Tools and Strategies to Address Uncertainties and Complexities of Infrastructure Design in Remote Northern Canadian Communities

By

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ABSTRACT

TOOLS AND STRATEGIES TO ADDRESS UNCERTAINTIES AND COMPLEXITIES OF INFRASTRUCTURE DESIGN IN REMOTE NORTHERN CANADIAN COMMUNITIES

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It is becoming increasingly evident that water and wastewater infrastructure in some northern communities is not appropriately designed to suit the local climatic, environmental, financial, or cultural context.

This research developed and assessed new tools and strategies to capture the unique complexities of remote northern contexts and help engineers develop more situationally appropriate infrastructure planning and design processes and practices. Water infrastructure planning in Rigolet, Nunatsiavut, Canada was used as a case study. Grounded in systems thinking and Post-Normal Science principles, the methods included: identifying and characterizing stocks and flows within the system; conducting document reviews, semi-structured interviews with stakeholders, focus groups, and a community questionnaire; and identifying and characterizing constraints and criteria for northern infrastructure development.

An infrastructure decision-making tool that captured technical, social and other local information was developed based on consultations with technical experts and community members to increase transparency, community trust and local control.

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THESIS INTRODUCTION

"The geopolitical importance of the Arctic and Canada's interests in it have never been greater. This is why our government has launched an ambitious Northern Agenda based on the timeless responsibility imposed by our national anthem, to keep the True North strong and free."

- Canadian Prime Minister Stephen Harper, August 28, 2008, Inuvik, Northwest Territories [1]

"Not only is the North a land of raw and majestic beauty that has inspired generations of authors, artists and adventurers, and not only is it the home to a rich culture shaped through the millennia by the wisdom of Aboriginal people, but it also holds the potential to be a transformative economic asset for the country."

- Canadian Prime Minister Stephen Harper, August 18, 2009, Iqaluit, Nunavut [1]

It is widely believed that Canada's northern regions will be the country's next economic driver and a place of massive development due to their natural resources, as well as their potential to be an important shipping route for global trade. The Arctic represents 40% of Canada's landmass and recent reports estimate it may hold 13% of the world's undiscovered oil deposits, and 30% of the world's undiscovered natural gas deposits [2]. The Canadian Arctic is also rich in other resource deposits, including, but not limited to large deposits of gold, diamond, and tin [3]. Indeed, the diamond mines of northern Ontario, the Northwest Territories and Nunavut already make Canada the world's third largest diamond producer, with an estimated annual value of 2 billion dollars [1,4]. The Northwest Passage is a potential shipping route through the Canadian Arctic from the Beaufort Sea in the west and Baffin Bay in the east. Due to climate change, there has been a reduction of multi-year sea ice, making the Northwest Passage easier to navigate [4,5]. In 2007 the route was classified as "fully navigable" for a number of weeks, as satellites estimated it to have less than 10 percent ice coverage [1]. Shipping traffic has increased dramatically through the Northwest Passage in recent years. For instance, in 1983, only 3 voyages were made by ship through the Northwest Passage [6], while in 2012 and 2013 ships made 30 and 22 journeys, respectively [6].

As climate change increases access to both favoured northern shipping routes and the North's precious natural resources, many countries are eager to participate in the development of these important assets. This interest has been demonstrated by a number of non-polar countries such as China, India, Italy, Japan, South Korea and Singapore seeking observer status on the Arctic Council, which is an intergovernmental body of polar nations tasked with tackling Arctic issues and protecting the interests of its Indigenous inhabitants [2].

GOVERNMENT INVESTMENT IN NORTHERN INFRASTRUCTURE

"*Canada has a real, growing, long-term presence in the Arctic*."

- *Canadian Prime Minister Stephen Harper August 11, 2007, Resolute Bay, Nunavut[1].*

In 2007, the Canadian Prime Minister, Stephen Harper stated that "*The first principle of Arctic sovereignty is: use it or lose it*". In keeping with this, Prime Minister Harper makes annual trips to the Canadian North and in recent years his government has promised numerous new programs and infrastructure investments designed to increase Canada's presence and assert its Arctic sovereignty while encouraging economic development. For example, in 2007 the government announced new military training bases in the communities of Resolute and Nanisivik (near Cambridge Bay) to increase Canada's military presence in the Arctic [7,8]. These military bases will include the expansion of the Canadian Arctic's only deep sea port in Nanisivik [7,9]. In 2007, the Canadian government also announced $3.1 billion in spending on the creation of a fleet of armed Arctic offshore patrol vessels that will be capable of breaking through sea ice, and patrol the Arctic waters, especially during the northern shipping season [10]. In 2010, the federal government announced the creation of an Arctic research station in the community of Cambridge Bay, with estimated costs of over $142 million [11]. Priority areas for the new research station will reportedly be resource development and exercising of Canadian sovereignty [12]. In 2013, the government announced its intention to claim the North Pole as part of an international bid to secure seabed rights and the potential natural resources located underneath them [6]. The federal government has also pledged to contribute $200 million to the construction of a permanent 137 kilometer-long gravel road from Tuktoyaktuk, NWT to Inuvik, NWT. Annual road maintenance including grading and snow clearing is expected to cost between $1.5 and $1.8 million each year [13]. Building this road will provide a permanent road connection to Tuktoyaktuk, which previously relied on winter ice roads. The road will decrease the cost of living for the residents of Tuktoyaktuk and will also save the Mackenzie natural gas pipeline project $385 million over its expected 45-year operating life [14].

"Modern public infrastructure will contribute to a stronger economy, a cleaner environment, and safer and more prosperous communities in the North."

- *Government of Canada's Northern Strategy [1]*

Many northern communities are undergoing rapid growth. The population of Indigenous Inuit residents is young and growing, and investments by the Canadian federal government and resource companies are creating an influx of workers. These growing communities require new infrastructure, including housing, businesses, hospitals, airports, schools, and utilities, such as water, wastewater, solid waste management, and electricity. Also, as a result of relatively recent land claims that Indigenous people have settled with the Government of Canada (i.e. Nunavut

Territory, Labrador Land Claims Agreement), the North is undergoing a process known as ‘devolution’ where the federal government is gradually transferring more authority to territorial, regional, and community governments [15–17]. While communities and regional governments are entitled to this control, experts often report that communities do not have the resources or technical expertise to fully manage the new infrastructure projects and consequently rely heavily on external expertise, such as engineering consultants. The planning, design, and operation of infrastructure in the Canadian north can be particularly challenging for external experts and engineering consultants due to the unique context, which encompasses biophysical, social, and economic conditions that are substantially different from those in southern Canada [18–23]. These conditions are becoming more and more complex and uncertain in the North due to increased industrial development, climate change, population growth, changing regulations, and the ongoing devolution process [23–29]. Despite this, the complexity and uniqueness of the northern context is commonly overlooked or misunderstood by engineers and other external agencies and has resulted in cases of inadequate infrastructure, ranging from housing [30–33], to transportation [34], to drinking water infrastructure [19,20,35,36]. Indeed, conventional scientific and engineering methods tackle problems by breaking down, simplifying, and reducing them into a number of small, manageable problems [37]. The drawback to these reductionist approaches is that they often fail in the face of complex problems where there is a high degree of uncertainty and high decision stakes, as is the current case in the Canadian North [38,39]. As both corporate and government investment in northern infrastructure continues to increase, it is in the best interest of all Canadians to also invest in the development of improved approaches and tools so engineers can better understand the northern context, and build more appropriate, longer-lasting infrastructure that encourages healthy, safe, economically stable, and resilient northern communities.

PROBLEM STATEMENT

Engineered systems need to be designed for the specific local context [18]; however, it is evident that a lack of appropriate planning and design methodologies and tools for engineers to understand and incorporate local context is becoming a major barrier to the successful implementation of new technologies and infrastructure in the Circumpolar North [20,22,40–42].

Research Goal and Objectives

The goal of this research project was to explore new tools and strategies to facilitate development of more appropriate infrastructure planning, design, construction, and operation practices in Inuit communities of the Circumpolar North. There were three specific objectives:

1. Conduct a document and literature review to gain a deeper understanding of the history of Inuit People, the challenges of engineering in the North, the types and causes of infrastructure failures that often occur, and to identify some alternative approaches that may be suitable.
2. Develop data collection and engagement tools and approaches that engineers can use to better understand the context and needs of their community clients.
3. Develop a decision making tool which, when used in collaboration with communities, would increase transparency, accountability, and local control of the infrastructure planning and design process by incorporating community values and priorities.

THESIS ORGANIZATION

Chapter 1: Introduction

This chapter introduces the rationale and structure of the thesis.

Chapter 2: The Current State of Knowledge

This chapter provides a review of the literature to provide the reader with an overall understanding of the history of Inuit People, the challenges of engineering in the North, the types and causes of infrastructure failures, and suggests different approaches that may be suitable for further research.

Chapter 3: Baseline Assessment

This chapter explores tools and approaches that engineers could use to better capture local northern context in the form of a case study that included a comprehensive assessment of a community's water infrastructure and explored different approaches and tools for community engagement.

Chapter 4: Development of Locally Appropriate Constraints and Criteria

This chapter develops a decision-making tool to increase the ownership and control exercised by community leaders when working with consultants and contractors. The development of the tool included the establishment of locally appropriate infrastructure constraints and criteria through literature review and consultations with technical, academic and government experts, and community members.

Chapter 5: Conclusion

This chapter reviews the key findings from the research project, discusses next steps in the development of community infrastructure plans, and provides recommendations for engineers working with indigenous northern communities.

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CHAPTER TWO

LITERATURE REVIEW: INFRASTRUCURE PLANNING AND DESIGN IN THE CIRCUMPOLAR NORTH

INTRODUCTION

Many communities in the Circumpolar North are experiencing rapid growth due to immigration driven by natural resource development, a young and growing Inuit population [1], and increased demonstrations of Arctic sovereignty by the Government of Canada [2]. These northern communities require water infrastructure that meets the growing demand for water, complies with national drinking water quality guidelines, is affordable to construct and operate, and provides the same level of service that other Canadian communities experience in the South. Building sustainable water infrastructure in the North requires an understanding of their unique context, which may not be present anywhere else in the world. There are many technical and logistical challenges that must be considered while working in the north, including a cold climate, changing permafrost, remoteness, a short construction season, and the requirement (predominantly) to import all necessary resources by ship or air. Due to the complexity and high cost of building in the North, infrastructure projects are typically joint ventures between all levels of government and require collaborations between many different stakeholders. Unique aspects of Inuit culture, including a deep connection with the land, values of consensus decision making, a history of challenging relationships with the Federal and Territorial/Provincial governments, and the emergence of Inuit self-governance all require a distinctive approach to community infrastructure planning [3].

Current literature on the subject of water infrastructure design and planning in the Circumpolar North is generally fragmented and uni-disciplinary, because this is traditionally how scientists and engineers practice [4,5]. Engineers and scientists are generally taught to tackle big, messy problems by attempting to reduce them into small manageable pieces [5]. Although this reductionist approach may be successful in addressing straight forward engineering problems, it does not seem to adequately address complex technical, social, cultural and/or capacity-related concerns [5–7]. Therefore, more comprehensive approaches that attempt to factor in all of the complex relationships and connections between culture, governance, climate and geography, and engineering are worth investigating. This literature review will provide: (1) an overview of Inuit history, culture, current demographics, and challenges; (2) a description of the current status of drinking water infrastructure in the Canadian north; (3) an assessment of the various challenges faced in the planning of northern infrastructure viewed through the lens of typical infrastructure failures; *and* (4) an exploration of strategies that could improve the sustainability of northern water infrastructure.

SECTION ONE: THE NORTHERN INUIT CONTEXT

For an engineering professional attempting to address water infrastructure challenges in remote northern communities, it is important to understand the unique context of the North and its residents.

Inuit Terminology

Indigenous people in Canada belong to one of three unique groups: First Nations, Métis, or Inuit. Inuit inhabit the Circumpolar North in various regions including Canada, Alaska (USA), Greenland and Russia and may also be known under different names in different regions. “Inuk” is the singular form for Inuit people. The Innu Nation is a First Nation that resides in northern Labrador and its members are not Inuit, a common misunderstanding in Canada [8].

Inuit Nunangat

Historically, Inuit lived in a vast area of land that spanned from the Mackenzie Delta in the West, to the north Coast of Labrador in the East, and from the southern shores of Hudson's Bay to the northern Islands in the High Arctic. This large area is known as Inuit Nunangat and includes the land, water, and ice of these regions [9]. Inuit Nunangat is divided into four different Inuit regions (Figure 2.1), based on land claims that have been settled with the Government of Canada. The four Inuit regions are Inuvialuit (northwestern North West Territories), Nunavut (Eastern and Central Arctic), Nunavik (northern Quebec), and Nunatsiavut (northern Labrador).

According to the 2011 Canadian census, there were almost 60 000 residents of Canada that self-identified as Inuit, of which 73% reside in Inuit Nunangat (Figure 2.2) [1]. In 2011, 37.5% of Inuit that lived outside of Inuit Nunangat, resided in large cities such as Edmonton, Montréal, Ottawa - Gatineau, Yellowknife or St. John's [1]. The majority of residents of Inuit Nunangat reside in small, isolated costal communities, designated as "special access" by the Federal Government [10], which means there is no year-round road access. Special access communities are only accessible year-round by air travel, and are seasonally accessible by boat during the short summer shipping season, and by Snowmobile in the winter season once the sea ice freezes. The remoteness and isolated location of northern communities is an important consideration when planning and designing water infrastructure projects.

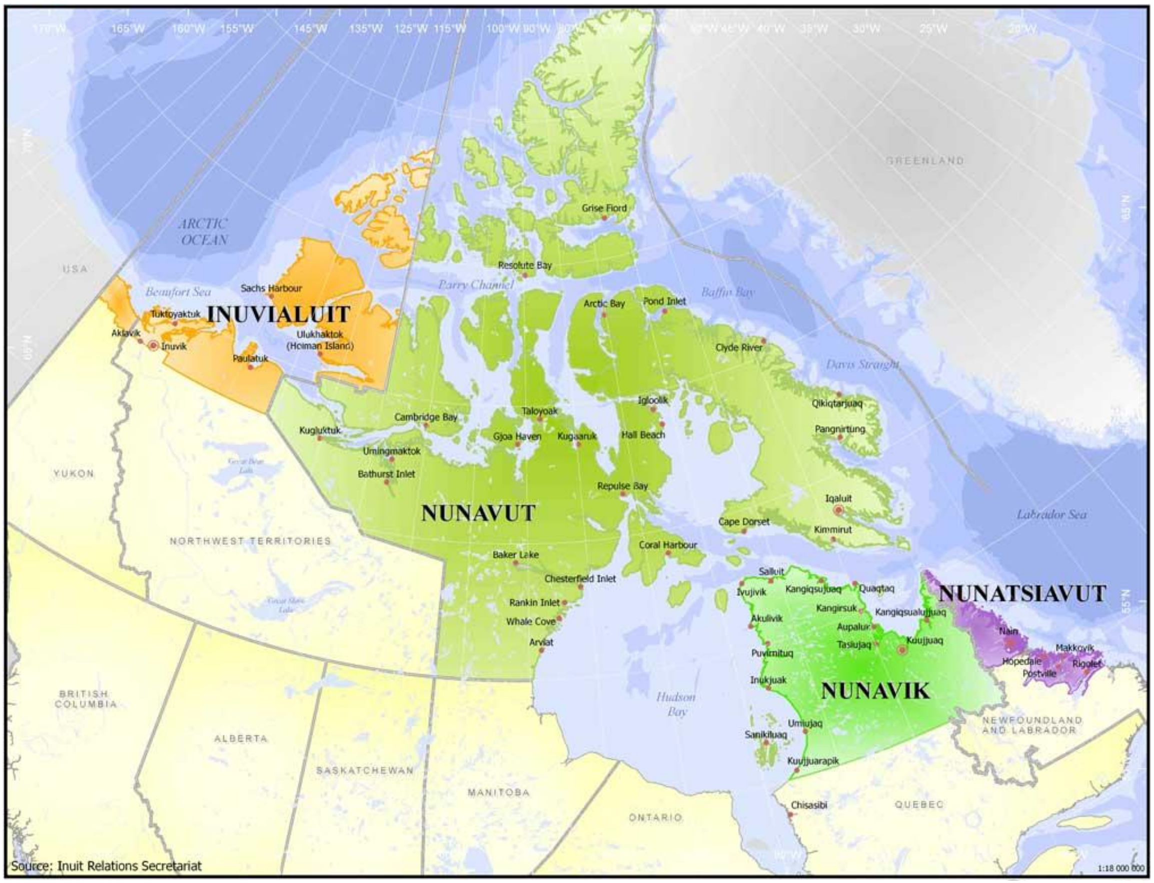

Figure 2.1. Map of Inuit Nunangat showing the four Inuit regions of Canada: Inuvialuit, Nunavut, Nunavik and Nunatsiavut [11]

Historical Context

Inuit have occupied Canada's Arctic and sub-Arctic regions for more than 4000 years [9]. Historically, Inuit were nomadic people that followed the migratory patterns of animals by foot or dogsled over large distances to ensure a continuous supply of food [12]. Archeological evidence has shown that early Inuit made the necessary tools to successfully harvest whales, seals, caribou, muskox, birds, and fish before the arrival of Europeans [9,12]. The history of colonization, forced relocation, and systematic removal of Inuit culture are very important in understanding how Inuit live today and the challenges that they face [13,14].

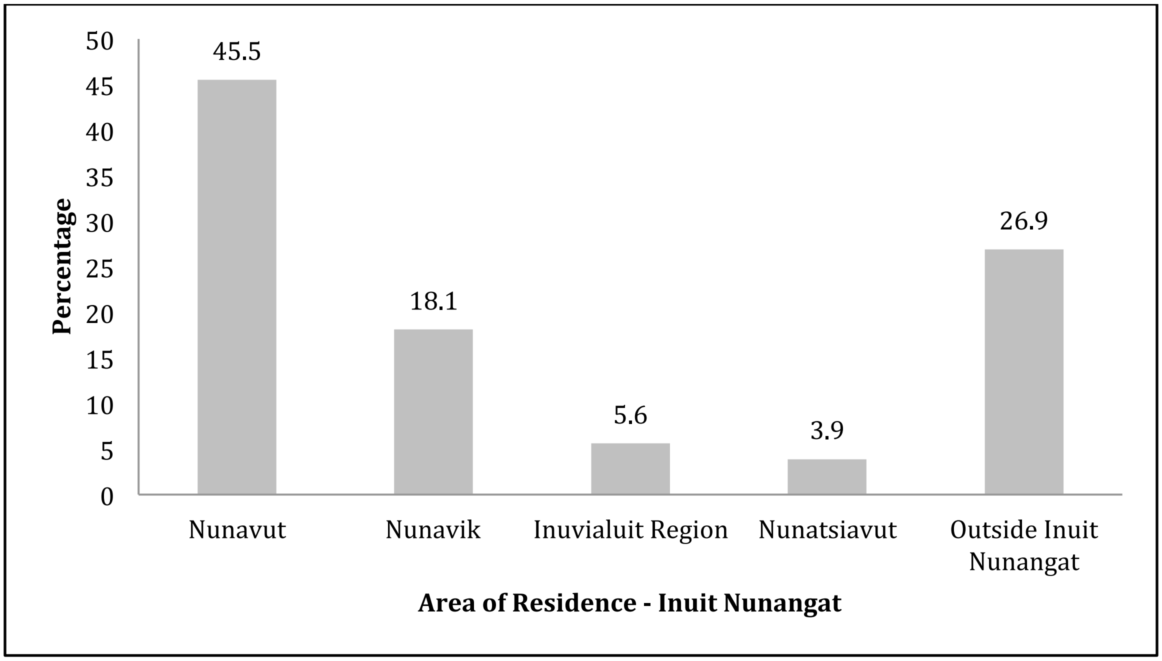

Figure 2.2. The distribution of the Canadian Inuit population by area of residence [1]

Arrival of Europeans

Starting in the 1700s European explorers, whalers, missionaries, and fur traders arrived in what is now Canada and the lives of Inuit began to change. Inuit exchanged their hunting expertise and local knowledge with Europeans for tobacco, tools, firearms, sugar, and other basic necessities [9]. While Europeans brought metal tools and firearms, likely making life easier for Inuit people, they also brought alcohol, Christianity, a cash economy, formal schooling, and eventually permanent community settlements, which drastically changed Inuit life [9,14–16]. Moravian Missionaries settled on the north coast of Labrador in 1771, followed by the Catholic and Anglican Churches in the rest of the Canadian Arctic a century later, usually next to an established trading post [9,16]. Although missionaries offered shelter and assistance to Inuit people, many of the church teachings conflicted with traditional Inuit philosophies, such as shamanism and drum dancing practices, which churches sought to eliminate [9]. Europeans also brought with them many new diseases such a measles, tuberculosis, and influenza which Inuit immune systems could not battle and led to the sickness and death of many Inuit [9].

National Sovereignty and Arctic Relocation

During the Second World War and the Cold War, the Canadian Government greatly increased its presence in the Canadian Arctic to demonstrate Canadian sovereignty and protect national boarders from attack. This influx of Southerners and infrastructure into the North resulted in an increase in permanent settlements in the Arctic. The Canadian Government also sought to increase the populations of these communities by permanently relocating Inuit families from their hunting camps. In one well known case in the 1950's, 19 families from the northern Quebec town of Inukjuak were relocated to Resolute Bay and Grise Fjord in the High Arctic [17]. Two families from Pond Inlet, Northwest Territories (now Nunavut) were recruited to help the families from northern Quebec adapt to the new climate and conditions in the High Arctic [17]. The federal government promised a new life to the families including new housing and better hunting opportunities compared to the relatively poor living conditions in northern Quebec [18]. However, when the Inuit families from Quebec arrived, they found a very different climate than they were used to. The housing promised by the government was not complete and the families spent the first winter living in tents [18]. The Government of Canada had promised that families could return to Inukjuak if they were dissatisfied with the relocation, but this promise was not honoured until decades later [18].

During this period of settlement throughout the North, the Government of Canada provided subsidized housing, healthcare and Southern-style education to Inuit families who relocated into settlements [19]. Children were sent to church-run residential boarding schools, where they were disconnected from their traditional language and culture and taught Southern values and religions [14]. School curriculum and healthcare were delivered in English with reportedly little concern for the preservation of Inuit culture and language [14].

Government Apologies and Compensation to Inuit People

In 2008 the Government of Canada officially apologized to Canadian Indigenous people and acknowledged the devastating impact residential schools have had on Indigenous culture in Canada [20] . Previously, in 2007 the courts approved a two billion dollar Indian Residential Schools Settlement Agreement (IRSSA), which provided a financial settlement for individuals and families impacted by the federally supported residential schools program [21]. It should be noted that the Government of Canada claims it did not directly fund residential schools in Newfoundland and Labrador and is therefore not responsible for providing any compensation to the Inuit, Innu and Metis of Labrador who were forced to attend Residential Schools [20]. However, in 2011 the supreme court of Newfound and Labrador approved a class action lawsuit for survivors of the Labrador residential schools to sue the Government of Canada for compensation [22]. In 1996, the Government of Canada also offered a $10 million settlement to those impacted by the relocation and in 2010, formally apologized to those families [18,23] .

Inuit Land Claims

The four Inuit regions of Inuit Nunangat were legally created by the settlement of land claims between Inuit and the federal and provincial/territorial governments. These legal agreements were settled on the principle that Inuit, unlike First Nations People, had not previously signed any treaties and their relationship with the Government of Canada is not dictated by the Indian Act. The timing of land claims settlements between the Government of Canada and Inuit often coincided with plans for major resource development on Inuit traditional lands. For instance, a court injunction filed by the James Bay Cree and Northern Quebec Inuit Association to stop the James Bay Hydro Electric Project in 1974, lead to the eventual signing of the James Bay and Northern Quebec Agreement in 1975 [24]. Similarly in northern Labrador, it was the development of the Voisey's Bay Nickel Mine project that led the Federal and Provincial governments to finally negotiate the Labrador Inuit Land Claim Agreement with the Labrador Inuit Association. The signing and ratification of the Labrador Inuit Land Claim Agreement in 2004 lead to the formation of the Nunatsiavut Inuit Government [25,26].

Inuit Today

Young and Growing Population

Similar to other Indigenous groups in Canada, Inuit are a young and growing demographic. In 2011, Inuit had a median age of 23 years old, which was the youngest of the three Indigenous groups and much lower than the Canadian median age of 41 years [1]. Between 2006 and 2011, the number of Inuit in Canada increased by 18%, or 9,090 persons [1], compared to the general Canadian population increase of 6% [27].

Poverty

There are low levels of formal education and employment among Inuit, which can contribute to poverty and social problems in communities. Data from 2006 indicate that 51% of Inuit men and women between the ages of 25 and 64 years old did not finish high school [28]. The most common reason for Inuit men to not finish secondary school was that they found school non-engaging (16%) or they either wanted (16%) or needed (13%) to start working [28]. The most common reason for Inuit women to not finish secondary education was to due to pregnancy or child care (25%), the need to help out at home (10%), or that they found school non-engaging

(10%) [28]. There is high unemployment among men (23%) and women (15%) ages 25-64, due mostly to lack of full time employment opportunities [28]. Although well-paying resource development, construction, and government employment opportunities are increasing in Inuit regions, most of those jobs require, as a minimum, the completion of secondary school or equivalency [29]. Many Inuit are not eligible for high paying resource, construction, and government positions and the jobs in Inuit regions are instead being awarded to non-Indigenous workers who immigrate from other regions [9,16].

In 2001, the median annual income for an Inuit adult was $13 699, while the median income for all Canadian adults was $22 120 [28]. This income gap is further amplified by the increased cost of living in the North. Although there are often government subsidies in place, families still often pay more for everything from energy, electricity, fuel, food, consumer goods, transportation, and shipping [30]. Most remote Inuit communities rely on diesel generators for electricity, where the cost of electricity can be ten times higher than that in the South [31]. Due to the harsh climate and frigid temperatures, Northerners have the highest per capita energy use in Canada, often twice the national average [31]. In remote northern communities, store bought food can be incredibly expensive. A 2008 government study found that it could cost $360 to $450 per week to provide a nutritious diet for a family of four, compared with about $200 to $250 in the South [32]. The high cost of food in the North contributes to high food insecurity in Inuit households. 2006 census data show that 27% of Inuit households experienced food insecurity, a rate higher than other Indigenous groups (22% and 15% for First Nations people and Métis respectively) and much higher than the 7% of non-Indigenous food-insecure households [33].

Poor Housing and Overcrowding

In 2011, Inuit were ten times more likely (31%) than non-Indigenous people (3%) to live in crowded homes in Canada. While Inuit have traditionally lived in multi-family groupings, reports have suggested that the high rate of families sharing a home may be due to the serious shortage of housing in many communities throughout Inuit Nunangat [34].

In 2006, it was reported that Inuit were four times more likely to live in homes in need of major repairs (28%) than non-Indigenous people (7%) [33]. Major repairs include defective plumbing or electrical wiring, as well as structural repairs to walls, floors, or ceilings [33]. It is suspected that poor housing conditions, including poor indoor air quality and ventilation along with high rates of crowding in houses are a contributing factor to poor respiratory health among Inuit [34]. In fact, in 2010 it was observed that Inuit aged 25 to 44 years had a particularly high rate of asthma [1]. The rate of tuberculosis in the Inuit population is 23 times higher than the rest of Canada [28]. High smoking rates among Inuit also contribute to lung cancer and respiratory diseases alone accounting for 21% of all deaths in Inuit Nunangat [35,36].

Connection With the Land

Living in remote northern communities means that residents have a significantly different life than those living in the South. According to Boult [16], Inuit have described themselves as having “one kamik in the modern world, and [one] solid foot in their distinct traditional culture,”[16, p.7] living a complex weave of tradition, family, and modern life. Inuit have a strong connection with their local environment, typically referred to by Inuit as “the land” [14,37,38]. Inuit are coping with a rapidly changing environment due to climatic changes [39–

41]. Studies have documented significant changes in temperatures, wind patterns, precipitation, costal erosion, permafrost stability, and sea ice across the Circumpolar North, which is expected to continue into the future [41] . Environmental change is impacting the health and livelihoods of some Inuit people, who depend on their local environment for survival as transportation routes and a source of food [42,43]. Today, many Inuit still spend a considerable amount of time out on the land when they hunt, fish, and harvest berries at their cabins and/or traditional hunting grounds [39,40,44]; activities that are considered to be an important part of their cultural identity [37]. The important connection Inuit have with the land also includes drinking water as it has been noted that many Inuit often prefer to consume water from natural sources while out on the land, and even while in their community, over municipal tap water or bottled water [39,40,45–48].

When Inuit cannot access the land, their cabins, or traditional hunting grounds due to poor travel conditions, bad weather, employment commitments or financial hardships, it can negatively impact their emotional health and well-being [14,37]. Emotional health among Inuit is a critical issue as census data from 2001 show that the rate of suicide among Inuit is 11 times higher than the national average [28]. The combination of many social and health challenges are reflected in an average life expectancy of 70.8 years in Inuit Nunangat, which is about 10 years lower than in the rest of Canada [49]. This gap has narrowed since 2001, when census data estimated the life expectancy gap between those living in Inuit Nunangat and the rest of Canada to be 15 years [28].

Research has shown that Indigenous inhabitants of the Circumpolar North always demonstrated the ability to adapt to changing environmental conditions and extreme weather [50]. Present day

Inuit are adapting to the changing climate using technologies, such as global positioning systems (GPS) to map their transport route to avoid hazards, radios to keep in touch with peers and communities in case of emergencies, and more powerful outboard boat motors to limit the time spent on dangerous open water while hunting and fishing [50]. Inuit headed out on the land are more likely to bring extra supplies, such as fuel, clothing, and food in the event that extreme weather causes them to be stranded for an extended period of time [50]. Many Inuit have also become more risk averse and are avoiding certain land based activities which pose a higher risk of injury, such as hunting narwhales on the ice edge [50].

SECTION TWO: DRINKING WATER INFRASTRUCTURE IN INUIT NUNANGAT

There are many reasons why communities choose to invest in drinking water infrastructure. The invention and adoption of water treatment systems in the last 150 years has drastically changed how people live by protecting public health, increasing economic opportunities, and protecting communities from property loss through fire protection services [51].

Protect Public Health and Quality of Life

A critical function of drinking water infrastructure is to improve the quality of life in communities by protecting public health. History and research show that the introduction and development of municipal water treatment systems can significantly reduce the levels of waterborne disease in a population [52–56]. The World Health Organization (WHO) estimated that improved water quality alone could reduce the global disease burden of acute gastrointestinal illness by 31% [57]. Even in developed countries such as Canada, the economic burden of lost work days and medical costs can be significant, even if typical incidences of acute gastrointestinal illness are usually minor and self-limiting [58].

Facilitate Economic Development and Reduce Likelihood of Loss from Fires

There are other important reasons for the development of community water infrastructure beyond public health benefits. Clean water is an important input in most industrial and commercial sectors, including power generation, garment industries, pulp and paper, manufacturing, food services, and agriculture. Therefore, as small businesses develop, even in remote communities, reliable water infrastructure is likely a prerequisite for business growth and success [51]. The development and success of businesses in small communities will likely create jobs and increase the quality of life of individuals and families. For example, a seasonal fish plant in the Nunatsiavut community of Nain is a large consumer of tap water, but also an important local employer. Fish processing plants which relied on treated tap water were also present in other Nunatsiavut communities before the drop in salmon stocks in the late 1990's [59].

Although, on a per capita basis, the instances of fires in remote northern communities are lower than southern communities, in the North the loss of life and property damage is significantly higher [51]. The cold, dry climate combined with wood framed building and high number of days where space heating is necessary can make homes in Inuit Nunangat a high risk for fires. The introduction of piped water distribution systems and water storage in remote communities can improve fire protection capabilities by providing a continuous source of water for fire suppression [51].

The Current Status of Drinking Water Infrastructure in Inuit Nunangat

Drinking water infrastructure can be divided into three different components: (1) the source water, where the natural water is collected from before it is treated and distributed to residents; (2) the actual drinking water treatment process that treats and disinfects the water, making it safe for human consumption; and (3) the distribution system that delivers the drinking water to residents of the community. Every community in Inuit Nunangat has some form of drinking water infrastructure, but the sophistication and size of each system depends on different local environmental or regulatory criteria. This section outlines the differences and similarities between drinking water infrastructures within Inuit Nunangat based on available data.

Source Water

Some of the important parameters in terms of source water are the source type, water quality, water quantity, and degree of source water protection in place. In all four Inuit regions, the majority of users receive their tap water from surface water sources, such as ponds, lakes, and rivers [44,60–62]. Some communities such as Rigolet, Nunatsiavut previously used a groundwater source for their drinking water, but it was replaced with a larger surface water source when a piped water system was installed in the 1990's [63]. Groundwater is a desirable source of drinking water in the Circumpolar North for many reasons: (1) the temperature and mineral content of the water is typically constant throughout the year, making treatment easier; (2) a deep aquifer (under the permafrost) is typically accessible all year around, and (3) deep groundwater sources are often more protected than surface water sources, minimizing the risk of contamination from animals or human activity [51]. Despite the advantages of groundwater as a source, there are factors that make this option challenging and expensive in Inuit Nunangat. Groundwater stored in the permafrost's active layer is generally not potable without extensive treatment due to high organic and mineral content. This water is only seasonally available, as it freezes in the winter with the active layer, and is more susceptible to contamination from animals and human activity than deep sub-permafrost aquifers due to its relatively shallow depth [51]. However, water from deep sub-permafrost aquifers often has low levels of dissolved oxygen and therefore high levels of iron, manganese, and hardness [51]. Extracting water from a sub-permafrost aquifer can also be expensive and technically challenging due the risk of melting the permafrost as water passes through the borehole to the surface and also the risk of the water itself freezing in the borehole as it passes through the permafrost [51]. Therefore, well casings often need to be insulated and heat traced (a system to warm pipes), drastically increasing the potential cost and complexity of the project [51]. By choosing the best possible source water, a community can minimize the cost of their water treatment and risks to public health.

Water Quality Parameters of Concern

Water quality can be subdivided into four categories: physical, chemical, microbiological, and radiological characteristics. The physical characteristics of source water quality (Table 2.1) can typically be detected by consumers by simple taste, sight, smell or touch and are therefore important aesthetic considerations in addition to health parameters [64].

Chemical characteristics of source water include the presence of dissolved ions and metals. Not all chemical characteristics are easily detectable to consumers in source water and can only be detected with specific testing equipment. Some chemical parameters of concern are indicated in Table 2.2.

The removal of pathogens, including bacteria, viruses, protozoa and helminths (worms) from drinking water before consumption is of utmost importance to public health [65]. These organisms originate either from the digestive tract of animals or other infected humans. It is very expensive to actually regularly test for the presence of the pathogenic organisms (e.g. *Escherichia coli* O157:H7), so instead water is tested for indicator organisms (e.g. coliforms, fecal coliforms, or non-specific *E. coli*), which indicate the likely presence of fecal contamination and therefore, potential for a higher risk of pathogen presence. Pathogens can be effectively removed or inactivated from drinking water sources with appropriate treatment, but the selection and protection of a non-fecal contaminated source is ideal. Table 2.3 lists some of the pathogens that may be found in fecal-contaminated drinking water supplies.

Table 2.1. Important physical characteristics of source water [64]

Parameter	Concern	Aesthetic impact	Health impact
Turbidity	Caused by fine suspended particles that give water a cloudy appearance	Visually unappealing	Without filtration, turbidity can interfere with chlorine or UV light disinfection during treatment steps
Colour	Brown-yellow colour caused by dissolved organic matter	Visually unappealing	Dissolved organic matter can react with chlorine during treatment steps to form potentially harmful disinfection by-products
Temperature	Cold water has higher viscosity, or resistance to flow	Physical discomfort or reduced enjoyment when drinking, optimal temperature for consumption is 10-15^{o}C	Particles suspended in cold, high viscosity water take longer to settle. Kinetic reactions taking place during disinfection take longer to occur
Taste and Odour	Natural sources of taste and odour include organic compounds, salts of dissolved gasses	Unpleasant taste or odour	Poor taste and odour might lead consumer to substitute for a higher risk water source

Maximum allowable concentrations of certain radiological parameters for drinking water supplies are set by Health Canada to limit exposure and reduce potentially harmful carcinogenic impacts. Some radiological sources may be natural, such as lead and radium, others may be anthropogenic, such as strontium, cesium or tritium. Exposure to any of these parameters above the recommended guidelines may lead to the development of various forms of cancer [66].

Source Water Protection Programs

A source water protection (SWP) program actively manages a drinking water source to prevent contamination or overuse to ensure a long lasting source of clean, safe drinking water [67]. SWP is one part of a multi-barrier approach to drinking-water safety, which has been largely adopted throughout the United States and Canada [25,68,69]. There are five main rationales for SWP: (1) it can reduce the risk of water borne disease outbreaks in a community by minimizing contamination of the drinking-water supply [70]; (2) it makes financial sense because it is more affordable to protect a source of water from contamination than to remediate that source or to clean contaminated water with an energy intensive treatment system [71]; (3) it is more worthwhile for a community and government to invest financial resources in the protection of natural capital, like land and water, than investing in physical capital, like advanced water treatment technology, which depreciates and wears out [72,73]; (4) the regular monitoring of source water conditions can reduce operational problems and costs at the water treatment plant [74], because operators can anticipate source water changes and proactively adjust treatment settings [68,75]; and, (5) if done properly, SWP can be a great way to engage community members by encouraging environmental awareness and education [76].

Table 2.2. Chemical parameters of concern present in source water and in treated tap water [51,64]

Parameter	Aesthetic impacts	Health impacts
Iron, Manganese (natural, from ground and surface water sources)	Can turn fixtures and white laundry a dark brown or black colour. Impacts taste of tea and coffee	
Fluoride (natural, from groundwater sources)		In optimum amounts, can result in positive dental effects by reducing tooth decay. Excessive fluoride can cause fluorosis (spotting or brittle teeth)
Inorganic Substances (e.g. Nitrates, Cyanides, Heavy Metals)		Ingestions can result in acute toxic effects or chronic diseases
Chlorine Disinfection By-Products (e.g. THMs, HAAs etc.), which occur *during* and/or *after* treatment with chlorine		Exposure through ingestion, absorption or inhalation of some DBPs over a long period of time may increase the risk of some cancers [65,68]. However the health risk is deemed to be much lower then the risk from ingesting water borne pathogens in untreated drinking water [65,68]

Table 2.3. Examples of water borne pathogens found in some drinking water supplies [64,65]

Pathogen	Examples
Bacteria	*E. coli* 0157:H7, *Campylobacter jejuni*
Viruses	Norovirus, Hepatitis
Protozoa	*Giardia lambila, Cryptosporidium parvum*
Helminths (worms)	*Schistosoma spp.*

Canada does not have a set of national regulations for source water protection, and it is the decision of the territorial/provincial government to implement SWP plans. Table 2.4 shows the SWP status of different provinces and territories within Inuit Nunangat.

Table 2.4. Source water protection status in Inuit Nunangat [77]

Inuit Region (Prov/Territory)	SWP in place for most communities in Region?
Inuvaluit (NWT)	Yes
Nunavut (NU)	No
Nunavik (QC)	Yes
Nunatsiavut (NL)	Yes

Source Water Quantity Concerns

In the North, there are also special considerations when evaluating the ability of a water source to provide sufficient quantities of water for a community. In northern regions, sources of surface water are often shallow and will freeze to a significant depth during the winter months. One study found that the thick layer of ice that forms on top of a reservoir during the winter months can reduce the effective volume by 50%, drastically reducing the amount of water available to communities [78]. Available capacity in a community reservoir is not only important in ensuring the continued supply of safe water to homes, but in many communities the continuous flow of water in the distribution system is what prevents the system from freezing. In some communities the piped system is designed so that water is in constant movement through a circulation loop to prevent freezing [51]. In some communities without circulating systems, households continuously must "bleed" taps or pipes in their homes throughout winter months to prevent the pipes or the water main from freezing, leading to significant water use [51]. This practice of bleeding pipes places some remote northern communities with a piped distribution system among the largest per capita water users in the country [51], as shown in Table 2.5.

Water supply quantity is also a major concern in the Circumpolar North. For instance, in the community of Nain, Nunatsiavut, an especially cold winter in the early 1990s led to the complete freezing of the communities shallow water reservoir [79]. Despite efforts by municipal works staff and volunteers, once the flow of water ceased the entire distribution system froze solid and was not successfully thawed until the end of the following summer [79]. As a result of the experience of communities like Nain, infrastructure planners may decide to increase the capacity of natural reservoirs by damming them, by dredging the reservoirs to increase the depth, or by storing sufficient water for the winter months in engineered water storage tanks or reservoirs [52].

Table 2.5. Actual water use in various Canadian cities and northern communities. Communities with pipes systems that require pipe bleeding use considerably more water than those who do not.

Community	**Water use (L/person/day)**	**Population**	**Type of system**	**Pipe bleeding for freeze protection?**	**Source**
Homer, Alaska (n.d)	1630	n/a	Conventional buried system	**Y**	[51]
Gulkana, Alaska (1993)	110	103	Circulating, buried system	N	[51]
Edmonton, Alberta (n.d.)	236	500 000	Conventional buried system	N	[51]
Aklvik, NWT	32	797	Truck haul	N	[51]
Dawson City Yukon (n.d.)	6400	745	Circulating, buried system	**Y**	[51]
City of Guelph (2011)	184	141097	Buried system	N	[79]
Canadian Average (2011)	274	_____	____	____	[79]

Status of Drinking Water Treatment

In Inuit Nunangat, most communities receive their drinking water from surface water sources (i.e. ponds, lakes and rivers). Since there are no national regulations for drinking water treatment in Canada, the treatment systems throughout Inuit Nunangat depend on the local provincial/territorial regulations or guidelines.

Health Canada's Guidelines for Drinking Water Quality [66] is a set of non-enforceable national guidelines for drinking water provided by the federal government. These guidelines, along with guidelines from the World Health Organization (WHO) state that any water from a surface water source (pond, lake or river) or a groundwater source that is under the influence of a surface water source must be filtered and disinfected before consumption [65,66]. Although chlorine can effectively kill bacteria and viruses, there are some pathogens, such as *Giardia* and *Cryptosporidium*, which are more resistant to the effects of chlorine [64]. For a disinfection process to be fully effective, even low levels of turbidity, or suspended particles need to be removed, typically by filtration, or the particles interfere with the action of the disinfecting agent

[64]. Filtration is important because a surface water source is more likely to be exposed to fecal contamination from animals (including birds) or humans than groundwater and therefore may contain pathogens. Regulations and/or design guidelines in the four provincial/territorial jurisdictions which control drinking water in Inuit Nunangat all officially require that drinking water from a surface water source must be filtered before disinfection occurs. However, each region also allows exceptions for individual systems, likely based on a risk assessment, which includes source water quality and also history of water borne pathogens in the source water. This exception was observed by the author in recent (2013) visits to Nunatsiavut communities, which at the time had no filtration of their surface water sources, and similar circumstances have also been recently reported in Nunavik [44,80]. By exempting a surface water source from filtration requirements, the complexity of the treatment system is reduced, as is the capital and operation costs. However, the community may also be at higher risk of exposure to higher levels of disinfection byproducts, and also certain water borne pathogens if environmental conditions were to change [60].

Regulations regarding the disinfection of drinking water from surface water sources also vary throughout Inuit Nunangat. The Health Canada and WHO guidelines [65,66] have treatment requirements that are designed to meet certain performance targets for the removal or inactivation of different microbiological pathogens (Table 2.6).

Table 2.6. Health Canada drinking water microbiological guidelines [66]

Microbiological related parameter	Maximum allowable concentration / treatment goal
Viruses	Minimum 4 log (99.99%) reduction
E. coli	None detectable per 100 mL
Protozoa: *Giardia* and *Cryptosporidium*	Minimum 3 log (99.9%) reduction and/or inactivation
Total Coliforms	*At exit of municipal treatment plant or throughout semi-public systems*: none detectable per 100 mL *In municipal distribution systems*: no consecutive samples or no more than 10% of samples should contain total coliforms
Turbidity	< 0.1 Nephelometric Turbidity Unit (NTU) at all times with following exceptions: ≤ 0.3 NTU (for chemically assisted filtration) ≤ 1.0 NTU (for slow sand filtration) ≤ 0.1 NTU (for membrane filtration)

For a given system to meet the Health Canada Guidelines for drinking water quality, it must contain the appropriate combination of treatment steps to meet the treatment goal, measured by the log removal of certain pathogens. Log removal is calculated using Eq. 2.1 [81].

$$\textit{Log Removal Value} = \textit{Log}\ (N_{\textit{raw water}}) - \textit{Log}\ (N_{\textit{treated water}})\ \textit{(Eq 2.1)}$$

Where N is the number pathogens in the raw water or the treated water

Many provinces and territories in Canada have adopted the log removal credit system into regulation, were a certain treatment technology, if functioning properly is rated for a certain pathogen removal. The effectiveness of a treatment system to inactivate water borne pathogens from the application of chlorine is a function of the strength of a chlorine dose and the amount of time that the chlorine is in contact with the water, denoted by the term "CT" (Eq. 2.2).

$$\textit{CT} = \textit{Chlorine residual concentration in water (mg/L) x Time (min) (Eq 2.2)}$$

Where "Time (min)" is the time taken for the first 10% of the water to pass through contact chamber

The log inactivation capability is determined from a series of tables for a given pathogen, water temperature, and pH range (Table 2.7).

Table 2.7. Tabulated CT values for inactivation of viruses by application of free chlorine [82]

Temperature (°C)	**Log Inactivation**					
	2		3		4	
	pH		pH		pH	
	6 to 9	10	6 to 9	10	6 to 9	10
0.5	6	45	9	66	12	90
5	4	30	6	44	8	60
10	3	22	4	33	6	45
15	2	15	3	22	4	30
20	1	11	2	16	3	22
25	1	7	1	11	2	15

The WHO and other jurisdictions provide tables of different treatment technologies and processes with an assigned pathogen removal credit [65,83]. For example Table 2.8 shows specific log removal credits for various filtration options in Ontario, Canada. Some areas of Inuit Nunangat have adopted the log removal credit system for the design of water treatment systems, while other regions have not (Table 2.9).

Table 2.8. Pathogen removal credits approved by the Government of Ontario (Canada) for various water filtration systems [82]

Treatment Technology	**Log Removal Credit**		
	Giardia Cysts	Viruses	*Cryptosporidium Oocysts*
Conventional Filtration	2.5	2	2
Direct Filtration	2	1	2
Slow Sand Filtration	2	2	2
Diatomaceous Earth Filtration	2	1	2*
Membrane Filtration	3.0 +	0.0 to 2.0 +	2*
Cartridge/Bag Filters	2.0 +	0	2*
* applies only when the process has been specifically tested and confirmed for this removal/inactivation or *Cryptosporidium* cysts or removal of surrogate particles.			

The Nunatsiavut region, under the jurisdiction of the province of Newfoundland and Labrador, relies on a simple requirement that a minimum free chlorine residual (or equivalent CT) of 0.3 mg/L remains after 20 minutes of chlorine contact time, regardless of water temperature or pH [85]. These simpler regulations in Nunatsiavut may be because, historically, there was believed to be limited pathogens in the source water and therefore no need for filtration [60].

Table 2.9. Disinfection specific regulations for drinking water throughout Inuit Nunangat and Alaska, USA

Region	Disinfection regulation for surface water sources	Reference
Nunavut	3.0-log reduction of Cryptosporidium 3.0-log reduction of Giardia 4.0-log reduction of viruses (Follows Health Canada Guidelines)	[84]
Nunatsiavut	Minimum 0.3 mg/L chlorine residual after 20 minute contact time	[85]
Inuvialuit	3.0-log reduction of Cryptosporidium 3.0-log reduction of Giardia 4.0-log reduction of viruses (Follows Health Canada Guidelines)	[86]
Nunavik	2.0-log reduction of Cryptosporidium 3.0-log reduction of Giardia 4.0-log reduction of viruses	[60]
Alaska (US EPA)	2.0-log reduction of Cryptosporidium 3.0-log reduction of Giardia 4.0-log reduction of viruses	[60]

The drinking water treatment system in each northern community varies depending on the region, source water quality, and applicable provincial/territorial regulations. In the Inuvialuit settlement region, most communities have treatment plants which utilize cartridge filtration systems and chlorination steps [61].

The role of the filtration cartridges is to remove particulate matter and some chlorine resistant pathogens, such as *Giardia* and *Cryptosporidium* from the water before it is disinfected with chlorine. Some remote Inuvialuit communities with excellent source water (i.e. low turbidity and colour) have actually been exempted from the filtration steps and instead have a dual disinfection system [61]. In duel disinfection systems, the water is initially disinfected with an ultraviolet lamp to deactivate any chlorine resistant pathogens, and then the water is treated again with chlorine to provide a disinfectant residual [61]. In Nunavut, most water treatment systems utilize cartridge or membrane filtration followed by chlorination [62]. Some communities in Nunavut with turbid source water are also investigating the use of sand filters, while other communities with very clear source water (such as Iqaluit) also utilize UV disinfection in addition to chlorine [62]. In Nunavik and Nunatsiavut, drinking water is typically chlorinated without filtration [60,80]; although this has recently been changing in the Nunatsaivut region where some communities have begun to receive a new water dispensing unit to provide additional treatment to existing tap water [87]. This new packaged water treatment unit requires that individuals collect their own water for drinking and cooking by filling and transporting their own water in containers from the dispensing unit to their homes [88]. This new water treatment unit uses ozone (to disinfect and remove colour), a multimedia filter (to larger remove particles), a granular activated carbon filter (to remove chlorine and organics), a reverse osmosis filter (to removed small particles and pathogens), and then disinfects the water again with UV before it is dispensed to the consumers [89].

Water Distribution Systems

The distribution systems that deliver drinking water to homes in Inuit Nunangat do not always resemble the systems typically seen in the South. With a couple exceptions, residences in Nunavut, Nunavik and Inuvialuit receive their treated drinking water by haul truck [44,48,61,62]. The tanker trucks are filled with treated water at the water treatment plant and water is delivered to households by pumping the treated water into 1200 L storage tanks located inside each home [48,51,62]. Trucked delivery systems offer flexibility for expanding municipalities and also have a lower capital investment than piped systems. The operating costs for trucked systems, however, can also be high when factoring in tanker truck operation and replacement costs, labour costs for drivers, and the need for year-round road maintenance and snow clearing in the community [48,51,62]. In Nunatsiavut and some larger communities in other regions such as

Iqaluit NU, and Inuvik NWT, treated water is delivered to residences through a piped distribution system [60,62,90]. The piped distribution system may be buried underground, or located above ground in an insulated conduit called a utilidor, depending on the age of the system and the and region it is located in [51,62,91]. Buried distribution systems are often preferred over above ground utilidors because they alleviate many community planning challenges such as road and pedestrian crossings, costs and aesthetics [51,91]. Buried piped systems are similar to southern systems, but may also include heavy insulation, electric heat-tracing, recirculation, and water wasting or bleeding valves [51]. In cold regions, pipes are insulated to either protect the water in the pipe itself from freezing or in regions containing permafrost, to reduce any heat being emitted from buried pipes into surrounding ground, degrading permafrost and causing land subsidence. Many of the older piped distribution systems in communities such as Inuvik and Iqaluit were built with above ground utilidor systems because at the time of construction, buried distribution systems were technically or economically unfeasible in ice-rich permafrost areas [51,91]. However after considerable improvements in building techniques and materials for buried systems (i.e. pre-insulated pipes and recirculation loops), above ground utilidors are now only used when it is difficult to obtain excavation equipment, for temporary utilities, and in areas that are extremely thermally sensitive due to ice-rich permafrost [51,91].

Tap-Water Quality and Drinking-Water Preferences

Throughout the North there is some variability in the quality of tap water that residents receive. For instance, in the community of Rigolet, Nunatsiavut, the tap water is high in colour and has objectionable taste and odour [45,92,93], while the tap water in the city of Iqaluit, Nunavut, is very clear. A common sentiment across Inuit Nunangat (often independent of the actual measured physical and chemical tap water parameters) is that many Inuit prefer natural, unfiltered water collected from the land over tap water, or even over bottled water [39,40,48,90]. One study found that in four Nunavik communities, 31% of survey respondents chose to collect drinking water from local brooks and rivers in the summer months and melt ice in the winter months instead of drinking tap water [44]. Another study in the community of Rigolet, Nunatsiavut found that 37% of respondents believed their tap water to be unsafe, while only 4% believed untreated water from the land to be unsafe [45,80]. Therefore, an important aspect in the planning and design of water infrastructure is to understand the taste preferences and consumption practices of the community who is receiving this infrastructure. In Inuit Nunangat, it seems that even if tap water meets regulatory requirements for quality, many residents prefer potentially more risky [65] natural water sources.

This brief snapshot of the current status of drinking-water infrastructure in Inuit Nunangat indicates that there is some variability in the quality of drinking water infrastructure investment in different regions. Even though all communities have drinking-water treatment systems, many Inuit prefer and chose to drink water from natural, untreated sources. This practice may indicate a gap in understanding between water treatment system designers, public heath practitioners, and Inuit community members, which ultimately represents a major shortcoming of the drinking water infrastructure. Stakeholders need to work together to improve the planning, funding, design, education, and understanding of cultural preferences and beliefs around drinking water and public health for water infrastructure to be truly successful.

SECTION THREE: WHY CURRENT DRINKING WATER SYSTEMS ARE FAILING

In engineering terms, failure means that there is an “unacceptable difference between the expected and observed performance” of a system [94, pg.]. There are generally three categories of failures: (1) failures that occur early in the design, planning, or construction process that lead to a poor product, (2) failures that occur throughout the operation of the infrastructure, and (3) failures that occur because the infrastructure or its components have reached the end of operating life [95]. This section discusses some of the specific causes of infrastructure failure within these three different timeframes.

Planning and Design Failures

The causes of designs failure in the planning and design phase are often due to inadequate budget, specific technical challenges, and/or poor consultation by the designers or engineers with the infrastructure users.

Failures Due to Limited Budget

Failures from limited budget can occur as a result of strategic cost cutting or when a project is only partially completed with the intention of completion once more funds are secured [95]. Examples of potential causes of infrastructure failure from cost cutting include lack of sufficient resources for community consultation and engagement activities; or insufficient collection and analysis of geotechnical data or source water samples. Without proper data collection, it is unlikely that infrastructure can be properly planned and designed.

Conceptual Design Failures

Conceptual design failures refer to when the design itself is flawed. This type of failure typically begins early as errors in the planning and design process and can be carried through to the construction and operation phases without proper quality control or safeguards [95]. For instance, when technology or building practices developed for more temperate zones are applied to cold regions and fail because of the unique technical, operational, cultural and governance differences in the North [51,95].

Technical Challenges that Can Lead to Conceptual Design Failures

Conceptual design failures for infrastructure in northern regions, such as Inuit Nunangat can occur because of technical engineering challenges like permafrost, variable source water quality, and extremely cold temperatures.

Permafrost and Frozen Ground

The presence of continuous or discontinuous permafrost in soil can significantly increase the cost and complexity of drinking water infrastructure [51]. Technically, permafrost is defined as a layer of soil or rock that has been below a temperature of 0^{o}C over at least two consecutive winters and the intervening summer [96–98]. There are two main categories of permafrost that occur on land in Canada: continuous permafrost, when there is permafrost in 90-100% of the soils; and discontinuous permafrost, which contains from 0-90% permafrost [99] as shown in Figure 2.3.

The active layer, which is on top of permafrost, will thaw and refreeze on a seasonal basis. The greatest challenges posed by building on permafrost and frozen ground occur if the permafrost begins to thaw. Heat generated by a building or structure on top of frozen ground or by pipes buried in the active layer can cause permafrost to melt, which can disturb the active layer and cause the structure to shift, leading to structural failures or broken transmission pipes [100]. Another concern of building on permafrost and frozen ground is frost heaving. In the North, steel or wooden piles are driven deep into the ground to provide a stable foundation for a structure because excavated foundations are not possible in some regions due to permafrost.

Without adequate drainage water can actually pool under the piles during the warm summer months. In the winter months, as the active layer freezes, this pooled water will freeze forming ice lenses and push up on the buried piles, a phenomena known as frost heaving [51]. Frost heaving of piles can also lead to the failures of structures or pipelines relying on the piles as foundational support [51,97]. As global temperatures gradually increase, scientists have documented that permafrost, especially discontinuous permafrost in the more southern regions, is melting causing landscape changes, landslides, sinkholes and the release of methane into the atmosphere [41,100]. This release of methane, a potent greenhouse gas, could produce a powerful feedback leading to increased climate warming [100].

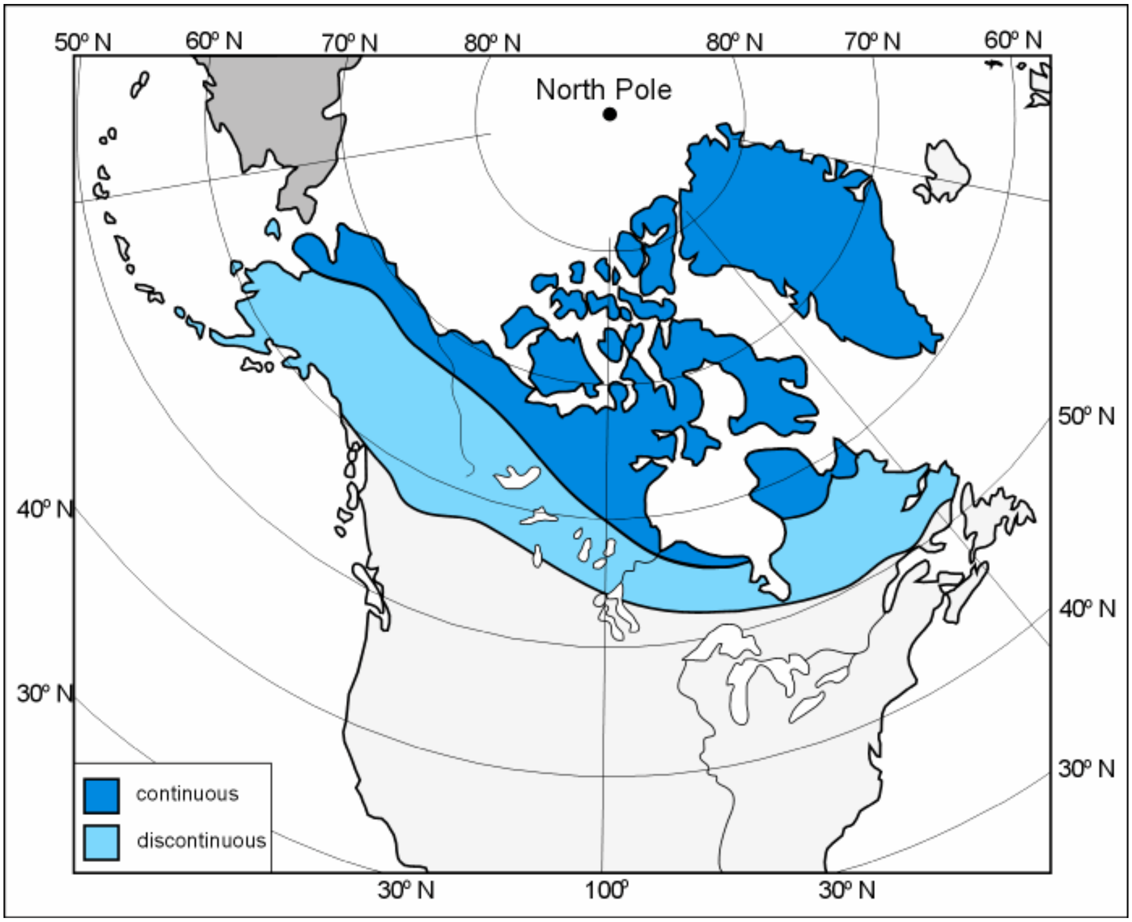

Figure 2.3. Map showing the distribution of permafrost in North America (2009) [101]

Climatic change is expected to have a great impact on infrastructure development in remote northern communities because of permafrost warming [102–104]. Interest in natural resource development and extraction will put additional need for effective building practices in the North [100]. In addition, surface vegetation provides insulation for permafrost and the clearing of land for development can also lead to permafrost warming and degradation [104]. Permafrost and frozen ground is a major technical challenge and an example of why infrastructure planning, design and construction practices from southern regions cannot simply be applied in the North [51,95].

Cold Temperatures

When designing infrastructure in cold regions the long cold winter months are a major challenge. Cold temperatures can impact the operation of a water treatment plant. For example, extremely cold water entering the treatment system through a water intake can also cause frazzle ice to form, quickly disrupting the flow of water and disrupting the treatment plant [51]. In cold regions, a water treatment plant needs to be equipped with a heat source to prevent system freezing. Despite best efforts, the assumption must be that at some point the system will freeze and proper access to thaw pipes and equipment must be provided in the design [95]. This exemplifies a key difference between northern and southern infrastructure: it may not be possible to design northern infrastructure so that is robust and "fail safe," it should instead be designed so that it can "fail safely" and be repaired easily [51,95].

Cold temperatures can impact important parameters in the water treatment process including chemical reaction rates, water viscosity, gas solubility, sedimentation and microorganism activity [105] . For example, the low temperatures in the North lead to an increase in water viscosity. This increased viscosity leads to an increase in the amount of time needed for particle settling, the amount of energy that is needed for chemical mixing, and the energy required to pump water through cartridge or membrane filters [51]. Considering the problems of infrastructure freezing and the impacts on water treatment processes, cold temperatures can add great complexity and cost to designs and are therefore an important consideration to northern infrastructure projects.

Challenging Source Water

Tap water quality depends not only on the performance of the treatment system, but also the initial quality of the source water. In cold regions, there can be large seasonal variability in source water quality. During the cold winter months when surface water is frozen over, the water may be very clear, but turbidity and colour may rapidly increase once the spring melt and ice break up occur due to run-off from rainfall and snow melt [47,106,107]. High organic matter content, especially in permafrost rich soils, can pose aesthetic concerns as untreated water can be high in colour and have odour [51]. If this source water is treated with chlorination without adequate removal of organic matter, disinfection byproducts might be formed that are potentially harmful to health [60,66,69,108,109]. The health risk from these disinfection byproducts are considered less than the health risks from inadequate disinfection. Therefore, disinfection should not be compromised in the name of disinfection by-product control [65,66,69].

In cold regions, source water quality can vary depending on the source, season, temperature, weather and other factors. Water infrastructure in cold regions has many unique technical challenges, which, when not appropriately addressed in the design stages, can lead to system failure.

Construction Failures

A construction failure is when a critical component of the design or project is not adequately installed, or has been improperly substituted for the component that was specified in the original design [95]. Causes of construction failure in the North might be lack of northern specific worker experience, poor judgment, financial constraints, lack of inspections or government oversight, or even as a result of decisions made due to the tough logistical challenges of working in isolated, northern communities [51,95].

Causes of Construction Failures

Lack of Northern-Specific Building Codes and Practices

Some regions of Inuit Nunangat, such as the government of the North West Territories have developed specific guidelines for building in their regions [84,110,111], while other regions have not. The establishment of regional specific codes and guidelines are important because many consultants and construction firms who work in remote northern communities may be based in the South; therefore, workers might not always be familiar with the unique technical challenges and building practices that are required. For example, when under pressure, these firms might make decisions to save time or money which may be less problematic in the South, but could lead to failure in the North [95]. For example, many of the consultants and construction firms that work in the Nunatsiavut region of northern Labrador are based in Newfoundland. There are substantial differences in the climate and terrain between these two regions (e.g. permafrost, temperature, geological features and so on), although both Labrador and Newfoundland follow the same building codes and practices. Many Inuit leaders in Nunatsiavut believe that the region needs to develop its own building codes and practices to reflect its unique geographic challenges and local culture [90].

Construction Logistics in Remote Communities

The degree of remoteness and access to a community are major factors in the planning, design, construction, operation, and ultimately cost of all infrastructure projects. Without regular road access, all construction materials, heavy equipment, supplies, and typically specialized labor need to be sent from southern communities by air, ship or for a select few, a winter ice road. Technically skilled certified tradespeople often need to be brought from southern centers including plumbers, electricians, carpenters, pipe fitters, or heavy equipment operators. While in these remote communities, these workers are provided lodging and paid a living allowance, which can greatly increases the overall labour costs of a project compared to projects in the South [51]. Also, the heavy equipment required for construction such as backhoes, dump trucks, and bulldozers are not always available for rent in communities by contractors. Typically, the majority of building materials must also be imported for construction projects. Air transport of building materials and equipment can be financially prohibitive or impossible due to limited payload capacity of small aircraft that are able to land in small, remote communities. The shipping season by boat cannot begin until late summer because the sea ice has to melt and disperse [51]. Remote northern communities do not typically have deep-sea ports, so in many communities materials need to be ferried from the cargo ship to shore by a small barge. Construction scheduling is also challenging, so work may take place immediately following arrival of supplies by ship, but much of the construction will likely begin the following spring. Over the winter months, equipment and construction materials require secure storage or they may become damaged, or go missing [51]. The delay, loss or damage of building materials or equipment may lead to construction failure, for example if due to a logistical delay a specified building material is substituted for a less appropriate or robust option [95] . The limited seasonal construction window in remote northern communities also results in increased project costs compared to the South because projects are often stretched over multiple building seasons, increasing travel costs for skilled labour and costs to store materials and equipment between construction seasons [51,95].

Operation and Maintenance Failure

Infrastructure failures during the regular operation and maintenance of water infrastructure could be due to a number of reasons. Operation and maintenance failures in the North are often due to operator error, inadequate maintenance, logistical challenges, or poor infrastructure design.

Causes of Operation and Maintenance Failures

Operator Error

System failure due to operator error can be simply defined to occur when an operator fails to maintain or operate a water treatment plant as the manufacturer or designer had originally intended [95]. Examples of a system failure as a result of operator error include: improper completion of scheduled maintenance, untimely replacement of a failed component, or failure to maintain required residuals of water chemistry parameters during regular operation [95]. In remote communities, it can often be very challenging to recruit, train, and retain a highly skilled water treatment plant operator [112]. Generally, the level of formal education in remote northern communities, especially Indigenous communities, is low [28,112–114]. Often community members who have left the community to pursue post secondary or a skilled trade get recruited for high paying jobs in urban centers or in the resource development sector. In some regions of Inuit Nunangat, there are no regulations requiring water treatment operators to be licensed or certified (Table 2.10). Operators in remote communities have varied levels of formal education, technical skills, and formal training [112,115]. Engineering consultants have noted (through personal communication in 2014), that many operators have not finished secondary school and fail to obtain water operator certification due to struggles with literacy and math components of the evaluation.

Table 2.10. Water system operator certification requirements in Inuit Nunangat [77]

Province/Territory	Operator certification requirements
Newfound and Labrador (Nunatsiavut)	No operator certification required, but encouraged
Quebec (Nunavik)	Operator certification required, renewal every 5 years under law
Nunavut	No operator certification required, but encouraged
Northwest Territories (Inuvialuit)	Operator certification required for level of treatment plant they operate

Operators often have an opportunity to take training and obtain certification, but it requires that they travel out of their communities, away from their families, for a number of days [112]. The training courses and evaluation are delivered in a conventional classroom style and are not always a comfortable learning or evaluation method for Indigenous operators. All of these factors are major barriers to training and certification among operators in small communities. The responsibility of water treatment operators for the public health of a community is immense and is not often reflected in their training, remuneration, and respect they receive in the communities that depend on them. Municipal governments in remote communities typically have no local tax base, and thus rely on transfer payments from the province/territory [51]. Due to limited operating funds, remote communities often cannot afford to pay water treatment plant operators wages that accurately reflect their responsibilities [116]. In remote communities, public works staffs often have multiple roles, on top of being the local water treatment operator. They may also be responsible for solid waste collection, animal control, snow removal, event planning, or other positions [112]. Public works staff in remote communities often do not have the time or technical skills to repair damaged equipment, such as pumps, and therefore just order new equipment when there is a break down [117]. Similarly, if a complicated operational issue arises, small system operators do not always have the technical ability to troubleshoot and thus rely heavily on outside consultants [117,118]. Operators in remote communities have also reported that they are often under intense social pressure from members of the community to limit the smell and taste of chlorine [112].

Inadequate Planning for System Operation, Maintenance, Repair, and Replacement

Inadequate planning and budgeting for the operation, maintenance, and repair of water infrastructure in remote communities can also lead to system failure. The high cost and long delivery times for replacement parts; the increasing cost of energy and chemicals; and increasing regulation, testing, and reporting requirements all point to an increase in the complexity and cost of operating a successful water treatment system [112,118]. Municipal governments in the North receive the majority of the funds needed for their annual operating budget from federal and provincial/territorial transfers [117]. Municipal budgets are always strained and there may not be sufficient funds budgeted for maintenance and replacement parts [117]. As a result, water infrastructure components in some small communities, such as pumps and meters are only replaced after the point of failure. When breakdowns occur, often there are no replacement parts available locally and they must be shipped in from the South. These reactive repairs place the community system at increased risk, either by operating without spare parts or operating without critical system redundancies. For example, if the community of Rigolet, Nunatsiavut needed a replacement pump it would likely take 6 weeks to be shipped from a supplier in St. Johns, Newfoundland. In the case where a community water treatment plant is without spare parts and without redundancy, the failure of a critical component (e.g. chlorine pump) would force the community in to a Boil Water Advisory [117]. This reactive response indicates a lack of maintenance capacity, and the lack of funds to implement a comprehensive maintenance plan. In addition, the cost of electricity and energy required to pump, heat, and treat drinking water in remote communities is increasing on an annual basis.

Failures from Engineers' Lack of Understanding of Northern Context

Lack of understanding of the unique social, political, cultural context of northern communities by engineers and designers is a cross cutting theme than can cause planning, construction, and operation and maintenance failures. Some of the most common design and construction failures that occur in remote northern communities are due to designs that are not culturally appropriate [51,95,113]. Understanding the preferences, beliefs, and concerns of community members who will be using a particular infrastructure is critical to success [51]. Unfortunately, development practices in remote regions rarely consider local Indigenous knowledge, practices, or cultural norms [113]. Often infrastructure designed by external companies and individuals is inappropriate, and the local community does not fully accept it, or will be not able to effectively operate or maintain it [113,119]. If infrastructure is to be long lasting and well cared for, it must be designed for the actual users of the technology. For example, when the government of Canada first started offering housing to Inuit communities as part of the "Eskimo Rental Housing Program" in the 1960's, these houses were poorly constructed and were not appropriate for the northern climate or for Inuit culture [19]. As Pulla described:

> *The intention behind these housing policies was consistent with housing policies in the South. Consultations with local northern communities, however, were not conducted and housing designs were ill suited, both physically and culturally, for the North. The enamel sinks in some of these houses, for example, served no useful purpose in the absence of running water. Due to the lack of housing infrastructure, bathrooms were typically used primarily for storing carcasses before butchering.* [112, p. 10]

In many ways, northern housing design has undergone relatively little change since the 1960's. In many regions houses are still inappropriate for the climate and culture, however there are various initiatives underway investigating new housing options for the North [120–123]. Ultimately proper consultation and engagement with users is a critical factor to successful infrastructure projects, especially in the Circumpolar North [3,51,95,118].

Figure 2.4 depicts various ways water infrastructure failures can occur in remote northern communities. The failure of drinking water infrastructure in cold regions can occur in any of the three parts of the system lifecycle: the design or planning stage, the construction stage, or the operations stage.

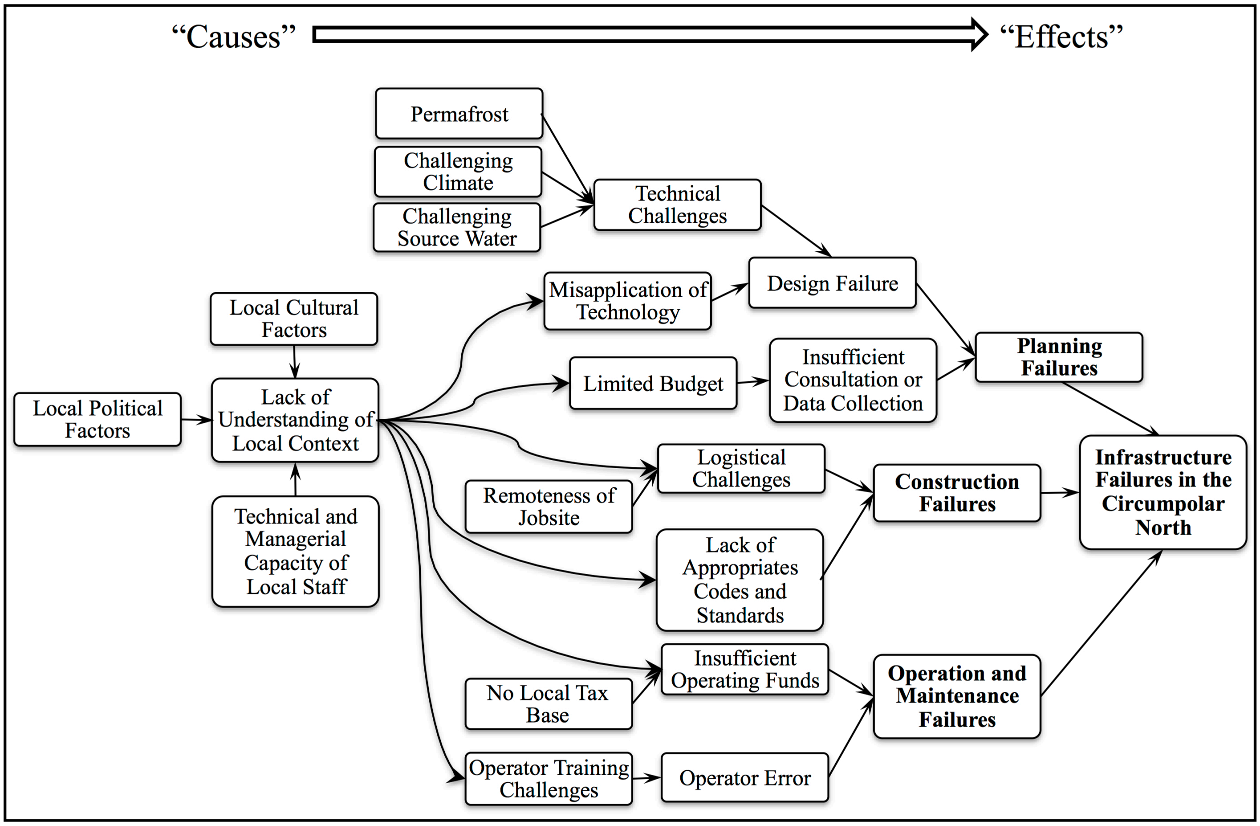

Figure 2.4. Relationships between different causes and categories of infrastructure failure in the Circumpolar North identified in published literature [3,51,95]

Major factors that can lead to failure are lack of appropriate funding, inappropriate application of engineering principles, misapplication of technology originally designed for a temperate climate without proper modification, failure to accommodate for unique cold-region issues, such as permafrost and frozen ground, variable source water quality, complex shipping and construction logistics, operator error, and inadequate operations and maintenance capacity. A successful water infrastructure in remote northern communities must accommodate for each of these factors.

SECTION FOUR: INNOVATIVE APPROACHES TO INFRASTRUCTURE PLANNING IN THE CANADIAN NORTH

Ultimately, the goal of all infrastructure development, especially in remote northern communities, should be the development of sustainable, appropriate infrastructure that protects public health and encourages economic growth of a community while protecting the environment [51,113]. Planning, construction, and operation of water infrastructure are complex engineering problems in the North (Figure 2.5). Working in remote northern communities requires an understanding of a unique combination of technical, financial, logistical, governance, and cultural factors.

The multifaceted condition of high uncertainties and high stakes are in part due to the increasing rate of exploration and development of Canada's North for natural resources, the rapidly changing landscape as a result of the impacts of the climatic change, interest in Arctic sovereignty by circumpolar nations, the young and rapidly growing Inuit population, the assertion of Ingenious rights by Indigenous people through self-governance and protest movements, and the transfer of authority from the Government of Canada to territorial, regional and community governments as part of the devolution process [124–126]. Some studies [95] have made certain specific suggestions for improved design and planning processes for northern infrastructure (Table 2.11). However, this review will focus on broader, systemic issues and innovative approaches to addressing infrastructure challenges in the North.

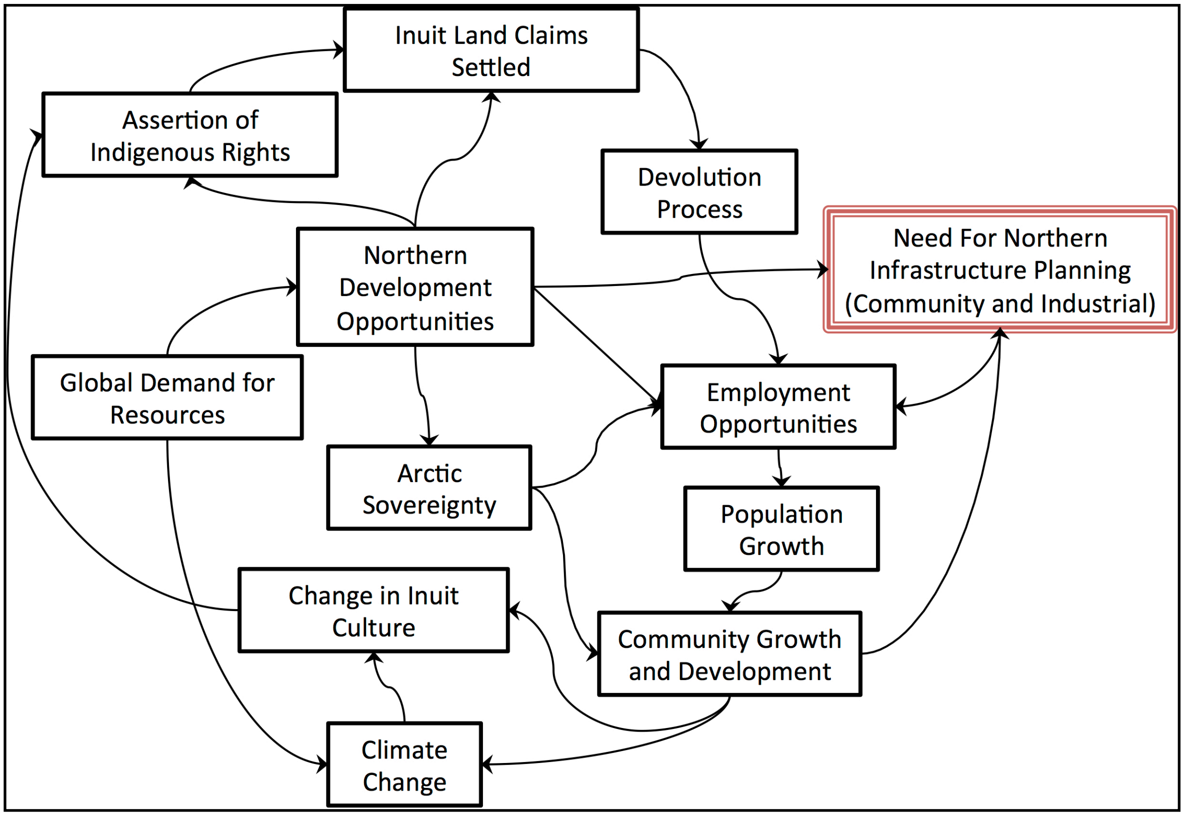

Figure 2.5. Causal diagram showing various factors and relationships driving the need for infrastructure planning in the Circumpolar North

Table 2.11. Suggestions for the design, planning, construction and operations of cold region water infrastructure [3,51,95]

Suggestions
Choose a concept, equipment, and materials that have been proven to work in similar conditions in cold regions, i.e. be wary of equipment with low serial numbers, which means that they are new product lines and have not necessarily been proven under northern operating conditions [95]
Design for the safe failure of components and systems when fail-safe is not possible, i.e. include backup power and backup heat on critical items (such as pump houses, and water storage tanks) to thaw them when they freeze [95]
Be aware of the cost, sources, and availability of energy in the community [51,95]
Design for ease of repair and maintenance; consider the technical abilities of the likely operator/mechanic [95]
Design with components and parts that can be stocked on site, or available within a reasonable amount of time
Develop life cycle cost comparisons between technology options on the expected design life (i.e. 20 years). Establish in advance who is responsible to pay for capital, operations, and replacement costs [95]
Once a source of drinking water is identified, the community must also implement policies to protect that source from contamination [51,95]
Ensure adequate budget for initial operator training and ensure owner and funding agencies are aware of the need for follow-up operator training in the future [95]
When working with communities or clients of a different culture or background, it is essential to first take the time to close the communication gap, learn about the clients and understand how they see the world [3]

Conventional scientific and engineering methods tackle problems by breaking down, simplifying, and reducing them into a number of small, manageable problems [4]. The drawback to these reductionist approaches is that they often fail in the face of complex problems where there is a high degree of uncertainty and high decision stakes [5,127]. A complex problem is different from one that is complicated. Noor differentiates complicated and complex systems using the example of a computer chip [128]. In the 1970's, Intel fabricated a computer chip that contained 2250 transistors, while in 2011 a microprocessor had over 3 billion transistors. The key difference between these two generations of microchip, is a factor of scale, as the fundamental principles and rules under which they operate are the same [128]. Although it is a complicated and expensive process to manufacture a modern microchip, if proper equipment and training are provided for each step in the manufacturing process, a new firm could reproduce a predictable and identical product. The outcomes of a complex system or process, however, cannot be predicted or explained by looking at its individual components, it must be analyzed in its entirety as a complete system. Waltner-Toews describes a complicated system as needing redundancies and buffers to ensure stability when stressed but as having predictable behavior given expert knowledge and a stable environment or context, such as flying a spaceship to Mars [129]. A complex system, however, has a changing context and its behavior cannot be predicted by anyone, such as raising a child [129]. A complex system is one that can face uncertainty [128], adapt to change [5,130], and may behave differently or result in different outputs or end states depending on initial conditions [131].

Funtowicz and Ravitz suggest that appropriate approaches to research and problem solving depend on levels of uncertainty and the decision stakes [132]. These approaches can be divided into four different classes: core science, applied science, professional consultancy, and post normal science, as shown in Figure 2.6. These authors suggest that most engineering problems are likely situated between applied science and professional consultancy. However, if a problem were to have either high decision stakes (e.g. conflicting purposes between project stakeholders), or have high system uncertainties (e.g. topics of ethics, epistemology, climate change), this problem requires a post-normal science (PNS) approach [132].

Extended Peer Communities

One of the key principles in the PNS approach to complex problem solving is the engagement of "extended peer communities," which are legitimate stakeholders who are typically outside the scientific community (e.g. community members, youth, elders, activists, local businesses, and so on) [132,133]. Extended peer communities extend the quality assurance role of conventional peer processes (e.g. peer review) to all legitimate stakeholders by enabling their participation in related policy debates and enriching the process by providing 'extended facts' involving unpublished local and "anecdotal" knowledge [132,133].

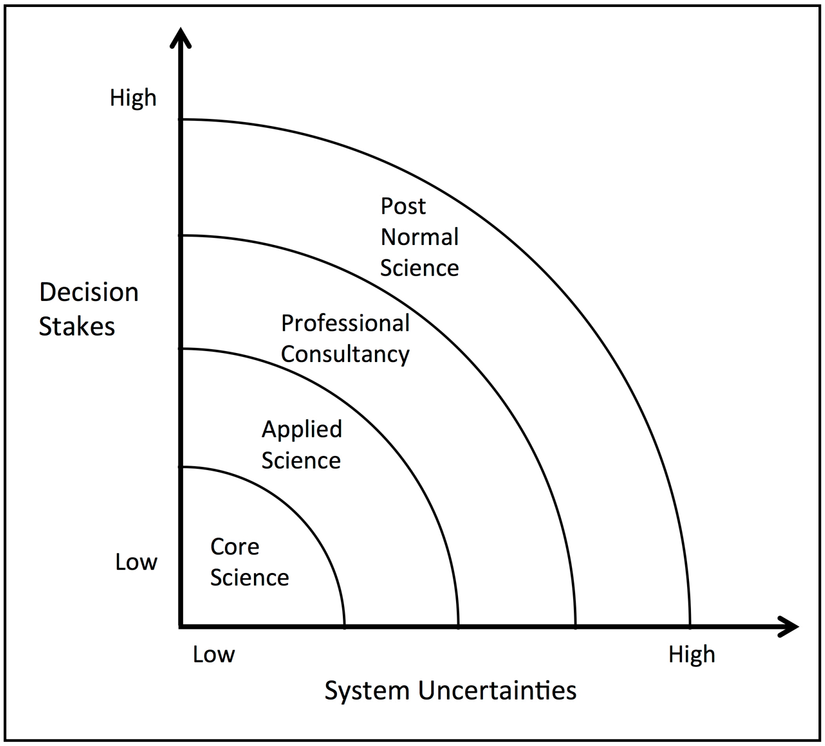

Figure 2.6. Diagram showing different approaches to scientific research based on the degree of systems uncertainty and level of decision stakes involved (adapted from [132])

Funtowicz and Ravetz have suggested that in cases where research will inform policy decisions, decision makers will benefit from diverse, although potentially biased local perspectives:

> *Knowledge of local conditions may determine which data are strong and relevant, and can also help to define the policy problems. Such local, personal knowledge does not come naturally to the subject-specialism experts whose training and employment predispose them to adopt abstract, generalized conceptions of genuineness of problems and relevance of information. Those whose lives and livelihood depend on the solution of the problems will have a keen awareness of how the general principles are realized in their 'back yards'* [132, p.753]

In cases of high decision stakes and high system uncertainty (such as is the case for water infrastructure in the Canadian North), it is important for experts and decision makers to develop "mutual respect among various perspectives and forms of knowing," which could ultimately lead to "the development of a genuine and effective democratic element in the life of science" [132, p.741]. In addition, in cases where there are important cultural differences Sullivan & Meigh, as cited in Plummer *et al*. suggests that "traditional reductionist approaches to derive best practices can be strengthened by building upon systems approaches that incorporate traditional knowledge and cultural values to engender more fully integrative models" ([134] cited in [135, p. 2]). Scholars and researchers are also becoming more vocal about the important role of Indigenous knowledge and are less concerned about the validation of Indigenous traditional knowledge; "Scholars have wasted (in my view) too much time and effort on a science versus traditional knowledge debate; we should reframe it instead as a science and traditional knowledge dialog and partnership" [136, p.151].

Critiques of a Post Normal Science (PNS) Approach

One critique of PNS is that the axis in the decision stakes and uncertainty diagram (Figure 2.6) are very subjective, not easily measured, or not discrete. For example, some authors [137–139] have suggested that in instances such as space exploration, the decision stakes may be relatively low, but the uncertainties are high, and therefore according to Figure 5 [132], PNS would be the appropriate approach for space research; however, the authors [137–139] suggest that space research would likely not benefit from an extended peer community. Further critiques exist from those who are unconvinced of the value of extended peer communities and the anecdotal evidence they may offer [138,140–142]. Other criticisms and critiques of the PNS approach are that PNS is simply selling “old wine” in a “new bottle” and neglecting previously documented participatory approaches to research [138,143].

Incorporating a Systems or PNS Approach in Planning

Researchers are now openly discussing how current planning, funding, design, and construction practices do not adequately address social, cultural, or capacity concerns [6,7,112,113]. Whether termed participatory approaches [6], systems approaches [134], or co-management strategies [136], the inclusion of extended peer communities is a fundamental aspect of complex problem solving. Infrastructure projects in remote northern communities already engage government stakeholders and technical experts, but the genuine engagement of community stakeholders is often missing [51,93,113,118].

While Indigenous communities are often excluded from the planning, design, and implementation of infrastructure projects [118], studies have shown that community participation in the planning process can develop local capacity and create a sense of community ownership over drinking water infrastructure. For instance, a study of water treatment system adaption in two different Alaskan Iñupiaq communities found that when water infrastructure was “brought into the village by the village itself” [116 p.81] that the “process therefore [was] locally driven and agency [was] retained" [116, p.81]. Among many other factors, the Iñupiaq study attributed the success of the treatment system to the involvement of respected community members who actually sought out government grants, advocated for treatment system upgrades, and were part of the decision making process irrespective of their technical expertise [118].

In some remote northern communities, particularly in the Nunatsiavut region of northern Labrador, communities are not often engaged in the infrastructure planning and decision making processes [93]. The federal or provincial/territorial government typically supplies funding for water infrastructure projects in the North. Smith and Low [51] discuss the importance of community engagement and consultation in the planning and design process and make an important distinction between the community and the public. The 'community' is the elected community government, community groups, or the entire community as a whole. Without adequate community level participation, infrastructure will likely physically or socially fail [51]. The 'public' includes individual members of the community, which could include residents, youth, elders, and so on [51]. It is especially important to engage individual members of the public when the values, preferences, commitment, and desires of residents vary, or if it is believed that the concerns or local knowledge of individuals is not being adequately represented [51] . Community and public consultations, however, should always be with the support of the local community government so that the decision making responsibilities of the locally elected government are not by-passed through public consultations [51].

Scenarios as a Tool for Planning and Community Engagement

It has been suggested that when approaching complex problems, conventional forms of planning and forecasting which rely on linear causal relationships are not fitting and that scenario planning is a more appropriate approach [5]. It can be impossible to accurately predict the future state of a complex system since it is based on a function of history and uncertain future events and therefore conventional anticipatory planning techniques alone are not appropriate [5]. Scenario planning and the creation of narratives may be a more appropriate approach [5]. Scenarios are "a description of a possible future state of an organization's environment considering possible developments of relevant interdependent factors in this environment" [144, p.32]. The development of scenarios can be a collaborative process in which stakeholders and the extended peer community identify plausible future system states that include scientific knowledge, alternative forms of knowledge, culture, and local values [5]. Scenario planning has been useful when there is a public call for an integrated source of accessible information and processes that build local awareness, capacity, support, and citizen engagement in the planning and decision-making processes [145]. Organizations have found scenario planning effective when addressing complex, uncertain topics, such as climate change adaptation [145,146], health priorities [147,148], global economic uncertainty [149], population growth [150], military planning [151], sustainable development [152,153], and water resource planning [154,155].

Conventional approaches for planning and designing complex water infrastructure in the North are not effective due to high decision stakes and high degrees on uncertainty. Innovative approaches from the field of PNS should be considered, including extended peer communities and participative scenario planning to improve the infrastructure planning and design process.

CONCLUSION

Based on the synthesis of background information on: the importance of drinking water infrastructure in terms of public health and opportunities for economic development; the current status of water treatment infrastructure in some remote northern communities; the unique technical and logistical challenges of developing infrastructure in remote northern communities; and the apparent suitability of PNS approaches in the North, it is apparent that engineers need new tools and strategies to capture the unique complexities of remote northern contexts and to develop more context appropriate infrastructure planning and design processes and practices.

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CHAPTER THREE

EVALUATING TOOLS AND APPROACHES TO CAPTURE LOCAL CONTEXT AND KNOWLEDGE TO INFORM INFRASTRUCTURE DESIGN AND PLANNING PRACTICES IN NORTHERN COMMUNITIES

INTRODUCTION: LOCAL CONTEXT IS EVERYTHING – EFFECTIVELY INFORMING ENGINEERING SYSTEM DESIGNS

An engineered system will be most successful if it is designed for the specific user and the local context [1] which includes aspects such as social, political, and cultural conditions; environmental conditions; and financial, technical, and managerial capacities of the users and owners. Knowledge and consideration of the local context helps ensure effective and appropriate infrastructure, which will then contribute to socioeconomic development, public health status, public safety, and the protection of the local environment [1]. Additionally, there is growing recognition from researchers, engineers, and planners that projects are more likely to be sustainable with local ownership, increased management capacity, enhanced political cohesion, explicit socio-cultural respect, and adequate local skills [1–6].

Despite the importance of the local context, a number of researchers have identified a lack of appropriate planning and design methodologies and tools available to adequately address local context as a major barrier to the successful implementation of new sustainable technologies and infrastructure projects all over the world [3,4,6–8]. For instance, considering the local context in the Circumpolar North is particularly important for infrastructure planning and design processes. Indeed, the planning, design, and operation of infrastructure in the Canadian North can be particularly challenging due to the unique biophysical, social, and economic conditions that are substantially different from other southern regions in Canada [1,4–6,9,10]. These conditions are becoming increasingly complex and uncertain in the North due to increased industrial development, climate change, population growth, and the transfer of more decision-making responsibilities from the federal to regional and community governments [10–16]. Relatively rapid and impactful changes in many northern communities are commonly overlooked, and have resulted in several examples of housing [17–20] and drinking water infrastructure [5,6,21,22] failures. Many of these failures were attributed to engineers and designers applying technologies appropriate for southern regions in a northern setting without attempting to adequately understand and address critical differences between the two situations [5,10]. For instance, in the 1960's when the Government of Canada first provided housing to Inuit communities as part of the "Eskimo Rental Housing Program", the houses built by consultants were poorly constructed and were not appropriate for the northern climate or for Inuit culture [20]. As Robson [23] described:

> *The houses were inferior, expensive, small, often not provided with services and above all else, clearly not constructed with a view to meet the housing needs of the local population. In this regard, the living space was compartmentalized, there was no workspace within the unit to clean or prepare meat or fix snow machines, [and] little thought was given to storage areas [...].*

Highlighting the efficacy of incorporating local context to infrastructure, a study by Marino *et al.*[6] found that there were many factors that influenced the adoption of centralized water infrastructure in two Alaskan Indigenous Iñupiaq communities, including the degree of community engagement and ownership in the planning process. Their study showed that factors impacting the community's adoption of the new water infrastructure included the perceived quality of the source water, the convenience of accessing the treated water, and also local perceptions of what constituted healthy and safe drinking water. Specifically, they found that residents from one community rejected the centralized water system because they did not trust the source water due to lack of decision-making transparency, low engagement in the decision-making process, and misunderstanding regarding the technology during the infrastructure planning and development process. In contrast, a centralized water system in another community was planned and implemented with local leadership, which increased a sense of ownership and pride, and led to increased adoption and wide support of the centralized water system.

These are but two examples that highlight failures of northern infrastructure that were traced back to engineers and planners inability to adequately understand and/or incorporate the local context into the design, construction, and operation of a system. Graduates of engineering programs, however, are not always provided with the appropriate tools or training to effectively engage with different cultures to develop sustainable designs [4], appreciate the unique contexts within which the infrastructure will be used, or be empathetic to the specific needs of the end-user [24]. As such, the lack of appropriate training and tools for designers and engineers could be a root cause of many engineering failures in the North, and presents a barrier to providing appropriate "place-based" infrastructure solutions in the Circumpolar North.

PARADIGMS, APPROACHES, METHODOLOGIES, AND TOOLS FOR UNDERSTANDING LOCAL CONTEXT

A paradigm is a particular worldview that is based on a specific set of assumptions that are necessary for the paradigm to be considered plausible [25]; or, as Khun described, a "*universally recognized scientific achievements that for a time provide model problems and solutions for a community of practitioners*" [25, p.48]. Working within an appropriate paradigm, engineers and planners can use a number of existing approaches, methodologies, and tools (Figure 3.1) to incorporate local context and enhance the planning and design of northern infrastructure. The approaches can include engaging with extended peer communities and "design thinking" (as described below).

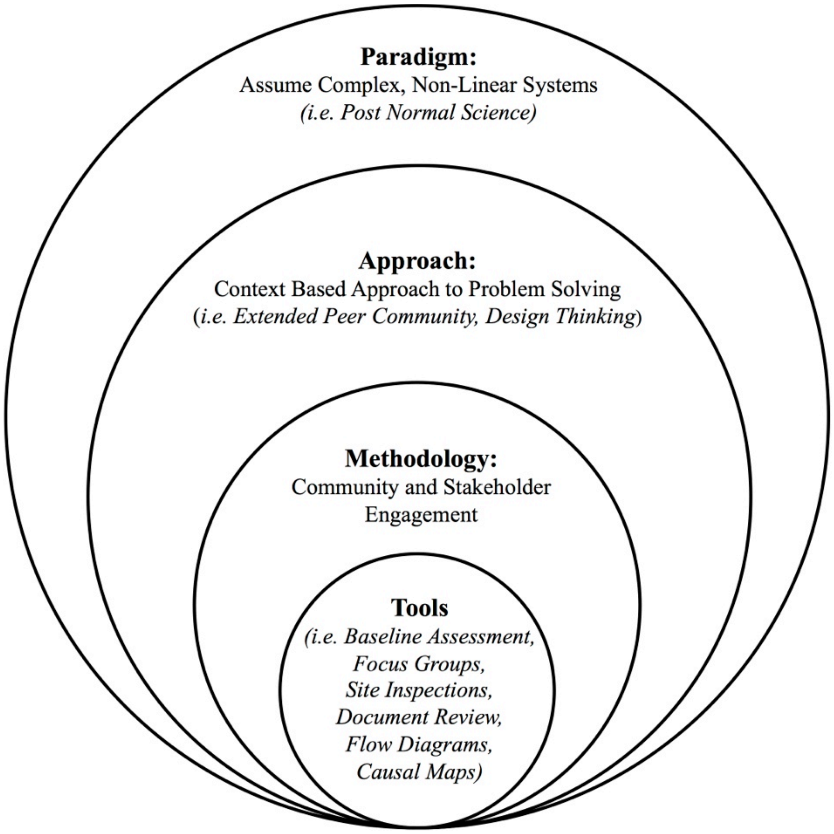

Figure 3.1. A diagram outlining the relationships between the paradigm, approach, methodology, and tools used in this study

Post Normal Science Paradigm

The dominant engineering paradigm has encouraged a reductionist approach to tackle problems by breaking down, simplifying, and reducing issues into a number of small, manageable items [26–28]. While this reductionist paradigm may be useful to address certain types of problems; modern discoveries, such as those in the fields of quantum mechanics[28], relatively theory [28], ecology [27,29], and many others, have confirmed that many human and ecological systems are complex, non-linear systems and therefore non-conventional paradigm are needed to address many of society's problems [27,28,30]. Funtowicz and Ravetz suggested that based on degrees of uncertainty and decision stakes, paradigms for problem solving could be divided into four different classes: core science, applied science, professional consultancy, and post normal science (Figure 3.2). Many engineering problems are likely situated between applied science and professional consultancy classes [30]. However, problems with either high decision stakes or uncertainties, including infrastructure design and planning in the North, may benefit from a post-normal science (PNS) perspective [30]. PNS openly acknowledges that each complex problem has unique attributes, characteristics, and relationships and therefore demands a context based approach to problem solving with collaborations across disciplines, as well as with non-conventional experts, referred to as the "extended peer community" [30]. The inclusion of extended peer communities expands the quality assurance role of conventional peer processes (e.g. peer review) to all legitimate stakeholders who are typically outside the scientific community (e.g. community members, youth, elders, activists, local businesses, and so on) [30]. The extended peer community enriches the peer process by providing 'extended facts,' including unpublished local and anecdotal knowledge [30,31], as well as Indigenous knowledge [32]. Expanding and incorporating this diversity of knowledge and expertise into problem solving processes can help effectively capture the local context. As Kay *et al.* [27] explained, planning and problem solving "can only occur in the context of human values and requires a diversity of views to be brought to bear on the question at hand" [25, p.729].

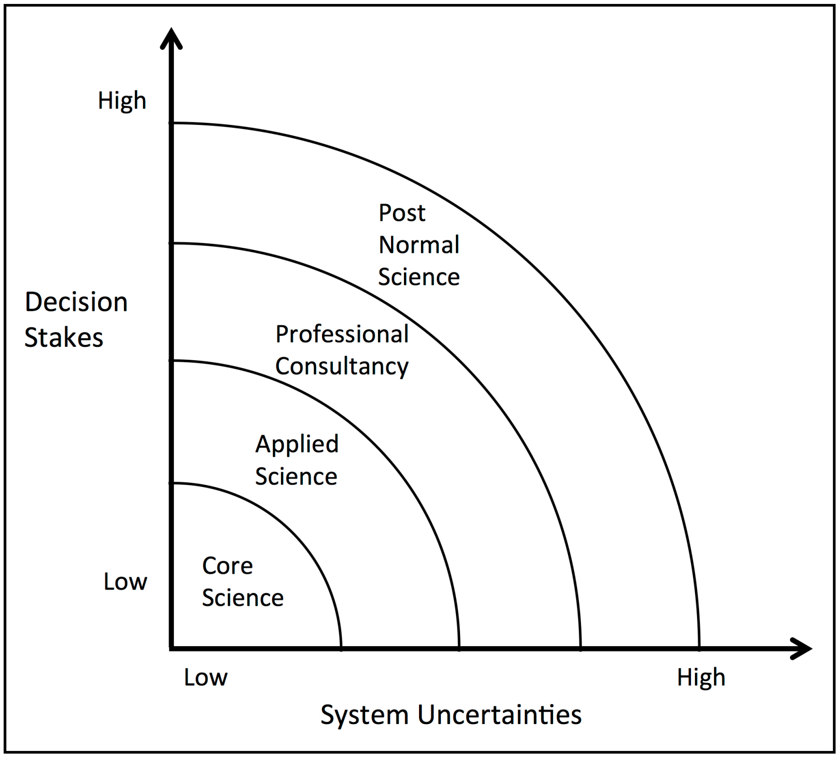

Figure 3.2. Diagram showing different paradigms to scientific research based on the degree of system uncertainties and level of decision stakes (adapted from Funtowicz and Ravetz [30])

Design Thinking Approach

"Design Thinking" is a context based approach that functions well within the PNS paradigm, and emphasizes the importance of designers using empathy, integrative thinking, optimism, experimentation, and collaboration to create effective designs [33,34]. According to Design Thinking, the principle of empathy is fundamental to good design, as it requires a designer to understand how a product or service will be perceived and used from a variety of perspectives including colleagues, decision makers, clients, and end users [33,34]. Design Thinking stresses the importance of considering the entire problem, exploring all of the possible solutions, and creating a holistic solution that addresses several aspects of the problem, rather than focusing solely on tradeoffs and identifying a single solution [33,34]. The Design Thinking principle of optimism encourages designers to believe that there is always a better solution than the existing status-quo and encourages designers to be “bold”, “try new things”, prototype, fail, and repeat until they are successful [33,34]. Finally, the Design Thinking principal of experimentation recognizes that the “lone creative genius” is a myth, and that real progress and change occurs when there is collaboration between individuals from a wide variety of backgrounds and expertise [33,34].

METHODOLOGIES AND TOOLS FOR CAPTURING LOCAL CONTEXT

Approaches such as Design Thinking and the development of extended peer communities recognize that to develop locally appropriate and context-tailored solutions, engineers and designers need to learn how to better engage with users and communities to understand their specific context. Within these approaches, there are several methodologies and tools available to engineers and designers to create an extended peer community to develop infrastructure that suits and reflects the local context. The following section discusses various data collection tools, which could be used by engineers to not only collect important technical data, but also to engage with project stakeholders and extended peer communities to capture the local context to better inform future infrastructure planning and design processes.

Baseline Assessment and other Tools for Capturing Community Context

Typically used in the field of environmental engineering and pollution prevention, the baseline assessment is a tool engineers can use to collect and organize in-depth information about an engineered system with the intent of identifying strengths, vulnerabilities, and opportunities for improvement [35]. The steps in the completion of a conventional baseline assessment commonly include: (1) defining the systems boundary (or the scope of assessment), (2) creating basic process flow diagrams of the system, (3) creating material flow diagrams for the system, (4) creating an inventory of the various system components input and outputs, *and* (5) completing materials (and/or energy) accounting and materials mass balance calculations to identify system losses and inefficiencies [35].

The baseline assessment is an established engineering tool for evaluating infrastructure and typically focuses solely on technological aspects of the system. For complex design situations, including assessing the water treatment infrastructure in a remote indigenous community, additional data collection tools are needed will that encourage community engagement and the development of an extended peer community to broaden and enhance the scope of a baseline assessment. Including an extended peer community will capture information and knowledge that are critical to understanding the local context of the issue, and will provide necessary breadth and depth of information required to adequately assess the system. Several tools can be adapted to capture this type of data. These tools could include, but are not limited to site inspections [36], document reviews [37], key informant interviews [38], flow diagrams [35], focus group discussions [39], causal maps [40–42], community questionnaires [43], and community meetings [43]. Each tool has different strengths and weaknesses, for example some tools (i.e. document reviews, site assessments, flow diagrams) are better suited for collecting or organizing technical or operating data, while others (i.e. interviews, focus groups, community events, questionnaires or causal maps) are better suited for capturing more social perspectives, preferences or concerns. In addition, there are many alternative tools for engagement, (i.e. photo voice, social media, digital storytelling, newsletter etc.) that are not addressed in this thesis and can be explored in other publications [44,45].

LOCAL CONTEXT INFORMING INFRASTRUCTURE DESIGN IN AN INUIT COMMUNITY: A CASE STUDY

A case study involving a small Canadian Inuit community was used to identify, explore and implement various approaches and tools to effectively engage a community in defining needs and wants for informing community infrastructure; in this case the infrastructure being considered was a new drinking water delivery system.

Case Study Description: Location

The coastal community of Rigolet (54^{o}N, 58^{o}W) is located on the east coast of Canada, and is the most southern of the five communities in the Nunatsiavut Inuit region (Figure 3.3). Rigolet has a population of 306 people and most (88.5%) residents identify as "Aboriginal" [46]. The official population of Rigolet grew by 13.9% between the 2006 and 2011 census, which is far greater that the national population increase of 5.9% over the same period [47]. There are no roads leading to Rigolet, it is accessible year-round by air travel, and is seasonally accessible by boat during the summer, and by snowmobile in the winter season once the sea ice freezes. Rigolet is located in the sub-Arctic region, where from 1970 to 2000, the observed temperature range was -45 ^{o}C to +34 ^{o}C [48,49], the annual number of heating degree days (below 18^{o}C) were 7653 [48], the max wind gusts reached 141km/h [48], and the max recorded snow depth was 331cm [49].

Figure 3.3: Map of northern Canada showing the Nunatsiavut Inuit region and the community of Rigolet, NL (adapted from www.itk.ca).

Case Study Description: Drinking Water System in Rigolet, Nunatsiavut

The provincial Department of Municipal Affairs and engineering consultants, the Rigolet Inuit Community Government (RICG) and the Nunatsiavut Government's Joint Management Committee (which includes representatives from each community) typically are responsible for planning and decision making and design of infrastructure in the Nunatsiavut Communities. Drinking water quality has been identified as an important topic by the community government and residents of Rigolet, Nunatsiavut [50–54]. Previous research and consultations suggest that major water-related concerns of residents include poor tap water aesthetics (i.e. taste, odour, and colour), and potential chemical contaminants [52]. Many community members also report that they do not consume tap water, and prefer to either purchase bottled water from the local grocery store, or collect untreated water from local brooks [51,55,56]. RICG and residents indicate that previously they were not meaningfully engaged in the infrastructure design and planning process in their community [50]. Studies suggest that engaging community members in the planning and decision making process results in increased community support, a sense of community ownership, and ultimately more sustainable infrastructure [4,6,57,58].

Case Study Goals

Considering the poor quality of tap water, the reported lack of community engagement in previous infrastructure projects, and the unique climate, geographical, and cultural context of the community, research was needed to address the concerns about drinking water provision in Rigolet, Nunatsiavut. As such, the researchers collaborated with the RICG to establish two goals. First, this case study aimed to facilitate development of a locally appropriate community drinking water infrastructure plan that would lead to more sustainable, locally appropriate technologies and solutions. Second, this case study aimed to pilot and evaluate new tools and methods to better capture local context and better inform a range of infrastructure design and planning practices using drinking water as a case study.

The steps in the Rigolet case study included:

1. The establishment of an extended peer community
2. The completion of a comprehensive baseline assessment that extended beyond a typical engineering assessment using quantitative and qualitative data collection tools use to capture and synthesize the local Rigolet context with respect to drinking water, and its drinking water infrastructure

Context Based Approach: Establishing an Extended Peer Community

To establish an extended peer community as part of this project, focus was placed on the meaningful engagement with stakeholders and Rigolet community members. This engagement was not only critical to develop an extended peer community, but also to ensure that the research approach was appropriate, culturally sensitive, participatory, and captured information that was important and relevant to the project stakeholders. This methodology, which focused on community and stakeholder engagement was completed by using tools to enhance community participation in the project, as described below.

Community visits

In August 2012, the community of Happy Valley-Goose Bay and the Nunatsiavut community of Nain were visited to meet with government stakeholders. During this visit, semi-structured, open-ended meetings were held with various government employees from both the province (i.e. the Department of Municipal Affairs and Housing, and the Labrador Grenfell Health Authority) and the regional Nunatsiavut Inuit Government (i.e. the Department of Lands and Natural Resources, and the Department of Health and Social Development). Topics of discussion included current challenges, vulnerabilities, and strengths of community water infrastructure; ideas for potential research and engineering interventions that could take place in Rigolet; as well as interest in being a potential project stakeholder. The process of identifying and engaging with new stakeholders was an iterative process that continued throughout this research project. In August 2012, meetings took place with the RICG Council, Rigolet public works staff, and Rigolet community members in Rigolet. In these meetings Rigolet's water infrastructure history, the state of the current reservoir, treatment and distribution systems, and the concerns of Rigolet residents and the RICG were explored.

Community outreach

Several visits to Rigolet were undertaken over the course of this research project. The August 2012 trip, which took place during a community festival, provided an opportunity to engage directly with community members. The research team facilitated free water themed games for youth and children. In addition, a table was set up at the festival where community members were invited to locate their cabins or favorite water sources on a topographic map, and discuss drinking water concerns. Informal gatherings were held with community members in their homes where residents shared tea, local food, stories and their water related priorities. Food sharing is an important part of Inuit culture [55,59,60]. As such, stakeholders and community members were offered a small gift, a sample of local Guelph, Ontario's maple syrup or honey for taking the time to meet and share their stories with the research team. The research team also tried to provide tangible benefits to the community during each visit. For instance, the Rigolet Inuit Community Government requested a preliminary assessment of their current water treatment plant that outlined recommendations in terms of operation, maintenance and general cleanliness. Water quality records were obtained from the provincial government water resource website [61] and a brief, plain language report was delivered to the members of Rigolet Inuit Community Government Council. The report outlined the current state of the water treatment system in relation to provincial design guidelines [62] and Health Canada Drinking Water Quality Guidelines [63].

Establishing a presence in the community

An important aspect of remaining engaged with the community was the establishment of an on-going, long-term presence for this research project in the community. Initially, the presence of this project in the community was established through visits by the research team and the building of relationships with community members and other stakeholders. With funds allocated from the research project, a Rigolet resident was hired by the RICG to function as a local member of the research team. Hiring a local Rigolet resident to be a member of every Rigolet research project is also strongly encouraged by the RICG [64]. When proposals were developed for this research project, the budget included funds specifically for the position of a community member on the research team. This individual fulfilled important local tasks, such as questionnaire administration, participant recruitment, data collection and liaison with local project stakeholders, and also helped maintain a local presence of the research project in the community.

Rigolet Baseline Water Infrastructure Assessment

In this study, Environment Canada's [35] baseline assessment tool was used along with different qualitative and quantitative data collection tools to gather a wide variety of technical, financial, social, cultural, political and environmental data about Rigolet's water infrastructure system. This comprehensive assessment approach reflected the need for the researchers to not only understand the technical and regulatory issues, but also the local needs, preferences and beliefs surrounding the system. The steps in the assessment are described below.

Step 1) Establishment of System Boundary

Creating a system boundary defines the scope of a project [35,65]. A system boundary for this project was established in consultation with project stakeholders facilitated through semi-structured, open-ended meetings with the RICG Council, Rigolet public works staff, Rigolet community members and the Nunatsiavut Department of Lands and Natural Resources. Social, technical, environmental, economic, political, population, regulatory, and health dimensions of the system were considered within the scope of this assessment.

Step 2) Identification and Characterization of System Stocks and Flows

Stocks are the foundations of any system and are defined as assets that can be counted, measured, or valued; however, they do not have to be physical assets [65]. For instance, stocks include information, equipment (e.g. spare parts, tools, machinery, pumps), infrastructure (e.g. buildings, pipes), reputation (e.g. a strong brand, consumer trust), natural resources (e.g. water reservoir, strong tides), financial (e.g. bank account balances, debts), and human resources (e.g. trained staff). Moreover, flows are defined as the change (e.g. decrease or increase) in the value of system stocks [65], and can include the loss or gain of information (e.g. through retirement, or training), the building or destruction of infrastructure, the increase or decrease of natural resources (e.g. the filling or draining of a water reservoir), and the spending or saving of money.

The baseline assessment tool is familiar to some engineers; however, capturing qualitative data and engaging an extended peer community in this type of assessment is less common. A variety of data collection tools are available to capture, synthesize, and communicate data about the local Rigolet context as part of the baseline assessment including document reviews, assessment checklists and site inspections, focus groups, causal maps, key informant interviews, community wide questionnaires, community meetings, and flow diagrams.

Document Reviews

Document reviews are often used in case studies to corroborate and supplement data from alternative, non-peer reviewed sources [37], including public documents [66,67], diaries [68], historical documents [68–70], clinical records [71], search and rescue data [72], digital stories [64,73], or policy documents [74]. In addition, other types of documents can be reviewed to aid in a baseline assessment, including old reports and drawings, community budgets, land claim agreements, or other historic documents. The review of existing documents, drawings and reports can provide important technical, historical, and other valuable contextual information about the infrastructure that will be useful in future designs. A completed document review can also be adapted to create a plain language summary, visual timelines, digital stories or presentations in other formats, which can serve as an important resource for local stakeholders and members of the extended peer community in future infrastructure planning or design activities. In Rigolet, the values of some system stocks and flows were obtained through the review of available documents, including old engineering reports, drawings, and other documents found in the community archive. Documents provided important information about the physical specifications of the system and useful historical context. Documents were obtained from stakeholders, the RICG archives, and from the website of the Provincial Department of Environment and Conservation [61,75].

Assessment Checklist

Typically, before any inspection takes place, the inspector develops a detailed assessment checklist [36], which helps identify all the important technical and operational aspects during the inspection. The process of creating a question checklist can be especially useful for novice engineers or designers, who are not familiar with the technical aspects, and ensures that all points are included and not overlooked. This assessment checklist may include important questions that are identified through the review of relevant guidelines, standards, regulations, best practices, and also questions identified by project stakeholders [36]. This tool can be expanded to include the extended peer community by including non-conventional, but locally important, items on the checklist, as well as engaging with non-conventional experts during the site visit to capture additional locally relevant information. In Rigolet, an assessment checklist was created to identify important technical, financial, and human resource components of the Rigolet water treatment based on existing evaluations [36], provincial design standards [62,76], guidelines from other regions [77], and topics identified by project stakeholders. Examples of topics from the assessment checklist are shown in Table 3.1, and the entire checklist is shown in Appendix A. Questions from the assessment checklist were discussed with community public works staff, and field notes were taken by two independent transcribers and later compared for consistency.

Site Inspections

A site inspection is often an initial step in a baseline infrastructure assessment. Before an upgrade or change to utility infrastructure takes place, trained professionals such as engineers or technicians will undertake a detailed physical inspection of the existing infrastructure to determine the current operational status, system capacity, flow rates, deficiencies, and other aspects. Site inspections may be completed with local public works employees, who are often the most knowledgeable about the operation, maintenance, and repair of the system. In Rigolet, data that could not be obtained from reviewing existing documents were gathered during site visits and filed inspections, in August 2012, March 2013, and July 2013. The field inspections consisted of a detailed survey of the water treatment and distribution infrastructure were conducted alongside community public works staff, and each lasted approximately 1-2 hours in duration. During the field inspections, over 260 photos were taken with digital cameras (Figure 3.4).

Table 3.1. Sample question topics from assessment checklist used for water infrastructure assessment Rigolet, Nunatsiavut adopted from Smith *et al.* [36].

Section	Sub Section	Question Topics
Source Water	Source water protection	Sources of pollution, signage present, physical barrier present
	Source water quality	Testing schedule, water quality parameters? (Turbidity, Colour)
	Other	Ice thickness in winter
Treatment/ Pump House	Water intake	Depth, diameter, length, distance from bottom of source, bank or bed intake, age, inspection frequency, bar screen size, frazzle ice problems
	Process pumps and flow meters	Number, type and size of pumps, number of spare parts available, presence of hour meters
	Filtration	Type of filtration
	Disinfection	Disinfection type, chemical storage capacity, chlorine pump type and model number
	Chlorinator feed pump	Back-ups available locally, replacement seals available locally, procedures in place if failure occurs
	Chemical storage capacity	Number of days of storage (winter and summer)
	Emergency and personal protective equipment	Fire extinguisher, working telephone, mask for mixing chlorine
	Generator	Model, capacity, age, testing procedure, maintenance procedures, amount of fuel available
Monitoring and Reporting	Chlorine residuals	Record keeping procedures, residual testing
	Microbial testing	Procedures, frequencies, record keeping
	Chemical and physical testing	Procedures, frequencies, record keeping
Distribution System	Storage	Storage capacity, fire flow abilities
	Water mains	Material, depth, age, insulation, total length
Human Resources	Operators	Number of available operators, training, certification
Financial	Capital costs	Available funds, procedures, annual expenditures
	Operating costs	Human resources, energy costs, consumable costs, spare parts budget, annual budgets

Figure 3.4. Examples of photos taken during field inspections. The photo on the right is of the interior of Rigolet's main pump house. The photo on the left is of the interior of the building adjacent to the water storage tank that provides chlorination as water travels from the storage tank to users' homes.

Focus group discussions

The purpose of a focus group is to gather information on how a group of people feels about a certain issue, product, or service in a comfortable, non-threatening environment [39,43]. Focus groups are comprised of 5-10 purposely selected individuals who share common characteristics or traits (e.g. age, gender, occupation, etc.) as research has shown that people are more likely to self-disclose personal information to others that resemble them, than to those who differ from them [39]. A facilitator guides the focus group discussion through a set of questions, called a "questioning route" or an "interview guide", that begins with broad, general questions to get the group talking, and then gradually becomes more focused to draw out specific information from participants [39]. Focus groups that are well planned and executed can provide valuable information about the extended peer communities' opinions, perceptions, and beliefs about the planning and development of infrastructure in their communities. The open ended nature of the questioning, the discussion and storytelling that take place between participants can provide important contextual information (i.e. historic, cultural, environmental, etc.) that may not be disclosed with any other engagement tool [39,78]. In Rigolet, a total of three focus groups (n=6) and three interviews (n=3) were conducted in person in March 2013. A trained member of the local research team selected participants based on their age and history of participation in land based activities. Focus groups and interviews were semi-structured (See Appendix B for focus group line of questioning). Qualitative data captured included local perceptions, attitudes and beliefs of drinking water quality and current water-related concerns in Rigolet. Focus groups lasted about 60 minutes in duration.

Causal maps

A causal map (also known as a cognitive map) is "a qualitative model of how a given system operates [and] is based on defined variables and the causal relationships between these variables" [40, p.44]. During focus group discussions or interviews, participants could create causal maps to help facilitate discussion [40,42,79], as was done in Rigolet. Throughout the focus groups and interviews, facilitators recorded keywords on Post-it notes™, and at the end of the discussions, the facilitators and participants built a causal map describing the relationships between the different focus group topics (Figure 3.5).

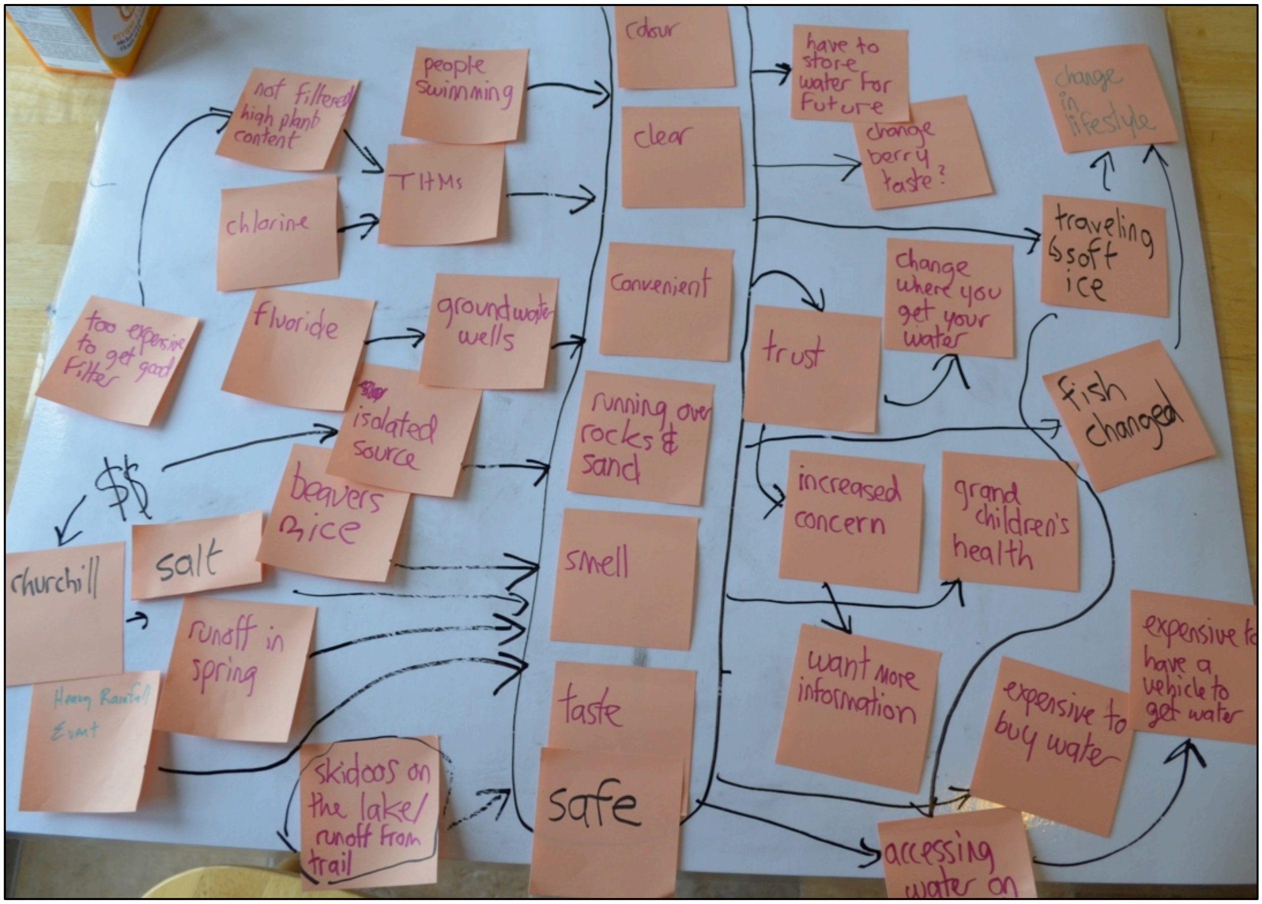

Figure 3.5. Example of a causal map made by Rigolet focus group participants to describe perceived relationships between environmental changes, brook water quality, and lifestyle changes.

The causal maps were reviewed with participants at the end of the interview to ensure it represented their views accurately. Focus group causal map data was digitized and aggregated using Microsoft Excel. This method allowed for common themes and responses across focus groups to be identified.

Key informant interviews

Common in the social sciences, key informant interviews take place with selected experts to learn more about the system that is under investigation. These key informants could include any experts from the extended peer community, including users, operators, managers, funders, planners, and engineers from government or private sectors. Interviews with project stakeholders and members of the extended peer community can help build relationships, clarify the objectives of a project, and most importantly better understand the local context, including history, politics, relationships, and operating realities. Interviews may take place over the phone or in person. Similar to focus groups, key informant interviews are based on a list of predetermined questions. The interviewer may take notes, or obtain permission to audio record the interview for later analysis. In Rigolet, five key informant interviews were conducted in person in March and July of 2013. Key informant interviews included RICG employees (n=1), council members (n=2), and public works staff (n=1); as well as a semi-formal conversation with representatives from the Department of Health and Social Development (n=1). Interviews were semi-structured and conducted in a conversational format, and lasted about 30 minutes in duration. One interview was audio recorded with permission, and the remaining interviews were captured with field notes, where two different individuals documented the discussion, and notes were compared later for consistency.

Community Questionnaire

A well-prepared and well-executed questionnaire can provide important qualitative and quantitative information regarding community perceptions, attitudes, beliefs, and habits in relation to infrastructure design and development. Questionnaires can be administered by mail, telephone, in-person, or online using a web based program [43]. Questionnaires can employ open- ended (i.e. fill in a blank); or close-ended questions like checklists (i.e. check all that apply), multiple choice questions, rating scale questions (i.e. rate the response on a defined scale), or ranking questions (i.e. rank items in list in order of priority) [43]. Questionnaires should be pretested with colleagues and community members to identify questions that may be confusing, misleading, or vague and also to ensure the language and terminology is appropriate for the study population [43]. In Rigolet, an existing water perceptions research survey [80] was adopted and modified using the results of the community focus groups to examine water related topics in Rigolet at the community level. The questionnaire captured data about drinking water preferences, water consumption, areas of concerns, acceptability of current tap water for various uses, and preferred methods of engaging with researchers (Appendix C). The questionnaire was pre-tested for content and context by academics and Rigolet community members. The questionnaire was administered by a pair of trained community personnel traveling door to door using iPads© with iSurveySoft© software in English, which is the first language of Rigolet residents [47]. Eligible participants included all available adults in Rigolet. The questionnaire response rate was 92.4% (n=159). Results from the community water questionnaire were exported to Microsoft Excel©, and basic counts for each question were collected. Based on questionnaire results, areas of major concern in the community, preferred methods of engagement on the topic of drinking water, and other useful results were identified. In-depth analysis of this survey data will take place in a later study.

Community Meetings

Community meetings are a method commonly used by consultants to engage with community members, deliver project updates, and/or solicit feedback from the public on infrastructure projects, but they are often poorly planed, conducted and attended. Adequate planning must take place to ensure that the meeting does not conflict with other local activities, or take place at a time when individuals are likely to be out of the community at cabins or hunting. Adequate, and appropriate local advertisement must take place to ensure that the community is aware of the meeting and its purpose. When used effectively, community meetings could provide engineers and designers with a strong platform to engage with community members and capture information and knowledge from end-users and better enable engineers to use the Design Thinking principal of empathy in infrastructure planning and development. In July 2013, an event was held in Rigolet to update the community on the status of the research project. In addition, a draft timeline of the history of water and wastewater infrastructure with major milestones and events was discussed and revised with community members (n=27), and feedback was provided to researchers to ensure the validity and accuracy of the results. The duration of the even was approximately 60 minutes, and field notes were taken by researchers present to document the discussions that took place.

Flow Diagrams

Commonly used in chemical and process engineering, process flow diagrams are a visual tool to identify and represent the components and processes in a system and illustrate the flows of material, energy, information, and finances into and out of a system [35,65]. The construction of these diagrams can help identify system inefficiencies, losses, strengths, and vulnerabilities. The creation of flow diagrams not only assists engineers and researchers in understanding the technical and financial context of a local engineered system, but can also be used to help communicate this information with the extended peer community. A flow diagram and other visual representations of engineered systems may help increase the local understanding and transparency of infrastructure operations, and also help communicate the options for system upgrades and changes. In this case study, flow diagrams were created to describe the entire water system (a process flow diagram) and to characterize the individual flows of materials, energy, and finances in and out of the Rigolet water system.

CASE STUDY RESULTS IN RIGOLET, NUNATSIAVUT

This comprehensive assessment of the Rigolet drinking water system provided an important opportunity to evaluate the entire system and identify its strengths and vulnerabilities. This section provides an overview of the results in two subsections: the first describing results from data collection tools and the second a detailed description of the strengths and vulnerabilities identified in the Rigolet water system in March 2013. These are representative of the types of results that may be identified in the assessment of other northern systems using the discussed approaches and tools.

Results From Baseline Basement and Data Collection Tools

This section provides the results from the baseline assessment and different data collection tools, including causal maps, various flow diagrams, and a stock and flow diagram. A causal map [8,40,41], created based on the results of individual causal maps from the Rigolet focus groups is shown in Figure 3.6. Flow diagrams created as part of this baseline assessment included: a financial flow diagram (Figure 3.7), a process flow diagram (Figure 3.8), a material flow diagram (Figure 3.9), and an energy flow diagram (Figure 3.10). Finally, the results of a baseline assessment were used to create a stock and flow diagram [65] of the entire Rigolet water and wastewater system, shown in Figure 3.11.

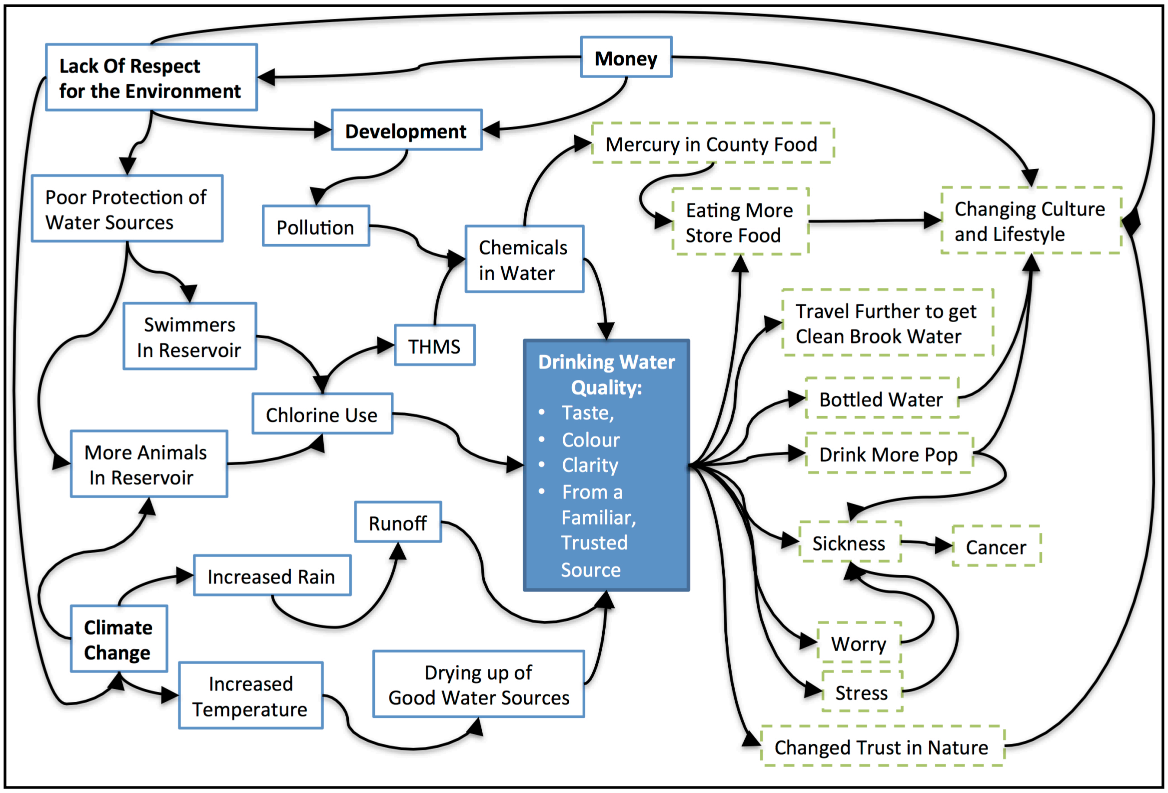

Figure 3.6. A causal map created based on the results of individual causal maps from the Rigolet focus groups. Drinking water quality (center) is the outcome. On the left side, in blue, are the factors that were believed to be impacting the quality of drinking water (both tap water and natural sources) In dashed green, are other factors that in turn were influenced by changes in drinking water quality. Participants identified the major factors that influence changes in drinking water quality to be climate change and development, both driven by society's high value of money, and lack of respect for the environment.

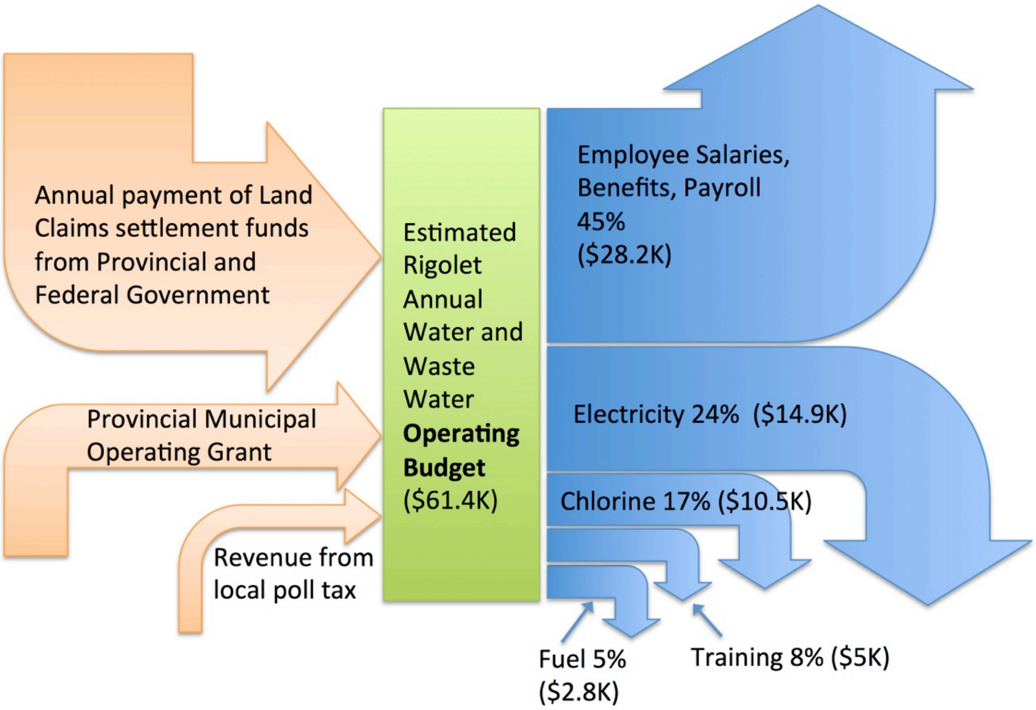

Figure 3.7. The 2013 Rigolet Inuit Community Government water and wastewater operating budget. The majority of revenue for the Rigolet municipal operating budget is derived from transfer payments tied to the Labrador Inuit Land Claims agreement from the Federal and Provincial governments. The Province also supplies a small municipal operating grant, and a small supplement comes from local poll tax collection, paid by every adult in the community. Adapted from Gordon *et. al.* [81]

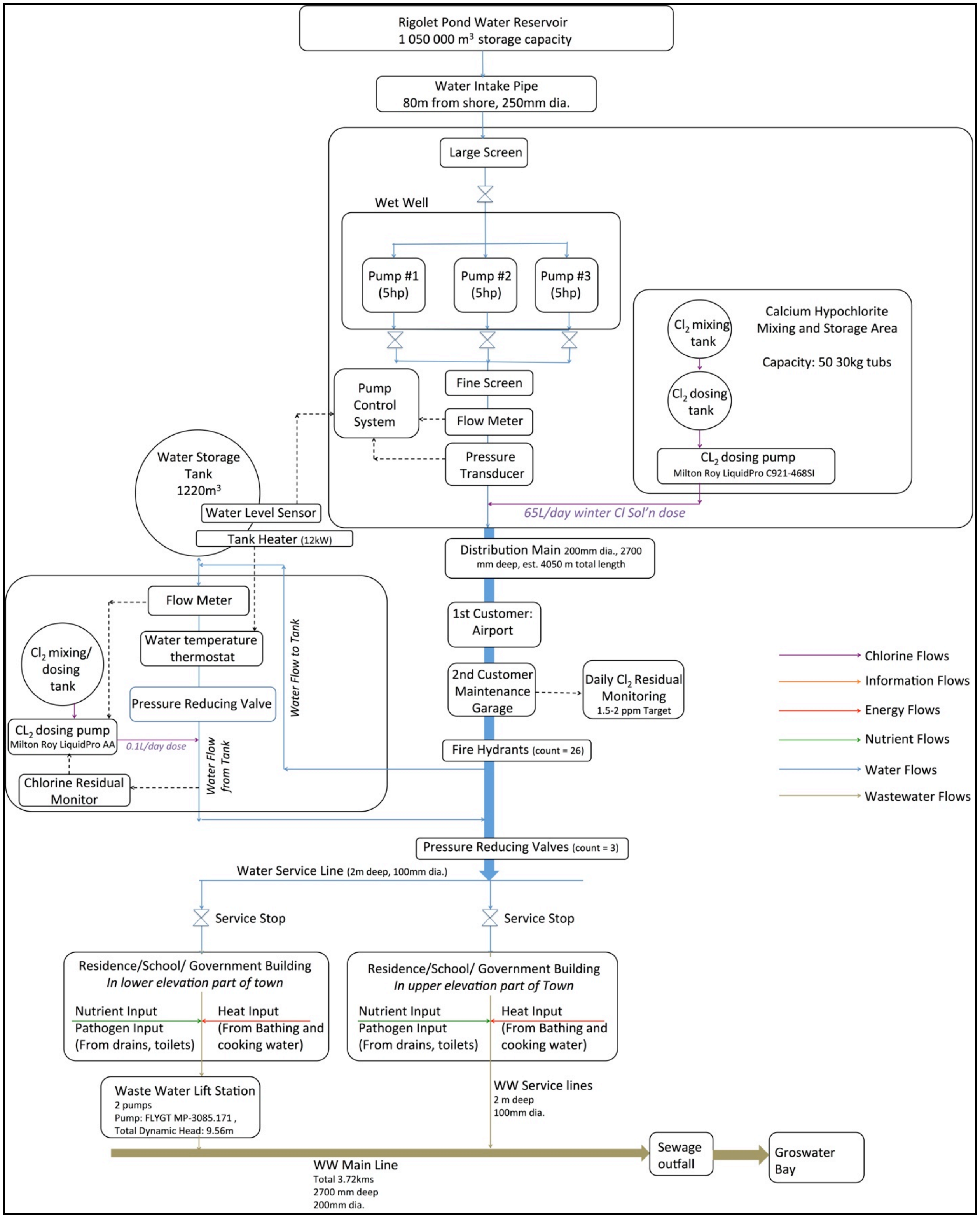

Figure 3.8. Process flow diagram for the Rigolet water and wastewater treatment system, adapted from Gordon *et. al.* [81]

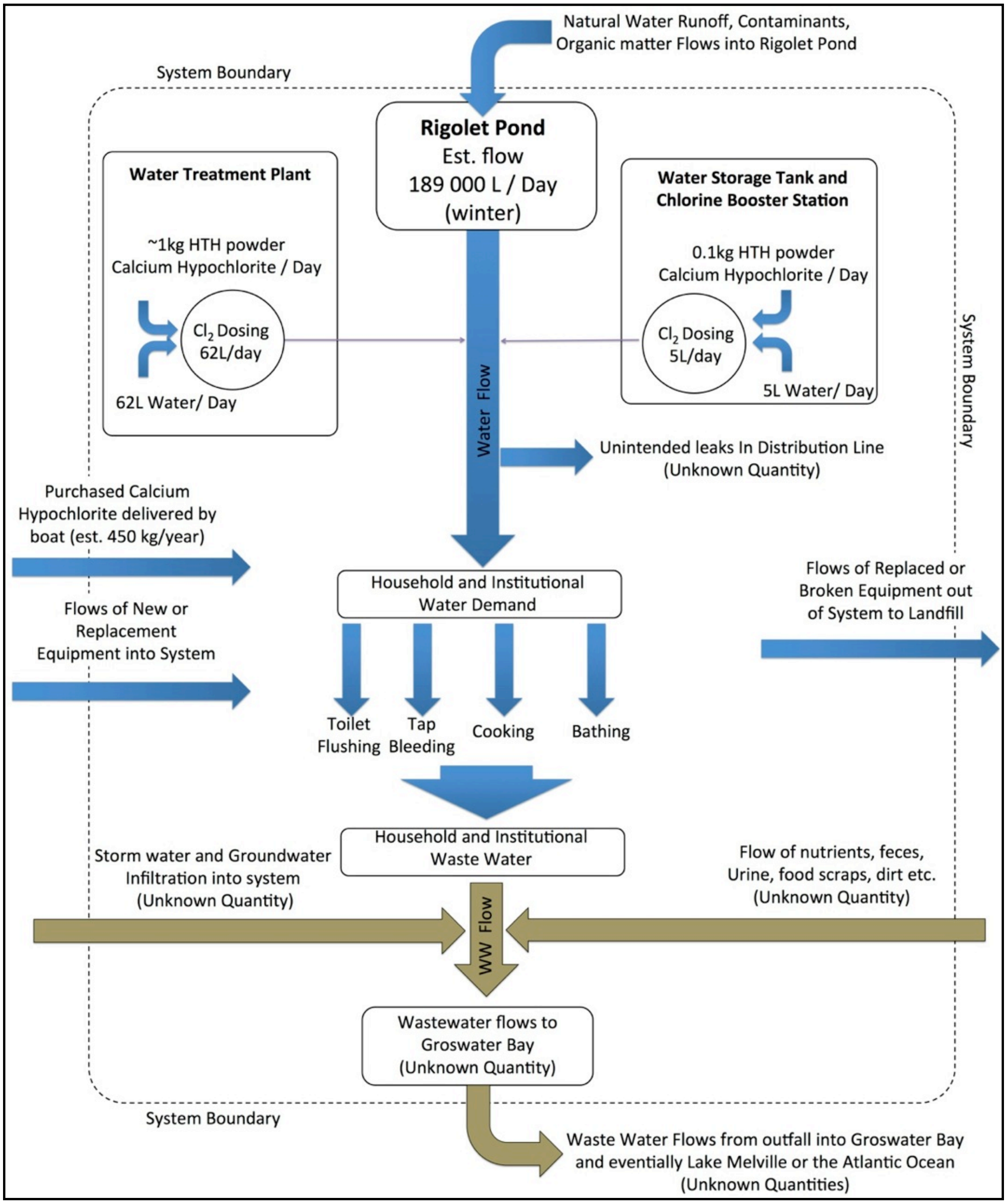

Figure 3.9. Material flows (Water, Chemicals, Nutrients, and Equipment) in the Rigolet water and wastewater system, adapted from Gordon *et. al.* [81]

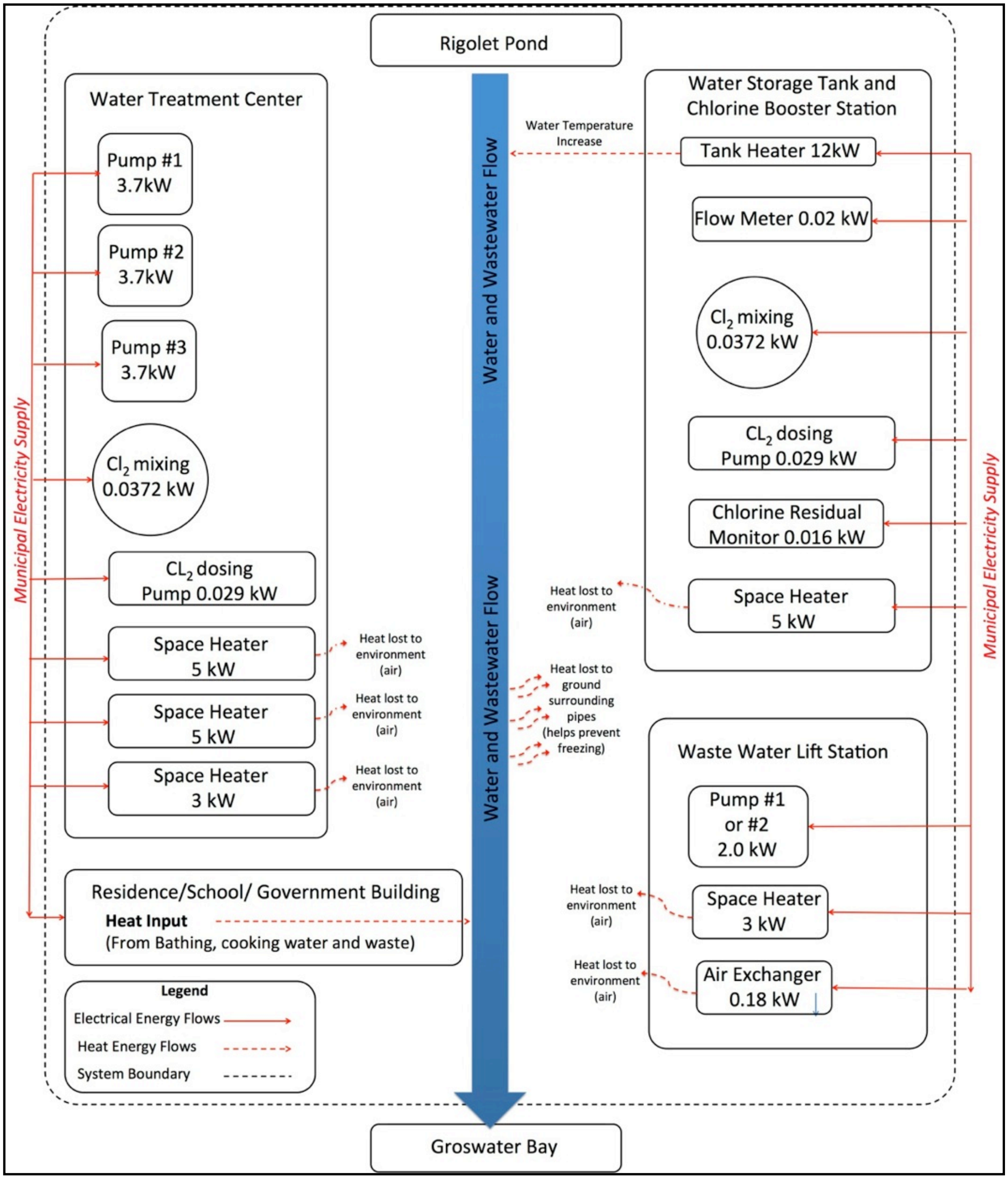

Figure 3.10. Energy flows and power consumption (kW) in the Rigolet water and wastewater system, adapted from Gordon et. al.[81]

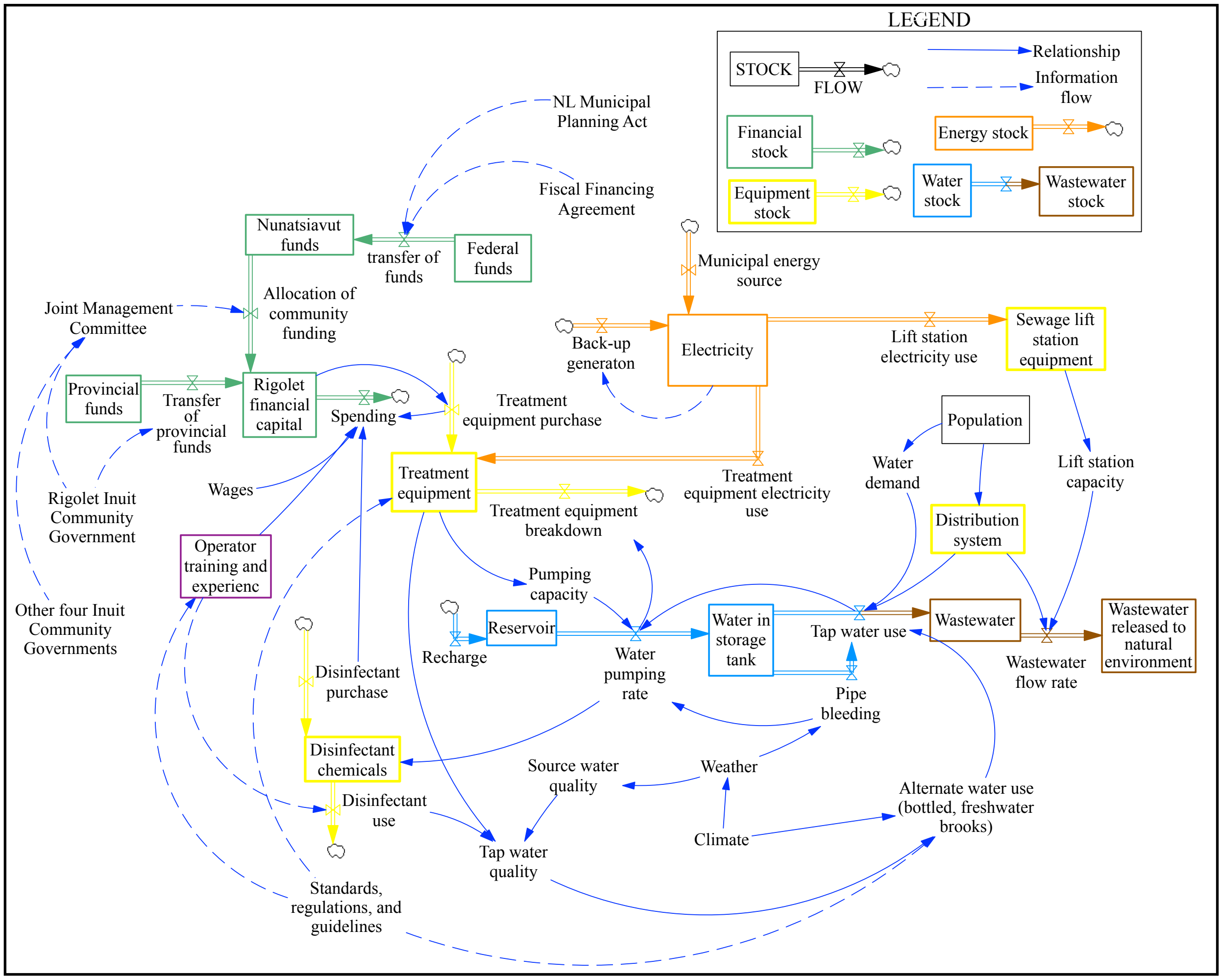

Figure 3.11. A Stock and flow diagram of Rigolet water system providing a visual overview of the movement of energy, material, and information throughout the system, causal relationships between variables that impact these stocks and flows, and identification of potential feedback loops, from Gordon et. al. [81]

System Strengths and Vulnerabilities

The Rigolet water system has two main strengths that were identified at the completion of this assessment; 1) the relatively low maintenance requirements due to system simplicity and 2) the large reservoir capacity. Due to the lack of filtration or chemical pretreatment steps, the Rigolet water treatment system was relatively simple. The system did not require the periodic replacement of cartridge filters or the maintenance of conventional or slow sand filters, unlike many other drinking water systems in northern Canada. More complicated filtration systems may require more highly trained local operators and would also likely consume more energy (electricity) and chemicals than the Rigolet water system assessed in 2013. There were some issues in the winter with pipe freezing in the service lines between the main distribution line and dwellings. These could be reduced with better pipe insulation and the continued practice of pipe bleeding in the winter months. Even though pipe bleeding is estimated to increase the water demand by 40% in winter in Rigolet, the current reservoir is estimated to have sufficient capacity to support this activity for the foreseeable future as the community expands.

Many vulnerabilities of the Rigolet water system were also identified in this assessment, including the long-term affordability (capital and operations), potential impacts of climate change (identified through focus groups and document review), concerns with energy security, potential regulatory changes, and the lack of local trust in the drinking water system.

Stakeholders reported that the vast majority of capital expenditures in the Nunatsiavut region go towards water and sewer upgrades and expansion. With a present housing shortage in the region and the recent cost of twelve new serviced building lots surpassing CAN$2.1 million (RICG, Personal Communication, 2013), there was a serious concern expressed about long-term affordability of housing in the region. There was also a concern about system operation and maintenance costs, as RICG must cover these expenses in their annual operating budget. The community of Rigolet, like most remote communities in the Canadian North, is reliant on a diesel generator for electricity. The operating budget for the Rigolet water treatment system in 2013 was determined to be extremely sensitive to the cost of electricity. An increase in electricity prices or any upgrades to the water system that require more energy (such as filtration or ozone generation) will require an increase in expenditures on electricity by RICG. New water treatment systems might also require expensive consumables such as cartridge filters and UV lamps and additional operators, which RICG may have to recruit and retrain. RICG has an obligation to provide safe drinking water to residents, but the increasing cost of water treatment could reduce the amount of resources available to support other important social and cultural programs.

Rigolet's electricity costs are vulnerable to the global oil prices and availability of diesel fuel. Diesel is delivered to Rigolet by tanker ships, and therefore shipping issues, bad weather, or ice conditions could interrupt delivery. Climate change could exacerbate some of these factors in the future [82]. Although there were no reports of past diesel shortages in Rigolet, participants reported that during the winter holiday season when energy consumption is at its peak, there can be intermittent power outages in the community. Although the communities' generator is currently relatively reliable, should prolonged operational issues arise, it could bring the community and the treatment system to a standstill.

Climate change is projected to increase periods of heavy rains and rapid snowmelt [82], which could increase the amount of organic matter and number and/or type of pathogens that are washed into Rigolet's water reservoir, potentially impacting public health [54,83]. When assessed in 2013, the Rigolet water treatment system did not filter the drinking water, which is required to effectively remove pathogens, such as *Giardia* and *Cryptosporidium* [84], that are resistant to chlorination [84]. Increased organic matter in the Rigolet reservoir could also lead to increasing levels of disinfection by-products, which could impact long-term health outcomes of residents and further undermine the public trust in the Rigolet tap water. Changes in climate can also limit people's ability to go out on the land to access alternate sources of drinking water [21,85–87].

One of the most striking results from Rigolet's water system is the reported lack of trust residents have in the drinking water system. Most Rigolet residents (58%) do not drink the tap water, which is likely due, in part, to cultural preferences, but also due to the particularly poor aesthetic quality of Rigolet tap water, the high levels of disinfection by-products, and related concerns over the development of chronic illnesses, such as cancer. Focus groups results and previous research [6,21,51,54,55,88,89] suggest that many Inuit in Rigolet and across the North prefer natural, untreated drinking water sources, especially when out on the land. Another vulnerability of the Rigolet system is that many residents (36%) indicated uncertainty as to whether chlorine provides either positive or negative health impacts.

Although system simplicity and reservoir size were identified as possible strengths of the Rigolet water management system, they may actually be a cause of the vulnerabilities and failures upon closer investigation. Discussions and focus groups with community members identified that the selection of Rigolet Pond, a water body that was reportedly once used as an airstrip, aircraft fueling point, and possible dumping point, has seriously undermined Rigolet residents' trust in their tap water.

DISCUSSION: APPROACHES, METHODOLOGIES, AND TOOLS USED TO CAPTURE CONTEXT IN THE RIGOLET CASE STUDY

This section will review the different tools used in the assessment of the Rigolet water infrastructure and discuss how these tools could be applied more broadly to other projects where engineering and regulatory specifications are critical, but where adaptations related to unique geographical and cultural situations will make them successful. Table 3.2 provides a summary of the different tools used in this assessment and outlines some of the strengths and challenges of each tool.

Site Assessment

In this project, the creation of the assessment checklist (Appendix A), the multiple tours of the water infrastructure, and the discussions with local staff were incredibly valuable. Since the engineering graduate students on this project had limited practical experience with small water treatment systems, this assessment process provided valuable technical and operational context for the system at different times of the year. More experienced engineers may have been able to complete the majority of the checklists by reviewing old documents or drawings and may not have needed multiple tours of the Rigolet system. The value of actually touring a system with the public works staff, however, can be critical because some "as built" drawings may no longer reflect the current system state and its operational realities. Some of the weaknesses of the site assessment tool were that little data were captured outside the topics outlined on the assessment checklist. Also, although researchers attempted to keep the interactions with public works staff as casual as possible to avoid response bias, the process of asking questions from a list felt very official and the public works staff possibly felt that they themselves were being evaluated, which was not the intention.

Document Review

The challenge of the document review process was that most documents related to the Rigolet water system were in paper form and located in the community or in Happy Valley-Goose Bay at the offices of the provincial government. Therefore, there was a limited amount of research that could be done on the system before actually traveling to the community. Once researchers arrived in Rigolet, many technical reports and drawings were found in the community archives. Although documents were generally organized by year, considerable time (i.e. a few days) was still spent searching through many boxes for relevant documents. It is recommended that researchers completing document review also scan or photograph important paper documents throughout the process and provide these electronic files to the community government for use in an electronic archive. There were additional documents available electronically from the Newfoundland and Labrador (NL) Provincial Department of Environment and Conservation website [75] that provided excellent background about different province-wide drinking water issues. The provincial government's water resources portal also posts test results for drinking water for all communities in the Province [61]. Although these provincial resources provided minimal Rigolet-specific information, they provided valuable background information throughout the course of this research project. The document review was a time and labour intensive process, but very valuable in providing technical and historical context to the Rigolet water system.

Focus Groups and Causal Maps

The open-ended nature of the focus groups permitted researchers to explore and capture important information about drinking water preferences and levels of trust in the community's tap water. For example, focus group participants explained that trust of a drinking water source; either tap water or a natural spring or brook was a key factor in perceived water quality and adoption of a water source. One strength of the focus group process was that it allowed for open-ended discussion and storytelling on topics around Inuit lifestyle and culture, the history of Rigolet, participants' own perceptions and preferences of drinking water, and their concerns for the future. The participants clearly felt comfortable sharing their views in this setting. Participants reported that they enjoyed using causal maps as a tool to document and organize their ideas and thoughts about drinking water preferences. The causal maps also allowed researchers to feel more confident that the participants' views were being accurately captured and documented. The focus groups and the use of causal maps helped identify, document, and communicate the different factors and relationships of natural drinking water sources, which helped researchers better understand how interrelated the technical, political, social, and cultural aspects may be in the local context. Information obtained from focus group discussions also helped informed the questions in the community questionnaire. If any participants in the focus group and causal map activity had low levels of literacy, they might not feel fully engaged in the discussion. To increase engagement and overcome this potential barrier, key factors could be represented by photos or symbols could be used instead of words on the causal maps. Another weakness of the focus group activity was that even with the assistance of a community researcher, it was challenging to recruit and co-ordinate focus groups with a wide range of participants over the week.

Community Questionnaire

The community-wide water perceptions questionnaire indicated that many of the results from the focus group discussions were true at the population-level: for example, the preferred sources of drinking water in the community, the perceived quality of tap water for different uses, the level of compliance with boil water orders, and the preferred methods of engaging in the development of a long-term water infrastructure plan. The results of the community questionnaire will provide important information for project stakeholders, and continue to influence decisions made by the project team and other stakeholder. The costs and time required to complete a successful questionnaire can be quite high. This research project was able to partner with another research project completing a questionnaire to share the administrative, labour, and honorarium cost. Each method of questionnaire administration (i.e. phone, online, mail, in person) has different strengths and weaknesses in terms of response rate, susceptibility to selection or response bias, data accuracy, cost, and time required for completion [43].

Community Events

The community events served many useful purposes, including allowing the researchers to provide updates on the projects, and also solicit feedback from community members. Community events provided Rigolet residents an opportunity to provide feedback on the project, ask questions, and also get to know the researchers. Displaying a draft timeline at a community event allowed for attendees to discuss amongst themselves, and come to consensus on the most accurate timeline of historical events. Although community events, such as meetings can be extremely valuable, they can also be challenging and problematic due to the logistical challenges of coordinating meetings with other social events, work schedules, and likeliness that residents will be out of the community participating in land based activities (i.e. trapping, hunting, fishing, berry or picking vising cabins). The focus of community meetings should also be to obtain feedback from residents, and meetings should be designed to encourage an atmosphere of mutual respect and the sharing of ideas.

Flow Diagrams

The creation of flow diagrams was a valuable exercise for the engineering researchers. The creation of these diagrams required researchers to synthesize information from the document review and site assessments into a simplified, visual format. Although these diagrams were an effective way to display and communicate information to other engineers, they may or may not be appropriate or useful for community government employees or the Rigolet council, who are the owners and operators of the infrastructure. The flow diagrams are conventional engineering tools that helped capture important technical information about the Rigolet water system including establishing the system layout; the various components and equipment in the treatment, storage and distribution processes; the number of spare parts; various flow rates; and number of employees and levels of operator training. However, without more research or evaluation by other project stakeholders, it was unclear whether the conventional engineering tools really encouraged community engagement, organized and displayed information in a way that was useful for project stakeholders, or created a sense of ownership over the information they contained. Also, on their own, the conventional tools did not necessarily capture a deeper contextual understanding of why Rigolet community members perceive the water system to be so inadequate.

Community Researcher

The most important factor for community engagement in this project was having a local community member as a member of the team; the value they added to the project cannot be overstated. This individual was recruited, interviewed and selected in consultation with the RIGC, based on a set of skills that RICG recommended based on the job description. The local community researcher filled an invaluable role in the development and testing of approaches and tools used in the research project, and provided important advice and feedback to ensure the project's engagement strategies, research methods, messaging, and approach were locally and culturally appropriate. Given the high cost of travel to remote northern communities, researchers can only make a limited number of trips to a community throughout the course of a project. Therefore the local community researcher maintained the project's presence in the community and also ensured that the other members of the research team were aware of local conditions and the individual also facilitated timely and effective feedback to community members and local stakeholders. Based on the process and results of this study, a local representative should be hired as an equal and respected member of the team for every research or infrastructure project that takes place in remote communities.

Limitations of Proposed Approaches, Methodologies, and Tools

There are important limitations to this baseline assessment that should be stated. Often important information about the quantities and qualities of Rigolet water system flows, including water and wastewater flow rates, energy use, and expenses were not available. A lack of available data required researchers to make some estimates based on published values from the literature, which may not be representative of the actual system in Rigolet. The majority of this baseline assessment occurred in March 2013, and largely represents the status of the Rigolet water system at a specific point in time and season. In addition, Inuit communities in the Nunatsiavut region and across the Circumpolar North are all unique. As such, caution should be exercised when extrapolating specifics to other Inuit communities.

However, the approach and tools used in this assessment could be adopted for use in many other communities (Indigenous and non-Indigenous), and for topics other than water infrastructure where community involvement is going to be a determining factor in the success of a project. Moreover, it should be noted that the author does not believe that every approach and tool used will be appropriate, useful or necessary for every infrastructure project. Some infrastructure consultants may already have excellent relationships with a community and a reasonable understanding of community context. Some infrastructure projects may be very narrow in scope, or very technical in nature and do not require much community input beyond the local government and public works staff. It is also recognized that some of the approaches and tools explored in this project are likely outside the expertise of many engineering consultants. This research is not suggesting that immediate, comprehensive change to infrastructure design and planning practices in the Canadian North should occur overnight, but that practices need to evolve. These tools are examples of how a research project or a consultant could incrementally change their approach to community engagement, consultation, and understanding of local context.

Table 3.2: A summary of the strengths and challenges of different data collection tools that may be useful to researchers and engineers for understanding community context

Data Collection Tool	Strengths of Tool	Challenges of Tool	Resources
Document Reviews	• Great way to understand the system from a historical and technical perspective • Can provide valuable background information in order to maximize discussions with stakeholders • Includes not only relevant peer reviewed academic literature, but also old correspondences, reports and engineering drawings	• Documents are often not available online or in electronic form • Documents are often obtained from project stakeholders and are only given after initial interviews take place • Often there are contrasting accounts depending on the author of the document • Consultants may not have access to academic, peer reviewed literature databases	[37]
Site Assessments and Checklists	• See system in context • Touring the system with local public works staff provides an invaluable insight to daily operational and maintenance challenges • Provides an opportunity for public works staff to provide a candid opinion of the challenges they face in their daily tasks • Provides an opportunity to take photos and document different system components that may not be reflected in any available reports or "as built" drawings	• Time consuming, must travel to community • Multiple visits may be required to assess the system in both warm and cold months due to snow cover • Success can depend on skill and openness of public works staff • Assessment checklist may limit the topics of discussion, it needs to be flexible • Atmosphere should be kept casual and informal, or public works staff may feel they are being evaluated, which may bias responses	[35,36]
Key Stakeholder Interviews	• Great way to obtain candid and honest information about the system context • Great method for building relationships with stakeholders • Can be incredibly valuable for collecting contextual information that is not well documented • Can also be a useful tool to receive candid, frank and in-depth discussions about sensitive topics or potential barriers to project success	• Time consuming, especially if done in person and stakeholders are scattered in different locations • It can be challenging to co-ordinate the schedules of stakeholders to complete interviews in a single trip • While, audio recording an interview may help capture all the topics covered in the interview, it may also impact the openness or frankness of an interviewee and limit the disclosure of sensitive, yet important, information or opinions • Conversation is often limited to the line of questioning by the interviewer, which will impact the results of the interview. A poorly designed interview guide can bias the interview results	[38,90]
Flow Diagrams	• Visual way to explain difficult contacts or to link concepts that may be seen as independent of each other	• Can be a discipline specific tool and not necessarily useful for all project stakeholders or decision makers • Building a flow diagram requires a deep understanding of the system and its components	[35]
Focus Group Discussions	• Often individuals are more comfortable sharing thoughts when in small groups, compared to a community meeting • This format encourages storytelling and discussions amongst participants • Responses of individuals are influenced by other participants, like in real life	• The results may only represent the views of the participants and not be scalable to the rest of the community • Can be time consuming to organize, recruit participants, and co-ordinate different schedules • Participants may try to intellectualize and rationalize their decisions, while in reality many are based on emotions giving false results	[39,78]
Causal Maps	• Great visual way to explain difficult concepts or to link concepts that may be seen as independent of each other • Provides immediate participant validation to ensure a conversation was accurately interpreted	• May only be useful for the facilitator or participant, not other stakeholders as causal maps may not be easily understood by those who did not participate in their construction • Due to low levels of literacy, the use of photos or drawings in building causal maps may be necessary in some situations	[40,41,65]
Community Questionnaires	• Can be a great source of data for decision makers • Provides an opportunity for all residents to engage in the process • Provides local employment and training opportunities for local questionnaire administrator(s)	• Requires local buy-in and trust • Should provide honorariums to participants, increasing cost of questionnaire • Questionnaire needs to be administered in locally appropriate language • Questionnaire design and administration requires expert to minimize response bias and clustering effects and maximize data accuracy	[43,83]
Community Meetings	• Provides an opportunity to engage with many different stakeholder and community members at one time	• Many community members may not feel comfortable speaking up at a community meeting and may decide not to attend • These meeting require extensive planning and advertising with community representatives to ensure attendance	[45]

CONCLUSIONS

There is a need for the development of new strategies that can incorporate unique local contexts into the engineering design process, especially in northern climates [4,6]. This study explored existing methodologies and tools to engage a remote northern Canadian community in the completion of a baseline assessment of its existing water infrastructure. The goal of the study was to more accurately identify all the strengths and vulnerabilities of a community's infrastructure by engaging the community in the assessment process. The results from the baseline assessment suggest that a lack of local engagement in the original water treatment infrastructure development process may have led to a sentiment of distrust in the safety of tap water. Increasing the levels of engagement with the extended peer community, including community members, may not only increase transparency and trust, but may also expand the quality assurance and review process, resulting in better, more locally appropriate designs [30]. Hiring a local community member as a member of the project team (community researcher) can ensure the appropriateness of the activity and greatly increase the success of any community engagement strategies. By more effectively engaging with communities and their members, engineers will not only increase the transparency of the process, but also create the opportunity to incorporate important local and traditional knowledge into designs.

Rigolet, like many remote communities in Canada's North, heavily relies on consultants and other external expertise in the planning, design, construction, and operation of its community water infrastructure. There will always be a necessary role for engineers and technical experts, particularly those with special expertise in cold regions where there are particular climatic, geographic, and remoteness challenges. However, there is also a critical role for communities and local decision makers in ensuring those designs and plans are locally and culturally appropriate. Based on the results of the Rigolet assessment, it is recommended that additional research take place to develop tools and approaches so communities could be better engaged, informed, and ultimately in control of the planning and development of their own futures.

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CHAPTER 4

DEVELOPMENT OF A DECISION MAKING TOOL FOR NORTHERN INFRASTRUCTURE USING CONVENTIONAL ENGINEERING AND COMMUNITY-DRIVEN CONSTRAINTS AND CRITERIA

INTRODUCTION

The planning, design, and operation of infrastructure in the Canadian North can be particularly challenging due to the unique local context, which encompasses biophysical, social, and economic conditions that are substantially different from other southern regions in Canada [1–6]. This unique context is increasingly complex and uncertain in the North due to industrial development, climate change, population growth, and the ongoing transfer of more decision-making responsibilities to the regional and community level [6–12]. However, due to financial and technical capacity limitations in most remote indigenous communities, there is a high degree of reliance on external funds and expertise for technical services, project management, construction, and operational aspects of community infrastructure projects.

The complexity and uniqueness of the local northern context is commonly overlooked or misunderstood by engineers and other external agencies and has resulted in cases of inadequate infrastructure, ranging from housing [13–16], to transportation [17], to drinking water infrastructure [2,3,18,19]. In an attempt to design and install systems in remote communities, engineers and designers often select conventional systems that are believed to be technically sound for the situation, but can often fail due to inadequate consultation with local stakeholders. Community engagement should be to ensure the technology is locally appropriate, especially in the North. In addition, poor local consultation in the infrastructure design, construction, and operation can create a sentiment among local users that the design and planning process is not transparent, resulting in poor understanding, mistrust, and reluctance in the adoption of the technology in remote Indigenous communities in Canada [20] and the state of Alaska, USA [3]. Indeed, transparency is recognized as an important principle for successful decision making processes in many fields, including the creation of community or national level sustainable plans [20–22]; water safety plans [23]; and risk assessments [24]. Any planning process that relies solely on external expertise without meaningful collaboration and partnership with community members often results in systems that do not reflect local culture and values, are reliant on imported energy and materials, are not flexible or resilient enough to survive an often harsh and changing climate, and will likely result in little community ownership, pride, and trust. As such, several Indigenous organizations in Canada, most notably First Nations organizations, have recognized the need for a culturally appropriate, meaningful and respectful community consultation process to ensure local control in the land use and natural resource planning activities [25,26]. For example, the National Aboriginal Health Organization developed the principles of Ownership, Control, Access and Possession (OCAP) to guide all health research concerning First Nations, and could be used as a guide to evaluate infrastructure projects within the Inuit and Metis communities.

Extended Peer Communities and Indigenous Knowledge

There are a number of established approaches to research and engineering design that address the need for engineers and designers to better engage with users and communities to understand their specific context and develop locally appropriate and context-tailored solutions. For instance, Post Normal Science (PNS) approaches are founded on the notion that in complex situations with high decision stakes and/or considerable system uncertainties, traditional reductionist approaches to problem solving may no longer be appropriate (Chapter Three). In complex situations, the problem must be understood in its entirety, not only considering all the components of a system, but also all the connections and relationships between those components. One of the key principles in PNS approaches is the engagement of 'extended peer communities', that are legitimate stakeholders who are typically outside the scientific community (e.g. community members, youth, elders, activists, local businesses, and so on) [27,28]. Extended peer communities extend the quality assurance role of conventional peer processes (e.g. peer review) to all legitimate stakeholders by enabling their participation in related policy debates and enriching the process by providing "extended facts", including unpublished local and Indigenous knowledge [27,28]. The understanding, consideration, and incorporation of Indigenous knowledge in any northern infrastructure planning process can help ensure designs are not only robust, but also culturally and locally appropriate. For instance, in Nunavut, Inuit knowledge is referred to as "Inuit Qaujimajatuqangit" (IQ), which means "the Inuit way of doing things: the past, present and future knowledge, experience and values of Inuit society" [30, p.103]. The Government of Nunavut strives to include IQ in its operations, decision-making, and long term planning. According to Rosmarie Kuptana, Inuit activist and environmentalist, IQ "needs to be respected for what it is, a science, in its own right, that can work in concert with western science to solve the complex problems of the world. However, it must be respected and must be used to benefit the holders of this knowledge" [29, p.43]. In a recent keynote address to

Arctic researchers, the president of Inuit Tapiriit Kanatami (Canada's National Inuit Organization) discussed how researchers are finally using Inuit Knowledge to help inform their western science. This change in perspective and willingness to embrace Indigenous knowledge systems represent a major shift for researchers working in the North. He suggested it is now time to focus on the next paradigm shift and he challenged Arctic researchers to move from thinking about how Inuit knowledge can help inform western science, to consider how science can inform Inuit knowledge systems [31]. Such a change in paradigm would likely shift the role of the engineer or technical expert and would place more control and responsibility for infrastructure development with the communities.

The Importance of Locally Appropriate Design Requirements

Engineering design "is a systematic process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients or users needs while satisfying a specific set of [design requirements]" [31, p.104]. One strategy for increasing local participation and control of infrastructure development is ensuring that systems are designed and built using locally identified principles, values, and priorities, known as design requirements. Design requirements are the parameters placed on the development of any product or system, and may include the safety needs, physical laws that will limit the development, available resources, cultural norms, and use of locally identified 'criteria' and 'constraints' [33]. In engineering design, constraints are used to set limitations on a design [33] and provide a method of narrowing down the possible options (Figure 4.1). A successful design must fall within the limitations defined in the constraints. Once the possible options are established by the constraints, design criteria are used to identify the desired elements and features of a product or system [33]. Design criteria allow engineers to rank different possible options; therefore, a successful design will typically satisfy as many criteria as possible.

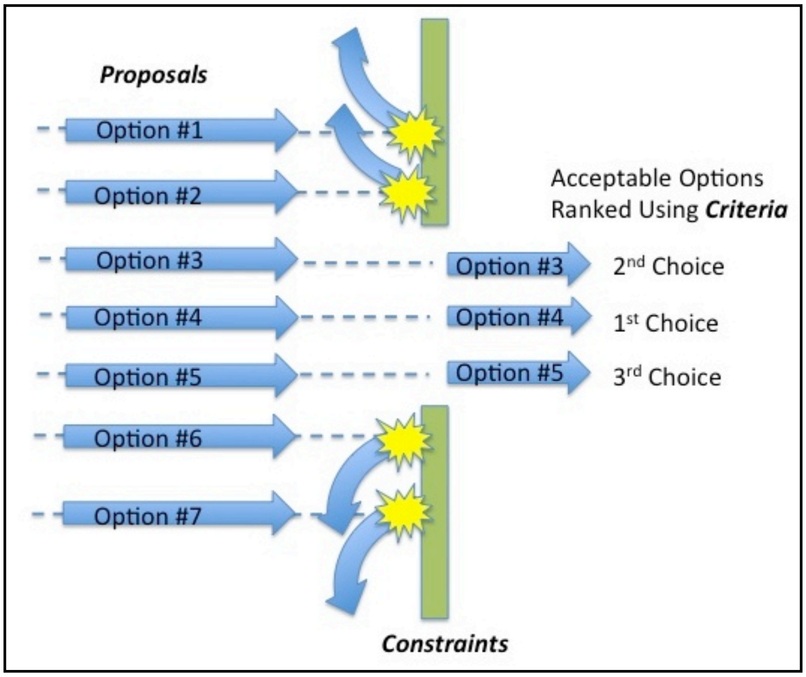

Figure 4.1. Two-step process to select design options: 1) Design constraints are used help identify a range of plausible options from a series of proposals and, 2) criteria are used to rank and select the most appropriate option.

Working with clients to create and define explicit criteria and constraints is an established engineering design approach that encourages transparency, good communication, and mutual understanding and trust between parties. If adopted for use in northern Indigenous communities, this approach of working with communities to create explicit and locally appropriate design criteria and constraints could increase transparency, trust, adoption, and sustainability of northern infrastructure. Once clients identify appropriate constraints and criteria, it is important to develop a system to rank different criteria relative to each other. Once ranked, the criteria can be incorporated into a decision analysis [34] or decision matrix tool, thereby bringing additional transparency to the decision making process.

STUDY GOALS AND OBJECTIVES

Due to an often high reliance on external expertise for infrastructure projects in remote Indigenous communities, there can be insufficient transparency in the planning and decision making process, resulting in low levels of community engagement, ownership, and trust in the designed infrastructure. Therefore, this study aimed to explore ways to increase the transparency and accountability of the infrastructure design processes by adapting the existing engineering design tools of constraints and criteria, and decision matrices. The intent was to incorporate these tools into an appropriate community-based decision-making process. The decision-making process incorporates an assortment of locally identified and culturally appropriate design priorities along with the necessary technical requirements identified by expert engineers and planners. This approach was piloted in collaboration with the Inuit community of Rigolet, Nunatsaivut, Canada for a decision-making tool to assist in future community water infrastructure planning.

METHODS

Case Study Description: Location

The costal community of Rigolet (54°N, 58°W) is located on the north-east coast of Canada, and is the most southern of the five communities in the Nunatsiavut Inuit region (Figure 3.3). Rigolet has a population of 306 people, and most residents identify as Aboriginal (88.5%) [35]. The official population of Rigolet grew by 13.9% between the 2006 and 2011 census, which is far greater that the national population increase of 5.9% over the same period [36]. There are no roads leading to Rigolet; it is accessible year-round by air travel, and seasonally accessible by boat during the summer and snowmobile in the winter season once the sea ice freezes. Rigolet is located in the sub-Arctic region where from 1970 to 2000 the observed temperature range was -45 ^{o}C to +34 ^{o}C [37,38], the annual number of heating degree days (below 18^{o}C) were 7653 [37], the maximum wind gusts reached 141 km/h [37], and the maximum recorded snow depth was 331 cm [38].

Figure 4.2: Map of northern Canada showing the Nunatsiavut Inuit region and the community of Rigolet, NL (adapted from www.itk.ca).

Case Study Description: Drinking Water in Rigolet, Nunatsiavut

The provincial Department of Municipal Affairs, engineering consultants, the Rigolet Inuit Community Government, and the Nunatsiavut Government's Joint Management Committee typically contribute to the decision-making process concerning infrastructure planning and design in the Nunatsiavut communities. Research and government reports have identified drinking water quality as an important topic to community government and residents of Rigolet, Nunatsiavut [20,39–42]. Previous research and consultations suggest that the major water-related concerns included poor tap water aesthetics (i.e. taste, odour, and colour) and potential chemical contaminants [20]. As such, many community members report that they do not consume tap water and prefer to either purchase bottled water from the local grocery store, or collect untreated water from local sources [40,43,44]. Rigolet Inuit Community Government (RICG) and residents indicated they were not meaningfully engaged in the infrastructure design and planning process in their community [39]; this could contribute to the reported lack of trust in the tap water (Chapter Three). Studies suggest that engaging community members in the planning and decision-making process results in increased community support, a sense of community ownership, and, ultimately, more sustainable infrastructure [3,5,21,45]. Based on their experience with previous participatory research in the community [42], RICG invited research partners to examine potential methods to improve the drinking water infrastructure.

Data Collection

The establishment of locally appropriate design constraints and criteria for infrastructure in the community of Rigolet was undertaken through multiple steps that included: a literature and document review, preliminary consultation with engineering colleagues, consultation with technical experts from across the Circumpolar North, consultation with community leaders, consultation with community members, and a validation process (Figure 4.3). Although the constraints and criteria must be locally appropriate for the community of Rigolet, it was also important that the proposed constraints and criteria contain all necessary technical and regulatory aspects related to infrastructure design in the North. Therefore consultation with technical experts preceded consultations with the community members.

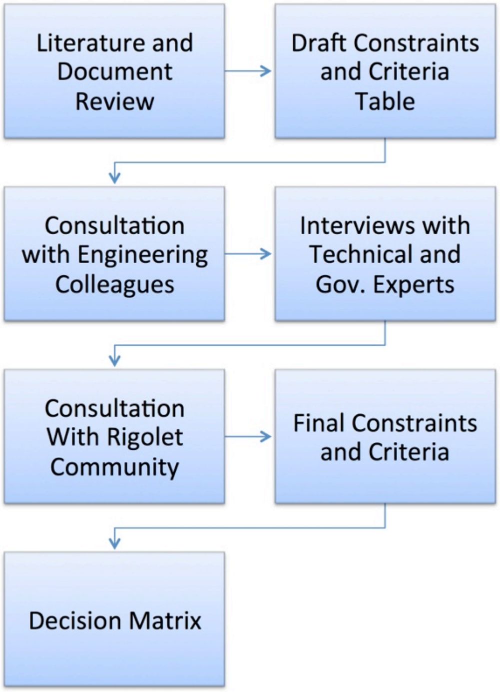

Figure 4.3. The development of constraints and criteria included literature review and consultation with the Extended Peer Community (engineering colleagues, technical and government experts, and community members).

Literature and Document Review

A literature and document review was completed to establish principles of appropriate design; gain an understanding of typical infrastructure failures in the Circumpolar North; and identify any relevant guidelines, codes, standards or regulations from other cold regions to help inform the creation of northern-appropriate design constraints and criteria. Peer-reviewed literature, government documents, policy briefs, relevant guidelines and regulations were reviewed. An initial list of criteria and constraints for northern designs was established based on the literature review.

Consultation with Engineering Colleagues

A consultation session with colleagues from the School of Engineering at the University of Guelph took place on October 9th, 2014 to solicit feedback on the items in the constraints and criteria list. A total of 3 individuals (1 faculty, 2 graduate students), with over 25 cumulative years of engineering experience, participated in this exercise. The draft constraints and criteria list was sent out in advance of the meeting by email. The meeting was conducted in a focus group discussion format with the author acting as a facilitator by asking a series of questions about specific criteria and constraints. In addition, the group identified and discussed metrics or indicators that could be used to evaluate how a potential criterion is being (or not being) met. The constraints and criteria list was revised based on the feedback from this consultation session.

Consultation with Experts from the Circumpolar North

After the consultation with engineering colleagues, selected experts from multiple disciplines (e.g. environmental and civil engineers, community planners, government employees, and university professors) at local, regional, provincial, national, and international levels were invited for interviews to provide feedback on the constraints and criteria list. Interviewees were identified through an iterative ‘snowball’ process, whereby interviewees and research team members identified and suggested other interviewees. An interview guide (Appendix D) was developed and was pre-tested for content with academic colleagues. The draft constraints and criteria list was shared with each interviewee prior to the interview. The interviews included open-ended questions to capture information about the expert’s experience working in rural, remote, northern, and/or indigenous communities, and also to learn about different factors they perceived to be associated with success or failure of infrastructure projects. Experts were then asked to provide detailed feedback on the constraints and criteria list, and provide a ranking of the importance of various criteria based on their experience. A revised list of design criteria were developed based on expert feedback and returned to participants for final validation.

A total of 17 experts were invited to participate in the interview from November 2013 to February 2014; eight agreed to participate, four declined due to time constraints, and five did not respond (response rate = 71%). Participants were from the fields of academia (n=2), consulting engineering (n=2), planning (n=2), and government (n=2). Five participants were male and three were female. Six interviews were conducted by telephone, one in person, and one by email correspondence. Interviews lasted 63 minutes on average and ranged from 48-79 minutes. All interviews were audio recorded with permission in accordance with the University of Guelph Ethics Review Board approval (Appendix E). A total of 7.33 hours of audio were recorded.

Community, Leadership, and Public Feedback

Finally, the constraint and criteria list was assessed by community members for context (e.g. use of locally relevant and appropriate language and terminology) and content (e.g. ensuring all constraints and criteria were locally relevant and that no important issue was missing). The list was first reviewed with local members of the research project (two community researchers) to receive feedback on the language and develop an appropriate and engaging activity to effectively communicate the concept and gather feedback at a community event on January 29th, 2014 in Rigolet (Figure 4.4). Approximately 87 Rigolet community members attended the community event, which represents approximately 28% of the communities' population [35]. The activity consisted of a 'fishing' activity, where the various design constraints and criteria were printed on paper fish with a paper clip added to the 'mouth' of the fish. Community members attending the community event were invited to 'catch' the fish off the floor with fishing poles with magnets instead of hooks. Once all the fish were 'harvested' from the floor, they were laid on a table. A hypothetical scenario where the local Rigolet Inuit Community Government was considering a new water treatment system was described, and participants (either individually or as part of a team) were asked to arrange the various constraint and criteria fish in order from most important to least important. Participants were also provided with blank fish, so additional constraints or criteria that were not previously identified could be included. In addition, community members were asked to exclude any constraint or criteria fish that were not locally appropriate. After the fish were ranked, the author took a photo of the list. The rankings were extracted from the photos and inputted into Microsoft excel to identify any common ranking patterns.

Figure 4.4. Rigolet residents participating in 'fishing' activity and ranking and identifying locally appropriate infrastructure design criteria (Photo Credit: A. Gordon and A. Cunsolo Willox)

To simplify the process and ensure that the activity was not too long in duration, no distinction between constraint and criteria were made. Similarly, when making the fish for the activity, the author and the local member of the research team decided to combine some constraints and rolled them into a criterion, for example the 'climate' & 'geological/site assessment' constraints were included in the 'robustness' criteria. The constraint 'affordability' and criteria 'range of affordability' were both blended to become the criterion ‘cost to community’. The constraint ‘accessibility’ also became a criterion to capture its relative importance from the community members’ perspective.

Development of Decision Making Tool

The constraint and criteria list was incorporated into a decision analysis tool, known as a decision matrix – a common implement used by engineers to transparently evaluate, rank, and choose the best solution for a given infrastructure problem [34]. In the decision matrix tool, all possible infrastructure design options are evaluated in terms of the established constraints and criteria. All options must satisfy the constraints to be considered. The criteria in the matrix were assigned a weight between 0 and 100, based on the ranking identified by experts and Rigolet community members. If there was a noted divergence between the rankings of different experts and community members, then the metric included a note recognizing the discrepancy and suggesting a range of possible weights to be considered.

RESULTS

The literature review resulted in seven constraints and six criteria being identified. This initial list evolved further to include seven constraints (Table 4.1) and 10 criteria (Table 4.2) based on feedback from university colleagues, experts, and the Rigolet community.

Table 4.1. Final list of design constraints with description and indicators identified through literature review and in consultation with technical experts and Rigolet community members

#	Constraint	Description (what does this mean?)	Indicator (How do you measure this?)
1	Climatic	Must be able to function within the climate extremes observed and anticipated in Rigolet.	Relevant Information (example data from Rigolet, NL): ☐ Temperature range observed: -45 °C to +34 °C[37,38] ☐ Number of heating degree days (18°C): 7653[37] ☐ Max wind gust observed: 141km/h[37] ☐ Max recorded snow depth: 331cm[38]
2	Site Assessment	Must be able to withstand effects from annual freeze/thaw cycles Must have adequate and appropriate land for infrastructure foot print in community	Local Profile ☐ Permafrost Present?: ☐ Yes ☐ No ☐ Unsure ☐ Typical geological profile: Clay (10m) Bedrock (46m)[46] ☐ Water table depth: 43m[46] ☐ Major drainage issues anticipated? ☐ Major erosion issues anticipated? ☐ Is adequate land available?
3	Regulatory	Meets current regulations, standards, and guidelines Will additional permits, studies, or assessments will be required to complete this project?	Applicable Regulations (check all that apply): ☐ National Building Code[47] ☐ National Plumbing Code[48] ☐ National Fire Code[49] ☐ NL Guidelines for Design and Construction[50] ☐ Health Canada Guidelines for Drinking Water Quality[51] ☐ WHO Guidelines for Drinking Water Quality[52] ☐ Specific cold regions guidelines? (GNWT) ☐ Other:________________________
4	Energy	New infrastructure will utilize existing available energy and fuel sources and operate within the energy budget of the community. Note: estimate of total 2008 Rigolet per-capita monthly power consumption during winter is: 755 kWh[53]	☐ What is estimated electricity demand of this option?________________ ☐ What is the energy budget currently in the community?________________
5	Affordability	Cost must be within range of existing or anticipated financial budget of the community. Is there adequate and available for this design option?	Current Municipal Budget Info: ☐ Current Capital Budget:_________________ ☐ Current Training Budget:_______________ ☐ Current Electricity Budget:_______________ ☐ Current Chemical/Consumable parts budget:__________ Does additional land need to be purchased? ☐ Yes (cost:___________) ☐ No ☐ What is the anticipated cost of this option?:__________
6	Accessibility	System and accompanying distribution network must be able to supply drinking water in a way that is accessible to the entire population of Rigolet, regardless of income or physical abilities.	Water System Delivery Type [1,4] (check all that apply): ☐ Watering point ☐ Trucked delivery ☐ Piped delivery ☐ Other delivery:__________________ ☐ Will households have equal access to services? ☐Yes☐No
7	Availability	Entire water system must meet the expected need of the community for all uses (i.e. drinking, cooking, laundry, cleaning, toilet flushing etc.).	Current water demands in community: ☐ Drinking and Cooking ☐ Laundry and Bathing ☐ Firefighting demand ☐ Commercial and Institutional demand

Table 4.2. Final list of design criteria with description and indicators identified through literature review and in consultation with technical experts and Rigolet community members

#	Criteria Name	Description (What does this mean?)	Indicator (How do you measure this?)
1	Range of Affordability	The anticipated lifecycle cost of a design. Can the community afford this without additional funding programs? Note: in Nunavut it is reported that the actual capital cost of a piece of infrastructure can be less than 20% of the total operation and maintenance cost over the planned life of the asset (20 years).	Complete with cost estimates ☐ Capital Cost:___________________ ☐ Annual Operation and Maintenance Cost (est. range of $85-$768/ML delivered)[54] ☐ Annual Labour Cost:_______________ ☐ Annual Training and Recertification Cost:______________ ☐ Annual Consumable Cost (Chem./Filters):_______________ ☐ End of Life Disposal Cost:___________________________
2	Time to Construct[15]	Many challenges to building in the North, including tough working conditions with cold temperatures, high winds, and shortened workdays due to reduced daylight. Minimizing the amount of time required to complete construction can be of advantage.	Does the infrastructure employ modular, prefabricated or other design styles aimed to minimize required construction time? Will additional training of construction firms be required? Is that cost being considered?
3	Robustness[55]	The reliability, durability, flexibility and resilience of the proposed infrastructure are important measures of the ability of the technology to endure in a remote northern community.	Reliability: the effectiveness of the system under normal and extreme operating conditions, the probability of failures, the impact of failures to system effectiveness[55]. Has this technology been proven in a cold region already?[2] Durability: estimated system lifespan[55], assume 20 years[56]. Flexibility: How easily the water system would be able to change or evolve to deal with uncertainties (e.g. changing population, environment, tastes, preferences, energy costs etc.) Resilience: is this technology able to be easily thawed out if frozen? If system freezes, is the system designed to be fail safe and if needed designed to fail safely?[2]
4	Simplicity, [56,57]	A system, that is overly complicated, may require specialized tools, or trained professionals from outside the community if it fails. A simple systems typically has fewer moving parts and fewer points of potential failure [2].	Measures of Simplicity Degree of automation:________________ Degree of presence required by operator:_______________ Number of moving parts:_____________ What is the class of the system?:_______________ What outside expertise is required?:______________ Training required for local operator?:________________
5	Consistency/Reputation[56,57]	This criterion would rank to which degree an option has already been proven and tested in similar real world working conditions.	Has this technology been successfully proven else ware in the region, or in similar conditions? Is technical support readily available if needed?
6	Quality of drinking water	This criterion would rank the quality of the water and delivery service that the system provides in terms of conventional and local criteria (i.e. taste, colour, smell, trust or source, etc.)	Locally Identified Water Quality Criteria[58,59] ☐ Taste ☐ Colour ☐ Clarity ☐ Odour ☐ Use of Chemicals ☐ Trust of Source Water
7	Environmental Impact	This criterion ranks the proposed system based on environmental impact. These rankings will be relative based on comparative alternatives.	Construction, Operation and Disposal activities that could negatively impact the Environmental (select all that apply) ☐ Green House Gas Emissions (transport and operation) ☐ Use of quarried material for construction

			☐ Disposal of filtrate, spent filters etc. in local landfill ☐ Construction impact on local environment ☐ Increased erosion leading to storm water or snow melt drainage challenges
8	Use of Local Resources[56]	Promoting and actively assisting communities to take on greater responsibility for their economic and social well-being is important[56]. Construction projects provide important opportunities for communities to become involved in their own development [56]. Infrastructure development is an opportunity to invest in local community members and build technical capacity in the community.	☐ Use of local labour: Short term construction: ☐ Yes (#:________) ☐ No Long term operations: ☐ Yes (#:________) ☐ No ☐ Training of local labour in skilled trades ☐ Use of local equipment, materials, knowledge and suppliers
9	Local Participation [55]	Public participation is often neglected when selecting the most appropriate water treatment technology for a particular community[55,60]. The perceptions and preferences of community members toward the selection and implementation of a particular system is important if the technology is to be sustainable[55,60]. The infrastructure should promote public participation and encourage a sense of community ownership and responsibility for the success of the project [55,60].	☐ What degree of public engagement would be incorporated into the planning and design process? ☐ Would the design process aim to solicit and incorporate local knowledge (i.e. snow drift patterns, use patterns, preferred location, erosion potential etc.)
10	Additional Water Treatment Specific Criteria	The goals of water infrastructure are to improve quality of life in a community by facilitating growth, economic development and improving the health and welfare of residents[1,4].	☐ Would this water infrastructure encourage good hygiene practices? ☐ Would this water decrease the risk of exposure to water borne disease? ☐ Would this infrastructure encourage or discourage the development of local enterprise and economic growth? ☐ If applicable, would this infrastructure help provide adequate firefighting capability?

Constraints

Climatic and Site Assessment Constraints

The site assessment and climatic constraints required any technology to function within the climate extremes and annual freeze-thaw cycles anticipated in Rigolet. The site assessment constraint was initially named ‘geologic’, until some technical experts noted that in reality, climatic and geological factors were often part of an initial conventional ‘site assessment’ process used to “*pick the site that makes the most sense from a physical standpoint*”, which includes “*questions that we have to ask ourselves, before we proceed*”. Site assessments also typically included identification of “*slope*”, “*erosion*” and “*flooding*” potential, and other geological features such as the presence of “*bedrock*”, “*marsh*”, or “*swamp*”. Experts indicated that it was becoming more challenging to predict how effective a cold-temperature-dependent technology will fair due to anticipated climatic change and warming, and they were concerned that traditional metrics, like *“northerness”* or latitude *“[are] sometimes irrelevant”*. For example, one interviewee commented that, *“some years, the far north lagoon systems [used for wastewater treatment] were outperforming more southern systems”*. This was not expected, as the southern systems typically performed better. Due to climatic change and variability, some engineers question if they should build *“a system that relies on the freeze back of engineered berms [barriers] to create an impervious retention – for instance for wastewater – or do we rely on the fact that with the climate change occurring… [we have to] switch [to a different] type of design?”*

Regulatory Constraint

The intention of the ‘regulatory’ constraint was to ensure that any proposed design met all relevant and necessary regulations, standards, and guidelines before any further consideration. Technical experts noted that regulations were helpful because they "*help us define what technology to use.*" For instance*,* the new wastewater effluent regulations proposed by the Canadian Council of Ministers of the Environment and Environment Canada [61] were often referenced in interviews. One expert planner noted that regulations from Transport Canada regarding airports can impact the location of "*sewage treatment and water reservoirs*" because these cannot be too close to airports since they are considered "*bird attractants*" and their presence could increase the risk of collisions with airplanes. Experts noted that engineers should design to accepted national standards or guidelines (i.e. Health Canada's Guideline for Drinking Water Quality), even if not required by current provincial or territorial laws because "*regulations are not relaxing, they are becoming more stringent.*" Health Canada's Guidelines for Canadian Drinking Water Quality are seen as *"the standard benchmark"* for drinking water treatment targets, and many northern regions are choosing to adopt them as regulation. Land ownership issues, source water protection measures, or presence of an 'at-risk' wildlife species can limit the type of infrastructure options due to regulations. For example, one expert noted that in the state of Alaska, to build on or "*cross over*" federally protected land requires an "*act of congress*" and a plethora of different permits.

Energy Use Constraint

The intent of the 'energy use' constraint was to ensure that any new infrastructure would operate within the current energy supply available in the community, or include the details of how to increase the energy supply as required. Technical experts noted some important aspects of this constraint include the phase of power available in the community and whether the utilities are currently located "*above ground or below* *ground*". Experts also noted that assessment of current energy-supply capability is critical because if a new piece of infrastructure unexpectedly uses a lot of electricity, the situation "*could be quite dire*" for a community and impact other pieces of infrastructure within the community. As one expert explained, most northern communities have their generator fuel "*barged in every single year*" and then fuel is "*stored in tanks*". Therefore, if there is a "*massive energy draw from putting in [a new] system, and if your fuel tanks are already in the 15% safety margin, you will need to expand your fuel tanks to accommodate for that extra usage.*" Rigolet community members, however, commented that "*energy use is really just a part of the cost of running it*" and suggested energy use should be included as part of the affordability constraint.

Affordability Constraint

The 'affordability' constraint implied that the total financial cost of the infrastructure must be within the range of the existing or anticipated financial budget of the community. Technical experts really stressed the importance of long term, "*lifecycle*" costs since "*capital cost to put that piece of infrastructure in likely only represents 20% or less of the lifecycle cost*". For example, oversizing a facility will not only have a "*larger footprint*" requiring "*increased amounts of material for building"* but it will also will require *"a lot more heat, a lot more electricity*" substantially increasing the costs over the life of the project. To reflect the importance of the entire lifecycle costs of infrastructure, 'range of affordability' is a listed criterion. Another technical expert, however, noted, "*at the end of the day, we say that we like to build to programs, and not to budget*". The "*programming goal*" for example could be "*health*" related, or it could be "*social political decision . . .[to] support an industry or a fishery*". As such, these experts noted that there is often a financial trade-off between "*what does the owner want versus what makes the most sense from an engineering standpoint*".

Accessibility Constraint

The 'accessibility' constraint requires that any infrastructure must be accessible to the entire population of a community, regardless of income or physical abilities. Community members and technical experts alike generally identified accessibility as an important constraint. One technical expert noted that new or upgraded "*systems should at least maintain that [current] level of accessibility if not improve it*". Accessibility was especially important to Rigolet community members, since a new drinking water system required users to go and collect drinking water with their own containers from a central dispensing point. Rigolet residents noted that this "*self haul*" type delivery system was difficult for users with disabilities, or those without a vehicle.

Availability Constraint

The 'availability' constraint was intended to ensure that a technology met all the expected 'programming' needs of the community. In the case of water treatment, this meant providing sufficient water for all uses (i.e. drinking, cooking, laundry, cleaning, toilet flushing, commercial use, industrial use, firefighting demand etc.). One technical expert noted that this constraint could also be used to assess the availability of natural resources, such as a sufficient source-water supply, or acceptable building plots. An expert noted that in some Alaskan communities "*water is not available year around; it dries up*". As such, availability can also impact accessibility because "*some communities do not have pipes because there is not enough water*" or "*water might be there, but too far away to transport to the community.*"

Criteria

While participants generally believed that all 10 criteria were important for infrastructure planning (Table 4.2), they often felt that the relative importance of each criterion would vary based on the diversity of answers between different experts, or between experts and community members. Technical experts most commonly ranked ‘local participation and leadership’ followed by ‘simplicity’ as the two most important criteria (Figure 4.5), whereas community members most often ranked ‘cost to community’ followed by ‘local participation ‘ as the two most important criteria (Figure 4.6). As the top ranked criteria, ‘local participation (and leadership)’, ‘system simplicity’, and ‘system affordability (or cost to community)’ will be discussed in detail in this section.

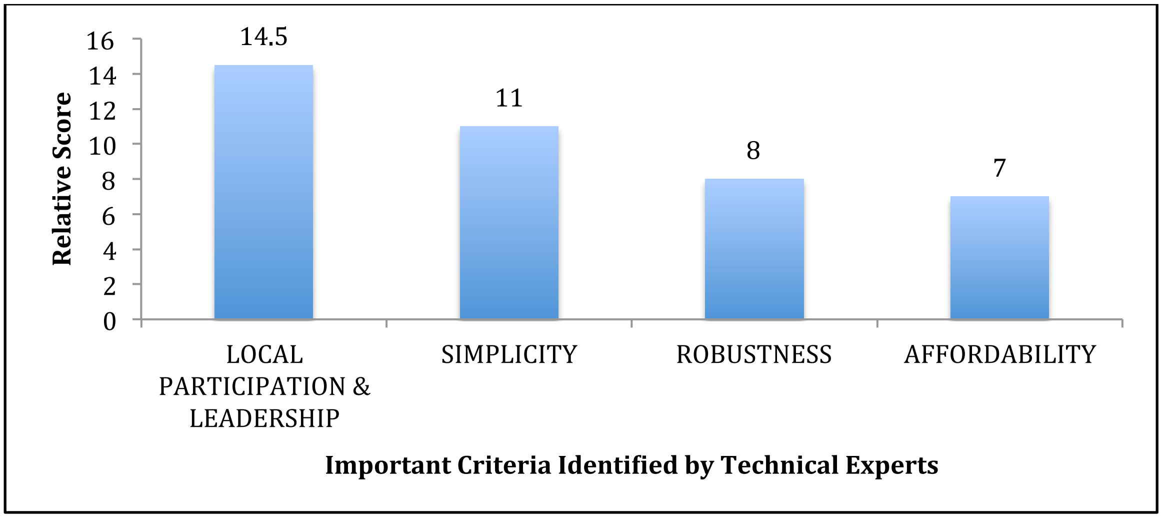

Figure 4.5. The top four criteria that were identified by technical experts during interviews held between November 2013 and January 2014. The relative score was calculated by scoring the top criteria of each participant as 4, the second criteria as 3 and so on, and then the scores for each criterion were tallied to identify the most important criteria. Note the criterion ‘Local Participation and Leadership’ was modified to include ‘Leadership’ based on feedback from technical experts. This change was not reflected in consultations that took place with community members (Figure 4.6)

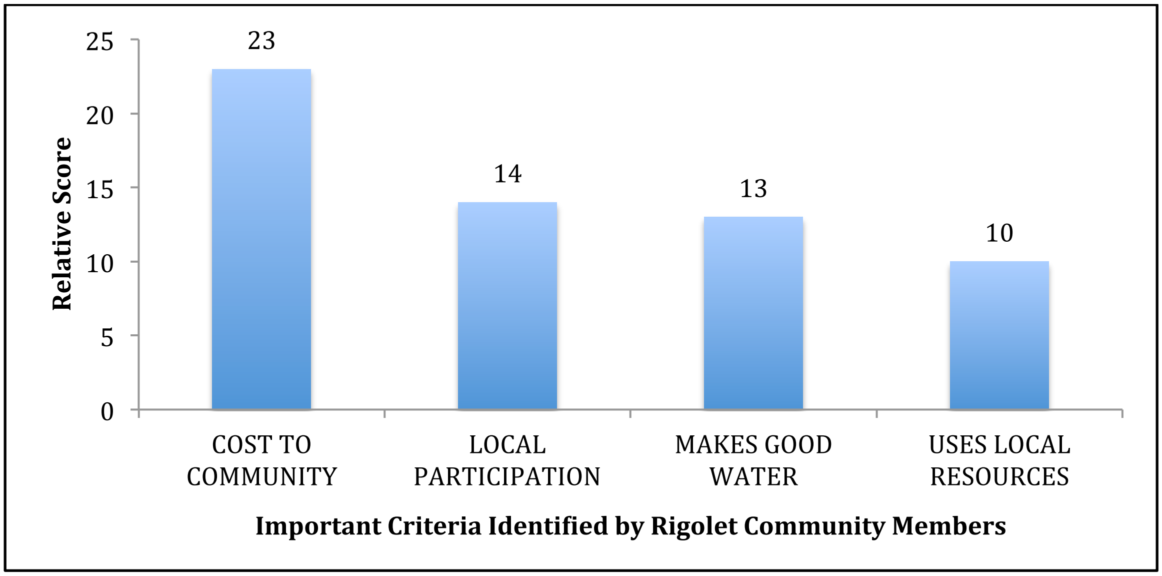

Figure 4.6. The top four criteria that were identified by Rigolet, Nunatsiavut community members during a community event held on January 29th, 2014. The relative score was calculated by scoring the top criteria of each participant as 4, the second criteria as 3 and so on, and then the scores for each criterion were tallied to identify the most important criteria.

Public Participation and Local Leadership Criterion

This criterion is an indicator of the community-level involvement in the infrastructure planning, design or decision-making process. Involvement could be at the community government level, or at the level that engages with all community members through meetings or public events.

Some technical experts noted that it could be "*tough*" to engage community members with respect to "*technical solutions*", because without community members having adequate technical knowledge, the value of their feedback "*may be limited*".

Engineers also commented that the scope of the project might be too limited or "*clinical*", and it was suggested that community participation might not be appropriate: **"***A body of* *people with no knowledge? To provide input to something that requires knowledge?"* Technical experts also noted that "*communities are being forced into [taking more responsibility] as part of the devolution process"* and although *"communities are entitled to [this control]"* they may not be *"ready for it",* and it may not always be *"appropriate".* One technical expert described a "*case where a community was given the opportunity to make the decision and the decision was found to be inappropriate, and the decision had to be overruled by regional government".* It was also noted that an important role for consultants is to advise communities because *"some communities do well [making technical decisions], if they agree to ask for help".* Technical experts, however, also noted the value of working with local *"residents and public works people"* to collect important local site information prior to the planning and design process, for example determining *"existing drainage patterns"* and the location of *"flood prone areas*".

Nonetheless, both technical experts and community participants noted that "*local participation is the most important"* criteria. Many technical experts also stressed the importance of a "*local champion*", "*local project manager*", or "*strong local leadership*" to ensure project success, stating that: "*local involvement has just as much to do with success as technology [does]."* The 'local leadership' component of the criterion was not included when consultations took place with Rigolet community members. One technical expert also noted that local participation could contribute to the long-term success of community infrastructure because "*local project managers – who see the importance of the project and have [the]support of the community – translate into dedicated operators."*

Community members and technical experts alike noted that an important component of community engagement is education and transparency. A technical expert noted: "*public perception and education as criteria for a new system is important"* and that communities need to be "*aware of these changes"* and need to*"know what is happening"*. For instance, it was noted that "*even if [a water treatment system] was culturally compatible, and created great water, if the engagement process is not taking place, it could fail"* because it would still be *"like [the system] came from a different planet",* and there is little inherent trust in engineered water systems. As the same technical expert further explained:

> *[Engineers] have to sell [the water treatment system], [they] have to be forthcoming with it, and [they] have to take the mystery away around water. [Community members] need to understand what it is [they] are drinking. Community members don't like to cut the treatment systems any slack, where they would if it was a natural water source.*

Furthermore, in the context of long term planning, one technical expert suggested that planners should ensure that all community members understand the motivations for new infrastructure, if they are to develop "*common goals*" and be more than *"just a group of individuals living together."* Finally, technical experts noted that the success of engagement strategies varies from project to project and that one "*can't make a checklist of community engagement."* Experts also commented that in Nunatsiavut and Nunavut, the only official requirement for local participation seems to be a financial credit for beneficiary (Inuit) ownership and/or employment in the bidding and construction portion of the projects.

Simplicity Criterion

A simple system typically has fewer moving parts and fewer points of potential failure than a more complicated system [2]. A system that is overly complicated may also require specialized tools or trained professionals from outside the community to operate or if it fails. Technical experts noted that simplicity was one of the most important factors for the success of northern infrastructure because it was related to so many different criteria. For example, one technical expert noted that northern regions try to "*limit the complexity [of the treatment system] so [they] can limit the 'class' of operator certification needed."* Limiting the class of operator was to avoid what was referred to as a *"classic problem"* in the North, where *"the second you train operators, they leave the municipality for other positions in the development sector*". Experts noted that providing lower levels of complexity and automation may also be more appropriate for the local context: *"Maybe the less automation means it is more simple, and more tailored to the local abilities of the community*". Also, it was suggested that a "*simple system could mean fewer moving parts and fewer points of failure,"* and *"reduc[ing] points of failure"* is *"a good place for engineering to focus their energy"*. However, some technical experts also noted that high levels of *"system automation*", a metric of system simplicity, *"can be both good and bad"*. Some technical experts noted that increased system automation can enhance a piece of infrastructure by adding "*automated safeguards*", remote access, and data logging capability through supervisory control and data acquisition (SCADA) systems. SCADA systems can automatically detect potential dangerous situations, such as a drop in detected free chlorine residual, ultra violet light intensity, turbidity levels, or changes in flow rates (which could signify a pipe burst), and shut down systems before unsafe water is distributed to users. One technical expert suggested that systems in remote northern communities may benefit from a water treatment system with a higher than the "*average*" level of safeguards due to "*the operator challenges that often exist in some locations"*. Technical experts also noted that "*sometimes simplicity is not an overriding factor*". For instance, the levels of desired system automation depends on a number of factors, including who is paying for the design, construction, operation, and maintenance of the system. Some owner-operators or venders may prefer more remote monitoring, instrumentation, and SCADA capability to assist with technical trouble shooting, while others do not want to deal with the automation.

Cost or 'Range of Affordability' Criterion

While the 'affordability' constraint requires that project cost must be within the range of the existing or anticipated financial budget of the community, the criteria of cost or 'range of affordability' allows decision makers and experts to rank the possible design options by anticipated lifecycle costs and programming benefits to the community. Most technical experts commented on affordability solely as a constraint, which is discussed in a previous section. In terms of drinking water treatment infrastructure, most Rigolet community members consulted were concerned about any direct costs for capital or operation expenses, either through a "*per use*" or "*at the tap*" charge for filing bottles of filtered drinking water, or through the increase to the community poll tax. However, one technical expert discussed affordability in terms of sustainability of government funding since infrastructure has improved as regulations strengthen, and there is increased demand for piped distribution systems in the northern communities. They asked "*does it make sense to spend this amount of money for a community with such a small population? It becomes a resource allocation question. How do you pick one community over another when you have limited resources."*

Additional comments from experts and community members on criteria not discussed in the previous sections are presented in Table 4.3.

Table 4.3. Comments from technical experts describing additional design criteria

Criteria	Comments
Robustness	One technical expert noted the value of "*demonstrated success*" with a particular technology in a similar circumstance, but that is not always possible. Often the technology has been successful in a completely different context, such as commercially on a mine site. Therefore *"we try it out as a pilot first before widespread adoption*." The particular example in this case was adopting technology proven for mine tailings ponds for use with sewage stabilization ponds/lagoons. It is particularly important for infrastructure in remote communities to be "robust" because "*It is difficult for a small community when a new piece of infrastructure goes in and it does not function, or it is not robust. They feel isolated and abandoned. When infrastructure fails it is really hard on the psyche of the people. It seems very personal."*
Flexibility	One example of infrastructure flexibility identified by technical experts is when a community facility is designed to have multiple uses e.g.*"an office and the community hall complex in one facility".* This technique is used because in the North *"many communities find it difficult to operate or hold events in multiple different locations"* and is intended to *"reduce[ ] the overall amount of operation and maintenance costs".* In some regions, this design practice may be know as "complexing"
Modularity	Also, technical experts recognized the ability to expand a system, as the community's needs increase. For example, one expert asked: "*do those systems have the ability to maintain that level of usage, especially with population growth?"* Technical experts described the concept of system modularity as "*interesting*". For example, there is potential for decreased design, "*project management*" and manufacturing costs by using modular systems, however there could be "*less local employment or capacity building",* due to the creation of fewer local construction jobs. However other technical experts warned, "*Don't assume modularity means lowered construction cost*". There have been some instances, particularly a northern housing project, where it is believed that the construction costs of a modular based housing system may have *"ended up being more expensive"* than conventional *"stick build"* because additional specialized training for local tradespeople was required and was "*not factored into the bids for the local construction tender*" resulting in losses for the project.
Resilience	An important part of resilience is the ability for a system to recover from damage, or failure. One technical expert identified the importance of any components to be manufactured with "off the shelf" parts. For instance the technical expert recounted a story about a broken generator that uses "*not a standard diameter bolt that had to be custom made threaded".* This bolt needed to be custom manufactured in the South and shipped north to repair the generator, "*Why would somebody use that in a remote community?"*

Developing a Decision Matrix Based on the Constraints and Criteria

Decision matrices are tools used to evaluate a variety of different courses of actions in terms of a number of often-conflicting criteria [62]. The decision matrix shown in Table 4.4 is designed for use by community governments and consultants in order to evaluate different infrastructure options. The upper portion of the decision matrix contains the constraints identified in Table 4.4 in a checklist format. Since the purpose of constraints are to limit the design options, the upper portion of the decision matrix is used to identify if the various options either 'pass' or 'fail' the constraint requirements, using the metrics or indicators also outlined in (Table 4.1). If a design option passes the required constraints, the decision maker(s) move onto the bottom design criteria portion of the decision matrix.

Table 4.4. Decision matrix designed for the selection of future drinking water infrastructure in Rigolet, Nunatsiavut based on consultations with technical experts and Rigolet community members in 2013-2014.

DESIGN CONSTRAINTS	**Design Option #1**		**Design Option #2**		**Design Option #3**	
	Pass ☑	*Fail* ☑	*Pass* ☑	*Fail* ☑	*Pass* ☑	*Fail* ☑
Climatic	☐	☐	☐	☐	☐	☐
Site Assessment	☐	☐	☐	☐	☐	☐
Regulatory	☐	☐	☐	☐	☐	☐
Energy	☐	☐	☐	☐	☐	☐
Affordability	☐	☐	☐	☐	☐	☐
Accessibility	☐	☐	☐	☐	☐	☐
Availability	☐	☐	☐	☐	☐	☐

DESIGN CRITERIA			**Design Option #1**		**Design Option #2**		**Design Option #3**	
	Locally Assigned Criteria Weight	*Suggested Criteria Weight Range*[1]	Rank[2] *(Assign# from 0-4)*	Score *(Rank x Weight)*	Rank[3] *(Assign # from 0-4)*	Score *(Rank x Weight)*	Rank[3] *(Assign # from 0-4)*	Score *(Rank x Weight)*
Affordability	25	*20-25*						
Time to Construct	2.5	*0-5*						
Robustness	10	*10-20*						
Simplicity	25	*15-25*						
Consistency/Reputation of Vendor	5	*0-10*						
Environmental Impact	5	*10-20*						
Use of Local Resources	10	*10-20*						
Local Participation	10	*10-20*						
Additional Project Specific Criteria #1: Quality of Drinking Water Produced	10	*10-20*						
Additional Project Specific Criteria #2: *BLANK*	*n/a*	*10-20*						
Note: Sum of assigned weights must be equal to 100								
TOTAL SCORE *(Sum of all scores for each design option)*								
FINAL RANK *(Identify design option with highest score)*								

1. The suggested range for criteria weighting is based on general infrastructure priorities identified by Rigolet residents and technical experts in Winter 2013-2014.

2. When ranking individual design options; 4 is considered 'very good', 3 is 'good', 2 is 'neither good nor poor', 1 is 'poor', and 0 is 'inadequate or unacceptable.

In the design criteria portion of the matrix, all the criteria from Table 4.2 are in the left column and have been assigned a relative importance or 'weight' based on feedback from technical experts and Rigolet community members. The weight of each criterion may need to be adjusted as priorities change, or as criteria are added and removed from project to project. However, the sum of all the criteria weights must always add up to 100, ensuring that the importance of each criterion remains relative, and the user recognizes the inherent tradeoffs that must take place when ranking criteria or making decisions. Once the weights are assigned, the user evaluates each remaining design option by ranking each of the criteria from 0 to 4, where 4 is considered 'very good', 3 is 'good', 2 is 'neither good nor poor', 1 is 'poor', and 0 is 'inadequate or unacceptable'. The common practice of ranking various options is as follows. Each criterion 'score' is determined by multiplying the rank by the weight. The total score for each design option is determined by adding up all the scores along the column. The design option with the highest total score is the best infrastructure option, as it is the option that satisfies the most of the user's criteria (see example in Appendix F). If after the scoring is complete, the users disagrees with the result, it may be due to errors in the criteria weight, the criteria rank, the scoring calculation, or possibly that the matrix is missing some important criteria.

Although the proposed infrastructure decision matrix was not a part of the consultation with the extended peer community, many participants expressed the value in creating a decision making tool that incorporated locally identified and constraints and criteria (Table 4.5).

Table 4.5. Comments from technical experts supporting the constraints and criteria table and development of a decision-making tool

Comment from Technical Expert
"it looks to likely be very valuable for the [Nunatsiavut Region] and other northern communities as well"
"*I really thought [the constraints and criteria table] was quite comprehensive and really well thought out"*
This tool could be used to help inform the case-by-case decisions made in communities"
On informing development policy: *"A decision making support tool that the community could use…[the community] decides what is paramount for them… and [the decision making tool] informs the creation of an actual policy, and that [policy] would actually ensure that development regulations are in place to make sure [communities are] making good decisions"*
On increasing transparency and accountability*: "communities are demanding more control, which they are entitled to, but at the same time we need to ensure the best use of the funding. The senior government needs some basis for protecting their interests"*
On increasing transparency and accountability: *"You have your committee, you make your selection criteria and your point system, but in practice, the way things sometimes go is a lot of it is feeling based. That is part of the reason this [decision making tool] is needed, because it could make [the process] more transparent."*
On the value of constraints and criteria: "*Consultants sometimes don't have the knowledge or expertise in the North, and unless there is really good directions provided, sometimes you see designs that don't meet the requirements, or are too advanced for the community to support*"

DISCUSSION

The goal of this study was to develop a process that would ultimately result in a superior decision making tool that would assist engineers working in unique and challenging circumstances, such as the design of northern infrastructure. The outcome of this study was a functional decision-making support tool that not only reflected the priorities of community members, but also satisfied the rigor expected by technical experts that work in the North. The process and the functional decision-making tool was developed in the specific context of assisting RIGC in establishing appropriate constraints and criteria for future water infrastructure projects, communicating those priorities to its consultants, and ultimately making informed decisions in a manner that will provide transparency and accountability, and increases community engagement and trust in the community planning process. However, the process and the functional tool can be easily adapted to other circumstances because it is the process and the tool itself that reflect the key elements that are critical to improved infrastructure in unique circumstances, such as in remote northern communities. The identification of technical constraints and criteria based on literature review and through consultation with technical experts ensures that the priorities for various technical aspects, which previously have been unwritten and simply implied, are now clearly documented in a transparent manner. Additionally, the collection and ranking of locally accepted and appropriate constraints and criteria helped to clarify the priorities and concerns of community members. Although the role of consultants, engineers, and contractors on northern projects is critical, by prescribing the constraints and criteria from the beginning helps to enable the community to take a position of authority, power, control, and ownership of a project. Upon hiring a consultant and presenting them with the constraints and criteria table with the accepted ranking, the community is able to clearly communicate its expectations and points of evaluation. When consultants engage with the community government or with the community members, they can reference the constraints and criteria and its language. For example, plain language reports and presentations can use the constraints and criteria as headings and discussion points. By using this decision-making support tool, the community could gradually increase its role in infrastructure projects as its technical and management capacity. For instance, community members could attend information meetings with consultants, and inquire how the criteria 'accessibility' and 'robustness' were factored into the design and planning process.

Potential Users of Constraints and Criteria Tool

Potentially, there are multiple uses for this decision-making support tool and the accompanying constraints and criteria list; the first user of this tool is the RICG. The RICG can use these criteria to evaluate its own community infrastructure needs and help prioritize future projects. The RICG can then use these constraints and criteria when hiring an engineering consultant to assist with a project and to receive initial estimates.

When representatives go to the Nunatsiavut Government's Joint Management Committee (the body that provides the majority of capital funding in the region), the RICG can explain the project, its estimated cost, and how it is the best fit for the community based on the constraints and criteria they identified as a community. Some expert interviewees noted that there are often suspicions and scrutiny over certain decisions made by community governments. As such, it is hoped that this tool might help address this issue. Indeed, a technical expert noted that often community decisions can appear biased, "*feelings-based*", and communities may be "*going towards companies that they know instead of newcomers*", even if the new companies have good credentials and track record. In a similar manner, the regional Nunatsiavut Government can be a potential user of this decision support tool. For instance, RICG could continue to pilot and hone the tool to be most effective, and it could become a policy for all five communities in the Nunatsiavut region to provide clear evidence of how a certain decision is made. Moreover, Rigolet community members are potential users of this tool because they can use the list of constraints and criteria to engage in discussions, design charrettes (an intensive planning session or workshop [63]), focus groups, or other activities with consultants, researchers, politicians, and each other. One of the major barriers to engagement with consultants previously identified by community members in this study was the lack of a common language. Community members often felt that they could not question consultants, because they did not use common language and terms. The creation of community-identified constraints and criteria could help break down these community and language barriers and ensure that both parties are communicating effectively and with respect. Finally, consultants are possible users of this tool because it could shape the terms of reference they use with the client and their sub-contractors. It helps to clearly identify the priorities of the community, shape the language of proposals and presentations, and encourage engagement strategies in the community.

Constraint and Criteria Tool Assessment

This project is based on the premise that the development of appropriate constraints and criteria for community infrastructure projects would be a valuable tool to help increase a community's control, transparency, and engagement in infrastructure projects. Certainly this notion was reinforced upon consultation with technical experts, academics, government employees, and Rigolet community members. Not only did experts comment that the tool was "*quite comprehensive and really well thought out*", and it would likely be "*very valuable for the [Nunatsiavut region] and other northern communities*", but more importantly experts agreed that "*everything seems so much better if people feel like the decisions were made locally and feel like local input was included.*" In addition, Rigolet community members noted the importance of community involvement and transparency of the decision-making and planning processes.

Evaluation Based on "OCAP" Principles: Ownership, Control, Access, Possession

The OCAP (Ownership, Control, Access, Possession) principles outlined for First Nations health research are intended to help rebuild trust, improve research quality and relevance, decrease bias, develop meaningful capacity, and empower communities to make change [64]. Schnarch states that:

> *Although OCAP originates from a First Nations context, many of the insights and propositions outlined are relevant and applicable to Inuit, Métis and other Indigenous Peoples internationally. Likewise, although many of the examples provided here are related to health information, the OCAP principles have broader application [47, p.81].*

Indeed, the OCAP principles can be used as benchmarks to evaluate how the development of constraints and criteria could increase the local ownership of RICG over the infrastructure development in their community. The OCAP principle of ‘Ownership’ in the context of infrastructure planning implies that the community owns the planning process and any information generated by a project [64]. The proposed decision-making tool allows the RICG to demand accountability from its consultants and contactors over future design and planning processes. ‘Control’ implies that communities are entitled to full control over the entire project planning process and any information management aspects that impact them [64]. Similarly, by agreeing on which constraints and criteria to include, and their relative weightings, the RICG, exercises a certain level of ownership and control over the entire process. ‘Access’ implies that communities should have access to all relevant information about the project in order to maintain control and to make the necessary decisions, and also have the right to decide about how information about the community is stored [64]. ‘Possession’ is a more literal version of ownership, and implies that a community should actually have physical possession of any important information that the community owns [64], which will further promote local ownership over the process and its outcomes [65].

Improving the Tool

The RICG and other users can further improve or modify the decision-making tool and constraints and criteria table iteratively through its continued use. Language used in the tool can further evolve to more accurately reflect the local needs as the tool is piloted and evaluated during various infrastructure planning projects. However, it is critical that updates or changes to the tool are done through a transparent method that is accepted by the respective community, to ensure the control and ownership principles. It is anticipated that large-scale consultations with circumpolar experts and community members (as conducted during this research project) will no longer be necessary and changes such as adjustments in criteria weighting or the addition of project-specific criteria and/or constraints can be introduced through consultation with respective communities.

Application to Scenario-based Approach to Planning

To further enhance the decision-making process, the next step in this process is to explore how to effectively present different infrastructure options to community leadership in a way that encourages decision-making. Literature has suggested that, at least traditionally, experience living in the rough arctic environment has shaped Inuit philosophy so that it *"may dictate that prediction, planning, and forecasting are impractical, foolhardy, and rather arrogant"* [48, p.91] and instead Inuit traditionally focused on *"preparation for uncertainty rather than rigid planning for the future"* [48, p.92]. Furthermore, it is suggested that "*Inuit distaste for efforts to plan and predict may clash with the preoccupations of Western science, which is increasingly focused on management founded on prediction"* [48, p.93]. Therefore, determining the most appropriate way for engineers to present infrastructure options so that decision-makers can effectively imagine or visualize how their choices will impact the future state of their community should be done in close consultation with a broad range of Rigolet community members and expert communicators including Elders, storytellers, artists, and youth. For instance, scenario based planning and the creation of narratives may be an interesting approach to present infrastructure options to communities. Scenarios are "*a description of a possible future state of an organization's environment considering possible developments of relevant interdependent factors in this environment*" [34, p.32]. The development of these scenario narratives can be a collaborative process in which consultants, stakeholders (Appendix G), and the extended peer community identify plausible future system states, which incorporate scientific knowledge, alternative forms of knowledge, culture, and local values [68]. Consultants could use the constraints and criteria to identify a ‘short list’ of infrastructure options, for which scenario narratives are envisioned with the community.

Adoption of the Constraint and Criteria Tools by Consultants

The establishment of constraints and criteria is an essential step in every engineering design, and should be part of every community infrastructure project. The process of identifying and validating constraints and criteria for remote northern communities starting from community and expert consultations from ‘first principles’ is a time consuming process, but it does not need to be repeated for every project. Although still in their first iteration, the tools developed in this and previous chapters are ready to be adopted and incorporated into infrastructure projects. For example, significant time and effort was taken as part of this project to ensure that the list of constraints and criteria were appropriate and robust for the northern context and were validated by a variety of experts and community members. For new projects, consultants will need to validate the tools through consultation with community leaders and adjusting the weights in the decision matrix based on community and project specific priorities.

Study Limitations

Some of the limitations of this study and the development of the constraints and criteria and decision matrix included: 1) the lack of existing literature on the subject; 2) relatively low participation rates from technical experts; 3) challenge of the criteria ranking activity with technical experts; 4) possible response bias from community members; and 4) limited scope of the community engagement activities. The relatively low participation rate of northern technical experts could be partially attributed to the high workload and busy schedules northern professionals endure. In the North, there are many job vacancies, especially in the government sectors, hence many employees have many roles, and there are often high turnover rates [69,70]. The existing literature on design requirements for northern infrastructure is fairly limited. Although there are some valuable resources, such as the 1996 ASCE Cold Regions Utility Monograph [1], and some codes and guidelines [56,71,72], most of the fundamentals for constraints and criteria were based on appropriate technology literature [55,57,73], usually focused on developing nations. Telephone interviews were an efficient and effective way to engage with technical experts from around North America. However, many experts struggled to provide a ranking of the various criteria, from most to least important, likely because the criteria were presented to them in a list format. However, during the only in person expert interview, the interviewee had the opportunity to rank criteria that were provided on individual index cards, which seemed much more effective. This is likely because the interviewee was able to physically shuffle around the index cards to establish their rankings, while the participants in the telephone interviews attempted to mentally rank the criteria in their head, a more challenging task. The first limitation of the consultation activity held with Rigolet community members was that the only participants were those that chose to attend the community event, indicating a potential response bias [74]. Attempts were made to attract the greatest number of participants possible. For instance, there were door prizes, games, and the event was held mid-week, to avoid missing those families traveling out on the land over the weekend, and sessions were held in both the afternoon and evening. This proved somewhat successful as a total of 87 community members (28% participation rate) attended the community event.

Some of the drawbacks of using a community event as a means of engagement are that the scope of the activity needed to be limited due to participants' available time. For instance, the activity with Rigolet community members only addressed criteria, and not constraints. Often the activity was completed with a small group of participants, and although the facilitator tried to draw out any conflicting opinions within the group, they may have gone unvoiced, and therefore the results of the ranking may not accurately reflect the views of all participants. The activity took place in a busy environment, and some participants may have had more or less time to rank the criteria. The activity also had participants rank the criteria in relation to a specific piece of technology (a community water treatment system), therefore additional stakeholder consultation should take place before the various criteria, and criteria weights are applied to other Rigolet infrastructure, or to infrastructure in another community.

Conclusion

Many remote Indigenous communities are reliant on external expertise for their infrastructure projects, which has led to low levels of local engagement, transparency, ownership, and trust in the infrastructure planning and design processes. This research aimed to increase the accountability and transparency of the process by adapting two existing engineering design tools, design constraints and criteria and decision matrices, to establish a community-driven decision-making tool. This tool incorporates an assortment of locally identified and culturally appropriate design priorities along with the necessary technical requirements identified by expert engineers and planners. This research focused on the process of engaging the community in identifying and ranking of criteria so that they can inform the decision matrix. The process that was piloted in Rigolet may be used by consultants, with additional tools such as scenario-narratives, to engage with respective communities before any design decisions actually take place. The tools developed in this chapter can be adopted by consultants and communities for unique conditions such as northern infrastructure projects, and by doing so will encourage consensus building and transparency, that in turn will translate into trust in, and ownership of, community infrastructure.

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CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

Based on a water-infrastructure case study in the Canadian Inuit Community of Rigolet, Nunatsiavut, the research presented in this thesis aimed to explore new tools and strategies to help develop more appropriate infrastructure planning, design, construction, and management practices for communities in the Circumpolar North. This research included a literature review that explored the unique context of the Canadian North and Inuit culture; the development of different tools and approaches that engineers could use to engage with community clients to better understanding their local context and needs; and the development of a decision making tool which, when used collaboratively with communities, could increase transparency, accountability, and local control of the infrastructure planning and design process. Community ownership and engagement in the design process has been shown to result in more resilient and appropriate systems[1]. This concluding chapter provides a synthesis of the thesis findings, outlines the next steps for this research project, provides recommendations resulting from this research, and closes with some final remarks.

RESEARCH SYNTHESIS

Chapter 2: Literature Review Key Findings

The planning, design, and operation of infrastructure in the Canadian North can be particularly challenging due to the unique context, which encompasses biophysical, social, and economic conditions that are substantially different from those in southern Canada [1–6]. These conditions are increasingly complex and uncertain in the North due to increased industrial and resource development, climate change, population growth, and the transfer of more decision-making responsibilities to community governments [6–12]. These conditions are commonly overlooked in the process of design and installation of vital community systems and have resulted in several examples of failed northern infrastructure, such as housing [13–16], transportation [17] and drinking-water systems [1,3,18,19]. Many of these failures were attributed to engineers and designers applying technologies from southern regions to the North without attempting to adequately understand and address the differences in the local context [3,6]. Despite the importance of considering the local context, a number of researchers have identified a lack of appropriate planning and design methodologies and tools available to adequately address it. This lack of available tools has been described as a major barrier to the successful implementation of appropriate technologies and infrastructure projects [1,5,20–22].

Chapter 3: Baseline Assessment

This chapter investigated, piloted, and evaluated different paradigms, approaches, methodologies, and tools to determine if they would be suitable for use by engineers for capturing local context and to better inform infrastructure design and planning practices. The various tools were piloted in a case study where researchers completed a comprehensive assessment of the drinking water infrastructure in the community of Rigolet, Nunatsiavut (Labrador).

Research Findings

A number of different approaches and tools are identified that engineers and consultants could incorporate into their practice to better understand local context and improve the appropriateness of their designs in northern communities.

Importance of Paradigm or Worldview

The dominant engineering paradigm (or worldview) involves a reductionist approach, in which problems are broken down and simplified until they become manageable [23–25]. Engineers need to acknowledge that many of the challenges they face while working with communities, especially communities in the North, will be messy and complex and therefore will require a non-reductionist paradigm (i.e. Post Normal Science) and context-specific approaches to problem solving. The most effective way to develop place-based approaches is to better understand the local context by collecting information, both by conventional engineering means and by engaging with local community members and other non-conventional experts known as an "extended peer community". Engaging with an extended peer community is not a conventional approach for engineers; therefore, various tools were evaluated as part of this study to help engineers facilitate that engagement.

Different Tools Evaluated for Understanding Local Context

A baseline assessment, which is an established engineering tool, can be used to collect and organize in-depth information about an engineered system with the intent of identifying strengths, vulnerabilities, and opportunities for improvement [26]. A baseline assessment typically focuses solely on technological aspects of the system [26]. To conduct a comprehensive assessment of Rigolet's water infrastructure, additional data collection tools were needed for community engagement and the development of an extended peer community. These tools help broaden the scope of the baseline assessment by capturing social, political, and cultural information critical in understanding the local context. The tools piloted included site inspections [27], document reviews [28], key informant interviews [29], flow diagrams [26], focus group discussions [30], causal maps [31–33], community questionnaires [34], and community meetings [34]. Different strengths and weaknesses of the above tools were identified. For example, some tools (e.g. document reviews, site assessments, flow diagrams) were better suited for collecting or organizing technical or operating data, while others (e.g. interviews, focus groups, community events, questionnaires or causal maps) were more fitting for capturing social perspectives, preferences, or concerns. The most important factor for community engagement in this project was inclusion of a local community member as a member of the research team. This local community researcher, recruited and hired by the RIGC, filled an invaluable role in the development and testing of approaches and tools used in the research project, and provided important advice and feedback to ensure the project's engagement strategies, research methods, messaging, and approach were locally and culturally appropriate. The local community researcher ensured that the other members of the research team were aware of local conditions and facilitated timely and effective feedback to community members and local stakeholders.

Chapter 4: Constraints and Criteria

Due to an often high reliance on external expertise on infrastructure projects in remote Indigenous communities, there can be real or perceived decreased levels of transparency in the planning and decision making process, resulting in low levels of community engagement, ownership, and trust in infrastructure. This chapter explored ways to increase levels of transparency and the accountability of external consultants by adapting two existing engineering design tools – design constraints and criteria, as well as decision matrices – to establish a community driven decision-making tool. This tool incorporated an assortment of locally identified and culturally appropriate design priorities along with the necessary technical requirements identified by expert engineers and planners. This approach was piloted in collaboration with the community of Rigolet, and resulted in the co-development of a decision-making tool intended to assist in future community water-system infrastructure planning.

Main Findings

Seven constraints and ten criteria were identified through a process of literature and document review, and consultation with technical experts (including planners, engineers, academics, and government employees) and Rigolet community members. While participants generally believed that all 10 criteria were important for infrastructure planning, there was some variation as to which criteria were most important. Technical experts most commonly ranked 'local participation', 'local leadership', and 'simplicity' (in that order) as the most important criteria, whereas community members most often chose 'cost to community' followed by 'local participation'.

The constraints and criteria were incorporated into a decision analysis tool, known as a decision matrix, which is a common tool used by engineers to evaluate, rank, and select the most appropriate solutions for a given design problem [35]. The importance of the contributions and expertise of various technical experts is unquestionable. However, local governments can use the decision making tool during consultations with engineers and contractors to ensure that the design process reflects the context, needs, and priorities of the community. The decision making tool can also be used to create transparency and trust among community members by illuminating and documenting how community planning decisions are made.

STUDY LIMITATIONS

Inuit communities in the Nunatsiavut region and across the Circumpolar North are unique. Therefore, caution should be exercised when extrapolating specific findings to other Inuit communities. For example, the criteria and constraints, and especially the relative importance of different criteria, should not be presumed in other communities without consultation with local community.

The objectives of this thesis included developing approaches and tools to create more appropriate infrastructure plans for northern communities. Given the complexity of working in the North, the level of training of the author, and the cost associated with traveling to a remote community, the actual scope of this research needed to focus on depth rather than breadth. As a result, some important 'next steps' are needed and have been outlined in the following section.

NEXT STEPS

The following next steps are recommended: 1) conducting an infrastructure scenario planning activity with the Rigolet Inuit Community Government (RICG) to pilot the decision-making tool, 2) evaluation and expansion of the pilot planning activity to include other communities and infrastructure topics, and 3) consult with the Nunatsiavut Government to determine if this research could inform regional planning policy.

1) Conduct a Planning Activity with the RICG to Pilot the Decision Making Tool

While the topic of drinking water treatment infrastructure was used to develop the decision-making tools, the final tool was not tested. As such, it would be useful to test the tool on an actual infrastructure project to get the feedback of both technical practitioners and local stakeholders regarding the suitability of the tool and proposed approach. A planning activity with the RICG could be conducted using either a hypothetical or real infrastructure topic to evaluate the usefulness of the decision making tool.

Scenario Planning as an Appropriate Tool for Infrastructure Planning in the North

Previous research has suggested that traditional Inuit planning practices would focus on *"prepar[ing] for uncertainty rather than rigid planning for the future"* [48, p.92]. As Bates discusses: "*Inuit distaste for efforts to plan and predict may clash with the preoccupations of Western science, which is increasingly focused on management founded on prediction"* [48, p.93], and actually Inuit may believe that *"prediction, planning, and forecasting are impractical, foolhardy, and rather arrogant"* [48, p.91] . Therefore, when engaging with community leaders to discuss various infrastructure options, it may be more appropriate to consider an approach to planning and design that focuses on addressing and preparing for uncertainty.

Similar to traditional Inuit planning philosophies, literature from the disciplines of ecology and systems theory imply that it may be impossible to accurately predict the future states of a complex situation or system since it will be based on the function of history and uncertain future events. Considering this, conventional anticipatory planning techniques alone may not be appropriate [24]. Scenario planning and the creation of narratives may be a more appropriate approach [24]. Scenarios are "*a description of a possible future state of an organization's environment considering possible developments of relevant interdependent factors in this environment*" [34, p.32]. The development of these scenario narratives can be a collaborative process in which stakeholders and the extended peer community identify plausible future system states that include scientific knowledge, alternative forms of knowledge, culture, and local values

[24]. Scenario planning and the creation of narratives has been useful when there is a public call for an integrated source of accessible information and processes that build local awareness, capacity, support, and citizen engagement in the planning and decision-making processes [38]. Organizations have found scenario planning effective when addressing complex, uncertain topics, such as climate change adaptation [38,39], health priorities [40,41], global economic uncertainty [42], population growth [43], military planning [44], sustainable development [45,46], and water resource planning [47,48].

Use Decision-Making Tools to Develop Scenario Narratives

Consultants would first use the decision matrix to develop a list of plausible infrastructure options that satisfy all the constraints and score well based on the community identified design criteria. The list of plausible options becomes the basis for the creation of different narratives depicting different future states of the Rigolet water infrastructure system. Initially during the pilot stage, narratives could be developed in consultation with a broad range of Rigolet community members and expert communicators including Elders, storytellers, artists, and youth. This step would ensure that the narratives contain all the necessary components to help decision makers visualize how their choices will impact the future state of their community. For example, these narratives could include short stories of how different water users (i.e. Elders, youth, men, women, institutions, and businesses) would interact with various technologies if they were implemented. The narratives could also explore how the system would be able to withstand, or adapt to, different uncertainties, such as climate change, population growth/decline, increased business demand, increased regulations or changes in capital/operations funding formulas with the regional/provincial/federal governments. The narratives should also explicitly incorporate the various constraints and criteria in their descriptions, so that it is clear how the system options differ in these important factors. Once all the important components for infrastructure narratives are identified through the piloting process, consultants would likely be able to create the narratives with a shorter consultation step. The shortening of the consultation step would help streamline the narrative building process, making it more likely to fit into the timeline of a typical infrastructure project. The narratives describing the different infrastructure options would then be shared and discussed with local decision-makers, who would then choose the option that they believe is the most desirable and appropriate for their community.

2) Evaluate and Expand the Pilot Planning Activity

Next it is recommended to evaluate the Rigolet pilot project to determine if it is effective at identifying appropriate infrastructure options, and increasing the transparency and local trust of the planning process. Specific indicators need to be developed to assess the effectiveness of the proposed process. The proposed scenario development process can then be expanded to other Nunatsiavut communities and infrastructure topics (e.g. wastewater, housing, roads, solid waste management). This step will determine if the approach and tools are flexible and remain appropriate in a different planning context.

4) Informing Nunatsiavut Regional Planning Policies

After completing piloting and evaluation of the planning process in multiple contexts, the next step would be to work with the Nunatsiavut Government to help inform regional planning policies.

How Engineers and Researchers Can Use This Research

Any tool has two major functions: to simplify a task and increase the quality of the output. As an analogy, consider how a graduated garden trowel makes digging earth much easier than doing it by hand and also helps make uniform holes of the correct depth for planting seedlings. Following this analogy, the various tools explored in this research are intended to make it easier for engineers and consultants to engage with communities (Chapter 3); capture and incorporate local context (Chapter 3); help communities choose and develop the most appropriate infrastructure plan using locally appropriate constraints and criteria (Chapter 4); and make transparent decisions using a decision matrix (Chapter 4). These tools are part of a framework and, when used together, will facilitate community engagement, encourage consensus building, and lead to a more transparent infrastructure planning and design process, leading to increased trust and eventually more community ownership of the implemented infrastructure.

Chapter 3: Context Based Approaches to Problem Solving

All of the tools explored for capturing and understanding the local context do not need to be employed in every engineering project. Consultants and engineers should choose tools based on the recommendations presented in this thesis, the scope of the project, and through consultation with community leadership. Using a context-based approach to design can take more time than a conventional infrastructure planning process. This can pose a barrier for adoption by some engineers and consultants. However, much of the groundwork for this approach has been completed and the decision-making tools have been developed as part of this research. Engineers and planner can utilize the proposed approach and tools to initiate a more inclusive and context-based design and planning process within the scope of a typical infrastructure project.

Chapter 4: Constraints and Criteria and Decision Matrix

The establishment of constraints and criteria is an essential step in every engineering design, and should be part of every community infrastructure project. The process of identifying and validating constraints and criteria for remote northern communities starting from 'first principles' is a time consuming process, but it does not need to be repeated for every project. Although still in their first iteration, the tools developed during this research and presented in this thesis can be adopted and incorporated into infrastructure projects. Significant time and effort was spent as part of this project to ensure that the list of constraints and criteria were appropriate and robust for the northern context and were validated by a variety of experts and community members. For new projects, consultants may need to validate the tools for their particular project and locale, including discussing the constraints and criteria with community leaders, and adjusting the weights in the decision matrix based on community and project specific priorities.

RECOMMENDATIONS

Based on the results of this research, it is advised that when engaging with remote Indigenous communities, engineers and researchers should consider the following recommendations.

1. Understand the local context

Each community is different and engineers need to make genuine efforts to understand the unique community context. If traveling to the community for the first time, it is suggested that engineers spend a reasonable amount of time in the community and meet community members before 'putting on their hard hat'. Small communities value personal relationships and trust and therefore, the time spent is a valuable investment towards future success.

2. Make intentions explicitly clear from the beginning

Depending on the previous history, the community may be wary of strangers who might not have any previous history or experience with the northern environment; therefore, engineers and researchers should be prepared to take time to discuss their intentions for visiting the community in clear, plain language. Additional time and effort invested at the beginning of the process meeting with community members and stakeholders can result in huge time and financial savings at the end of the project. This approach can encourage community members to share their opinions and concerns, which will help the engineers and researchers understand the local context and also build trust and relationships with the community.

3. Build and utilize an extended peer community

Engaging with community members provides an important quality assurance step, but also engages users and increases transparency and local buy-in, leading to more appropriate and sustainable infrastructure designs.

4. Respect and incorporate Indigenous and local knowledge

Taking the time to discuss local and Indigenous knowledge will provide important contextual information about local preferences, concerns, and beliefs, and can also provide valuable information about past land use, snow drifting patterns, water drainage pathways, animal migration routes, hunting schedules, and observed environmental changes. As Berkes [49] stated: *"scholars have wasted ... too much time and effort on a science versus traditional knowledge debate; we should reframe it instead as a science and traditional knowledge dialog and partnership"* [46, p. 151].

5. Hire community members as local representative of the project

Community members are a great addition to a research or infrastructure team. They can help recruit fellow community members for engagement activities (i.e. focus groups or meetings), and ensure that any communication materials or messaging is locally appropriate. In addition, including community members early in the project helps build local capacity and contributes to the long-term sustainability of local projects. The community team member should be hired in partnership with the community partner, likely the local government. The community partner can typically help advise on the necessary qualifications and skillsets required for the position, create a job description, recruit, interview, select the individual(s), leaving the engineer or researcher to specify the individuals' required tasks.

6. Document and share successes and failures

Even though a number of technical, economic, and social challenges are involved in working in the North, there is a relatively small amount of literature that discusses those experiences. A small but growing number of consultants specialize in northern and cold region infrastructure design and who can benefit from the knowledge gained during infrastructure projects in the North.

CLOSING REMARKS

The Canadian North is an increasingly dynamic and complex region due to a number of factors, including increasing resource development, climatic change, Arctic sovereignty concerns, a young and rapidly growing Inuit population, Indigenous self-governance, and the transfer of authority to territorial, regional and community governments as part of the devolution process [50–52]. Engineered systems need to be designed for the specific user and the local context [2]. The required expertise of engineers is not in question, however, it is evident that a lack of appropriate planning and design methodologies and tools for engineers to understand and incorporate local context is becoming a major barrier to the successful implementation of new technologies and infrastructure in the North. It is also apparent that existing infrastructure planning and design practices are not sufficiently transparent and do not provide communities with adequate engagement, ownership and control. Projects are more likely to be sustainable with local ownership, increased management capacity, enhanced political cohesion, explicit socio-cultural respect, and adequate local skills [1–3,5,20,53]. As corporate and government expenditure on northern infrastructure continues to increase, it is in the best interest of all Canadians to support investment in the research and development of practical approaches and tools for appropriate infrastructure design in the North. Feedback from engineers, planners, academics, government employees, and community members, suggest that the work conducted in this research project will be a valuable contribution to many disciplines and will help enhance sustainable community development in the North.

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APPENDIX A – ASSESSMENT CHECKLIST

Source water

Source water protection

Sources of pollution? (list)
Source protection in place?
Source protection types? (e.g. fence)
Assessments for Cripto/Giardia?

Water quality

Testing schedule?
Raw water quality parameters Turbidity:
Colour:

Water quantity

Supply issues in the winter when bleeding is also happening and water quantity demand goes up?

Winter considerations

Do ice jams at dam cause flooding in pond?

Water Intake

Depth
Diameter
Length
Distance from bottom of source
Bank or bed intake? (see cold region monograph)
Is there an intake filter, where water passes through a pile of gravel before entering the inlet?
What size is the bar screen?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?
Lifespan?

Operational issues

Are there frazil ice problems (eg ice sticking to intakes or bar screens?)

Winter Issues

How thick is the ice above the inlet in the winter months?

Treatment/pumping plant

What is the capacity of the treatment system?
Chemical storage capacity? It is properly stored?
Is there adequate safety equipment?
Is there an operations manual?
Are there high voltage signs where necessary?
Are pipes labeled and colour coded?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?
Lifespan?

Generator

Is there a back up generator?
Is it tested regularly? (1/month)
How much fuel is available?
What is the contingency plan if the generator does not work?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?

Lifespan?

Chlorinator feed pumps
Are there back up pumps available?
Are they already installed inline?
Are there repair kits available for existing feed pumps?
Who would do the repairs if there were a pump failure?
What is the procedure if there is a failure?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?
Lifespan of equipment?

Main Process Pumps
How many pumps are there?
Are there backups?
Are there repair kits for pumps?
Who would do the repairs?
How long does it take to get repairs done or obtain spare parts?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?
Lifespan?
By Passes
Could there ever be a chlorine bypass?
What effect would it have?

Monitoring and Reporting
How are records kept? (paper, hardcopy, none)
Is there regular reporting required to the province, NG or the health authority?
What is recorded? Chlorine residuals? Turbidity?
What is reported? to whom? How often?
If there is an alarm/breakdown, how do you find out?
Is there a SCADA (supervisory control and data acquisition) system in place?
Are there back up personnel incase the primary operator is unavailable?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often does it need upgrades?

Building Security
Are there parameter fences?
Locks on the doors? Who has keys?
Any unauthorized access in past?
Ever any vandalism?

Building Operation
What is the general condition? Is it clean?
Could the door ever be accidently left open?
Is there a working phone in the building?
Age of Building?

Water Distribution System
What is the depth of the distribution pipes?
What is the diameter of the distribution pipes?
What is the material of the distribution pipes?
What is the frost depth?

Are there any known permafrost locations?
What is the age of the system?
When was the last time there was a major problem in the distribution system?
Are there any problems with: Pressure? Leaks? Freezing? Others?
Age of equipment?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service your equipment?
Lifespan?
Disinfection in the distribution system
Who is the first customer?
What is the residence time in the pipe before this customer at peak flows
What is the chlorine residual at first customer?
Where else is the chlorine residual tested?
How often is the chlorine residual tested?
What happens if the chlorine residual is found to be too low or too high?
Are there any chlorine booster stations in the distribution system?

Water storage tanks
How old are the tanks?
Lifespan?
Are the storage tanks insulated?
Does ice ever accumulate in the tanks?
Are there any cracks or leaks in the tanks?
Are there problems with birds or insects gaining access to the tanks?
Are there scheduled inspections of the tanks? How often? What is inspected?
Operation and maintenance costs?

Fire suppression system
Are there fire hydrants in the system?
Do any buildings have other fire suppression systems (e.g. sprinklers)?
Do you have problems with freezing or leaking of the hydrants?
Do you have problems with vandalism or tampering with the hydrants?
If a fire is being fought, how does it impact the drinking water? Is a BWA issued?
Are there regular flushing of the hydrants?
How old are the hydrants?
Lifespan?
Operation and maintenance costs?
How often do you have to service the hydrants?

Water system in homes and other buildings
Do people have to do anything to adjust the water as it enters the house? (pressure reduction?)
Do people complain about the tap water quality?
What do you tell them?
Do you think people understand why you have to add chlorine to the water?
Are drains connected to the storm sewers?
Depth, diameter of pipes?
Special proximity to Potable water?
Leakage Problems?
Infiltration?
How old are the pipes, storm sewers, etc?
Operation and maintenance costs to homeowners?
How often do you have to service the pipes?
Lifespan of pipes?

Wastewater collection system and pumping lift stations
Are there Manholes?
Sampling point?
How often cleaned out?
Duplicate pumps?
Duplicate chambers?

Sloped drain floor?
Check valves?
Age of pumps, check valves, etc?
Reliability of equipment?
Operation and maintenance costs?
How often do you have to service the equipment?
Lifespan?
Location and protection of pump control system
Any connection with potable water lines (cleaning, lubrication, cooling)
Safety related issues
Is it a Confined space?
Is there Proper ventilation?
Are there Proper procedures for maintenance and replacements?

Wastewater outfall
Wastewater volumetric and mass flow rates?
Diameter of pipe
Length and depth of pipe?
Signage if within 100m from shore?
Age of pipe?
Reliability of pipe?
Operation and maintenance costs?
How often do you have to service it?
Lifespan?
Are there any freezing problems?
Are there clogging problems?
What concerns (if any) do residents have?
Are there any plans for upgrades?

Receiving environment
Any monitoring?
What is the dilution ratio?

Training ***- Have you taken formal training on any of the following topics?***
Overview of Northern Small Water Systems
Small Water System Standards/Regulations
Surface Water Treatment
Groundwater Treatment
Small Water System Disinfection
Hypochlorination
Roles and Responsibilities (Managerial, Operator)
Financial Considerations
Wellhead Protection
Source Water Protection
Monitoring
Sampling and Testing
Emergency Preparedness
Water Storage Tanks
Distribution Systems
Inspecting a Pump Station
Electrical Controls
Any other training you would like to task?

Question about financial operations
Costs associated with current water/wastewater management
Did any equipment have really big transportation costs at time of purchase?
Is there any income from water/wastewater services (from taxes, etc.)?
Are there any other sources of income that go to the water/wastewater systems?
Who is in charge of making financial decisions about the water system?
What process, if any, is undertaken to come to a financial decision?

Financial planning: ***Are there funds set aside for or future plans for*:**
The building service connections?
Water mains?
Sewer mains?
Operation and maintenance?
Training?
Source water protection?
Field investigations?
Monitoring?
Emergency planning?
Surveillance of water-borne disease outbreaks?

APPENDIX B – FOCUS GROUP LINE OF QUESTIONING

Rigolet Community Focus Group Guide

Pre-Amble

In the past, you have probably spoken with Sherilee Harper, Marilyn and Inez or somebody else about water in Rigolet. From the research we have done already, and from just talking with folks, we know than many Rigolet like to drink brook water when they go out on the land, going hunting, trapping or visiting their cabins. We would really like to learn more about drinking brook water while out on the land. You have all been invited to this meeting you are all (trappers/hunters/youth/cabin goers) and we consider you experts. We are hoping that by learning more about brook water on the land, maybe we can use this information and knowledge to help design better drinking water systems for the town. Everything you say it totally confidential, and nobodies name will be on anything. (The other facilitator) and I are also going to be writing down some things on sticky notes as we go, and this will help us bring all of our ideas together at the end, and you will get a chance to give us feedback on it before we leave today.

Opening Questions

1. Just to get things going, I was wondering if we could all go around the table to share something about ourselves. How about you tell us about the last time that you were out on the land hunting/trapping/at a cabin. I will go first. The last time I was out on the land …

(Quick round table introductions – approximately 5 minutes each encourage everyone to speak to set an open and participatory tone)

2. Since we're not from here, we were hoping that you could tell us about where you get drinking water when you are out on the land?

Transition Question: What is good water?

3.When you are out on the land, what is it about the water that makes it so good?

Prompts:	Clarity	Colour	Taste	Smell
	Location of source	Tradition of source	Trust of source	

Key Questions: Choosing good water

4. Walk me through the steps of finding food brook water. What if you had to teach me, or a family member how to pick good water on the land? What would you tell them?

Prompts:	Sign of good/bad source	Do you have a set of rules for picking a source?

5. What things do you look for to be sure water is safe for drinking? What makes water unsafe? (May be some repetition from Question.4.)

6. Is there anything that can make a water source turn bad? (Prompts: rains, erosion, development, contamination)

7. When your water changes on you (because of Q6 answers), what does it do to you? Does it change your life in any way? Does it create other problems? (Prompts: Health, well being, culture, financial situation)

That was my last question. Do you have any comments to add, or were there questions you thought I would ask and didn't? Are there any important points or topics that didn't come up in our conversation?

Next step:

Assemble post-it notes on white paper, and build causal maps with participants

APPENDIX C – COMMUNITY WATER QUESTIONNAIRE

2013 Rigolet Adult (18+) Water Questionnaire, May-June 2013

1. This survey is only for adult community members to fill out. Administrator, is this person an adult (18+)?
2. Is the participant male or female?
3. What is the house number?
4. How old are you?

The following questions are about Boil Water Advisories in Rigolet.

5. How often do you feel that Rigolet is under a Boil Water Advisory?

Never
Almost Never
Sometimes
Almost Always
Always
Don't know
Refused to answer

6. Where do you usually get information about Boil Water Advisories in Rigolet? Select all that apply.

a Radio
b Clinic
c Friends, Family, or Neighbours - Word-of-Mouth
d Council office
e Facebook
f Notices
g Don't know
h Other (specify):
i Refuse to answer

7. Do you usually follow Boil Water Advisories? (e.g. you boil your water at a rolling boil for 1 minute)

Yes
No
Don’t Know
Refuse to Answer

8. Why do you usually follow Boil Water Advisories? (if answered Yes to #7)

9. Why don't you usually follow Boil Water Advisories (if answered no to #7?)

10. How do you feel when Rigolet is under a Boil Water Advisory?

Not concerned
Somewhat not concerned
Neutral
Somewhat concerned
Concerned
Don't know
Refused to answer

The following questions are about tap water in Rigolet

11. How important is it that Rigolet tap water...

		Not important	Slightly not important	Neutral	Slightly important	Important	Don't Know	Refuse to answer
a	Has good taste							
b	Has good smell							
c	Has the right colour							
d	Has the right							

	clarity/cloudiness							

12. Please rate the quality of Rigolet tap water for the following...

		Very poor	Poor	Fair	Good	Excellent	Don't Know	Refuse to answer
a	Taste							
b	Smell							
c	colour							
d	Clarity/cloudiness							
e	Safety for you to drink							

13. How is the quality of Rigolet tap water for the following uses?

		Very poor	Poor	Fair	Good	Excellent	Don't Know	Refuse to answer
a	Drinking							
b	Bathing/Showering							
c	Cooking							
d	Doing Laundry							
e	Food Preparation							
f	House Cleaning							
g	Making Tea							
h	Flushing Toilets							

Other communities say they have problems with their drinking water systems. I am going to ask you questions to see whether or not Rigolet has any of the same issues

14. Tell me how you feel about the following in Rigolet tap water...

		Not concerned	Slightly concerned	Somewhat concerned	Concerned	Extremely concerned	Don't Know	Refuse to answer
a	Chemicals or Pollutants like PCBs left over from the military							
b	Chlorination By- Products like THMs or HAAs							
c	Germs / Bacteria							
d	Colour							
e	Smell							
f	Mercury, Lead or other minerals							
g	Taste							
h	Clarity/Cloudiness							
i	Chlorine							

15. How do you think chlorine in tap water impacts your health?

Positive health impact
Positive and Negative health impact
Negative health impact
Don't know
Refused to answer
It does not impact my health

16. How do you feel about the following...

		Not concerned	Slightly concerned	Somewhat concerned	Concerned	Extremely concerned	Don't Know	Refuse to answer
a	Quality of water in the lake							
b	Tap water treatment							
c	Condition of the Underground water pipes							
d	Results of tap water tests							
e	Cost of running the water treatment plant							

17. Do you think you, or anyone in your family has got sick from drinking water from...

		Yes	No	Don't Know	Refuse to answer
a	Rigolet tap water	30%	52%	17%	0%
b	Brook water from around town	2%	90%	9%	0%
c	Bottled water	0%	94%	6%	0%
d	Store water	1%	94%	5%	0%
e	Brook water from your cabin	1%	91%	8%	0%

18. How often do you use the following sources for drinking water in your home?

		Never	Rarely	Sometimes	Often	Always	Don't Know	Refuse to answer
a	Water straight from your tap (not treated with anything else)							
b	Tap water treated with a Brita jug filter, tap mounted filters, boiling or other							
c	Bottled water (e.g. Desani, Evian, Aquafina, or mineral water)							
d	Store water (filtered water from Northern)							
e	UNTREATED water collected from brooks							
F	TREATED (Brita, Boiled etc.) water from brooks							

19. Do you use a Brita filter in your home?

Yes
No
Don’t Know
Refuse to Answer

20. How often do you usually change the Brita filter? (Only answered by those who answered yes to #19)

Once a Year
Twice a year
Once every 2 months
Once a month
Once a week
Don't know
Other (specify)
Refuse to answer
Never change the filter

21. What are the reasons you use a Brita? (Only answered by those who answered yes to #19)

		Yes	No	Don't Know	Refuse to answer
a	Improve Taste				
b	Improve Smell				
c	Reduces Germs /Bacteria				
d	Reduces Mercury, Lead or other minerals				
e	Reduces chemicals like PCBs in the water				
f	Reduces Chlorine By-products like THMs or HAAs				
g	Reduces the Cloudiness of the water				
h	Reduces the colour of the water				
i	Reduces Hardness of the water				
j	It is cheaper than bottled/store water				

Note to administrator: please take out the glass to show to the participant

22. How many glasses of TAP water do you drink in a normal day?

None
1 to 2 glasses
3 to 4 glasses
5 to 6 glasses
More than 6 glasses
Don't Know

Refuse to Answer

The following questions are about bottled water and filtered water that you can buy from the Northern store.

23. Do you ever drink bottled water or water from the store?

Yes
No
Don’t Know
Refuse to Answer

24. How many glasses of bottled water or water from the store do you drink in a normal day? (Only asked to those who answered yes to Q#23)

None
1 to 2 glasses
3 to 4 glasses
5 to 6 glasses
More than 6 glasses
Don't Know
Refuse to Answer

25. What are the reasons you drink bottled water or water from the store? (Only asked to those who answered yes to Q#23)

		Yes	No	Unsure	Don't Know	Refuse to answer
a	Improve Taste					
b	Improve Smell					
c	Reduces Germs / Bacteria					
d	Reduces Mercury, Lead or other metals					
e	Reduces chemicals like PCBs in the water					
f	Reduces Chlorine By-products like THMs or HAAs					
g	Reduces the Cloudiness of the water					
h	Reduces the colour of the water					
i	Reduces Hardness of the water					
j	Better safety testing of the bottled water					
k	Convenience of bottled water					
l	Bottles are a more trusted source of drinking water					

The following questions are about drinking BROOK water while in town. The questions are NOT about drinking brook water at your cabin or while out on the land

26. Do you ever drink Brook water at home? This could be water collected from local brooks or brought back from your cabin.

Yes
No
Don’t Know
Refuse to Answer

27. Do you treat the Brook water before drinking it at home (e.g. Brita, boiling, filtering)? (only asked to those who answered Yes to Q#26).

Yes (Specify)
No
Don’t Know
Refuse to Answer

28. How many glasses of Brook water do you drink in a normal day? (only asked to those who answered Yes to Q#26).

None
1 to 2 glasses
3 to 4 glasses

5 to 6 glasses
More than 6 glasses
Don't Know
Refuse to Answer

29. Why do you drink brook water at home? (only asked to those who answered Yes to Q#26).

		Yes	No	Don't Know	Refuse to answer
a	Improved Taste				
b	Improved Smell				
c	Reduced Germs / Bacteria				
d	Reduced Mercury, Lead or other metals				
e	Reduced chemicals like PCBs in the water				
f	Reduced Chlorine By-products like THMs or HAAs				
g	Reduced the Cloudiness of the water				
h	Reduced the colour of the water				
i	More natural water source				
j	More trusted water source than tap water				
k	More trusted water source than bottled water				
l	Cheaper than bottled water				
m	More environmentally friendly than bottled water				

30. How do you normally store brook water at home? Select all that apply. (only asked to those who answered Yes to Q#26).

a	In water cooler jugs
b	In small containers
c	In buckets
d	Other (specify)
e	Don't Know
f	Refuse to answer

31. Where do you normally store brook water at home? Select all that apply. (only asked to those who answered Yes to Q#26)

a	In the refrigerator
b	On the counter
c	Outside
d	In a water cooler
e	Under the house
f	In a shed
g	In the porch
h	On the step
i	Other (specify)
j	Don't Know
k	Refuse to answer

32. How much money do you normally spend on drinking water each week?

		$0	$1-10	$11-25	$25-40	$41-60	$61-75	Over $75	Don't Know	Refuse to answer
a	Money Spent on bottled water (e.g. Desani, Evian, Aquafina, or mineral water)									
b	Money Spent on filtered water from Northern									
c	Money spent on fuel getting brook water									

33. How important is it that you get more information on the following...

		Not important	Somewhat important	Important	Don't Know	Refuse to answer
a	The quality of the water in the lake					
b	How the tap water is treated					
c	Condition of underground water pipes					
d	Results of tap water tests					
e	Chlorine By- Products (THMs, HAAs)					
f	Quality of local brook water					
g	Quality of alternatives to the lake					

The survey is almost done! There are just have a few more questions

34. What is the best way for Rigolet make a long term plan for its drinking water system to ensure we have good and safe water in the future? Select all that apply.

a	Hold community meetings and ask residents what they want
b	Have small focus group discussions
c	Organizers should go to peoples' homes to talk about it
d	Create digital stories about drinking water and what makes good water
e	Work together with university researchers and other experts
f	Don't Know
g	Refuse to Answer
h	Other (specify)

35. What could you do to help make a long term drinking water plan in Rigolet?

		Yes	No	Maybe	Don't Know	Refuse to answer
a	I could be on the planning committee					
b	I could help PLAN community events					
c	I could GO to community meetings					
d	I could go to focus group discussions					
e	I could help set up / clean up after community events					
f	I could prepare some snacks or meals for a community meeting					
g	I could babysit so other adults could participate					
h	I could share stories with people about water					
i	I could make a digital story					
j	I could help build or construct different treatment options for testing					

The survey is complete! Thanks so much for participating

APPENDIX D – EXPERT INTERVIEW GUIDE

(Date)

RE: Expert opinion requested for "Envisioning water and wastewater treatment & management through a community-driven process" research project

Dear *(Expert's Name)*,

I would like to warmly invite you to participate in a private and confidential telephone interview on the topic of the infrastructure planning, design and operation in remote northern communities. The telephone interview would last approximately 45-60 minutes.

As you are aware, remote northern communities have unique geographical, financial, cultural and capacity challenges for engineers, planners and operators when it comes to water infrastructure. In this research project we are investigating ways to increase the levels of community engagement in the planning, design and operation of infrastructure in remote communities to help overcome these challenges. You have been identified as someone with considerable experience in this area.

The goal of this initial phase of the research project is to develop a list of general design requirements that all infrastructure projects should consider at the planning and design stages, specifically for drinking water treatment storage and distribution in remote communities. Based on some preliminary research, we have developed a draft list of general design requirements and we were hoping to get your expert feedback.

I will be contacting you again in a few days to ask if you would be interested in participating. Thank you for taking the time to consider this request. If you decide to participate, I can send you the draft list of general design requirements in advance, so you have a chance to read it over before the interview.

Should you have any questions about this initiative, or would like to confirm your participation, please do not hesitate to contact me by email or telephone as provided below.

Kindest regards,

(Signature)

Allan Gordon, P.Eng.
MASc. Candidate
School of Engineering
University of Guelph
Guelph, Ontario, Canada N1G 2W1

INTERVIEW INFORMATION SHEET

TITLE: Envisioning Water and Wastewater Treatment & Management Through a Community-driven Process
SPONSOR: The Canadian Water Network

You have been invited to take part in an interview for a research study. Taking part in this interview is voluntary. It is up to you to decide whether to do the interview or not. If you decide to take part, you are free to stop the interview at any time. Before you decide, you need to understand what the study is for, what risks you might take and what benefits you might receive. This form explains the study. Please read this carefully. Take as much time as you like. Mark anything you do not understand or want explained better. The researcher will discuss the study with you, answer your questions, keep confidential any information that could identify you, and be available during the study to answer questions.

If you have any questions or concerns about the research, please feel free to contact either

Allan Gordon, P.Eng.	**Dr. Khosrow Farahbakhsh, P.Eng.**
MASc. Candidate	Associate Professor
School of Engineering	School of Engineering
University of Guelph	University of Guelph
(*phone number*)	(*phone number*)
(*email address*)	(*email address*)

INTRODUCTION/BACKGROUND

The project intends to support remote Aboriginal communities in exploring and developing community-driven approaches and methodologies for community development, particularly water and wastewater systems. We are interested in developing a list of general design considerations that all infrastructure projects should consider at the planning and design stages. The research team has already generated a preliminary list, and based on your experience and expertise, we were hoping to get your feedback.

DESCRIPTION OF INTERVIEW

If you volunteer to participate in this study, we would ask you to participate in an interview. The interview will take about 1 hour and you will be asked to answer questions to get your feedback on a preliminary list of design considerations, which we have already generated. If you wish, the list can be sent to you in advance by email to give you a chance to review it before the interview takes place.

POTENTIAL RISKS AND BENEFITS

We do not foresee any risks associated with this interview. It is not known whether this study will, benefit you. We will offer to share the results of our research with you. Project outcomes will be used to assist communities in taking a more active and meaningful role in the physical development of their communities.

WHAT ABOUT MY PRIVACY AND CONFIDENTIALITY?

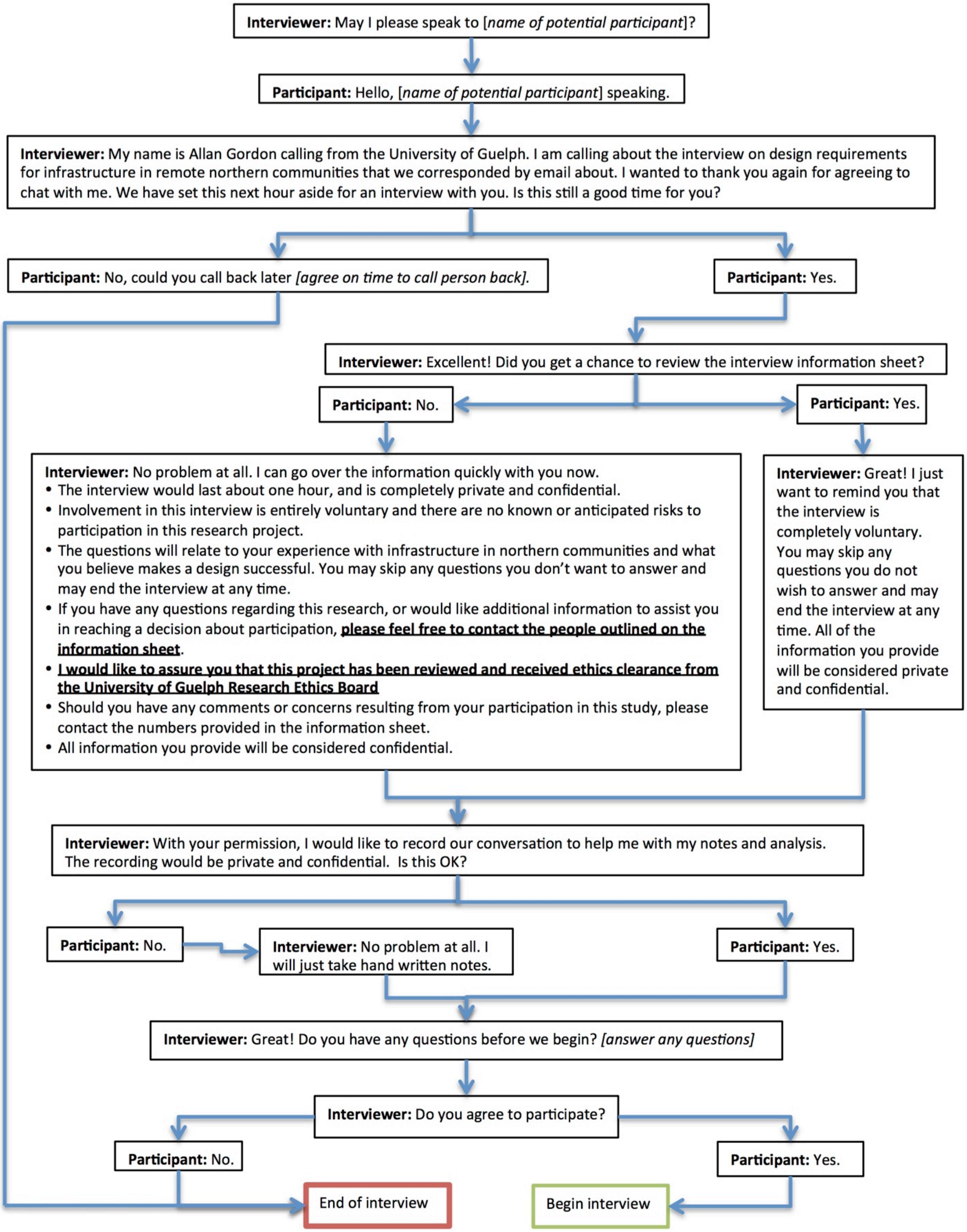
Protecting your privacy is an important part of this study. Your name and contact information will be kept secure and will not be shared with others. Your name will not appear in any report or article published. The information collected will be kept for 5 years and will only be used for the purposes of this study. If you decide to withdraw from the study, the information collected up to that time will be destroyed.

QUESTIONS?

If you have questions about participating, you can also talk to someone who is not involved with the study:

Research Ethics Coordinator
University of Guelph, 437 University Centre
Guelph, ON N1G 2W1
(*email address*)
(*phone number*)

Interview Consent Script



Interviewer: May I please speak to [*name of potential participant*]?

Participant: Hello, [*name of potential participant*] speaking.

Interviewer: My name is Allan Gordon calling from the University of Guelph. I am calling about the interview on design requirements for infrastructure in remote northern communities that we corresponded by email about. I wanted to thank you again for agreeing to chat with me. We have set this next hour aside for an interview with you. Is this still a good time for you?

Participant: No, could you call back later *[agree on time to call person back].*

Participant: Yes.

Interviewer: Excellent! Did you get a chance to review the interview information sheet?

Participant: No.

Participant: Yes.

Interviewer: No problem at all. I can go over the information quickly with you now.

- The interview would last about one hour, and is completely private and confidential.
- Involvement in this interview is entirely voluntary and there are no known or anticipated risks to participation in this research project.
- The questions will relate to your experience with infrastructure in northern communities and what you believe makes a design successful. You may skip any questions you don't want to answer and may end the interview at any time.
- If you have any questions regarding this research, or would like additional information to assist you in reaching a decision about participation, **please feel free to contact the people outlined on the information sheet**.
- **I would like to assure you that this project has been reviewed and received ethics clearance from the University of Guelph Research Ethics Board**
- Should you have any comments or concerns resulting from your participation in this study, please contact the numbers provided in the information sheet.
- All information you provide will be considered confidential.

Interviewer: Great! I just want to remind you that the interview is completely voluntary. You may skip any questions you do not wish to answer and may end the interview at any time. All of the information you provide will be considered private and confidential.

Interviewer: With your permission, I would like to record our conversation to help me with my notes and analysis. The recording would be private and confidential. Is this OK?

Participant: No.

Interviewer: No problem at all. I will just take hand written notes.

Participant: Yes.

Interviewer: Great! Do you have any questions before we begin? *[answer any questions]*

Interviewer: Do you agree to participate?

Participant: No.

Participant: Yes.

End of interview

Begin interview

EXPERT INTERVIEW QUESTIONS

(To be completed after the consent script)

Building the Rapport: the Interviewee Background

1. So can you tell me a bit about what you do and your experience with northern infrastructure?

2. In your experience, what are the typical causes of infrastructure failure in remote northern communities? (Ask them to define project failure)
Prompts:

- ☐ Technical
- ☐ Over designed (too complex)
- ☐ Not appropriate for source water
- ☐ Not accepted by community
- ☐ Specific points of failure (e.g. curb stops)
- ☐ Problems with operator(s) (e.g capacity)

3.In you experience, what factors can cause infrastructure to be successful in a remote northern community? (Ask them to define project success)

Feedback on Design Requirements Table

Explain Design Requirements, Constraints and Criteria. Indicate that Rigolet has been used as an example in the sheet they have.

4. What do you think of the constraints and criteria that I identified in this list? Do you agree, disagree with any of them? Are there any that you think I should be adding or removing?

5. Would you change the definition of any of them from what I have there?

6. Would you change the indicator or metrics that you use to measure these constraints or criteria?

7. Which constraints or criteria are most important to consider in your job? How would you rank the criteria shown in the table from most important to least important? What would you say are the top 5 criteria?

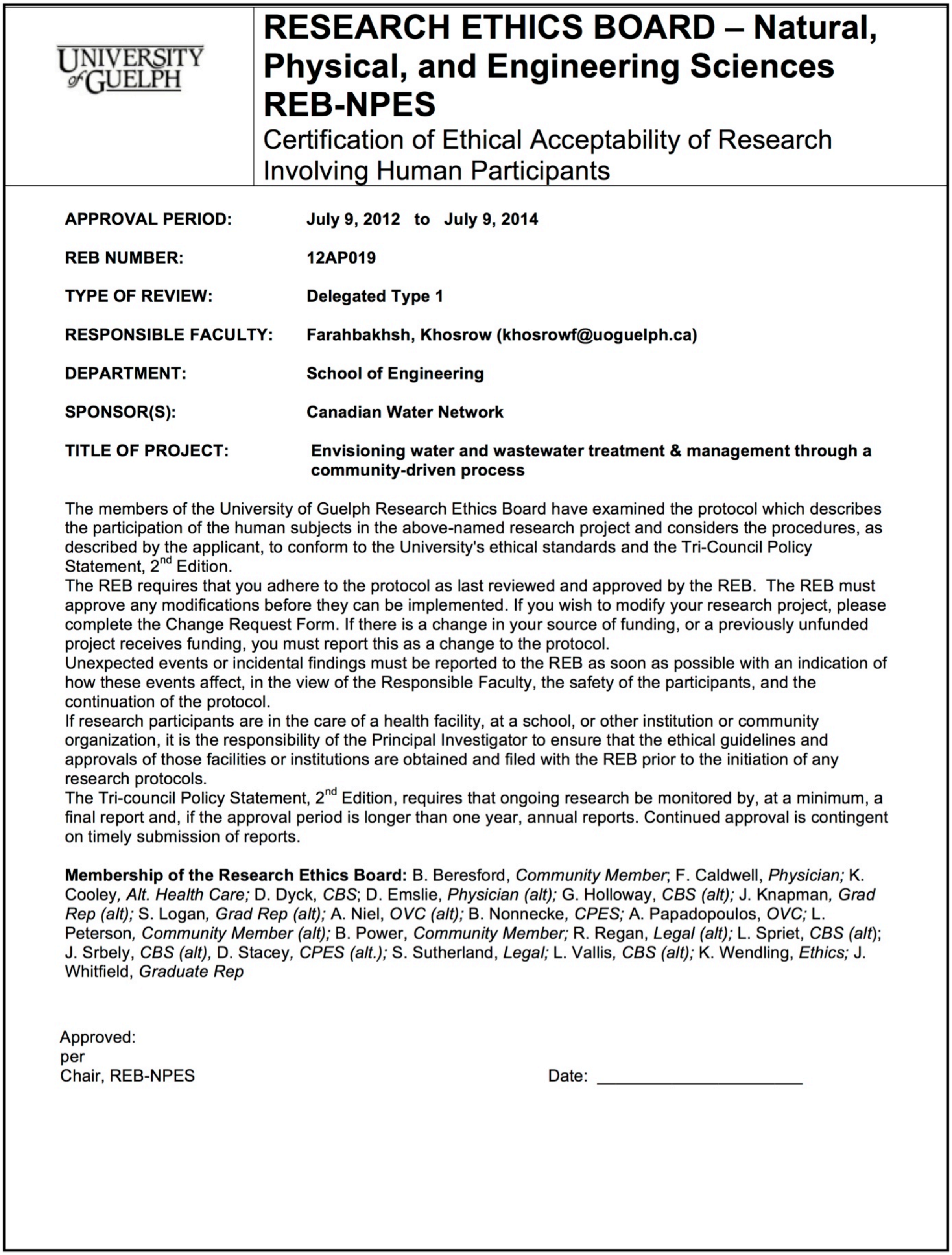
8. Are there any factors that you think should be given more consideration and are not?

9. Are there any particular guidelines or best practices that you recommend I review that you find helpful in your job? Are there any codes or standards (i.e. building codes, plumbing codes), that you find limit your ability to be innovative?

10. *Describe Rigolet.* What treatment technology would you recommend? Why? Do you have example of similar communities I should check out as examples?

That was my last question. Do you have any questions or comments that you would like to add?

APPENDIX E – GUELPH RESEARCH ETHICS BOARD APPROVAL



UNIVERSITY of GUELPH

RESEARCH ETHICS BOARD – Natural, Physical, and Engineering Sciences REB-NPES

Certification of Ethical Acceptability of Research Involving Human Participants

APPROVAL PERIOD:	**July 9, 2012 to July 9, 2014**
REB NUMBER:	**12AP019**
TYPE OF REVIEW:	**Delegated Type 1**
RESPONSIBLE FACULTY:	**Farahbakhsh, Khosrow (khosrowf@uoguelph.ca)**
DEPARTMENT:	**School of Engineering**
SPONSOR(S):	**Canadian Water Network**
TITLE OF PROJECT:	**Envisioning water and wastewater treatment & management through a community-driven process**

The members of the University of Guelph Research Ethics Board have examined the protocol which describes the participation of the human subjects in the above-named research project and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement, 2nd Edition.

The REB requires that you adhere to the protocol as last reviewed and approved by the REB. The REB must approve any modifications before they can be implemented. If you wish to modify your research project, please complete the Change Request Form. If there is a change in your source of funding, or a previously unfunded project receives funding, you must report this as a change to the protocol.

Unexpected events or incidental findings must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Responsible Faculty, the safety of the participants, and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and approvals of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-council Policy Statement, 2nd Edition, requires that ongoing research be monitored by, at a minimum, a final report and, if the approval period is longer than one year, annual reports. Continued approval is contingent on timely submission of reports.

Membership of the Research Ethics Board: B. Beresford, *Community Member*; F. Caldwell, *Physician;* K. Cooley*, Alt. Health Care;* D. Dyck, *CBS*; D. Emslie, *Physician (alt);* G. Holloway, *CBS (alt);* J. Knapman*, Grad Rep (alt);* S. Logan*, Grad Rep (alt);* A. Niel, *OVC (alt);* B. Nonnecke*, CPES;* A. Papadopoulos, *OVC;* L. Peterson*, Community Member (alt);* B. Power, *Community Member;* R. Regan, *Legal (alt);* L. Spriet, *CBS (alt*); J. Srbely, *CBS (alt),* D. Stacey*, CPES (alt.);* S. Sutherland, *Legal;* L. Vallis*, CBS (alt);* K. Wendling, *Ethics;* J. Whitfield, *Graduate Rep*

Approved:
per
Chair, REB-NPES

Date: ____________________

APPENDIX F –EXAMPLE COMPLETION OF A DECISION MATRIX

The example decision matrix shown below is demonstrating how a community governments and consultants may evaluate different drinking water infrastructure options. This example shows three different options being considered (design options #1,#2,#3). In this example, Design Options #1 and #2 met all the constraints, but #3 failed to meet the accessibility constraint. As shown in this example, if any options fails any of the constraints, its consideration as a possible design solution is withdrawn.

If a design option passes the required constraints, the decision maker(s) move onto the bottom design criteria portion of the decision matrix.

In the design criteria portion of the matrix, all the criteria are in the left column and have been assigned a relative importance or 'weight' based on feedback from technical experts and Rigolet community members. The weight of each criterion may need to be adjusted as priorities change, or as criteria are added and removed from project to project. However, the sum of all the criteria weights must always add up to 100, ensuring that the importance of each criterion remains relative, and the user recognizes the inherent tradeoffs that must take place when ranking criteria or making decisions. Once the weights are assigned, the user evaluates each remaining design option by ranking each of the criteria from 0 to 4, where 4 is considered 'very good', 3 is 'good', 2 is 'neither good nor poor', 1 is 'poor', and 0 is 'inadequate or unacceptable'. Each criterion 'score' is determined by multiplying the rank by the weight. The total score for each design option is determined by adding up all the scores along the column. In this example, design option #2 scored slightly higher than design option #1. Therefore option #2 should be considered as the best choice for the community

Example decision matrix completion for the ranking of three different options for a piece of water treatment infrastructure

DESIGN CONSTRAINTS	**Design Option #1**		**Design Option #2**		**Design Option #3**	
	Pass ☑	*Fail* ☑	*Pass* ☑	*Fail* ☑	*Pass* ☑	*Fail* ☑
Climatic	☑	☐	☑	☐	☑	☐
Site Assessment	☑	☐	☑	☐	☑	☐
Regulatory	☑	☐	☑	☐	☑	☐
Energy	☑	☐	☑	☐	☑	☐
Affordability	☑	☐	☑	☐	☑	☐
Accessibility	☑	☐	☑	☐	☐	☒
Availability	☑	☐	☑	☐	☑	☐

DESIGN CRITERIA	**Locally Assigned Criteria Weight**	***Suggested Criteria Weight Range[1]***	**Design Option #1**		**Design Option #2**		**Design Option #3**	
			Rank[2] *(Assign# 0-4)*	Score *(Rank x Weight)*	Rank[2] *(Assign # 0-4)*	Score *(Rank x Weight)*	Rank[2] *(Assign # 0-4)*	Score *(Rank x Weight)*
Affordability	25	*20-25*	2	50	3	75	✗	✗
Time to Construct	2.5	*0-5*	2	5	1	2.5	✗	✗
Robustness	10	*10-20*	2	20	3	30	✗	✗
Simplicity	25	*15-25*	3	75	3	75	✗	✗
Consistency/Reputation of Vendor	5	*0-10*	2	10	1	5	✗	✗
Environmental Impact	5	*10-20*	4	20	4	20	✗	✗
Use of Local Resources	10	*10-20*	3	30	4	40	✗	✗
Local Participation	10	*10-20*	3	30	3	30	✗	✗
Additional Project Specific Criteria #1: Quality of Drinking Water Produced	10	*10-20*	3	30	3	30	✗	✗
Additional Project Specific Criteria #2: *BLANK*	*n/a*	*10-20*	-	-	-	-	-	-
Note: Sum of assigned weights must be equal to 100								
TOTAL SCORE *(Sum of all scores for each design option)*				**270**		**277.5**		✗
FINAL RANK *(Identify design option with highest score)*				**#2**		**#1**		

1. The suggested range for criteria weighting is based on general infrastructure priorities identified by Rigolet residents and technical experts in Winter 2013-2014.

2. When ranking individual design options; 4 is considered 'very good', 3 is 'good', 2 is 'neither good nor poor', 1 is 'poor', and 0 is 'inadequate or unacceptable.

APPENDIX G – PROJECT STAKEHOLDERS

List of Stakeholders and Their Role in the "*Tools and Strategies to Address Uncertainties and Complexities of Infrastructure Design in Remote Northern Canadian Communities*" Project

Stakeholders	Inform Project Proposal	Inform Research Design	Project Management	Data Collection	Data Analysis	Results Sharing	Likely to Inform Policy Changes	Project Funding
Project Management Team[1]	⊙	⊙	•	•	⊙	⊙		
Rigolet Inuit Community Government[2]	•	•				•	⊙	
Community Researcher		⊙	⊙	⊙	•	⊙		
Rigolet Community Members	•	⊙		⊙		•		
Researcher			⊙	⊙	⊙			
Provincial Government[3]	•	•					•	
Nunatsiavut Government[4]	•	•					⊙	
Technical, Government and Academic Experts				⊙				
Canadian Water Network							•	•
Aboriginal Affairs and Northern Development Canada							•	•
Canadian Institutes of Health Research (IK-ADAPT)[5]								⊙
Tri-Councils and International Development Research Center (IHACC)[6]								•

• Indicates that the stakeholder provided important support in this role

⊙ Indictates that the stakeholder provided substantial support in this role

1 Rigolet AngajukKak (Mayor), Rigolet Town Managers, University of Guelph Faculty Members and Graduate Students

2 Rigolet Council, Public Works staff

3 Labrador Grenfell Health Authority and/or Newfoundland and Labrador Department of Environment and Conservation and/or Newfound and Labrador Department of Municipal Affairs and Housing

4 Nunatsiavut Government's *SakKijânginnatuk Nunalik* (Sustainable Communities) Initiative and/or Nunatsiavut Government Department of Health and Social Development

5 Research project that provided direct financial support (www.ikadapt.ca)

6 Research project that provided in-kind support (www.ihacc.ca)