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Water safety plans as a tool for drinking water regulatory frameworks in Arctic communities

Kaycie Lane[1] · Amina K. Stoddart[1] · Graham A. Gagnon[1]

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Abstract Arctic communities often face drinking water supply challenges that are unique to their location. Consequently, conventional drinking water regulatory strategies often do not meet the needs of these communities. A literature review of Arctic jurisdictions was conducted to evaluate the current water management approaches and how these techniques could be applied to the territory of Nunavut in Canada. The countries included are all members of the Arctic Council and other Canadian jurisdictions considered important to the understanding of water management for Northern Canadian communities. The communities in Nunavut face many challenges in delivering safe water to customers due to remoteness, small community size and therefore staffing constraints, lack of guidelines and monitoring procedures specific to Nunavut, and water treatment and distribution systems that are vastly different than those used in southern communities. Water safety plans were explored as an alternative to water quality regulations as recent case studies have demonstrated the utility of this risk management tool, especially in the context of small communities. Iceland and Alberta both currently have regulated water safety plans (WSPs) and were examined to understand shortcomings and benefits if WSPs were to be applied as a possible strategy in Nunavut. Finally, this study discusses specific considerations that are necessary should a WSP approach be applied in Nunavut.

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✉ Graham A. Gagnon
graham.gagnon@dal.ca

[1] Department of Civil & Resource Engineering, Dalhousie University, Halifax, NS B3J 1Z1, Canada

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Introduction

Meeting current drinking water regulations has proved a major challenge, particularly for Arctic communities, such as the communities located in Nunavut. In the capital of Iqaluit, a traditional piped distribution system is in use, facilitated by the use of a utilidor system for maintaining an acceptable temperature in pipes that would otherwise freeze. However, in most communities in Nunavut, water is delivered by hauling trucks rather than conventional piped methods, a system for which few guidelines have been developed nationally (Health Canada 2014). A map of the communities present in the territory of Nunavut is provided for reference purposes (Fig. 1).

The current approach in the water industry relies heavily on the use of water quality guidelines, specifying parameters to be measured and compared to acceptable concentration levels at the end of a treatment train in a drinking water supply system (Baum et al. 2015). However, stringent regulations on a suite of chemical and microbiological parameters at the end of a treatment facility are often not practical for small and remote communities (Summerill et al. 2010). Furthermore, a regulatory approach that is driven by sampling for contaminants opposed to preventing the occurrence of contamination does not identify underlying systemic issues that may be present in the water supply system. In addition, there may be parameters not included in water quality guidelines in southern communities because they are not commonly present at these latitudes but are present and, more importantly, a risk in northern communities. For example, sources of microbial contamination may or may not be present in the north or are transmitted via different pathogenic pathways; a study by

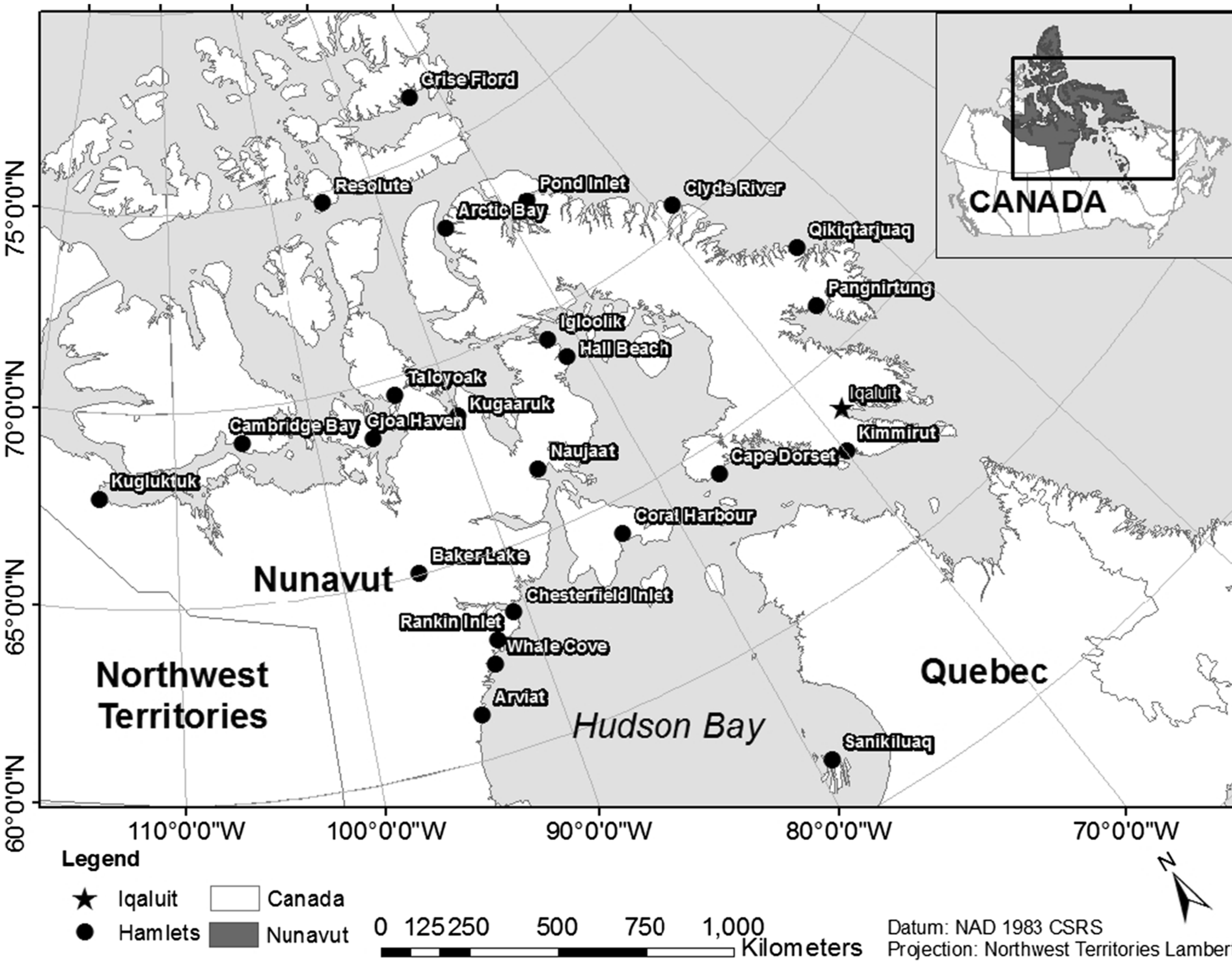

Fig. 1 A map of the locations of the remote communities in Nunavut

Iqbal et al. (2015) demonstrated the prevalence of *Cryptosporidium* and *Giardia* in the Qikiqtani Region in Nunavut and cited zootonic transmission through seals and whales as possible methods of transmission (Iqbal et al. 2015). In southern climates, *Cryptosporidium* and *Giardia* are most often transmitted to human populations via surface water sources through cattle populations and other domesticated farm animals (WHO, Protozoan Parasites).

Previous reports from Arctic communities have demonstrated the prevalence of gastrointestinal illness in remote communities (Pardhan-Ali et al. 2012). A study performed in the Northwest Territories calculated prevalence of gastrointestinal illness in communities as a result of waterborne disease and concluded that campylobacteriosis, giardiasis, and salmonellosis are common in these communities, because of contamination sources not found in southern communities (Pardhan-Ali et al. 2012). A study of transmission pathways for *Cryptosporidium* and *Giardia* in Nunavut also confirms a higher prevalence of gastrointestinal illness associated with waterborne pathogens in Northern communities (Iqbal et al. 2015). Furthermore, the study attempted to understand the species of these pathogenic organisms that are present in the North; current data on the longevity of these pathogens in Arctic climates is limited by insufficient knowledge of the specific species of *Cryptosporidium* and *Giardia* present in the arctic (Iqbal et al. 2015).

Water safety plans (WSPs) are a water quality management tool that have been introduced to drinking water systems to provide a risk analysis tool that applies a proactive approach instead of the current reactive regulatory approach (Kot et al. 2014). Current regulatory structures that require testing for specific chemical, microbiological, and esthetic parameters rely on sampling that occurs at set points within the treatment facilities and distribution systems themselves, not at every potential hazardous location for feasibility reasons. However, this generates an approach that pinpoints the hazardous event after it has already occurred. A WSP attempts to curb this reactionary approach to drinking water management by locating and managing hazardous situations, not by measuring the full suite of parameters in a federal or provincial guideline. WSPs attempt to prevent hazards from occurring by promoting good maintenance practices, by active engagement of the community served by the water supply, and by using identified hazards to help meet water quality guidelines (Baum et al. 2015). Water quality guidelines can still be used and met with a water safety plan; the key difference is knowledge is generated about the system via risk management practices.

Arctic communities are often unable to meet many of the federal regulations for microbiological and chemical contaminants due to small size and lack of access to communities. Kot et al. (2014) highlighted specific reasons why regulations may be difficult to meet in these small Arctic communities: a lack of capacity to sample-specific parameters, lack of knowledge of proper sampling procedures, and parameters that are not applicable to small communities (Kot et al. 2014). Previous studies conducted within the past 20 years have highlighted the following unique issues in Arctic communities: problems with trucked water supply, overcrowding and inadequate housing (Daley et al. 2014), and use of untreated water sources for consumption and hygienic purposes. In addition, Harper et al. (2015) demonstrated that the incidence of gastrointestinal illness is higher on average in northern communities in Canada than the national average for the country as a whole. Thus, the need for unique and robust drinking water regulations is still required.

The objective of this study was to examine strategies for drinking water regulation in Arctic communities. As a case study, the Canadian territory of Nunavut was used to assess the applicability of water safety plans as an approach to water governance.

Methods

Currently in Nunavut, many policies regarding water quality and water utility operation are under revision to determine which methods are used in Arctic regions globally to safeguard public health. In conducting this review of Arctic policies, the countries included on the Arctic Council were chosen for comparison. In addition, provinces and territories in Canada which have Arctic regions or policies specific to communities located north of 60° latitude were considered. Canadian policies were examined to determine provincial and territorial strategies for meeting and implementing the Guidelines for Canadian Drinking Water Quality (GCDWQ) which are set at the federal level but legally enforceable only at the provincial and territorial level (Health Canada 2014).

The review of Arctic policies presented examined several key components of the drinking water quality policies and practices in the chosen locations. Management practices were considered by examining which governmental entity or document details water quality policies; many times, there is no Ministry dedicated specifically to water management and the responsibility of managing water can fall under "environmental" or "public health" branches of the government. Treatment requirements, where available, were examined to determine minimum regulations for drinking water utilities. These minimum requirements facilitate an understanding of advisable treatment methods that may be applicable in Nunavut or advisable treatment requirements (for example, 0.2 mg/L chlorine residual required in the distribution system after treatment). Disinfection was a focus as it is considered a safeguard for public health (Health Canada 2014).

In addition, consideration was given to the type of source waters present in Arctic regions. Groundwater and surface water sources often require different methods of treatment to ensure that delivered water quality is free of possible pathogenic organisms (Health Canada 2014). Regulated drinking water quality parameters were also considered; specifically, which chemical and physical versus microbiological parameters are measured and monitored and with which frequencies. These review topics were chosen to facilitate comparisons between Nunavut and other Arctic Regions for future regulation consideration. Sources of relevant information were varied, including previous peer-reviewed studies and regulatory documents stipulating water quality standards.

Strategies and legislation in Arctic jurisdictions

The Arctic Council identifies eight countries as having Arctic communities or regions: Iceland, Alaska (USA), Denmark (Greenland), Norway, Sweden, Finland, Russia, and Canada (Yukon, Nunavut, and Northwest Territories and the provinces of Manitoba, Quebec, and Newfoundland and Labrador). A review of the current drinking water legislation, guidelines, and administration of water management was conducted to ascertain similarities in water governance policies and water management strategies. The comparison of the Arctic jurisdictions considered is presented in Table 1.

European Union Drinking Water Directive

The European Union (EU) outlined the Drinking Water Directive (Council Directive 98/83/EC on the quality of water intended for human consumption [2001] OJ L330/32) to define minimum requirements for drinking water quality for members in the council of the EU in 1998 (European Commission: Environment 2015). The Directive applies to all distribution systems within an EU member state that serve more than 50 people or supply more than 10 m^3 water/day. The Directive also applies to drinking water from tankers, bottles, and containers and water that is used in the food industry and for other commercial activities served by a utility (European Commission: Environment 2015).

Table 1 A comparison of global arctic jurisdiction water quality regulations and practices

	tbcolw90ptIceland	tbcolw65ptNorway	Sweden	Finland	Russia	Alaska, USA
Governing body	The Ministry of Industry and Innovation	The Ministry of the Environment	Ministry of Agriculture, National Food Administration	Ministry of Social Affairs and Health		Division of Environmental Health
Governing document	Icelandic Drinking Water Regulations, The Foodstuffs Act, 1995				Russian Federation Water Code	Alaska Drinking Water Regulations
Source water type	95% groundwater 5% surface water	90% surface water 10% groundwater	50% surface water	70% groundwater	70% surface water 30% groundwater	80% groundwater 20% surface water or rainwater
Common treatment methods	There are no specifications for treatment of groundwater. Surface water is treated with filtration and UV disinfection.	No requirements specified	Typical waterworks include flocculation, coagulation, sedimentation, filtration, disinfection, and storage components.	No requirements specified	No requirements specified	Filtration required for surface water sources. Disinfection required for all sources.
Water quality parameters	EU Drinking Water Directive	EU Drinking Water Directive	EU Drinking Water Directive	EU Drinking Water Directive	Russian Federation Water Code	US EPA Safe Drinking Water Act
Special considerations by community size	Yes	Yes	Yes	Yes	Not Specified	Yes
Water Safety Plan (WSP)	Yes	No	No	No	No	No
Primary references	Gunnarsdóttir et al. 2012a	Ministry of Health Care and Services 2012	Swedish Water and Wastewater Association 2000	Finnish Institute of Drinking Water/Prizztech Ltd. 2008	Organization for Economic Co-operation and Development, 2006, Dudarev et al., 2013	State of Alaska: Department of Environmental Health, 2016

Emphasis was put on understanding how water management is conducted and whether there are provisions in legislation or regulation specifically for small systems

The Directive sets guidelines for parameters that must be monitored in drinking water treatment facilities; specifically, the Directive provides guidance on 48 microbiological and chemical parameters to be monitored regularly to ensure water cleanliness (European Commission: Environment 2015). These parameters were generated from the World Health Organization (WHO) Guidelines for Drinking Water Quality and from the European Commission's Scientific Advisory Committee (European Commission: Environment 2015). Members of the EU must regulate the parameters defined by the Directive and cannot lower the prescribed maximum acceptable concentrations of regulated substances. Member countries can, however, regulate other parameters, in addition to those prescribed in the Directive, that are specifically relevant to their country. Member countries are also required to provide documentation and regular information to consumers. Drinking water quality must be reported to the European Commission every 3 years for evaluation of compliance with the Directive but only for water utilities that serve greater than 5000 people (European Commission: Environment 2015).

Iceland

Iceland has regulated drinking water quality through the Icelandic Drinking Water Regulation in accordance with the EU Drinking Water Directive since 2001. The Icelandic Drinking Water Regulation outlines source water protection requirements for the largely groundwater (~95%) sources (Gunnarsdóttir et al. 2012a) present in the nation. These groundwater sources are typically not treated prior to distribution, whereas the surface water source or groundwater under the direct influence of surface water is typically treated by filtration (Gunnarsdóttir et al. 2012a). Treatment, when applied, is most often achieved by UV disinfection; it is of note that no residual chlorine is required for the distribution systems in Iceland which is 100% piped (Gunnarsdóttir et al. 2012a).

Water utilities in Iceland have had a legal obligation since 1995 to implement a WSP as outlined in *The Foodstuffs Act, 1995*. Implementation began in 1997, and by 2008, approximately 80% of the population was served by a utility with a WSP in place (Gunnarsdóttir et al. 2012a). Compliance with water safety plan requirements is governed by a Local Competent Authority (Gunnarsdóttir et al. 2012a). Larger utilities (i.e., those serving >5000 customers) are required to implement a Hazard Analysis and Critical Control Point model, while small utilities (i.e. those serving 500–5000 customers) may implement a smaller five-step model. The smallest communities (serving 100–550 customers) may use a sanitary checklist to complete the requirements of the WSP (Gunnarsdottir and Gissurarson 2008).

Norway

The Ministry of the Environment acts as the governing body in Norway for the implementation of the EU Drinking Water Directive (Ministry of Health Care and Services 2012). Every 3 years, the Ministry submits a report to the EU Commission to fulfill the monitoring requirements of the directive. Norway currently does not employ a water safety planning approach, and any initiatives for source water protection are under the jurisdiction of the Ministry of the Environment. Source water in Norway comes primarily from surface water source (~90%) and secondarily from groundwater (~10%). Microbial parameters are therefore a concern in Norway as more than 80% of the population is served by a drinking water system serving more than 5000 people (Ministry of Health Care and Services 2012).

Sweden

At the federal level, the Ministry of Agriculture oversees drinking water quality and compliance with the EU Drinking Water Directive. The Ministry of the Environment oversees source water protection plans in Sweden aided by the Swedish Water and Wastewater Association in regards to water utility organization (Swedish Water and Wastewater Association 2000). Many of the regulations and policies generated in reference to water policy come from the Swedish Water and Wastewater Association as well.

In Sweden, about 50% of the population is served by publicly owned waterworks that are based on surface water withdrawal. The remaining population is served by either traditional or artificial (infiltrated) groundwater (Swedish Water and Wastewater Association 2000). Per the Water Works Association policies, a typical water utility for surface water includes the following types of treatment: screening, flocculation, sedimentation, a rapid sand filter, and disinfection while in storage before the water is released to the distribution system (Swedish Water and Wastewater Association 2000).

Finland

The Finnish Ministry of Social Affairs and Health issued regulations and recommendations in 2000 for drinking water quality based on the Decree Relating to the Quality and Monitoring of Water Intended for Human Consumption (Finnish Institute of Drinking Water/Prizztech Ltd. 2008). The Finnish Decree adheres to the same distribution system sizes presented in the EU Drinking Water Directive (systems supplying 50 or more people a day or supplying >10 m^3/day) and uses the Drinking Water Directive as a guiding document to establish regulations for chemical, physical, and microbiological parameters within the water supply system (Finnish

Institute of Drinking Water/Prizztech Ltd. 2008). The Ministry of Social Affairs and Health is responsible for reporting compliance to the EU Commission every 3 years (Finnish Institute of Drinking Water/Prizztech Ltd. 2008).

Approximately 70% of the water used in utilities comes from groundwater in Finland (Katko et al. 2006). Groundwater is regarded as a source less prone to pathogenic activity; hence, microbiological parameters in Finland are divided into two categories for monitoring and compliance. Microbes that are subject to quality standards include enterococci and *E. coli*, as well as quality recommendations including *Clostridium perfringens* and coliform bacteria (Katko et al. 2006). This twofold definition of microbial risks in Finland highlights the need to consider microbial activity specifically for the region the regulations are being applied to; different source waters in other Arctic regions may be more susceptible to other types of microbial activity that need to be taken into consideration.

Russia

Russian federal law stipulates that local governments are responsible for the maintenance, organization, and development of municipal water supplies under the General Principals of Local Self-Governance (Organisation for Economic Co-operation and Development 2006). Water utilities are operated as unitary enterprises and must be based on contractual agreements delineated by the federal government. The Russian Federation Water Code was developed initially in 1995, and was most recently updated in 2006 (Organisation for Economic Co-operation and Development 2006). The Water Code regulates use and protection of water resources and maintains the quality of source waters to meet environmental and sanitary regulations under the Ministry of the Environment and the Ministry of Healthcare, respectively (Organization for Economic Co-operation and Development 2006).

In the Russian Federation, approximately 70% of the population is served by surface water and 30% by groundwater (Dudarev et al. 2013). While Russia does have a large percentage of the world's fresh water supply, most is inaccessible due to permafrost and groundwater is often considered underused (Dudarev et al. 2013). Surface water is more commonly used, especially in the Arctic regions. The study by Dudarev et al. (2013) showed that approximately 40% of the distributions systems in Northern Russia do not comply with hygienic standards, and that 16% of systems do not employ disinfection in treatment facilities. Treatment processes in Russia currently have no standardized requirements based on treatment technology or facility sizing (Dudarev et al. 2013) and no current water management or safety planning in legislative documentation although reorganization of water facilities has been highlighted as an important need in the Russian Federation (Organisation for Economic Co-operation and Development 2006).

Alaska, USA

The Division of Environmental Health in Alaska implements the federal drinking water regulations stipulated by the US Environmental Protection Agency as laid out in the National Primary Drinking Water Regulations (State of Alaska: Department of Environmental Health 2016). These regulations are legally enforceable standards designed to protect public health by setting maximum contaminate levels for microbiological, chemical, and physical parameters (USEPA 2016). In the Alaskan Drinking Water Regulations specifically, there is a focus on the following microbial parameters: *Cryptosporidium*, *Giardia*, heterotrophic plate counts, *Legionella*, total coliforms (including both *E. coli* and fecal coliforms), turbidity measurements, and enteric viruses. No WSPs are currently formalized in Alaska; however, the state implements Endorsed Drinking Water Protection Plans based on the size of the water system (State Department of Alaska: Natural Resources Department 2016).

Approximately 80% of public water systems in Alaska draw from groundwater sources as of a 2008 report (Alaska Department of Environmental Conservation 2008). Since groundwater is the primary source in Alaska, usually only the minimum Environmental Protection Agency requirements of filtration and disinfection are applied (USEPA 2016). For surface water sources and groundwater sources under the influence of surface water, the Environmental Protection Agency stipulates log-removal requirements for *Giardia* and viruses specifically as well as turbidity measurements after treatment (USEPA 2016).

Yukon, Canada

In the Yukon, the Department of Health and Social Services is responsible for compliance with drinking water standards. The Yukon Drinking Water Regulations specify treatment regulations for disinfection treatment methods (Environment Yukon 2015) in the Yukon Territory, and no regulations beyond disinfection are outlined. However, all public water systems are required to have an emergency response and contingency plan in place (Commissioner of Yukon 2015). Testing of physical and chemical parameters must be conducted once per year under the Yukon Drinking Water Regulations.

The majority of communities in the Yukon use groundwater as their source. In the Yukon, the Department of the Environment in responsible for monitoring the health of both surface water and groundwater sources (Government of Yukon, 2011). As described in the Drinking Water

Regulations for the Yukon, bacteriological parameters that must be analyzed include total coliforms, *E. coli*, and turbidity with monitoring frequency dependent upon system size. Chlorine residuals are required for public systems, with a residual chlorine measurement of 0.4 mg/L set specifically for a trucked distribution system. Disinfection requirements stipulate that no water may enter a trucked distribution system unless it has been treated by chlorine (Commissioner of Yukon 2007). Piped distribution systems are also required to have a chlorine residual unless another form of disinfection is used.

Northwest Territories, Canada

Standards for drinking water systems in the Northwest Territories are set through the *Public Health Act* and *Water Supply System Regulations*, which use the GCDWQ as the legally binding standard for drinking water quality (Government of the Northwest Territories 2014). Environmental Health Officers are responsible for ensuring that community governments are following sampling protocols (Government of the Northwest Territories 2014). The Water Supply System Regulations require sampling and analysis of bacteriological parameters; these include total coliforms, *E. coli*, and turbidity. Monitoring frequency for these parameters is dependent on source water type and size of the treatment facility (Government of the Northwest Territories 2014).

Quebec, Canada

In Quebec, there are different treatment and management requirements for communities located north of the 55th parallel. These are governed by the *Regulations Respecting the Quality of Drinking Water* which consider treatment system size and community location. Surface water sources or sources under the influence of surface water are required to use filtration and disinfection unless the facility can provide evidence of consistently low turbidity, there is no production of disinfection by-products, and it is unlikely to be impacted by changes in source water quality.

Monitoring and sampling frequencies are dependent on system size, with smaller systems having to sample less frequently for microbiological parameters. Treatment systems supplying less than 20,000 people must maintain records for turbidity and free residual disinfectant. Of note are systems serving less than or equal to 500 people and/or are north of the 55th parallel; no turbidity measurements and no disinfection equipment is required. Furthermore, record keeping requirements are relaxed and alarms can be limited to the disinfection process if applicable.

Newfoundland and Labrador, Canada

Water regulation legislation in Newfoundland and Labrador consists of the Water Resource Act and the Municipal Affairs Act, with the Department of Health and Community Services in charge of public community water supplies. Drinking water quality data for parameters such as chlorine residual, *E. coli*, and total coliforms are reported monthly to the Department of Environment and Conservation (Newfoundland and Labrador: Health and Community Services 2014). Environmental Health Offices are responsible for collecting these samples in public water supplies (Newfoundland and Labrador: Health and Community Services 2014).

According to the annual report published in 2014, about 60% of source water in Newfoundland comes from surface water sources (Department of Environment and Conservation 2014). No percentages were reported for Labrador. As of 2014, treatment standards for Newfoundland were under development with the province applying a Multi-Barrier Strategic Action Plan similar to the approach in the GCDWQ (Department of Environment and Conservation 2014). Monitoring of bacteriological parameters (*E. coli* and total coliforms) is required monthly. No sampling procedures are specifically detailed for small communities although it is known that approximately 70% of public water systems serve less than 500 people (Department of Environment and Conservation 2014).

Nunavut, Canada

The Nunavut Water Board is an institution of the public government that controls licensing for water use in the territory. Indigenous and Northern Affairs Canada manages water resources in Nunavut, and this responsibility is set in by the *Department of Indian Affairs and Northern Development Act*. Responsibilities related to drinking water include compliance and enforcement of terms and conditions of water licenses issued by the Nunavut Water Board and provisions of the *Nunavut Waters and Nunavut Surface Rights Tribunal Act*. As stipulated in the *Public Water Supply Regulations*, samples for bacteriological, physical, chemical, and radiological parameters should be collected in a frequency and manner determined by the Chief Medical Health Officer. Physical parameters are to be sampled daily, chemical parameters at least once every 2 years, and microbiological samples by community size on a monthly basis.

Treatment requirements include specifying types of filters allowable if filtration is used, guidelines for fluoridation where applicable, and disinfection residual requirements specifically for chlorine disinfection. These chlorine disinfection residuals and contact time guidelines apply to both groundwater and surface water sources with wells and storage containers. For water haulage trucks, the *Public Water Supply Regulations* make some stipulations with respect to cleanliness, including the ability to be drained and flushed as well as clean storage space for hoses to prevent contamination of nozzles. For a visual comparison of the Canadian jurisdictions to practices in relation to Nunavut, please refer to Table 2.

Application of WSPs in Arctic jurisdictions

Applying a water safety plan to Nunavut and other Arctic jurisdictions would require provisions that specifically address problems unique to these communities. As an example, the communities in Nunavut currently use a trucked water distribution system with disinfection as the primary method of treatment, a system dissimilar to southern communities. Unique water quality parameters would need to be explored and documented to understand greatest risks and hazards present. In addition, the ability of each community to implement and sustain a water safety plan would be critical to the functionality of a WSP approach long-term. Without the capacity to continually improve the water safety plan by re-assessing hazards and implementing new monitoring plans and control measures, the sustainability of the WSP in these communities is not assured.

Water Safety Plans

Water safety planning is an approach promoted by the World Health Organization (WHO) that aims to develop a preventative framework that protects and manages water supplies from source to consumption (World Health Organization 2012). Water safety plans (WSPs) are designed to be adaptable and flexible; they are designed with community structure and socioeconomic variables considered as critical inputs. An effective WSP structure enhances the capabilities of the water supply and identifies areas of improvement that are feasible for a community by using tools that determine the cost effectiveness of the improvements needed in a community (World Health Organization 2012). A WSP is meant to be a "living document"; it evolves and improves as the plan is used by the community (World Health Organization 2012).

The WHO has developed a document that defines six steps that can be used to develop a WSP for small communities. Small communities are often defined by small populations and

Table 2 A comparison of Canadian arctic jurisdiction water quality regulations and practices

	Yukon	Northwest Territories	Newfoundland and Labrador	Northern Quebec	Nunavut
Governing body or document	Department of the Environment	*Public Health Act* and *Water Supply System Regulations*	Department of Health and Community Services	*Regulations Respecting the Quality of Drinking Water*	Nunavut Water Board
Microbiological water quality parameters	*E. coli* Total coliforms Turbidity	*E. coli* Total coliforms Turbidity	*E. coli* Total coliforms	*E. coli* Total coliforms Turbidity	*E. coli* Total coliforms
Treatment requirements	Disinfection	Not specified	Under development	Filtration and disinfection unless approved otherwise	Disinfection for source waters with wells and reservoirs
Specific considerations by community size	Yes	Not specified	Not specified	Yes	Yes
Source water types	Mainly groundwater sources	Not specified	60% source water 40% groundwater	Not specified	Not specified
Monitoring frequency	Physical and chemical—yearly for all GCDWQ Microbiological—dependent upon system size	Dependent upon source water type and treatment technology	Microbiological—monthly	Dependent upon community size	Physical—daily Chemical—every 2 years Microbiological—monthly
Primary references	Commissioner of Yukon 2007	Government of the Northwest Territories 2014	Newfoundland and Labrador: Health and Community Services 2014	Regulation respecting the quality of drinking water, CQLR-c-Q-2-r-40	Nunavut Water Board 2016

Focus was concentrated on determining whether small systems had different sampling requirements and determining the current regulations for microbial water quality parameters. For clarity, monitoring frequency defines how often samples are collected for each category of water quality parameter rates of flow, but the true determining factors that make systems "small" are the ways in which water is managed and treated and the challenges that are unique to the systems utilized by the community (World Health Organization 2012). The WHO defines a water supply system as the source water, treatment, and distribution components of water management in a small system. The division of the water system into these components allows development of the WSP to be community specific in the way that current drinking water regulations do not (World Health Organization 2012).

First, a community must "buy in" to the WSP: if a community does not have engaged members and stakeholders, the WSP will not be effective because the community is not informed and active in the WSP implementation process (World Health Organization 2012). The second step involves understanding and categorizing the water supply in the community so that the source water is clearly defined. This will assist community members in identifying sources of possible pollution and contamination of the water source (World Health Organization 2012).

Next, hazards, hazardous events, risks, and existing control measures for these events must be evaluated; then a community can begin the development and implementation of an improvement plan for the water supply system (World Health Organization 2012). The improvement plan is incremental and identifies the improvements that are the most critical and/or the improvements that are available given the capital reserves of the community (World Health Organization 2012). After these improvements have begun, it is important that the changes are monitored to determine whether improvements are effectively alleviating the risks identified. If improvements are not effective, then the WSP needs revisions. Continual evolution of the WSP is critical to the effectiveness of the plan since it ensures that the system is being continually evaluated for error and new sources of contamination (World Health Organization 2012). Finally, documentation of the improvements, monitoring outcomes, and the WSP plan structure are important to ensuring continuity within the community so that an understanding of the WSP and the hazards faced by the community are transferred to community members as management staff and stakeholders transfer leadership (World Health Organization 2012).

The key principles governing WSPs include the following: community understanding and commitment to a WSP, a focus on preventative risk management, a framework that is flexible and adaptable with incremental improvements, and a regular review of the WSP to gauge effectiveness (World Health Organization 2012). In addition, there is a need for a focus on disease-causing organisms and an approach with multiple barriers to prevent pathogens and microbiological agents from contaminating drinking water and impacting public health (World Health Organization 2012). Customer input is also important, and records of customer complaints can be an effective method to involve the consumer in the WSP. Understanding sudden changes in the environmental conditions is also important to a WSP since they can introduce new hazards into the water supply (World Health Organization 2012).

Currently, 35 countries in the world have experience with WSPs, either at the national level or as specific community case studies (Baum et al. 2015). Since the introduction of WSPs as a possible water regulation structure, the following countries have adopted this approach to varying degrees: the UK, Iceland, New Zealand, and Australia (Baum et al. 2015), with the province of Alberta in Canada being the only province to implement a WSP. At the national level, countries with risk-based approaches have demonstrated an improvement in microbial water quality; there have been fewer outbreaks of waterborne disease reported (Baum et al. 2015). Case studies have been conducted in countries such as Uganda, Senegal, and Sri Lanka, and frameworks have been developed specifically for the communities included in the case study. Many countries, such as the USA, have implemented sanitary surveys as a part of new regulations. However, the use of regulated WSPs only occurs in these four countries and one province. To date, there is little information available comparing a WSP approach to the traditional regulatory approach of sampling and comparing parameters to water quality standards.

The adoption of a WSP approach in Nunavut would facilitate assessment of water supplies from source to distribution and allow for identification of hazards and risks on a case-by-case basis or community level. While several jurisdictions currently employ WSPs, both Iceland and Alberta regulate their use and are useful to discuss as part of this review to provide both a Northern and Canadian context for water safety plan applications.

Applying the Iceland WSP framework to Nunavut

The WSP approach has been applied with success in Iceland since 1997. Gunnarsdottir et al. (2012b) investigated the effectiveness of WSPs in Iceland in terms of regulatory compliance, microbial water quality, and public health factors. The study found a statistically significant improvement in microbial water quality including fewer instances of noncompliance and fewer heterotrophic plate counts exceeding 10 colony forming units per milliliter of sample (Gunnarsdottir et al. 2012a). From a public health perspective, implementation of WSPs has reportedly resulted in a significant decrease in incidence of diarrhea and a reduction in the likelihood of developing a clinical case of diarrhea (Gunnarsdottir et al. 2012b). One of the main goals of a WSP is to improve public health in water supply systems (WHO 2012), and the Icelandic approach shows promise for water safety plans as an alternative to regulating a large suite of physical, chemical, and microbiological parameters.

The current sanitary checklist (for communities ≤500 people) addresses five sections: water catchment area, well zone, reservoirs, pump stations and main pipe, distribution system and connection, and fire hydrants (Gunnarsdottir, personal communication, Feb 2016). The identified hazards within each of these headings were analyzed to determine which hazards could be applicable in Nunavut. Since wells are used in Iceland but Nunavut has mainly surface water sources, when comparing hazards between the two jurisdictions, general source water risks were considered for both the water catchment area and well zone sections since these hazards could be applicable in the case of both surface water or groundwater. The small systems checklist was available to the authors at the time of the study and was considered the best model for ascertaining applicability of the Iceland approach to Nunavut.

Of the hazards presented in the WSP for small systems in Iceland, the most relevant sections include source water risks and reservoir risks (presented in Table 3). While communities in Nunavut do not usually use wells, the source water hazards presented in the Iceland WSP remain valid despite a difference in source between the two regions. Iceland relies mainly on groundwater sources for drinking water supply; Nunavut contains many surface water sources, especially where permafrost inhibits groundwater extraction. The Iceland WSP contained provisions for maintenance plans, risks of vandalism, contamination of reservoirs, ablation, and motor oil contamination from snowmobiles. Many of these hazards are applicable for Nunavut due to its arctic location, a benefit of the Icelandic model. However, the WSP for small systems would not be an ideal model for Nunavut regarding distribution and fire hydrant sections. While the Icelandic WSP approach is adaptable to system sizes (Gunnarsdottir et al. 2012b), 100% of the distribution system is piped in Iceland. Critical control points would be needed for water hauling trucks and for surface water hazards in order for a similar WSP model to be applied in Nunavut.

Table 3 Applicability of the Iceland small system drinking water safety plan to hamlets in Nunavut by section of the WSP template

Section of WSP	Number of applicable hazards	Total possible hazards	Percentage of applicable hazards
Water catchment area	8	12	67%
Well zone	7	9	78%
Reservoirs, pump stations, and main pipe	4	7	45%
Distribution system and connections	3	7	33%
Fire hydrants	0	5	0%

Source water hazards from the Iceland model were the most applicable to the hamlets of Nunavut

Applying the Alberta WSP framework to Nunavut

The Alberta Environmental Protection and Enhancement Regulation (Alta Reg 118/1993, Part 2) stipulates that waterworks must have a water safety plan and that the WSP must use a template (provided as an Excel document) by the province. After reviewing the identified risks in the Alberta framework for applicability in the Nunavut context, about 50% of the risks from the Alberta Framework would be logical risks to also assess in Nunavut, given the treatment systems described in the Operation and Maintenance Manuals for each community (where available from the Nunavut Water Board). While the current Alberta WSP contains risks that are possible at a variety of different water treatment facilities, from conventional treatment to membrane filtration, the plan does not differentiate based on size of a water supply system. Previous research conducted on the effectiveness of the new Alberta WSP template in small communities showed that community readiness is also a factor in water safety plan implementation (Kot et al. 2017). Communities must have the capacity to implement a WSP and the resources and support necessary to complete the plan to obtain the greatest benefits for their water supply systems (Kot et al. 2017).

The Alberta WSP framework contains four sections: Source, Treatment, Network, and Customer. Within each of these sections, there are associated risks which can be assessed at each drinking water treatment facility for risk level. The percentage of each WSP section applicable to Nunavut can be seen in Table 4.

Of the sections, Treatment is the least relevant, which is logical considering the treatment processes that are most commonly used in Nunavut. Alberta's framework contains questions regarding flocculation, coagulation, sedimentation, and advanced forms of disinfection that are not common in Nunavut (Nunavut Water Board, personal communication, 2016) and furthermore would not be feasible options for treatment (due to chemical supply, operator knowledge, plant footprint and size, etc.). In addition, the Treatment Risks address issues with pump stations and storage of water before and during pre-treatment. The Treatment section would be most

Table 4 Applicability of the Alberta Drinking Water Safety Plan to hamlets in Nunavut by section of the WSP template

Risk section	Applicable questions	Total questions	Percentage applicable
Source	27	38	71%
Treatment	31	84	37%
Network	20	48	42%
Customer	10	20	50%

Source water hazards in Alberta showed the highest applicability to Nunavut while the Treatment and Network sections are considered incomplete if applied to hamlets in Nunavut useful for the chlorination systems used in Nunavut as well as the filtration systems available in some communities.

The majority of the Source Risk Questions from the Alberta Framework that are applicable deal with reservoir storage. Most of the relevant questions deal with microbiological contamination of the source water as a result of improper procedures of control and security; these include contamination as a result of wildlife activity and cross contamination due to the location of a sewage treatment lagoon, situations applicable in Nunavut (Krkosek et al. 2012). Network risks available in the Alberta Framework mostly deal with piped systems which are not available in the North; however, the framework does address the issue of reservoir circulation. Customer Risk questions that could be used in Nunavut apply specifically to bulk water delivery and hygienic storage of water within households, which has been previously described as a sanitary issue (Daley et al. 2014).

A Nunavut WSP model

Trucked water considerations

For most communities in Nunavut, water is pumped from a holding reservoir to a water hauling truck and chlorinated in the truck, delivered to home storage tanks at in each household within a community. There are concerns with this specific method of water delivery as southern jurisdictions have few barriers developed for the potential hazards that could occur in these types of systems. Some of these identified hazards include chlorination method and contact time, biofilm growth and accumulation in home storage tanks, and effectiveness of treatment methods as adequate barriers to protect public health. The WHO publishes a set of guidelines specifically for this type of distribution system which may be useful in the hazard identification process (WHO 2012).

Of note during the review of northern Canadian water management systems was the Manitoba Bulk Water Hauling Guidelines. In Manitoba, bulk water haulers must have permits to sell and convey drinking water under the Public Water Act (Manitoba Health 2013). Bulk water is considered water that is potable and intended for human use that is delivered to households or businesses in an approved vehicle that meets the standards of the Bulk Water Hauling Guidelines (Manitoba Health 2013). Drinking water tanks used by bulk water haulers are approved exclusively for water hauling and may not be used for any other purpose. In addition, any hoses, nozzles, and equipment used in conjunction with the water hauler must be of food grade materials to prevent water contamination (Manitoba Health 2013). Under the Drinking Water Safety Act, water may only be hauled from approved sources. Many of the provisions listed in these guidelines would be key control points to include in Nunavut drinking water management strategies in the future.

Development of a framework specific to communities in Nunavut

Community specificity is a key component of the WSP approach (WHO 2012); while models used in other jurisdictions may be assessed for applicability in the planning stage of WSP implementation, ultimately a set of hazards and a monitoring method would need to be developed for Nunavut. A possible WSP framework for communities in Nunavut is presented in Fig. 2; four sections of the water supply system have been chosen: Source Water, Treatment, Distribution System, and Household Storage. The local factors detail possible hazards that would exist in communities that would need to be included in a Nunavut WSP. The likelihood measure describes how a water utility operator would be able to determine the probability that this hazard is present in their particular community. The hazardous events that would result from these factors describe the risk a WSP would hope to mitigate using monitoring and preventative practices applicable to the specific situation present in each community.

As an example, in Fig. 2, risks at the household level must address the security of household storage tanks, from animal incursion or possible recontamination by environmental pollutants or organic matter. In addition, there are concerns that biofilm growth in storage tanks could be a contributing factor to gastrointestinal illness (Daley et al. 2014). The WSP would assess the likelihood of this hazardous event by either measuring biofilm growth, *E. coli* presence/absence testing, or water retention time or even by visual inspection of the storage unit. This process can be applied to all the proposed local factors in the Nunavut WSP framework to begin the implementation of a WSP approach in communities in Nunavut.

The proposed WSP structure for Nunavut would need development mainly for the distribution and household storage sections. Hazard identification for source water and treatment modules has been conducted previously in several WSP models (Iceland, Alberta, New Zealand, Australia, etc.) and has a clear starting point. However, community engagement with local operators and stakeholders would be critical to understanding community perceptions of safe water practices so that the hazards described for the communities in Nunavut would reflect local conditions. For example, in the distribution module, disinfection residual is identified as a local factor and likelihood measure; however, community understanding of the need for a disinfection residual may cause homeowners to alter their water quality or obtain another source that is considered "cleaner" esthetically. Community education will therefore also be an important component of implementing a WSP. The WHO manual for developing a WSP in small systems has iterated this fact; if a community does not comprehend the purpose of the WSP monitoring measures and identified hazards, the WSP is more likely to fail over time (WHO 2012).

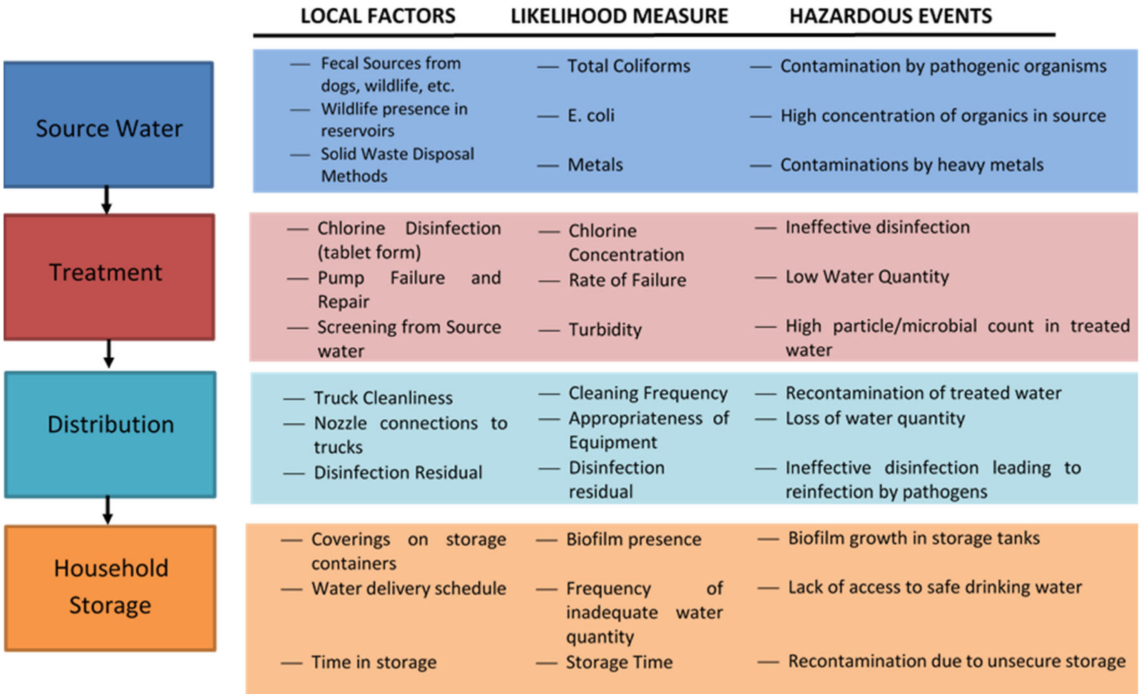

Fig. 2 Elements of a water safety plan framework for the unique characteristics present in hamlets in Nunavut. Local factors that would impact source water quality and treatment are presented in relation to likelihood measure (parameters that could be used to determine probability of failure) and hazardous events (identified risks that could potentially occur in a water supply system)

The elements identified in Fig. 2 form the information basis of the WSP; a structure applicable and easily usable in the remote communities in Nunavut is necessary. Hazard identification documentation is vital to the WSP process but is not sufficient to ensure the sustainability of the approach. Presentation of the hazard information needs to engage the community in a manner that correctly assesses hazard likelihood and consequence: multiple stakeholders must be involved to avoid human error and information bias, the WSP tool must accurately define levels of risk, and the structure requires flexibility to add and delete hazards as the water supply system improves over time.

The model presented for Nunavut is an initial understanding of hazard identification for communities; it is not considered all-inclusive and would need further development with the aid of local territorial authorities. Monitoring in the WSP structure is the other critical component of any WSP approach applied in communities. Reviewing Arctic jurisdiction sampling practices demonstrated that disinfection residual, *E. coli*, turbidity, and total coliforms are measured in most locales; however, other parameters may be better suited due to remoteness, operator knowledge, and practicality. Biofilm presence in household storage tanks would be a new addition to the monitoring parameters the government of Nunavut already requires and should be considered, especially if a WSP approach were to be adopted. Without monitoring of the likelihood measures proposed in the Nunavut WSP framework, indication accuracy of hazardous events is diminished.

Conclusion

Review of Northern jurisdictions and water management policies in Arctic countries have demonstrated that community size, remoteness (access to resources), and understanding a trucked water distribution system are all critical factors in the development of a water management strategy for Nunavut. The current regulatory environment predicated on regulation of set water quality parameters may not be the most effective method for the small communities in Nunavut because of methods of treatment and distribution. A water safety plan approach may be more suitable to Nunavut due to the unique challenges these communities face and would give communities more ownership over their water supplies and a better method to protect public health through hazard identification and monitoring. While the Iceland and Alberta drinking water safety plans provide a starting point for hazard identification in the WSP framework development process, ultimately, hazards specific to the conditions in Nunavut require further consideration, especially with regard to distribution system methods and household storage practices. The possible framework presented here represents beginning steps that may be taken to further the discussion of the applicability of a water safety plan approach in Nunavut.

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