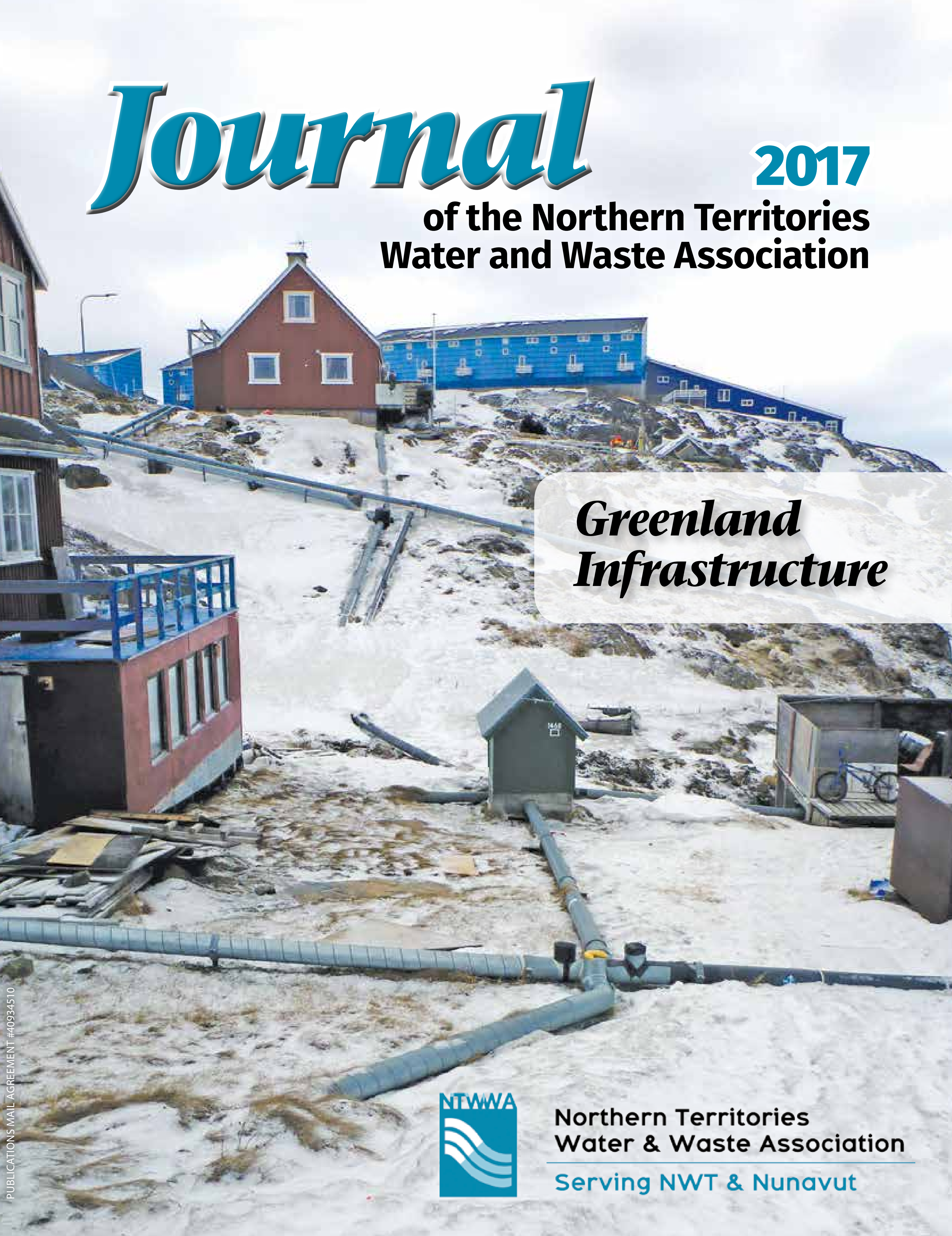

Journal

2017

of the Northern Territories Water and Waste Association

Greenland Infrastructure

Northern Territories
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Water and sewer piping in Sisimiut, Greenland.

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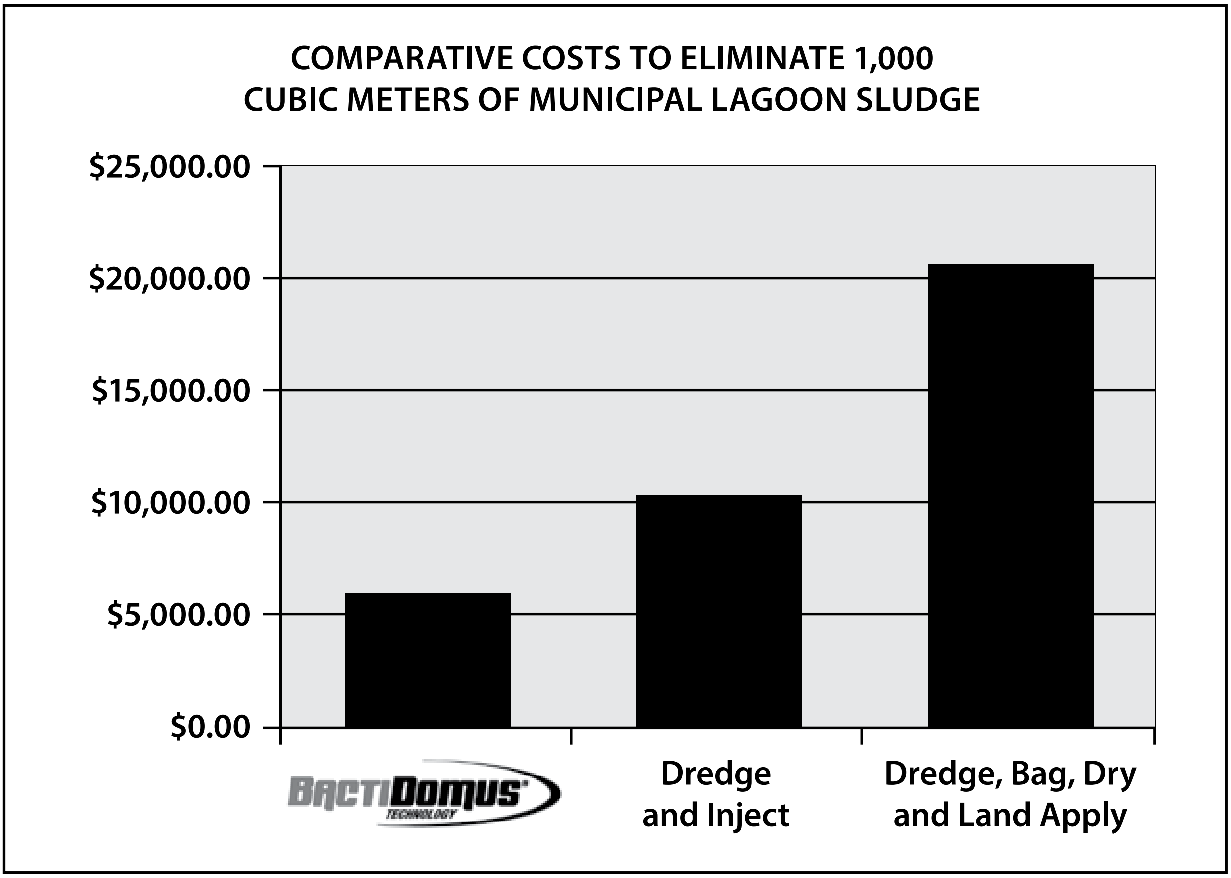

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Editor's Notes

KEN JOHNSON

NAAK W.C-II ? (WHERE'S THE TOILET)

My interest in the theme of the 2017 *Journal* goes back almost 30 years to my first visit to Iqaluit in 1988, when I was a MACA rookie. The proximity of Iqaluit to Nuuk, Greenland at a mere 800 kilometres captured my curiosity on how water and sanitation services are provided in this close northern neighbour. The opportunity to present this theme emerged by accident, as many opportunities often do in the north, with a visit to the National Research Council and our northern water peers Andrew Colombo and Yehuda Kleiner in January 2016. Andrew mentioned that he was planning to attend a water conference in Sisimiut, Greenland, and he wondered if I wanted to attend. My response was an immediate yes. The ARTEK conference (Google "artek presentations") was the opportunity to fulfill a decades-old interest, and has provided new opportunities for the exchange of ideas and experiences with our Greenland, and northern European water peers.

Many thanks to these peers for their informative articles in the 2017 edition of the *Journal*. Specifically, I would like to thanks Kare Hendrikson, Pernille Jensen, and Frank Rasmussen. Frank was able to attend the 2016 conference in Yellowknife, and his presentations were a welcome addition to the program.

Many thanks as well to Pearl Benyk for her valuable editorial comments (without apologies) on all of the articles. As much as technical people think they can write, we have a tendency to depart from plain language communication, which is important to broad audience of the *Journal*. I won't even bother to comment on our punctuation skills (laugh).

The most astounding bit of information from Greenland is the cost of water in Qaanaaq (Thule), which is a whopping $120 per cubic meter, which tops the cost of water even in Grise Fiord. The solid waste management techniques in Greenland offer some interesting insight on the possibilities in the Arctic, which Canadians can probably learn from.

As always, any questions, and comments are welcome by email kenneth.johnson@stantec.com or cryfront@gmail.com, text 780.984.9085 or telephone 780.904.9085. Anyone wishing to contact any of the authors may also send me a note, and I will forward their contact information.

JESSE SKWARUK DOESN'T TAKE DRINKING WATER FOR GRANTED

Jesse's volunteer work around the globe inspired him to complete his university studies in water politics and policy. It was his training in NAIT's Water/Wastewater Technician program that gave him the practical experience he needed to turn his passion into a career.

He's now a technologist at an Edmonton plant, testing and treating drinking water. He continues to travel the world, working with development agencies that help provide clean water for communities in need.

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Skyline in Nuuk, Greenland.

LIFE IN GREENLAND, AND ITS SUPPORTING INFRASTRUCTURE

Introduction

Greenland is a massive island of 2.2 million square kilometres, and geologically part of North America, with most of its land surface is covered in ice. Politically, it is an autonomous Danish territory, and most of its 56,186 people live in 75 communities along the ice-free, fjord-lined coast.

Nuuk is the capital and largest community, and consequently the government centre and the headquarters of the crown corporations that operate in Greenland. With a population of 16,000, it is almost twice the size of Iqaluit and, by Arctic standards, a large urban center. It is natural to compare it with Iqaluit, since the cities are relatively close neighbors at the same latitude of 64 degrees north, and a mere 800 kilometres apart across Davis Strait.

Nuuk is a modern community with a European flavour, with buildings that include a small two-storey shopping mall and a few large conventional supermarkets. While private home ownership is common in Nuuk, there's still a significant amount of public housing. The old area of Nuuk has detached family homes, and modern condominium style and rental apartment buildings are found in the new suburbs and in town. Nuuk is almost entirely built on coastal bedrock, and this geology supports relatively tall buildings with stable foundations in spite of the presence of permafrost. A district heating system provides heat to the entire community.

There are 75 communities in Greenland, consisting of 13 communities with a population of more than 1,000; 17 communities with a population between 200 and 1,000; 12 communities with a population between 100 and 200; and 21 communities with a population of less than 100. Sisimiut, 330 kilometres north of Nuuk, is the second-largest community, with a population of 5,600. Ilulissat, 600 kilometres north of Nuuk, is the third-largest community, with a population of 4,500.

Transportation

Nuuk enjoys year-round sealifts and is well supplied with European consumer goods. The Royal Arctic Line is a sea-going freight company in Greenland, wholly owned by the Greenland Home Rule Government. Royal Arctic Line has the monopoly on cargo routes among Greenlandic communities, and between Nuuk and Aalborg in Denmark. It manages 13 harbours in Greenland, as well as the Greenlandic base-harbour in Aalborg.

Fish harvested around Greenland makes up roughly half of the cargo shipped from Greenland to Denmark, and construction materials account for roughly a quarter of the shipments from Denmark to Greenland. Fish and beverages bottled at Nuuk (principally water and beer) account for most of the shipping between Greenland communities. The key settlements of western Greenland are ice free

By Andrew Colombo and Yehuda Kleiner,
National Research Council of Canada;
and Ken Johnson, Stantec

year-round, whereas eastern Greenland experiences seasonal sea ice and operates a seasonal sealift similar to Nunavut.

Air Greenland is the sole air carrier operating within Greenland, with fleet of almost 30 aircraft, including one Airbus jet, seven Dash 8 aircraft and 21 helicopters. The large fleet of helicopters is necessary because only 18 of the 75 of the communities in Greenland have runways. Nuuk's airport is not the largest or most modern air terminal in the country. In fact, the gateway to Greenland by air is the Kangerlussuaq airport, situated 130 kilometres inland from the coast on a fjord, which is a location that is less vulnerable to adverse coastal weather. A daily flight to Copenhagen leaves from Kangerlussuaq, and most flights within Greenland pass through Kangerlussuaq, which is also the only airport long enough for a large jet.

Water, power, heating and sewage

A Crown corporation called Nukissiorfit is responsible for drinking water, electricity and district heating in communities where these amenities are available. The drinking water sources are typically glacial melt lakes and rivers. In most communities, water is filtered and disinfected with UV and/or chlorination. In Nuuk, Sisimiut and Ilulissat, water is piped directly to consumers, and distributed through pipes which are typically insulated High Density Polyethylene.

Nukissiorfit also operates the country's five hydroelectric facilities. The first hydro facility was commissioned only in 1993. Prior to the advent of hydro power in Greenland, fuel-burning facilities were used for power generation and to heat water for district heating. In both Nuuk and Sisimiut waste incineration also contributes heat for the district heating systems. In the smallest and most remote communities diesel fuel is used for heating.

In most of Greenland, sewage is not treated, but rather discharged directly into the marine environment through collection systems that include bagged sewage, trucked sewage, and piped sewage. One "traditional" approach to sewage disposal in Greenland, which is still in use in some communities, is known as "Natrenovation" or night renovation. Natrenovation involves placing bagged sewage at the edge of fjords at night, and allowing the tides to carry the bags away by morning. A variation on Natrenovation involves transporting the bags to dedicated disposal buildings, fondly referred to as "chocolate factories", where sewage bags are opened and deposited in a common basin that discharges directly into the ocean. In the case of Nuuk, there are bagged, trucked and piped wastewater systems.

Insulated high density polyethylene pipe with freeze protection conduits.

Sewage dump station, or "chocolate factory".

Incineration facility in Sisimuit, Greenland.

Solid waste management in Greenland

Greenland's solid waste challenges are similar to Nunavut's because of its geography, however the use of incineration, and the heat it produces, is making a dent in improving waste management. Only six communities have incineration plants, but these plants feed heat into the communities' district heating systems. Half of the communities have what may be referred to as incineration ovens, and the rest of the communities use open burning.

In 2011, the municipality of Sermersooq, which includes the community of Nuuk, considered scrapping the current incinerator facility and building a new one. In the end, a decision was made to upgrade the current incinerator instead, saving the municipality an estimated 33 million euros. The upgrade was completed in in 2014 and included new fire tubes, a boiler shunt system, a water-cooled feeding chute, a new grate and water-cooled wear zones. The plant has a sophisticated pollution control system that involves a baghouse for particulate extraction. Collected particulates and ash are sent periodically to Denmark for appropriate treatment and landfilling.

Conclusion

Although Greenland is physiographically and ethnically an Arctic island nation associated with the continent of North America, politically and historically Greenland has associated with Europe, specifically Iceland, Norway, and Denmark. Greenland is, by area, the world's largest island and not a continent. The infrastructure in Greenland is somewhat unique by Canadian Arctic standards, but the issues for the development, operation and maintenance of the infrastructure are not so different from those in the Canadian Arctic. With more similarities than differences between Greenland and Canadian Arctic infrastructure, there is a significant opportunity to learn from each other.

Call for articles

2018 edition for the NTWWA Journal - the theme of the 2018 edition will be "Resiliency in Northern Infrastructure" contact Ken Johnson if you want to prepare an article

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Greenland solid-waste management

By Frank Rasmussen, Chief of Operations,
Environment Department,
Semersooq Municipality, Greenland

Solid-waste baling machine used in small communities.

Baled solid waste in wrapping machine.

Wrapping of solid-waste bale underway.

It's a wrap.

Loading wrapped bales for transportation to incineration facility in larger community.

Incineration facility in Nuuk, Greenland.

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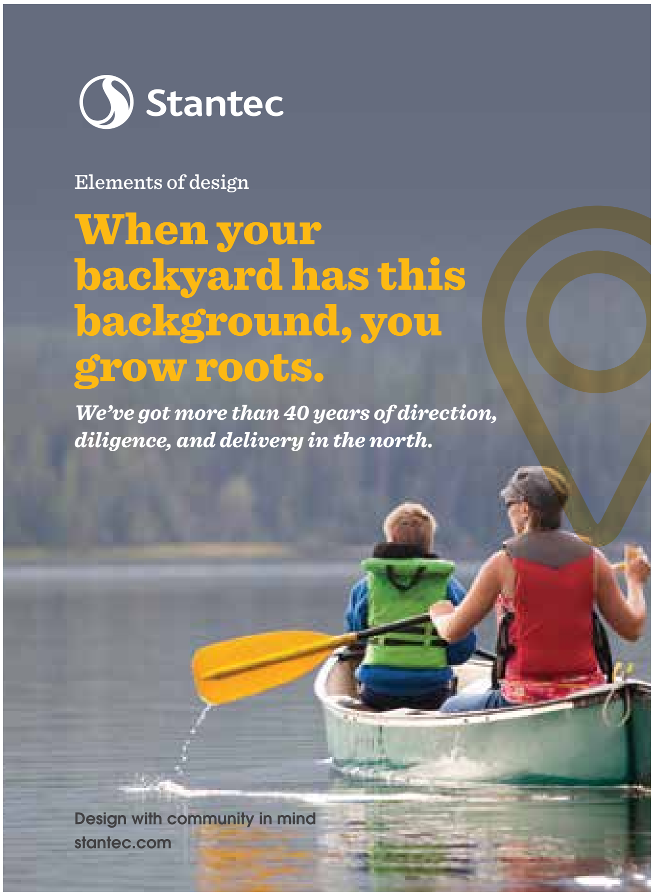

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Shoreline in Qaanaaq (Thule), Greenland.

WATER SUPPLY AND SOCIO-ECONOMICS IN QAANAAQ (THULE), GREENLAND

Several places in the Arctic, including North Greenland, have major challenges in ensuring adequate drinking water supplies at a reasonable price. In Greenland, these challenges include the location of communities on small islands without an adequate freshwater resource. Adding to these challenges is the Arctic desert climate which produces less than 120 millimetres of precipitation a year.

Qaanaaq is the world's most northerly inhabited region with indigenous people, which experiences four months of winter darkness, a long period of midnight sun, and a fjord system covered by sea ice eight to 10 months a year. The Village of Qaanaaq, which has 640 residents, is situated on a moraine slope with permafrost. During the short summer, the nearby river drains the local water catchment area, and to a lesser extent, meltwater from the local glacier, located above the community. In the four months of summer the water supply comes from the river and the flow is also used to fill two large water storage tanks to provide the water supply for another four months. During the remaining four months of the year, pieces of icebergs are harvested with a loader and placed in a melting chamber to supply the community with water. The task of collecting fresh water ice on the sea ice is dangerous, especially late in the season when the condition of the sea ice becomes increasingly uncertain. Climate change has exacerbated this problem because the sea ice remains thin in some areas during much of the winter period, while the period for the getting the supply of fresh water from the river has not increased accordingly. In addition, the method of collecting icebergs for freshwater is very costly, resulting in Greenland's most expensive water with a production cost of about 600 DKK per cubic metre ($120 Canadian per cubic metre) in the winter season.

Qaanaaq is one of Greenland last hunting districts, and until recently the catch of marine mammals, reindeer and muskoxen constituted the district's primary livelihood. But the interplay of numerous concurrent factors has gradually undermined the subsidence economy of hunting.

Seasonal water supply stream in Qaanaaq, Greenland

By Kare Hendriksen, Arctic Technology Centre, Technical University of Denmark

With the gradually reduced sea ice caused by climate change, walrus, and sea mammals have been moving further off shore, which requires a significantly greater effort bringing the catch to the community. The disappearing sea ice has also reduced polar bear hunting opportunities. At the same time, the possibility of selling skins and ivory or crafts produced from ivory has been significantly reduced as a result of changing international regulations. Also, the hunting quotas, especially for marine mammals and polar bear, have been reduced.

A gradual transformation from a subsistence hunting society into a fishing society is occurring, and fishing for Greenland halibut is becoming increasingly more significant. This is the case in much of the rest of Greenland. Qaanaaq has a small fish factory with limited freezer capacity for halibut.

Fishing for halibut only occurs in the winter when there is sea-ice, because the halibut migrate out of the range for fishing in the summer when narwhals migrate into the fjords. This means that the halibut fishery in Greenland takes place during the period when freshwater is produced by melting icebergs, and from an economic perspective, with the cost of freshwater, it makes no sense to process halibut locally. Therefore, halibut is frozen whole, which provides no jobs in the fish processing sector.

A clear link between ensuring a cheap year-round water supply and the development of the district's industrial base thus exists, and the need for water has to be viewed as an issue when considering sustainability. It is crucial for the development of the district that a solution for a cheaper and stable water supply is found. The Arctic Technology Centre is in dialogue with, among others, the national electricity and water company Nukissiorfilt to discover or develop implementable solutions. Different options such as reverse osmosis, the establishment of additional storage tanks, or the establishment of an open-water storage reservoir are being considered.

Ice berg melting box in Qaanaaq, Greenland.

Skyline of Sisimuit, Greenland.

SISIMUIT, GREENLAND WASTE INCINERATOR

Introduction

Sisimiut is a small town located on the west coast of Greenland, just north of the Arctic Circle. With roughly 5,500 inhabitants, it is the second largest locality in the country. The remoteness and clustered infrastructure of Greenlandic communities makes appropriate waste management challenging at local and national scales. In total, roughly 3,000 tons of waste are incinerated every year in Sisimuit, and hot water is produced from the process in order to supply district heating to a neighboring part of the city.

District heat is also provided in this network by two dedicated heat plants in which electric boilers and oil boilers are operated. Priority is given to the utilization of heat generated by the waste incinerator over the boilers located in the plants, since this recovered heat is considered as a "free" by-product from a necessary process. Utilizing waste heat from the incineration plant therefore reduces the consumption of oil in the district heat system, and lowers the carbon emissions of the city.

Edited from thesis by Simon Challet, Sustainable Energy Engineer WIP - Renewable Energies, Munich, Germany

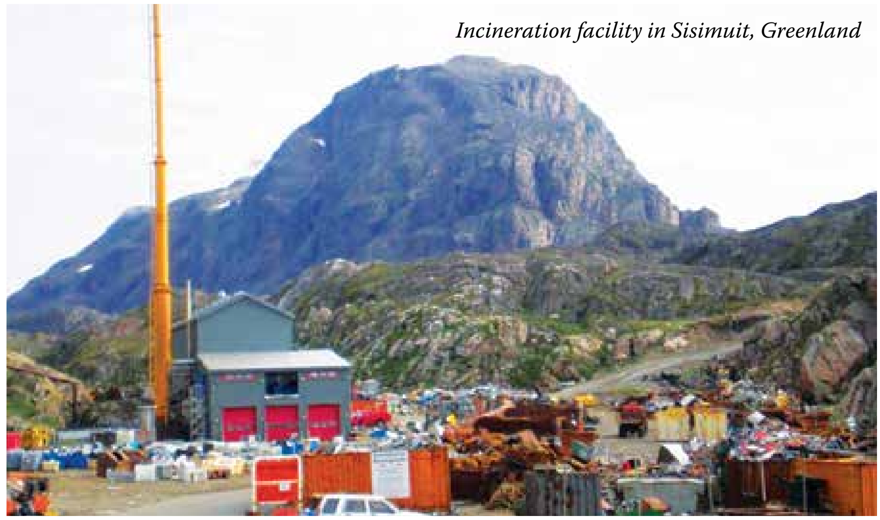
Energy context in Greenland

Since the 1950s, electricity generation in Greenland has been based mostly on diesel engines. Diesel engines commonly have a thermal efficiency close to 35 per cent, which means that 65 per cent of their fuel consumption is lost as heat. In order to utilize this "waste" heat, most of the diesel generators in Greenland have progressively been converted to Combined Heat and Power (CHP) technology, making the waste heat from the engines available for heating purposes. The efficiency of the process can be very high in well-designed systems, with up to 90 per cent of the heat produced being utilized.

Space heating for buildings is required all year round, and heat is supplied in two different ways: with individual oil boilers (mostly in individual houses and small settlements) or by connection to a district heat network. District heating is mostly now available in the largest Greenlandic towns, where building density is high and good infrastructure is available. In large district heat systems the heat is transferred from the pipe network to the heating and domestic hot water systems of the customer buildings through heat exchangers called substations. In this way water from the district heat network is not directly circulated inside the buildings.

Waste context in Greenland

Overall, little is known of the quantities and exact compositions of waste in Greenland, especially in the smallest settlements. It is estimated that the largest fraction of all waste generated in Greenland comes from packaging from imported goods and post-consumer waste, and that the total waste resource is around 50,000 tons per year for the whole country. The layout of Greenlandic landfills is very basic, withoutany kind of ground liner or leachate control, and results in the direct contamination of local soil and water by wash-off from toxic products contained in the waste.



Incineration facility in Sisimuit, Greenland

Electricity and heat supply in Sisimiut

A new hydropower plant for Sisimuit was completed in 2010 and supplies elec-

Grappling hook transfer of solid waste.

Excess heat ventilation system for incinerator.

tricity through a 27-kilometre-long high-voltage line. The plant has a capacity of 15 MW but in normal operating conditions delivers between five and 10 MW, which covers the total electricity demand of the community. Nukissiorfiit maintains the old generation plant located on the harbour and keeps it as a back-up in case the hydropower plant breaks down. Heat supply in Sisimiut is currently provided by either individual oil burners or district heating.

Waste Incineration Facility in Sisimiut

The waste incineration facility has three main parts: the receiving area, the treatment area, and the residual area. The receiving area includes the ramp used by the collection trucks to deliver household and commercial waste to the incinerator, a waste pit in which the waste is stored before being fed into the furnace, as well as a waste shredder used to reduce the size of voluminous waste.

The treatment area is the largest part of the incineration facility. The treatment begins with a mixing of the waste to ensure that it is as homogenous as possible; a grappling hook is used for this purpose. Once the waste is mixed, the grappling hook transfers the waste to an inlet funnel to the furnace. In the furnace, the incineration is controlled for an optimal combustion temperature of about 1,000 °C. The ash is collected from the furnace after roughly two hours of incineration time. The flue gases are channeled through a closed loop heat exchanger. Another heat exchanger transfers the heat to the district heating circuit. If the heat demand in the district heating network is lower than the heat production from the waste incinerator, a secondary cooling system is used to ventilate the recovered heat into the air.

The flue gases are passed through an electro-filter, which extracts the heaviest pollution particles or fly ash. The ashes typically represent 10 to 25 per cent of the volume of incinerated waste and also include the remaining from non-combustible waste such as metals and glass. The non-combustible waste residue (ash) is buried in the ground in Sisimiut, whereas the fly ash is collected and transported to Denmark for treatment.

Conclusion

The municipal waste incinerator in Sisimiut allows the city to sustain a continued growth in population and living standards, without the negative impacts of an increasing amount for the landfill, and the environmental issues associated with landfilling. Improvements to the incineration are ongoing with continuing optimizing of the operation and maintenance.

Qaanaaq (Thule) Harbour

WASTEWATER HANDLING IN THE ARCTIC ISLAND-OPERATED SOCIETIES OF GREENLAND

In Greenland, there are major challenges regarding all kinds of infrastructure, including sanitation and waste handling. It is partly a consequence of the climatic conditions, but it is heavily connected to the fact, that all societies in Greenland are challenged by island operation. In addition, over the past decades, Greenland experienced a sector division of the infrastructure that for many tasks has complicated the necessary cooperation.

Greenland, with its limited population of only 56,000 inhabitants, should be viewed as a micro-state. In addition, the fact that Greenland is not one but essentially an association of 75 small or very small "island economies" is a central challenge. In Greenland, all trade currently takes place directly between individual settlements and Denmark. The export of relatively unprocessed fish and shellfish accounts for 90 per cent of the export income and the processing often takes place in low-wage countries, which means a large part of the added value is gained outside Greenland.

The Greenlandic dependency on external labour is observed throughout the country. It is not possible to commute between settlements on a daily basis anywhere in Greenland. At the same time, Greenland faces the challenge of a costly and complex supply infrastructure. Each settlement not only has its own means of producing electricity, but also a backup, because if the power supply fails for just a short period during the winter, all plumbing systems and fixtures are destroyed by freezing, and the settlement has to be evacuated.

Transport infrastructure is costly, and in areas closed off winter sea-ice, storage capacity and supplies for longer periods are needed. It is also crucial that each community have the capacity to freeze its catch until the first ship arrives. Thus, it is not possible

Sewer pipe repair in winter

By Kare Hendriksen, Arctic Technology Centre, Technical University of Denmark

to compare Greenland to Iceland, northern Norway or the Faroe Islands, as is often done. The simple reason is that in these other northern areas each settlement is part of a more coherent infrastructure an electricity supply network, and road and/or regular ferry connections, enabling continuous supplies, exports and even commuting. The nature of Greenland as a micro-state with island operated sub-units require unique solutions for development, of a sustainable industrial base, local skills, and handling of infrastructure related challenges.

Sectorization and its impact

The island operation situation is further challenged by the increased level of sectorization of the infrastructure that has characterized the development of Greenland since the late 1980s. Greenland's infrastructure sector has, in recent decades and in a broad sense, been divided into 94 individual limited companies fully or partially owned by the Government of Greenland, as well as a few "net managed" companies owned by the Government of Greenland. The objective was that each company could optimize its services within their own core business and thus achieve greater efficiency and consequently savings. The owner of these companies, usually only the Self Government Rule, has a natural expectation that the individual company generates a profit.

The challenge, however, is that with this sectorization and desire that each company generate a profit, what follows is a natural sub-optimization, where each company focuses on its core business and cuts functions that are not essential for this operation. From a business economic point of view, this strategy makes good sense, but looking at it from a societal perspective, this approach weakens a holistic use of resources. Overall, this sectorization results in very high costs for each of the fully or partially self-government owned enterprises. At the same time the consequence is that a number of socially necessary tasks are not resolved, and that each community at times more or less comes to a halt, triggering a number of secondary social costs and pushing towards a more dysfunctional society.

Wastewater management with "island" economies

Island-operating issues by themselves challenge all kinds of sanitation infrastructure in several areas. For small island-operated societies, constructing sewage collection systems is disproportionately costly, and in Greenland more expensive and complicated because all piping has to be freeze protected with


Bagged sewage dump station or "Chocolate Factory"

Bagged sewage in landfill

electric thaw cables. Therefore, a large portion of the larger Greenlandic communities do not have a sewer system, or only a partial sewer system. None of the smaller communities have any sewer systems, and instead rely on bagged sewage collection.

The grey water is discharged onto the ground, and the bagged sewage is collected and disposed of by "Natrenovation", which involves placing bagged sewage at the edge of fjords at night, and allowing the tides to carry the bags away by morning. It might also involve transporting the bags to dedicated disposal buildings, fondly referred to as "chocolate factories, where sewage bags are opened and deposited in a common basin that discharges directly into the ocean.

The black-water handling in Qaanaaq (formerly Thule) is challenged by the fact that a reef is located a couple of hundred meters from the shore, so it is not possible to manually pour toilet waste into the sea. Therefore the filled toilet bags are left at the landfill, resulting in uncontrolled leakage into the surrounding environment.

Conclusions

Wastewater handling in the Arctic island operated societies of Greenland is a complex technical, administrative and political situation. The progress to improve wastewater handling is slow, but incremental improvements are being made.

Untreated wastewater outfall in Sisimiut, Greenland

GREENLAND WASTEWATER LEGISLATION

By Pernille Jensen, Arctic Technology Centre, Technical University of Denmark

Greenland has over 70 settlements with populations ranging from 20 to over 17,000 with a median population of 150. Most of the settlements (83 per cent) have a population of less than 1,000 with 50 per cent having a population less than 200. Three per cent of Greenland's population is dispersed across 40 per cent of the settlements. This reality of population distribution greatly impacts the priorities for wastewater treatment and management. The proportion of households that are dependent on a water tanks or collecting water and utilizing a bagged dry toilet increases as one goes further north in Greenland.

There are three typical system configurations for managing household wastewater in Greenland, and these systems discharge untreated wastewater to the marine environment:

1. Piped sewage system discharging directly into the ocean;
2. Trucked sewage system with a single household tank, which is emptied by a vacuum truck, and discharged directly into the ocean; and
3. Bagged sewage system with a household dry closet, with bags collected and emptied directly into the ocean, or deposited in a landfill. .

Greenland introduced new legislation in 2015 regarding the disposal of wastewater. The new legislation requires cities and hamlets to develop wastewater plans. The wastewater plans for the cities are due on August 1, 2018 and for the hamlets on August 1, 2020.

The wastewater plans must indicate the placement of the sewage discharge and the expected quantity of wastewater. Treatment and information regarding the expected quality of the wastewater is optional.

If the sewage discharge system serves less than a 50 person equivalent, which applies a one-person equivalent corresponds to 21.9 kg organic compounds/year, 4.4 kg Total Nitrogen/year and 1.0 kg Total Phosphorous/year, and the sewage discharges into the ocean, then the local municipality issues the sewage discharge permit. Otherwise, the Greenlandic Office of the Environment assess the situation and issue the permit.

The legislation does refer to developing wastewater plans for the receiving environment; however, there are presently no effluent quality parameters or timelines associated with developing wastewater plans.

BIOELECTRICALLY-ASSISTED ANAEROBIC SEWAGE TREATMENT IN THE NORTH

Most communities in the Canadian Arctic use waste stabilization ponds (also known as sewage lagoons) as the primary or sole treatment for municipal wastewater. Sewage lagoons are robust and relatively simple and inexpensive to operate. However, it appears that most existing lagoons cannot produce effluent that meets Environment Canada's standards. The National Research Council of Canada (NRC), through its Arctic research program, has endeavoured to address this issue by developing a novel approach for the biotreatment of sewage.

The bioelectrically-assisted anaerobic sewage treatment (BeAST) technology developed at the NRC uses microbially-catalyzed electrochemical reactions to achieve a high degradation rate of organic wastes. This process does not require aeration, and the electroactive (anodophilic) bacteria were shown to perform well even at low temperatures. Moreover, the process is energetically net positive, and if the biomethane produced is captured, it could potentially be burned for heat or used for electricity generation.

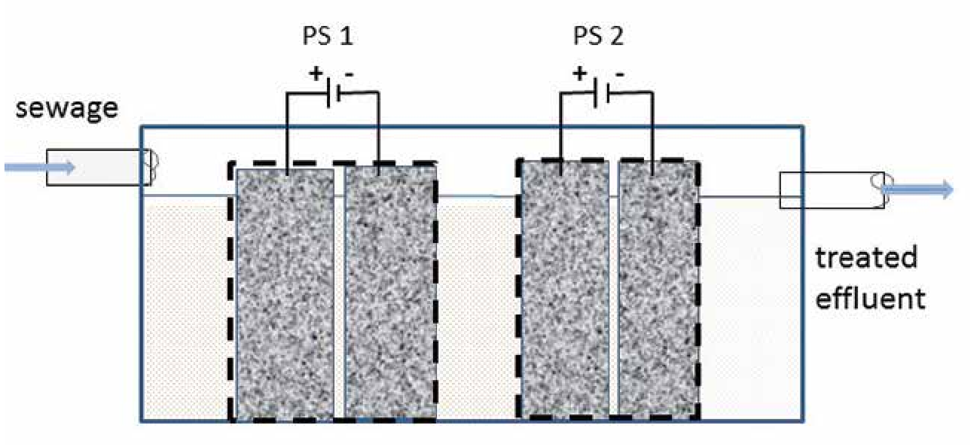


Figure 1

Laboratory trials

The BeAST reactor is essentially a septic tank equipped with electrodes composed of electrically-conductive porous medium, such as granular activated carbon (GAC). Laboratory experiments examined the process performance at various temperatures and organic loads. Synthetic wastewater consisting of proteins, cellulose fibre and salts was used in initial tests to simulate high-strength (five-day Biological Oxygen Demand [BOD5]) concentration of approximately 350 to 500 mg/L wastewater typical in Arctic communities, where water is distributed and sewage is collected by trucks. These trials were followed by tests using actual raw sewage taken from a municipal treatment plant in the Montreal area.

The general design of the reactors used in laboratory tests is illustrated in Figure 1. The 20-litre, rectangular-shaped reactor, similar in design to a conventional septic tank, houses two pairs of electrodes (each pair comprising an anode and a cathode). The electrically conductive porous material in the electrodes is suitable for microbial attachment and biofilm formation, as well as for facilitating electron exchange between the electrochemically active microorganisms and the electrodes.

The process was tested at temperatures of 23°C, 15°C and 5°C. BOD removal efficiencies as high as 97 per cent and suspended solids reduction of up to 98 per cent were observed at a hydraulic retention time of only 3.3 days. For comparison, a conventional septic tank was also operated under similar conditions to provide a baseline (Figure 2). The bioelectrochemical process of sewage treatment converts organic wastes predominantly to methane gas (70 to 80 per cent content of methane in the biogas), resulting in potential energy production as well as low sludge volume. The biomethane

By B. Tartakovsky, Y. Kleiner, A. Columbo,
National Research Council of Canada, Ottawa, ON; and
R.C. Tsigonis, R.M. Tsigonis,
Lifewater Engineering Company, Fairbanks, AK

produced by the BeAST had an energy content that far exceeded the electrical energy required to support the bioelectrochemical activity, resulting in net energy gain (calculated as a difference between energy production as biomethane and energy consumption for electrode operation) even at low temperatures.

Pilot tests

There are currently two scaled-up pilot tests underway, with plans to conduct more northern-based tests at increasing scales. A 240-litre reactor is showing excellent results in Sainte-Catherine, Quebec (Figure 3), where a five-month-long test was carried out covering both winter and summer conditions with wastewater temperatures ranging from 10°C to 26°C. Throughout this pilot test, effluent BOD5 values remained below 15 mg/L (Environment Canada's effluent standard is 25 mg/L BOD5, 25 mg/L Total Suspended Solids (TSS)) when the reactor was operated at a hydraulic retention time (HRT) of two days, with most measurements showing BOD and total suspended solids (TSS) values of less than 10 mg/L. This test confirmed the efficiency of the passive flow and the ultra-low power consumption (0.1 kW per g of Chemical Oxygen Demand (COD) removed) of the bioelectrochemical reactor.

A larger scale test (approximately 2,500 litres) is ongoing in collaboration with Lifewater Engineering Company in Fairbanks, Alaska. The partnership with NRC involves testing the BeAST under controlled conditions in a tank designed by Lifewater Engineering (Figure 4), with the intent of deploying such systems in rural Alaska.

The full-scale pilot at was designed to treat the wastewater load of a single-family, three-bedroom home. It is fully modifiable with a removable lid and access hatches to each of the compartments. In addition to the Granular Activated Carbon (GAC)

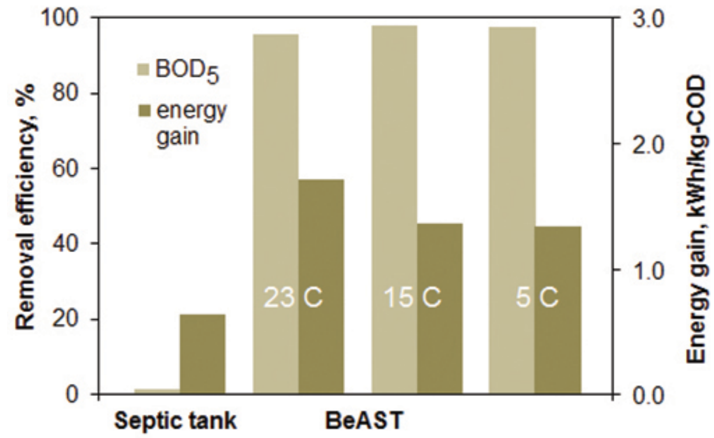


Figure 2

Figure 3

Figure 4

electrodes, Lifewater's BeAST has fixed-film media to facilitate formation of anaerobic biofilm. Currently the BeAST is treating the high-strength wastewater generated at Lifewater's shop and is achieving a 73 per cent reduction of COD. The system is being continuously monitored and modified to improve treatment efficiency.

The BeAST technology is fully scalable and can be designed to provide adequate wastewater treatment for a single dwelling or for a small community. In a community, it could also function as an upstream process to be used in conjunction with an existing lagoon in order to significantly decrease the amount of organic wastes (organic load) entering the lagoon, while also producing biogas. While a single-home application is not expected to generate a sufficient amount of methane to render it economically viable for energy capture (except to ensure the reactor vessel remains warm enough to sustain the biotreatment), the amount of gas produced from a community of a few hundred people is likely to justify the cost of harnessing it for heat production or electricity generation.

Preparations are underway to test the BeAST in different configurations and venues in the Canadian North. For example, we are planning to test the BeAST with a cluster of homes and in a small community of a few hundred inhabitants, in order to work through the challenges of handling larger volumes of sewage and greater gas production. Appropriate handling of biogas (biomethane) will be addressed in future testing. Community-level deployment is expected to provide enough gas for heating moderately-sized enclosure, such as a workshop, storage area or greenhouse.

SECOND EDITION OF *GOOD ENGINEERING PRACTICE FOR NORTHERN WATER AND SEWER SYSTEMS* (GEP)

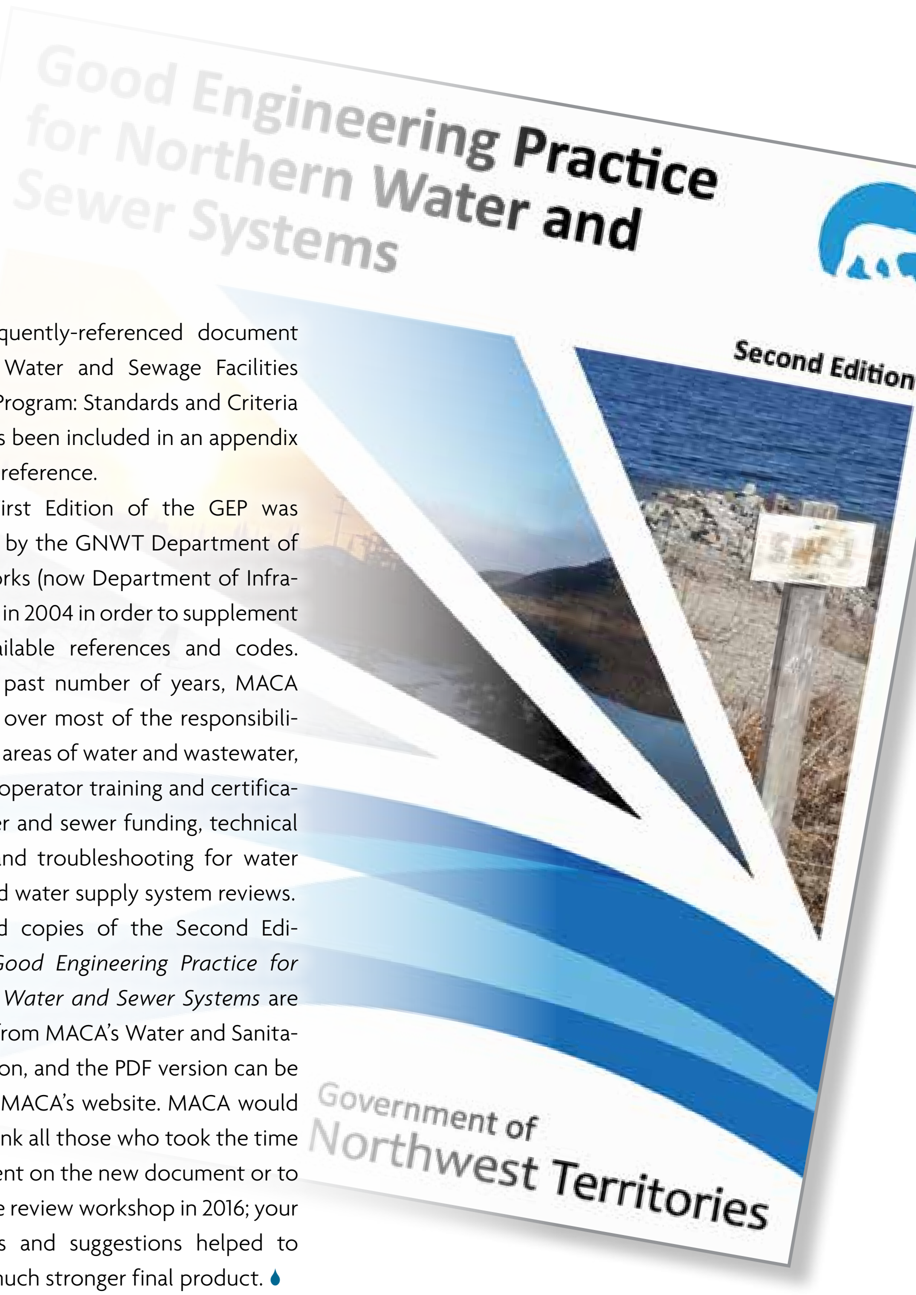
Jaime Goddard, Department of Municipal and Community Affairs, GNWT

The GNWT Department of Municipal and Community Affairs (MACA) recently completed work on the Second Edition of *Good Engineering Practice for Northern Water and Sewer Systems* (GEP), and the new version is now publically available. The entire document has been reviewed and updated to reflect current regulations, products, and practices, and several sections have been added or expanded. Some of the changes in the Second Edition include:

- A new section on "Cold Regions Design Considerations" provides an overview of some of the challenges of northern engineering in order to alert designers who may be new to the region to some of the issues they need to look at.
- Regulatory changes have led to truckfill stations being replaced by water treatment plants in the NWT. In order to include more information on water treatment plants, the "Truckfill Stations and Pump Houses" section has been split into "Intakes, Buildings" and "Trucked Services" sections, which have all been expanded.
- A new section on "Wastewater Treatment Technologies" has been added in order to summarize the current information on lagoon and wetland wastewater treatment. At this time, the science on northern wastewater treatment is still evolving; MACA anticipates that this section will be greatly expanded and revised as more northern-specific data and research becomes available.
- In keeping with drinking water regulatory changes that now require filtration, the "Water Quality and Treatment" section has been expanded to include information on the types of treatment now in use in the NWT.
- The frequently-referenced document "MACA Water and Sewage Facilities Capital Program: Standards and Criteria 1993" has been included in an appendix for easy reference.

The First Edition of the GEP was published by the GNWT Department of Public Works (now Department of Infrastructure) in 2004 in order to supplement other available references and codes. Over the past number of years, MACA has taken over most of the responsibilities in the areas of water and wastewater, including operator training and certification, water and sewer funding, technical support and troubleshooting for water plants, and water supply system reviews.

Printed copies of the Second Edition of *Good Engineering Practice for Northern Water and Sewer Systems* are available from MACA's Water and Sanitation Section, and the PDF version can be found on MACA's website. MACA would like to thank all those who took the time to comment on the new document or to attend the review workshop in 2016; your comments and suggestions helped to create a much stronger final product.



Buried installation of insulated high-density polyurethane (HDPE) water line in Resolute, Nunavut.

NORTHERN WATER: AN ABUNDANT RESOURCE IN SHORT SUPPLY

Introduction

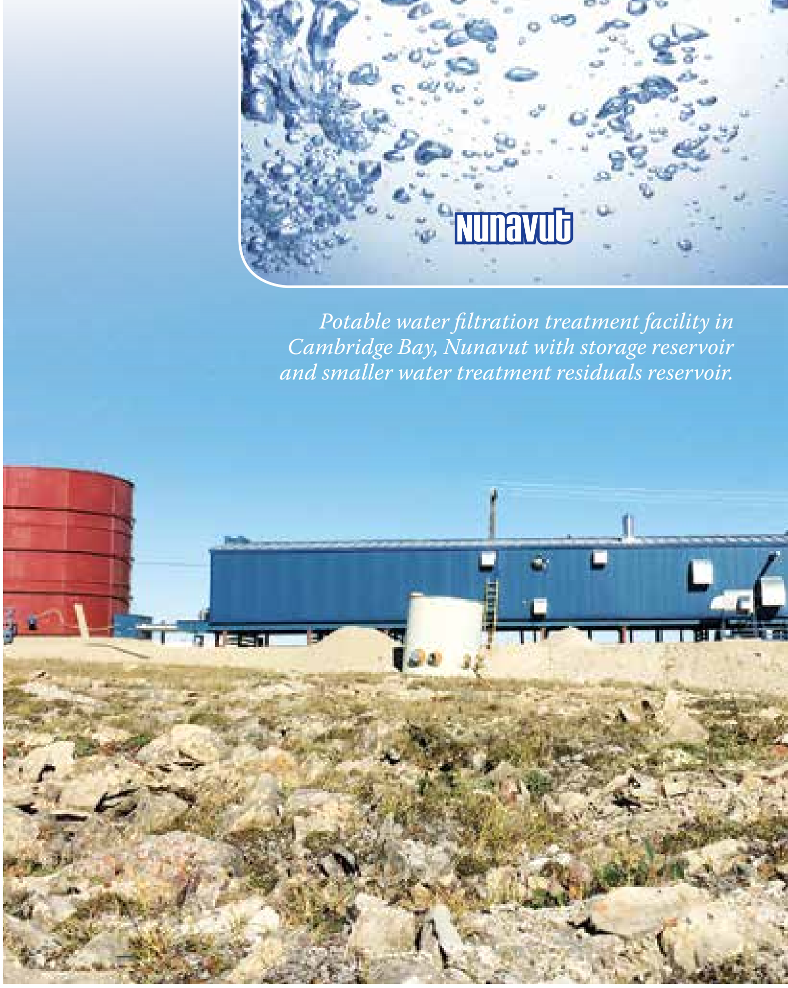
It is estimated that 37 per cent of Canada's total freshwater is contained in the three territories. In spite of this abundant resource, water can be a scarce commodity, particularly in Northern communities that require a clean source of water year-round. Winter can last eight to 10 months of the year, and in winter, most of the surface water is frozen with ice up to two metres thick covering it. The north is also a desert, with most regions receiving less than 250 millimetres of annual precipitation, most of it as snow. Given these fundamental challenges, community water supply in Nunavut is particularly challenging due to geographic isolation, an extreme cold climate, permafrost geology, extreme costs, limited level of services, and other unique northern community attributes.

Twelve-month water supply reservoir in Chesterfield Inlet, Nunavut excavated into bedrock

Water supply and delivery in Nunavut communities

Nunavut is the largest of the three territories with 20 per cent of Canada's land mass and only 30,000 people. The 25 communities of Nunavut range in size from Grise Fiord in the far North, with 140 people, to Iqaluit, with 7,000 people, in the south. Eleven of the 25 communities have over a 1,000 people, and all of the communities except one (Baker Lake) are coastal. Surface water

By Ken Johnson, Stantec



Potable water filtration treatment facility in Cambridge Bay, Nunavut with storage reservoir and smaller water treatment residuals reservoir.

provides drinking water to all of the communities because permafrost does not permit access to any groundwater resources.

Community water supplies come from lakes and rivers, and provide either year-round or a seasonal water supply. To use lakes and rivers year-round as a water source, the surface ice, up to two metres thick, must be taken into consideration. The ice formation can damage the piping in lakes if it is placed in water which is too shallow, and in rivers it is vulnerable to damage, particularly during spring break of river ice. Lakes and rivers that provide a seasonal water supply are used to fill long-term storage reservoirs. Nine Nunavut communities have engineered storage reservoirs that have sufficient water stored for up to a year of the community's needs. An allowance for the formation of ice must be considered in the design of these reservoirs.

Proximity of water to the community itself presents another challenge because of the cost of roads and pipelines, including the operation and maintenance to keep the roads and pipelines functioning. At nearly $1 million (Canadian) per kilometre to build for a road and a pipeline in some locations, the economics places distant piped water sources beyond the reach of most communities. Add to this cost the potential for pipeline freezing, and the severe operating conditions during blizzards, and closer becomes a lot better.

Drinking water is disinfected in Nunavut before delivery to the users. More substantial treatment using filtration technologies is being introduced into Nunavut communities to provide a multi barrier against the potential for drinking water contamination. Water treatment improvements are encouraged by public health officials, and may ultimately be mandated by public health regulations.

The cost of Nunavut water

The cost of northern water, including both the capital cost, and the operation and maintenance costs, is a function of the cost of labour and materials, which are influenced by the geographic isolation, the extreme cold climate, and the permafrost geology. The water and sewer systems have operating challenges associated with the potential freezing of the piping due to heat loss, which is solved with pipe insulation, water circulation, and heating the water.

An example of the capital cost of a piped system in Nunavut is the replacement of the piped system in Resolute, which was tendered several years ago. The lowest tender received for the project was $44.4 million, which put the project budget approximately $18 million (70 per cent) over the pre-tender construction estimate of $26 million. Resolute has a population of 250 people, so the cost per person for the system replacement was nearly $180,000.

An example of the operation and maintenance costs of a water and sewer system in this Territory are the costs for water and sewer in the community of Grise Fiord. Grise Fiord is the northern-most community in Canada. The annual cost was over $2,200 per person in 2002, or 6.4 cents per litre for water and sewer (4.5 cents per litre or $45 per cubic metre for water only); the overall water use was 5,680,000 litres or 95 litres per capita per day.

Extreme water issues and the future of Nunavut water

As challenging as "normal" water supply is in Nunavut, there are several examples of extreme water use issues in Nunavut. In Grise Fiord, the stream that annually fills the water reservoirs dried up during one filling season, and the community ran out of drinking water before the reservoir could be refilled the following spring. The community resorted to harvesting icebergs, chopping and placing the ice into the reservoir to maintain the water supply.

The communities of Kugluktuk and Kugaaruk are experiencing issues with saltwater intrusion into their river-water supply systems because tidal action is creating a salt water wedge that advances up the river to the point of the water supply intake. In the community of Sanikiluaq, saltwater intrusion may also be occurring with the ocean water making its way into the lake that supplies the community.

Most northern communities also have limited capacity for dealing with water issues, whether they be financial, administrative or human capacities resources capacities. In spite of this limited capacity communities are facing the increasing demands for finance, administration and human resources being driven by increasing regulatory demands, and the increasing sophistication in the technology associated with the water for treatment of drinking water and waste water management.

Climate change is also emerging as an issue for water supply in Nunavut. The water supply issues in Grise Fiord, Kugluktuk, Kugaaruk and Sanikiluaq may not be conclusively caused by climate change, but the warming of the Arctic is making the problems such as these worse. It is anticipated that the warming Arctic climate in Nunavut will influence the quantity and quality of water that is already in short supply. Water supply options for the future are being studied to appropriately increase redundancy, and resiliency.

Haines Junction sewage lagoon cell with Kluane Mountains in the background.

PH REDUCTION FOR HAINES JUNCTION SEWAGE LAGOON

Based upon information and photographs from Lalith Liyanage and Tyler Heal, Stantec; Dave Hatherley, Village of Haines Junction; and Nick Rodger, Community Development, Yukon Government

Background

Retention ponds for sewage treatment in the far north are an appropriate, and common, process technology, and operate with a periodic, usually seasonal, discharge. Overall, these systems tend to perform well because of the simple technology. The performance data on lagoon systems (retention lagoons) in the north is limited, but indicate a five-day Biological Oxygen Demand (BOD5) reduction in the range of 90 to 95 per cent (BOD5 less than 150 mg/L and as low as 11 mg/L), Total Suspended Solids (TSS) reduction in the range of 90 to 95 per cent (TSS less than 80 mg/L and as low as 5 mg/L) and fecal coliform reduction in the range of two to four logs (fecal coliforms less than 2 million and as low as 30).

Algae is an inherent part of the process and this biological activity is responsible for most of the pH variation in the lagoon; in fact, high effluent pH is almost always attributed to algae. Algae consume Carbon Dioxide (CO_2) as part of the photosynthesis process, driving up pH, which is highest in the late afternoon – up to about 7.6 – when algae is most active, and lowest just before dawn – at around 6.8 – as photosynthesis stops overnight.

Alum shipping container with transfer pump .

By Ken Johnson, Stantec, and
Pearl Benyk, NTWWA Administrator

Haines Junction lagoon

The Haines Junction retention lagoon system operates with two anaerobic cells and three aerobic cells, with a periodic discharge every few years. A condition that has developed in the past several years is an elevated pH in cell #3 of the system with measurements as high as 10.7. This is above the water licence discharge range of 6.5 to 9.5 and prevents the required discharge from taking place. In the past, the pH has naturally decreased with the die-off of the algae fall, but over the past two discharge opportunities in the fall of 2016 and the late summer of 2017, the pH has remained high. This became particularly critical in 2017 because the lagoon was approaching its hydraulic capacity, and there was also a need to facilitate construction of upgrades to the lagoon system. With this critical issue, the Government of Yukon retained Stantec to provide a work plan for the addition of alum to reduce the pH.

The chemistry and quantity required

Alum (aluminum sulfate) is acidic in water and can reduce total alkalinity and pH by neutralizing carbonate and bicarbonate compounds with a greater decline in pH when added to water with low initial total alkalinity. Alum treatments of 15 to 25 mg/L have been reported to lower pH by 0.4 to 1.5 units in 48 hours when it is added to ponds.

Based on the available chemistry data for the Haines Junction lagoon, it was estimated that approximately 14,000 litres of 50 per cent alum would be required to neutralize the volume of aerobic cell #3 using a dose of 130 mg/L. Based on experience elsewhere, this would reduce the pH to below 9.5. The exact alum dose cannot be calculated theoretically due to the complexity of wastewater constituents. This value was only an estimate, and it was determined that a larger quantity than originally estimated (20,000 litres) should be available for addition to the lagoon. The alum was shipped from Edmonton to Haines Junction on a flatbed truck containing twenty 1,000-litre containers. The total cost of the chemical and shipping was $25,000 for a shipping distance of 2,100 kilometres.

Work plan iterations

The initial delivery system (Plan A), tried was pumping alum through a hose to a boat traveling around the lagoon. Unfortunately, this approach was not successful because the supply hose kept sinking into the lagoon and becoming tangled in the weeds. A Plan B delivery system for the alum was devised, which was to spray the solution onto the surface of the lagoon and mix it in with the movement of the boat around the lagoon. This methodology also did not work because the spray could only reach about five metres from the shore of the lagoon, and the mixing did not extend very far beneath the surface.

Boat used for alum addition to lagoon with 250-litre barrel and transfer pump.

A Plan C was devised placing of an empty plastic 250-litre barrel in the boat, and filling from the 1,000-litre shipping container. A generator-powered pump was used to pump from the barrel to a point near the prop wash of the boat engine. Plan C successfully achieved good dispersion of the chemical. Using this method took four to five re-fillings of the barrel to empty the shipping container, which took about 2.5 hours. After the addition of three containers of alum, the pH at the end of the lagoon had dropped to 10.0, while the pH in the middle and at the opposite end was still at 10.3.

Success

With the initial of 10,000 litres of alum, the pH was reduced to approximately 9.5, which was at the discharge threshold. An additional 2,000 litres of alum were added to bring the pH down further to about 9.3, and the lagoon was left to settle down for a week. A pre-discharge test at the end of the week confirmed that the pH was below the maximum discharge criteria. Effluent quality at the start of the official lagoon discharge was very good, with BOD5 and TSS below the laboratory detection limit, and only a few coliforms, along with pH within the effluent quality criteria.

NTWWA President's Report
JUSTIN HACK

Finding long-term, reasonable solutions to waste and water management in Arctic Canada is a daunting task. A unique regulatory environment, extreme temperatures, impressive weather events, fly-in only communities, and the costs of doing business are just some of the challenges that hinder waste and water services in the Arctic amongst a myriad of other issues that you may not find anywhere else.

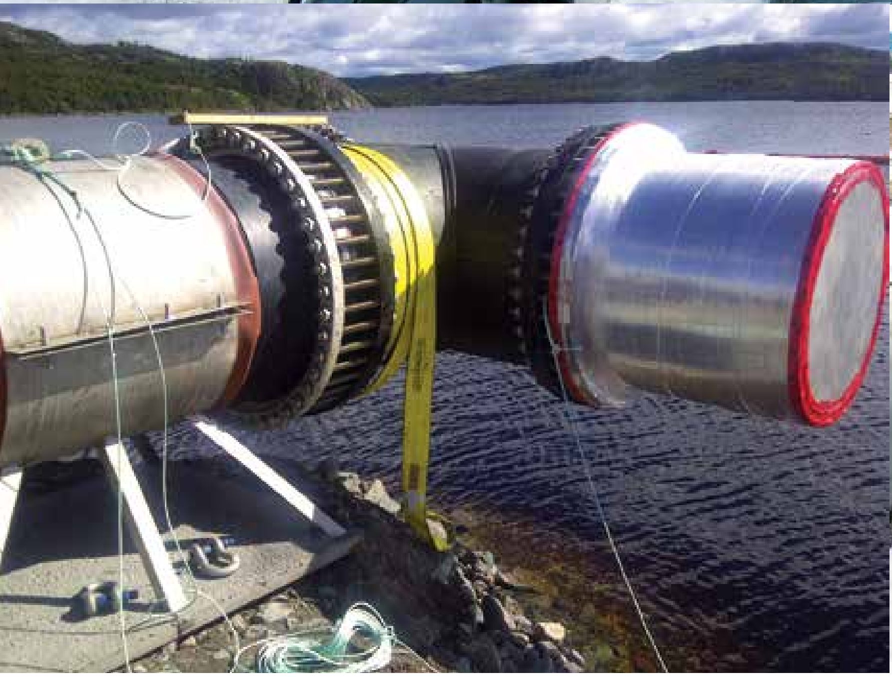
How can we even practically keep up with all the pressures facing our Arctic communities and environment, given the high population growth rates, the pressures of climate change, and rapid influx of development around the Arctic? These pressures are being felt all over the Arctic, and in some instances, they have developed into situations that have had profound effects on the environment, economics, and human health.

As we continue to operate and strive to do our best in this field, a great deal of knowledge is being generated in the Arctic about best practices and even about some of the inevitable mistakes we have committed in this unique environment.

The NTWWA strives to give the people who are part of this knowledge development a forum to communicate about water and waste issues in the North. Whether the medium of knowledge transfer is through our website, our annual magazine, or our conference, the NTWWA encourages all stakeholders to come and share their stories, successes, failures, and perspectives of working in the North with each other. And given all the challenges we face trying to do our best, communication is especially important so that we can continually learn and progress forward.

We are looking forward to our NTWWA conference in Iqaluit this year. It is an event that attracts people who care and contribute to improving water and waste services. The NTWWA is committed to improving the water and waste situation of the North, and I am continually amazed at the new ideas I learn each year at our conference. The conference creates an informal atmosphere that allows delegates access to a range of stakeholders and gives all participants the opportunity to explain their stories and perspectives on the real issues facing them in their everyday lives and jobs.

The NTWWA will be hosting the 2018 conference in Yellowknife during the month of November. This is an exciting time for the NTWWA as we have just finalized our new website and have developed a scholarship fund to educate our leaders of tomorrow. I encourage everyone to attend this conference, prepared with your own stories of the successes and difficulties managing water and waste in the North so can learn and develop new ideas to deal with this unique and wonderful environment.



2016 NTTWA CONFERENCE *Highlights*

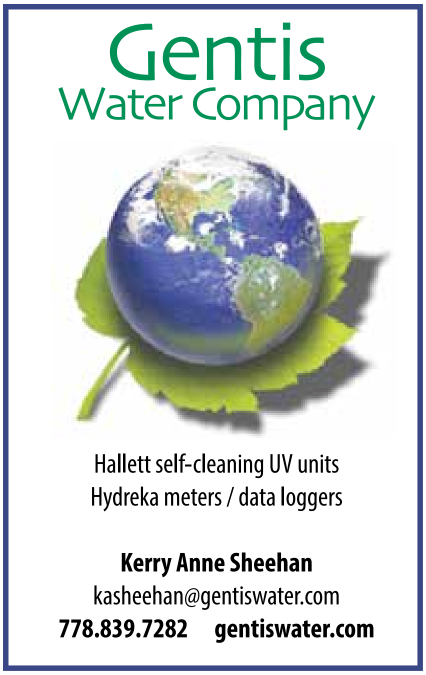
1) 2016-2017 NTWWA board and staff, Arlen Foster, Justin Hack, Justine Lywood, Megan Lusty, Ryan Ethier, Pearl Benyk (administrator), Bill Westwell, Cynthia Ene, Galvin Simpson, Jeanne Arsenault, and Crystal Sabel (executive director).

2) Conference registration table with Pearl Benyk, Crystal Sabel, and Jennifer Spencer.

3) Feat of strength by Jennifer Spencer holding a model sewage pump.

4) Great Northern Water Challenge winners Steven Pootoogook and David Saila representing the Hamlet of Cape Dorset receive trophy from Justin Hazenburg.

5) Operator workshop attracted 45 people.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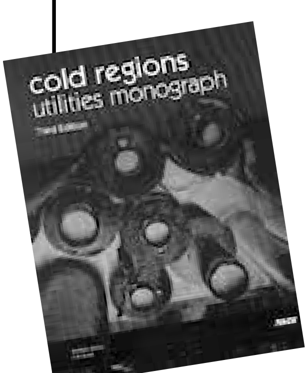
The Cold Regions Utilities Monograph (CRUM)

is the ultimate reference for water and sanitation in the panarctic world. The CRUM is currently under revision for the publication of the 4th edition in 2018. If you are interested in contributing to the 4th edition, please contact

Aaron Dotson
(addotson@alaska.edu)

***or* alternatively**

Ken Johnson
(kenneth.johnson@stantec.com)



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