



Chemical and microbial characteristics of municipal drinking water supply systems in the Canadian Arctic

Daley, Kiley; Hansen, Lisbeth Truelstrup; Jamieson, Rob C. ; Hayward, Jenny L; Piorkowski, Greg S; Krkosek, Wendy ; Gagnon, Graham A. ; Castleden, Heather; MacNeil, Kristen; Poltarowicz, Joanna

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1 **Title: Chemical and Microbial Characteristics of Municipal Drinking Water**

2 **Supply Systems in the Canadian Arctic**

3

4 Kiley Daley, Lisbeth Truelstrup Hansen¹, Rob C. Jamieson, Jenny L. Hayward, Greg S.

5 Piorkowski², Wendy Krkosek, Graham A. Gagnon, Heather Castleden³, Kristen

6 MacNeil, Joanna Poltarowicz, Emmalina Corriveau, Amy Jackson, Justine Lywood,

7 Yannan Huang

8

9 Centre for Water Resources Studies, Dalhousie University, Halifax, Nova Scotia,

10 Canada B3H 4R2

11

12 Present address:

13 1. National Food Institute, Technical University of Denmark, Kgs. Lyngby, Denmark

14 2. Alberta Agriculture and Forestry, Edmonton, Alberta

15 3. Queen's University, Kingston, Ontario Canada

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17 * Corresponding author: Lisbeth Truelstrup Hansen (litr@food.dtu.dk)

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20 **Abstract.**

21 Drinking water in the vast Arctic Canadian territory of Nunavut is sourced from
22 surface water lakes or rivers and transferred to man-made or natural reservoirs.
23 The raw water is at a minimum treated by chlorination and distributed to customers
24 either by trucks delivering to a water storage tank inside buildings or through a
25 piped distribution system. The objective of this study was to characterize the
26 chemical and microbial drinking water quality from source to tap in three hamlets
27 (Coral Harbour, Pond Inlet and Pangnirtung – each have a population of <2,000) on
28 trucked service, and in Iqaluit (population ~ 6,700), which uses a combination of
29 trucked and piped water conveyance. Generally, the source and drinking water was
30 of satisfactory microbial quality, containing *Escherichia coli* levels of <1 MPN/100
31 mL with a few exceptions, and selected pathogenic bacteria and parasites were
32 below detection limits using quantitative polymerase chain reaction (qPCR)
33 methods. Tap water in households receiving trucked water contained less than the
34 recommended 0.2 mg/L of free chlorine, while piped drinking water in Iqaluit
35 complied with Health Canada guidelines for residual chlorine (i.e., >0.2 mg/L free
36 chlorine). Some buildings in the four communities contained manganese (Mn),
37 copper (Cu), iron (Fe) and/or lead (Pb) concentrations above Health Canada
38 guideline values for the aesthetic (Mn, Cu and Fe) and health (Pb) objectives.
39 Corrosion of components of the drinking water distribution system (household
40 storage tanks, premise plumbing) could be contributing to Pb, Cu, and Fe levels, as
41 the source water in three of the four communities had low alkalinity. The results
42 point to the need for robust disinfection, which may include secondary disinfection

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43 or point-of-use disinfection, to prevent microbial risks in drinking water tanks in
44 buildings and ultimately at the tap.
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46 Keywords: Drinking water, chlorination, arctic communities, surface water,
47 *Escherichia coli*, microbial pathogens, metals, lead

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48 **Introduction**

49 The typical model of potable water delivery and safety assurance in Arctic
50 Canadian communities is fundamentally different than in communities south of 60
51 degrees latitude. Within the 25 remote communities of Nunavut, a vast arctic
52 territory of northern Canada (approximately 2.1 million km²), water is extracted
53 from lakes, rivers or glacial streams and either treated immediately, or conveyed by
54 pipes or trucks to reservoirs within the hamlets where it is subsequently
55 chlorinated as a minimum. The water is then trucked or, less commonly, piped to
56 individual households and buildings (Johnson, 2008). Homes and buildings on
57 trucked services receive water deliveries into water holding tanks located inside the
58 buildings.

59 In Nunavut, the raw water is typically extracted directly from source lakes
60 and rivers and transferred to an intake pumphouse/truckfill station or an
61 engineered reservoir, from which the water is pumped to the truckfill station
62 (Williams Engineering Canada Inc. 2014). In many hamlets, the raw water is
63 disinfected by chlorination using in-line injection pumps operating simultaneously
64 with the filling of the water trucks at the truckfill stations (Daley et al. 2014). A
65 multi-barrier approach to ensure water safety is used in Iqaluit, where the water
66 treatment plant (WTP) system consists of slow sand filtration and UV-disinfection in
67 addition to chlorination. The Government of Nunavut (GN) is currently moving
68 toward implementing multiple barriers in the drinking water treatment in all
69 communities. This implementation in the Canadian Arctic’s small, fly-in
70 communities is, however, facing several challenges including availability of technical

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71 expertise, difficult year-round access and prohibitive shipping and construction
72 costs (Kot et al. 2015; Johnson 2007). Other challenges include permafrost and
73 distances to service companies (e.g., accredited analytical laboratories).

74 Drinking water distribution pipes are expensive to operate in the Arctic as it
75 is necessary to keep the water heated and moving at all times to avoid freezing and
76 subsequent failure of the above ground distribution infrastructure. Within Nunavut,
77 there are currently only three communities where drinking water is supplied by
78 completely (Resolute) or partially (Rankin Inlet and Iqaluit) piped distribution
79 systems. In Iqaluit (pop. ~6,700, Statistics Canada 2012), the majority of
80 neighbourhoods are served by a piped system (ca. 62%) while the remaining areas
81 are serviced by water trucks (Trow Consulting Engineers Ltd. 2002).

82 Trucked systems, although requiring significantly less infrastructure than
83 piped distribution, have their own set of drawbacks. Trucks must be regularly
84 maintained and staffed with trained operators, and community roads must be
85 cleared of snow to enable trucks to access reservoirs and buildings. Compared to
86 on-demand water delivery via piped systems, trucked distribution to homes and
87 buildings yields a defined amount of available drinking water determined by the
88 capacity of the water tanks and frequency of delivery.

89 There are several points along the delivery train where water may become
90 contaminated with microbes (bacteria, viruses, protozoa) or chemicals (heavy
91 metals, organics, disinfection by-products). The surface water resources, which are
92 used for extraction of drinking water in the area, are vulnerable to contamination
93 from anthropogenic or wild-life activities (Davies & Mazumder 2003) and may be

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94 sensitive to climate change as alterations to seasonal precipitation and temperature
95 patterns may affect run-off events, available fresh water resources, and microbial
96 ecology (Harper et al. 2011a; Martin et al. 2007; Medeiros et al. 2017). The delivery
97 train, the management and maintenance of municipal (truck, pumps, pipes), as well
98 as in-home infrastructure (plumbing and water tanks), play a large role in the
99 potential for water contamination (Ashbolt 2015; Ercumen et al. 2014). In
100 particular, the risk of microbial and chemical contamination may be greater due to
101 stagnant water in tanks receiving an intermittent supply (World Health
102 Organization 2011). Corrosion of drinking water distribution system components,
103 such as pipes and household plumbing fixtures, and the subsequent release of heavy
104 metals including lead, copper, and zinc is an issue that has been widely studied in
105 non-Arctic municipalities in Europe and North America (Zietz et al. 2010). In
106 particular, drinking water has been shown to be a potentially significant source of
107 lead exposure (Renner 2010). Heavy metal release is influenced by a number of
108 factors including, but not limited to, water quality (alkalinity, pH, etc.), stagnation
109 times, temperature, and disinfectant residuals (Wang et al. 2014). Biofilm formation
110 and detachment in water conveyance and storage systems has also been
111 documented to adversely affect water quality in conventional piped distributions
112 systems, and can potentially facilitate the survival and proliferation of opportunistic
113 pathogens such as *Pseudomonas aeruginosa* (Liu et al. 2013; Falkinham et al. 2015).
114 To date, metal corrosion potential has not been investigated within remote, arctic
115 communities which are serviced by trucked distribution systems.

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116 The collection and representativeness of health data appertaining to water-
117 related illness and disease in Canada’s northern regions is limited (Metcalf et al.
118 2011; Harper et al. 2015a; Harper et al. 2011b). Based on self-reported health
119 outcomes, Harper et al. (2011a; 2015b) have suggested that rates of gastrointestinal
120 illness in northern communities are comparatively higher than the Canadian
121 national average and may be associated with water resources. To date, evidence
122 linking higher incidence of gastrointestinal illness or other adverse health effects to
123 specific drinking water-related exposures remains uncertain (Martin et al. 2007;
124 Messier et al. 2012; Fillion et al. 2014; Goldfarb et al. 2013; Harper et al. 2011a;
125 Hastings et al. 2014; McKeown et al. 1999; Pardhan-Ali et al. 2012a; 2012b; 2013).

126 The objective of this work was to assess the municipal drinking water
127 quality and identify potential sources of contamination from the original source
128 (e.g., lake, river, glacier) to the tap (the point of human use) in Coral Harbour,
129 Pangnirtung, Pond Inlet and Iqaluit, representing four different locations, water
130 treatment systems, and community sizes in Nunavut, Canada. It should be noted
131 that this was exploratory and proactive research aiming to assess the drinking
132 water quality and water delivery methods (piped versus trucked) rather than to
133 respond to known water quality issues (reactive research).

134

135 **Materials and Methods**

136

137 Source and drinking water samples were obtained from four communities in
138 different geographical locations of Nunavut, Canada (Figure 1, Table 1).



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140 Figure 1. Location of study sites in the territory of Nunavut, Canada.

141

142 The population size of the studied communities varied from 834 in Coral
 143 Harbour to 6,699 in Iqaluit (Table 1). Each hamlet was visited once: Coral Harbour
 144 (March, 2013), Pond Inlet (July, 2013) and Pangnirtung (August, 2013). The town of
 145 Iqaluit, which has a mixed distribution system, was visited twice (June and
 146 September, 2014) to study temporal differences.

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7 149 Table 1. Drinking water quality in Nunavut: Characteristics of each study site and
8 150 sampling program.

Study Site	Location	Population (2011 census ^a)	Source water	Treatment	Distribution	Sampling dates	Total sample numbers
Coral Harbour	64°08'N; 83°09'W	834	Post River, Reservoir	Direct chlorination in trucks	Trucked	March 12-14, 2013	16
Iqaluit	63°44'N; 68°31'W	6,699	Lake Geraldine, Reservoir	Sand filter, UV and chlorination	Mixed truck and piped	June 23-27, repeated September 21-24, 2014	69
Pangnirtung	66°08'N; 65°41'W	1,425	Duval River, Reservoir	Chlorination at pumping station	Trucked	July 24-28, 2013	21
Pond Inlet	72°41'N; 77°57'W	1,549	Salmon River, Surface, Reservoir	Chlorination at pumping station	Trucked	July 19-22, 2013	31

27 151 ^a–Statistics Canada, 2012.

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32 153 With the exception of Coral Harbour (due to winter conditions), samples
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34 154 were obtained from the fresh water source (i.e., rivers, water reservoirs, and/or
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36 155 engineered lakes), from which the community extract drinking water prior to the
37
38 156 treatment. Treated drinking water samples were obtained from the freshly treated
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40 157 water (water treatment plants), and along the distribution system, which included
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42 158 samples from delivery trucks, domestic water tanks (Coral Harbour), and taps in
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44 159 public/commercial buildings and homes. In Iqaluit, tap water samples were
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46 160 obtained from all types of buildings supplied by the piped distribution system or
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48 161 trucks.

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54 162 The sampling plan was designed to obtain representative water samples in
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56 163 each community for a mixture of private and public housing buildings of different
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58 164 ages, as well as public buildings such as libraries and community halls. As Coral

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165 Harbour was the pilot site, treated water samples were obtained both from building
166 water tanks and from cold water taps in the kitchen (area of food and beverage
167 preparation) to determine if there were differences in the water quality. As there
168 were no discernable differences (data not shown), it was decided only to sample the
169 cold water tap fixtures in the remaining communities. Such tap water samples were
170 assumed to be the most representative of the human oral exposure to potential
171 waterborne contaminants originating from the source water, distribution system, or
172 cold-water premise plumbing; contaminants specific to hot water distribution, such
173 as the opportunistic pathogen *Legionella pneumophila*, were not assessed in this
174 exploratory study. Table 1 contains detailed information about the community
175 location, size, drinking water treatment, distribution system, sampling dates and
176 number of samples that were obtained from each community for this study.

177 At the time of sampling, household inhabitants and public building managers
178 were interviewed to provide context for the chemical and microbial results. They
179 were asked about their views on the drinking water supply, perceptions of health
180 risk, habits of water usage, the age of their home or building, and the condition of
181 the water tank and premise plumbing. Local research assistants were hired in each
182 community to assist with the interviews and provide language translation between
183 Inuktitut and English when needed.

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185 ***Sample Collection and Water Quality Analysis***

186 A 1 L sample was retrieved in a sterilized Nalgene High Density Polyethylene
187 (HDPE) container (Fisher Scientific, Nepean, ON, Canada) from each sample location

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188 for general water quality analysis, and for treated water samples measurement of
189 the residual free chlorine concentration. This sampling approach was used in Pond
190 Inlet, Pangnirtung and Iqaluit; Coral Harbour, which served as a pilot study site, was
191 sampled using a different method, described in the next section. The tap was run for
192 approximately 1-2 minutes before collection of the water sample, to simulate a
193 typical ingestion scenario (Deshommes et al. 2016). General physicochemical water
194 quality indicators which included temperature, pH, and specific conductivity (SpC)
195 were measured with a multi-parameter water quality sonde (600R, YSI
196 Environmental Incorporated, San Diego, CA, USA). Free chlorine was measured by
197 the DPD free chlorine method (Hach Method 2001; 0.02-2.0 mg/L) using a portable
198 photometer (Pocket Colorimeter II; Hach Company). These analyses were carried
199 out in a field laboratory within two hours of being sampled.

200

201 ***Metals and Alkalinity Analysis***

202 Coral Harbour served as the pilot study for the sampling program, and in this
203 community the Tier 1 sampling protocol suggested by Health Canada (2009a) was
204 used to investigate heavy metals indicative of corrosion issues, particularly Pb, in
205 the drinking water. In Coral Harbour, first-flush water samples (500 mL) were
206 obtained by the primary occupants or user in the buildings after an overnight
207 stagnation period. Further samples (4 L) were retrieved from the tap later in the day
208 when additional samples were retrieved for microbiological parameters. On these
209 occasions the taps were run for 1-2 minutes prior to collecting a bulk water sample.
210 The sampling strategy was revised for the remaining communities due to logistical

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211 challenges with obtaining the first flush samples. For Pond Inlet, Pangnirtung and
212 Iqaluit, samples for metals were collected at the same time as the other water
213 quality parameters (i.e., after a 1 minute flushing period). A 100 mL subset of each
214 sample was preserved (pH <2) with nitric acid and transported to the Clean Water
215 Laboratory (CWL) located at Dalhousie University, Halifax, Nova Scotia, Canada. An
216 additional 200 mL subset was kept at 4°C and transported to the CWL for alkalinity
217 analysis.

218 Total metals contained in the drinking water samples were measured through
219 inductively coupled plasma mass spectrometry (ICP/MS) following Standard
220 Methods 3125 (APHA, 1998) on an XSeries2 ICPMS (Thermo Scientific, Mississauga,
221 Ontario, Canada) following manufacturer’s instructions. Prior to analysis, the
222 samples were heat digested with nitric acid according to Standard Method 3030D
223 (APHA, 1998). Alkalinity was measured following Standard Method 2320 (APHA,
224 1998), using the low alkalinity procedure (4d). Filtered water (0.22 µm; Millipore)
225 was used as a blank control sample in all analysis. Appropriate standards were used
226 according to the respective standard methods.

227

228 ***Microbiological Analysis***

229 For microbiological analysis, 8 L of water was collected in two 4 L sterilized
230 plastic containers (Fisher Scientific, Nepean, Ontario, Canada). A 200 mL subsample
231 was removed for fecal indicator bacteria analysis, and preserved with 0.2 mL of 3%
232 (w/v) sodium thiosulphate to inactivate residual chlorine. The subsamples were
233 transported at 4°C to the Northern Water Quality Laboratory (NWQL) located at the

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234 Nunavut Research Institute in Iqaluit, Nunavut, where they were analyzed within 24
235 hours of being sampled.

236 The remaining portions of each sample were used for molecular detection of
237 selected waterborne pathogens. Waterborne microbial cells were concentrated onto
238 a filter with a pore size of 0.45 µm nitrocellulose membrane filter (Whatman
239 Laboratory Division, Maidstone, UK); specific volumes depended on the turbidity
240 and solids content of the water, but a minimum of 1 L was concentrated in the field.
241 These filters were transported (4°C) to NWQL and subjected to DNA extraction
242 within 24-48 hours.

244 ***Enumeration of Total Coliforms and Escherichia coli***

245 Fecal indicator bacteria consisting of total coliforms and *E. coli* were
246 enumerated in 100 mL sample volumes using the Standard Method 9223 (APHA,
247 1998), which is based on the addition of the Colilert defined substrate (IDEXX
248 Laboratories, Inc., Westbrook, ME, USA) to the sample followed by transfer to
249 QuantiTray/2000 (IDEXX Laboratories, Inc.) incubation trays following
250 manufacturer's protocols. Each water sample was analyzed in duplicate.

252 ***Pathogen Marker Tests***

253 The presence of waterborne bacterial and parasitic pathogens was analyzed
254 using quantitative polymerase chain reaction (qPCR) procedures. First, DNA was
255 extracted from the microbes on the drinking water filters using the PowerWater
256 (Coral Harbour), or PowerSoil (the other communities) DNA Isolation kits (MoBio

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257 Laboratories Inc., Carlsbad, CA, USA) following manufacturer’s instruction. Where
258 PowerSoil kits were used, the filters were placed in a 15 mL centrifuge tube (Fisher
259 Scientific) with 10 mL of 0.85% saline. Cells were released from the filters by
260 vortexing sample tubes for three minutes and then harvested by centrifugation at
261 3200 x *g* for 10 minutes after removal of the filters. The resuspended pellet (250 µL)
262 was used for DNA extraction. Extracted genomic DNA was stored at -20°C and
263 transported to CWL in Halifax (NS) for further analysis.

264 Presence of the pathogens was detected through qPCR protocols that were
265 based on previously published primer sequences targeting the following zoonotic
266 waterborne pathogens: *Listeria monocytogenes*, *eae* positive pathogenic *Escherichia*
267 *coli*, *Helicobacter pylori*, *Campylobacter jejuni*, *Salmonella enterica*, *Giardia lamblia*,
268 and *Cryptosporidium parvum* (Table 2). The selection of pathogens was based on
269 information in Goldfarb et al. (2013) and the prevalence of *H. pylori* infections
270 reported by local health authorities in Coral Harbour and other Nunavut
271 communities (McKeown et al. 1999, Goodman et al. 2008). Other zoonotic
272 pathogens relevant to Arctic carnivores (e.g., *Trichinella*, *Echinococcus*) or
273 opportunistic pathogens of hot water distribution (e.g., *Legionella pneumophila*,
274 *Mycobacterium avium*) were not included, yet may be important for community
275 health in Nunavut.

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280 Table 2. Primers used in Taqman assays for detection of bacterial and protozoan
 281 pathogens.
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Pathogen and primer names	Sequence 5' to 3'	Annealing temperature (°C)	Reference
<i>Campylobacter jejuni</i>			
hipO-F	TGCTAGTGAGGTTGCAAAAGAATT	60	LaGier et al., 2004
hipO-R	TCATTTTCGCAAAAAAATCCAAA		
hipO-p	FAM-ACGATGATTAATTCACAATTTTTTTTCGCCAAA-TAMRA ^a		
<i>Cryptosporidium parvum</i>			
JVAG - F	ACTTTTTGTTTTGTTTTACGCCG	55	Jothikumar et al. 2008
JVAG- R	AATGTGGTAGTTGCGGTTGAA		
JVAG2 - p	FAM-ATTTATCTCTTCGTAGCGGCG-BHQ1 ^b		
<i>Escherichia coli eae</i> -positive ^c			
EaeF	GTAAGTTACACTATAAAAGCACCGTTCG	59	Ibekwe et al., 2002
EaeR	TCTGTGTGGATGGTAATAAATTTTTG		
EaeP	FAM-AAATGGACATAGCATCAGCATAATAGGCTTGCT-BHQ1		
<i>Giardia lamblia</i>			
G118s-F	GACGGCTCAGGACAACGGTT	60	Verweij et al., 2004
G118s-R	TTGCCAGCGGTGTCCG		
G118s-p	FAM-CCCGCGGCGGTCCCTGCTAG-TAMRA		
<i>Helicobacter pylori</i>			
HP-FOR	TTATCGGTAAAGACACCAGAAA	54	He et al., 2002
HP-REV	ATCACAGCGCATGTCTTC		
<i>Listeria monocytogenes</i>			
HlyQF	CATGGCACCACCAGCATCT	56	Rodriguez-Lazaro et al., 2004
HlyQR	ATCCGCGTGTCTTTTCGAA		
HlyQP	FAM ^a -CGCCTGCAAGTCCTAAGACGCCA-TAMRA		
<i>Salmonella enterica</i>			
InvAF	AACGTGTTTTCCGTGCGTAAT	56	Cheng et al., 2008
InvAR	TCCATCAAATTAGCGGAGGC		
InvAP	FAM-TGGAAGCGCTCGCATTTGTGG-BHQ1		

283 ^a–FAM – fluorescein

284 ^b–BHQ1 – Black hole quencher

285 ^c–The Ibekwe et al. (2002) method, which targets the *eae* gene (intimin), detects
 286 enterohemorrhagic and enteropathogenic *E. coli* (e.g., O157:H7, O145:H28, O55:H7 and
 287 O111:H7 (see Huang et al. 2017 for details).
 288

289 All qPCR analyses were performed on a CFX96 Touch system (Bio-Rad
 290 Laboratories Inc., Hercules, USA). Each qPCR reaction (25 µL) contained 7.7 µL of
 291 DNase-free water (Fisher Scientific), 12.5 µL of TaqMan master mix (SsoAdvanced

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292 Universal Probes Supermix 2x, BioRad), 0.3 µL each of the forward and reverse
293 primers (10 µM), 0.2 µL of TaqMan hydrolysis probes (10 µM), and 4 µL of sample
294 DNA. For the *Helicobacter* assay, 12.5 µL of SybrGreen master mix (SsoAdvanced
295 Universal SybrGreen 2x, BioRad) was used in place of the TaqMan master mix, and
296 no hydrolysis probes were added. Positive controls contained DNA extracted from
297 *Salmonella* Typhimurium (American Type Culture Collection, ATCC 14028), *E. coli*
298 O157:H7 (strain EC 961019, kindly provided by H. Schraft, Lakehead University,
299 Thunder Bay, ON, Canada), *Campylobacter jejuni* (kindly provided by L. Waddington,
300 Canada Food Inspection Agency, Dartmouth, NS, Canada), *L. monocytogenes* 568
301 (serogroup IIa), *Helicobacter pylori* (ATCC 43504), *Giardia lamblia* (Waterborne
302 Inc., G/C Positive Control, PC101; New Orleans, LA, USA) and *Cryptosporidium*
303 *parvum* (Waterborne Inc., PC101). Blank DNA extraction controls, no template
304 controls, and positive DNA controls were included in the qPCR runs. qPCR
305 efficiencies and limit of detection (LOD) was obtained from standard curves of 10
306 fold-dilutions of DNA extract produced from cultures with known concentrations of
307 cells or (oo)cysts/mL for all pathogens, resulting in qPCR efficiencies ranging from
308 82% to 108%, and R² values from 0.986 to 0.998. Two technical replicates were run
309 for all standards, samples, negative controls, non-template controls and the
310 difference of the threshold cycle (Ct) value between the replicates was less than 0.5.
311 Results were reported as the presence/absence of the selected waterborne
312 pathogen in 1 L. The LODs were 150 copies/L for bacterial pathogens and 1500
313 copies/L for *Giardia* and *Cryptosporidium*.

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315 ***Statistical Analyses***

316 The characteristics of the water samples were compared among and within
317 communities using T-tests and analysis of variance (ANOVA, unbalanced to
318 accommodate differently data sets) where relevant (GraphPad Prism version 5, San
319 Diego, CA, USA). Results were considered significant at the 5% level (p<0.05).

320

321 **Results and Discussion**

322 ***General Water Characteristics and Microbial Quality***

323 The pH-values of the source water in the three communities were
324 comparable, ranging from an average of 7.0 in Iqaluit to 7.4 in Pond Inlet (Table 3).
325 Due to the winter conditions, source water samples could not be obtained from
326 Coral Harbour.

327 In contrast, the specific conductivity was slightly different between sites,
328 with values of 15, 33 and 73 $\mu\text{S}/\text{cm}$ in the water reservoirs of Pangnirtung, Iqaluit
329 and Pond Inlet, respectively (Table 3). The specific conductivity in the Pond Inlet
330 water reservoir, which is normally filled with surface and subsurface runoff from
331 the contributing watershed, was markedly higher than in the adjacent river (22
332 $\mu\text{S}/\text{cm}$) that is used to refill the reservoir when necessary. The river in Pangnirtung
333 was used to refill the water reservoir which likely resulted in the similar specific
334 conductivity at both of the sampling sites in Pangnirtung.

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338 Table 3. Source water quality of the study sites.

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Community	Source (#Samples)	Temp. (°C)	pH	SpC ^a (µS/cm)	Total coli-forms (MPN /100 mL)	<i>E. coli</i> (MPN /100 mL)	Pathogens
Iqaluit	Lake Geraldine/Water reservoir (7)	5.7±2.2	7.0±0.3	33±7	5	<1 ^b	BDL ^c
Pangnirtung	Water reservoir (2)	12.1±0.3	7.2±0.1	15±2	<1	<1	BDL
	Duval River (3)	14.9±0.6	7.1±0.2	8.9±4	2	<1	BDL
Pond Inlet	Water reservoir (6)	12.7±0.1	7.4±0.1	73±0.5	1	<1 ^b	BDL
	Salmon River (4)	12.3±0.3	7.3±0.1	22±0.7	300	<1	BDL

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^a – Specific conductivity

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^b – One sample tested positive for 1 MPN/100 mL

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^c – Below the detection limit of the qPCR assays for pathogenic agents

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Coliform bacteria were detected within the raw water of the rivers and

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engineered water lake/reservoirs of Iqaluit and Pond Inlet, as well as in the

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reservoir in Pangnirtung (Table 3). Levels of *E. coli* were mostly below the

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detection limit (1 MPN/100 mL), except for positive results in one out of seven or

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six samples in the water reservoirs of Iqaluit and Pond Inlet, respectively.

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357 Table 4. Quality of treated water sampled from delivery trucks and taps.

Community	Site	Service (# truck or building samples)	Temperature (°C)	pH	SpC ^c (μ S/cm)	Alkalinity (mg CaCO ₃ /L)
Coral Harbour	Truck	(6)	2.2 ± 1.0 ^b	7.6±0.2	181±16	-
	Tap ^a	Trucked (28)	17.1 ± 3.8	7.6±0.2	167±29 ^{Ad}	76±2.2 ^A
Iqaluit	Truck	(6)	9.1 ± 2.1	6.8±0.2	51±10	-
	Tap	Trucked (21)	20.8 ± 3.4	7.0±0.4	41±10 ^B	14±1.8 ^B
		Piped (36)	12.8 ± 2.0	6.7±0.2	42±11 ^B	14±2.1 ^B
Pangnirtung	Truck	(3)	15.6 ± 2.6	7.5±0.5	15±0.4	-
	Tap	Trucked (12)	21.2 ± 3.5	7.1±0.2	15±0.6 ^C	6.3±3.2 ^C
Pond Inlet	Truck	(4)	12.2 ± 0.7	7.4±0.1	78±1	-
	Tap	Trucked (18)	21.8 ± 3.3	7.3±0.2	82±14 ^D	21±1.1 ^D

358 a - Samples from building water tanks and taps were combined as samples from
 359 within the building were not significantly ($p>0.05$, data not shown) different from
 360 each other.

361 b - Temperatures in water samples obtained from trucks and taps in buildings
 362 serviced by trucks (and in Iqaluit a piped distribution system) were significantly
 363 different ($p<0.05$) from each other within each of the communities.

364 c - Specific conductivity

365 d - Different capital letters following tap water conductivity or alkalinity values
 366 indicate significant differences ($p<0.05$) among samples.

367
 368 The quality of the tap water varied among communities (Table 4). Within
 369 each of the communities, truck water temperatures were consistently significantly
 370 ($p<0.05$) lower than the tap water temperatures. This may be due to the common
 371 placement of water tanks next to furnaces, an assumption supported by significantly

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4 372 (p<0.05) higher tap water temperature in Iqaluit buildings served by trucks than in
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7 373 buildings served by piped connections. Specific conductivity and alkalinity of the tap
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9 374 water also varied significantly (p<0.05) among all four communities, reflecting
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11 375 different contents of charged ions and buffering capacity or water hardness. With
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13 376 the exception of Coral Harbour (76 mg CaCO₃/L), the alkalinity of the drinking water
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15 377 was very low (≤20 mg CaCO₃/L). Low alkalinity may be problematic in these
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17 378 communities as corrosion of lead, copper and iron pipes increases under low
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19 379 alkalinity conditions (Health Canada 2009a; Boulay and Edwards 2011).
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26 381 Table 5. Presence of fecal indicator bacteria and pathogens in truck and tap water
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28 382 samples.
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Community	Service	Total coliforms (Positives/total samples)	<i>E. coli</i> (Positives/total samples)	Pathogens (Present/absent)
Coral Harbour	Truck	1/6 ^a	1/6 ^a	BDL ^d
	Tap (trucked)	1/28 ^b	1/28 ^b	BDL
Iqaluit	Trucks	0/6	0/6	BDL
	Taps (trucked)	3/21	0/21	BDL
	Taps (piped)	2/36	0/36	BDL
Pangnirtung	Trucks	0/3	0/3	BDL
	Taps (trucked)	0/12	0/12	BDL
Pond Inlet	Trucks	0/3	0/3	BDL
	Taps (trucked)	1/18 ^c	1/18 ^c	BDL

383 ^a –One of the truck samples tested positive for total coliforms and *E. coli*.
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384 ^b–One of two tap samples from the same building was positive for total coliforms
385 and *E. coli*
386 ^c–One of two tap samples from the same building tested positive for total coliform
387 and *E. coli* following the water tank running dry.
388 ^d–Below the detection limit
389

390 In general, the fecal indicator bacteria (total coliform and *E. coli*) levels were
391 low or below detection limit from the treated drinking water samples (Table 5). *E.*
392 *coli* was detected in one water sample from a truck and from a building tap in Coral
393 Harbour. In Pond Inlet, the only *E. coli* detection was associated with a water tank
394 that had run dry and then been refilled. As with the source water, none of the
395 pathogens were detected in any of the treated water samples. Although this result
396 does not exclude source waters as potential reservoirs for some common pathogens
397 prevalent in Arctic communities, it is consistent with Hastings et al. (2014) and
398 Pardhan-Ali et al. (2013) investigations of possible risk factors and exposures in the
399 region. It should be noted, however, that in some cases the methods of
400 concentration and quantification yielded detection limits that were higher than the
401 infective dose for humans; thus, true pathogen risk cannot be asserted in this study.
402 For example, giardiasis can occur with exposure of as few as 10 *Giardia* cysts
403 (Furness et al. 2000). Particularly for protozoan pathogens, employing more
404 advanced techniques of high-volume cartridge filtration, immunomagnetic
405 separation, and/or flow cytometry may improve quantification levels approaching
406 infective doses (Hsu et al. 2005; Keserue et al. 2011; Wohlsen et al. 2004).

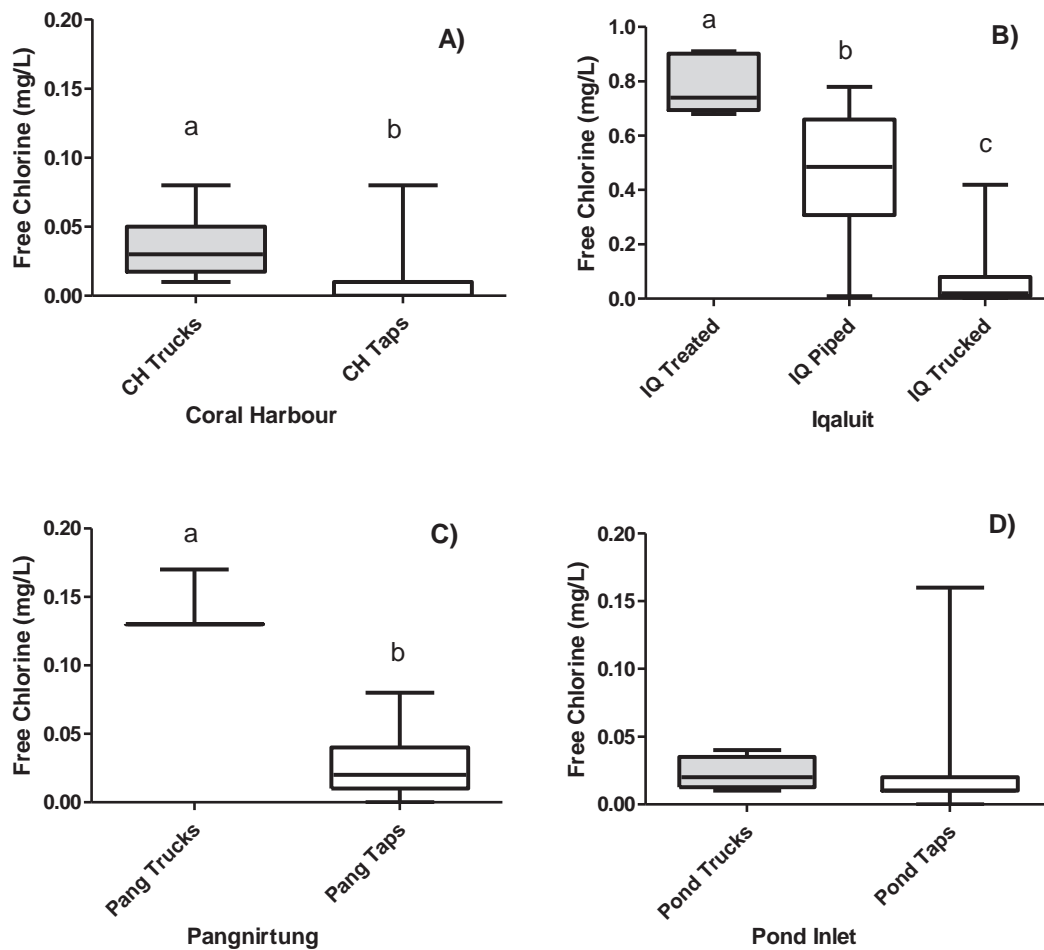


Figure 2. Box plots showing residual free chlorine concentrations (mg/L) in the treated water from delivery trucks and water taps in A) Coral Harbour, B) Iqaluit, C) Pangnirtung and D) Pond Inlet. In each plot, the labelling of boxes with different letters indicates significant ($p < 0.05$) differences among samples. The median (50th percentile) free chlorine content is shown as the central line in the box plot, while the lower and upper hinges represent the 25th and 75th percentiles, respectively, and the whiskers the 10th and 90th percentiles.

The average concentrations of free chlorine in freshly treated drinking water samples ranged from very low values of 0.03 mg/L in Coral Harbour and Pond Inlet to the intermediary level of 0.14 mg/L in Pangnirtung and 0.87 mg/L in Iqaluit (Figure 2). This demonstrated that the free chlorine content in the drinking water in

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420 all communities, with the exception of Iqaluit, fell below Canadian recommendations
421 for free chlorine residuals (0.2-1.0 mg/L) in drinking water to provide the water
422 with protection in the distribution system (Health Canada 2009b). Factors that may
423 be contributing to levels below recommendations in trucked systems are lack of
424 training for operators, operator variability, lack of on-site chlorine test instruments,
425 and difficulties in controlling dosage.

426 In Iqaluit, tap water from buildings on a trucked service contained
427 significantly ($p < 0.05$) less free chlorine residuals than tap water obtained from
428 buildings serviced by the piped system (Figure 2b). In the latter case, the drinking
429 water complied with the Health Canada guideline with an average free chlorine
430 concentration of 0.51 mg/L. In Pangnirtung the free chlorine was also observed to
431 decrease significantly ($p < 0.05$, Figure 2c) from 0.14 mg/L in the freshly treated
432 water, to 0.02 mg/L in the tap water samples.

433 This lack of residual chlorine in the tap water samples from buildings on
434 trucked services could have been caused by a number of different factors related to
435 the reactivity of chlorine such as depletion from biofilms in the tanks, lack of routine
436 cleaning and disinfection, high water temperatures and residence time in the
437 storage receptacles (Rossman et al. 1994; Niquette et al. 2011).

438 According to residents who participated in the study, domestic water tanks
439 in the four communities were refilled every 1 –3 days. Daley et al. (2014) have also
440 reported, however, that delays in refill service to houses on truck systems, which
441 resulted in water tanks running dry, may occur up to several times per month.

442 These interruptions may occur because of weather, mechanical failure, or increased

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443 water demand within the home. Large disruptions in water distribution systems, as
444 well as more routine problems like water outages, inadequate secondary
445 disinfection, and loss of chlorine residual have been shown to increase risk of
446 waterborne illness (Craun and Calderon 2001; Ercumen et al. 2014). Consequently,
447 biofilm formation and microbial regrowth within trucked systems may warrant
448 further examination given the high frequency of disruptions. Maintenance of
449 residual chlorine in the distribution trucks can be improved with operator training
450 on dosage and contact time requirements for disinfection. In cases where low
451 residual chlorine is problematic due to low water use, it may be prudent to install
452 UV disinfection on a household level.

453

454 ***Heavy Metals and Corrosion Issues***

455 In Coral Harbour, where alkalinity levels and pH levels were highest, concentrations
456 of heavy metals in tap water samples were below Health Canada guidelines, with the
457 exception of two houses that had elevated Fe concentrations (Table 6). This was
458 also the only community where first flush samples were collected, which would
459 represent a worst case scenario. This contrasted with Pond Inlet, Pangnirtung, and
460 Iqaluit where concentrations of heavy metals exceeded Health Canada guidelines in
461 tap water samples collected from several buildings (Table 6). Lead concentrations,
462 in particular, exceeded the Health Canada Maximum Acceptable Concentration
463 (MAC) in 7 – 50% of the buildings sampled in these three communities. Other
464 metals that exceeded Health Canada Aesthetic Objectives (AO) at least once included
465 Cu in all three communities, Fe in Iqaluit and Pond Inlet, and Mn in Pond Inlet.

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Table 6. Number and percentage of buildings with exceedances for the metal concentrations in tap water within the four Nunavut communities.

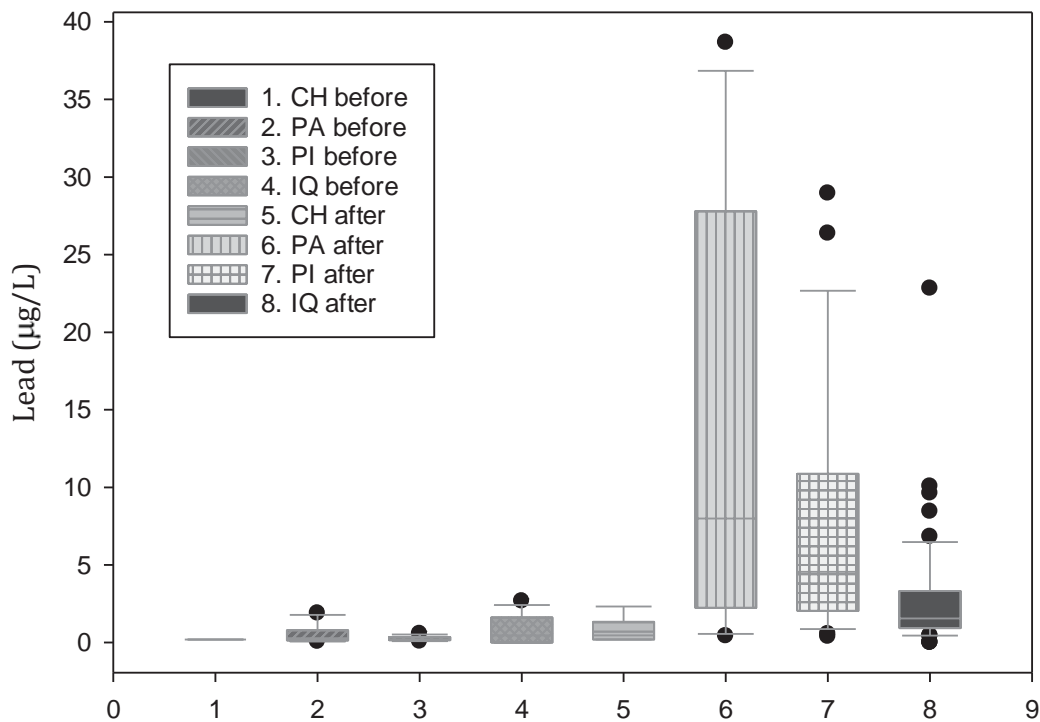
Metal	Health Canada Health Objectives ^a Concentration (µg/mL)	Community			
		Coral Harbour (9) ^b	Iqaluit (30)	Pangnirtung (14)	Pond Inlet (17)
Pb	MAC ≤ 0.01	-	4 (7%)	6 (50%)	4 (7%)
Cu	AO ≤ 1.0	-	9 (16%)	2 (17%)	3 (18%)
Fe	AO ≤ 0.3	2 (13%)	1 (2%)	-	3 (18%)
Mn	AO ≤ 0.05	-	-	-	2 (12%)
Zn	AO ≤ 5	-	-	1 (8%)	-

^a –Health Canada (2006) – MAC: maximum acceptable concentrations and AO: aesthetic objectives

^b –Number of buildings that were sampled within each community

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473 Concentrations of these metals in source waters and truck samples were all less
474 than the Health Canada guidelines. Using Pb as an example, Figure 3 shows the low
475 levels of Pb in the water from the source, water treatment plants and trucks before
476 its passage through the water tanks and premise plumbing after which higher Pb
477 levels, including several exceedances, were observed in the tap water. Therefore it is
478 likely that the Pb and perhaps also the other metals in the tap water originated from
479 corrosion of household storage tanks and premise plumbing.



480
 481 Figure 3. Lead (Pb) concentrations in drinking water before (source water, water
 482 treatment plant and truck samples) and after (tap samples) passage through the
 483 premise plumbing distribution system in the communities of Coral Harbour (CH),
 484 Pangnirtung (PA), Pond Inlet (PI) and Iqaluit (IQ), Nunavut, Canada. Health Canada's
 485 maximum acceptable concentration for lead is 10 µg/L. The median (50th percentile)
 486 lead concentration is shown as the central line in the box plot, while the lower and
 487 upper hinges represent the 25th and 75th percentiles, respectively, and the whiskers
 488 the 10th and 90th percentiles. Outliers are represented as dark circles.
 489

490 Low alkalinity levels (e.g., ≤ 20 mg CaCO₃/L) in these three communities would
 491 make water distribution components susceptible to this process (Health Canada
 492 2009a). It should also be noted that the building tap water samples collected in
 493 these three communities were not specifically collected after a stagnation period,
 494 and it is possible that concentrations of these metals may be higher if a stagnation
 495 period was captured (Health Canada 2009a). Fillion et al. (2014) reported that

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496 blood lead levels in adults and children in Nunavut were higher than in other parts
497 of the country, and also suggested that tap water, in addition to other environmental
498 sources, could be a contributing factor. It is recommended that further sampling,
499 utilizing Health Canada or other sampling protocols (Deshommes et al. 2016) for
500 corrosion assessment, be conducted in Nunavut communities with low source water
501 alkalinity (e.g., ≤ 20 mg CaCO₃/L), to assess lead exposure through drinking water.
502 Once the true risk of heavy metal exposure due to corrosion is determined,
503 strategies to mitigate corrosion can be prepared, which may include alterations to
504 water treatment, such as increasing alkalinity or adding corrosion inhibitors, or
505 replacing water distribution infrastructure with non-corrosive materials such as
506 polyvinyl chloride (PVC) piping (Health Canada 2009a).

507

508 ***Conclusions***

509 Source waters in the four study communities were observed to be of relatively good
510 quality. Selected pathogens were not detected in any samples, and levels of fecal
511 indicator organisms were low. However, additional sampling during high risk time
512 periods (i.e., snowmelt) or follow-up investigation using more sensitive
513 concentration and quantification methods is warranted to fully characterize source
514 water vulnerability for microbial hazards. Free chlorine levels in water samples
515 collected in residences and public buildings serviced by trucked water delivery were
516 below Health Canada guidelines, representing a vulnerability in the drinking water
517 management system in small arctic communities. Microbial regrowth in water tank
518 biofilms is a potential concern due to the lack of secondary disinfection; this would

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519 particularly be an issue for tanks that are not cleaned on a regular basis. Lead and
520 several other metals were detected at concentrations that exceeded Health Canada
521 guidelines in tap water samples in three of the four communities (Pond Inlet,
522 Pangnirtung, and Iqaluit). Future research should focus on (i) establishing best
523 practices for maintaining secondary disinfection within trucked water distribution
524 systems, (ii) identifying if corrosion associated with water distribution system
525 components (trucks, household storage tanks, premise plumbing) is contributing to
526 elevate metal concentrations, and (iii) establishment of storage tank cleaning and
527 residual disinfection maintenance programs in communities which receive trucked
528 water.

529

530 ***Acknowledgments***

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532 the City of Iqaluit for assistance with this research. The staff at Nunavut Research
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542 **References**

543

544 APHA (American Public Health Association) (1998) Standard Methods for the
545 Examination of Water and Wastewater. Twentieth Edition. United Book Press, Inc.
546 Baltimore, Maryland, United States.

547

548 Ashbolt NJ (2015) Microbial contamination of drinking water and human health
549 from community water systems. *Curr Environ Health Rep* 2:95-106.

550

551 Boulay N, Edwards M (2001) Role of temperature, chlorine, and organic matter in
552 copper corrosion by-product release in soft water. *Water Res* 35(3): 683-690.

553

554 Cheng C-M, Lin W, Van KT, Phan L, Tran NN, Farmer D (2008) Rapid detection of
555 *Salmonella* in food using real-time PCR. *J Food Prot* 71(12):2436-2441.

556

557 Craun GF, Calderon RL (2001) Waterborne disease outbreaks caused by distribution
558 system deficiencies. *Journal of American Water Works Association*, 93:64-75.

559

560 Daley K, Castleden H, Jamieson R, Furgal C, Ell L (2014) Municipal water quantities
561 and health in Nunavut households: an exploratory case study in Coral Harbour,
562 Nunavut, Canada. *Int J Circumpolar Hlth*, 73:23843.

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64
65

564 Davies J, Mazumder A (2003) Health and environmental policy issues in Canada: the
565 role of watershed management in sustaining clean drinking water quality at surface
566 sources. J Environ Management 68:273-286.

568 Deshommes E, Bannier A, Laroche L, Nour S, Prevost M (2016) Monitoring-based
569 framework to detect and manage lead water service lines. J Am Water Works Assoc
570 108(11):E555-E570.

572 Ercumen A, Gruber JS, Colford Jr. JM (2014) Water distribution system deficiencies
573 and gastrointestinal illness: A systematic review and meta-analysis. Environ Health
574 Perspect 122(7):651-660.

576 Falkinham JO, Hilborn ED, Arduino MJ, Pruden A, Edwards MA, (2015) Epidemiology
577 and ecology of opportunistic premise plumbing pathogens: *Legionella pneumophila*,
578 *Mycobacterium avium*, and *Pseudomonas aeruginosa*. Environ Health Perspect
579 123(8): 749-758

581 Fillion M, Blais J, Yumvihoze E, Nakajima M, Workman P, Osborne G, Man Chan H,
582 (2014) Identification of environmental sources of lead exposure in Nunavut
583 (Canada) using stable isotopes analyses. Environ Internat, 71:63-73

585 Furness BW, Beach MJ, Roberts JM (2000) Giardiasis surveillance --- United States,
586 1992 - 1997. CDC MMWR Surveillance Summaries, 49(SS07): 1-13

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587

588 Goldfarb DM, Dixon B, Moldovan I, Barrowman N, Mattison K, Zentner C et al. (2013)

589 Nanolitre real-time PCR detection of bacterial, parasitic, and viral agents from

590 patients with diarrhea in Nunavut, Canada. *Int J Circumpolar Health* 72:19903.

591

592 Goodman KJ, Jacobson K, van Zanten SV (2008) *Helicobacter pylori* infection in

593 Canadian and related Arctic Aboriginal populations. *Can J Gastroenterol Hepatol*

594 22(3): 289-295.

595

596 Harper S, Edge V, Shuster-Wallace C, Berke O, McEwen S (2011a). Weather, water

597 quality and infectious gastrointestinal illness in two Inuit communities in

598 Nunatsiavut, Canada: potential implications for climate change. *Ecohealth* 8:93-108.

599

600 Harper SL, Edge VL, Schuster-Wallace CJ, Ar-Rushdi M, McEwen SA (2011b)

601 Improving Aboriginal health data capture: evidence from a health registry

602 evaluation. *Epidemiol Infect* 139(11):1774-1783.

603

604 Harper SL, Edge VL, Ford J, Thomas MK, Pearl DL, Shirley J, IHACC, RICG, McEwen S

605 (2015a) Healthcare use for acute gastrointestinal illness in two Inuit communities:

606 Rigolet and Iqaluit, Canada. *Int J Circumpolar Health* 74:26290.

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65

608 Harper SL, Edge VL, Ford J, Thomas MK, Pearl DL, Shirley J, IHACC Research Group,
609 McEwen S (2015b) Acute gastrointestinal illness in two Inuit communities: burden
610 of illness in Rigolet and Iqaluit, Canada. *Epidemiol Infect* 143(14):3048-3063.

611
612 Hastings EV, Yasui Y, Hanington P, Goodman KJ, CANHelp Working Group (2014)
613 Community-driven research on environmental sources of *Helicobacter pylori*
614 infection in arctic Canada. *Gut Microbes*, 5(5):606-617.

615
616 He Q, Wang JP, Osato M, Lachman LB (2002) Real-time quantitative PCR for
617 detection of *Helicobacter pylori*. *J Clin Microbiol* 40(10):3720-3728.

618
619 Health Canada (2009a) Guidance on controlling corrosion in drinking water
620 distribution systems. Federal-Provincial-Territorial Committee on Drinking Water,
621 Ottawa, ON, Canada. (Catalogue No. H128-1/09-595E).

622
623 Health Canada (2009b) Guidelines for Canadian drinking water quality: Guideline
624 technical document - Chlorine. Federal-Provincial-Territorial Committee on
625 Drinking Water, Ottawa, ON, Canada. (Catalogue No. H128-1/09-588E).

626
627 Hsu BM, Wu NM, Jang HD, Shih FC, Wan MT, Kung CM (2005) Using the flow
628 cytometry to quantify the *Giardia* cysts and *Cryptosporidium* oocysts in water
629 samples. *Environ Monit Assess* 104(1-3)155-162.

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631 Huang Y, Truelstrup Hansen L, Ragush CM, Jamieson RC (2017). Disinfection and
632 removal of human pathogenic bacteria in arctic waste stabilization ponds. Environ
633 Sci Pollut Res. DOI: 10.1007/s11356-017-8816-9
634
635 Ibekwe AM, Watt PM, Grieve CM, Sharma VK, Lyons SR (2002) Multiplex fluorogenic
636 real-time PCR for detection and quantification of *Escherichia coli* O157:H7 in dairy
637 wastewater wetlands. Appl Environ Microbiol 68(10):4853-4862.
638
639 Johnson K (2008) A brief history of the past 60 years of Northern water and waste.
640 Published in the proceedings of the Annual Conference of Western Canada Water
641 and Waste Association, September 23-26 2008, Regina, Saskatchewan, Canada.
642 www.wcwwa.ca. Accessed 8 December 2016.
643
644 Johnson K (2007). The social context of wastewater management in remote
645 communities. Published in the proceedings of the Annual Conference of the Western
646 Canada Water and Waste Association, October 23-26 2007, Edmonton, Alberta,
647 Canada. www.wcwwa.ca. Accessed 8 December 2016.
648
649 Jothikumar N, da Silva AJ, Moura I, Qvarnstrom Y, Hill VR (2008) Detection and
650 differentiation of *Cryptosporidium hominis* and *Cryptosporidium parvum* by dual
651 TaqMan assays. J Med Microbiol 57:1099-1105.
652

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65

653 Keserue HA, Fuchslin HP, Egli T (2011) Rapid detection and enumeration of *Giardia*
654 *lamblia* cysts in water samples by immunomagnetic separation and flow cytometric
655 analysis. Appl Environ Microbiol 77(15): 5420-5427

656
657 Kot M, Gagnon G, Castleden H (2015) Water compliance challenges: how do
658 Canadian small water systems respond? Water Policy 17:349-369.

659
660 LaGier MJ, Joseph LA, Passaretti TV, Musser KA, Cirino NM (2004) A real-time
661 multiplexed PCR assay for rapid detection and differentiation of *Campylobacter*
662 *jejuni* and *Campylobacter coli*. Mol Cell Prob 18:275-282.

663
664 Liu G, Verbeek J, Van Dijk J (2013) Bacteriology of drinking water distribution
665 systems: an integral and multidimensional review. Appl Microbiol Biotech 97:9265-
666 9276.

667
668 McKeown I, Orr P, Macdonald S, Kabani A, Brown R, Coghlan G et al. (1999)
669 *Helicobacter pylori* in the Canadian arctic: seroprevalence and detection in
670 community water samples. Am J Gastroenterol 94:1823-1829.

671
672 Martin D, Bélanger D, Gosselin P, Brazeau J, Furgal C, Déry S (2007) Drinking water
673 and potential threats to human health in Nunavik: Adaptation strategies under
674 climate change conditions. Arctic 60(2):195-202

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676 Medeiros AS, Wood P, Wesche SD, Bakaic M, Peters JF (2017) Water security for
677 northern peoples: review of threats to Arctic freshwater systems in Nunavut,
678 Canada. *Reg Environ Change* 17(3):635-647

679
680 Messier V, Lévesque B, Proulx JF, Rochette L, Serhir B, Couillard M, Ward BJ, Libman
681 MD, Dewailly É, Déry S (2012) Seroprevalence of seven zoonotic infections in
682 Nunavik, Quebec, Canada. *Zoonoses Public Hlth* 59:107-117

683
684 Metcalfe C, Murray C, Collins L, Furgal C (2011) Water quality and human health in
685 Indigenous communities in Canada. *Global Bioethics*, 24(1-4): 91-9

686
687 Niquette P, Servais P, Savoir R (2011) Bacterial dynamics in the drinking water
688 distribution system of Brussels. *Water Research* 35(3): 675-682.

689
690 Pardhan-Ali A, Berke O, Wilson J, Edge VL, Furgal C, Reid-Smith R et al. (2012a) A
691 spatial and temporal analysis of notifiable gastrointestinal illness in the Northwest
692 Territories, Canada, 1991-2008. *Int J Health Geogr* 11:17.

693
694 Pardhan-Ali A, Wilson J, Edge VL, Furgal, C, Reid-Smith R, Santos M et al. (2012b) A
695 descriptive analysis of notifiable gastrointestinal illness in the Northwest
696 Territories, Canada, 1991e2008. *BMJ Open* 2:e000732.

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65

698 Pardhan-Ali A, Wilson J, Edge VL, Furgal C, Reid-Smith R, Santos M et al. (2013)
699 Community-level risk factors for notifiable gastrointestinal illness in the Northwest
700 Territories, Canada, 1991-2008. BMC Publ Health 13:63.
701
702 Remmer R (2010) Exposure on tap: Drinking water as an overlooked source of lead.
703 Environmental Health Perspectives, 118:69-74.
704
705 Rodríguez-Lázaro D, Hernández M, Scotti M, Esteve T, Vázquez-Boland JA, Pla M
706 (2004) Quantitative detection of *Listeria monocytogenes* and *Listeria innocua* by
707 real-time PCR: assessment of hly, iap, and lin02483 targets and AmpliFluor
708 technology. Appl Environ Microbiol 70(3): 1366-1377.
709
710 Rossman LA, Clark RM, Grayman WM (1994) Modeling chlorine residuals in
711 drinking-water distribution systems. Journal of Environ Eng 120(4): 803-820.
712
713 Statistics Canada (2012) Census Profile. 2011 census. Statistics Canada
714 Catalogue no. 98-316-XWE. Ottawa. Released October 24, 2012. Retrieved from:
715 [http://www12.statcan.gc.ca/census-recensement/2011/dp-
717 pd/prof/index.cfm?Lang=E](http://www12.statcan.gc.ca/census-recensement/2011/dp-
716 pd/prof/index.cfm?Lang=E)
718 Trow Consulting Engineers Ltd. (2002) Water and sewer study. Technical report
719 prepared for the City of Iqaluit. Report #MP14882A. 89 pp. Retrieved from:
720 <ftp://ftp.nwb-oen.ca/registry/3%20MUNICIPAL/3A/3AM%20->

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722 [IQA1626/3%20TECH/3%20WATER%20USE%20\(D\)/2004%20Renewal/](#)

723

724 Verweij JJ, Blangé RA, Templeton K, Schinkel J, Brienen EAT, van Rooyen MAA, van

725 Lieshout L, Polderman AM (2004) Simultaneous detection of *Entamoeba histolytica*,

726 *Giardia lamblia* and *Cryptosporidium parvum* in fecal samples by using multiplex

727 real-time PCR. J Clin Microbiol 42(3):1220-1223.

728

729 Wang Z.M, Devine H.A, Zhang W, Waldroup K (2014) Using a GIS and GIS-assisted

730 water quality model to analyze the deterministic factors for lead and copper

731 corrosion in drinking water distribution systems. J Environ Eng, ASCE, 140(9):

732 A4014004.

733

734 Williams Engineering Canada Inc. (2014) Locate alternate sources of drinking water

735 for each Nunavut hamlet. Technical report prepared for the Government of Nunavut.

736 Report #26525. 246 pp.

737

738 Wohlsen T, Bates J, Gray B, Katouli M (2004) Evaluation of five membrane filtration

739 methods of recovery of *Cryptosporidium* and *Giardia* isolates from water samples.

740 Appl Environ Microbiol 70(4): 2318-2322.

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63
64
65

742 World Health Organization (2011). Guidelines for drinking-water quality. Geneva:
743 world health organization. Retrieved from:
744 http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf
745
746 Zietz,B.P, Lab J, Suchenwirth R, Dunkelberg H (2010) Lead in drinking water as a
747 public health challenge. Environ Health Perspect 118:154-155.
748