Chapter 4. Freshwater resources in a changing environment

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Abstract

Northern lakes, rivers and wetlands provide many ecosystem services including drinking water supplies for northern residents, habitats for Arctic charr and other aquatic wildlife, and water for industries such as hydroelectric power generation, recreational fishing, eco-tourism and mining. Nunavik and Nunatsiavut have a rich natural heritage of freshwater ecosystems ranging from shallow permafrost thaw ponds, which are expanding in size and abundance at some sites, to wild rivers and deep ancient lakes of outstanding scenic, cultural and ecological value. The impacts of climate change and economic development on the water quality and supply for these vital aquatic resources have been viewed with increasing concern by Inuit communities. The creation of northern parks provides an effective way to protect many of these environments in the face of climate change and rapid development of the North, as well as a way to stimulate eco-tourism and associated economic activity. A variety of drinking water problems, including those associated with the storage and use of untreated water, have been identified throughout Nunavik, and a set of recommendations are outlined to reduce these problems. The effects of local pollution, as well as the continuing rise in certain long range contaminants such as mercury require continuing surveillance. Two of the largest underground power stations in the world are located in northern Québec and Labrador, and there is further potential for hydroelectric development. Future projects will require close and timely consultation with all stakeholders, including analysis of the tradeoffs in ecosystem values. Future and current installations require ongoing research to project future water supply in the rapidly changing northern climate, and paleoclimate analyses will continue to help assess the magnitude of natural fluctuations in the past.

4.1 Introduction

Lakes, rivers and wetlands are major ecosystem features of the circumpolar Arctic. These vital resources provide many essential services including drinking water supplies for northern residents, habitats for Arctic charr (see Chapter 7) and other aquatic wildlife, transport routes by boat in summer and surface vehicles in winter (see Chapter 5, see also Prowse et al. 2011), and water for industries including hydroelectricity, recreational fishing, eco-tourism and mining. Subarctic freshwater ecosystems are intrinsically important as rich sites of biodiversity, and they also provide records of change in the past (e.g., Saulnier-Talbot et al. 2003, Pienitz et al. 2004, Saulnier-Talbot and Pienitz 2009) and present that will help guide environmental monitoring and management. These diverse aquatic resources are vulnerable to ongoing climate change, and changes in water supply and quality are increasingly observed with concern by Inuit and other indigenous peoples (Moquin 2005). This and other climate related issues are of special concern in the eastern Canadian Subarctic where climate warming is now proceeding at unprecedented rates after centuries or longer of prolonged environmental stability (Bhiry et al. 2011).

This chapter first describes the range of aquatic resources of Nunavik and Nunatsiavut, and their potential ecological responses to climate change. We then briefly summarize the work to date on contaminants in snowpack and freshwaters of this region, and examine specific issues concerning protected aquatic environments in parks, drinking water supplies, mining needs, and hydroelectric resources. We end this chapter with general conclusions and recommendations for the future.

4.2 Climate impacts on northern freshwater ecosystems

The effect of ongoing climate change on lakes and reservoirs has been identified as one of the most serious issues facing human society throughout the world, and northern lake and river ecosystems may be especially prone to alteration given the greater magnitude of climate change at higher latitudes (ACIA 2005). The projected changes in regional water balance will alter the capacity of lakes and rivers to provide ecosystem goods and services such as inland fisheries and adequate supplies of safe drinking water, and result in modified discharge and erosion in rivers. The ongoing warming trend will affect the physical, chemical and biological properties of freshwater ecosystems (Figure 1), with implications for water quality; for example, through the likely increased abundance of noxious cyanobacteria, and for wildlife habitats; for example, through changes in runoff, productivity, oxygen and thermal regimes.

At the most basic physiological level, changes in water temperature and ice cover will affect the metabolic rates and life cycle of aquatic organisms, and for some species

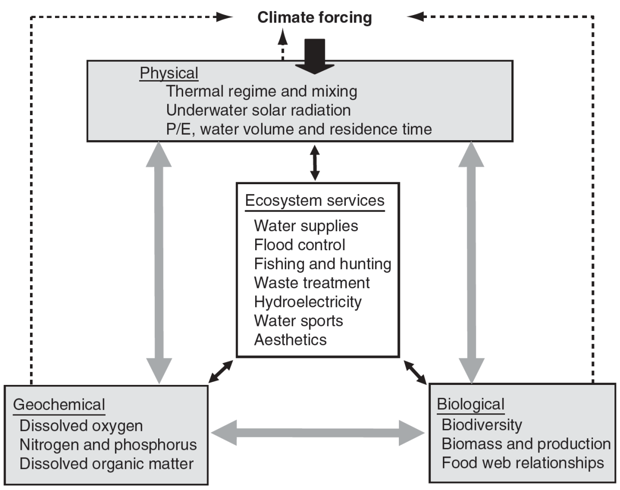


Figure 1. *Changes in climate affect the physical environment of lake and river ecosystems and thereby alter their chemical and biological properties. These changes modify the capacity of freshwaters to provide ecosystem services. P/E refers to the Precipitation to Evaporation ratio. Dotted lines indicate positive feedback effects, e.g., via decreased ice cover or the release of greenhouse gases from lakes and rivers into the atmosphere. From Vincent 2009.*

there may be shifts beyond their critical threshold for survival. Warming may also be accompanied by increased stratification, algal biomass production, and loss of oxygen, to the detriment of many aquatic communities. On the other hand, warmer temperatures will allow some newly invading species to survive and complete their life cycles, although this may come at the expense of any original species that are driven to extinction through predation or competition. In the North, this may result in an increase of biodiversity at a local scale while many native species disappear, causing shifts in biotic interactions, a decline in global biodiversity, and serious impairment of traditional hunting and fishing practices (Vincent et al. 2011). At the broader ecosystem level, climate change will have pervasive effects on the physical structure and connectivity of lake and river ecosystems, and on their food webs, biogeochemical characteristics and overall metabolic properties, including greenhouse gas emissions. This section examines different types of aquatic ecosystems in Nunavik-Nunatsiavut and their potential sensitivity to climate change, with emphasis on thaw lakes because of their significance in greenhouse gas emissions as well as abundant wildlife habitats.

Figure 2. *Examples of thaw lakes in Nunavik. The striking differences in colour are the result of underwater light absorption and scattering by different combinations of coloured dissolved organic matter (CDOM) and soil particles derived from the surrounding landscape. These colour differences can be quantified by radiometric sensors, which may provide a way to estimate ecosystem properties, including greenhouse gas emissions, by satellite remote sensing (details in Watanabe et al. 2011).*

4.2.1 Thaw lakes

Permafrost thaw lakes (thermokarst lakes, see Figure 2) are a key component of many northern landscapes, developing in depressions that result from the thawing of permafrost (Pienitz et al. 2008). They have attracted much attention with the realization that they are not only habitats for aquatic flora and fauna, but also for microbiological life. They act as microbial reaction sites for greenhouse gas production (Walter et al. 2006, Laurion et al. 2010) and have the potential to exert a strongly positive feedback on global climate in the future, as they appear to have done in the past (Walter et al. 2007).

In many parts of the Arctic, the permafrost has begun to warm and the active layer has deepened (see Chapter 6 for description of their geophysical dynamics). However, the extent of these changes is highly variable regionally, with a deepening of the active layer by several metres at some sites and yet no detectable change at others. In parts of Nunavik, thermokarst lakes and wetlands are expanding as a result of permafrost thawing and erosion (e.g., Payette et al. 2006, Vincent et al. 2011), thereby producing more habitats for aquatic birds and other animals as well as greater areas of intense greenhouse gas production. Elsewhere in the circumpolar Arctic, however, the degradation of permafrost is causing a rapid draining of the landscape and loss of aquatic and semi-aquatic ecosystems (e.g., in Siberia, Smith et al. 2005; on Bylot Island, Arctic Canada, Laurion et al. unpublished). Such changes may result in a more homogeneous northern landscape, with reduced habitat and species diversity.

ArcticNet studies on thaw lakes in Nunavik have shown that, despite their shallow depths (typically 1-4 m) and exposure to the wind, they are poorly mixed and have striking gradients in their physical, chemical and biological properties with depth throughout most of the year (Breton et al. 2009, Laurion et al. 2010, see Figure 3). In summer, and probably through much of winter, their bottom waters are depleted in oxygen as a result of the lack of mixing, and these anoxic (devoid of oxygen) conditions favour microbial processes that convert carbon coming in from tundra soils to the powerful greenhouse gas methane, which is ultimately released to the atmosphere by ebullition and other processes (Walter et al. 2006). CO_2 dynamics are influenced by the level of photosynthetic activity, and observations show that thaw lakes colonized by microbial mats and aquatic plants can act as CO_2 sinks, at least during summer, however they all represent methane sources (Laurion et al. 2010).

Globally significant quantities of organic matter are stored in frozen northern soils (Tarnocai et al. 2009). Some of this tundra carbon is released into lakes, rivers and coastal seas as a result of thawing and erosion, and may be converted to CO_2 and methane by aquatic microbial processes

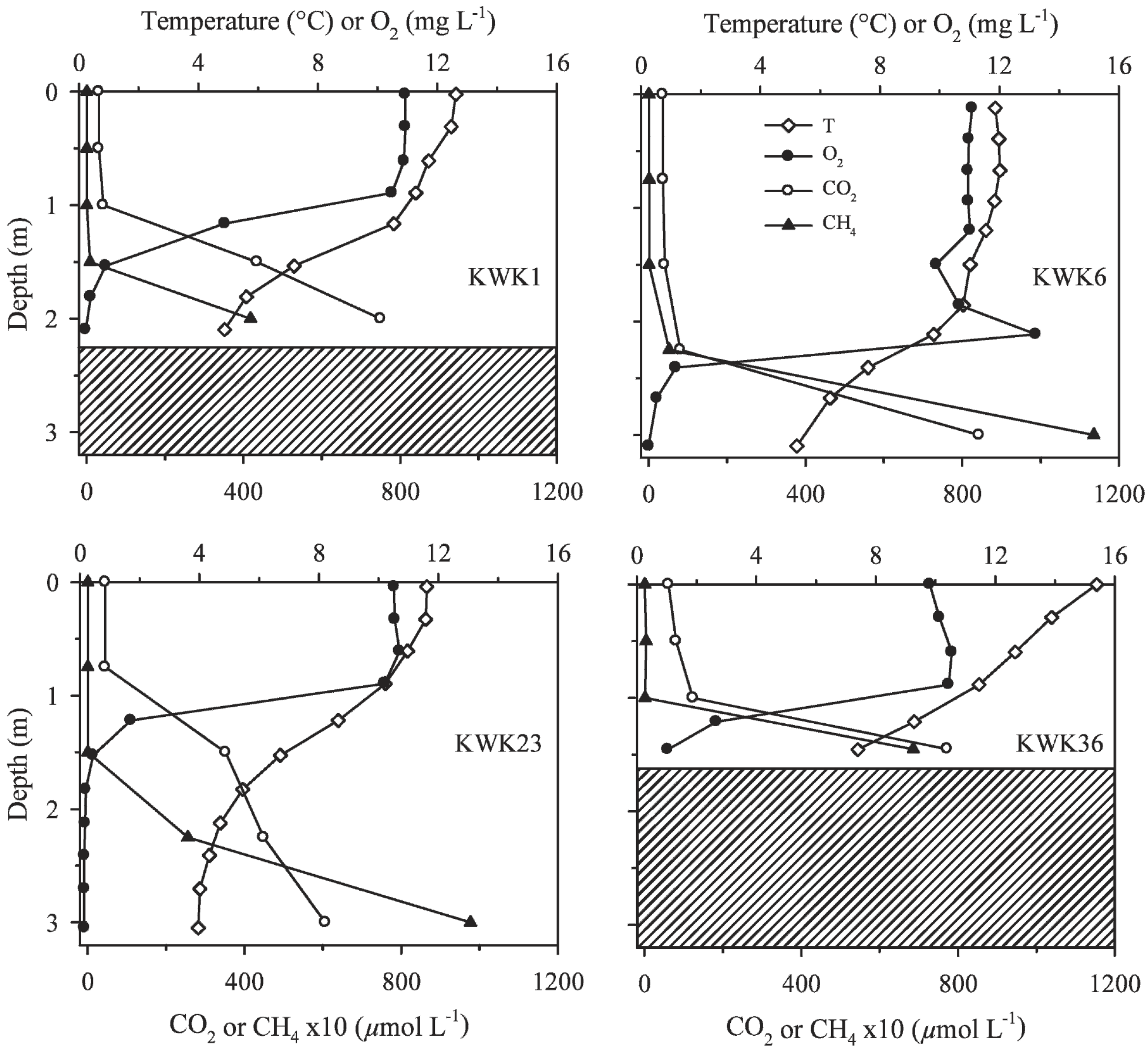


Figure 3. *Profiles for thaw lakes near Kuujjuarapik showing their strong stratification and high concentrations of greenhouse gases. From Laurion et al. 2010.*

(Schuur et al. 2008). There are large temporal variations in thaw lake gas emissions, indicating the need for a better understanding of diurnal and seasonal changes in carbon fluxes, as well as the influence of physical processes on air-water exchanges. One of the main questions is the relative importance of old organic carbon stocks released from melting ice in peat as carbon sources for aquatic microbial processes, as compared to the newly fixed carbon in plants and algae, which is also likely to be increasing with climate warming. There is also considerable spatial variability in greenhouse gas emissions, with large differences between even nearby water bodies (Laurion et al. 2010). Promising satellite remote sensing methods have been developed in Nunavik that may help scale up local estimates to the landscape level (Watanabe et al. 2011). Understanding these biogeochemical processes and their spatial and temporal variability will be essential steps towards assessing the magnitude of positive feedback from these thaw lakes on the global carbon cycle and climate system.

4.2.2 Other shallow water lakes

The Subarctic region also contains many shallow lakes and ponds in rock basins that have been carved by glacial activity. Studies on these water bodies have shown that they are often rich in zooplankton (Swadling et al. 2001, Rautio and Vincent 2006, Rautio et al. 2011), with benthic algae and plants that favour other aquatic life including insects, ducks, loons and geese. Changes in the precipitation-evaporation balance associated with climate change could result in higher evaporation leading to dryness and the loss of some of these habitats, as has been observed in Nunavut (Smol and Douglas 2007, Vincent et al. 2009).

4.2.3 Deep lakes

Subarctic Québec and Labrador contain many large (>100 km^2), deep lakes. The ecology of these freshwater ecosystems has been little explored to date, however they are important sites for northern outfitter operations and recreational fishing. Of particular interest are the deep lakes derived from meteoritic impact events. Two such lakes have attracted particular attention in Nunavik: Pingualuit Crater Lake, and Lac à l'Eau-Claire (Clearwater Lake – Box 1). The former contains an isolated population of Arctic charr (*Salvelinus alpinus*) that has attracted scientific interest for its survival strategies and low contaminant levels (Delisle and Roy 1989, Gantner et al. 2012) in one of the world's most dilute and transparent freshwater ecosystems, while the latter has been the site of detailed studies on periphyton (Maltais and Vincent 1997), phytoplankton production (Milot-Roy and Vincent 1994) and UV radiation effects (Laurion et al. 1997, Laurion and Vincent 1998). As in deep clear lakes elsewhere, the plankton is dominated by extremely small species, with most of the phytoplankton biomass in the size fraction less than 2 µm. The cold stratification regime of these deep lakes allows frequent mixing, however this could change in the future with increased warming and a shorter duration of ice cover, which in turn may influence plankton growth and fish habitats.

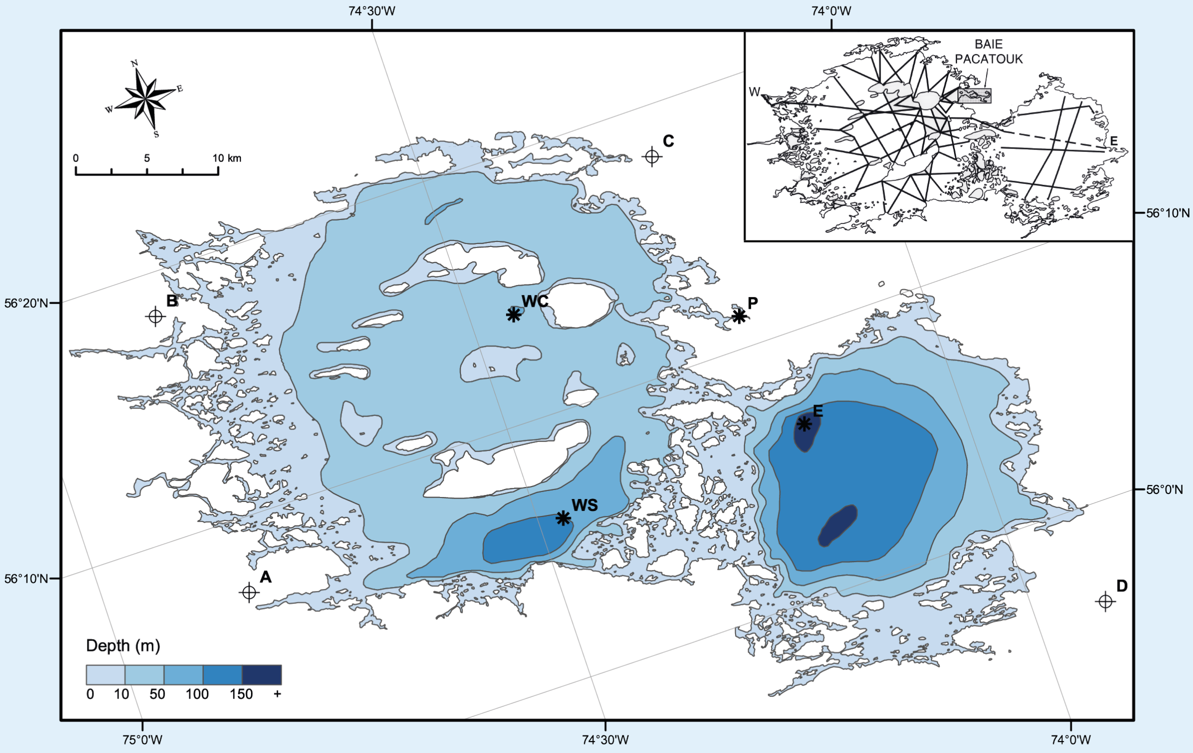
4.2.4 Rivers, streams and wetlands

Flowing water ecosystems are a critically important part of the freshwater resources of the Subarctic (Woo and Young 2010 and references therein). Apart from providing transport routes for northern communities, they are habitats for key wildlife species (notably Arctic charr), they discharge water, nutrients and organic carbon into the sea, thereby supporting the coastal marine ecosystem, and they are resources for drinking water supplies, hydroelectricity, mining and other industrial needs.

Accelerated thawing of permafrost may release increasing amounts of organic matter, gases, inorganic solutes and microbiota into rivers and the coastal ocean. Organic-rich particles that are transferred by erosion from the permafrost into rivers provide substrates for microbial communities, specifically *Bacteria* and *Archaea* (Garneau et al. 2008). Climate effects on these organisms combined with increased light limitation of phytoplankton may drive Arctic rivers and estuaries towards even greater heterotrophy

BOX 1. Lac à l'Eau-Claire (Clearwater Lake), Nunavik.

Clearwater Lake and its vast watershed lie within the proposed Tursujuq National Park, and will thereby benefit from long term environmental protection. The unique shape of the lake is the result of a double meteoritic impact crater that was formed 285 to 300 million years before the present (Plante 1990). The lake has a total estimated area of 1239 km^2, a maximum depth of 136 m (western basin) and 178 m (eastern basin), an average depth of 37 m and an estimated hydraulic residence time (the time an average drop of water resides in the lake) of 14 years (Arsenault 1993, Milot-Roy and Vincent 1993). The cold, transparent waters of the lake are oligotrophic (low nutrients and algal concentrations), and the lake supports a renowned traditional and recreational fishery for lake and brook trout.



This bathymetric map was derived from a total of 335 km of profiling transects across the lake (top right insert) using a Furono BG-11 MARK 3 echo-sounder at a boat speed of 10 km h^{-1}, combined with additional transect data from Plante (1986). The asterisks mark the water column sampling stations as in Milot-Roy and Vincent (1993): WC, western basin central; WS, western basin south; P: Baie Pacatouk; E: eastern basin. A, B, C, and D are georeference sites; details in Arsenault (1993).

and net CO_2 efflux in the future (Vallières et al. 2008). In the boreal forest region, streams represent only 1% of the total freshwater area, but are disproportionately important as CO_2 emitters (25% of total aquatic carbon emissions), with gas efflux rates rising with increasing Dissolved Organic Carbon (DOC) concentrations (Teodoru et al. 2009). Further to the south, in the USA, changes in precipitation have recently been identified as a controlling factor for river CO_2 emissions (Butman and Raymond 2011), and this will require further attention in the North.

High latitude wetlands are important sites for plant biodiversity and wildlife, and are vulnerable to changes in precipitation, evaporation and lateral flow (Wolf et al. 2011). In the Arctic, late-lying snow banks are an important source of water for wetlands (Woo and Young 2003), which are therefore sensitive to the ongoing trend of decreasing duration of snow cover (Vincent et al. 2011). Wetlands are also biogeochemically active “hotspots” for carbon and nitrogen metabolism, and climate change will affect their exchanges with the atmosphere. Boreal wetlands are significant greenhouse gas (GHG) emitters, with evidence that the smaller and shallower pools (ombrotrophic raised bogs) have larger CO_2 and CH_4 emissions (McEnroe et al. 2009), and that winter contributes significantly to the annual CH_4 fluxes from this type of system (Pelletier et al. 2007). In Subarctic Sweden, recent changes in permafrost and vegetation have been shown to be responsible for 22-66% increases in CH_4 emissions between 1970 and 2000 (Christensen et al. 2004). A larger study covering wetland sites in Greenland, Iceland, Scandinavia and Siberia showed that temperature and the organic carbon substrates for the microbiota explained almost 100% of the variation in mean annual CH_4 emission (Christensen et al. 2003).

4.3 Protected environments – Parks

Conservation is emerging as a major priority for the North in the face of climate change, with the recognition that because high latitude ecosystems have less biodiversity, and therefore less functional redundancy, they are inherently more sensitive to perturbation (Post et al. 2009). The new parks created in Nunavik and Nunatsiavut with their protected areas are therefore timely and extremely valuable investments for the future sustainable development and preservation of the northern landscapes. Lakes, rivers and wetlands are key elements of the natural heritage of these two territories, and the parks contain some excellent examples for protection. In Nunatsiavut, the largest park is Torngat Mountains National Park, which includes many pristine fjords, lakes and rivers, for example in the Komaktorvik-Chasm lakes area. In Northern Québec (Nunavik), the first of a series of parks, the Parc national des Pingualuit, has recently been created. Under the terms of the Sanarrutik Agreement, and noting that “Nunavik has an under-exploited tourism potential”, the Government of Québec committed to provide resources to develop a series of northern parks, specifically Monts-Torngat-et-de-la-Rivière-Koroc, Lac-Guillaume-Delisle-Lac-à-l’Eau-Claire (now known as Tursujuq – see Box 1), Mont Puvurnituk and Cap Wolstenholme parks. The government also committed 9.6M$ to the creation, capital expenses and initial 5-year operational costs of Parc national des Pingualuit.

Research and monitoring are central activities conducted by Parks Canada throughout the country, with regular status reports provided to the public. Such an approach should also be integral to the management of these northern parks. Some of the lakes contain remarkable resources of great public and scientific interest. For example, Pingualuit Crater Lake (Figure 4) contains a remarkable paleoclimate record in its sediments potentially going back 1.4 million years, more than eight glacial cycles. Lac à l’Eau-Claire (Box 1) is another intriguing ancient crater lake of great geological as well as ecological interest, and nearby, Lacs des Loups Marins contain a landlocked freshwater seal population with a total size estimated at 500 individuals (Ministère du Développement Durable, de l’Environnement et des Parcs 2008).

Figure 4. *Pingualuit Crater Lake, Nunavik. Photo by Denis Sarrazin, CEN/ArcticNet.*

4.4 Chemical pollution

Given the remote, pristine nature of the Subarctic and the lack of large cities and heavy industry, chemical pollution of waters from local sources is generally not a major issue in Nunavik and Nunatsiavut at present. However, abandoned mines, current mining wastes and waters in the vicinity of municipal waste disposal sites may pose environmental concerns at some sites. Furthermore, the impacts of chemical pollution are likely to rise with industrial development, increased shipping, and the rapid expansion of populations in northern townships in the past and present. Analysis of sediments from Lac Dauriat by Laperrière et al. (2009) at Schefferville showed that there was a major deterioration of water quality associated with the discharge of municipal and mining wastes during the mining boom development of this town. The sediments received maximum metal pollution during the 1930-1970 period, however even 20 years after the closure of the mine and the population exodus, the lake has still not returned to its original ecological state.

Long-range pollution continues to be of great concern throughout the North, including within this IRIS region. Mercury has been detected in the snowpack (Steffen et al. 2005, 2006) and perfluorocontaminants have been detected even in the most pristine lakes of the region, albeit in extremely low concentrations (Gantner et al. 2012). Analysis of mercury in lake sediments, including from lakes in Nunavik and Nunatsiavut (examples in Figure 5) show that the input of this toxic metal is continuing to increase (Muir et al. 2009). Further analysis has shown that these increased mercury fluxes were primarily due to long range transport and deposition of anthropogenic Hg rather

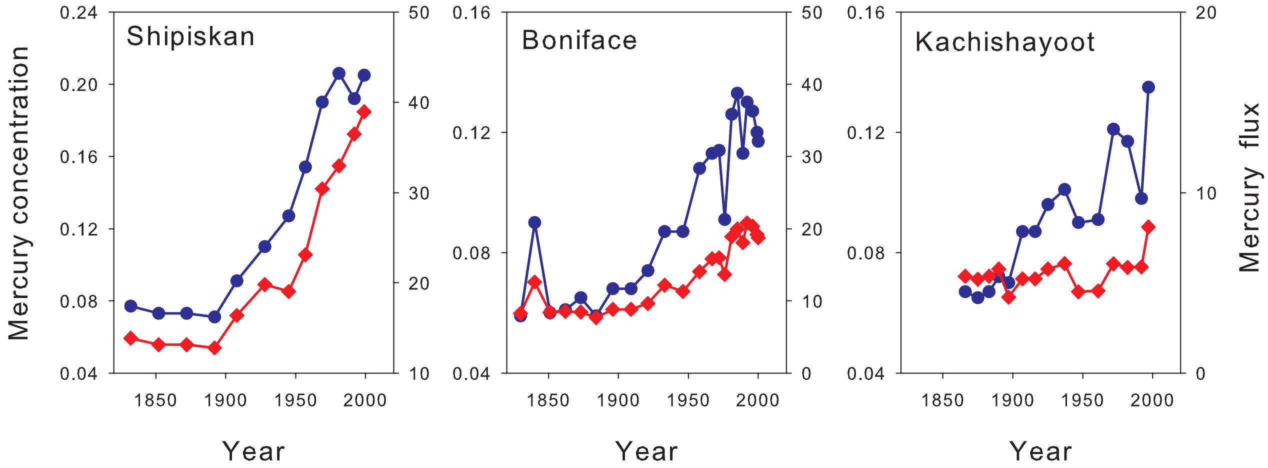


Figure 5. *Trends in mercury concentrations in lake sediments (µg Hg per g dry weight of sediment; blue circles; left-hand Y-axes) and mercury deposition fluxes (µg Hg per m² per y; red diamonds; right-hand Y-axes) in Shipiskan Lake, Labrador (54.5°N, 62.2°W); Lake B2 at Boniface, northern Québec (57.5°N, 76.1°W); and Lake Kachishayoot (55.2°N 77.4°W), northern Québec. Derived from Muir et al. 2009.*

than remobilization of natural background sources. This and other contaminants will require ongoing monitoring, particularly in local water supplies and fish that are routinely harvested for food.

4.5 Drinking water supplies

The following excerpt is from the report prepared by ArcticNet and Nasivvik that was presented to Nunavik mayors (Martin et al. 2005), and Martin et al. (2009).

Most Nunavik communities are now equipped with a water plant, but houses do not benefit from aqueduct systems because of permafrost. As throughout many parts of the North, water is delivered daily by truck to houses where it is kept in large tanks (Figure 6). A large portion of Nunavimmiut use untreated water. This water is drawn from lakes, creeks and rivers during the summer months or is obtained by melting ice or snow in winter and spring months. In Nunavik, one person out of five is under five years of age, representing an at-risk group for gastroenteritis due to that group's fragile immune system. During the *Qanuippitaa?* Health Survey (Fall 2004), onboard the CCGS *Amundsen* icebreaker, ArcticNet researchers visited 232 houses and 19 external sites (creeks, rivers and lakes used for raw water supply), in 14 Nunavik communities. Water samples were analyzed in the microbiological

Figure 6. *Delivery of drinking water by truck at Kangiqsujuaq, Nunavik (Photo: R. Pienitz, CEN/ArcticNet).*

laboratory onboard the ship, except for DNA tests where samples were obtained and treated on the ship, but analysed at the Infectious Diseases Research Center (CRI), in Quebec City.

The main goal of the study was to evaluate water consumption habits that could place Nunavik residents at an increased risk of disease, in a climate change context. The first objective was to evaluate if water coming from household tanks, raw water sources and raw water stored in individual plastic containers had low microbiological contamination and was safe to drink. Secondly, the study aimed to compare the water quality of household tanks in a community with municipal regulation for tank cleaning (Puvirnituq) to other Nunavik communities without regulations regarding tank cleaning, with the objective of making recommendations for water tank cleaning (frequency of cleaning and cleaning procedures). This project also had an educational component: four Inuit trainees from the Nunavik, Nunavut, Inuvialuit and Labrador region were involved in water sampling and analytical methods for testing drinking water quality.

Total coliforms (TC), *Escherichia coli* (EC) and *enterococci* (EI) were selected as indicators of water quality and were assayed using Colilert™ and Enterolert™ techniques. These techniques are similar to those used in Nunavik communities to check water quality at the water plant and water tank outlet. The water was considered unsafe for human consumption if contamination was equal to or exceeded the following thresholds:

* 10 total coliforms/100 ml
* 1 *Escherichia coli* /100 ml
* 1 *enterococcus* /100 ml

The presence and levels of *Escherichia coli* and *enterococci* bacteria, obtained by DNA and membrane filtration methods were compared to results obtained by Colilert™ and Enterolert™ methods. Additionally, *Cryptosporidium parvum/hominis* and *Giardia duodenalis* presence/absence tests were carried out by DNA methods.

In the samples, 71% of the consumed water came from household tanks and 29% was raw water (water directly from creeks, rivers, lakes). In this study, it was determined that water coming from household tanks (disinfected or partly disinfected) was of good microbiological quality and safe to drink. Raw water was often stored in plastic containers (jugs), and most of the time, this water was not refrigerated in the house. Plastic containers were more contaminated (TC, EC, EI) than household tanks, and contrary to expectation, the percentage of contaminated household tanks was lower among households having cleaned their tank more than 6 months ago. It appears that frequent but inadequate cleaning may contribute to the re-circulation of bacteria in the tank, indicating the need to improve cleaning protocols. The procedures established a few years ago in Puvirnituq seem to be adequate but further investigation of cleaning frequency is necessary.

The *Qanuippitaa?* Health Survey raised a lot of interest among Inuit trainees participating in sampling and testing operations. Upon completion of the analyses, abnormal results were communicated to community health centres. In April 2005, community mayors received a report on their community water results (Martin et al. 2005) and a summary for all Nunavik communities.

Results obtained from this survey can be used to make general recommendations to Nunavik residents and to initiate projects pertinent to drinking water quality. If water quality was good in household tanks during the study, it does not mean that it is safe to drink all the time. Residents should follow the boiling advisories when announced. Raw water from rivers, lakes and creeks could be at risk and should always be boiled before drinking (1 minute). As raw water stored in plastic containers is frequently contaminated, containers should be cleaned on a regular basis and water should always be boiled before drinking (1 minute).

In February 2005, following the *Qanuippitaa?* Health Survey, a workshop gathering drinking water managers and people involved in public health (scientists and medical practitioners), was held in Kuujjuaq. The workshop began with presentations of microbiological results obtained during the campaign. During the second part of the workshop, participants were invited to put forward priorities and to share ideas about projects related to drinking water quality. Priorities were: 1) Encouraging water consumption, instead of pop and juice, especially among children; 2) implementation of small disinfection systems (UV) at specific locations to avoid parasite contamination; 3) training for tank cleaning and evaluation of water quality (microbiological) before/after cleaning, in different situations (type of tanks, type of cleaning, frequency); 4) information on cleaning plastic containers (used to store raw water); 5) projects on gastroenteritis surveillance (public health) and; 6) projects on environmental surveillance.

There are cultural factors that must also be considered in the implementation of improved protocols for water security. In many communities there is a long tradition of using specific springs, lakes and rivers for drinking water purposes, and the idea of shifting to hygienic, treated supplies may be treated with suspicion. For example, a survey of the aboriginal community of Rigolet showed that only 4% of the population considered water from the land to be unsafe, while 37% considered tap water to be unsafe (Goldhar 2011) .

4.6 Hydroelectricity

Hydroelectricity is a major ecosystem service (Figure 1) that harnesses water resources in northern Québec and Labrador. Two of the largest underground power stations in the world are located in this region: the Robert-Bourassa generating station at 53.8ºN, 77.4ºW (5616 megawatts (MW), and the adjacent La Grande-2-A that can generate 2106 MW (collectively these are referred to as the La Grande complex) and the Churchill Falls station at 53.6ºN, 64.3ºW (5428 MW installed, expandable to about 6300 MW). These are at somewhat lower latitudes than the southern limit of Nunavik (55ºN) and Nunatsiavut (about 54ºN), but there has been considerable interest in extending this exploitation of hydro-resources northwards, including via small-scale schemes (Box 2).

In the 1970s, Hydro-Québec initiated planning of a project located along the Great Whale River, east of the village of Whapmagoostui-Kuujjuaraapik, with an installed capacity of 3200 MW and requiring 575 km of access roads to be constructed. This project was subject to considerable debate concerning its economic viability and environmental impacts, and was shelved in 1982, reactivated in 1989, and re-suspended by the Government of Québec in 1994. However, there is growing need for energy as well as sustainable industries in the North, and the Nunavik Environment Commission (2009) notes that "*It would be imprudent to assume that the coastal waters, rivers, and lakes of Nunavik will remain unharnessed as sources of energy and interest*".

In 2002, the Sanarrutik Agreement was signed between the Makivik Corporation, the Kativik Regional Government and the Government of Québec (details available online at: http://www.saa.gouv.qc.ca/relations_autochtones/ententes/inuits/sanarrutik-consolidee_en.pdf). This agreement estimated the total hydro-potential of Nunavik as within the range 6300 to 7200 MW, and identified several northern rivers with high hydroelectric power potential (Nastapoka; Whale, George, Aux Mélèzes Caniapiscau, Leaf) and others with low power potential (Kovik, Decoumte, Buet). The agreement explicitly states that "*there will be full and timely disclosure by Québec to Makivik and the concerned Nunavik Inuit communities with respect to all proposed new hydroelectric projects*" and that "*Makivik and communities that may be affected will be involved and consulted in the technical description of potential projects in order to reduce environmental and social impacts on the communities*". As in each of the water resource issues discussed in this chapter, this consultation process is critically important given that hydro-development has a variety of potential ecological and social impacts, including a trade-off in wilderness

Box 2. The Innavik hydro project.

An example of sustainable socio-economic development.

This information is derived from the website www.innavik.com/

Innavik started in 2007 as a project to construct an 8 MW hydroelectricity generating plant (near the village of Inukjuaq in Nunavik). Despite its small size, the plant could substantially reduce diesel fuel consumption and dependency while lowering greenhouse gas emissions of the community by an expected average of 15 thousand tonnes of CO_2 per year. A priority of the Innavik project is to ensure environmental protection of the Inukjuak River and surroundings. The supervision by local Pituvik Landholding Corporation (PLC) ensures that community and regional interests are at the very centre at all stages of the project. One of the main objectives is to provide reliable cost-effective power, in tune with long term sustainable economic development of the community. The plant is majority-owned by PLC and will therefore economically aid all beneficiaries and Inukjuakmiut.

values. For example, development of the Nastapoka River as a hydroelectric resource could have implications for the quality of habitat of the freshwater seals in its headwater Seal Lakes (Lacs des Loups Marins), and protecting this unique biodiversity feature would be an issue of international concern. Such features are also of considerable local concern. For example, as a result of the consultation process with northern communities for the creation of Tursujuq National Park, the Kativik Environmental Advisory Committee (KEAC) recommended in its position paper that "Given the exceptional scenery of the Nastapoka River and the wildlife resources of this river and its drainage basin, specifically the fresh-water seal population of Upper Seal Lake which is unique in North America, as well as the eastern Hudson Bay stock of beluga and the landlocked salmon population, which are considered vulnerable, the KEAC recommends that the Nastapoka River and its entire drainage basin be included in the future park" (Kativik Environmental Advisory Committee 2008). These considerations may have been viewed as secondary to mineral resource claims and hydroelectricity resources as outlined in the Sanarrutik Agreement, since the provisional park management plan excluded the Seal Lakes and Nastapoka River from the

proposed park (Carte 4 La limite proposée; in: Ministère du Développement Durable, de l'Environnement et des Parcs 2008). The limits of the park are currently under review to include these unique features (Service des parcs MDDEP, communication, 2 May 2012). Additional considerations concerning land use management are given in Chapter 1 of this volume.

Hydroelectricity developments will also need to carefully assess the implications of climate change for shifts in water supply, specifically the current and future magnitude of precipitation gains (likely to increase with climate change, see Chapter 2), the extent of evaporation losses (likely to increase with warmer water temperatures, and longer ice free conditions), and changes in water plant species and density that may influence storage volume and operating protocols. Future shifts in lake and river ice conditions may also affect hydroelectric operations (Prowse et al. 2011). Additionally, close attention will need to be given to the magnitude of natural variability in hydroclimate. Assessments based on tree-ring analysis in northern Québec suggest that this variability in the past has yielded fluctuations of the order of 25% (Lemay and Bégin 2008). The research project ARCHIVES (*Analyse Rétrospective des Conditions Hydro-climatiques à l'aide des Indicateurs et de leur Variabilité à l'Échelle Séculaire*) is currently underway in partnership with ArcticNet to analyse sediment and tree ring records, the latter from 120 chronologies of 200 years at 20 to 30 trees per site. The past variations in hydro-regional climate are being reconstructed from these multiple indicators by the extraction of common signals, for example by neural network analysis (details at: http://archives.ete.inrs.ca).

4.7 Conclusions and recommendations

The most successful strategies for long-term sustainable management of aquatic ecosystems are those combining global perspectives and scientific knowledge with a local understanding of cultural, environmental and economic factors (Kumagai and Vincent 2003). Although this integrative approach towards aquatic resource management has been applied with success in several parts of the world, it has been little considered at high northern latitudes where environmental change is likely to have major repercussions for the supply of safe drinking water, freshwater habitats for aquatic wildlife and water resources for human needs (Wrona et al. 2007, Vincent and Laybourn-Parry 2008). As described in this chapter, this combination of approaches is especially pertinent in Nunavik, where the success of water resource development hinges not only on the best scientific insight and advice, but also on full consultation with northern communities, and on respect for, understanding and inclusion of cultural perspectives. This central theme of global science plus local community integration is at the heart of the following key recommendations:

* Nunavik and Nunatsiavut have a rich natural heritage of lakes, rivers and wetlands that require ongoing stewardship and protection. Northern communities and authorities should continue to develop their leadership and managerial roles in monitoring and protecting these vulnerable ecosystems.

* Permafrost thaw lakes (thermokarst lakes) are a major category of northern freshwater ecosystems, and they appear to be increasing in abundance and total surface area in parts of the circumpolar North, including Nunavik, as the permafrost continues to warm and degrade. Given their very active production of greenhouse gases as well as their importance for aquatic plants and wildlife, they will require close ongoing monitoring and research.

* The creation and management of parks is an effective way to achieve the best possible protection in the face of climate change and ongoing development of the North, as well as a way to stimulate eco-tourism and the associated economic activity. Research and monitoring should be essential parts of the strategic management plan for these northern parks.

* The avoidance and mitigation of chemical pollution of northern aquatic ecosystems requires ongoing vigilance. The continuing rise in some long range contaminants such as mercury requires surveillance, in collaboration with northern communities and global partners.

* A variety of drinking water problems have been identified throughout Nunavik, and a set of recommendations has been communicated to reduce these problems. Raw water from rivers, lakes and creeks could be at risk and should always be boiled before drinking. Raw water stored in plastic containers is frequently contaminated, hence containers should be cleaned on a regular basis and water should always be boiled before drinking.

* The North continues to offer considerable potential for hydroelectric development at both small and large scales. Such projects will require close and timely consultation with all stakeholders, especially local communities, to assess the environmental and social impacts, including effects on wilderness values. Potential and currently operating hydroelectricity complexes will also require ongoing research to project future water supply. These needs include downscaled, local projections of future precipitation and ice cover, evaluation of evaporation scenarios in the changing northern climate, and analyses of interannual and other natural fluctuations. Paleoclimate research approaches will continue to play a valuable role in these assessments.

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