# Navigating the Waters of Change:

## Strengthening the Capacity of NWT Communities to Respond to the Impacts of Climate Change on Municipal Water and Wastewater Systems

ECOLOGY NORTH

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Ecology North is a NWT-based charitable, non-profit organization formed in 1971 to support sound environmental decision-making on an individual, community and regional level. Current priorities for Ecology North include climate change, sustainable living and public education.

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## Executive Summary

The Western Canadian Arctic has experienced some of the most rapid and intense climate changes on Earth, with global climate models predicting that average surface temperatures may increase by 4 - 7 °C by the 2080s. Global Climate Models project a 15-30% increase in precipitation in the Western Arctic by the 2080s; however, projected precipitation changes are quite variable across regions. Changes in precipitation and temperature, and their impacts on ecosystem processes, will affect many facets of life in the NWT, including how communities manage water and wastewater.

The purpose of this paper is to provide a preliminary assessment of the potential impacts of climate change on water and wastewater systems in the NWT, and recommend actions to increase the capacity of communities to respond and adapt to changes. Information in this paper was collected through interviews with individuals working in water and wastewater managment in the NWT, and through review of scientific studies on this subject.

Climate change may impact community water and wastewater treatment systems in a number of different ways. Sourcewater quality may be affected by increased turbidity, and changes in concentrations of organic compounds, inorganic minerals, and trace metals such as mercury and arsenic. A potential positive impact of climate change is that it may increase the biological treatment season, which could improve wastewater effluent quality.

Changing permafrost conditions may increase maintenance and construction requirements, and costs for water and wastewater infrastructure including cisterns, pipes, buildings and roads. Permafrost melt may also alter hydrological conditions around wastewater lagoons, and in wetlands used for wastewater treatment. These changes could increase the impacts that wastewater effluent has on the surrounding environment. Permafrost melt may alter leachate flow from solid waste facilities, which could change the pathway of contaminants into nearby freshwater ecosystems and wastewater treatment facilities.

A key vulnerability for many NWT communities with respect to potential impacts of climate change on water and wastewater systems is a lack of consistent water quality, wastewater and landfill leachate monitoring data. There is also a need for community-specific assessments of the potential impacts of climate change on water and wastewater systems.

The following actions would strengthen the capacity of NWT communities to respond to the potential impacts of climate change on water and wastewater systems: 1) Conduct site-specific assessments of the vulnerability of community water and wastewater systems to potential impacts from climate change; 2) Support NWT communities in ensuring that water licenses are issued and kept current; 3) Undertake more comprehensive and consistent source water, wastewater and landfill leachate monitoring programs; 4) Implement source-control measures and public education programs to control the release of hazardous substances and contaminants into waste streams; 5) Support education, training and professional development opportunities for NWT water and wastewater system operators; 6) Conduct further research on how climate change may impact mercury dynamics in aquatic ecosystems; 7) Create a climate change adaptation fund for community infrastructure; and 8) Explore diverse options for wastewater treatment.

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# 1. Introduction

The Western Canadian Arctic has experienced some of the most rapid and intense changes in climate on Earth, with global climate models predicting that average surface temperatures may increase by 4 - 7 °C by the 2080s (Furgal and Prowse 2008). Climate change will impact ecosystem processes, and many facets of life for citizens of the Northwest Territories during the coming decades. Two cornerstones of adapting to climate change are gathering as much knowledge as possible about what potential changes will occur, and planning how to best prepare for these changes.

The *Arctic Climate Impact Assessment* (ACIA) (2004) warned that permafrost thawing, coastal erosion and other climate related changes have the capacity to negatively impact drinking water quality, cause direct damage to facilities, and limit the efficiency of delivery services related to water and wastewater. Community drinking water provision and wastewater treatment are already topics of interest for many NWT citizens, and water quality, quantity and aquatic ecosystem health are areas of growing concern in the North.

The purpose of this paper is to provide a preliminary assessment of the potential impacts of climate change on water and wastewater systems in the NWT, and encourage thought and action to increase the adaptive capacity of communities with respect to these potential impacts.

Specific objectives of this project include the following:

- Review existing research and knowledge about the likely impacts of climate change on wastewater management and water provision systems in the NWT
- Recommend actions communities should take to prepare for the potential impacts of climate change on water and wastewater systems
- Stimulate further knowledge-sharing, discussion, and thought on the topic of climate change impacts on water provision and wastewater management among citizens and decision-makers in the NWT
- Highlight areas where further research and information gathering are needed

## 1.1. Scope and Methodology

This preliminary assessment focuses specifically on the potential impacts of climate change on water and wastewater systems at the municipal level in NWT communities. The report does not address potential impacts of climate change on water and wastewater systems at industrial sites.

This assessment was prepared by conducting a review of scientific research and existing studies into the potential impacts of climate change on water and wastewater systems and aquatic ecosystems. A central component of the study was to conduct informal interviews with a wide variety of agencies and individuals who work in the field of water and wastewater treatment in the NWT. Appendix I contains a list of people who were interviewed while writing this report, and their contact information.

Information gathered through research and interviews focused on issues, trends and recommendations that would be applicable for multiple, and in some cases all, NWT communities. No specific community case studies, or in-depth vulnerability assessments were completed as part of this preliminary report, although examples from specific communities are used to illustrate particular issues discussed.

# 2. Current and Predicted Climate Changes in the Northwest Territories

The 2004 *Arctic Climate Impact Assessment* reported that winter temperatures in the Mackenzie Valley have increased by 3-5°C and annual temperatures have increased by 1-2°C over the past fifty years (ACIA 2004). This rate of change is approximately twice that of the global average temperature increase of 0.74°C over the past 100 years (IPCC 2007). Global Climate Models project that by the 2080s the mean temperatures in the Western Arctic will have increased by 4-7°C from the 1961-1990 baseline temperature, and that warming will be most pronounced during the winter and fall (Furgal and Prowse 2008).

Significant changes in overall precipitation levels in the NWT have occurred over the past 50 years. Inuvik and Norman Wells have experienced a decline in total precipitation, while Yellowknife and Fort Smith have experienced increased precipitation (GNWT - ENR 2008). Precipitation rates in these four communities have also become more variable in recent years (GNWT - ENR 2008). Global Climate Models project a 15-30% increase in precipitation in the Western Arctic by the 2080s (Furgal and Prowse 2008). However, projected annual and seasonal precipitation changes are quite variable across regions, and the inherent variability in Arctic and Subarctic climates increases the uncertainty of projected changes (Furgal and Prowse 2008).

*Summer squall on Fish Island, Mackenzie Delta*

Increasing temperatures and changing precipitation patterns are markedly impacting ice conditions. Freeze-up is occurring later in the fall, and break-up earlier in the spring (GNWT - ENR 2008). Continued warming will likely further shorten the ice season, and reduce the thickness of lake and river ice. The severity of river-ice events such as ice-jam flooding may increase or decrease in the future, according to how climate change affects the interplay of snowfall, spring river discharge and ice characteristics (Magnuson *et al.* 2000).

Increasing average surface temperatures are causing the degradation of permafrost and a reduction in the areal extent of permafrost. The degradation and disappearance of permafrost will potentially have significant impacts on hydrological processes, including a shift from surface-water dominated systems to groundwater-dominated systems, the disappearance of some lakes and wetlands, and expansion or creation of others, and alterations in the timing and volume of river flow (ACIA 2004; Frey and McClellan 2009). These changes in turn may affect water and wastewater treatment processes and infrastructure.

It is very difficult for hydrologists to predict how climate change will affect water dynamics, including seasonal water levels and flow rates, in various regions of the NWT. Very high levels of inter-annual temperature and precipitation variability (Furgal and Prowse 2008), short and geographically limited historical climate records, and uncertainty about potential changes in regional climate dynamics limit the ability to predict precise future hydrological conditions (Prowse *et al.* 2006).

Although community decision-makers may not know precisely how water dynamics may change in their communities, it is clear that the climate, and in particular precipitation, is becoming more variable. Large shifts in arctic climate patterns have occured over short timescales in the past (ACIA 2004). In community meetings and interviews with Elders that Ecology North has held on the topic of climate change, many community members have spoken about how it has become more difficult recently to predict the weather using traditional methods.

NWT communities need to take action to ensure they have the knowledge and capacity to deal with the impacts this increasing climatic variability may have on their water and wastewater systems.

# 3. Potential Impacts of Climate Change on Water Treatment Systems & Source Water Quality in the NWT

## 3.1. Drinking Water Treatment and Provision in the NWT

Under the 'New Deal', NWT communities are responsible for planning, operating and maintaining their drinking water treatment facilities, water provision and wastewater infrastructure. Water and wastewater treatment facility operators are hired at the community level. Many NWT communities find that due to staff turnover, it is a challenge to retain trained water and wastewater treatment facility staff.

GNWT Municipal and Community Affairs (MACA) provides technical, training and operational support to assist communities in carrying out water and wastewater treatment. MACA staff conduct training programs for water and wastewater treatment plant operators, and assist communities in decision-making related to water and wastewater treatment infrastructure. The GNWT provides funding to communities for capital and operational costs related to water and wastewater treatment projects. The GNWT is also responsible for inspecting water treatment plants and reviewing water quality data from communities to ensure that drinking water is safe (GNWT-MACA 2007).

There are a total of 34 public drinking water systems in the NWT. Twenty-seven of these systems draw source water from rivers or lakes, four draw water from underground wells, and three communities truck in treated water from another NWT community (GNWT-MACA 2007). Most small NWT communities use trucks to deliver drinking water to citizens. Yellowknife, Inuvik, Hay River, Norman Wells, Fort Smith and Fort Simpson service the majority of their citizens using a piped water system, either underground, or in above-ground utilidors (Dillon Consulting Ltd. 2006).

*Wha ti water treatment plant*

In 2005 the GNWT outlined a framework and strategy to guide decisions related to drinking water treatment and provision (GNWT-PWS 2005). The drinking water quality framework proposes a multi-barrier approach for providing safe drinking water which includes the following: a) keeping NWT water clean; b) making drinking water safe; and c) proving drinking water is safe.

Water licenses are one of the primary mechanisms used to guide communities in their decisions to protect community drinking water sources. All communities in the NWT that use more than 50 $m^3$/day of water or deposit waste for a population of more than 50 are required to hold a water licence under the NWT Waters Act. As of 2009, nine out of 33 NWT communities do not have a current water license; however, three of these nine communities are in the process of applying (O. Lee, personal communication, 2009).

Communities apply for a water license through the Land and Water Board in their jurisdiction, and the conditions of the water license are enforced by the federal government. Water licenses regulate the volume of water a community can withdraw from source water bodies, the quantity and characteristics of liquid and solid waste that will be disposed of in the environment, and water and wastewater quality monitoring parameters.

The GNWT - Environment and Natural Resources (ENR) has a mandate to protect source water for drinking water provision in the NWT. In 2008, GNWT - ENR published a series of maps that depict the watershed where each NWT community draws its source water. These maps identify potential threats to the community drinking water supply, and are a tool to encourage sound land-use decisions that take drinking water source protection into consideration.

## 3.2. Drinking Water Quality Sampling & Monitoring in the NWT

Drinking water was identified as a topic of concern for many citizens during recent community meetings held by the GNWT throughout the territory to discuss a proposed NWT Water Strategy. During community workshops Ecology North has held on the topic of climate change over the past few years, we have observed that mistrust of drinking water quality, and misunderstandings about the drinking water treatment process, are quite common.

Drinking water in the NWT must meet *NWT Public Water Supply Regulations* and the *Guidelines for Canadian Drinking Water Quality* (Federal-Provincial-Territorial Committee on Drinking Water 2008). In the spirit of improving trust in the drinking water supply, the GNWT maintains an on-line NWT Drinking Water Quality Database to make the results from chemical and bacteriological tests on drinking water in each community available to the public[1]. The database is a joint initiative of the GNWT departments of Municipal and Community Affairs (MACA), Public Works and Services (PWS), Health and Social Services, and the Stanton Territorial Health Authority.

Drinking water quality sampling and testing requirements for communities in the NWT are outlined on the NWT Drinking Water Quality Database website. Treated water must be tested for bacteriological parameters (faecal and total coliforms) at a minimum of once per week, with additional testing required for communities with a population greater than 4000. Turbidity sampling is to be carried out on a daily basis at minimum, and one water sample is to be collected annually for 28 additional physical and chemical parameters. The Department of Health and Social Services is responsible for ensuring that these sampling and testing requirements are met. The sampling and testing requirements are authorized by the Chief Medical Health Officer for the NWT, as stipulated in the Public Water Supply Regulations.

According to the NWT Drinking Water Quality Database website, water quality test data are updated on the website twice per year, to ensure that the most recent results are available to the public. As outlined in the *2006 NWT Drinking Water Quality Report* (GNWT-MACA 2007), a number of communities were not regularly collecting source water samples for testing and monitoring. As a result, since 2007, Environmental Health Officers have been collecting the annual water samples for physical and chemical parameter testing (D. Fleming, personal communication, 2009). Currently, annual water samples are not collected at the same time each year, which makes it more difficult to compare data from one year to the next. It would be advantageous to consistently collect water samples during the spring melt to test for maximum physical and chemical water quality parameters (E. Kelly, personal communication, 2009).

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[1] This database is available at: http://www.maca.gov.nt.ca/operations/water/homepage.asp

The quality of the surface or groundwater that is treated to drinking water standards determines a number of parameters in the drinking water treatment process. These parameters include the amounts and types of chemicals that are used, treatment processes, and training that is required for water treatment plant operators. It is therefore very important that both source and treated water be sampled and monitored for physical, chemical and bacteriological parameters as outlined on the website for the NWT Drinking Water Quality database.

## 3.3. Naturally-Occurring Organic Compounds and Inorganic Minerals

Vincent Tam, Senior Water and Sanitation Engineer with GNWT- Public Works and Services (PWS), has observed that in a few communities in the Deh Cho region, there have been increases in the concentration of naturally-occurring organic compounds, such as humic acids, in source waters during the past few years. Source water drawn from regions with organic soils where there is a lot of peat present tend to naturally have high levels of humic acids, which originate in peat materials. However, permafrost melt may be increasing the concentration of these humic acids present in source water (Macdonald *et al.* 2005).

Water is not able to flow through frozen organic soils. However, as the permafrost in these soils melts, there is an increase in the surface area of organic soils through which water flows. This can lead to an increase in the organic content of sourcewater in regions where permafrost melt occurs in organic-rich soils (Macdonald *et al.* 2005; Frey and McClelland 2009). Naturally-occurring organic compounds such as humic acids are not a health concern themselves. However, as organic loading increases, greater amounts of chlorine are required for water treatment, as some free chlorine molecules used to disinfect water become bound by the naturally-occurring organic compounds, and the organic compounds can provide a habitat for bacteria, protozoa and other potential water-borne pathogens.

Permafrost melt may also alter the inorganic mineral content of sourcewater. In regions where changing permafrost causes surface-water dominated systems to be more influenced by groundwater, movement of water through deeper mineral soils, instead of through shallow organic surface soils will likely change the mineral content in the water (Frey and McClelland 2009).

There are still many uncertainties with regards to how climate change may impact organic and mineral constituents in source water. These impacts will likely exhibit a high degree of variability related to local topography, soil, climate and hydrological conditions. This variability and uncertainty highlights the importance of regular and consistent sampling and monitoring of sourcewater as outlined in the NWT Public Water Supply Regulations.

## 3.4. Turbidity

Turbidity is a measure of the light-scattering potential of water, which indirectly describes the amount of suspended and colloidal particles that are present in the water. Turbidity in rivers and lakes tends to increase during the spring when meltwater carrying sediment enters water bodies at a greater rate. Increased slumping of river banks and lakeshores due to permafrost melt has the potential to increase turbidity levels in NWT water bodies (Frey and McClelland 2009).

As turbidity increases, the risk that water could carry bacteria, viruses or protozoa attached to the suspended particles increases. In addition, chlorine molecules that are used to disinfect water react with suspended particulates in turbid water. As a result, as turbidity increases, increased amounts of chlorine are needed to treat water for drinking (GNWT - MACA 2009). When turbidity in source water become very high, communities may need to issue a 'boil water advisory' if their treated water does not meet the Guidelines for Canadian Drinking Water Quality.

Community water treatment facilities that use water from river sources are usually designed to handle high turbidity occurrences; however, human resource and/or system maintenance challenges can prevent these facilities from operating at an adequate capacity to handle high turbidity (D. Fleming, personal communication, 2009). For example, some communities along the Mackenzie River encounter problems with clogged filters at high turbidity levels, and the community of Hay River is often required to issue boil water advisories during spring breakup because the water treatment plant is not able to operate at full capacity.

If climate change increases the frequency or intensity of high turbidity events, this may increase the number of boil water advisories experienced by NWT communities. More frequent episodes of high turbidity may increase maintenance costs for affected water treatment facilities, as water filters and membranes would need to be replaced more often.

## 3.5. Potential Interactions Between Climate Change and Contaminants in Northern Aquatic Ecosystems

A main pathway by which heavy metals such as lead or mercury, and persistant organic pollutants, such as PCBs, enter arctic ecosystems is through atmospheric transfer on air currents from heavily populated and industrial regions of the northern hemisphere. Once these air masses reach the arctic, dry and wet deposition events play a role in depositing the pollutants into aquatic and terrestrial ecosystems. (ACIA 2004). As a result, any changes in precipitation patterns and/or prevailing air currents due to climate change may impact the delivery of metals and other contaminants to Arctic ecosystems (Macdonald *et al*. 2005).

With industrialization, organic pollutants and heavy metals have been deposited to arctic and subarctic ecosystems for many years. As climate change causes permafrost to break up and recede, water is able to access previously deposited pollutants, which can increase the concentration of heavy metals and persistant organic pollutants in waterbodies.

Changes in the delivery of metals or persistant organic pollutants to northern aquatic ecosystems will unlikely be at a magnitude that would make source water unsafe to drink, or necessitate changes to water treatment processes. However, these potential changes in contaminant concentrations underline the importance of consistent annual monitoring of drinking water quality for physical and chemical parameters, in addition to regular bacteriological monitoring. Drinking water samples should be compared against the *Guidelines for Canadian Drinking Water Quality* (Federal-Provincial-Territorial Committee on Drinking Water 2008) which outline the maximum acceptable concentrations of chemical parameters and levels of physical characteristics.

Although changes in precipitation and air current patterns may impact deposition and concentrations of a spectrum of metals in Arctic ecosystems, mercury and arsenic are two metals whose complex geochemistry makes them susceptible to further impacts due to climatic changes. As a result, these two metals are discussed in further detail below.

### *3.5.1. Potential Increased Availability of Arsenic*

Increased temperatures and changing precipitation patterns associated with climate change have the potential to alter the carbon cycle. If climate change leads to greater primary productivity and increased carbon loading in northern aquatic ecosystems, this may cause changes to the sediment geochemistry of lakes, which can alter arsenic speciation. For example, a study of an arsenic-contaminated lake in northern Ontario found that when remediation efforts reduced metal loadings to the lake, a subsequent increase in phytoplankton growth led to increasing anoxic conditions in lake bottom sediments (Martin and Pedersen 2002). This led to a subsequent increase in the conversion of solid-phase arsenic, As(V), to dissolved-phase arsenic, As(III). Such an example illustrates the complexity of arsenic chemistry in dynamic ecological systems, and emphasizes the importance of consistent sourcewater quality monitoring to detect any changes that may be occurring.

### *3.5.2. Climate Change May Increase Mercury Levels in Northern Aquatic Ecosystems*

Mercury has been a heavy metal contaminant of concern for many years in Arctic ecosystems (ACIA 2004), and currently provides the greatest concern with respect to the interaction between contaminants and climate change (Macdonald *et al.* 2005). Mercury is often considered separately from other heavy metals due to its volatility, and tendency to go through biogeochemical transformation (Macdonald *et al.* 2005). Global air circulation patterns tend to transfer atmospheric mercury from industrial and heavily-populated regions of Europe, Eurasia, Eastern North America and China northwards to the Arctic. The natural mercury cycle has been impacted by human activities such that currently there is two to three times as much mercury cycling through the atmosphere and upper ocean than there was prior to industrialization (Macdonald *et al.* 2005). Naturally-occurring mercury is also present in some NWT ecosystems, which can complicate efforts to predict the presence and levels of mercury in local ecosystems.

Mercury contamination poses a particular threat to northern aquatic environments where inorganic mercury can be transformed from inorganic forms into its most toxic methylmercury form by bacteria. Methylmercury is of great concern as it can subsequently be bioaccumulated in the food web, particularly in arctic aquatic biota such as fish and marine mammals which serve as food sources for people (Macdonald *et al.* 2005).

A number of recent studies in the Canadian Arctic have found that mercury levels in arctic aquatic biota have increased over the past 30 years at a greater rate than global atmospheric mercury concentrations (Leitch *et al.* 2007). Although there is still a need for much more research into mercury transformations and dynamics in northern ecosystems, there is a growing set of studies that indicate that climate change may be contributing to increased mercury levels in aquatic ecosystems through the following mechanisms:

- Melting permafrost tends to discharge increased amounts of soil and organic carbon that contain mercury to waterbodies. Reduced sulfur groups in organic matter tend to bind mercury (Grigal 2003); as organic carbon in peatlands is mobilized through permafrost melt, it can release the mercury it has accumulated over decades or centuries from naturally-occurring and anthropogenic sources. The mercury may then undergo methylation through bacteria-assisted pathways (Macdonald *et al.* 2005).
- Melting permafrost may result in local and regional increases in methylmercury concentrations by increasing the proportion of small wetlands in some ecosystems. Permafrost melt often leads to altered local and regional hydrology, and can increase the size and amount of wetlands on a landscape (Quinton *et al.* In Review). Wetlands and wetland sediments are net producers of methylmercury (Suchanek *et al.* 2000), and studies have shown that as the amount of small wetlands in a watershed increases, there is a correlated increase in the amount of methylmercury observed in small fish (Greenfield *et al.* 2001).
- Methylmercury, which is the most toxic form of mercury to organisms, may be produced at a greater rate within aquatic environments with higher surface water temperatures, as increasing temperatures tend to cause higher methylation rates (Booth and Zeller 2005).
- Projected increases in boreal forest fire activity are expected to increase the transfer of mercury from peatlands to the atmosphere and aquatic ecosystems, as fires mobilize relatively harmless mercury stored in saturated soils into potentially more mobile and toxic forms (Turetsky *et al.* 2006).

### *3.5.3. Mercury Does Not Pose a Likely Threat to Drinking Water Quality*

Mercury is a toxic element that serves no beneficial physiological function in people, and can cause severe damage to the nervous system and reproduction. The Canadian Drinking Water Quality Guidelines (Federal-Provincial-Territorial Committee on Drinking Water 2008) set the maximum acceptable concentration of mercury in drinking water at 0.001 mg/L. In the NWT, it is very rare that surface or drinking water would approach the maximum acceptable concentration level for mercury (GNWT-MACA 2009; V. Tam, personal communication, 2009). Although mercury may rarely be a concern with respect to drinking water quality, it is an environmental contaminant of concern in the food web because it can bioaccumulate in the fatty tissue of fish and marine mammals and biomagnify in the food web (ACIA 2004). The pathway through which mercury affects humans is most often through food consumption, rather than exposure through drinking water.

Regular monitoring and communication of water quality results is critical as an indicator of overall aquatic health, to build trust in NWT water supplies, and to show that contaminant concentrations are within guidelines for Canadian drinking water quality.

# 4. Potential Impacts of Climate Change on Both Water & Wastewater Infrastructure

## 4.1. Changing Permafrost Conditions Can Impact Infrastructure

Construction and maintenance of infrastructure has always been a challenging task in areas with continuous and discontinuous permafrost. Both the construction process and infrastructure itself can cause thaw and settlement in the ground where the infrastructure is located (Canadian Standards Association 2009).

Permafrost thaw associated with increasing temperatures has been causing structural problems with buildings throughout the NWT, including water and wastewater treatment infrastructure in some communities. For example, in 2008 Norman Wells replaced its water reservoir, as the previous reservoir had structural cracks in it that had been caused by ground settlement. Fort Smith had chronic issues with its water treatment plant due to river bank slumping, which was likely accelerated by climate change (A. Fowler, personal communication, 2009). The water treatment plant has now been relocated.

Often it is not possible to determine if structural problems related to permafrost can be attributed specifically to climate change. However, as climate change causes increased rates of permafrost melt, there will likely be increased maintenance costs and structural challenges to overcome for a wide variety of community infrastructure. This infrastructure includes water treatment and wastewater treatment facilities, pipes, and roadways frequented by water and sewer trucks.

## 4.2. Designing Infrastructure for New Climatic Conditions

There is currently much research being conducted to determine how to best design infrastructure in permafrost areas to withstand changing ice and soil stability conditions. The Canadian Standards Association (CSA) is researching and producing a new guide specifically designed to support decision-makers who are working in permafrost regions. The working title for this guide, which will soon be available, is: *Community infrastructure, permafrost and climate change: An overview for practitioners with a focus on infrastructure that requires foundations* (CSA 2009).

Prior to the construction of new community infrastructure, including water and wastewater infrastructure, it is important that geotechnical studies be completed to ensure that structures are designed according to local soil, hydrology and permafrost conditions. New facilities that are designed for changing permafrost conditions may have higher capital costs at the outset; however, by planning for potential permafrost changes, the risk of building failure and expensive maintenance costs can be avoided in the longer term (S. Kokelj, personal communication, 2009).

# 5. Potential Impacts of Climate Change on Wastewater Management in the NWT

## 5.1. Wastewater Management in the Northwest Territories

Wastewater in most NWT communities is primarily of domestic origin. However, some waste streams include effluent from local industries and/or waste from local hospitals and medical centres.

Smaller communities in the NWT rely on trucked sewage collection. The communities of Yellowknife, Inuvik, Hay River, Norman Wells, Fort Smith and Fort Simpson have piped sewage collection for the majority of their residences and businesses, with supplemental trucked collection (Dillon Consulting Ltd. 2006).

Due to size, remoteness and cold climate conditions, most NWT communities rely on an annual storage lagoon to treat sewage effluent. Many communities also use wetland treatment or a land treatment area to further treat wastewater before it is discharged to a fresh or marine water body. (Dillon Consulting Limited 2006)

*Norman Wells Sewage Lagoon*

In February, 2009, The Canadian Council of Ministers of the Environment (CCME) released a Canada-Wide Strategy for the Management of Municipal Wastewater Effluent[2]. This strategy sets out National Performance Standards for the physical and biological characteristics of wastewater that is being released to the environment. The Canada-Wide Strategy recognizes that northern Canadian communities face specific challenges in achieving wastewater effluent standards due to climatic conditions,

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[2] The Canada-Wide Strategy for the Management of Municipal Wastewater Effluent is available at: http://www.ccme.ca/ourwork/water.html?category_id=81

remoteness and landscape characteristics. Therefore, current National Standards do not include northern Canada, and the Canada-Wide Strategy has established a five-year period during which working groups will study wastewater treatment processes in northern Canada. This will inform the development of a set of future wastewater performance standards specific to Northern Canada.

The creation of a Canada-Wide Strategy for wastewater management has prompted efforts to characterize and monitor wastewater effluent quality in NWT wastewater treatment facilities. Prior to the initiation of this process, there was very little investigation or understanding of the quality of wastewater effluent in the NWT (R. Bujold and C. Mallet, personal communication, 2009).

## 5.2. Wastewater Monitoring in the NWT

Each NWT community is required to monitor the wastewater treatment process and quality of wastewater effluent released to the environment according to the water license they hold with the Land and Water Board in their jurisdiction. Sampling for water license compliance is carried out at designated 'Surveillance Network Program' (SNP) sites throughout the wastewater treatment system. The SNP sites are determined as part of the water license application process, and are specific to each wastewater treatment system (Dillon Consulting Ltd. 2006).

However, currently there are a number of gaps that exist in the wastewater effluent monitoring system. These limit the ability of decision-makers and citizens to track wastewater effluent quality or recognize if wastewater treatment processes are being impacted by climate change. These monitoring gaps include the following:

- A number of NWT communities do not hold current water licenses, and therefore do not currently monitor and report on the wastewater treatment process and released effluent quality. Presently, 9 out of 33 NWT communities do not have a current water license; however, three communities are in the process of applying (O. Lee, personal communication, 2009).

- It is common for a community to miss taking an annual wastewater effluent quality sample (Dillon Consulting Limited 2006).

- Water licenses for some NWT communities do not require that wastewater effluent be tested for contaminants such as heavy metals or hydrocarbons prior to release to the receiving environment (Dillon Consulting 2007).

- There is a need for long-term monitoring of wetland areas that are used for wastewater treatment (Dillon Consulting Ltd 2007) and wastewater effluent quality at the final outflow point. There is currently little information available on the impacts of wastewater treatment on the surrounding environment, or water quality in receiving water bodies.

## 5.3. Does Climate Change Pose a Critical Threat to the Integrity of Sewage Lagoons?

During workshops and meetings Ecology North has held in communities around the NWT, citizens have expressed concerns about the quality of sewage effluent, and the risk of leakage from sewage lagoons into the surrounding environment. Similar concerns were expressed during community meetings on the NWT Water Strategy between October 2008 and February 2009.

The Arctic Climate Impact Assessment (2004) outlines that permafrost melt can pose a risk to the stability of waste containment structures when permafrost melts around lagoons that have been designed to rely on permafrost to maintain their structure.

Following up on these concerns, Ecology North asked a variety of professionals working in the fields of wastewater management and engineering in permafrost regions to share their perspective on what, if any, threats they felt climate change may pose to the integrity and stability of sewage lagoons in the NWT.

A number of the professionals we contacted noted that according to their knowledge, many wastewater lagoons in the NWT have not been designed with the intention that permafrost would provide an impervious barrier between wastewater and the surrounding environment (E. Hoeve, C. Mallet and H. Scott, personal communication, 2009). Ed Hoeve (personal communication, 2009) noted that the initial impoundment of water when the sewage lagoons were commissioned would itself tend to thaw the ground around the sewage lagoon, given that water has such a high heat capacity.

However, some sewage lagoons in the high Arctic have been designed to rely on permafrost. When such lagoons are currently designed, geotechnical modelling is done to justify that permafrost around the sewage lagoon will prevent sewage infiltration, and therefore act as a lagoon liner (H. Scott, personal communication, 2009). For sewage lagoons that rely on permafrost that were established decades ago, there may not have been geotechnical modelling completed. There is also currently little information available on average permafrost temperatures around lagoons that rely on the permafrost to maintain their integrity. More research and compilation of community sewage lagoon information is needed to determine the vulnerability of specific lagoons to changing climatic conditions.

In addition to the potential vulnerability of some NWT sewage lagoons to slumping due to permafrost thaw, there are lagoon construction and maintenance techniques related to permafrost in use that increase the risk and likelihood of lagoon failure. For example, in some communities, frozen organic soil has been used to build the berms around sewage lagoons. When this soil thaws in the summer following construction it tends to slump, which can cause wastewater release from the lagoon (R. Bujold, personal communication, 2009; Dillon Consulting Ltd. 2006).

The Northwest Territories Water & Waste Association and GNWT - Municipal and Community Affairs (MACA) runs courses and training for wastewater operators. Further support for such training programs, and inclusion of modules to increase awareness about monitoring change, and the particularities of working with soil in permafrost zones, could help to reduce the risk of lagoon breaches.

## 5.4. Melting Permafrost May Alter the Hydrology Around Sewage Lagoons & Wastewater Treatment Wetlands

Climate change is increasing the depth of the active permafrost layer in many regions of the NWT (Mackenzie River Basin Board 2004), and causing a decline in the areal extent of permafrost in discontinous permafrost zones (Quinton *et al.* In Review). These changes will likely lead to greater groundwater storage, increased infiltration, and increased base flow (Mackenzie River Basin Board 2004), as well as potential changes in surface water hydrology.

Often there is little knowledge available about groundwater and surface water dynamics around current wastewater lagoons and wetlands (C. Mallet, personal communication, 2009). Ground or surface water contamination is likely not a threat in all NWT communities; a risk assessment would need to be done on a case-by-case basis to determine where action is required to decrease the risk of wastewater effluent contaminating ground or surface water.

## 5.5. Climate Change May Impact Wastewater Levels in Sewage Lagoons

Changes to the quantity, timing, and type of precipitation falling in a region have the potential to impact the amount of runoff entering wastewater lagoons. Wastewater operators are required to maintain a freeboard level of 1 m in sewage lagoons (Dillon Consulting Ltd. 2007). When a lagoon reaches capacity, it may be necessary for a wastewater operator to release wastewater from the lagoon, even if the wastewater has not been held for the required retention time for treatment. Precipitation changes caused by climate change have the potential to increase the frequency of such early wastewater releases (O. Lee, personal communication, 2008), particularly in regions where precipitation is expected to increase. Communities that already require expansion and/or sludge removal in their lagoons to increase the freeboard are more vulnerable to these changes.

## 5.6. Climate Change May Impact Wetland Treatment of Sewage Effluent

Differential soil settling as a result of permafrost melt may cause changes to drainage patterns and the distribution of surface water in some areas. In areas of the Deh Cho, there have been increases in the size and number of wetlands (Quinton *et al.* In Review).

Increases in the depth of the active layer, or changes in the hydrological dynamics of the region around a lagoon and treatment wetland system would have the potential to change the depth and areal extent to which sewage effluent can impact wetlands used to treat wastewater effluent and/or the receiving environment (M. Kelly, personal communication, 2009). Other potential impacts include alteration of the retention time and effectiveness of wastewater effluent treatment in lagoons or wetlands.

Site-specific studies would be required to determine where such impacts are more likely and how to best monitor and prepare for potential changes.

## 5.7. Climate Change Will Likely Extend the Biological Wastewater Treatment Season

Low temperatures and long periods of ice cover are two of the most critical limiting factors to biological treatment in wastewater lagoons and wetlands of the NWT (Dillon Consulting Ltd., 2006).

As the temperature of wastewater decreases (at any temperature below 50°C) there is a decrease in the biological activity of the microorganisms that decompose organic compounds in wastewater (Hydromantis *et al.* 2006). For example, microbiological nitrification processes cease when the temperature falls to approximately 5°C, while carbon-consuming heterotrophic bacteria become dormant at around 2°C (Metcalf and Eddy 1991). As a result, a major limiting factor for wastewater treatment systems in the NWT is the limited season during which temperatures are high enough to enable biological treatment (Hydromantis *et al.* 2006).

If climate change lengthens the ice-free period on wastewater lagoons, and increases water temperatures, this would extend the season during which biological treatment of wastewater occurs (C. Mallet and M. Kelly, personal communication, 2009). This would likely increase the rate of biological treatment, and improve wastewater effluent quality by reducing the levels of biological oxygen demand and total suspended solids (Dillon Consulting Limited 2006).

Further research, and increased monitoring of wastewater treatment systems on a site-by-site basis will be needed to determine the impact of an extended biological treatment season on wastewater effluent quality.

# 6. Potential Impacts of Melting Permafrost on Leachate Movement from Community Solid Waste Facilities

## 6.1. Permafrost Melt May Alter Landfill Leachate Flow

Melting permafrost, and the potential hydrological changes this may cause, are of particular concern around waste disposal sites where hydrological change could alter landfill leachate flow. Permafrost restricts the movement of water within the ground to the active layer near the surface that thaws each year, and to permanently unfrozen areas called taliks. Permafrost thaw and differential soil settling may cause changes in surface runoff, groundwater flow, and drainage patterns (Mackenzie River Basin Board 2004).

*Community landfill*

No community solid waste facilities in the NWT have been built with an engineered liner to contain leachate that flows from the landfill site. In most NWT communities, the current or previous community landfills are located adjacent to the sewage lagoon, and therefore movement of leachate from the landfill has the potential to introduce contaminants such as metals, hydrocarbons or other pollutants to the wastewater effluent stream, and to surrounding freshwater ecosystems. A wastewater effluent quality sampling program conducted by INAC in 2007 found elevated metal levels in the wastewater effluent of more than half of the communities where sampling was conducted. The 2007 final sampling report suggested that this contamination could have been caused by leachate movement from nearby landfills, lagoon performance or introduction of contaminants at the raw sewage source. Further research is needed on a site-specific basis to confirm the source of elevated metal levels in wastewater.

## 6.2. Current Water Quality Monitoring Around Solid Waste Facilities

The same water license a community holds to undertake wastewater treatment also specifies that water quality samples be collected at one or more points downstream of the solid waste disposal facility. The purpose of this downstream surface water and/or groundwater quality monitoring is to determine if contaminants are leaching from the landfill into the surrounding aquatic environment.

The frequency at which such water sampling should be carried out is described in a community's water license. Many NWT communities are required to take one water sample per month downstream of their solid waste facility during periods of flow. This water sample is to be tested for water quality parameters including heavy metals and hydrocarbons (Dillon Consulting Ltd. 2007). However, many communities do not have yearly water quality data downstream from their landfill because no surface water flow has been detected every year, or samples have not been not collected.

Given the limited water quality monitoring around NWT solid waste facilities, communities currently have a minimal capacity to identify if and how contaminants may be moving away from unlined landfill sites and impacting the surrounding environment. There is therefore also limited capacity to detect any changes in leachate movement that may occur due to hydrological and landscape changes associated with permafrost melt. If consistent water, wastewater and leachate quality data were collected and made publicly available, communities would be able to increase their understanding of current leachate composition and migration patterns. This would make communities better equipped to respond to changes in leachate movement that may occur due to climate change, and plan for infrastructure responses. Even if no changes in leachate movement occur due to climate change, improved water monitoring would be a proactive and positive public policy action.

## 6.3. Removal of Contaminants from the Waste Stream

In addition to implementing a comprehensive system to monitor water and wastewater for contaminants, it is equally important to develop public policy and educational tools that reduce the quantity of toxic substances that enter the wastewater and solid waste streams.

### *6.3.1. Implementation and Enforcement of Sewage Use By-laws*

Sewage use by-laws specify the types and characteristics of wastes that can be discharged to the wastewater stream, and are considered a best practise in wastewater management (CCME 2009). They are a mechanism used by communities to require industries, businesses, institutions and individuals to remove or reduce contaminants at the source, prior to their entry into the wastewater stream. For example, sewage by-laws may prevent the discharge of photographic developing solutions containing silver or untreated fish plant effluent. The CCME has a model sewer use by-law available to assist jurisdictions in implementing contaminant source control measures. Such source control measures would need to be accompanied by education and training programs that provide citizens with the awareness and skills to facilitate their proper implementation, as well as rigorous enforcement. Implementation of sewage use by-laws would need to be built upon the guidelines the GNWT has established under the Environmental Protection Act to prevent commonly generated dangerous and/or hazardous wastes from entering the wastewater system or local landfills.

Wastewater effluent samples collected at sewage lagoons in 23 NWT communities in 2007 and 2008 showed that in some communities heavy metals such as silver, mercury and cadmium were present in various segments of the wastewater treatment stream at concentrations that exceed Canadian freshwater guidelines. These three metals are common targets in sewage use by-law programs, as they each have common institutional and industrial sources that can be controlled at the source. Further community-specific research is needed to determine levels of these metals at the point of wastewater discharge, and to determine the sources of these contaminants.

### *6.3.2. Increased Inter-governmental Collaboration to Implement Source Separation of Contaminants*

Interviews conducted to write this report demonstrated that staff in both GNWT - ENR and INAC - Water Resources would like to work with communities to implement programs to reduce contaminants entering the wastewater and solid waste streams. There are opportunities for wastewater sampling data collected by INAC - Water Resources to be used by waste specialists at the GNWT - ENR to pinpoint what contaminants to target for contaminant source separation education programs.

Staff from both the GNWT - ENR and INAC - Water Resources participate in the Northern Research Working Group for municipal wastewater effluent. Source control of contaminants is of interest for this group. This working group could therefore provide an appropriate venue through which contaminant source control initiatives could be developed in collaboration with NWT community leaders and citizens.

### *6.3.3. Waste Education Campaigns*

There is a need for expanded education campaigns to increase public awareness about the importance of properly handling and disposing of contaminants and hazardous waste. The GNWT - Environment and Natural Resources has already taken a positive step in this direction by increasing the number of Household Hazardous Waste Days in NWT communities. A further positive step the GNWT could take to reduce hazardous waste and contaminants would be to establish regional waste educator positions.

Expanded waste education campaigns should focus on increasing the ability of NWT residents to identify the impacts contaminants can have on human health and the environment, including hands-on education about how to separate these materials from the wastewater and solid waste streams. Regional waste educators could provide additional technical and logistical support to community waste and wastewater system operators, assist with implementing sewage use by-laws, help collect and ship hazardous waste products to appropriate disposal sites, and give public waste education workshops and presentations.

Increased diversion of environmental contaminants and hazardous materials from the wastewater and solid waste streams will provide long-term benefits to residents across the NWT, and enhance overall adaptive capacity, regardless of the precise impacts of climate change on waste management and water infrastructure.

# 7. Strengthening Our Ability to Adapt to Change: Conclusions and Steps for Further Action

## Conclusions

Climate change may impact community water and wastewater treatment systems in a number of different ways:

- Sourcewater quality may be affected by changes in turbidity, and concentrations of organic compounds, inorganic minerals, and trace metals such as mercury and arsenic.
- Changing permafrost conditions may increase maintenance and construction requirements and costs for water and wastewater infrastructure including cisterns, pipes, lagoons, buildings and roads, and landfill infrastructure, including engineered landfill liners.
- Permafrost melt may alter hydrological conditions around wastewater lagoons, and in wetlands used for wastewater treatment. These changes could increase the impacts that wastewater effluent has on the surrounding environment.
- Climate change may increase the biological treatment season, which could improve wastewater effluent quality.
- Permafrost melt may alter leachate flow from solid waste facilities, which could alter the pathway of contaminants into nearby freshwater ecosystems and wastewater treatment facilities.

A key vulnerability for many NWT communities with respect to potential impacts of climate change on water and wastewater systems is a lack of consistent water quality, wastewater and landfill leachate monitoring data. There is also a need for community-specific assessments of the potential impacts of climate change on water and wastewater systems.

## Steps for Further Action

### 1. Develop and implement a protocol to conduct site-specific assessments of the vulnerability of community water and wastewater systems to potential impacts from climate change

Given the variability of permafrost conditions, source water quality and climate changes across the NWT, the vulnerability of water and wastewater infrastructure to climate change needs to be assessed on a community-by-community basis. Such assessments could be used by communities to determine what, if any, specific actions are required to prepare their water and wastewater systems for more changing and more variable climate conditions.

### 2. Support NWT communities in ensuring that water licenses are issued and kept up to date, including adequate monitoring

Water licenses are an important tool to help guide communities in testing and monitoring source water use, wastewater treatment, and solid waste management. GNWT - MACA already plays a role in providing funding and support to communities to apply for and retain water licenses. Such support will be necessary to assist NWT communities without a current license to go through the application process.

A territorial public education campaign about the importance of water licenses, and how the water license process is set up to help protect human and environmental health could further encourage communities to keep their water licenses up-to-date. This campaign would need to be targetted at community staff, community managers, and health officials, as well as the general public, including school students. This would also be a way to dispel some misunderstandings about water and wastewater treatment processes, and increase trust in water monitoring systems.

### 3. Undertake more comprehensive and consistent source water, wastewater and landfill leachate monitoring programs

It is impossible for a community to react to changes in environmental conditions, and their impacts on water and wastewater systems, if citizens are not aware of the changes that are occurring. A key way to increase community adaptive capacity is to ensure that effective monitoring of source water, treated water, wastewater effluent and landfill leachate is occurring in NWT communities. Information from these monitoring programs will provide citizens with crucial information about how water and wastewater and solid waste containment systems are performing, and what changes need to be made to respond to environmental conditions.

Comprehensive and consistent monitoring of surface and groundwater surrounding community landfills and wastewater treatment systems is necessary to ensure that communities know if contaminants have moved from waste disposal and treatment sites into the surrounding environment, and can respond accordingly to this information.

### 4. Implement source-control measures and public education programs to control the release of hazardous substances and contaminants into waste streams

Increased diversion of environmental contaminants and hazardous materials from the wastewater and solid waste streams through implementation of sewage use by-laws, and public education campaigns will provide long-term benefits to residents across the NWT. Such actions will enhance overall adaptive capacity in communities, regardless of the precise impacts of climate change on waste management infrastructure.

### 5. Support education, training and professional development opportunities for NWT water and wastewater system operators

One of the most significant challenges that most NWT communities face with respect to water and wastewater systems is the ability to retain trained wastewater and water system operators. GNWT - MACA, and the Northern Territories Water and Waste Association play a critical role in increasing adaptive capacity of communities by planning, designing and offering education and training opportunities for water and wastewater operators. It is important that these educational and training efforts continue to be supported, and that information related to the potential impacts of climate change and the importance of water quality sampling and monitoring be integrated into learning modules.

### 6. Conduct further research on how climate change may impact mercury dynamics in aquatic ecosystems

Growing research suggests that climate change may be contributing to increased mercury levels in northern aquatic ecosystems. However, the mechanisms by which climate change may impact mercury dynamics in northern ecosystems are still poorly understood.

Although mercury may rarely be a concern with respect to drinking water quality, it is an environmental contaminant of great concern in the food web because it can bioaccumulate in the fatty tissue of fish and marine mammals and biomagnify in the food web (ACIA 2004). Increasing knowledge around the risks that mercury poses in the aquatic ecosystem, and sharing this knowledge through public outreach activities are important steps in building trust in NWT water supplies and water quality monitoring.

### 7. Establish a climate change adaptation fund for NWT community infrastructure

Adaptation to a changing and more variable climate will likely require many NWT communities to upgrade infrastructure, including water and wastewater treatment systems. Establishment of a cost-sharing climate change adaptation fund for community infrastructure will provide a financial incentive to encourage and support NWT communities to identify and make infrastructure improvements that are needed to prepare for climate change impacts.

### 8. Explore diverse options for wastewater treatment

Small-scale, on-site wastewater treatment systems are an alternative to centralized treatment that requires extensive trucking or piping of wastewater. On-site wastewater systems accept either black or grey water, cleanse the water to "swimming pool" standards (safe for human contact), and return the water for reuse in toilets and for laundry.

In the North, grey and black water treatment systems have been piloted in Iqaluit and N'dilo. These small-scale systems were designed to service approximately 20 people, and were located within the building serviced, or in close proximity. These systems successfully eliminated the need for sewage pump-out service, increased the volume of water available for household use, and reduced the need for potable water delivery by 50% (Aleta Fowler, personal communication, 2009). Additional benefits of small-scale, on-site wastewater treatment systems include the potential to reduce maintenance costs for local roads being impacted by permafrost melt, and to reduce transportation costs and fossil fuel used for moving water and wastewater.

Five years of monitoring in N'dilo produced highly satisfactory water quality testing results; however, the pilot showed that more user education, and trained maintence people were required for successful continued operation. Further pilot studies of on-site wastewater treatment are needed to determine the viability of using such systems on a broader scale.

*Mackenzie River near Taglu Island, Mackenzie Delta*

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# APPENDIX I. Individuals Interviewed for this Assessment

Ecology North is grateful to the following individuals who shared their expertise and ideas with us in the preparation of this report.

- Ron Bujold, Environmental Assessment Technician, Environment Canada
- Gerald Enns, Hazardous Waste Specialist, GNWT - Environment and Natural Resources
- Aleta Fowler, Policy and Planning Advisor, Indian and Northern Affairs Canada
- Duane Fleming, Chief Environmental Health Officer, Stanton Territorial Health Authority
- Greg Hamann - Water Quality Environment Specialist, GNWT - Municipal and Community Affairs
- Ed Hoeve, EBA Engineering Consultants
- Patrick Hough, Solid Waste Specialist, GNWT - Environment and Natural Resources
- Mary Kelly, Northern Wastewater Researcher
- Heather Scott, Project Manager, Dillon Consulting, Ltd.
- Steve Kokelj, Environmental Scientist, INAC
- Olivia Lee, Engineering Team Lead, GNWT - Municipal and Community Affairs; Executive Director, NWT Water and Waste Association
- Catherine Mallet, Regulatory and Science Advisor, INAC
- David Mate, Researcher, Geological Survey of Canada
- Jim Sparling, Manager, Climate Change Programs, GNWT - Environment and Natural Resources
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