria B.C. conducted all taxonomic identifications.

Density of organisms/m^2 was determined from the total number of organisms enumerated, adjusted for surface area sampled. Like zooplankton, several groups of benthic organisms, such as nematodes and ostracods (very small crustaceans), are too small to be reliably retained by the 250 µm sieve. Therefore, these groups were not included in density calculations, although the taxonomist reported their abundance. Similarly, small numbers of planktonic copepods or adult insects (the very abundant and annoying mosquito and blackfly) were present in some samples, but were also not included in density calculations because they were not actually part of the bottom sample. Consequently, all benthic data sets were re-analyzed and harmonized to allow for relatively unbiased comparisons between years (notwithstanding depth differences).

6.4.1 Project Lakes

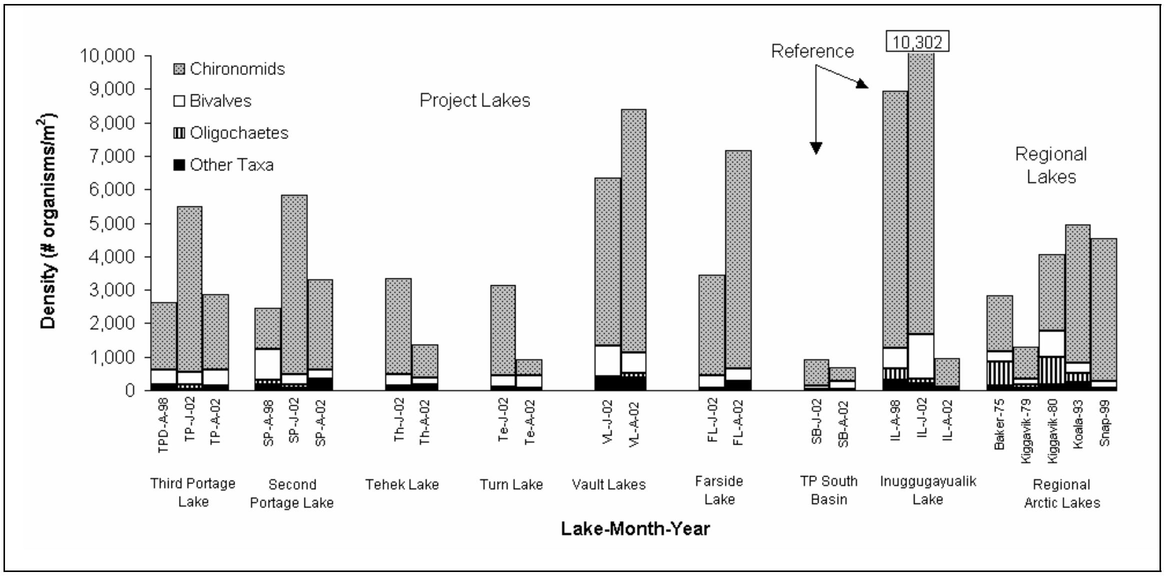
The benthic invertebrate community of project lakes was numerically dominated by the aquatic larval stages of insects, especially chironomids, both in terms of abundance and species diversity, which is typical of most Arctic and temperate lakes. The predominance of chironomids was consistent during all studies conducted between 1996 and 2003. However, anyone familiar with the Arctic will certainly not notice chironomids for the mosquitoes and blackflies! Mosquito larvae are usually found in small ponds, not in bottom sediments, and not on the water surface of large lakes. Blackfly larvae are associated with bottom substrates, but are typically found in moving water such as streams, not in large lakes, and thus are usually poorly represented in benthic samples. Therefore, despite the apparent abundance of mosquito and blackflies, chironomids typically compose the majority of the food source for young lake trout, young Arctic char, whitefish, and minnow species.

Mean density (pooled over stations within lakes) of major benthic invertebrate taxonomic groups (oligochaetes, bivalves, chironomids, and other taxa such as mites and insects) from Meadowbank project lakes were reasonably similar in 1998 and in July and August 2002, ranging from 2,500 to 8,300/m^2 (Table 6.7, Figure 6.6).

Table 6.7: Mean Density & Richness of Major Benthic Invertebrate Taxa from Project & Reference Lakes, 1997-2003 (250 µm Sieve)

Year/Lake/Depth (m)	**No. of Sample Stations**	**Mean Density (# organisms/m²)**					**Mean Richness (# taxa)**
		Oligochaetes	**Bivalves**	**Chironomids**	**Other Taxa**	**Total**	
August 1997							
Project Lakes							
Third Portage Lake (14 – 20)	(n=3)	29	196	566	109	657	13
Second Portage Lake (9)	(n=1)	15	44	218	0	276	5
Tehek Lake (6)	(n=1)	-	73	203	58	334	10
Turn Lake (9)	(n=1)	44	73	73	44	232	9
Reference Lakes							
Third Portage South Basin (21)	(n=1)	-	102	58	15	174	4
August 1998							
Project Lakes							
Third Portage Lake	(n=2)	73	450	2,001	102	2,625	12
Second Portage Lake	(n=2)	145	928	1,218	160	2,451	15
Reference Lakes							
Inuggugayualik Lake	(n=1)	334	638	7,671	308	8,950	19
Amarulik Lake	(n=1)	261	638	2,233	334	3,466	20
July 2002							
Project Lakes							
Third Portage Lake (8 – 11)	(n=5)	113	377	4,971	49	5,510	15
Second Portage Lake (9 – 10)	(n=3)	73	319	5,355	82	5,829	11
Tehek Lake (7 – 10)	(n=2)	-	358	2,837	135	3,330	15
Turn Lake (8 – 11)	(n=2)	36	363	2,697	51	3,147	16
Vault Lakes (8 – 11)	(n=3)	68	947	4,986	331	6,332	14
Farside Lake (10)	(n=1)	58	370	3,016	15	3,458	15
Reference Lakes							
Third Portage South Basin (9)	(n=1)	15	116	783	15	928	11
Inuggugayualik Lake (8 – 9)	(n=1)	138	1,327	8,642	196	10,302	15
August 2002 (Summer and Fall Samples)							
Project Lakes							
Third Portage Lake (9 – 10)	(n=5)	41	476	2,242	102	2,859	15
Second Portage Lake (9)	(n=3)	34	276	2,692	300	3,301	14
Tehek Lake (9 – 10)	(n=3)	15	218	972	155	1,358	12
Turn Lake (9.5)	(n=2)	7	370	479	58	914	6
Vault Lakes (8 – 10)	(n=4)	151	586	7,273	374	8,384	15
Farside Lake (8 – 10)	(n=1)	29	348	6,518	261	7,156	15
Reference Lakes							
Third Portage South Basin (9)	(n=1)	44	218	421	-	682	11
Inuggugayualik Lake (7)	(n=1)	29	44	841	29	943	11
August 2003							
Project Lakes							
North Portage 1 (Dogleg) (6)	(n=2)	15	471	3,197	22	3,705	12
North Portage 2 (4)	(n=2)	54	1,671	3,537	966	6,228	15
North Portage 3 (5)	(n=2)	-	597	1,617	65	2,279	8

Figure 6.6: Comparison of Mean Benthic Invertebrate Density (# organisms/m²) by Major Taxa for Project, Reference & Regional Lakes



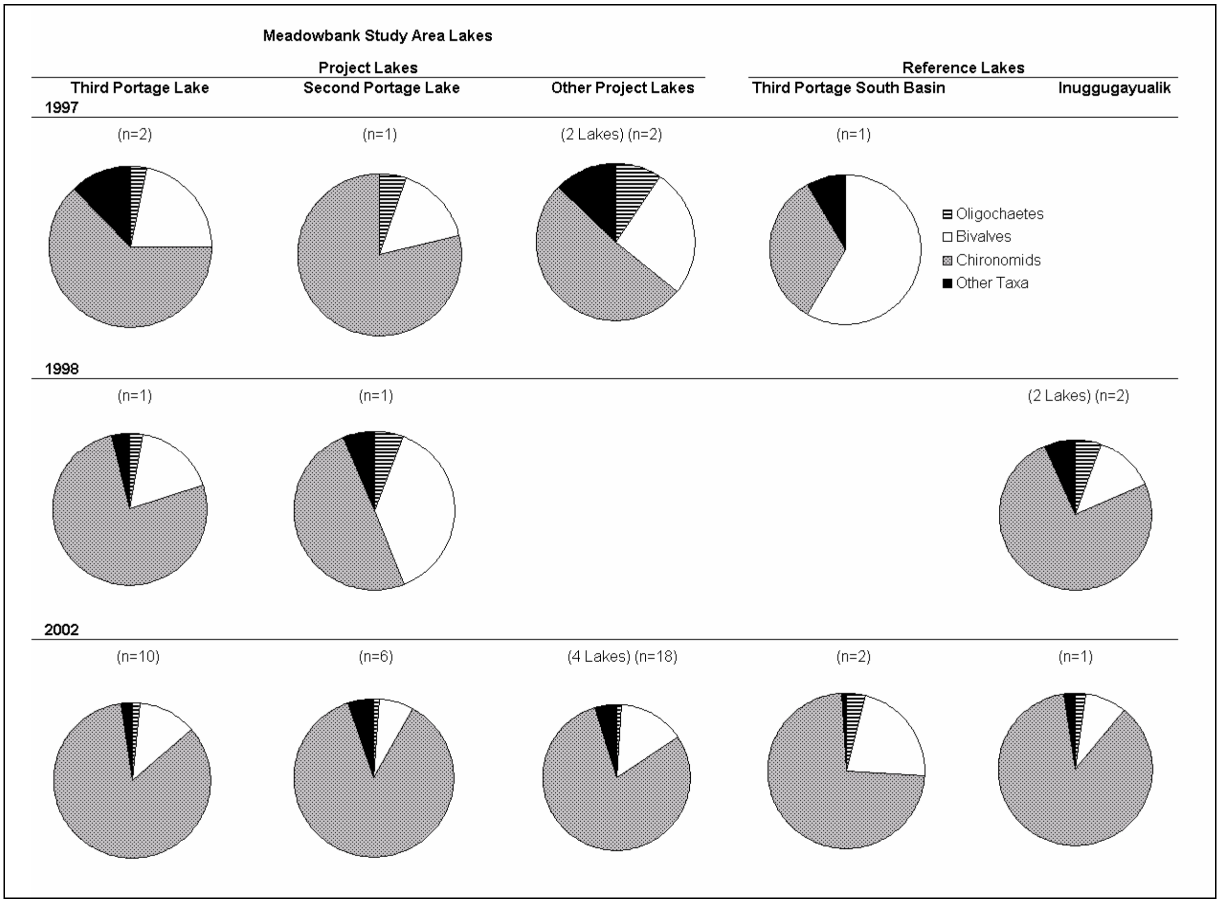
Note: Samples from Meadowbank, Koala, and Snap lakes were sieved through a 250 µm mesh net. Samples from Kiggavik and Baker lakes were sieved through a 500 µm mesh net.

In the small isolated ponds (NP-1, NP-2, NP-3) north of Second Portage Lake, chironomids dominated invertebrate density (57% to 86% of totals), with a similar density range (2,279 to 6,228/m²) as project lakes (Table 6.7). In lake NP-2, small bivalves clams (*Pisidium* sp. and *Sphaerium* sp.) comprised 27% of the benthic community. Oligochaetes typically composed a small proportion of the benthos. For unknown reasons, average density of benthic invertebrates in all project lakes in 1997 was about an order of magnitude less than in subsequent years, ranging between 174 and 657/m² in all lakes.

The predominance of chironomids is all project lakes can be clearly seen in Figure 6.7. Chironomid larvae comprised between 50% and 86% of organisms in benthic samples from all study lakes and ponds between 1997 and 2003. The dominant genera in 2002 were *Procladius*, *Tanytarsus*, *Paratanytarsus*, *Tanytarsini*, and *Heterotrissocladius*. These results are consistent with data collected in August 1997 and 1998, where the genera *Procladius*, *Tanytarsus*, *Rheotanytarsus*, *Phaenospectra*, *Microspectra*, and *Heterotrissocladius* dominated abundance. Chironomids also dominated abundance in reference and regional lakes and is typical of Arctic lakes. Other important insect taxa such as mayflies (Ephemeroptera) and stoneflies (Plecoptera) are uncommon or absent in many Arctic lakes.

In addition to chironomid insects, Sphaeriidae bivalves (i.e., small clams consisting of the genera *Pisidium* [2002] and *Sphaerium* [1997, 1998]) were the second most abundant benthic group in Meadowbank project lakes (12% to 26%). Other groups identified in benthic samples from these lakes included oligochaetes (1% to 9%), Hydracarina (mites), cladocerans, harpacticoid copepods, eubranchiopods (tadpole shrimp; a common organism found in stomachs of round whitefish), amphipods, Turbellaria (flatworms), and stoneflies (Trichoptera). With the exception of oligochaetes, one of the “other” groups contributed more than 1% of total density of organisms in benthic samples.

Figure 6.7: Relative Abundance (%) of Major Benthic Invertebrate Taxa in Project & Reference Lakes, 1997 to 2002 (250 µm sieve)



Note that in addition to the above groups, nematodes (very small pseudocoelomate round worms) and ostracods (small bivalved crustaceans) were present in all benthic samples, but were not included in the present analysis, as discussed above. Although these groups are abundant and widespread, they are typically much smaller than the 250 µm mesh size used in these studies; therefore, their abundance is simply random and would confound density estimates.

The average number of genera identified in benthic samples from project lakes ranged from 11 to 20 taxa and was reasonably consistent among stations and seasons (Table 6.7). Chironomids were the most diverse group taxonomically, with 20 genera identified over all stations. Within stations, an average of 10 to 12 chironomid genera were identified per station, with most common chironomid taxa being present in all lakes. Overall, there were no large differences in species diversity among lakes as the total number of taxa identified in each lake was quite similar.

6.4.2 Reference Lakes

The benthic invertebrate communities of Third Portage south basin (internal reference) and Inuggugayualik Lake (external reference) were similar to project lake communities in terms of density and community composition, although there were some differences. For example, mean density of benthos in Third Portage Lake south basin was lower than the other basins, except the north basin in fall 2002. This trend of lower abundance from this station is likely due to the small number of samples collected from this area, or to spatial heterogeneity in abundance of organisms, which is common in benthic data sets. This is illustrated by the density estimates for Inuggugayualik Lake. Mean density from this external reference lake was higher than all other project lakes in July (10,302/m^2), but lower than nearly all other lakes in August 2002 (943/m^2). This was primarily due to poor weather conditions in 2002, which prevented acquisition of a good, representative sample. Also, this lake was sampled last. Therefore, significant hatching of chironomids may have occurred, resulting in a concomitant reduction in the benthos. These data illustrate the natural variability in benthic data due to differences in timing of collections (e.g., resulting in differences due to hatching by specific taxa), natural heterogeneity of benthic communities, and poor sampling conditions.

Notwithstanding seasonal differences in density, relative abundance of major groups was consistent among reference and project lakes (Figure 6.7, Table 6.7), as chironomids dominated abundance in Third Portage south basin and Inuggugayualik Lake, followed by bivalves and oligochaetes. These data provide further evidence of the similarity of benthic invertebrate communities over this geographic region, both within and among project lakes, although natural seasonal and inter-annual differences in density are evident owing to the relatively small areas sampled for benthos throughout the project area.

6.4.3 Regional Lakes

Benthic invertebrate samples have been collected from several local regional lakes (Table 6.8), such as Baker Lake (1975; McLeod et al, 1976) and Kiggavik lakes (1979, 1980; Urangesellshaft, 1981; McKee et al, 1989). Benthic data have also been collected from lakes elsewhere in the territories including Koala area lakes (1993, 1994; Rescan, 1994), Lac de Gras (1995, 1996; Diavik and Aber, 1998), Lac du Sauvage (1996; Diavik and Aber, 1998), and Snap Lake (1999; De Beers, 2002). It is difficult to make quantitative comparisons in benthic community structure and abundance because of the large natural variability in physical (i.e., grain size, TOC, depth) and biological features (foraging by fish, time of year, status of hatch) associated with sampling. Also, the reports reviewed often contain insufficient information to determine how comparable data sets from regional lakes are to project lakes. For example, information such as mesh size used for sieving, number of sample composites, sample depth, grain size, season, taxonomic detail (e.g., were nematodes included in density calculations?), and other information, is not available in summary reports. Therefore, comparisons of species composition and density of benthos between project lakes and lakes elsewhere in Nunavut and the Northwest Territories must be viewed with caution.

Notwithstanding the above factors, it appears as if relative abundance of major taxonomic groups from project lakes (Figure 6.7) is very similar to Baker Lake (1975) and Kiggavik area lakes (1979, 1980) (Figure 6.8). The rank order of community abundance in study lakes relative to Baker Lake and Kiggavik lakes was the same. Chironomids dominated benthic community abundance and species composition, followed by bivalves, other taxa, and oligochaetes (Figures 6.6 and 6.7). This was also true for data collected more recently from regional lakes (Koala and Snap lakes). Despite large geographic and temporal differences, notwithstanding possible differences in sampling conditions and methodology, basic benthic community structure of project lakes is similar to reference and regional Arctic lakes.

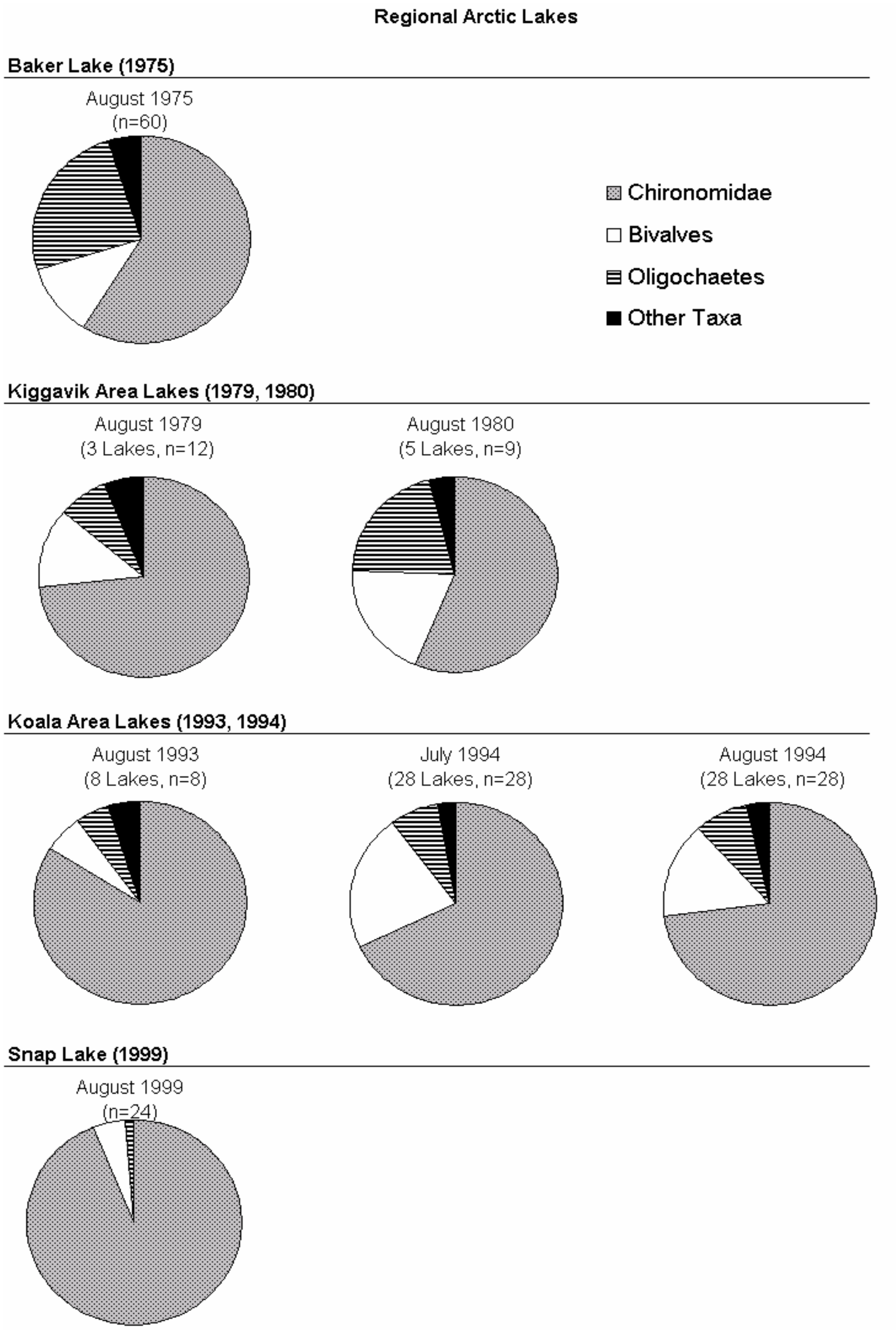
Table 6.8: Relative Abundance & Density of Major Benthic Invertebrate Taxa from Regional Arctic Lakes

Region/Lake/Year	No. Lakes	Sample Size	Sample Depth (m)	Mesh Size (µm)	Relative Abundance (%)				Mean Density (#/m²)	Mean Richness (#)
					Chironomidae	Bivalves	Oligochaetes	Other Taxa		
Baker Lake[1]										
August 1975	1	(n=60)	15	500	58.8	11.5	24.8	4.9	2,842	-
Kiggavik Area Lakes										
August 1979[2]	3	(n=12)	1.5 - 4.6[A]	500	73.3	12.9	7.8	6.0	1,283	10
August 1980[3]	5	(n=9)	1.5 - 6.0[A]	500	56.5	19.0	20.2	4.3	4,053	6
Koala Area Lakes[4]										
August 1993	8	(n=8)	1-4, 4-10, >10[B]	250	83.8	6.3	5.0	5.0	4,955	-
July 1994	25	(n=28)	1-4, 4-10, >10[B]	250	68.1	21.7	7.2	2.9	982 – 5372[C]	-
August 1994	25	(n=28)	1-4, 4-10, >10[B]	250	72.9	15.3	8.2	3.5	882 – 8002[C]	-
Lac de Gras[5]										
July 1995	1	(n=18)	-	-	NR	NR	NR	NR	967	-
August 1995	2	(n=18)	-	-	NR	NR	NR	NR	2,011	-
August 1996	1	(n=16)	-	-	NR	NR	NR	NR	2,725	-
Lac du Sauvage[5]										
August 1996	1	(n=3)	-	-	NR	NR	NR	NR	18,774	-
Snap Lake[6]			-	-						
August 1999	1	(n=24)	6 - 7	250	93.5	4.6	1.4	0.0	4,572	14

Notes: A. Mean depths of lakes reported, samples taken from "deep lake areas." **B.** Triplicate samples from the three depths reported were composited. **C.** Range shown is profundal to littoral lake zones.

References: 1. McLeod et al, 1976. **2.** McKee et al, 1989. **3.** Urangesellschaft, 1981. **4.** Rescan, 1994. **5.** Diavik Diamond Mines, 1998. **6.** De Beers, 2002.

Figure 6.8: Relative Abundance (%) of Major Benthic Invertebrate Taxa from Regional Arctic Lakes



Note: 500µm mesh sieve used in Baker and Kiggavik lakes; 250µm mesh sieve used in Koala and Snap lakes.

In general, density of benthic invertebrates from project lakes (Figure 6.5) was similar to or higher than densities observed in other northern region lakes, including Snap Lake (4,570/m^2), Baker Lake (2,840/m^2), and Kiggavik area lakes (1,280/m^2 in 1979 and 4,050/m^2 in 1980) (Tables 6.7 and 6.8) Invertebrate density from Inuggugayualik Lake, Vault lakes, Farside Lake, and Second Portage Lake was higher than those in other systems, but similar to the high range of densities observed from Koala study area lakes and Lac de Gras, Northwest Territories. Thus, density of benthic invertebrates from project lakes is comparable to densities observed in other lakes over a wide geographic area, and suggests that the benthic invertebrate community in project lakes is typical of other pristine Arctic lakes.

With respect to diversity (richness) of taxa, average taxonomic diversity of benthic invertebrates generally ranged between 11 and 16 unique taxa per sampling lake (Table 6.7). Chironomids typically dominated about two-thirds of all taxa identified. The mean number of benthic invertebrate genera in samples from Snap Lake (14 in 1999) was comparable to the Meadowbank project lakes (Table 6.8; De Beers, 2002). Kiggavik area lakes exhibited slightly lower species diversity than did Meadowbank (10 in 1979 and 6 in 1980; Table 6.8; MacDonald and Stewart, 1980; McLeod et al, 1989). Kiggavik area lakes tend to be smaller and shallower than Meadowbank area lakes, which may partly explain the differences in benthic communities. There were no data on taxa richness from Koala area lakes (1993, 1994; Rescan, 1994), nor from Lac de Gras and Lac du Sauvage (Diavik and Aber, 1998).

Data on species composition, density, and taxonomic richness of Meadowbank project area lakes, relative to similar data from lakes elsewhere in Nunavut and the Northwest Territories, indicate widespread similarity in these parameters, over both time and wide geographic scales. The benthic communities of project lakes are relatively healthy and diverse, and are typical of pristine Arctic, oligotrophic lakes. Benthic invertebrates were collected from more stations over a wider geographic area and over a longer time period from the Meadowbank area relative to many other areas. This provides a good understanding of the benthic invertebrate community of Meadowbank project lakes, and a reasonable data set against which to address impacts in the EIA. It will also assist with siting stations as part of the federal Environmental Effects Monitoring program used to gauge potential impacts of mine effluents on receiving environment biota.

SECTION 7 • FISH

7.1 BACKGROUND

Fish are the most recognizable aquatic organisms in the Meadowbank study area. Consistent with the typical species composition of Arctic lakes (Scott and Crossman, 1979), lake trout and round whitefish dominate abundance in all lakes. In small isolated ponds, lake trout is frequently the only species present. Fish represent the top of the food chain and ultimately provide a food source for some fish-eating birds such as loons. According to traditional knowledge, local residents of Baker Lake have fished within Third Portage Lake on an infrequent basis. Fishing on Third Portage Lake is conducted during late winter or early spring through the ice and lake trout are most frequently captured. Rarely is an Arctic char captured. The favoured area for fishing is Whitehills Lake, again during winter through the ice.

Arctic lakes typically contain a large biomass of fish, characterized by many, very large (>5 kg), old (>20 years) lake trout; however, the productivity of Arctic lakes is very low. That is, the rate at which the biomass is replaced, or turned over, is very small. This is because in oligotrophic systems there is a limited amount of nutrients available to fish, and there is great competition for it. Given the short growing season, limited nutrient availability, and very cold water, growth rates of Arctic fish are exceedingly slow.

The main food source of lake trout is usually smaller lake trout, because they are highly cannibalistic. If lake whitefish or round whitefish are present in the same lake, these species can also compose a significant portion of the diet of trout (Scott and Crossman, 1979). This partly explains why most lakes contain healthy populations of large lake trout of a similar, narrow size range; smaller fish are eaten and the replacement rate into the larger, older cohort of fish is slow.

The Meadowbank project area lakes are situated in the extreme headwaters of the Quoich River drainage basin and within the larger region flowing into Chesterfield Inlet and eventually to Hudson Bay. St. Clair Falls near the mouth of the Quoich River is a barrier to upstream migration by fish (MacDonald and Stewart, 1980), and precludes access by anadromous Arctic char from Chesterfield Inlet to upstream lakes.

The project lakes lie on the boundary with the Back River drainage system, which flows north to the Arctic Ocean. Because the project lakes are headwater lakes, there is no significant inflow or outflow from the lakes; the drainage area relative to lake surface area is very small; and the sedimentation rate, nutrient addition, and productivity are very low. Lakes are connected by small, ephemeral, boulder-strewn channels, which do not allow for fish passage during most of the open water season.

Third Portage Lake drains into Second Portage Lake via three small connecting channels that flow across a narrow isthmus of land (Figures 4.1 and 4.2). The majority of the flow occurs beneath the surface, or between the large rock and boulder substrate that separates the lakes. Because of permafrost, cold winter temperatures, the low relief, and the small elevation change between the lakes, drainage is very slow and diffuse. Movement of water from Third Portage into Second Portage Lake occurs primarily during spring freshet, with declining flows throughout the summer and fall.

Movement of fish between the lakes during any other time but spring is very difficult or impossible. Thus, the magnitude of fish movement between Third Portage and Second Portage lakes is small and opportunistic, and no dedicated migrations of fish have been observed. This physical and hydrologic setting is a strong determining factor in the species composition, abundance, and distribution of fish in this region. Also, the absence of stream habitat, preferred by Arctic grayling, would explain why no grayling are present in study area lakes.

This section is organized slightly differently than the previous ones. Here, comparisons of biological parameters of fish communities (e.g., species community, age structure, metals concentration in tissue) between project lakes, reference lakes, and regional Arctic lakes are made within each subsection, according to the biological parameter being discussed. This comparative information is woven through the discussion of each subsection, rather than undertaking this review at the end of the fisheries section.

7.2 SURVEY APPROACH AND METHODS

Quantitative fisheries surveys were conducted in project and reference lakes in 1997, 1999, 2002, 2003, 2004, and 2005 in project and reference lakes and in regional/candidate reference lakes in 1998. Index gill nets measuring 25 m long x 1.8 m deep with stretch mesh sizes of 38 mm, 51 mm, 76 mm, 95 mm, 108 mm, and 127 mm were used in all years. In 1999 Gee minnow traps and fine mesh “Swedish” style nets were also used periodically to capture juveniles of major species (trout, whitefish, char) and determine if minnow species (e.g., lake chub, stickleback) were present in project lakes. Hoop nets were set downstream of major connecting channels between project lakes (e.g., Portage lakes, Second Portage – Tehek, Vault – Wally) in 1997, 1998, 1999, 2004, and 2005.

Fishing effort with gill nets, Swedish nets and minnow traps was primarily directed towards nearshore, littoral zone habitat associated with platforms, shoals and aprons in depths usually less than 10 m. The majority of habitat fished has been classified as medium or high value habitat based on a quantitative habitat mapping exercise (FHAP, 2005). Substrate consisted predominantly of large boulder and cobble nearshore, to depths of 3 to 4 m. Deeper than this, boulder cobble still predominated, but there was a gradual transition to finer substrates draped over coarse substrate to about 8 m. Bottom substrate consisted almost exclusively of silt/clay at depths greater than 8 m (BAEAR, 2005). Nets were typically set perpendicular to shore, taking advantage of points, shoals or other features that might optimize capture of fish. Net sets varied from a few hours to overnight (up to 8 hours), depending on weather and helicopter availability. Because of the great clarity of the water, even at deeper depths, fish capture was always low during the daytime because fish can see and avoid the nets. To acquire adequate sample sizes of fish, nighttime gill net sets were required. Fishing activities were usually restricted to either spring or fall periods, when water temperatures were cold to minimize mortality of fish.

Medium and high value habitat was targeted because of its importance to lake trout, round whitefish and Arctic char as spawning, rearing, and foraging habitat. Note that gill nets were set in 2 x 75 m gangs that spanned a diverse range of micro-habitat (substrate, complexity, depth). It is not possible to determine subtle, spatial differences in habitat utilization by fish using gill nets because of the length of time nets are set and the mobility of fish. Nevertheless, fishing effort over a period of many years (1997 to 2005) within similar habitat types between lakes does allow for relatively unbiased comparisons of species composition, size, habitat utilization and other life history parameters such as spawning. Gill nets have been used successfully to target suspected spawning grounds by lake trout.

The objectives of the fisheries surveys were to determine:

- fish species composition
- relative abundance
- catch-per-unit-effort (number of fish per 100 m of net per 24 h)
- relationship between habitat and abundance and species composition (e.g., spawning habitat)
- population statistics (length, weight, age, maturity, diet, fish movement)
- tissue metals and mercury concentrations.

Systematic gill net surveys of Third Portage, Second Portage and Tehek lakes were first carried out in fall 1997 to acquire baseline information on species composition, relative abundance, and life history (gender, maturity, diet) of resident fish populations.

In summer, 1998, six candidate reference lakes (Figure 4.2) were sampled, in the same manner as the study lakes in 1997, to investigate the regional fish population characteristics, and to identify one or more lakes as candidates for reference lakes for long-term monitoring purposes. The candidate reference lakes sampled included Turn Lake, Amarulik Lake, Inuggugayualik Lake, Pipedream Lake, Ihipqiituq (due east of Amarulik Lake, just off the map), and Farside Lake (Figure 4.2).

Efforts to better understand the fish communities of project and reference lakes were continued in 1999, with a greater focus on fish movement patterns both within and between project lakes. A key component of the 1999 study was to apply numbered Floy (spaghetti) tags to fish captured from the project lakes and Inuggugayualik Lake. Fish re-captured during subsequent fisheries programs would provide data on growth or movements within or between lakes. Supplemental gill netting was conducted in 2002 (Portage and Inuggugayualik lakes) to gather information on metals concentrations in muscle tissue (2002) and anadromy of Arctic char. In 2003, fish species composition, abundance, and life history of fish was determined from numerous small, isolated ponds north of Second Portage Lake. Gill netting of Vault and Phaser lakes was undertaken in 2005 to provide additional information on fish resources of that lake. Note that the same gill net mesh sizes and dimensions (length, depth) were consistently used in the 1997, 1998, 1999, 2002, 2003, and 2005 surveys of all project lakes and in the 1998 survey of candidate reference lakes. This facilitated comparisons of CPUE data. Additional gear such as fine mesh Swedish nets and minnow traps were used to augment data collected from gill nets. These data were not included in CPUE calculations.

Inuggugayualik Lake was chosen as an external reference lake because of the similarity in fish population species composition and biological characteristics with project lakes, as well as greater similarity in the benthos and zooplankton community than the other lakes. This is despite the fact that this lake lies at the headwaters of the Meadowbank/Back river system that flows to the Arctic Ocean. It is possible that anadromous Arctic char can access this lake, more than 200 km from the Arctic coast, although the abundance of anadromous char relative to resident fish, especially lake trout, is exceedingly small.

Hoop nets were used to determine fish movements between lakes by setting them in the small connecting channels between several key project lakes. A hoop net consists of a series of 1.3 m diameter hoops strung with nets, within which is a nested trap where fish are captured and retained alive as they move up- or downstream, depending on which way the net is orientated. They are ideal for monitoring fish movements in streams. Hoop nets were set in the channels connecting project lakes in 1997, 1998, 1999, 2003, 2004, and 2005 to document fish movement between Second and Third Portage lakes, Drilltrail and Second Portage Lake, Second Portage and Tehek and between Vault and Wally lakes.

Very fine mesh, “Swedish”-style gill nets (mesh sizes of 25 mm, 37 mm, and 51 mm) and baited minnow traps were used in the 1999 survey of project lakes and the external reference Inuggugayualik Lake to capture juveniles of major species, as well as “minnow” species such as ninespine stickleback and sculpins (*Cottus* sp.), which are not captured in standard gill nets.

Brief fisheries surveys were conducted in August 2002 and 2003 to increase the understanding of the distribution and ecology of fish populations of the study area, as the spatial boundaries of mine exploration expanded to include the Vault Deposit, for example. In 2002, Third Portage, Second Portage, Inuggugayualik, and the Vault lakes were sampled, primarily to gather biological information on fish from Wally Lake and to acquire tissue samples from lake trout, round whitefish, and Arctic char from these lakes to establish background tissue metals concentrations in advance of mining.

In 2003, three small ponds between Second Portage Lake and Turn Lake were fished to determine whether fish existed in these waterbodies. These ponds (NP-1, NP-2, NP-3) have no hydraulic connections to Second Portage or Turn Lake, and the resident fish populations are truly isolated.

Fish captured in nets were measured for length (mm), weight (g), and examined for external condition. Mortality of fish was minimized as much as possible; however, a subset of fish from each lake was autopsied to determine: internal condition and parasite load; sex and gender ratio; diet, from examination of stomach contents; and age, by sampling the appropriate structure (e.g., fins, otoliths).

Fish species composition, population statistics, and tissue metals concentrations (including mercury) from Meadowbank project lakes are compared with similar data from nearby reference and from small lakes in the Baker Lake region, as well as from regional lakes elsewhere in Nunavut and the Northwest Territories.

The 2005 fisheries survey focussed on streams crossed by the proposed all-weather road between Baker Lake and Meadowbank camp and on connecting channels between the project lakes. There are 25 planned stream crossings along the proposed 115 km road. The majority of these crossings are small, ephemeral drainage channels that drain small ponds and lakes. The channels are typically shallow and diffuse, flowing over grassy, marshy substrate. A small number of these channels contain ninespine stickleback. Based on a helicopter survey during late winter, many of the ponds upstream and downstream of these ephemeral streams are very shallow and appeared to be frozen to the bottom and likely contain few if any fish.

Some of the stream channels connect fish-bearing lakes up- and downstream of the road crossing and had sufficient flow to support fish migrations. Hoop nets were set in all streams that connected larger, fish-bearing lakes and which contained fish other than ninespine stickleback. Data on fish movements, size distribution, fish larval drift and habitat utilization were collected from all streams containing grayling. All streams containing grayling drain south into the Prince River watershed that flows south towards Baker Lake. Arctic grayling were not found in any stream draining east towards Third Portage Lake.

Hoop nets were set in the connecting channel between Second Portage and Third Portage and between Second Portage and Tehek Lake during the majority of the open-water season. Hoopnets were also set between Vault and Wally lakes. Species composition, fork length (mm) and direction of movement of fish were recorded.

7.3 SPECIES COMPOSITION

Lake trout was by far the most abundant species present in all project lakes accounting for between 64% (Ihipqiituq Lake) and 99% (Pipedream Lake) of fish captured in gill net surveys (Figure 7.1). Round whitefish was consistently more abundant than char in all study lakes in the 1998, 1999, and 2002 surveys, except in Second Portage Lake in 1997. Arctic char was the third most abundant species captured from project lakes, with larger numbers in Second Portage Lake (28%) than Third Portage Lake (8%) in 1997.

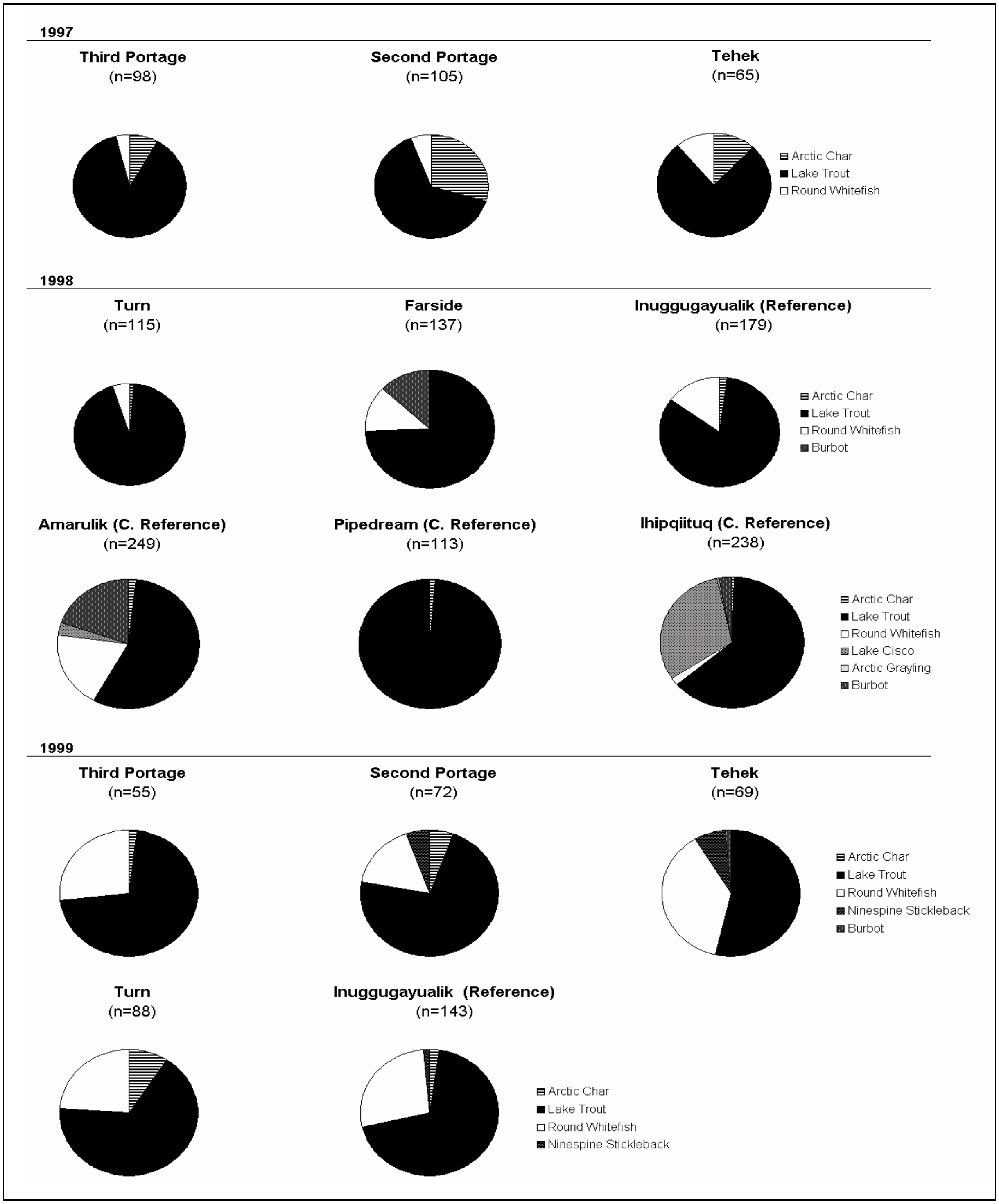
The low species diversity and large abundance of lake trout observed is typical of most Arctic lakes (McPhail and Lindsey, 1970; Kalff, 1970; Johnson, 1976). MacDonald and Stewart (1980) also found that lake trout and round whitefish were the most abundant species captured in gill net surveys on the Quoich River, just downstream from Tehek Lake, and reported capturing Arctic grayling, slimy sculpin, and a single Arctic char (purported to be landlocked) from the Quoich River. Lake whitefish and lake cisco were notably absent from the Quoich River system and other rivers draining the north side of Chesterfield Inlet (MacDonald and Stewart, 1980).

Three small isolated ponds between Second Portage and Turn Lake were surveyed with gill nets in August 2003 (Figure 4.2). Each of these ponds, NP-1 (Dogleg), NP-2, and NP-3, contained fish, despite there being no surface drainage from the ponds. NP- 1 and NP-2 appeared to contain only lake trout, while NP-3 contained round whitefish (40%) and lake trout (60%). These were the only small ponds to contain fish, as all others were too shallow (<3 m) to maintain fish during overwintering. A late spring helicopter survey of these ponds confirmed they are frozen to the bottom and bottom sediment was clearly visible on the underside of the ice cover on all of these ponds.

The dominance of lake trout in small, isolated lakes and ponds is typical of the Arctic. Rebound of the land after retreat of the glaciers captured and isolated small fish populations in ponds and lakes. These ponds and their isolated fish communities have persisted for perhaps hundreds of years. Given the isolated nature of the ponds, they do not contribute nutrients or fish to the larger lakes, such as Second or Third Portage; therefore, their regional habitat value is quite small.

The smaller number of char in Third Portage Lake may be related to low lake productivity and possibly the difficulty in overcoming the barrier that exists between Second and Third Portage lakes. Arctic char are frequently anadromous (i.e., at least part of their life history is spent in a marine environment, with overwintering and spawning in fresh water). The impassable St. Clair Falls on the Quoich River precludes upstream movements by anadromous Arctic char. All char in this system are landlocked.

Figure 7.1: Relative Abundance (%) of Fish Species in Project, Reference & Candidate Reference Lakes



Overall, round whitefish was the second most abundant species captured, after lake trout, from most candidate reference lakes (except Pipedream). Arctic char was the third most abundant species and was found in most lakes (except Farside Lake), including Pipedream and Inuggugayualik, both of which are headwater lakes of the Back River system that flows to the Arctic.

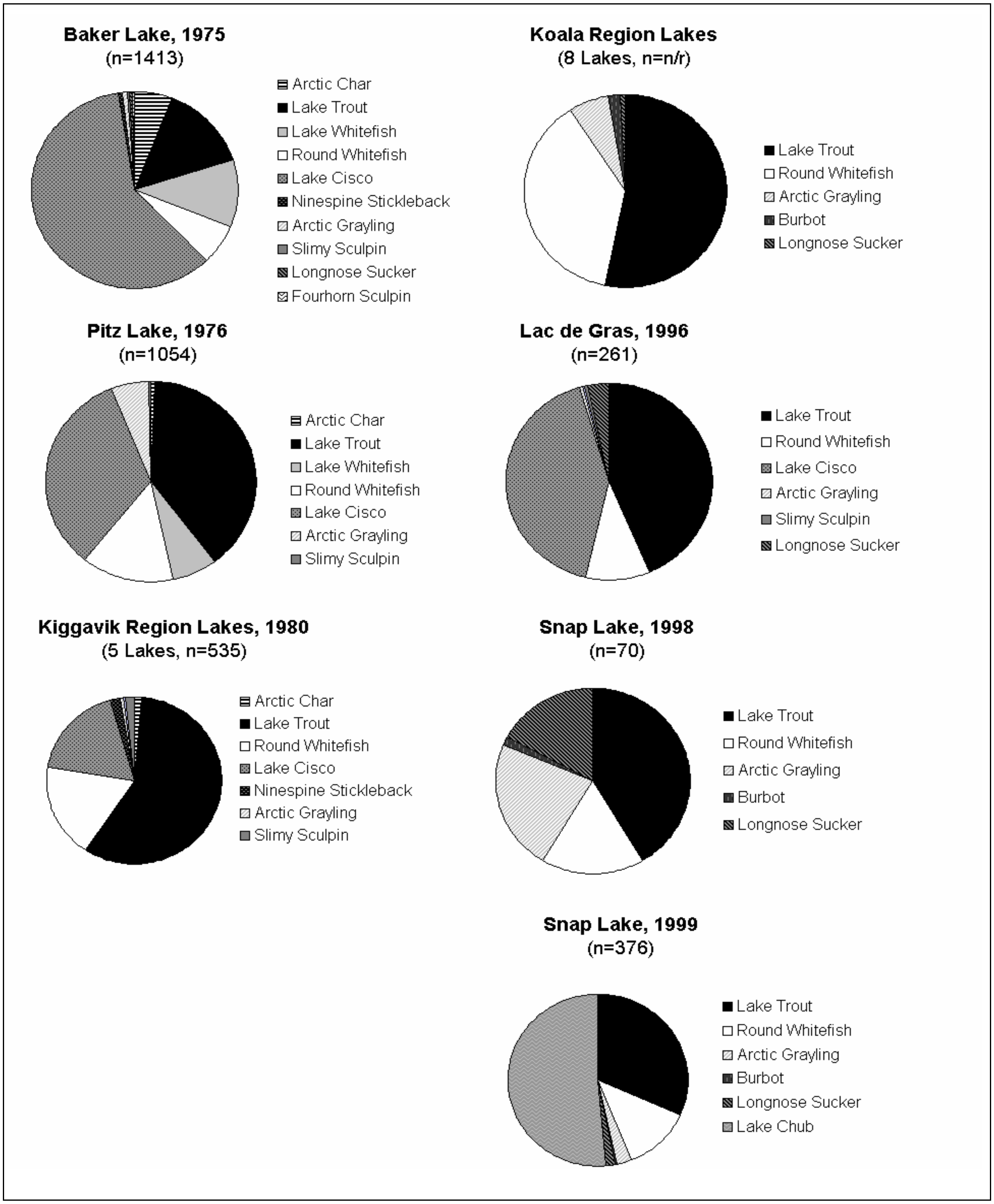
Lake cisco (*Coregonus artedii*) was present in two of the candidate reference lakes (Amarulik and Ihipqiituq) in 1998, but was not present in any of the project lakes. Ihipqiituq Lake contained a relatively large abundance (31%) of lake cisco. A few lake cisco were also present in larger streams connecting large lakes in the southern part of the Prince River system draining towards Baker Lake. Cisco were not captured within the watershed of Third Portage Lake, part of the Quoich drainage.

In a review of the ecology of lake-dwelling Arctic fish populations, Johnson (1976) stated that the lake trout/whitefish complex in Arctic lakes typically composes 95% of the total fish population, except in unusual situations. The few exceptions to this general trend are lakes that have a good connection to, or are situated near, marine environments in the southern Arctic. Such lakes may also contain a higher proportion of anadromous fish such as Arctic char and/or lake cisco. This is because when lake cisco occur in lakes or rivers in close proximity to Hudson Bay, they are often semi-anadromous. Cisco will make annual journeys during spring/summer to estuarine, coastal habitats to feed, before returning to overwinter in lakes or large rivers (Schneider-Vieira et al, 1993). Lake cisco was present in Ihipqiituq and Amarulik lakes (part of the Prince River drainage), both of which are well connected to Baker Lake and Chesterfield Inlet. Lake cisco was the most abundant species captured in Baker Lake in 1975 (Figure 7.2). It is likely that cisco in these lakes are anadromous to some extent. The large distance and barriers between the project lakes and the marine environment of Chesterfield Inlet precludes the existence of cisco, although they are present in lakes further south. This is supported by the absence of lake cisco in Pipedream and Inuggugayualik lakes, both of which are also headwater lakes, but within the Arctic drainage.

Arctic char composed less than 4% of total abundance in candidate reference lakes in 1998, followed by burbot (3%). Burbot were also captured in Tehek Lake, but not in Second or Third Portage lakes. Burbot were recorded in the gut of a lake trout from Turn Lake in 1999. A single burbot was captured from Vault Lake in 2004. Burbot are a piscivorous species that dwell in profundal areas of large lakes (Scott and Crossman, 1979) and are relatively rare in the project lakes. Slimy sculpin (*Cottus cognatus*) also occurs in the project lakes in small numbers. Sculpin have been recorded in the gut contents of lake trout from Turn Lake, Pipedream Lake, and Vault/Wally lakes in 1999 and 2002. The only other fish species present in the project area lakes is ninespine stickleback (*Pungitius pungitius*). Stickleback were captured with Gee minnow traps in small numbers from Second Portage, Tehek and Inuggugayualik lakes in 1999. Individual stickleback have also been observed in small numbers in the gut contents of lake trout from Inuggugayualik Lake (1999 and 2002), Second Portage Lake, and Tehek Lake. Stickleback are likely widespread in the project lakes, although their abundance and biomass relative to all other species is very low. They prefer slow streams, shallow bays in lakes, and tundra ponds. Ninespine stickleback exhibit riverine and lacustrine life histories, preferring stream habitat with a heterogeneous substrate of mud and sand. Given the lack of this habitat, they are restricted to shallow, nearshore habitat over coarse substrate and are uncommon in the project lakes.

Slimy sculpin are also typically found in clear or muddy waters in rivers, streams and creeks with rocky or gravel substrate (Evans et al, 2002) and are seldom found in lakes. Unfortunately information on slimy sculpin in the north is limited. Spawning occurs in early spring beneath the ice.

Figure 7.2: Relative Abundance (%) of Fish Species in Regional Arctic Lakes



Eggs require four weeks to hatch depending on water temperature. Young-of-the-year and juvenile slimy sculpin prefer cobble and boulder substrate and low velocity currents. Adult fish in the Arctic have very small home ranges in nearshore habitat of lakes, especially in areas of limited stream habitat. The importance of small species such as sculpins and stickleback in the diet of lake trout is minor because of their small size and infrequent occurrence in gut contents.

There are no other fish species present in the project lakes. Although Arctic grayling are known from the Quoich River system downstream of Tehek Lake (Stuart and McDonald, 1980), they have not been identified from Tehek Lake or the project lakes and their connecting channels. Arctic grayling are primarily a stream-dwelling species and are relatively common in lake systems with abundant stream habitat. For example, grayling were very common in large streams connecting lake systems with overwintering habitat and fish populations along the proposed all-weather road within the Prince River system, flowing towards Baker Lake, west of the Quoich River drainage. Grayling were not present in any streams draining towards Third Portage Lake. Arctic grayling have not been captured within any of the connecting channels between the project lakes, based on hoopnet and gill net surveys conducted since 1997. Because of the extreme headwater nature of the project lakes, there is no stream habitat. Wide, flat, shallow, boulder fields connect project lakes with shallow or subsurface flow. Such conditions do not suit Arctic grayling and explains their absence within the upper Quoich River system.

The absence of stream habitat and climatic conditions precludes the also presence of other spring spawning species in streams like sucker species (Catostomus sp.) or minnows such as chub. The northern range of lake chub (*Coesius plumbeus*), a minnow species, is south of the project lakes.

Species composition from several Arctic lakes including Baker Lake (McLeod et al, 1976), Pitz Lake (Lawrence et al, 1977), Kiggavik region lakes (Urangesellshaft, 1980), Koala region lakes (Rescan, 1994), Lac de Gras (Diavik and Aber, 1998), and Snap Lake (De Beers, 2002) showed that, with the exception of Baker Lake, lake trout was the most abundant species in all lakes, accounting for 14% to 58% of the fish captured (Figure 7.2 in Section 7.5). MacDonald and Stewart (1980) also showed, in a broad survey of rivers and lakes (Back River, Thelon River, Quoich River) of the central Keewatin region of the former Northwest Territories, that lake trout was by far the dominant species in all lakes and rivers surveyed. Lake cisco are relatively abundant in Pitz Lake, the Kiggavik region lakes, Lac de Gras, and especially Baker Lake, where, as discussed previously, this species is likely anadromous to some extent. Lake whitefish occurred in Pitz Lake and Baker Lake in a similar abundance as round whitefish in the Meadowbank study lakes. Other common species, south of Tehek Lake, included Arctic grayling, longnose sucker, and Arctic char.

Longnose sucker, burbot, and Arctic grayling are relatively common in central Arctic lakes where there is suitable stream habitat appropriate habitat complexity, greater productivity, and longer growing season. These conditions favour more temperate fish, such as chub and suckers, which were relatively abundant in Snap Lake in 1999, for example. For the reasons discussed above, the project lakes do not contain these species.

The information gathered from regional and reference lakes indicate that fish species composition of project lakes is similar to local (e.g., Kiggavik lakes) and regional lakes in Nunavut and the Northwest Territories. The number of confirmed species in the project lakes is lower than in lakes that are closer in proximity to a marine environment (e.g., Baker Lake, Kiggavik area lakes), or in lakes with more stream habitat (e.g., Lac de Gras, Snap Lake), where greater diversity of habitat will support greater species diversity.

7.4 ABUNDANCE

The number of fish present in lakes is typically a function of the abundance of food that is available to support the resident population, and is a direct reflection of lake productivity (i.e., abundance of phytoplankton, zooplankton, and benthos). The statistic used to determine relative abundance of fish is catch-per-unit-effort (CPUE) in units of number of fish per standardized net size (100 m) and time (24 hours). Comparing CPUE (# fish/net/24 h) among lakes provides an estimate of the relative abundance of fish for each lake. To make unbiased comparisons of CPUE between lakes, study areas, and over time, it is important that the same type of fishing gear be used. Also, time of day is very important, as CPUE is often much higher at night when fish cannot see the fishing gear and they are more active, especially during dawn and dusk. We are aware of the difficulty in comparing daytime and nighttime CPUE data because of differences in daylight (and darkness) at different locations throughout the Arctic, as well as throughout the spring and summer. It is difficult to make unbiased comparisons. Nevertheless, CPUE of study lakes was calculated separately for daytime and nightime sets, and is a reflection of relative abundance of fish in study lakes (Table 7.1). As noted above, all CPUE units reported herein are # fish/100 m net/24 hours (e.g., if five fish were captured in a 150 m net in 8 hours, the CPUE would be 10).

Table 7.1: Mean Catch-Per-Unit-Effort (CPUE) Data (# fish/100 m net/24 h) in Project & Reference Lakes, 1997 to 1999

Year/ Lake	Net Sets	Daytime Mean CPUE (SD)	Net Sets	Nightime Mean CPUE (SD)
1997				
Third Portage	6	8.5 (7.7)	7	20.6 (8.1)
Second Portage	2	26.1 (19.9)	3	50.7 (2.8)
Tehek	6	6.2 (4.0)	4	23.8 (5.2)
1998				
Turn	4	19.9 (16.1)	4	36.6 (10.3)
Farside	6	9.6 (7.9)	6	29.9 (14.6)
Inuggugayualik	6	20.2 (14.5)	6	38.6 (9.9)
Pipedream	6	7.4 (5.3)	6	25.5 (9.3)
Ihipqiituq	4	13.0 (18.0)	6	48.7 (26.2)
Amarulik	6	17.4 (10.4)	6	62.5 (9.9)
1999				
Third Portage	4	14.9 (11.6)	6	15.5 (11.1)
Second Portage	6	11.4 (4.9)	6	19.0 (10.0)
Turn	4	10.1 (3.2)	6	32.8 (22.5)
Tehek	6	13.4 (8.5)	6	25.5 (10.2)
Inuggugayualik	6	21.0 (16.2)	6	40.1 (30.1)

Note: SD = Standard Deviation

Fishing effort was directed towards medium or high value habitat based on a quantitative habitat mapping exercise over substrate that consisted of large boulder and cobble nearshore in depths from 2 to 12 m. Nets were typically set perpendicular to shore, taking advantage of points, shoals, and wind direction. Gill nets were set over a diverse range of micro-habitats (substrate, complexity, depth) and depth to understand utilization of productive, nearshore habitat throughout the lakes, with a focus on areas potentially affected by the mine development.

Relative abundance (CPUE) of fish was higher from Second Portage Lake during nighttime (50.7) and daytime (26.1) sets in the 1997 survey of project lakes than all other lakes (Table 7.1). CPUE values from Third Portage (nighttime 20.6; daytime 8.5) and Tehek lakes (nighttime 23.8; daytime 6.2) were similar, and less than half the CPUE values for Second Portage Lake. These data suggest that the relative abundance of fish in Second Portage Lake was greater than in other project lakes in 1997. Data from 1999 corroborated what was found in previous surveys (Table 7.1). CPUE was consistently higher in nighttime sets than during the day. However, relative abundance of fish in Second and Third Portage lakes was similar, unlike 1997 data. Inuggugayualik Lake CPUE was somewhat higher than project lakes in 1999 but was similar in the 1998 survey.

In the 1998 survey of candidate reference lakes, mean daytime CPUE ranged from a low of 7.4 in Pipedream Lake to a high of 62.5 in Amarulik Lake. Part of the reason for the greater relative abundance of fish in Amarulik was the presence of lake cisco, which was not present in the other lakes.

Daytime CPUE data ranged from 8.5 to 26 and from 19 to 40 in nighttime sets from project lakes (Second Portage, Third Portage, Tehek, Turn) between 1997 and 1999. CPUE data must be interpreted with some caution because of inherent variability in duration of net sets, weather conditions, level of darkness, and water temperature. These uncontrollable factors compound natural variability in differences in habitat, water depth, fish movements.

There are few CPUE data from Arctic lakes with which to compare to these values, partly because much of this information is in the grey literature, and because care must be taken to ensure that similar fishing gear was used, such that unbiased comparisons can be made.

In a study of Prosperous and Prelude lakes north of Yellowknife, Roberge et al (1990) used experimental nets (38 to 139 mm, similar in range to those used in these studies) and obtained a mean CPUE of 34. In a similar study of Indin Lake, northeast of Yellowknife, Jessop et al (1993) observed a mean CPUE of 22.1. These results are similar to the CPUE results from project lakes.

Long-term monitoring studies conducted in several reservoir lakes in northern Manitoba, using the same gill nets as the current studies, had CPUE values that ranged from 38 to 84 (Kirton, 1986; Hagenson, 1990; MacDonell and Horne, 1994). Reservoir lakes in more southerly latitudes are generally more productive, so higher CPUE values are expected. Results from these studies indicate that the relative abundance of fish in the lakes on the Meadowbank property is similar to other unexploited lakes in the central Arctic at similar latitudes. Recently collected traditional knowledge from community elders confirms that local residents of Baker Lake have traditionally fished Third Portage Lake and on occasion, still do. The majority of fishing by Baker Lake residents occurs on Whitehills Lake during winter, through the ice.

7.5 SIZE & CONDITION

7.5.1 Lake Trout

Lake trout from project lakes were relatively large in terms of length and weight and appeared healthy and in good condition in all years. Table 7.2 provides mean length, weight, and condition factor (K) for dominant species from project lakes, from the 1997, 1998, 1999, 2002, and 2005 fisheries surveys. The same gear was used in each of these years and an overall summary of fish size and condition data for each lake, pooled over years is presented in Table 7.3.

The large size of lake trout is a function of their relatively old age (it is not uncommon for trout to exceed 40 years of age), and the fact that fish populations in these lakes are not exploited. Lake trout in Arctic lakes typically reach a large size, frequently exceeding 10 kg, especially in large, pristine, remote lakes (Johnson, 1976). Mean length of lake trout in most project lakes ranged from 393 mm (Tehek Lake) to 494 mm (Inuggugayualik Lake). The largest lake trout captured was from Second Portage Lake with a length of 1.1 m and a weight of approximately 20 kg. The largest trout captured from Third Portage Lake was 13 kg. Every reasonable effort was made to ensure that as many fish are possible were released unharmed after they were captured and processed.

The size distribution of trout in Third Portage, Second Portage, and Tehek lakes covered a wide range, up to 1.1 m, indicating that there were no deficiencies in particular size classes. Figures 7.3 to 7.10 depict length-frequency distributions for lake trout from each project lake and regional candidate reference lakes using 1997 to 2005 pooled data. The size distribution of lake trout from all lakes was somewhat bimodal, with a relatively larger number of fish between 200 and 300 mm in length, and a second mode between 500 and 550 mm. Modal size for trout from all major project and reference lakes (Second Portage, Third Portage, Inuggugayualik, Turn lakes) was similar between 500 and 550 mm. Mean length and weight of lake trout from Second Portage (452 mm, 1,240 g) and Third Portage (471 mm, 1,480 g) was very similar (Table 7.3). Condition factor of lake trout was also very similar among all project and reference lakes, ranging from 1.07 to 1.10.

A few large (>800 mm) individuals were captured from each lake, except Phaser Lake (2005). The mean length (39 cm) and size distribution of lake trout from Phaser Lake was smaller and narrower than other lakes and is a reflection of the small size of Phaser Lake and that it is isolated from Vault Lake, thus there is no immigration or emigration of fish. The distribution in fish size between all other lakes was quite similar, although Tehek Lake had a relatively larger number of small fish. This bi-modal size distribution is very typical of long-lived Arctic fish populations (Johnson, 1976).

Mean body weight was also well correlated with mean length, with the largest trout found in Second and Third Portage lakes, and Inuggugayualik Lake. Despite differences in mean length and weight, mean condition factor (derived from a ratio of length and weight) exceeded 1.0 in all lakes (except a few trout from Wally Lake, although sample size was small), indicating that, overall, lake trout were very healthy and in good condition.

Lake trout collected during studies of other Arctic lakes in Nunavut and the central Northwest Territories, using similar fishing gear, had similar biological characteristics. For example, lake trout collected from Indin Lake (Jessop et al, 1993) ranged in size from 185 to 987 mm, with a median length of 500 to 549 mm and a mean of 569 mm. Lake trout from Prelude and Prosperous lakes had mean lengths of 512 mm and 480 mm and a mean condition of 1.13 and 1.15, respectively (Roberge et al, 1990).

Table 7.2: Mean Length, Weight &Condition Factor Data for Arctic Char, Lake Trout & Round Whitefish from Project &Candidate Reference Lakes from 1997, 1998, 1999, 2002 & 2005 Studies, Respectively

	Lake	N	Mean Length (mm)	Range	Mean Weight (G)	Range	Mean K
Lake Trout	Third Portage (1997)	83	432	171 - 990	1422	25 - 13000	1.08
	Third Portage (1999)	36	492	105 - 910	2060	11 - 7500	1.07
	Third Portage (2002)	5	409	255 - 572	847	150 - 1975	0.95
	Third Portage (2005)	49	530	270 - 740			
	Second Portage (1997)	64	463	165 - 1100	1716	50 - 20000	1.11
	Second Portage (1999)	51	389	109 - 825	1053	12 - 8800	1.09
	Second Portage (2005)	27	545	250 - 910			
	Phaser (2005)	40	390	240 - 640			
	Wally (2002)	6	340	191 - 556	488	50 - 1525	0.78
	Turn (1998)	108	437	173 - 850	1263	75 - 7800	1.09
	Tehek (1997)	50	364	178 - 820	464	50- 2650	1.05
	Tehek (1999)	37	431	208 - 791	1372	100 - 6250	1.15
	Inuggugayualik (1998)	149	468	180 - 845	1409	50 - 765	1.12
	Inuggugayulik (1999)	99	531	169 - 945	2078	49 - 9500	1.11
	Inuggugayulik (2002)	22	471	191 - 887	1444	50 - 6600	0.98
	Pipedream (1998)	112	445	166 - 915	1470	50 - 7050	1.15
	Farside(1998)	117	407	175 - 784	1120	75 - 5700	1.16
	Ihipqiituq (1998)	151	476	174 - 960	1799	75 - 7250	1.14
	Amarulik (1998)	175	446	160 - 930	1693	50 - 8575	1.20
Round Whitefish	Third Portage (1997)	4	224	210 - 231	138	100 - 175	1.21
	Third Portage (1999)	13	267	182-361	237	75 - 500	1.12
	Third Portage (2002)	9	301	210 - 370	295	85 - 540	1.00
	Third Portage (2005)	4	355	330 - 370			
	Second Portage (1997)	6	372	291 - 416	671	300 - 975	1.23
	Second Portage (1999)	10	306	193 - 395	393	75 - 775	1.14
	Second Portage (2005)	10	323	270 - 370			
	Phaser (2005)	14	340	250 - 380			
	Wally (2002)	6	299	216 - 364	271	100 - 500	0.93
	Turn (1998)	6	330	214 - 431	471	75 - 900	1.04
	Turn (1999)	20	340	133 - 422	493	23 - 900	1.14
	Tehek (1997)	7	325	196 - 400	425	50 - 700	1.07
	Tehek (1999)	26	305	146 - 395	383	25 - 650	1.18
	Inuggugayualik (1998)	26	322	205 - 397	412	100 - 775	1.14
	Inuggugayualik (1999)	39	314	190 - 381	412	59 - 700	1.23
	Inuggugayulik (2002)	11	301	216 - 364	277	75 - 500	0.93
	Pipedream (1998)						
	Farside (1998)	19	260	183 - 385	250	75 - 875	1.20
	Ihipqiituq (1998)	5	286	204 - 341	270	100 - 425	1.09
	Amarulik (1998)	59	287	185 - 500	290	50 - 1350	1.11

	Lake	N	Mean Length (mm)	Range	Mean Weight (G)	Range	Mean K
Arctic Char	Third Portage (1997)	7	245	176 - 520	338	50 - 1575	1.02
	Third Portage (1999)	1	545		1525		0.94
	Third Portage (2002)	2	579	567 - 590	2175	2100 - 2250	1.12
	Third Portage (2005)	1	620		~3000		
	Second Portage (1997)	26	473	186 - 580	1098	75 - 2100	1.10
	Second Portage (1999)	4	508	460 - 539	1363	1200 - 1500	1.05
	Second Portage (2005)	9	467	290 - 570			
	Turn (1998)	1	250		200		1.28
	Turn (1999)	8	489	448 - 515	1075	800 - 1325	0.91
	Tehek (1997)	8	459	325 - 510	968	350 - 1350	0.99
	Tehek (1999)						
	Inuggugayualik (1998)	4	695	626 - 860	3898	3050 - 6400	1.16
	Inuggugayulik (1999)	3	532	300 - 810	2742	325 - 6500	1.22
	Inuggugayulik (2002)						
	Pipedream (1998)	1	163		75		1.73
	Farside (1998)						
	Ihipqiituq (1998)	1	341		525		1.32
	Amarulik (1998)	4	407	200 - 520	1044	100 - 1900	1.24

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Table 7.3: Pooled Length, Weight & Condition Factor Data for Arctic Char, Lake Trout & Round Whitefish from Second Portage Third Portage, Turn & Inuggugayualik Lakes (1997, 1998, 1999, 2002 & 2005)

Species	Lake	n	Mean Length (mm)	Range	n	Mean Weight (g)	Range	n	Mean K
Lake Trout	Third Portage	173	471	105 – 990	124	1480	11 - 8600	124	1.07
	Second Portage	142	452	109 – 1100	115	1240	12 - 8800	115	1.10
	Tehek	87	393	178 - 820	87	918	50 - 6250	87	1.10
	Turn	168	434	132 - 930	168	1205	23 - 7800	168	1.07
	Inuggugayualik	270	494	169 - 1525	270	1678	49 - 9500	270	1.10
Round Whitefish	Third Portage	30	284	182 - 370	26	242	75 - 540	26	1.09
	Second Portage	26	327	193 - 416	16	497	75 - 975	16	1.17
	Tehek	33	309	146 - 400	33	392	25 - 700	33	1.16
	Turn	26	338	133 - 431	26	488	29 - 900	26	1.12
	Inuggugayualik	65	317	190 - 397	65	412	59 - 775	65	1.14
Arctic Char	Third Portage	11	367	176 - 620	11	965	50 – 3000	10	1.03
	Second Portage	39	475	186 - 580	30	1136	75 - 2100	30	1.09
	Tehek	8	459	325 - 510	8	968	350 - 1350	8	0.99
	Turn	9	462	250 - 515	9	978	200 - 1325	9	0.96
	Inuggugayualik	7	625	300 - 860	7	3454	325 - 6500	7	1.19

Figure 7.3: Lake Trout Length-Frequency Distribution, Second Portage Lake (1997, 1999 & 2005)

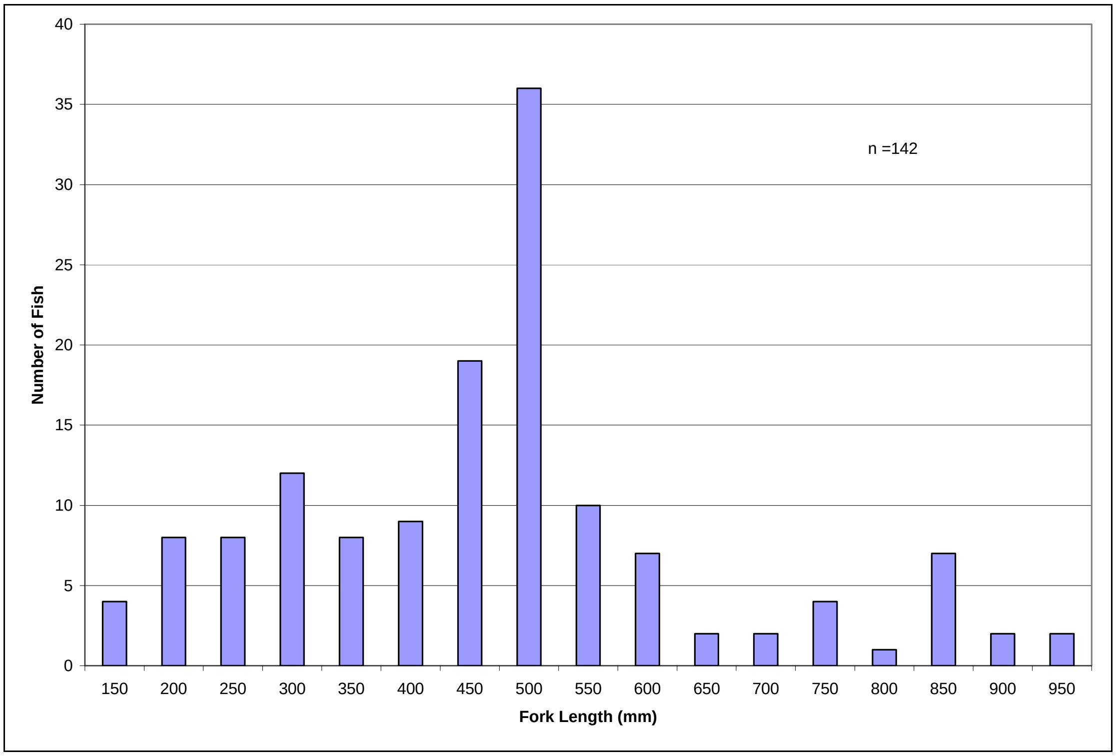


Figure 7.4: Lake Trout Length-Frequency Distribution, Third Portage Lake (1997, 1999, 2002 & 2005)

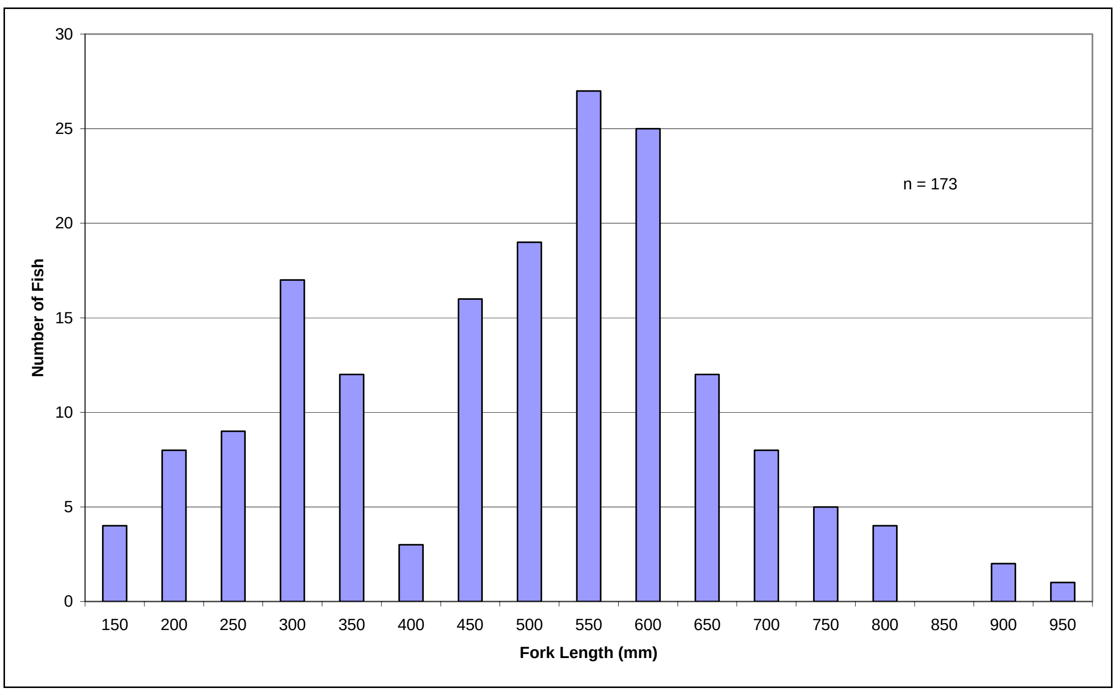


Figure 7.5: Lake Trout Length-Frequency Distribution, Tehek Lake (1997 & 1999)

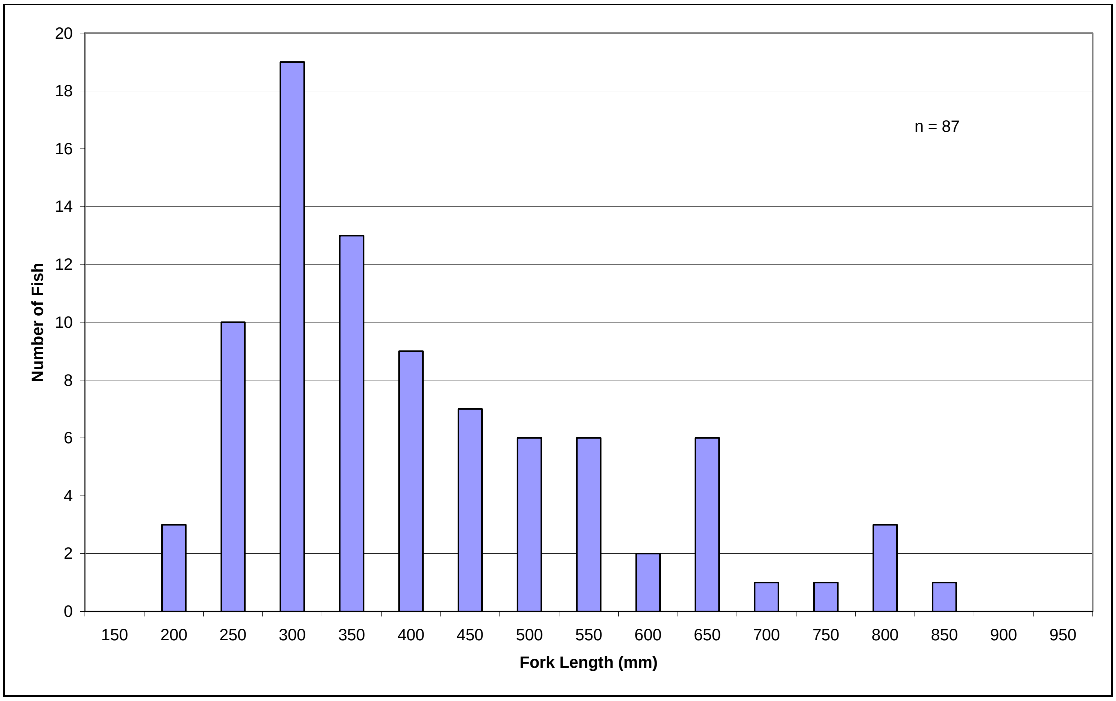


Figure 7.6: Lake Trout Length-Frequency Distribution, Inuggugayualik Lake (1998, 1999 & 2002)

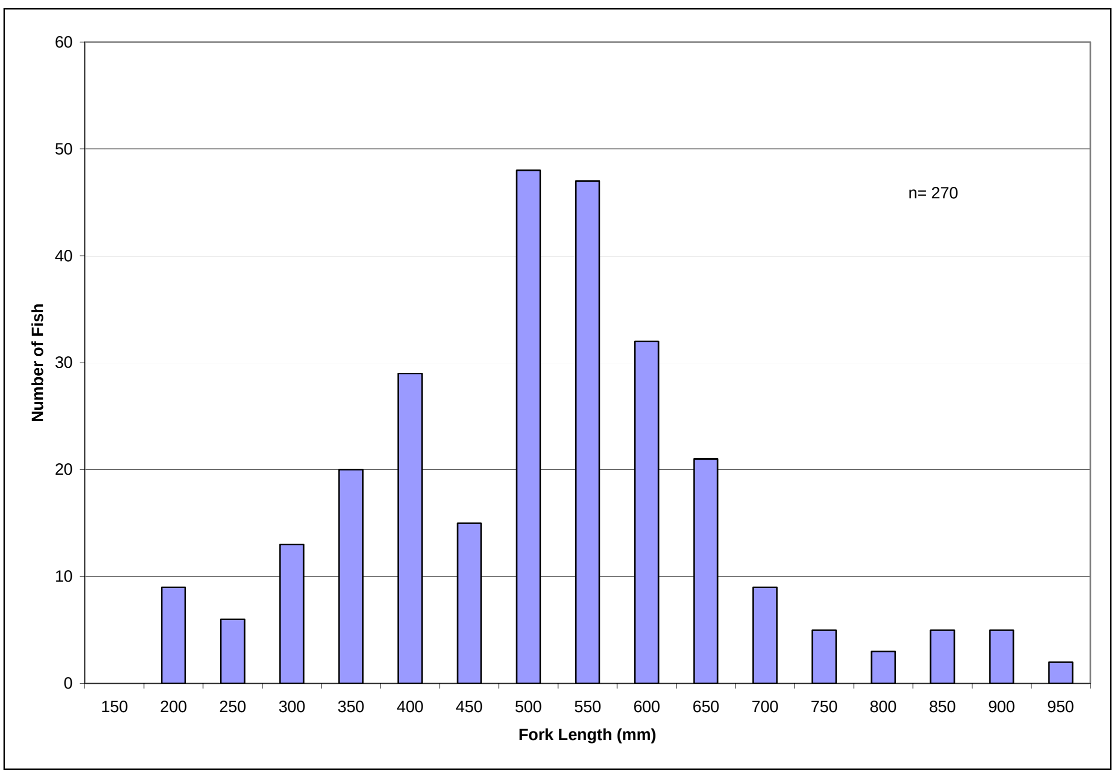


Figure 7.7: Lake Trout Length-Frequency Distribution, Turn Lake (1998 & 1999)

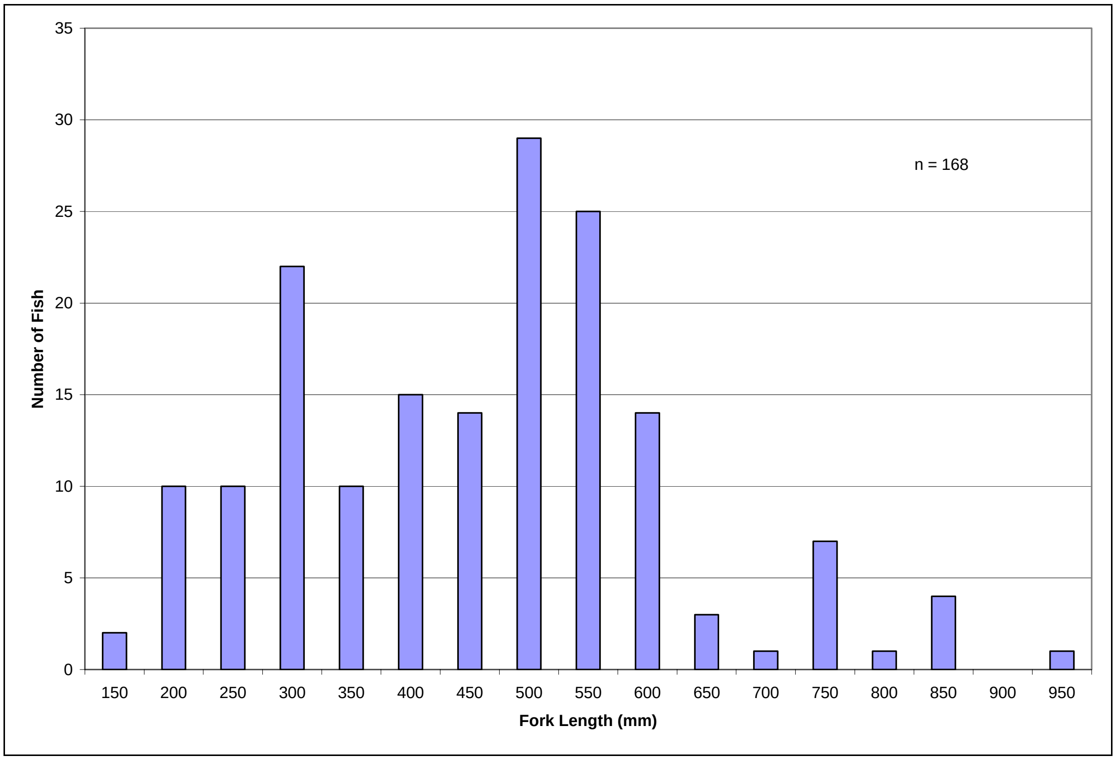


Figure 7.8: Lake Trout Length-Frequency Distribution, Ihipqituq Lake (1998)

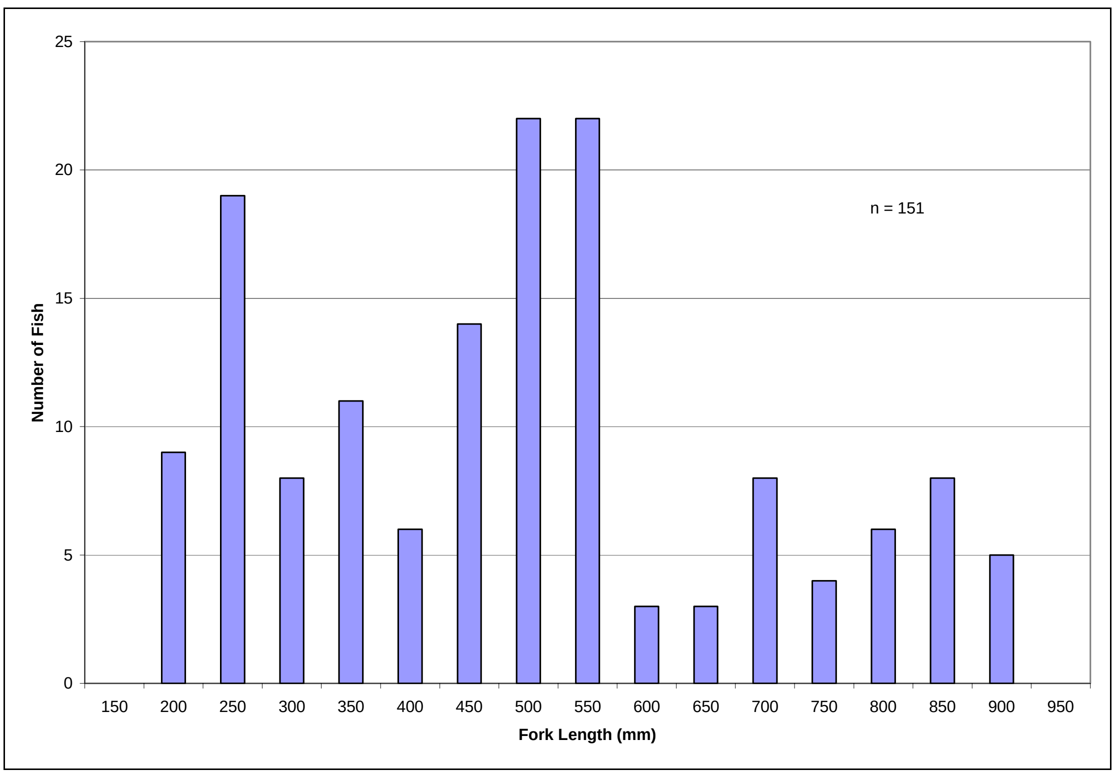


Figure 7.9: Lake Trout Length-Frequency Distribution, Amarulik Lake (1998)

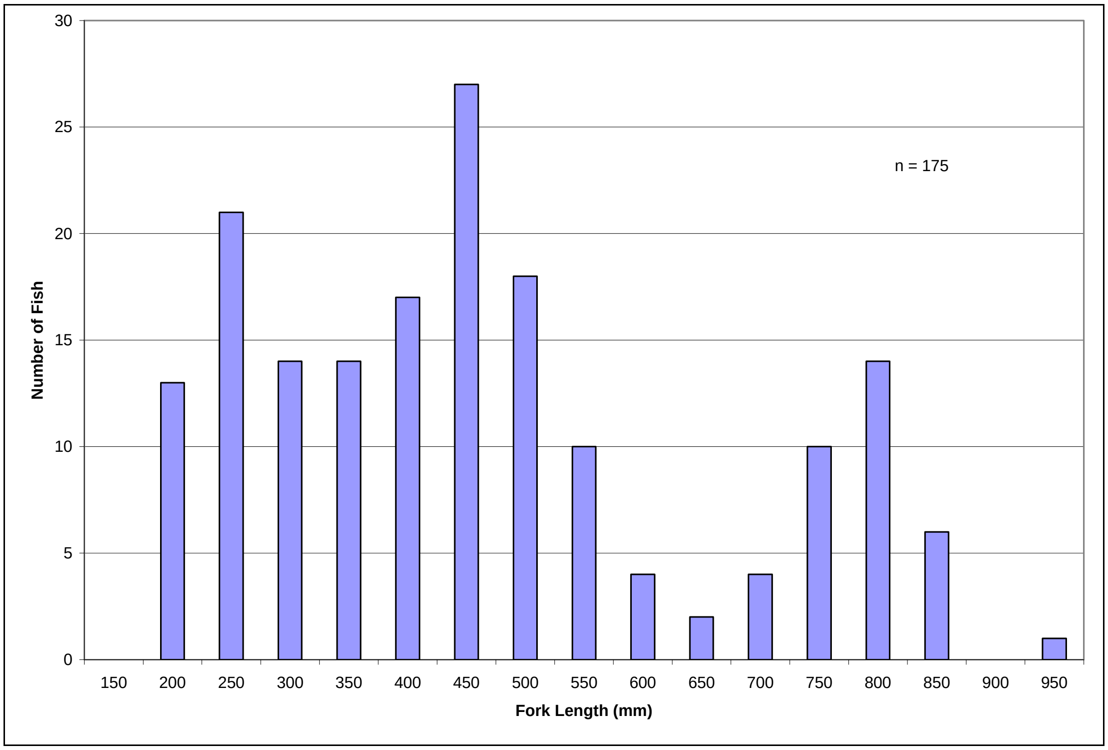


Figure 7.10: Lake Trout Length-Frequency Distribution, Pipedream Lake (1998)

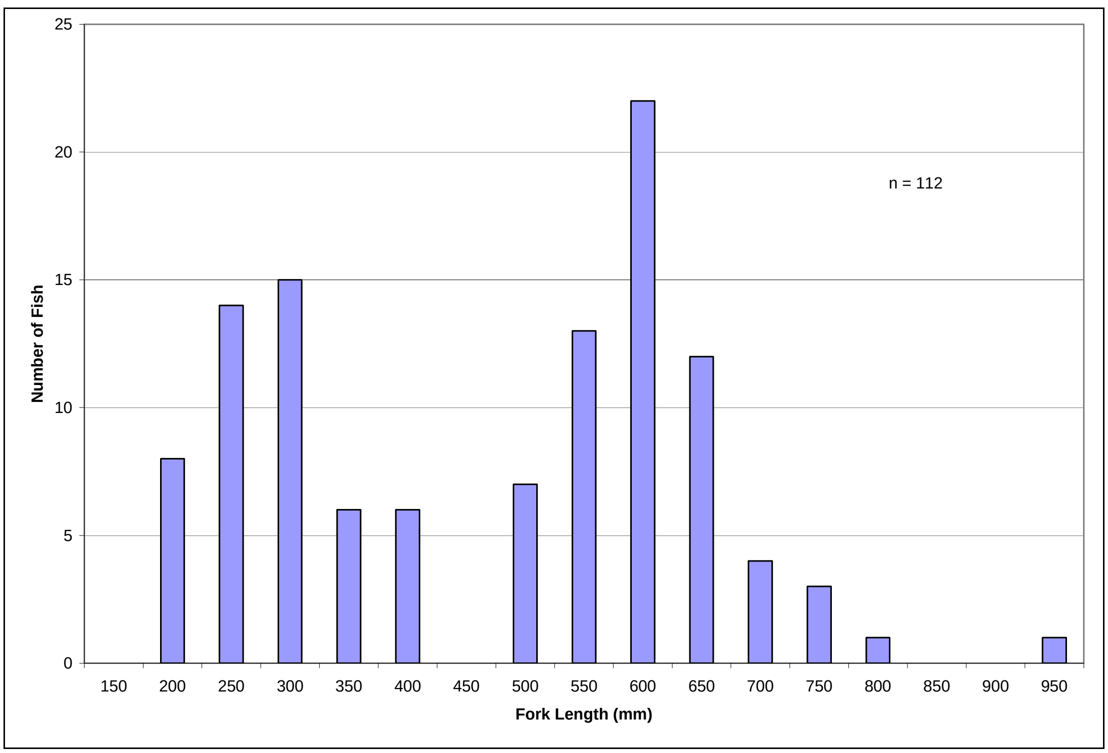


Table 7.4 contains an extensive data set of length, weight, age, and condition factor data for lake trout, lake whitefish, and round whitefish from several lakes in Nunavut and Northwest Territories. Making detailed comparisons with these lakes is not practical because many different fishing methods and net sizes were used to capture fish, which affects the size distribution and, therefore, calculated means. Notwithstanding differences in methods, size data for lake trout from project lakes fall within the range observed for other lakes, both locally, including Baker Lake and Kiggavik region lakes, as well as lakes elsewhere in the Arctic. Lake trout tended to be larger in Baker Lake, Lac du Sauvage, and Lac de Gras than in project lakes. There is a general positive correlation between lake size and fish size. Given that the project lakes are smaller than the above lakes, this may explain why mean and maximum fish sizes are greater than in project lakes.

Size and condition data of trout from project lakes are similar to, or slightly lower than, data for trout elsewhere in remote Arctic lakes. This may be due to the highly oligotrophic, low productivity nature of the project lakes, which limits growth rate and, ultimately, fish size.

Johnson (1976, 1980) has demonstrated that the size distribution of Arctic char and lake trout in unexploited lakes changes very little over time, as the population resembles a climax community, similar in structure to an old growth forest. Thus, pooling lake trout size-distribution data over a number of years (the gear used to capture trout was identical) is justifiable. These pooled data illustrate the similarity in the relative abundance and size-structure of lake trout populations in the project and reference (Inuggugayualik) lakes. This is due to the great similarity in habitat that exists between the lakes. Given that the limnology, morphometry, substrate composition, depth and morphology of the project lakes is very similar (FHAP, 2005), it is not surprising that population dynamics, habitat utilization and life history of the dominant species, lake trout, should also be similar among lakes.

7.5.2 Round Whitefish

Round whitefish were the second most abundant species in all project lakes in the gill net surveys between 1997 and 2005 surveys (Table 7.2), although they typically only contributed to between 10% to 20% of all fish captured. Mean length of round whitefish from project lakes ranged from 284 (Third Portage Lake) to 340 mm (Vault Lake) (Table 7.3). Mean weight of round whitefish from Third Portage (242 g) was smaller than for round whitefish from Second Portage (497 g), Tehek (392 g), and Turn (488 g) lakes. This trend is similar to what has been observed for lake trout and Arctic char, in that mean size and condition factor of round whitefish from Second Portage Lake exceeded those of Third Portage Lake (Table 7.2), and were among the highest of all project lakes. This may be partly due to the older average age of whitefish in Second Portage than Third Portage, although very few fish were aged. Because relatively few whitefish (26 to 65) have been captured from each of the study lakes during baseline studies, categorical statements about mean size or age of fish among lakes cannot be made, as it is difficult to represent true population statistics from such small sample sizes, owing to the low abundance of this species.

Mean size and size range of round whitefish from Inuggugayualik Lake were similar to round whitefish size data from project lakes. Condition factor of round whitefish was high in all project lakes (1.09 to 1.17), and was slightly lower for Third Portage Lake (Table 7.3). These data suggest that, given the similarity in biological data for round whitefish from project and reference lakes, there are no large

Table 7.4: Mean Length, Weight, Age & Condition Factor for Lake Trout, Lake Whitefish & Round Whitefish in Regional Arctic Lakes

Lake/Region	Date	Lake	n	Fork Length (mm)		Weight (g)		Age (yr)		Condition Factor (K)	
				Mean	Range	Mean	Range	Mean	Range	Mean	Range
LAKE TROUT											
Baker Lake[1.]	July 1975	n/a	217	466	127 - 820	n/r	-	12.0	1 - 30	-	-
Baker Lake Inland Region[2A]	July 1967	Baker	40	458	342 - 574	1,329	286 - 2,372	n/r	-	1.12	-
	July 1963	Lockhart	32	525	415 - 635	1,811	99 - 3,523	n/r	-	1.06	-
	July 1959	Macdougall	114	576	-	2,720	-	n/r	-	1.42	-
	July 1959	Macdougall	-	-	-		-		-	-	-
	July 1959	Meliadine	93	589	-	2,760	-	n/r	-	1.35	-
	July 1968	Meridian	-	-	-		-		-	-	-
	July 1968	Peter	99	627	471 - 783	3,240	3,058 - 3,422	n/r	-	1.12	-
Pitz Lake[3]	July 1976	n/a	400	490	101 - 950	n/r		18.8	0 - 51	-	-
Kiggavik Region[4]	July 1979	Pointer +	187	582	228 - 829	2,627	143 - 6,833	19.9	1 - 41	1.10	0.90 - 1.51
		Sissons	-	-	-	-	-		-	-	-
Koala Region[5]	July 1994	Long	300	432	150 - 850		-	10.5	-	-	-
	July 1994	Panda	302	386	150 - 700		-	9.9	-	-	-
	July 1994	Fox 1	201	346	150 - 600		-	9.1	-	-	-
Lac de Gras[6]	July 1995	n/a	143	513	-	2,040	-	12.7	-	1.14	-
	August 1995	-	185	431	-	1,604	-	12.7	-	1.17	-
	July 1996	-	97	520	-	2,097	-	11.0	-	1.23	-
	August 1996	-	109	546	-	2,446	-	11.0	-	1.14	-
Lac du Sauvage[6]	July 1996	-	135	556	-	2,174	-	11.1	-	1.16	-
	August 1996	-	115	634	-	3,197	-	11.1	-	1.19	-
Snap Lake[7]	July 1999	Snap	119	566	269 - 790	2,427	200 - 5,400	15.0	1 - 23	1.18	0.77 - 1.88
	July 1999	Reference	33	541	196 - 838	2,049	100 - 6,300	15.0	5 - 23	1.09	0.68 - 1.55
LAKE WHITEFISH											
Baker Lake[1]	July 1975	n/a	154	383	169 - 520	n/r	-	9.4	1 - 17	-	-
Baker Lake Inland Region[2A]	July 1967	Baker	49	468	88 - 848	1,447	277 - 2,617	n/r	-	1.41	-
	July 1959	Baker	81	507	-	1,590	-	7.4	-	1.22	-
	July 1959	Macdougall	124	523	-	2,070	-	21.1	-	1.45	-
	July 1968	Meridian	37	523	481 - 565	2,056	1,492 - 2,620	n/r	-	1.39	-
ROUND WHITEFISH							-				
Baker Lake Inland Region[2A]	July 1959	Macdougall	43	369	-	540	-	13.3	-	1.07	-
Koala Region[5]	July 1994	Long	197	348	-	-	-	10.8	-	-	-
Snap Lake[7]	July 1999	Snap	44	243	150 - 335	162	50 - 360	6.6	5 - 9	1.06	0.50 - 1.50
	July 1999	Reference	24	266	199 - 315	188	80 - 300	7.4	5 - 11	0.98	0.58 - 1.15

Note: A. Lower and upper standard deviations are reported, rather than minimum and maximum values.

References: 1. McLeod et al, 1976. **2.** Monshenko, 1980; **3.** Lawrence et al, 1977. **4.** McKee et al, 1989. **5.** Rescan, 1994. **6.** Diavik Diamonds Baseline Report, 1998. **7.** De Beers, 2002.

differences in life history parameters (e.g., growth rate, size, condition) among the lakes. Given the large size of Second and Third Portage lakes and the abundance and similarity of available habitat to whitefish, similarities in size, condition, and life history are not unexpected.

Few other studies that have examined round whitefish, except for a few historic studies in the Baker Lake region (Moshenko, 1980), and other northern mine developments at Ekati (Koala, Rescan, 1994), and Snap Lake (De Beers, 2002) (Table 7.4). Round whitefish in these lakes tended to be of a similar size or slightly smaller (Snap Lake) than in project lakes, possibly because of different fishing gear used or differences in productivity. Condition factors were also slightly lower (0.98 to 1.07) relative to project lakes (1.17).

7.5.3 Arctic Char

Arctic char were captured in small numbers from each of the project and reference lakes during the 1997, 1998, 1999, 2002, and 2005 surveys to determine population characteristics, life history, tissue metals concentration, and anadromy. Char were the third most abundant species captured, but only comprised a small portion of the population (<10%). Although sample sizes were relatively small, Arctic char from Second Portage Lake were larger (475 mm) and had a slightly higher condition factor (1.09) than char from all other lakes except Inuggugayualik Lake (625 mm; K = 1.19) (Table 7.2).

Char from Third Portage Lake were among the smallest in mean length (284 mm) and had average condition (1.03). Mean size of char in remaining lakes was roughly similar to char from Second Portage. Although few char were captured from each of the project lakes, the fact that they are present indicates that they are widespread throughout the system and are present in Quoich (Hudson Bay) and Meadowbank (Arctic) drainage systems. Char from the project lakes are landlocked and are typically smaller than their anadromous relatives (Johnson, 1980).

One of the char captured from Inuggugayualik Lake during the 1999 survey was quite large (860 mm and 6.4 kg) and may be anadromous (Table 7.2), although condition factor was only 1.01, which is on the lower end of the scale. It would be unusual for a fish of this size to be landlocked. Two other char captured in 1998 were also relatively large, at about 3 kg. However, a 2.25 kg and a 3 kg char were also captured from Third Portage Lake in 2002 and 2005, respectively, and these are definitely landlocked, based on fin strontium concentrations which ranged from 155 to 174 µg/g. The concentration of strontium in hard parts of fish is much higher in anadromous individuals than landlocked fish. Strontium concentration from the fins of Arctic char from Turn Lake (25 cm, 200 g; 185 µg/g strontium), Amarulik Lake (520 cm, 1900 g; 108 µg/g strontium) and Inuggugayualik Lake (66 cm, 3,350 g, K = 1.18; 150 µg/g strontium) were measured in 1998. Turn Lake is within the Quoich River drainage and contains only landlocked char. Amarulik Lake is within the Prince River drainage that flows to Baker Lake and these fish do have access to Chesterfield Inlet, although the distance is far. The strontium concentration of the char taken from Inuggugayualik Lake was from a large (3.3 kg), sexually mature fish that, based on strontium, is non-anadromous. These data indicate that large (>3 kg) char from Inuggugayualik Lake are not necessarily anadromous. However, the presence of a 6.8 kg non-anadromous char is unusual.

Inuggugayualik Lake is approximately 250 km from the Arctic Ocean. Although the marine environment is accessible, it would be unusually for a char to migrate such a long distance because of the great energetic cost to migrate back and forth over such a distance, especially when there is abundant, similar habitat nearer the ocean. Nevertheless, it is possible that a small proportion of the char in this reference lake are anadromous. It is possible that a small number of char do migrate from the ocean to Inuggugayualik Lake to spawn and overwinter. However, fin strontium data from large and small char from project lakes, regional lakes and Inuggugayualik Lake suggest that all of the char captured to date are non-anadromous or lake resident, even large fish (>3 kg).

Mean size of char from Second Portage Lake was 475 mm with a mean condition factor of 1.09. Although few surveys of Arctic char have been conducted using experimental nets, a survey of Brown River in the vicinity of Baker Lake showed char had a mean length of 628 mm (range 530 to 815 mm), with a mean K of 1.14, which is similar to data from Second Portage Lake char. Biological data for migratory char on the Hudson Bay coast, including the Meliadine River, Rankin Inlet (McGowan, 1992), and the nearby Diana River (McGowan, 1987), were also similar. Meliadine River and Diana River char had mean fork lengths of 429 mm (K = 1.29) and 480 mm (K = 1.25), respectively, similar to the mean length of char from Second Portage Lake (473 mm). The higher condition of the char taken near coastal rivers is probably because fish had just returned from Hudson Bay, where they would have fed heavily on marine organisms.

Despite the fact that Arctic char found in the project lakes are non-anadromous, they have generally similar mean length, weight, condition factor as anadromous char in western Hudson Bay. It is unusual that landlocked char should be of a similar size and condition as anadromous char from nearby lake/river systems. Further discussion of the issue of anadromy is found in at the end of this section.

7.6 AGE & GROWTH

Generally, fish in cold, northern systems tend to be older relative to the age of their counterparts of similar size in southern, more temperate waters. This is because the cold water, short growing season, and lack of nutrients result in slow growth rates; therefore, large fish can exceed 40 or 50 years of age in unexploited Arctic lakes (Machniak, 1975; Johnson, 1976), and this cohort can comprise a relatively large portion of the population and limit recruitment into larger size classes (Johnson, 1976).

Growth is expressed as a function of increasing size (length and weight) with age. Growth rates of skinny fish (i.e., of lower condition) are generally slower than fish in good condition, which have the energy stores to devote towards growth. Relationships between length and weight of fish from 1997, 1998, and 1999 surveys of project and regional lakes for lake trout showed that length-weight relationships for trout were quite similar among lakes, indicating that growth rates of fish were also similar. This is to be expected, given the great similarity in species composition, abundance, and biomass of lower trophic level biota across the study lakes.

Mean size at age relationships (a measure of growth rate) for lake trout from Third Portage, Second Portage, and Tehek lakes were compared using statistical techniques, and there was no significant difference in length-age relationships of trout among study lakes. These data indicate that growth rates of lake trout in the study lakes are very similar to one another.

Mean age of lake trout, based on fin ray cross-sections, for age of fish sacrificed from the project and reference lakes ranged from 12.6 years (Tehek Lake) to 16.0 years (Second Portage Lake) and was correlated with mean fish size (Table 7.3). That is, larger fish tended to be older. Mean age of lake trout did not differ greatly among lakes, and the age-frequency distributions from the study lakes illustrate that there is a wide range in age of trout from all lakes studied, with a maximum age of 26 to 38 years (Table 7.3) for those specimens aged.

Note that not all specimens captured, particularly the largest lake trout, were aged. Many of the large trout captured (e.g., 13 kg and 20 kg) in the 1997, 1998, and 1999 surveys were released alive and no ageing structures were collected; therefore, it is likely that there are many older fish in the system than were aged during our studies. These data confirm that fish from these lakes are old and slow growing which is to be expected of oligotrophic Arctic lakes.

When age data for lake trout were combined over all study lakes, there was a bi-modal distribution of age, with relatively more fish of 8 to 9 years of age and 16 to 19 years of age than in other age classes. Age-frequency distributions were positively correlated with length-frequency distributions in project lakes, suggesting that environmental factors influencing abundance of trout within particular size or year classes was common among lakes within this geographic region. That is, no one lake appeared to be deficient in, or appeared to have greater abundance of, particular size or age classes of lake trout, which is to be expected, given the remote location and pristine nature of the lakes.

The mean age of lake trout in project lakes was similar to slightly higher than mean age from other lakes in Nunavut and the NWT (Table 7.4), notwithstanding the fact that many of the largest, presumably older fish were released alive, without being aged. Kiggavik area lake trout ages were higher than those measured in the Meadowbank baseline studies, which would support this. Nevertheless, the regional data confirm that lake trout from project lakes have similar age and size distributions.

Thirty Arctic char captured from Second Portage Lake in 1997 and 1999 ranged in age from 2 to 13 years, with a mean age of 9.3 years (Table 7.5). Fish of this age and size correspond to anadromous char from the Diana River and Meliadine River on the Hudson Bay coast. Only five Arctic char from Third Portage Lake were aged, and they ranged from 3 to 5 years because only small char were aged (180 to 230 mm). Three Arctic char were captured from Second Portage Lake in 2003 for purposes of confirming anadromy. Age ranged from 7 years (430 mm and 800 g) to 12 years (580 mm and 1,750 g), which is a reasonably good size for non-anadromous char. As discussed above, a large (3.3 kg) non-anadromous char was captured from Inuggugayualik Lake as was aged at 12 years. This is a rapid growth rate for a non-anadromous fish.

Mean size at age of Arctic char that are land-locked is usually smaller than for their anadromous counterparts, so it is to be expected that size and age relationships for non-anadromous project lake char should be smaller than their anadromous relatives.

7.7 DIET

Fish diet strongly depends on species, life history stage (young-of-the-year, juvenile, adult), fish size, and seasonal availability of different food sources. Lake trout are highly piscivorous (fish-eating) and as adults will eat other fish species, particularly whitefish, if available. They are also cannibalistic, preferentially consuming smaller (but not much smaller!) lake trout (Machniak, 1975). The frequency

Table 7.5: Summary of Size, Age & Mercury Concentration in Fish from Project & Reference Lakes, 1997 to 2002

Species	Lake	n	Length (mm)		Weight (g)		Condition (K)		Age (yr)			Mercury (mg/kg)		
			Mean	Range	Mean	Range	Mean	Range	n	Mean	Range	n	Mean	Range
Lake Trout	Third Portage	121	458	171 - 990	1,615	25 - 13,000	1.07	0.57 - 1.59	44	13.9	3 - 38	12	0.24	0.07 - 0.60
	Second Portage	105	449	165 – 1,100	1,526	50 - 20,000	1.11	0.69 - 1.57	26	16.0	4 - 26	7	0.49	0.10 - 1.17
	Tehek	80	390	178 - 820	840	50 - 6,250	1.08	0.66 - 1.44	18	12.6	6 - 35	3	0.31	0.20 - 0.52
	Farside	117	407	175 - 784	1,120	75 - 5,700	1.16	0.85 - 1.54	48	11.9	3 - 28	5	0.57	0.41 - 0.74
	Amarulik	175	446	160 - 930	1,693	50 - 8,575	1.20	0.73 - 1.67	47	15.0	4 - 40	5	0.72	0.57 - 0.84
	Pipedream	112	445	166 - 915	1,470	50 - 7,050	1.15	0.88 - 1.68	46	15.6	4 - 37	5	0.80	0.26 - 1.48
	Inuggugayualik	237	496	180 - 945	1,700	50 - 9,500	1.11	0.63 - 1.49	48	14.9	4 - 32	12	0.38	0.15 - 1.03
Arctic Char	Third Portage	8	288	176 - 520	577	50 - 1,575	1.03	0.42 - 1.62	5	3.6	3 - 5	-	-	-
	Second Portage	30	478	186 - 580	1,133	75 - 2,100	1.09	0.71 - 1.49	14	9.7	2 - 13	6	0.10	0.07 - 0.18
	Tehek	8	459	325 - 510	968	350 - 1,350	0.99	0.75 - 1.23	5	11.2	7 - 15	4	0.06	0.03 - 0.09
Round Whitefish	Third Portage	22	267	182 - 370	233	75 - 540	1.11	0.52 - 1.90	3	4.3	4 - 5	5	0.02	0.02 - 0.02
	Second Portage	15	329	193 - 426	495	75 - 975	1.17	0.95 - 1.44	5	14.0	7 - 23	3	0.08	0.05 - 0.10
	Tehek	30	323	196 - 400	425	50 - 700	1.19	0.47 - 1.67	5	11.6	7 - 17	2	0.03	0.03 - 0.04

of cannibalism is dependent on the proportion of different fish sizes available. In many lakes where lake trout are the only fish species, there is nothing else to eat. As juveniles, lake trout will consume benthos, insect larvae, and zooplankton, as well as small fish, if available (Scott and Crossman, 1979).

In project lakes, the majority (70%) of lake trout stomachs examined for gut contents were empty. Those stomachs with food items consisted primarily of fish remains, although zooplankton and tadpole shrimp (Notostraca) were present in the stomachs of some trout from all lakes. There was no apparent seasonal or spatial difference in diet preference of lake trout within or between lakes. Lake trout appeared to be highly cannibalistic, as trout fro all lakes preferred fish, regardless of season or lake, and consisted of round whitefish or lake trout. Sculpin, ninespine stickleback, and/or burbot were infrequently identified in gut contents of trout from surveys of Second Portage, Tehek, Pipedream, Vault, and Inuggugayualik lakes. Juvenile lake trout stomachs contained insects and benthic invertebrates (chironomid larvae and oligochaetes). In the 1999 survey, many stomachs from all sized trout from Inuggugayualik Lake and Amarulik Lake contained tadpole shrimp. These data suggest that lake trout are opportunistic feeders and will consume whatever is available, depending on relative abundance and ease of capture. Juvenile fish that are too small to consume other fish will target larger invertebrate taxa in nearshore areas where their abundance is greater and their feeding efficiency is higher. . The high proportion of empty stomachs also indicates that feeding by trout is opportunistic and infrequent.

Round whitefish are omnivorous and consume a wide variety of prey, including insect larvae, zooplankton, tadpole shrimp (Notostraca), bivalve clams, and oligochaete worms. Diet does not vary as much with age of fish as for lake trout. As round whitefish get older, they will consume proportionally larger prey items and, sometimes, small fish or fish eggs if available.

Round whitefish stomachs were less frequently empty (30%) and had a much more diverse assemblage of dietary items, including insects, zooplankton, bivalves, and other benthic invertebrates. All autopsied whitefish from Third Portage Lake were relatively small, and their diet consisted of zooplankton and unidentified benthos. The general composition (i.e., fish, zooplankton, benthos) of prey items consumed by Meadowbank project area fish is typical for these species, based on general literature (Machniak, 1975; Scott and Crossman, 1979). We could not discern spatial patterns in diet of round whitefish within or between lakes. There was a seasonal component to the diet of whitefish, however, as fish would likely target hatches of different chironomid species at different times of the summer.

The proportion of empty stomachs in Arctic char from each of the project lakes was similar to lake trout, averaging 70% empty. Stomach content from six Arctic char has been examined. Three were empty (1998) and three contained zooplankton (2002). Food items in stomachs of Arctic char from all project lakes containing food consisted exclusively of zooplankton. This was consistent in all years and all lakes from which char were captured and examined for gut contents.

7.8 METALS & MERCURY

It is important to determine baseline tissue mercury and metals concentration in fish to establish natural background levels in advance of mining activity. Very few metals in the environment are accumulated by aquatic biota. Mercury is of particular importance because it is the only known metal to biomagnify (i.e., concentrations become higher with increasing steps up the food chain), with highest concentrations in aquatic systems being found in fish. Larger, piscivorous fish will also have higher tissue mercury concentrations than smaller piscivorous or non-piscivorous species, such as lake whitefish (Bodaly et al, 1984). Because of the tendency of mercury to biomagnify, monitoring for mercury is needed to determine whether there is any potential danger to wildlife that consume fish, or to humans. However, given the lack of anthropogenic sources of mercury and lack of use of mercury in the mining process, it is very unlikely that any change in mercury concentration in fish tissue would be observed over time. The concentrations of nearly all other metals can vary among species, but generally do not vary in muscle with differences in fish size or age. Metals are taken up and retained to different degrees in the liver and kidney of fish.

Fish muscle tissue was collected from a subsample of lake trout, round whitefish, and Arctic char to determine background, baseline mercury concentrations from project lakes and candidate reference lakes in 1998 (Table 7.6). A smaller number of fish were also acquired from Third Portage, Wally Lake, and the reference, Inuggugayualik Lake in 2002 to determine baseline muscle metals concentrations in lake trout and round whitefish (Table 7.6).

Muscle tissue samples from the largest fish captured were analyzed to provide worst-case concentrations for mercury. Because there is a well-known positive relationship between fish size and mercury concentration (Scott and Armstrong, 1972; Somers and Jackson, 1993), it is important that mercury data are presented according to fish size. Ideally, a range of sizes would be sampled with a species/lake combination to remove the influence of differences in fish size from comparisons among lakes and years; however, the “worst-case” sampling strategy was adopted to minimize fish mortality.

Lake trout had the highest mercury concentrations in the study lakes in 1997 (Table 7.5), with mean values of 0.49 mg/kg (or parts per million, ppm) in Second Portage Lake (mean length 579 mm), 0.24 mg/kg in Third Portage Lake (593 mm), and 0.31 mg/kg in Tehek Lake (586 mm). The maximum concentration observed in Second Portage Lake was 1.17 mg/kg in a large trout (6.3 kg, 822 mm). One trout (7 kg) from Pipedream Lake on the Meadowbank system had a maximum mercury concentration of 1.40 ppm. Most of the values were below the concentration recommended for commercial sale in Canada (0.50 mg/kg). The majority of these values are low for fish of this size and age (i.e., large, old fish that have accumulated mercury in their tissues over a lifetime), and is typical of pristine lakes.

In Inuggugayualik Lake, the mean mercury concentration was 0.38 mg/kg (Table 7.5) in fish that were of larger mean size than in study lakes (656 mm). Again, concentrations were quite low for lake trout of this size. In the Koala lakes of eastern NWT (Table 7.7), the mean mercury concentration of fish (no species or size given, although presumably lake trout) was 0.37 mg/kg (Rescan, 1994), which was also similar to the present study. Mean mercury concentrations from lake trout in Kiggavik lakes (602 mm mean size) and Pointer Lake (616 mm mean size) were 0.69 mg/kg (1.23 mg/kg maximum) and 0.68 mg/kg (maximum 1.02 mg/kg), respectively. In pristine lakes in northwestern Ontario (Table 7.7), lake trout of a similar size had mean mercury concentrations that ranged from 0.29 to 0.89 mg/kg, with a combined mean of 0.57 mg/kg (Somers and Jackson, 1993). The higher mercury concentration in lake trout from project and regional Arctic lakes is presumably due to the large size and old age of trout, relative to trout in more temperate lakes, such as northwestern Ontario, as well as to regional geology.

Table 7.6: Metals Concentrations in Lake Trout & Round Whitefish Muscle Tissue from Project & Reference Lakes, 2002

	Lake Trout						Round Whitefish			
	Project Lakes				Reference Lake		Project Lakes			
	Third Portage Lake (n=4)		Wally Lake (n=4)		Innugugayualik Lake (n=7)		Third Portage Lake (n=5)		Wally Lake (n=2)	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Weight (g)	1,009	200 - 1,975	694	75 - 1,525	2,093	867 - 4,475	368	190 - 540	271	267 - 275
Total Metals (mg/kg ww)										
Aluminum	<2	<2 - <2	4	2 - 7	2	2 - 2	<2	<2 - <2	3	2 - 3
Antimony	<0.01	<0.01 - <0.01	<0.01	<0.01 - <0.01	<0.01	<0.01 - <0.01	<0.01	<0.01 - <0.01	<0.01	<0.01 - <0.01
Arsenic	0.02	0.01 - 0.05	0.04	0.02 - 0.07	0.01	0.01 - 0.02	0.02	0.01 - 0.03	0.02	0.02 - 0.02
Cadmium	<0.005	<0.005 - <0.005	<0.005	<0.005 - <0.005	<0.005	<0.005 - <0.005	0.01	0.01 - 0.01	<0.005	<0.005 - <0.005
Calcium	148	75 - 255	161	106 - 242	499	302 - 715	195	118 - 320	403	274 - 532
Chromium	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1
Cobalt	<0.02	<0.02 - <0.02	<0.02	<0.02 - <0.02	<0.02	<0.02 - <0.02	0.02	0.02 - 0.02	<0.02	<0.02 - <0.02
Copper	0.30	0.26 - 0.36	0.32	0.25 - 0.37	0.35	0.21 - 0.52	0.39	0.28 - 0.66	0.40	0.38 - 0.41
Lead	0.02	0.02 - 0.02	0.03	0.02 - 0.05	<0.02	<0.02 - <0.02	0.02	0.02 - 0.03	0.03	0.02 - 0.03
Magnesium	321	303 - 334	314	300 - 335	306	282 - 329	351	312 - 374	311	307 - 315
Manganese	0.12	0.10 - 0.16	0.28	0.10 - 0.50	0.31	0.14 - 0.61	0.22	0.15 - 0.30	0.40	0.40 - 0.40
Mercury	0.10	0.07 - 0.16	-	-	0.29	0.15 - 0.46	0.02	0.02 - 0.02	-	-
Nickel	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1	<0.1	<0.1 - <0.1
Selenium	1.03	0.70 - 1.20	0.53	0.40 - 0.60	0.53	0.40 - 0.60	1.30	1.00 - 1.80	0.65	0.60 - 0.70
Strontium	0.23	0.11 - 0.36	0.17	0.08 - 0.28	0.88	0.48 - 1.25	0.42	0.23 - 0.78	0.73	0.47 - 0.98
Tin	<0.05	<0.05 - <0.05	<0.05	<0.05 - <0.05	<0.05	<0.05 - <0.05	<0.05	<0.05 - <0.05	<0.05	<0.05 - <0.05
Zinc	3.5	3.2 - 3.7	3.6	3.5 – 3.8	3.8	3.3 - 4.5	3.9	3.6 - 4.3	4.1	3.6 - 4.5

Table 7.7: Metals Concentrations in Lake Trout Muscle Tissue from Regional Arctic Lakes

	Kiggavik Area Lakes[1]		Pointer Lake[2]		Snap Lake[3]		Snap Reference Lake[3]	
	1980 (n=7)		July-1988 (n=3)		1999 (n=10)		1999 (n=10)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Length (mm)	602	388 - 760	616	527 - 724				
Weight (g)	2,617	435 - 5,250	2,900	1,600 - 4,800				
Total Metals (mg/kg ww)								
Aluminum	-	-	-	-	15	<3 - <30	15	<3 - <30
Antimony	-	-	-	-	0.1	<0.1 - <0.1	0.1	<0.1 - 0.1
Arsenic	0.07	0.02 - 0.15	<0.2	<0.2 - <0.2	0.1	<0.1 - 0.2	0.1	<0.1 - 0.2
Cadmium	0.01	0.01 - 0.01	<0.01	<0.01 - <0.01	0.1	<0.1 - <0.1	0.1	<0.1 - <0.1
Chromium	0.09	0.03 - 0.21	-	-	0.2	<0.3 - <0.3	0.3	<0.3 - 0.6
Cobalt	-	-	-		0.1	<0.1 - 0.1	0.1	<0.1 - <0.1
Copper	0.52	0.21 - 0.76	-	-	2.7	1.2 - 4.3	1.3	0.7 - 2.4
Lead	0.03	0.02 - 0.07	0.1	<0.1 - 0.1	0.1	<0.1 - <0.1	0.1	<0.1 - 0.1
Manganese	-	-	-		0.5	0.3 - 0.7	0.4	0.3 - 0.5
Mercury	0.69	0.33 - 1.23	0.69	0.44 - 1.02	0.57	0.11 - 1.50	0.476	0.17 - 0.86
Nickel	-	-	0.1	<0.1 - 0.1	0.2	<0.1 - 0.5	0.1	<0.1 - 0.2
Selenium	0.30	0.23 - 0.34	0.2	0.2 - 0.2	2	1 – 3	1	1 - 2
Strontium	-	-	-	-	0.2	<0.1 - 0.5	0.66	0.1 - 3.4
Zinc	13.6	5.4 - 24.0	-	-	17	14 – 26	15	10 - 23

References: **1.** Stewart, 1981. **2.** McKee et al, 1989. **3**. De Beers, 2002.

As expected, mercury concentrations in round whitefish (0.08 mg/kg) and Arctic char (0.03 mg/kg) in 1997 were very low, relative to lake trout, and are typical of pristine lakes. These values are considerably lower than the commercial export guideline, as well as the domestic guideline, and are also typical of non-piscivorous fish from pristine lakes.

A small number of fish were captured in 2002 from Third Portage, Wally Lake, and Inuggugayualik Lake for the purposes of determining baseline tissue metals concentrations (Table 7.6). Depending on fish size, tissues samples were either composites of several fish (small fish size) or from an individual fish (larger fish). Biological data for the fish captured in each lake are consistent with the 1997 study in that lake trout dominated the catch, followed by round whitefish and Arctic char.

Tissue metals concentrations in lake trout and round whitefish muscle tissue from Third Portage Lake and Wally Lake were very low and were near or below laboratory detection limits for most metals (Table 7.6). There were also no differences in metals concentration for detectable metals of importance (e.g., arsenic, cadmium, copper, lead, zinc) between species or among different fish sizes within species. Maximum concentrations of the above-listed metals in project lakes are 0.07 (arsenic), 0.01 (cadmium), 0.66 (copper), 0.03 (lead), and 4.5 (zinc) mg/kg.

Metals concentrations in lake trout from project lakes were very similar to tissue concentrations from trout in the reference Inuggugayualik Lake (Table 7.6). When project and reference lake metals concentrations are compared against regional Arctic lakes (Kiggavik area lakes, Snap Lake) in Table 7.7, it is apparent that project fish have low tissue metals concentrations relative to lake trout from other lakes as well. Maximum concentrations of arsenic (0.15 mg/kg), cadmium (0.10 mg/kg), copper (4.3 mg/kg), lead (0.07 mg/kg), and zinc (26 mg/kg) from regional Arctic lakes were, on average, two- to ten-fold higher than in trout from project lakes. These data illustrate the low metals bioavailability in the Meadowbank system and the high quality of the fish tissue from a mercury and metals perspective.

7.9 ARCTIC CHAR ANADROMY

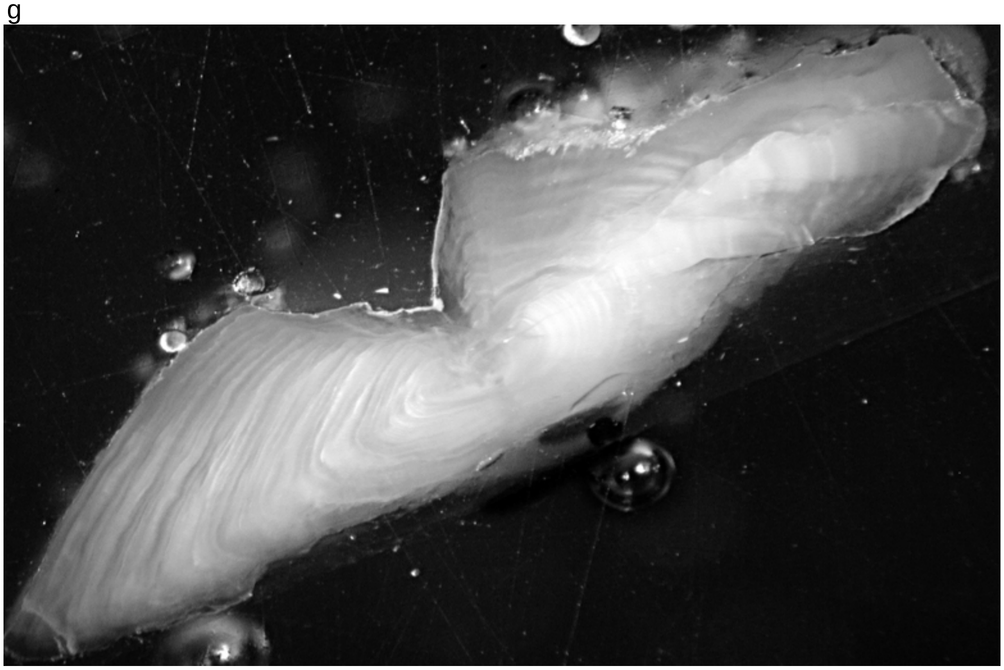
Arctic char are typically anadromous where there is convenient access to a marine environment; that is, they undertake annual summer migrations to marine waters to feed before returning to freshwater lakes to overwinter. Spawning takes place exclusively in freshwater lakes every two to four years after fish first reach sexual maturity. In isolated lakes, where char do not migrate to the sea (i.e., non-anadromous) or there is no connection to the sea (e.g., due to a falls), char populations are referred to as landlocked. Landlocked char are usually smaller and have lower growth rates than anadromous char, although this is not always the case (Johnson, 1980). Non-anadromous char from project lakes can achieve a large size (> 3 kg) and have similar morphological parameters as anadromous char from the Hudson Bay coast.

To determine whether or not Arctic char are anadromous, the concentration of strontium was measured in the fins of a subset of char from Second Portage, Third Portage, and Tehek lakes in 1997 and from Amarulik Lake, Inuggugayualik Lake, and Third Portage in 1999. This was repeated again in 2003, with fins and otoliths from three Arctic char from Second Portage and fins from lake trout. Because the concentration of strontium is much higher in marine water than in fresh water, and the concentration of strontium in hard parts of fish has been shown to be positively correlated with the extent to which char feed on organisms from the marine environment. Thus anadromous fish naturally have much higher strontium concentrations in their tissues than non-anadromous fish (Morin and Dodson, 1986). Uptake of strontium from marine prey items accumulates in hard parts and ultimately leaves a signature that can be detected, indicating whether char are anadromous or not. Thus, the strontium concentration in bones of anadromous char is much higher than strontium in bones of non-anadromous char.

Strontium concentrations in pelvic fins taken from Arctic char collected in Second Portage Lake in 1997 ranged from 140 to 176 µg/g or ppm. In Tehek, strontium in char was 165 µg/g. In 2002, the fin from a single large Arctic char captured from Third Portage Lake had a strontium concentration of 78 µg/g. Strontium concentration obtained from fins of Arctic char from candidate reference lakes in 1998 from Turn Lake (185 µg/g), Inuggugayualik Lake (150 µg/g), and Amarulik Lake (108 µg/g) are in the same range as the project lakes. Furthermore, these concentrations were similar to strontium concentration measured in fins from lake trout from the Portage lakes (180 to 254 µg/g). Given that lake trout are certainly not anadromous, this seems to confirm that char in the project lakes are landlocked. The impassable St. Clair falls on the lower reaches of the Quoich River obviously prevent char from accessing the project lakes. To further confirm that all Arctic char captured from the project lakes, as well as other lakes where access to the marine environment, although distant, is possible (Amarulik Lake, Inuggugayualik Lake), the Department of Fisheries and Oceans, Freshwater Institute, Winnipeg, analyzed the three sets of char otoliths from Second Portage Lake using a sophisticated methodology that uses a focussed beam of protons to drill very tiny holes throughout the length of the otolith. Photographs of the otoliths (AC800, AC1075, AC1750; corresponding to fish weight) are presented in Figure 7.11.

Figure 7.11: Photographs of Sectioned Otoliths from Second Portage Lake

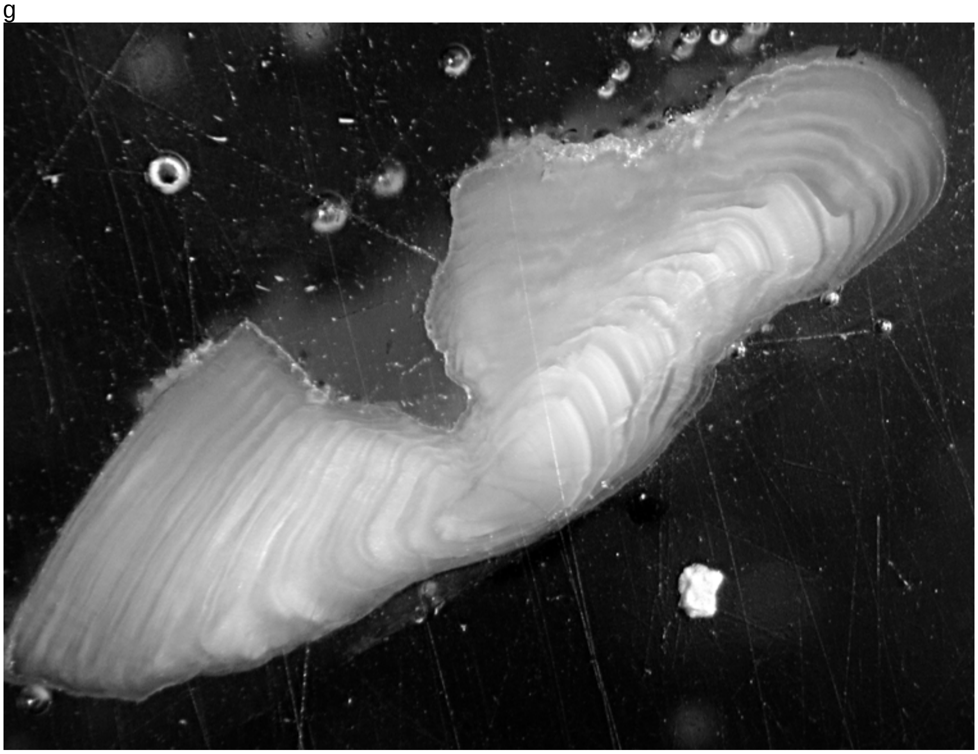
AC 800 g



AC 1075 g

Figure 7.11 – Continued

AC 1750 g



Alternating light and dark rings indicate periods of rapid summer and slow winter growth, respectively. The strontium signal, returned from the proton microprobe and compiled over the whole otolith, can determine the entire strontium history of the char, indicating exactly if/when feeding was conducted in a marine environment (indicated by a spike in strontium concentration), and when feeding was conducted in freshwater (low strontium concentration).

Strontium (Sr) concentration is typically measured as a ratio with calcium (Ca) in the bony material of the otolith. According to the literature, a Ca to Sr ratio of less than 0.002 is indicative of non-anadromy (J. Babaluk, Department of Fisheries and Oceans, Winnipeg). Proton microprobe results for each char otolith tested indicated that there was no peak in strontium concentration anywhere within the otolith (Figure 7.7) and that Ca:Sr ratios for all three char were consistently below 0.002. These results, combined with the fin strontium data, confirm that at no time did any of the three char captured from Second Portage Lake acquire nutrients from a marine environment, and they have been landlocked their entire life. The fact that the fin strontium concentrations from non-anadromous char in 2003 were similar to concentrations from char captured previously from other lakes in the project area confirms that all Arctic char captured in Meadowbank project area lakes are landlocked. Also, given that a large char (3.3 kg) from the reference lake, Inuggugayualik Lake had a similar fin strontium concentration (150 µg/g) as the project lakes, this result indicates that char from this lake are also non-anadromous, despite their large size and potential for access to the Arctic Ocean via the Meadowbank/Back River system. Figure 7.8 depicts the Ca:Sr ratio for an anadromous fish, for comparative purposes. Differences of greater than an order of magnitude in the strontium signature of anadromous versus non-anadromous fish can clearly be seen.

Figure 7.7: Results of Proton Microprobe Analysis of Strontium: Calcium Ratios for Arctic Char Otoliths (DFO Freshwater Institute, Winnipeg)

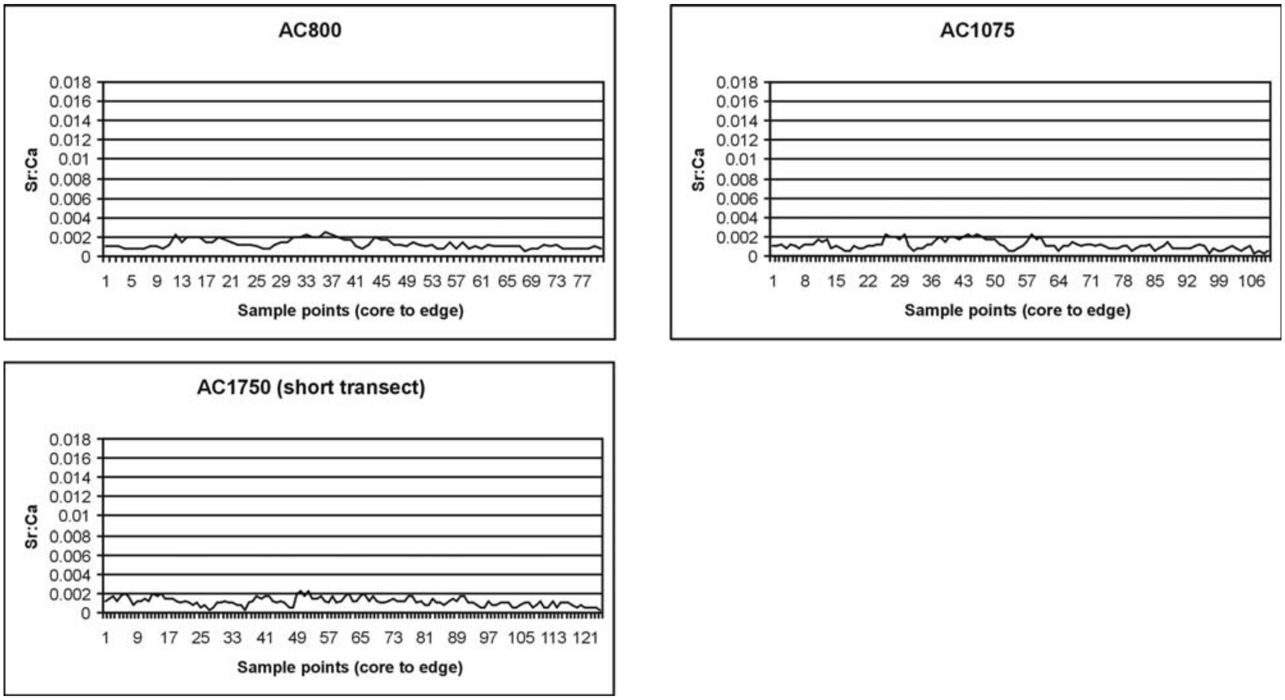
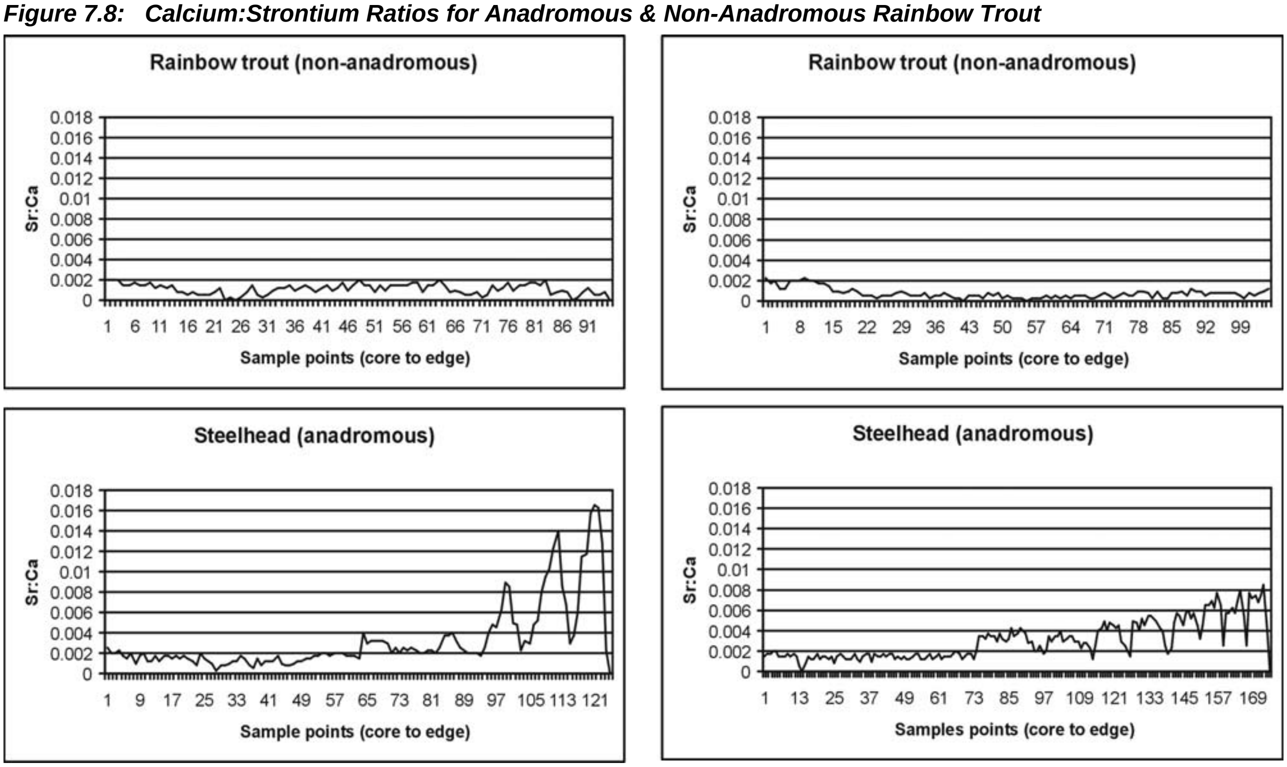


Figure 7.8: Calcium:Strontium Ratios for Anadromous & Non-Anadromous Rainbow Trout



Had the char tested been to sea at least once in its life history, this would have been detected by this test. These results confirm that the St. Clair Falls on the Quoich River is an impassable barrier that prevents char from accessing this system. Furthermore, hydrological work also seems to confirm that there are no secondary outlets from Tehek Lake that might bypass St. Clair falls. Given that the Arctic char analyzed using the microprobe technology are typical in size to char captured in previous years, and had similar fin strontium concentrations, it is highly unlikely that there are any anadromous char in this system above St. Clair Falls.

7.10 FISH MOVEMENTS BETWEEN PROJECT LAKES

Field investigations were conducted in 1997, 1998, 1999, 2004, and 2005 to determine the possibility, timing, species composition, and magnitude of movement by fish between project lakes. Movement by fish between lakes is a function of stream discharge, water depth, and substrate composition. Many of the channels are wide and boulder strewn, making movements by fish between lakes difficult. The 2005 investigation supplemented historic assessments of fish movement to provide more a more definitive seasonal assessment of fish movement among all project lakes. Appendix A provides a representative set of photographs depicting the connecting channels between project lakes and examples of ephemeral channels between ponds and lakes.

7.10.1 Third Portage – Second Portage Lake

Three channels connect Third Portage Lake to Second Portage Lake (Appendix A). A small hill separates the west channel from the middle and east channel. Although water discharges through all three channels, only the westernmost channel is passable by fish. The east channel is wide, diffuse and shallow, with boulder and cobble substrate and between or subsurface boulder flow. A wide scattered boulder shelf at the outflow impedes fish passage. The middle channel is a straight defined channel with three boulder obstructions, up-, mid-, and downstream. The boulder obstructions prevent fish passage as the discharge in these sections is between the boulders or subsurface. Substrate is predominantly large angular boulders.

Paired hoop nets were set in the west channel, a wide shallow channel with boulder and cobble substrate, from July 20 to August 7, 2005, to determine direction and abundance of fish moving up- and downstream. Hoop nets were set in the middle of the channel with the greatest flow covering approximately 65% of the wetted width of the channel. A total of six lake trout were collected; five moving upstream and one moving downstream (Table 7.8). These data corroborate data collected from hoop nets in this channel in 1999. Hoop nets were set from just after ice-off on July 4 to Aug 20, 1999. Only 16 fish, comprised only of lake trout and round whitefish, were collected the entire summer.

Shallow water depth, large boulder substrate obstructions, and decreased flow through open water season prevent fish from moving between Third Portage and Second Portage lakes. Mean annual discharge through the three channels is considerable, at least 10 Mn^3. Thus, despite the large flow, and notwithstanding the fact that fish can move between the lakes, movement by fish is very low. Third Portage is the largest lake in the project lake area, and the west channel is the only channel where movement by fish to or from Second Portage Lake is possible. Given the significance of this channel, the abundance of fish moving between these lakes is minimal. No Arctic grayling or any other species have been observed.

Table 7.8: Results of Fish Movements within Project Lake Channels (2005)

	Second Portage Lake to Tehek						*Third Portage Lake to Second Portage Lake*		*Vault to Wally*	
Date	**Lake Trout**		**Round Whitefish**		**Arctic Char**		**Lake Trout**		**Lake Trout**	
	US	DS	US	DS	US	DS	US	DS	US	DS
4-Jul	1	0	0	0	1	0				
8-Jul	2	0	0	0	1	0				
17-Jul	1	0	0	0	0	0				
18-Jul	0	0	1	0	0	0	0	0	0	0
27-Jul	2	4	0	0	0	0	1	0	0	1
6-Aug	4	3	0	0	0	2	4	1	1	2
8-Aug	1	3	0	0	0	0				
10-Aug	0	1	0	0	0	0				
14-Aug	5	1	0	0	0	0				
17-Aug	1	2	0	0	0	0				
21-Aug	9	2	1	1	0	0				
Total	***26***	***16***	***2***	***1***	***2***	***2***	***5***	***1***	***1***	***3***

7.10.2 Second Portage – Tehek Lake

The channel that connects Second Portage Lake to Tehek Lake drains all project lakes including, the Portage lakes, Turn, Vault, Wally and Drilltrail lakes. Mean annual discharge via this channel is at least 30 Mm^3 of water (AMEC, 2005). It is approximately 1 km long and has three defining portions: an upstream chute, a large mid-channel pool, and a downstream riffle/run section. The channel is well confined with small hills to the north and south. Substrate is composed predominantly of large boulders with some cobble. This channel is the largest channel in the project lake area with reasonably consistent flow and water level throughout July and early August, with discharge diminishing through September with freeze-up in October. It is possible for fish to move both up- and downstream through the channel throughout the open water season. Hoop nets were set in 1997, 1998, and 2005 to monitor movements by fish within this large connecting channel (Tables 7.9, 7.9).

One hoop net was set to collect fish going upstream from June 29 to July 18, 2005 and set to capture approximately 35% of the width of the channel in the middle of channel with the greatest flow velocity (Appendix A). From July 19 to Aug 21, 2005, two hoop nets were set across 100% of the channel. A total of 42 lake trout, three round whitefish, and four Arctic char were collected through most of the open-water season. There were no defined movements either up- or downstream by any species.

The 1997 field investigations collected only six lake trout, two arctic char, and one round whitefish between August 13 and September 1. Between August 20 and September 8, 1998, a hoop net was set to capture fish moving upstream. Twenty-one lake trout, three round whitefish, and two arctic char were collected.

Second Portage to Tehek channel is the largest channel in the project lake system and facilitates all of the drainage of the system into Tehek Lake. The 1997 to 2005 investigations indicate that, considering the large discharge and ease of fish passage, very few fish move either up- or downstream between these lakes. The relative abundance of Artic char and round whitefish captured by hoop nets was similar to the abundance of char in the project lakes from gill nets and confirms that there is no upstream migration by any fish species. Movements by fish between Tehek and the upper lake system are random and undefined. If Arctic grayling were present in the vicinity of the project lakes, they would be found here, given that this is the only channel to resemble a stream. The absence of grayling despite suitable discharge, water depth, connectivity, and substrate confirms that grayling are not present in the upper Quoich River watershed.

7.10.3 Vault – Wally Lake

A wide (80 m) narrowing connects Vault Lake and Wally Lake. There is little elevation change evident between these two lakes that is confined northwest by a hill and unconfined to the southeast. Depth and flow thru the channel is adequate to allow for fish passage throughout the open water season. Paired hoop nets were set between July 19 and August 7, 2005 to block virtually the entire channel width. Only four lake trout were collected moving between these lakes, one into Vault and three into Wally Lake (Table 7.8). Hoop nets were also set between these lakes between July 27 and September 2004. No fish were collected from hoop nets, indicating that fish were not moving between these lakes, despite adequate water depth and no obstructions. These data indicate that fish move between these two lakes in small numbers and only opportunistically.

7.10.4 Wally – Drilltrail Lake

Wally Lake discharges to Drilltrail Lake via a shallow channel dominated by large boulder substrate. Shallow riffles wind between boulders descending approximately 1.5 m from Wally to Drilltrail Lake. Although it is possible for fish to pass through this channel during freshet, there is likely insufficient discharge or water depth to accommodate fish passage through the majority of the open water season. A middle channel that connects a small northern lake to the main southern basin divides Drilltrail Lake. This channel is short and has a well-defined central channel with alternating riffle and run portions. In early July 2005, discharge in the central channel was sufficient to allow fish passage. However, connectivity significantly decreased over the course of July and August such that fish passage would have been difficult or impossible by late July or early August. Water depth was insufficient to set hoop nets.

7.10.5 Turn – Drilltrail Lake

Turn Lake to Drilltrail Lake channel is wide and shallow with boulder and cobble substrate. The channel was visited on June 4, 2005 before ice-off. At this time water level was low and fish passage was difficult but not impossible. By early July water depth had further diminished and likely restricted movement of fish because of lack of water depth and large substrate size in the channel. Although there is a reasonable discharge volume, much of the flow is dispersed in the wide channel, is subsurface or flows between large boulders. It may be possible for fish to opportunistically pass through this channel during spring freshet, but is not possible for the majority of the open water season, with many obstructions due to between boulder and cobble flow. Hoop nets were not deployed between Turn and Drilltrail because of insufficient water depth.

7.10.6 Drilltrail – Second Portage Lake

A 1.0 km long channel connects Drilltrail Lake and Second Portage Lake. The upstream portion of the channel is a wide, deep, riffle channel that transitions into a large pond, where it descends downstream through a chute to Second Portage Lake. Fish may easily move between Drilltrail Lake and the large pond throughout the open water season. The downstream chute may restrict movement between Second Portage and Drilltrail lakes, especially later in the summer as water levels decrease.

In 2005 water level decreased from July to August at both upstream and downstream channel portions (15 and 12.8 cm, respectively). A hoop net was set downstream of the channel in 1999 from near ice-off on July 4 throughout freshet to July 20 (Table 7.9). No fish were collected.

Table 7.9: Results Summary of Stream Monitoring 1997 to 2005

Connecting Channels	Date	Dates	Number of Fish		Species
			Upstream	Downstream	
Third to Second Portage	1999	July 4 to 20	16	0	LKTR, RNWH
	2005	July 20 to Aug 7	5	1	LKTR
Second Portage to Tehek	1997	Aug 13 to Sept 1	5	4	LKTR, RNWH, ARCH
	1998	Aug 20 to Sept 8	26	0	LKTR, RNWH, ARCH
	2005	June 29 to Aug 21	30	19	LKTR, RNWH, ARCH
Vault to Wally	2004	July 27 to Sept 2	0	0	-
	2005	July 20 to Aug 7	1	3	LKTR
Drilltrail to Second Portage	1999	July 4 to 20	0	0	-

Note: LKTR = Lake trout, RNWH = round whitefish, ARCH = Arctic char

This channel drains all of Phaser, Vault, Wally, Turn, and Drilltrail lakes, discharging to the lower end of Second Portage Lake just upstream of its connecting with Tehek Lake and is a major bottleneck in the system. Despite relatively large discharge volume (15 to 25 m^3/y at a rate of 5 to 8 m^3/s during peak freshet in late June and early July), the magnitude of fish movement between Second Portage and upstream lakes is very small. This is consistent with what has been observed from several years of hoop nets set between Tehek and Second Portage lakes, just downstream from this connecting channel. Diminished discharge and large boulders within the connecting channel will make fish movement between these lakes increasingly difficult after July. Freeze-up of this channel occurs in September.

7.10.7 Phaser – Vault Lake

There is no defined channel connecting Phaser Lake and Vault Lake (Appendix A). Very low below surface flow was noted between these two water bodies during freshet, which was dominated by a boulder field with large angular boulders and cobbles east of Phaser Lake. Fish are unable to move between Phaser Lake and Vault Lake, even during freshet.

7.10.8 Dogleg Lake – Second Portage Lake

There is no evidence of a navigable hydraulic connection between Dogleg Lake (NP-1) and Turn Lake. Dogleg Lake is isolated from Second Portage Lake but contains a discrete population of lake trout and round whitefish. During the July 2005 survey there was no evidence of surface flow between the lakes and fish are unable to move between Dogleg Lake and Second Portage Lake. There is a depression to the east and boulder field to the west of the lake that facilitate collection of local runoff during freshet, most of which is likely absorbed by the tundra. A small volume of this may eventually drain to Second Portage Lake.

7.10.9 Upland Ponds – Second Portage Lake, Turn Lake

Two small ponds, NP-2 and NP-3 (NNL, 2005), contain small, discrete populations of fish. NP-2 is a small round lake (maximum depth 8 m) that flows via an ephemeral braided channel over tundra and grassy substrate to join another smaller shallow fishless pond (NF-1). This pond is connected to Second Portage Lake via an ephemeral, diffuse grassy channel. Fish are unable to move between these two ponds at any time during the open water season.

NP-3 is up to 12 m deep and contains and isolated population of lake trout and round whitefish. This pond drains to Turn Lake via an ephemeral grassy, boulder-strewn channel with a relatively steep incline. Movement by fish between NP-3 and Turn Lake is not possible because of shallow depth, and large boulder barriers.

Finally, two small, isolated ponds north of Second Portage Lake (NF-2 and NF-3) are situated northwest of the proposed Waste Rock Facility of Second Portage Lake. Both of these ponds were surveyed via helicopter in early June 2005. The substrate of both ponds could clearly be seen adhered to the bottom of the ice. Thus, overwintering by fish, if any were present is not possible. The channels connecting these ponds were evaluated to determine if fish movement between the ponds and Second Portage Lake was possible during spring. NF-2 and NF-3 discharge to the eastern basin of Second Portage via small, ephemeral grassy braided channels with some exposed boulders. The channels descend from the ponds down a hill with an elevation change of approximately 5 m. Hoop nets were not set in these channels because of the poor quality substrate, shallow depth, and ephemeral nature. The habitat value of these channels is negligible.

7.10.10 Overall Evaluation of Fish Movement between Project Lakes

Results of hoop netting studies (1997 to 2005) to determine the timing and magnitude of fish movements between all project lakes have demonstrated that there are no dedicated migrations by any fish species between any of the project lakes via their connecting channels. Although not all connecting channels were evaluated every year, the overwhelming weight-of-evidence from multiple years during freshet, mid-summer and fall indicates that movements by fish between lakes are random and small and are not related dedicated spawning, or overwintering migrations. Although water depth, substrate, and discharge between lakes is adequate for movement by fish between the larger lakes (i.e., between Third and Second Portage lakes; Vault and Wally lakes; Drilltrail and Second Portage lakes; and Second Portage and Tehek lakes), only small numbers of fish have been captured in hoop nets (Table 7.10) and in similar proportions as they have been found from gill net surveys of the project lakes.

The absence of movement or migrations by fish between the lakes is not unexpected. Lake trout and round whitefish are common lake-dwelling species that do not typically move between lakes. The project lakes are large and provide all necessary habitats (spawning, rearing, foraging, overwintering) these species require to survive. Thus, there is no biological imperative to move between lakes. This is not to say that movements by fish related to spawning or overwintering do not occur within lakes. Certainly lake trout, Arctic char and round whitefish will move within the lakes seek out suitable habitat during fall for spawning.

No migrations by Arctic char between the project lakes have been observed. It is well know that anadromous char returning from the marine environment, will, during summer and fall, move into upstream lakes to spawn and overwinter. Although it has been demonstrated that char in the Quoich River system upstream of St. Clair Falls are landlocked, the absence of movements or migrations by char indicates that char remain within their natal lakes and do not move between lakes.

Table 7.10: Overall Assessment of Timing/Flow Condition, Potential for Movement & Observed Magnitude of Movement By Fish Between Project Lakes

Project Lake Connecting Channels		**Timing/Flow Conditions**	**Potential for Movement**	**Magnitude of Movement**
Third Portage Lake to Second Portage	West Channel	Summer/Fall	Good	Poor
	Middle Channel	Restricted	Nil	-
	East Channel	Restricted	Nil	-
Second Portage to Tehek		Summer/Fall	Excellent	Poor
Vault to Wally		Summer/Fall	Excellent	Poor
Wally to Drilltrail		Freshet	Poor	-
Drilltrail Middle Channel		Freshet	Fair	-
Turn to Drilltrail		Freshet	Poor	-
Drilltrail to Second Portage	US*	Open water	Excellent	-
	DS*	Open water	Fair	Poor
Phaser to Vault		Nil	Nil	-
Dogleg to Second Portage		Nil	Nil	-
NP-2 to Second Portage		Nil	Nil	-
NP-3 to Turn		Nil	Nil	-
NF-1 to Second Portage		Nil	Nil	-
NF-2 to Second Portage		Nil	Nil	-

Arctic grayling are not present within the project lakes. Although grayling are present in the Quoich River downstream of Tehek Lake, their presence in Tehek Lake or upstream lakes has not been demonstrated. Concerted effort within connecting channels, especially between Tehek and Second Portage lakes has failed to discover grayling. Grayling have also not been captured in gill nets from project lakes (1997 to 2005). Arctic grayling were commonly observed in all major streams along the all-weather road throughout the open water season, when water levels within streams permitted. However, all of the streams containing grayling were within the Prince River drainage. The absence of Arctic grayling from the project lakes and their connecting channels is due to the lack of spawning habitat for this species. Connecting channels are short and thaw late in spring. Lawrence and Davies (1977) suggested that cold water temperatures and inadequate flow conditions are not sufficient to support spawning by grayling in the upper watershed of this system. Bottom substrate of most channels is very coarse, consisting of large boulders with very little cobble or gravelly/rocky parts of main rivers that is favoured for spawning by grayling (Scott and Crossman, 1979).

Lake cisco have also not been collected within or moving into project lakes. Cisco have been collected from streams draining to the Prince River system along the all-weather road. The Prince River discharges to Baker Lake and it is well known that lake cisco will move upstream from larger lakes or the marine environment to spawn in lakes during fall. The absence of cisco from the project lakes indicates that they are likely absent from Tehek Lake.

Data collected at project- lake connections indicate that the magnitude of the fish moving between the project lakes is poor (Table 7.10), relative to the overall abundance of lake trout, round whitefish, and Arctic char in the project lakes.

SECTION 8 • SUMMARY OF KEY AQUATIC FEATURES

The overall goal of this BAEAR was to assemble and interpret the existing information on the aquatic environment in the Meadowbank project area Lakes, and to serve as a foundation for subsequent environment impact assessment (EIA) activities. Predicting potential impacts of mine development on aquatic life and developing appropriate mitigation strategies cannot be accomplished without having a good understanding of the receiving environment. Central to this understanding of baseline conditions in the study area lakes is a thorough characterization of spatial, seasonal, and inter-annual variability in key aquatic features. This has been discussed in some detail in the previous sections. Having a good understanding of lake-wide conditions (water and sediment chemistry, lower trophic level biota, fish populations, and habitat) from major project lakes will allow for better comparisons to be made between discrete areas potentially affected by mine development and the wider environment. This approach was necessary to ensure that site specific locations targeted for monitoring within the AEMP (2005) can be placed in proper perspective.

Highlights from previous sections are summarized in Table 8.1 to provide an objective overview of the baseline results to date. The table is organized according to the specific objectives of the BAEAR report, which were as follows:

- document the physical, chemical, and ecological characteristics, including spatial, seasonal, and inter-annual variability, of project lakes prior to mine development
- document the physical, chemical, and ecological characteristics, including spatial and seasonal variability, of reference lakes
- compare and contrast the existing data between project lakes and reference lakes to provide a baseline context to which future data can be compared
- compare and contrast the existing data for Meadowbank project area lakes with published data from regional lakes elsewhere in Nunavut and the Northwest Territories to place the Meadowbank results into a broad, regional context.

The Meadowbank project area lakes are situated in a remote area of the sub-Arctic region of Canada in the headwaters of the Quoich River system. All of the lakes share similar physical, limnological, chemical and morphological/habitat features that are consistent with soft-water, ultra-oligotrophic, and nutrient-poor lakes found elsewhere in Nunavut and the Northwest Territories.

Primary and secondary productivity of the project lakes and the reference lakes (Third Portage south basin, Inuggugayualik Lake) were relatively similar among lakes and over years. Overall, biomass and/or density of lower trophic level groups (e.g., benthos, zooplankton) were similar to values from regional Arctic lakes. Differences in these parameters among lakes or years for lower trophic level groups can partly be explained by differences in sampling methods, seasonal effects, and heterogeneity of natural populations. These factors would overwhelm subtle trends or differences that might be evident among Meadowbank project area lakes. In general, abundance and biomass of lower trophic level biota was similar among lakes, or perhaps slightly lower in Third Portage Lake than other lakes.

Table 8.1: Summary of Key Physical, Chemical & Biological Features for Meadowbank BAEAR

Meadowbank Study Area Lakes[1]	Physical Setting	General Limnology	Water Chemistry	Sediment Chemistry	Periphyton	Phytoplankton	Zooplankton	Benthic Invertebrates	Fish
PROJECT LAKES Third Portage (East and North basins), Second Portage, Turn, Vault, Wally Farside, Tehek	• Subarctic (65° N), barren tundra with permafrost. • Complex, indistinct, low gradient drainages. • Headwater lakes with little stream habitat. • High lake surface area: drainage ratios. • Watershed drains into Baker Lake then Chesterfield Inlet, Hudson Bay.	• Ultra-oligotrophic, nutrient poor, isothermal, neutral pH, low hardness, and high oxygen concentration. • High water clarity and low dissolved and total solids. • Low sediment/nutrient inputs; nutrient limited. • Ice-free season short. • Depth, volume, bathymetry, retention time unknown.	• Low nutrients (nitrogen, carbon, phosphorous). • Metals concentrations generally below detection limits and CCME guidelines. • Only Al, Cd, Pb, and Zn detected. • Pb marginally exceeded CCME guidelines for aquatic life at a few locations. • Results consistent among years.	• Headwater lakes have low sediment inputs and deposition rates. • Grain size range primarily clay and silt (90%). • Organic carbon content 2 to 5%; fairly high for oligotrophic lake, but explained by low inorganic sediment inputs. • Metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Zn) concentrations naturally elevated and exceed CCME guidelines. • Metals consistent among lakes and years.	• This feature subject to high natural variability. • Diatoms, cyanophytes and chlorophytes were dominant taxa. • Biomass and major taxa composition variable among lakes and years. • High variability limits the utility of monitoring this feature (i.e., subtle impacts impossible to detect).	• Large difference in biomass between 1998 and 2002, but likely related to sampling techniques. • Total biomass and relative biomass of major taxa consistent among lakes/seasons in 2002. • Productivity low, but consistent with oligotrophic, Arctic lakes.	• Dominated by calanoid and cyclopoid copepods, and less so by cladocerans. • Diversity/abundance low, but consistent with oligotrophic, Arctic lakes. • Biomass increased with season, but was fairly consistent among lakes. • High similarity of species present among lakes/years. • Inter-annual variability likely related to seasonal affects and sampling techniques.	• Community dominated by chironomid (midge) larvae, followed by bivalves and oligochaete worms. • Density and richness fairly consistent among lakes within years. • Density relatively consistent among years, with the exception of 1997, which was considerably lower. • Seasonal density differences were related to hatching of chironomids.	• Community dominated by lake trout, followed by round whitefish and Arctic char. • Large, old, unexploited, climax communities. • All fish species in good condition with few parasites. • Catch per unit effort (CPUE) was higher in Second Portage than other Project Lakes and Reference Lakes. • Mercury tissue concentrations were higher in lake trout (to 1.2 ppm) than in whitefish (to 0.1 ppm) char (to 0.2 ppm). • Metals tissue concentrations were very low. • Strontium and circumstantial evidence suggests Arctic char are anadromous; more work needed to confirm.
REFERENCE LAKES Inuggugayualik (external) and Third Portage (South Basin; internal)	• Similar to Project Lakes • Inuggugayualik Lake drains to Arctic Ocean. • South basin of Third Portage Lake is far and upcurrent from any proposed mining activities.	• Similar to Project Lakes. • Water temperature in internal reference slightly colder than Project Lakes.	• Nutrient levels similar to Project Lakes. • Metals concentrations generally below detection limits and always below CCME guidelines.	• Sediment inputs and grain size similar to Project Lakes. • Organic carbon content similar to Project Lakes. • Metals concentrations similar to Project Lakes.	• Biomass and major taxa composition more variable than Project Lakes. • Composition similar to Project Lakes.	• Variability among years was high and likely related to sampling technique. • Taxa group composition and biomass similar to Project Lakes in 2002. • Addition data would be useful to determine annual variability.	• Similar in biomass and composition to Project Lakes. • High similarity of species present with Project Lakes. • Variability among years relatively small after accounting for season effects.	• Community composition and diversity similar to Project Lakes. • Densities were variable but generally comparable to Project Lakes. • Seasonal variability in Inuggugayualik Lake in 2002 likely due to suboptimal sampling location in August.	• Community composition and fish condition similar to Project Lakes. • CPUE relatively similar to Project Lakes. • Mercury tissue concentrations similar to Project Lakes for all species. • Metals tissue concentrations were similar to Project Lakes. • Arctic char appear to be anadromous in Innuggugayualik Lake
REGIONAL LAKES[2] Baker, Koala Region, Pitz, Lac de Gras, Kiggavik Region, Snap	• Lakes are situated across a broad geographical region and do differ in some characteristics from Study Area Lakes.	• Similar to Meadowbank Study Area Lakes in most general aspects. • Typical of cold oligotrophic, nutrient poor Arctic lakes.	• Similar or slightly higher nutrient levels than Study Area Lakes. • Similar or slightly higher metals concentrations than Study Area Lakes.	• Sediment grain size variable; typically larger than Study Area Lakes. • Organic carbon levels higher than Study Area Lakes. • Metals concentrations similar or lower than Study Area Lakes; possibly due to coarser substrates in Regional Lakes.	• No regional data available.	• Differences observed in biomass and composition relative to Study Area Lakes, but no more so than differences among lakes/years within the Study Area.	• Reasonably comparable to Study Area Lakes. • Typically dominated by calanoid and cyclopoid copepods. • Moderate similarity of species present with Project Lakes. • Biomass and richness relatively similar to Study Area Lakes.	• Community composition similar to Study Area Lakes. • Densities similar to Study Area Lakes. • Diversity similar to Study Area Lakes.	• Community composition relatively similar to Study Area Lakes; round whitefish or lake whitefish present; char largely absent. • CPUE difficult to compare due to gear differences. • Mercury concentrations were similar to or slightly lower than Study Area Lakes. • Metals concentrations were often slightly higher than Study Area Lakes.

Notes: 1. Certain lakes (e.g., candidate reference lakes: Pipedream, Ihipquituq, Amariulik) with limited data are not included herein. **2.** Other regional lakes were also used for comparative purposes depending on data availability.

Fish species composition, mean size, and condition were similar for most lakes. Lake trout dominated all project, reference, and regional lakes, and were characterized as being large, old, climax community populations typical of oligotrophic Arctic lakes. Round whitefish and landlocked Arctic char were the next dominant species in all lakes. Fewer Arctic char are present in Third Portage Lake than in the other project lakes.

Based on catch-per-unit-effort statistics (CPUE) in between 1997 and 1999, there were minor differences among fish populations in project lakes. Second Portage Lake appeared to contain a higher density of fish than the other lakes, especially Third Portage Lake in 1997, but CPUE between Second and Third Portage lakes was similar in 1999. Third Portage Lake is larger, colder, and deeper than the other project lakes and, consequently, may not be as productive per unit area as Second Portage.

Overall, the Meadowbank project lakes support healthy communities of plankton, benthos, and fish that are typical of oligotrophic Arctic lakes. Baseline studies to date have been conducted over a period of several years over a wide geographic area in order to gain a good understanding of the physical, chemical, and biological features of the upper Quoich River watershed. This understanding, combined with site-specific studies within more discrete areas in project lakes (see the AEMP, 2005 and MMER, 2005), will provide the necessary information required to predict potential impacts that might occur as a result of mine development. The level of understanding of the physical, chemical, and ecological relationships within and between the Meadowbank project area lakes is dependent on the frequency of sampling and the spatial and temporal scope of work. Understanding of natural systems can always be improved by collecting further data and addressing data gaps. While extensive baseline studies have been conducted to date, additional information gathered in future years will contribute further to our ability to characterize the receiving environment, and provide the foundation for planning and conducting specific studies related to effluent discharge from the mine as part of the federal Environmental Effects Monitoring program (MMER, 2005). This document represents Azimuth's and Cumberland's current understanding and assessment of the Meadowbank project area lakes based upon the best available information.

SECTION 9 • REFERENCES

AMEC Earth & Environmental, 2003 (January). Environmental Impact Statement - Doris North Project, Nunavut, Canada. Chapter 3, Environmental Baseline Conditions; p 3-1 – 3-12. A report prepared for Miramar Mining Corporation (Miramar Hope Bay Ltd.), North Vancouver, BC, by AMEC Earth & Environmental Ltd., Burnaby, BC.

AMEC Earth & Environmental. 2005. Meadowbank Gold Project hydrologic monitoring 2004 data report. Prepared by AMEC Earth & Environmental, Calgary AB for Cumberland Resources, Vancouver BC. February, 2005

AEMP 2005. Meadowbank Gold Project Aquatic Environment Effects Management Report. Prepared by Azimuth Consulting Group, Vancouver BC for Cumberland Resources Ltd. September 2005.

Bodaly, R.A., R.E. Hecky, and R.J.P. Fudge, 1984. Increases in fish mercury levels in lakes flooded by the Churchill River Diversion, northern Manitoba. Can. J. Fish. Aquat. Sci. 41: 682 – 691.

Canadian Council of Environment Ministers, 2001. Water quality guidelines for the protection of aquatic life. CCME, Ottawa Ontario. Revised 2001.

De Beers Canada Mining Inc, 2002 (February). Snap Lake Diamond Project Environmental Impact Assessment. Chapter 9, Aquatic Resources + App.; p 9-1 to 9-416.

Diavik Diamond Mines Inc, 1998 (September). Diavik Diamonds Project Environmental Effects Report, Fish and Water. Volume I. Chapter 3; p 3-1 to 3-31.

Diavik Diamond Mines Inc. and Aber Resources Ltd, 1998 (March). Diavik Diamonds Project Integrated Environmental and Socio-Economic Baseline Report. Volume I. Chapter D-6, Water Quality; p 154-175, and Chapter D-7, Aquatic Ecosystem; p 176 - 222.

Environment Canada, 1984. Guidance document on collection and preparation of sediments for physicochemical characterization and biological testing. Environmental Protection Series. Report EPS 1/RM/29. Ottawa, Ontario.

Fee, E.J., M.P. Stainton, and H.J. Kling (Department of Fisheries and Oceans Western Region), 1985. Primary Production and Related Limnological Data for Some Lakes of the Yellowknife, NWT Area. Canadian Technical Report Fisheries and Aquatic Sciences 1409: v + 55 p.

Findlay, D.L., and J.A. Shearer, 1992. Sedimentary diatom assemblages and their relationships with lakewater pHs from 36 lakes in the Experimental Lakes Area, northwestern Ontario. Journal of Paleolimnology 7: 145-156.

Findlay, D.L., S.E.M. Kasian, M.T. Turner, and M.P. Stainton, 1999. Responses of phytoplankton and epilithon during acidification and early recovery. Freshwater Biology 42: 159-175.

Hagenson, I., 1990. Fish population data from Split and Stephens lakes, 1989. Manitoba Department of Natural Resources Fisheries Branch. Rep. No 90-07 70 p.

Holmgren, S., 1983. Phytoplankton biomass and algal composition in natural, fertilized and polluted subarctic lakes. Acta Universitatis Upsaliensis Abstracts of Uppsala Dissertations in Science. 674: 125

Jessop, E.F., K.T.J. Chang-Kue and G. MacDonald, 1993. Fish resource data from Indin Lake, Northwest Territories. Canadian Data Report Fisheries and Aquatic Sciences. 907: v + 52 p.

Johnson, L.L., 1976. Ecology of Arctic populations of lake trout, *Salvelinus namaycush*, lake whitefish, *Coregonus clupeaformis*, Arctic char, *S. alpinus*, and associated species in unexploited lakes of the Northwest Territories. Journal of the Fisheries Research Board of Canada 33: 2459 – 2488.

Johnson, L.L., 1980. The Arctic charr, *Salvelinus alpinus*. *In*: E.K. Balon [ed.]. Charrs: salmonid fishes of the genus *Salvelinus*. Dr. W. Junk Publishers. The Hague, Netherlands. p. 15 – 98.

Kalff, J., 1970. Arctic lake ecosystems. *In*: M.E. Holgate [ed.]. Antarctic ecology. Academic Press Inc. London. p. 651 – 663.

Kalff, J., Kling, H.J., Holmgren, S.H., and Welch, H.E., 1975. Phytoplankton, phytoplankton growth and biomass cycles in an unpolluted and in a polluted Polar lake. Verh. Int. Ver. Theor. Angew. Limnol 19.

Kirton, J.A.W., 1986. Fish population data from Split and Stephens Lake, 1984. Man Dept. Nat. Res. Fish. Br. MS Rep. No. 86-04. 60 p.

Komarek, J., H. Kling and J. Komarkova, 2002. Filamentous Cyanobacteria. *In*: Wehr, J.D. and R.G., Sheath [eds.] Freshwater Algae of North America. Ecology and Classification. Academic Press. U.S. 918 p.

Lawrence, M., S. Davies, G. Collins, F. Hnytka, K. Kroeker, and R. Sie (Environment-Social Program Northern Pipelines), 1977. Aquatic Resources Survey-Keewatin District Preliminary Report 1977. ESCOM No. AI-07. 50 p.

Lawrence, M. and S. Davies. Aquatic resource survey of Keewatin and Franklin Districts. Environmental-Social Program Northern Pipelines ESCOM Report No. A1-31.

MacDonald, G. and Stewart, D.B., 1980. Arctic land use research program 1980: a survey of the aquatic resources of the central Keewatin region of the Northwest Territories. Northern Affairs Program Environmental Studies Vol. 17. March, 1980. Ottawa, Ontario. 111 p.

MacDonell, D., 1997. Hornaday River, Paulatuk NWT Arctic charr spawning location study, August/September 1997. Prepared for Department of Fisheries and Oceans, Winnipeg MB by North/South Consultants Inc., Winnipeg MB. 25 p.

MacDonell, D.S. and B. Horne, 1994. Lower Nelson River forebay monitoring program 1993 – Year V. A report prepared for Manitoba Hydro by North/South Consultants, Winnipeg, MB. xii + 111 p.

Machniak, K., 1975. The effects of hydroelectric development on the biology of northern fishes (reproduction and population dynamics) IV. Lake trout *Salvelinus namaycush* (Walabum). A literature review and bibliography. Fisheries and Marine Services Division Technical Report No. 530. 52 p.

Mannik, Tom (personal communication), July, 1998. Baker Lake, Nunavut.

McGowan, D.K., 1987. Data on Arctic charr, *Salvelinus alpinus* (L.) from the Diana River, Northwest Territories, 1986. Canadian Data Report Fisheries and Aquatic Sciences 666: iv + 19 p.

McGowan, D.K., 1992. Data on Arctic charr, *Salvelinus alpinus* (L.) from the Meliadine River, Northwest Territories, 1990. Canadian Data Report Fisheries and Aquatic Sciences 867: iv + 9 p.

McKee, P., R. Watters, and D.L. Lush (Beak Consultants Ltd.), 1989 (December). Supporting Document No.4. Aquatic Baseline Conditions – Kiggavik Project Area, District of Keewatin, Northwest Territories. A report prepared for Urangesellschaft Canada Ltd. Toronto, ON, by Beak Consultants Ltd. Brampton ON. 59 p. + App.

McLeod, C.L., P.J. Wiebe, and R.A. Mohr (Renewable Resources Consulting Services Ltd.), 1976. An Examination of aquatic ecosystems in Baker Lake – Lower Thelon River, N.W.T., Area in Relation to Proposed Polar Gas Pipeline Development. 164 p. + App.

McPhail, J.D. and C.C. Lindsey, 1970. Freshwater fishes of northwestern Canada and Alaska. Fisheries Research Board of Canada. Bulletin 173. 381 p.

MMER. 2005. Meadowbank Gold Project Metal Mining Effluent Regulations (MMER) Report. Prepared by Azimuth Consulting Group, Vancouver for Cumberland Resources Ltd. September 2005.

Morin, R. and J.J. Dodson, 1986. The ecology of fishes in James Bay, Hudson Bay and Hudson Strait. p. 293 – 325. *In*: I.P. Martini [ed.]. Canadian Inland Seas. Elsevier Publishers, Netherlands.

No Net Loss (NNL). 2005. Meadowbank Gold Project No Net Loss of Habitat report. Prepared by Azimuth Consulting Group, Vancouver for Cumberland Resources Ltd. September 2005.

Moshenko, R.W., 1980. Biological data on the major fish species from fifty-nine inland lakes in the Northwest Territories, 1959-1968. Fisheries & Marine Service Data Report No. 175. v + 59 p.

Patalas, K. J. Patalas and A. Salki, 1994. Planktonic crustaceans in lakes of Canada (Distribution of species, bibliography). Canadian Technical Report of Fisheries and Aquatic Sciences. No. 1954. v + 218 p.

Patrick, R. and C.W. Reimer, 1966. The diatoms of the United States, 1. Academy of Natural Sciences Monograph No. 13. 688 p.

Prescott, G.W., 1962. Algae of the Western Great Lakes Area. Wm. C. Brown Company Publishers. U.S. 977 p.

PSEP, 1997. Recommended guidelines for sampling marine sediment, water column and tissue in Puget Sound. Puget Sound Estuary Program. U.S. Environmental Protection Agency, Seattle WA and Puget Sound Water Quality Authority, Olympia WA. April 51 p.

Rescan, 1994. NWT Diamonds Project Environmental Impact Assessment. A report prepared for BHP Environmental. Chapter 3.1, Aquatic Life; p 3.3 – 3.143.

Richardson, E.S., J.D. Reist and C.K. Minns. 2002. Life history characteristics of freshwater fishes occurring in the Northwest Territories and Nunavut, with major emphasis on lake habitat requirements. Can. Man. Rep. Fish. Aquat. Sci. 2569.

Roberge, M.M., J.B. Dunn, M.R. Falk, 1990. Catch, effort and biological data of fish, in particular lake trout (*Salvelinus namaycush*), from Prelude and Prosperous lakes, Northwest Territories, 1973 and 1979. Canadian Data Report Fisheries and Aquatic Sciences. No. 817: v + 52 p.

Schneider-Vieira, F., R.F. Baker and M.J. Lawrence, 1993. The estuaries of Hudson Bay: A case study of the physical, chemical and biological characteristics of selected sites. A report prepared for the Hudson Bay Program, Ottawa, by North/South Consultants Inc., Winnipeg MB.

Scott, W.B. and E.J. Crossman, 1979. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada. 966 p.

Scott, D.P. and F.A.J. Armstrong, 1972. Mercury concentration in relation to size in several species of freshwater fishes from Manitoba and northwestern Ontario. Journal of the Fisheries Research Board of Canada. 29: 1685 – 1690.

Somers, K.M. and D.A. Jackson, 1993. Adjusting mercury concentration for fish size covariation: a multivariate alternative to bivariate regression. Canadian Journal of Fisheries and Aquatic Sciences. 50: 2388 – 2396.

Tahera Corporation, 2003 (January). Jericho Project Final Environmental Impact Statement. Chapter 3.2 – 3.2: p 16 – 21.

[Urangesellschaft] Urangesellschaft Canada Ltd., 1981 (February). Environmental Studies Report – 1980 (Baker Lake Region). Prepared by Urangesellschaft Canada Ltd. Toronto, ON.

US Environmental Protection Agency (US EPA), 1996. Method 1669 – Method for sampling ambient water for determination of metals at EPA ambient criteria levels. Office of Science and Technology, Engineering and Analysis Division, Washington DC.

Uttatauaq, Marcel (personal communication), July 1998. Baker Lake, Nunavut.

Vincent, W.F., 2000. Cyanobacterial dominance in the polar Regions. *In* Whithon B. and M. Potts. Ecology of the Cyanobacteria: their diversity in space and time. Dordrecht: Kluwer Academic Press. p. 321 – 340.

Vollenweider, R.A., 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Tech. Rep. Organization for Economic Cooperation and Development, Paris 27: 1 – 182.

Welch, H.E, J.A. Legault, and H. Kling, 1989. Phytoplankton, nutrients, and primary production in fertilized and natural lakes at Saqvaqjuac, N.W.T. Canadian Journal of Fisheries and Aquatic Sciences 46: 90 – 107.

Wetzel, R.G., 1983. Limnology. W.B. Saunders Co. Toronto. 743 p.

APPENDIX A

Glossary

GLOSSARY

Aquatic – Pertaining to plants or animals that live in freshwater or marine environments.

Arctic **–** The Arctic is a geographic region that is circumpolar in extent, and generally characterized as being north of the treeline, in an area of continuous permafrost.

Anadromous fish – Fish that spend at least part of their adult lives feeding in marine water and making annual or semi-annual migrations into freshwater lakes to over-winter and reproduce.

Baseline studies – Initial scientific investigations that determine the present condition of an area to establish a basic reference for future studies.

Benthic – Pertaining to the bottom region of a water body, such as a lake.

Benthic invertebrates / Benthos – Assemblage of organisms living in or on the bottom sediment of a water body and dependent upon the decomposition cycle for most, if not all, of their food supply.

Biodiversity – An expression that describes the relative variety of organisms or species that exist within an ecosystem, on a local, regional, or global scale.

Biomass – The total mass of living organisms usually expressed as a weight per unit area or volume (e.g., mg/m^3 of water).

Bivalves – Mollusks with shells consisting of two halves (i.e., valves) such as clams.

Carnivore – An animal that acquires all of its food by feeding on other animals, not on plants.

Chironomids – Midges (two-winged insects) in the order Diptera. The aquatic larval form of this insect is typically the most abundant and diverse group of insects found in lakes.

Density of organisms – A term that describes abundance. The total number of living organisms expressed per unit area (e.g., $\#/m^2$) or volume ($\#/m^3$).

Detritus – Unconsolidated material composed of both inorganic and dead and decaying organic material.

Dissolved concentrations (water) – The concentration of chemical parameters in water filtered through a 0.45 µm glass fibre filter. This is operationally defined as the dissolved fraction in water.

Dipteran insects – Insects of the order Diptera, consisting of flies having two-wings that includes chironomids, flies, and mosquitoes.

Diversity – A measure (e.g., Shannon-Weaver index) of the variety of living organisms in an area (e.g., number or richness of species).

Drainage basin – The term given to a geographic area that contributes surface and groundwater to a particular lake, river, or stream (also see watershed).

Ecosystem – A community of interacting organisms considered together with the chemical and physical factors that make up their environment.

Effect – A change to an ecosystem component due to human activities. The effect may have a negative, positive, or neutral impact.

Environment – Components of the earth including land, water, air, and all layers of the atmosphere. Also included are organic and inorganic matter, living organisms, and all interacting natural systems.

Epibenthic – Benthic animals that live on, or just above, the bottom sediment.

Eutrophic – Nutrient-rich waters with high primary productivity.

Food chain – Organisms that are linked together in a series that, by consuming lower level organisms, transfer nutrients and energy from one group to another.

Food web – The concept used to describe the relationships of organisms within an ecosystem that are interconnected through various feeding linkages, resulting in the transfer of nutrients and energy.

Freshet – The increased flow of water over a relatively short period of time, usually during spring, caused by snowmelt.

Geographic Information System (GIS) – A mapping tool that is used to depict large amounts of information in a spatial context.

Global Positioning System (GPS) – A sophisticated system used to define a precise geographic location with the aid of a satellite system. Units are typically expressed as UTM (Universal Transverse Mercator) or in latitude and longitude.

Groundwater – Water found in soil, or in pores and crevices under the ground.

Habitat – Any area that provides food, water, and/or shelter for an organism.

Herbivore – An animal that feeds exclusively on plant matter and not on animal matter.

Hydrology – The study of the properties of water and its movements in relation to land.

Impact – An effect, either positive or negative, of an activity or process on ecological components of a receiving environment.

Invertebrates – A collective term for all animals without a backbone or spinal column and includes all aquatic animal organisms except fish.

Larva – The immature stage between egg and pupa of an insect with complete metamorphosis. Many insect larvae are (plural term) aquatic, including chironomids, mayflies, stoneflies, and caddisflies.

Limnology – The study of freshwater lakes including biological, geological, physical, and chemical aspects.

Littoral – The region of a lake, including water and sediment, from the surface to a depth at which photosynthesis ceases, usually within the upper 10 m of the water column.

Meadowbank Project Area lakes – Those lakes that are potentially directly or indirectly affected by mine development, including Third Portage, Second Portage, Turn, Tehek, and the Vault lakes.

Mesotrophic – Waters with moderate nutrient concentration and primary productivity.

Micro (µ) – A unit of measurement denoting a factor of one-millionth, such as µg/g.

Milligram (mg) – A unit of measurement denoting a factor of one-thousandth, such as mg/g.

Mitigation – An activity aimed at avoiding, controlling, or reducing the severity or duration of adverse physical, biological, and/or socioeconomic impacts of a project activity.

Monomictic lakes – A lake that undergoes continual vertical mixing of the water column and does not stratify.

Nitrogen fixation – A term ascribed to plants (e.g., periphyton) that are able to convert gaseous nitrogen (N_2) to ammonia (NH_3) for use in the manufacture of amino acids, proteins, and vitamins. Bacteria and blue-green algae accomplish this process. The organelle capable of this is called a heterocyst.

Nutrient – Any substance that provides essential nourishment for the maintenance of life (e.g., carbon, nitrogen, and phosphorous).

Nutrient enrichment – The enhancement of nutrients in a water body over and above the concentration that would be considered typical for the region.

Oligochaetes – True worms from the Phylum Annelida (segmented worms) that are common in sediment of freshwater habitats.

Oligotrophic – Nutrient deficient waters with low productivity. The vast majority of Arctic lakes are oligotrophic.

Organic Carbon (sediments) – The non-mineral fraction of the sediments that consists of organic carbon, expressed as a percent (%) of the total weight of sediment. This includes all forms of carbon except carbonates.

Otolith – A small bone in the ear canal of a fish that is used by the fish for equilibrium, and may be used for aging of fish by sectioning.

Periphyton – The collective name given to the community of algae that exists attached to underwater surfaces, such as rocks, in lakes, and streams.

Permafrost – Subsoil that has been frozen for at least two years.

Photosynthesis – The process by which the energy of sunlight is captured by organisms, especially green plants, and used to manufacture organic tissue by combining the energy with carbon dioxide and water.

Phytoplankton – Microscopic or small floating plants suspended in the water column of aquatic ecosystems.

Planktonic – Referring to organisms with limited mobility that are free-floating and living in the water column.

Piscivore – Any animal that feeds on fish (e.g., lake trout).

Predator – Any organism that consumes another organism.

Prey – Any organism that is consumed by another organism.

Primary consumers – Organisms such as zooplankton that feed on primary producers (e.g., phytoplankton) for their source of nutrients and energy.

Primary production – Production by photosynthetic organisms such as algae, phytoplankton, and periphyton. Photosynthetic organisms compose the bottom of the food chain.

Primary productivity – A term given to the rate at which new biomass (i.e., plant tissue) is generated by photosynthetic organisms (i.e., plants) using energy captured from the sun.

Probable Effect Level [PEL] – Reference concentrations of contaminants in sediments that, if exceeded, indicates that organism-level effects are likely to occur.

Quality Assurance / Quality Control [QA/QC] – Sampling and analytical procedures (such as lab replicate sample analysis) that are integrated into field collection and analytical procedures to ensure acceptable data quality.

Residual effects – Effects that persist after mitigation measures have been applied.

Reference lakes – Lakes that are used as controls for comparison to project lakes and include an internal reference lake (Third Portage Lake south basin) and an external reference lake (Inuggugayualik Lake).

Richness – The number of unique taxa (e.g., species) found at a particular location.

Secondary productivity – The rate of increase in biomass of organisms that consume plants or other primary producers.

Secondary consumer – Organisms such as forage fish that consume primary consumers (e.g., zooplankton) for their source of nutrients and energy.

Sediment grain size – Refers to the size and relative size distribution of the particles that make up the sediment. Typically they are divided into four groups including clay, silt, sand, and gravel.

Sediment Quality Guidelines (Interim) [ISQG] – Reference concentrations of contaminants in sediments that, if exceeded, indicates that organism-level effects may occur.

Stratification – Vertical differences in water temperature, causing a density difference between warm, less dense surface water, and cold, more dense bottom water, retarding or preventing mixing of surface and bottom water.

Total metals concentrations (water) – The total concentration of a metal in the water, which includes both freely dissolved and particle-bound forms of the metal.

Total Suspended Solids (TSS) – The weight of solids that are suspended in a given volume of water, expressed as weight per unit volume (e.g., mg/L).

Trophic Levels – A functional classification of organisms in an ecosystem according to feeding relationships, from primary producers through primary consumers through secondary consumers.

Tundra – Habitat typically found in the Arctic north of the treeline that is adapted to cold temperatures, a short growing season, and low precipitation. Typical tundra vegetation includes moss, lichen, Labrador tea, and small shrubs.

Turbidity – A condition of reduced transparency in water caused by suspended colloidal or particulate material; measured by a turbidimeter and recorded as nephelometric turbidity units (NTU).

Ultra-oligotrophic – Lakes with extremely low nutrient levels, high water clarity, low primary productivity, and a dominance of small unicellular phytoplankton species. Total phosphorous concentrations are typically <0.005 µg/L in these lakes (Vollenweider, 1968).

WAD – Weak acid digestible (e.g., cyanide). WAD cyanide is the form of cyanide that is most easily broken down to become free cyanide, which is toxic to aquatic biota.

Watershed – An entire geographic area that contributes-surface-and groundwater to a particular lake, river, or stream.

Water Quality Guidelines – Reference concentrations of contaminants in water that, if exceeded, indicate that organism-level effects may occur.

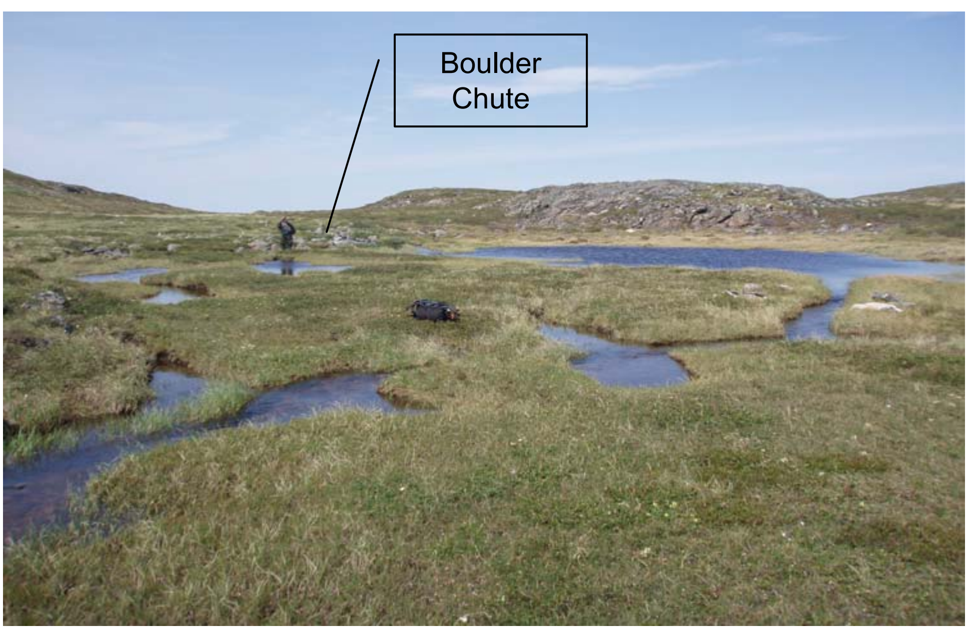
Zooplankton – Small, floating or weakly swimming animals found in fresh and marine waters, such as copepods and cladocerans.

APPENDIX B

Photographic Library of Project Lake Channel Connections, 2005

Appendix B: C01 Photographs

July 14/05 C01Braided channels near proposed crossing



July 14/05 C01 Pools downstream of boulder chute.

Appendix B: Bridge 01 Photographs

June 4/05 Downstream of proposed Bridge 01 crossing

June 30/05 B01, View from hill on south side of watercourse, hoopnets visible beyond exposed granite

Appendix B: Bridge 01 Photographs

June 30/05 Hoop net collection at Bridge 01

August 14/05 Hoopnets at Bridge 01

Appendix B: Bridge 01 Photographs

June 30/05 Fish data compilation at Bridge 01. Hoopnets in background.

August 10/05: Round whitefish collected at Bridge 01

Appendix B: C03 & C04 Photographs

June 30/05 C03 crossing. Imperceptible flow in wetland depression

June 30/05 C04 small ephemeral stream in wetland depression

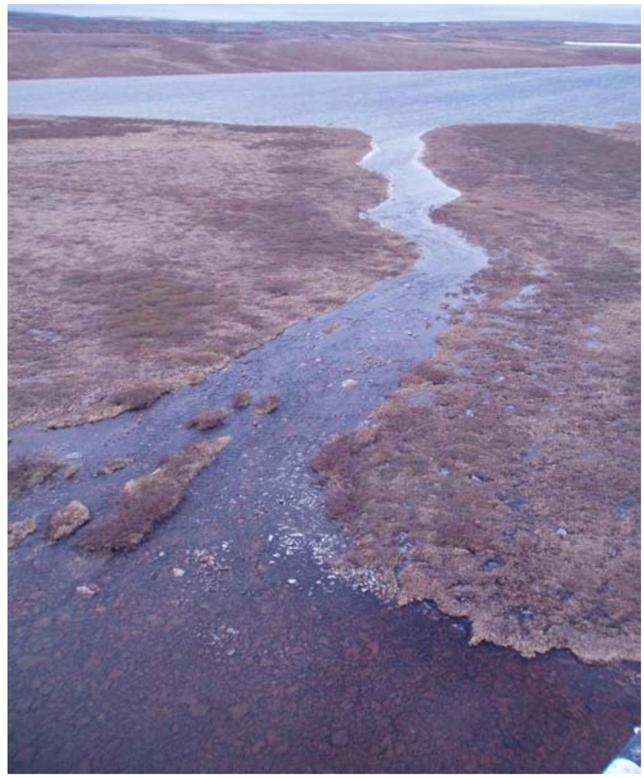
Appendix B: C05A Photographs

July 7/05 C05A Braided channels in wetland depression

Aug 22/05 C05A aerial. Standing pools and braided channels

Appendix B: Crossing 05 Photographs

June 28/05 Aerial photograph of Crossing 05



June 28/05 Habitat assessment and evaluation at C05

Appendix B: Crossing 05 Photographs

August 14/05 Hoopnet location at Crossing 05

August 10/05 Sample of Arctic grayling collected at Crossing 05

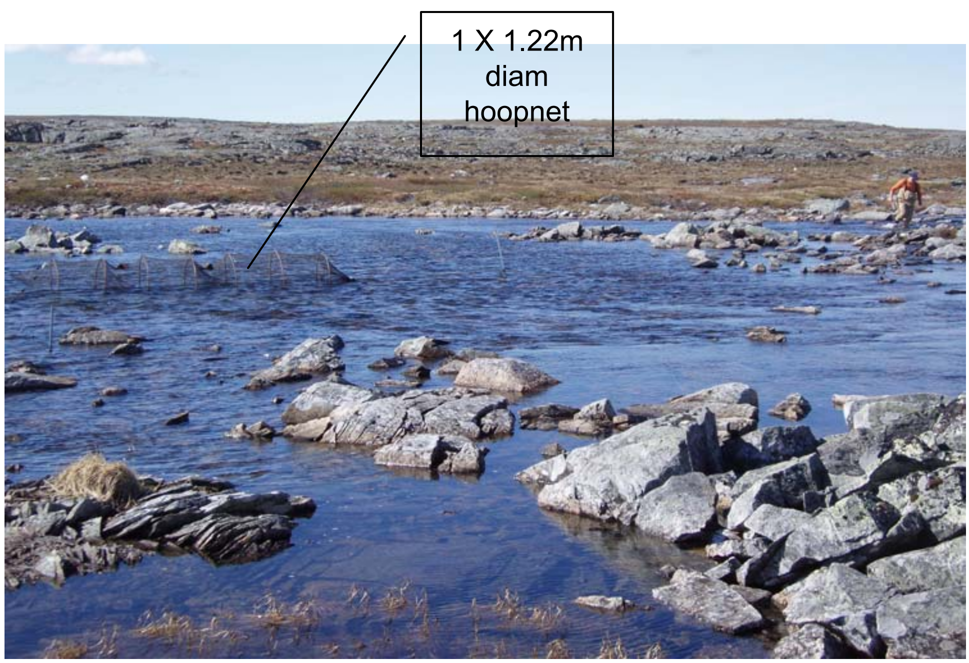
Appendix B: Bridge 02 Photographs

June 4/05 B02 Early spring aerial photograph

June 28/05 Late spring early summer aerial photograph of B02

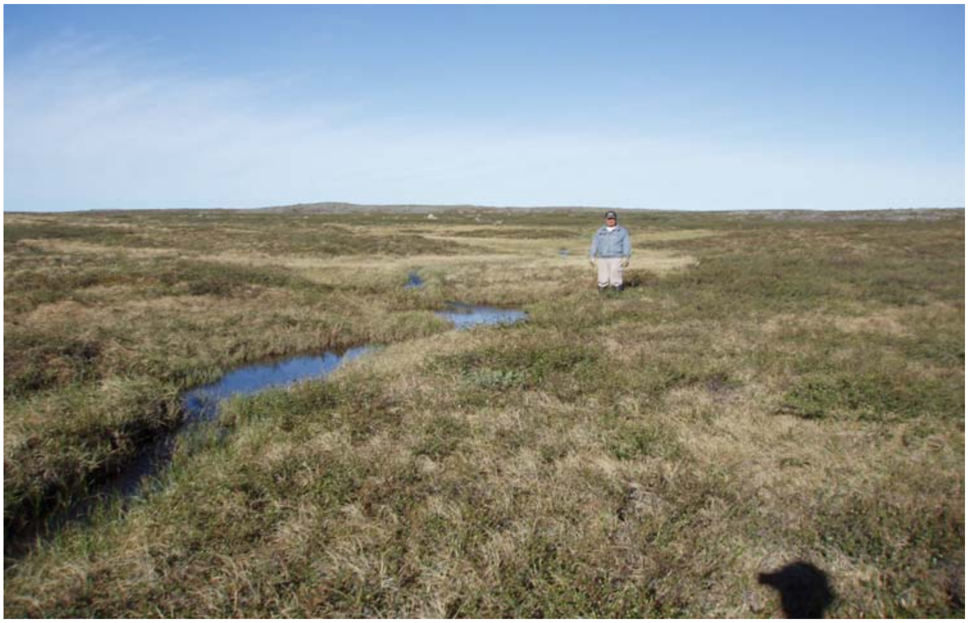
Appendix B: Bridge 02 Photographs

July 9/05 B02 View from hill on north side of watercourse, hoopnets visible east of cobble/ boulder in-stream ledge



June 30/05 Drift Trap collection. Hoopnets set to collect fish moving upstream at Bridge 02

Appendix B: C07 & C07A Photographs



July 7/05 Small emergent channel at C07

July 7/05 Standing pools east of proposed crossing C07A. ATV throughway in background

Appendix B: C08 Photographs

June 28/05 Aerial of C08, small ephemeral stream winding around gravel deposit.

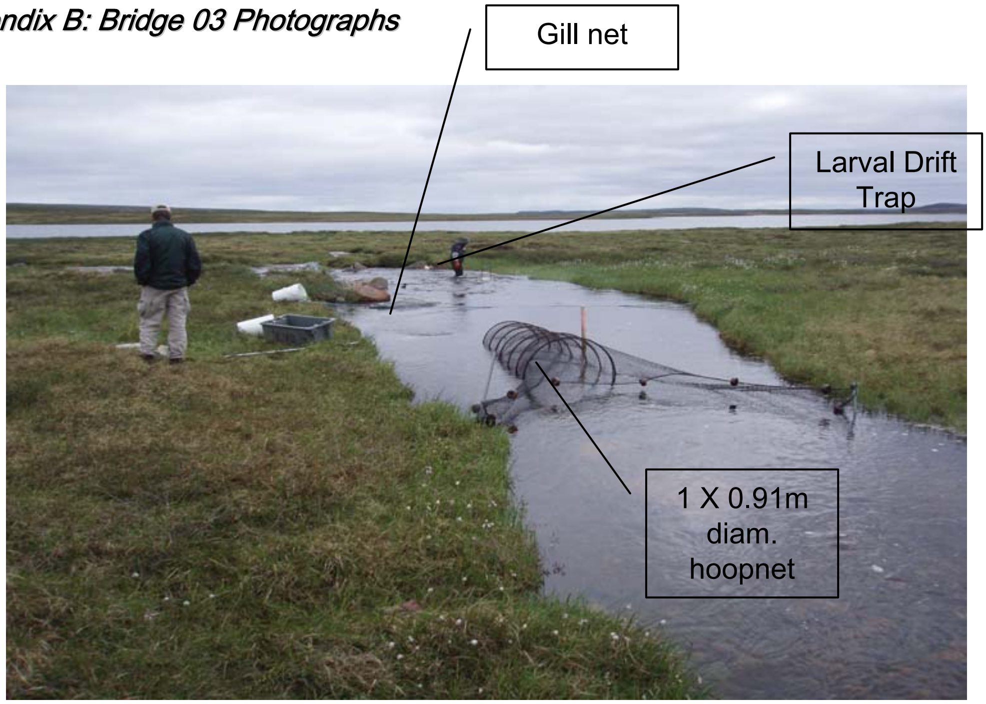
July 7/05 Overview of C08 to the south from adjacent hill

Appendix B: Bridge 03 Photographs

June 4/05 Bridge 03 in early spring during ice break

June 29/05 B03, photograph taken during habitat evaluation, immediately prior to setting hoopnets

Appendix B: Bridge 03 Photographs



July 17/05 B03 hoopnet extending 100% of the stream width to collect fish migrating downstream. Larval drift trap collection and gill net set to collect trapped fish migrating upstream.

July 12/05 43 cm ripe female arctic char collected at B03

Appendix B: C10 Photographs

June 28/05 Aerial photograph of C10 downstream of boulder barrier.

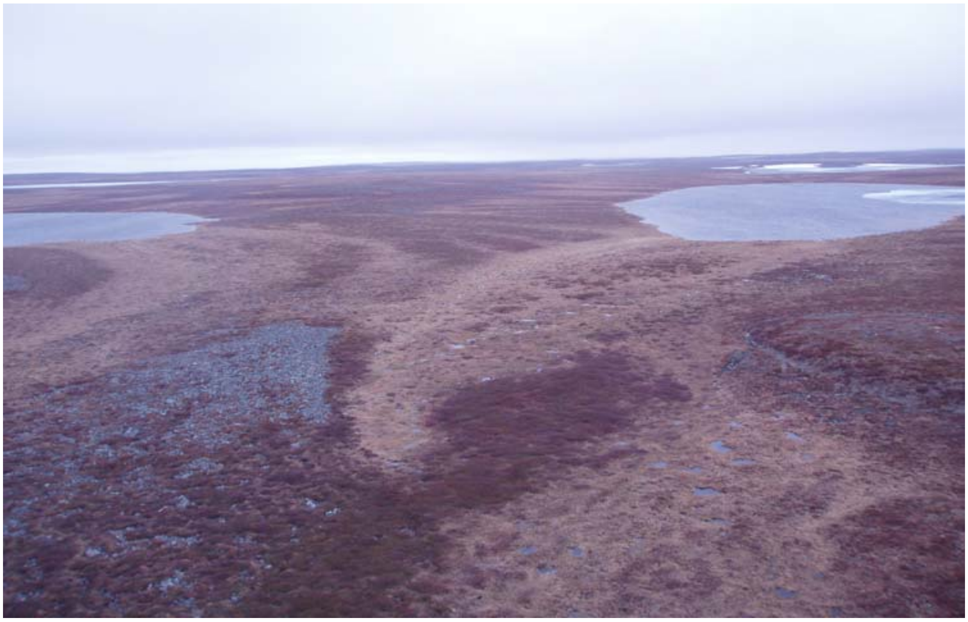
July 3/05 C10 Small riffle downstream of boulder barrier (background)

Appendix B: C11 Photographs

July 3/05 C11 Braided central channel near headwater.

July 3/05 Ninespine stickleback habitat at C11

Appendix B: C12 Photographs



June 28/05 Aerial photograph of C12

July 3/05 C12 Standing pools in wetland depression

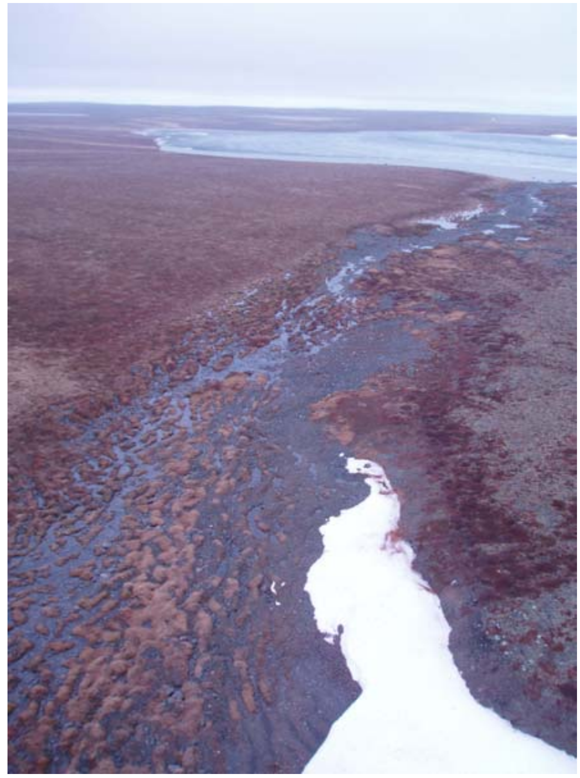
Appendix B: C13 Photographs

August 22/05 Small grassy central channel at C13

July3/05 Pool at C13 inhabited by ninespine stickleback

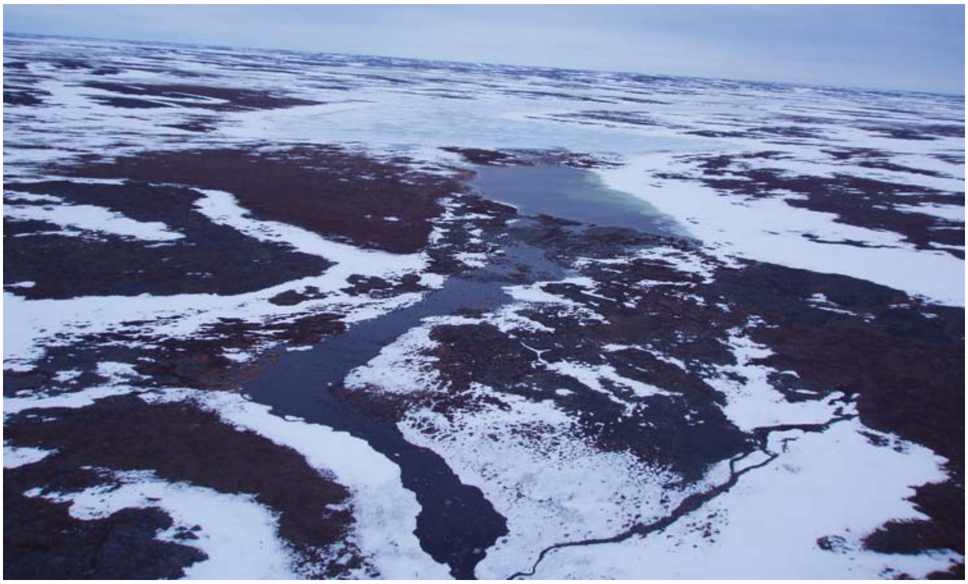
Appendix B: C14 Photographs

June 28/05 Aerial photograph of C14



August 8/05 C14 Below surface flow reemerging in cobble and boulder field.

Appendix B: B04 Photographs



June 4/05 Aerial photograph of B04 in early spring

June 28/05 Aerial photograph of B04 in late spring.

Appendix B: B04 Photographs

June 4/05 Early spring photograph at proposed crossing B04
during ice-break

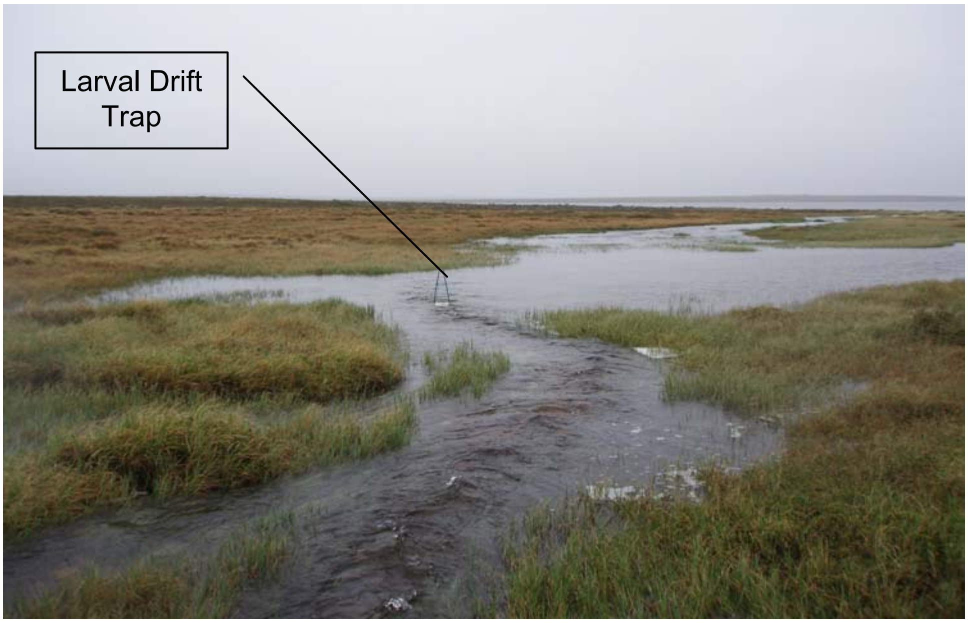
July 4/05 Hoopnet and larval drift trap set at B04.

Appendix B: B04 Photographs

June 30/05 View from hill on south side of watercourse, hoopnets visible beyond exposed granite

August 8/05 Outflow boulder barrier at B04

Appendix B: C16 Photographs



July 10/05 Drift trap set in riffle area up-stream of pool at R16

July 10/05 Riffle portion upstream of larval drift trap at R16

Appendix B: C17 & C18 Photographs

July 1/05 C17 Standing pools in grassy wetland

July 1/05 C18 Boulder field with imperceptible flow between boulder hummocks

Appendix B: C18A & C19A Photographs

July 1/05 C18A channel downstream of boulder shoot

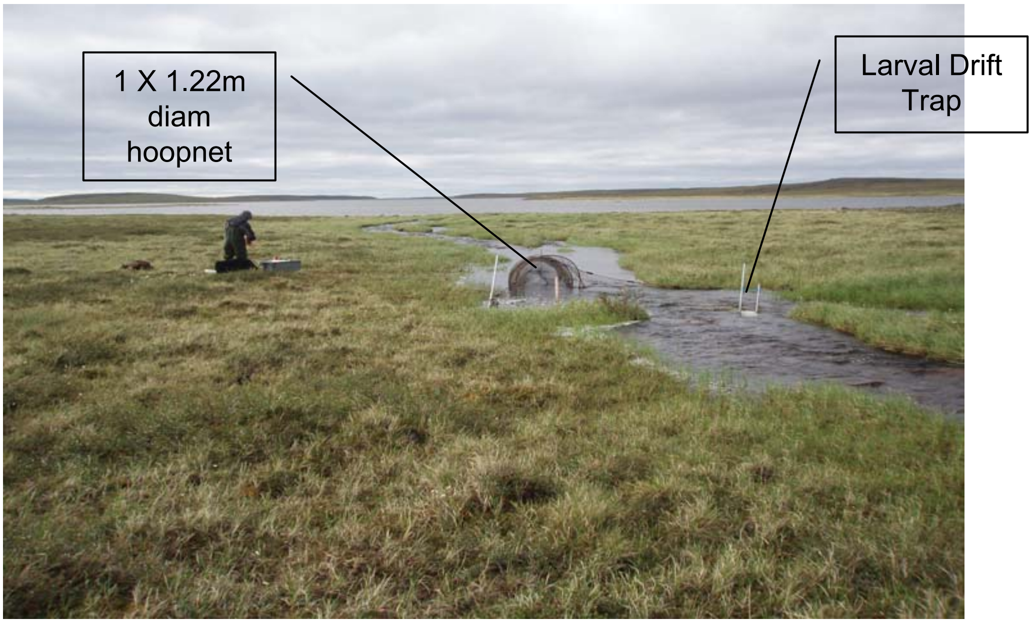
July 19/05 C19A Diffuse wetland channel colllecting regional melt and runoff from rain events

Appendix B: B05 Photographs

June 4/05 Early Spring photograph at B05. Note: wetted width in comparison to aerial photograph below.

June 28/05 Aerial photograph of B05

Appendix B: B05 Photographs



July 17/05 Hoopnet collecting fish migrating downstream and drift trap in foreground at B05

August 7/05 Hoopnet set in summer/fall field program at Bridge 05

Appendix B: C20 & C20A Photographs

July 1/05 C20 boulder barrier and side channel.

July 5/05 Boulder field with imperceptible flow between boulders

Appendix B: C21 & C22 Photographs

July 1/05 Boulderfield at C21.

July 1/05 Vegetated depression at C22

Appendix B: C23 & C24 Photographs

July 1/05 Downstream braided channel at C23

July 1/05, C24 boulderfield. TPL in background

Appendix B: C25 Photographs

July 4/05 C25 small ravine type stream. Upland from outflow into TPL