Assessing protozoan risks for surface drinking water supplies in Nova Scotia, Canada

Wendy Krkosek, Victoria Reed and Graham A. Gagnon

ABSTRACT

Protozoa, such as *Cryptosporidium parvum* and *Giardia lamblia*, pose a human health risk when present in drinking water. To minimize health risks, the Nova Scotia Treatment Standards for surface water and groundwater under the direct influence of surface water require a 3-log reduction for *Giardia* cysts and *Cryptosporidium* oocysts. This study determined the protozoan risk of municipal surface source waters in Nova Scotia, through the use of a pre-screening risk analysis of water supplies, followed by subsequent water quality analysis of the seven highest risk supplies. The water supplies were monitored monthly for 1 year to obtain baseline data that could be used for a quantitative microbial risk assessment (QMRA). The QMRA model outcomes were compared to the Health Canada health target of 10^{-6} disability-adjusted life years/person/year. QMRA modeling shows that the treatment facilities meet the required log reductions and disability-adjusted life year target standards under current conditions. Furthermore, based on the results of this work, Nova Scotia should maintain the current 3-log reduction standard for *Giardia* cysts and *Cryptosporidium* oocysts. The results of this study show that a pre-screening step can help to inform water sources that are particularly vulnerable to protozoan contamination, which can lead to more focused, cost-effective sampling, and monitoring programs.

Key words | *Cryptosporidium*, drinking water, *Giardia*, protozoa, QMRA, surface water

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INTRODUCTION

Microbial contamination of surface waters used for drinking water can occur through bacterial, protozoan, or viral contamination from point or non-point sources (United States Environmental Protection Agency (USEPA) 2010). In a review of waterborne disease outbreaks in the United States from 1971 to 2006, 423 cases had a documented cause. Of those outbreaks with a known cause, parasites caused 18.3% of the outbreaks, and of the parasites, *Giardia* was associated with 6.3% of the parasitic outbreaks and *Cryptosporidium* was identified as the sole pathogen in 9.1% of the parasitic drinking water outbreaks (Craun *et al.* 2010). In a review of 325 global outbreaks in 2007, 40.6% of these outbreaks were attributed to *Giardia duodenalis* and *Cryptosporidium parvum* (Karanis *et al.* 2007). In an update to this study in 2011, from a further 199 outbreaks, 60.3% were attributed to *Cryptosporidium* spp. and 35.2% to *Giardia lamblia* (Baldursson & Karanis 2011).

Cryptosporidium is a waterborne protozoan pathogen that can cause gastrointestinal difficulties and diarrhea in humans. It causes an inconvenient infection in healthy adults, but in infants, the elderly, and people with compromised immune systems it can cause extreme sickness and death (Logan *et al.* 2001). Although cattle feces is the primary source of contamination, human, domestic, and wild animal feces are also sources (Health Canada 2009; Nichols *et al.* 2010). Over 80 species of *Cryptosporidium* have been identified (Fayer *et al.* 2010; Smith & Nichols 2010). The three main species known to cause human infection are *Cryptosporidium parvum*, *C. hominis*, and *C. meleagridis* (Zhou *et al.* 2004; Connelly *et al.* 2008; Plutzer & Karanis 2009; Nichols *et al.* 2010).

doi: 10.2166/wh.2015.034

Within Nova Scotia, there are 82 municipal water sources, of which, 54% use surface water and another 12% use a combination of surface water and groundwater (Nova Scotia Environment (NSE) 2010). In general, the surface water in Nova Scotia is of high quality, with very little agricultural, industrial, wildlife, and human impacts upstream of source waters. A description of the source water for the largest plant in Nova Scotia has been provided elsewhere (Knowles *et al.* 2012) and is a useful example of the general characteristics of surface water in Nova Scotia. In general, surface waters in Nova Scotia are characterized as low alkalinity, low turbidity waters (Waller *et al.* 1996).

In Nova Scotia, an owner of a public drinking water supply must follow the Guidelines for Canadian Drinking Water Quality to ensure the provision of safe drinking water. In addition, the Nova Scotia Treatment Standards for surface water, or groundwater under the direct influence of surface water, requires the following for pathogen removal: filtration and disinfection to provide 3-log reduction for *Giardia* cysts and *Cryptosporidium* oocysts and 4-log reduction for viruses (NSE 2012). The 3-log removal of *Cryptosporidium* oocysts was added to the treatment standards in 2012.

Health Canada suggests the use of quantitative microbial risk analysis (QMRA) as part of a multi-barrier approach to better understand the risk related to a water system (Health Canada 2010a). QMRA uses mathematical modeling combined with source water quality data, treatment barrier information, and pathogen-specific characteristics to estimate the burden of disease associated with pathogen exposure in a drinking water source (Health Canada 2010a). To perform QMRA on a particular source, distributions of microbial presence (*Escherichia coli* or protozoa) from direct monitoring or assumed distributions are incorporated into the model, along with treatment performance factors to determine an overall risk of illness, effectiveness of treatment barriers, adequacy of existing control measures, and to evaluate system response to changes in microbial source water quality.

The level of risk given as an output from the QMRA model uses the concept of disability-adjusted life years (DALYs) (World Health Organization (WHO) 2008). DALYs take into account the probability of experiencing an illness and the impact of the associated health effects (e.g., years lost due to mortality and number of years lived with a disability). Health Canada suggests adopting the World Health Organization (WHO) health target of 10^{-6} DALYs/person/year (Health Canada 2010a).

The objective of this study was to determine the protozoan risk of municipal surface water sources in Nova Scotia, in order to validate the incorporation of a 3-log reduction for *Giardia* cysts and *Cryptosporidium* oocysts in the Nova Scotia Treatment Standards. This was accomplished in three steps. First, a regulatory analysis was conducted to determine the protozoan monitoring/treatment standard approaches used in other jurisdictions to ensure that the standards are in line with other jurisdictions. Second, a semi-quantitative risk analysis was used as a pre-screening tool to determine the most vulnerable sites for protozoan presence in Nova Scotia surface source waters. Finally, results from a 1-year monthly protozoan sampling program were used to provide inputs to a QMRA assessment to determine the human health risk posed by the identified highest risk water sources and their existing treatment processes.

METHODS

Regulatory analysis

A regulatory analysis and review of source water monitoring and microbial treatment standards was conducted for the following jurisdictions: Canada (British Columbia, Yukon, Nunavut, Alberta, Saskatchewan, Manitoba, Québec, Ontario, New Brunswick, Nova Scotia, Newfoundland), the United States, the United Kingdom, and Australia. Only free and online sources were used for this analysis. The review was conducted to ensure that Nova Scotia's Treatment Standards were in line with best practices from other jurisdictions.

Nova Scotia surface water vulnerability assessment

A semi-quantitative risk analysis, based on experience and existing knowledge, was developed as a pre-screening tool for determining microbial risks to 34 municipal surface water sources in Nova Scotia. Six different microbial risks

were examined in the semi-quantitative risk analysis. Each risk was assigned a weighting factor based on the perceived contribution to overall contamination. These risk categories included: wastewater discharge, on-site septic wastewater, agricultural livestock, agricultural crops, and stormwater impacts. Within each of these risk categories, values between 0 and 5 were assigned for each source water based on the level of perceived risk; these are listed in Table 1. The assigned risk values were multiplied by the weighting factor and then summed to give an overall relative risk value for each water source. The risk weightings and determination of values used a consistent approach for all surface source waters.

Table 1 | Assigned risk values for each risk category

Category	Risk level	Assigned risk value
Protected areas	Protected with restrictions	P-R
	Protected with no restrictions	P-NR
	Not protected	NP
Wastewater discharge	No wastewater discharges	0
	1 or 2 wastewater discharges	2
	>10 wastewater discharges	5
On-site septic wastewater	None	0
	<5 systems	1
	Few on-site septic but low density	2
	Many on-site septic but low density	3
	Many on-site septic and high density	5
Agricultural livestock	None	0
	One or two farms	2.5
	Multiple farms	5
Agricultural crops	None	0
	One or two farms	2.5
	Multiple farms	5
Stormwater impacts	None	0
	Minimal	2.5
	Yes	5

Source water sampling

The seven highest risk source waters, as determined by the pre-screening tool, were then used for further analysis of microbial risk through microbial water sampling. Five of these water sources were sampled monthly for protozoa and general water quality over a 1-year period. Samples were taken either from a raw water tap within the water treatment facility (Communities A, D, and E), or directly from the surface water (Communities B and C), depending on accessibility. Protozoan results from the remaining two communities were obtained directly from the utility, as they have their own protozoan sampling program. Data were gathered for these final two communities between 2009 and 2013.

Each of the five systems (Communities A–E) were sampled monthly from May 2012 to April 2013 to provide a seasonal database of *Cryptosporidium* and *Giardia* presence for Nova Scotia source waters. Samples were collected each month over a 2- to 3-day period. Samples were filtered and sent to Clancy Environmental Consultants (CECs), Inc. in St Albans, Vermont, which operated as a subsidiary of Tetra Tech, Inc. at the time of this study. CEC is a United States Environmental Protection Agency (USEPA) certified laboratory for *Cryptosporidium* and *Giardia* analysis. In addition to protozoa sampling, the pH and *E. coli* were also determined for each sample at the five sites. Sample analysis for these parameters was conducted in the Clean Water Technologies Laboratory (CWTL) at Dalhousie University.

Sample collection and analysis

For *Cryptosporidium* and *Giardia,* 10 L of water was filtered through the Pall Corporation's Envirochek™ HV 1.0 μm filter through use of a raw water tap where available. In situations where raw water taps were not available, >10 L was collected in a 20 L plastic jug and either filtered on-site using a mobile pump, or taken to the Dalhousie laboratory where it was processed accordingly. A 10 L sample was chosen for this study to be consistent with methodology used by the utility that provided results for Communities F and G from their monthly source water sampling program. The Envirochek™ filters were then placed on ice and shipped overnight to CEC laboratories in Vermont where they

were processed for *Cryptosporidium* and *Giardia* according to USEPA Method 1623 (2005).

A 100 mL sterilized bottle was used for collection of a sample for *E. coli* testing. *E. coli* analysis was performed using the IDEXX Colilert-18 test kit (ISO 9308-2:2012), a Colilert powder pack was added to the 100 mL samples, and the liquid was transferred to and sealed in Quanti-Trays. Trays were incubated at 35 °C for 18 hours prior to counting positive wells (those that fluoresce under UV light) to obtain the most probable number of colonies per 100 mL sample.

A 1 L amber glass bottle was filled headspace free with a sample for testing pH. pH was measured at the CWTL using an Accumet Excel XL50 Dual Channel pH/ion/conductivity meter with an Accumet pH probe calibrated daily using pH 4.0, 7.0, and 10.0 buffers from Fisher Scientific.

QMRA modeling

To determine whether the seven communities achieved the acceptable health-based reduction targets for protozoa and *E. coli*, QMRA was performed using a spreadsheet developed and provided by Health Canada.

For all communities, two different cases were modeled through QMRA to assess the health impacts due to the presence or absence of treatment barriers. For each site, all treatment barriers were assumed to be in place for Case 1. For Case 2, it was assumed that no treatment barriers were in place, which would be akin to drinking untreated water.

To gather the data for QMRA analysis, the following information was collected from the seven communities: population size served by the facility, treatment processes used, chlorine contact time, chlorine residual, highest operating pH, and UV dose (if applicable). These data were extracted from the 2013 System Assessment Reports submitted to Nova Scotia Environment in April 2013. The highest (worst case) sample results from water quality monitoring of the seven highest risk systems for *Cryptosporidium*, *Giardia*, and *E. coli* were used as inputs for source water quality. A summary of system input parameters used for each site is provided in Table 2.

There were several assumptions made in the model. It was assumed the daily consumption of water for each person was 1.0 L/day based on Health Canada recommendations (Health Canada 2010a). The standard deviation was set to equal the mean value inputted, given the limited data available. The fraction of human-infectious pathogenic strains for *Cryptosporidium* and *Giardia* was set at 0.40, and 1.00 for *E. coli*. The temperature for primary disinfection was kept constant at 0.5 °C, which was chosen to assume a worst case for disinfection.

Several instances occurred where the actual treatment process used in a system was not an available input option in the QMRA model, and these had to be adjusted to comply with the model's treatment options. In Communities A and B, dissolved air flotation is used in the facility, but this had to be entered as 'coagulation, flocculation, sedimentation' in the model. In Communities F and G, both nano- and ultra-filtration membranes are used, but the only membranes included in the QMRA model are ultra-filtration membranes. Thus, these two communities have greater levels of filtration in their facilities, but the model could not capture this.

Table 2 | Treatment conditions used for select Nova Scotia surface source waters

Community	Population	Pre-treat	Filtration	Contact time (min)	Chlorine dose[a] (mg/L)	pH	Temp (°C)	UV-dose[b] (mJ/cm)
A	8,200	Coag, floc, sed	Rapid Granular (coag/sed)	45	1	6.5	0.5	
B	1,500	Coag, floc, sed	Rapid Granular (coag/sed)	155.7 (52.3)	0.8	8.5	0.5	
C	5,250	Coag, floc, sed	Membrane (ultra)	70	1.5	8.5	0.5	
D	600	None	Membrane (ultra)	75	1	8	0.5	
E	8,200	Coag, floc, sed	Rapid Granular (coag/sed)	67.06	0.6	6.5	0.5	
F[b]	83	None	Membrane (ultra)	18.25	0.8	8	0.5	40
G[b]	700	None	Membrane (ultra)	36.65	0.8	8	0.5	40

[a]Free chlorine was chemical disinfectant applied at all facilities.
[b]UV disinfection was also applied (in addition to chlorine) at this facility.

For all sites, the maximum values for all protozoa were inputted as the 'mean' values in the QMRA model. These maximum values were also inputted for the standard deviations. Maximum values indicated a worst case scenario over a 1-year period. For two sites there were no *E. coli* data available, thus these data are not presented for these communities (Communities F and G). In many instances there were non-detects/10 L for *Cryptosporidium* and/or *Giardia* in the source sample data. This does not necessarily indicate there was no *Cryptosporidium* present, just that it was below the detection limit of the method used. If the data were all non-detects for a particular microbial parameter, no health-based risks were calculated for that organism in the QMRA model.

RESULTS

Comparison of microbial monitoring and treatment requirements

Microbial monitoring varied among the jurisdictions reviewed. Some did not require any microbial monitoring (British Columbia, Saskatchewan, and Newfoundland). Others were population dependent (Alberta and the United States), had monitoring requirements solely at the beginning stages to determine source water quality and treatment level (Yukon and Manitoba), or based the protozoa monitoring on the results from *E. coli* monitoring (Ontario and the United Kingdom). The remaining jurisdictions (Québec, New Brunswick, Nova Scotia, and Australia) only required *E. coli* monitoring. In Canada, only Alberta and Manitoba required monitoring of *Cryptosporidium*. These results are presented in Table 3.

The minimum reduction requirement for *Cryptosporidium* also varies by jurisdiction, as shown in Table 4. The required minimum protozoa and virus reductions across Canada and in the United States, the United Kingdom, and Australia were reviewed. A 3- and 4-log reduction are required by all jurisdictions for *Giardia* and viruses, respectively. For *Cryptosporidium*, a minimum 3-log reduction is required by Health Canada, British Columbia, Yukon, Alberta, Saskatchewan, Nova Scotia, and the United Kingdom. All other jurisdictions require either a 2-log reduction or do not have one listed. These are all minimum requirements and based upon protected, pristine source water quality. Most are subject to increases as source water quality decreases (Drinking Water Inspectorate (DWI) 1999; Department of Environment & Conservation 2001; New Brunswick Health 2002; Safe Drinking Water Act 2002; National Health & Medical Research Council (NHMRC) 2004; Alberta Environment 2006; USEPA 2006a; Drinking Water Safety Act 2007; Saskatchewan Environment 2007; Yukon Public Health & Safety Act 2007; Environmental Quality Act 2010; Health Canada 2010b; NSE 2012; British Columbia Health 2012).

Table 3 | Microbial monitoring requirements for select jurisdictions

Location	*E. coli*	*Cryptosporidium*	*Giardia*	Viruses
British Columbia Health (2012)	No	No	No	No
Yukon (2007)	Yes[b]	No	No	No
Alberta (2006)	Yes	Yes[b]	Yes[a]	No
Government of Saskatchewan (2002)	No	No	No	No
Manitoba (2007)	Yes	Yes[b]	Yes[b]	No
Quebec (2010)	Yes	No	No	No
Ontario (2006)	Yes	No[c]	No	No
New Brunswick (2002)	Yes	No	No	No
Nova Scotia (2005)	Yes	No	No	No
Newfoundland (2001)	No	No	No	No
United States (USEPA 2006a)	Yes	Yes[a]	Yes[a]	No
United Kingdom (DWI 1999)	Yes	No[c]	No	No
Australia (NHMRC 2004)	Yes	No	No	No

[a]Population dependent. For utilities serving more than 10,000, it is required. For utilities serving less than 10,000, monitoring of *Cryptosporidium* is required if there are elevated *E. coli* concentrations. All unfiltered systems are required to sample for *Cryptosporidium*.
[b]Required initially to establish source water quality and determine required level of treatment. Not continuous.
[c]Based on determined risk from *E. coli* monitoring. Will be required if *E. coli* presence exceeds maximum level. Population has no bearing.

Nova Scotia surface water vulnerability assessment

The results of the Nova Scotia semi-quantitative risk analysis are presented in Table 5. The source water for Community A was given the highest risk (112.5) value.

Table 4 | Microbial treatment reduction requirements for select jurisdictions

Location	Minimum *Cryptosporidium* reduction	Minimum *Giardia* reduction	Minimum virus reduction
Canada (Health Canada 2010b)	3-log[c]	3-log	4-log
British Columbia Health (2012)	3-log	3-log	4-log
Yukon (2003)	3-log	3-log	4-log
Nunavut (2002)	–	–	–
Alberta (2006)	3-log	3-log	4-log
Government of Saskatchewan (2002)	3-log	3-log	4-log
Manitoba (2007)	2-log[a]	3-log	4-log
Quebec (2005)	2-log[b]	3-log[b]	4-log[b]
Ontario (2003)	2-log	3-log	4-log
New Brunswick	–	–	–
Nova Scotia (2012)	3-log	3-log	4-log
Newfoundland (2001)	–	–	–
United States (USEPA 2006b)	2-log[c]	3-log	4-log
United Kingdom (DWI 1999)	3-log	3-log	4-log
Australia (NHMRC 2004)	–	–	–

[a]At directors' discretion. Normal requirement is a 3-log reduction unless source water deemed high quality.
[b]Based on highest quality raw water, referring to found *E. coli* concentrations of less than 20 per 100 mL.
[c]This pertains to filtered systems. Additional treatment is required for unfiltered systems and systems at higher risk (bin system).
[d]Recommended value.

This source water is downstream of 14 wastewater discharges, many on-site septic systems at high density, and several livestock and crop operations. The next highest risk of 95 was assigned to Community G, which has two schools with wastewater treatment systems discharging into the source water, many on-site septic systems (at low density), and multiple livestock and agricultural operations. The next four highest risk systems, Communities B, C, D, and E, ranged from 75 to 62.5 and had few wastewater discharges, low numbers and densities of on-site septic systems, and several small agricultural inputs. Community F had a risk value of 45 and contained wastewater discharges. Beyond these seven systems, the risk values drop considerably as there are very few wastewater discharges, very few on-site septic systems and virtually no agriculture or stormwater impacts within the other watersheds.

Source water sampling

The results of monthly sampling (and/or utility data) at the seven surface water sources in Nova Scotia are presented in Table 6. For the first month, only a presence/absence test was done for total coliforms and *E. coli*. The utility took monthly samples at these two sites for 2 years and all results are presented. Sample results for *Cryptosporidium* and *Giardia* in Table 6 are presented as cysts/100 L even though the detection limit was cysts/10 L. This was done to be consistent with the input to the QMRA model and the Health Canada log-reduction requirements. There was one positive sample for *Cryptosporidium* out of 111 samples. This positive sample was at Community F in February 2011 and had a count of 132 oocysts/100 L. Out of 111 samples, there were 14 positives for *Giardia* with the highest being 1,067 cysts/100 L in August 2011, also at Community F. The majority of samples from Communities B and C that had positive results for *Giardia* were associated with a rain event or wet weather within a few days prior to sampling. Communities D and E both had non-detects for both *Cryptosporidium* and *Giardia* for all sampling events.

QMRA modeling

All seven systems assessed met NSE's 3-log reduction requirement for *Cryptosporidium* and *Giardia* when all treatment barriers were in place (Table 7). Health Canada recommends the use of 10^{-6} DALYs/person/year as an acceptable level of risk. Figure 1 presents the results of QMRA health risk for Cases 1 and 2. The vertical axis presents the –log (DALY/person/year) which shows an estimate of the disease burden. The horizontal black line in the figure represents the WHO health target and all bars that are above that line provide an adequate barrier, with those bars falling below the line showing cases where the health target is not being met. All of the systems met the Health Canada

Table 5 | Semi-quantitative risk analysis for select Nova Scotia surface source waters

	Community	Wastewater Weight (10)	On-site wastewater Weight (5)	Agricultural livestock Weight (7)	Agricultural crops Weight (6)	Stormwater impacts Weight (2)	Risk
1	A	5	5	2.5	2.5	5	112.5
2	G	2	3	5	5	2.5	95
3	B	0	3	5	5	2.5	75
4	D	0	3	5	5	2.5	75
5	E	2	2	2.5	2.5	5	67.5
6	C	2	2	2.5	2.5	2.5	62.5
7	F	2	3	0	0	5	45
8	H	0	2	2.5	2.5	2.5	42.5
9	I	0	2	2.5	2.5	2.5	42.5
10	J	0	2	2.5	2.5	0	37.5
11	K	0	2	0	2.5	2.5	30
12	L	0	2	0	2.5	0	25
13	M	0	1	0	2.5	0	20
14	N	0	1	0	2.5	0	20
15	O	2	0	0	0	0	20
16	P	0	0	2.5	0	2.5	17.5
17	Q	0	0	0	2.5	0	15
18	R	0	2	0	0	2.5	15
19	S	0	2	0	0	2.5	15
20	T	0	1	0	0	2.5	10
21	U	0	1	0	0	2.5	10
22	V	0	2	0	0	0	10
23	W	0	1	0	0	0	5
24	X	0	1	0	0	0	5
25	Y	0	1	0	0	0	5
26	Z	0	1	0	0	0	5
27	AA	0	1	0	0	0	5
28	BB	0	1	0	0	0	5
29	CC	0	0	0	0	0	0
30	DD	0	0	0	0	0	0
31	EE	0	0	0	0	0	0
32	FF	0	0	0	0	0	0
33	GG	0	0	0	0	0	0
34	HH	0	0	0	0	0	0

health-based reduction target for *Cryptosporidium*, *Giardia*, and *E. coli* when all treatment barriers are in place as shown in Figure 1, noting that QMRA was only completed for systems that showed the presence of microbial parameters. For all seven systems, if all treatment barriers fail (i.e., raw water is consumed), all systems would fail the health target for the three microbes.

Table 6 | Protozoan and general water quality results for Communities A–G surface water sources

Water system	Parameter	Average	Min.	Max.	Standard deviation	Number of positive samples/total number of samples	Number of samples requiring >3-log reduction
A	pH	6.6	5.9	7.2	0.4		
	E. coli (CFU/100 mL)	8	< 1	19	5	11/12	
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/12	0
	Giardia (cysts/100 L)		< 10	10		2/12	0
B	pH	6.5	5.8	7.2	0.4		
	E. coli (CFU/100 mL)	75	1	461	139	12/12	
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/12	0
	Giardia (cysts/100 L)		< 10	140		3/12	2
C	pH	6.8	6.5	7.5	0.3		
	E. coli (CFU/100 mL)	27	2	78	24	12/12	
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/12	0
	Giardia (cysts/100 L)		< 10	200		4/12	2
D	pH	6.5	6.1	6.8	0.2		
	E. coli (CFU/100 mL)	6	< 10	15	4	9/12	
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/12	0
	Giardia (cysts/100 L)		< 10	< 10		0/12	0
E	pH	5.5	5.4	6.6	1.8		
	E. coli (CFU/100 mL)	3	< 10	8	4	4/12	
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/12	0
	Giardia (cysts/100 L)		< 10	< 10		0/12	0
F	pH	7.0	5.7	8.4	0.8		
	Cryptosporidium (oocysts/100 L)		< 10	130		1/26	1
	Giardia (cysts/100 L)		< 10	130		1/26	1
G	pH	6.8	6.0	7.8	0.5		
	Cryptosporidium (oocysts/100 L)		< 10	< 10		0/25	0
	Giardia (cysts/100 L)		< 10	1,067		4/25	3

CFU: colony forming units.

DISCUSSION

Surface source water monitoring

Many jurisdictions, including the USEPA, Ontario and Alberta, require small systems (those <10,000 people) to use *E. coli* monitoring to inform whether *Cryptosporidium* and *Giardia* sampling needs to be initiated. Only one sample from this study had a positive result for *Cryptosporidium*; however, 14 samples had a positive result for *Giardia,* nine of which had *E. coli* results to compare with. There was no correlation found between the presence/absence of *E. coli* as an indicator organism, and the presence/absence of *Giardia*. It should be noted that, as mentioned previously, the detection limit for *Giardia* in this study was cysts/10 L, therefore a non-detect for *Giardia* and/or *Cryptosporidium* in the sample results does not necessarily represent complete absence in the source water. In addition, the USEPA only requires protozoa sampling if the *E. coli* levels are greater than 10 CFU/100 mL for lakes and rivers, and 50 CFU/100 mL for flowing streams. Of the nine positive samples for *Giardia,* two occurred when the concentration of *E. coli*

Table 7 | Log reduction credits associated with treatment processes for select Nova Scotia surface source waters treatment plants based on outputs of QMRA modeling

Community	*Cryptosporidium*	*Giardia*	*E. coli*
A			
Coagulation	1.86	1.61	1.39
Filtration	2.41	1.92	1.57
Chlorine disinfection	0.01	0.76	12.00
UV disinfection			
Total	4.28	4.29	14.95
B			
Coagulation	1.86	1.61	1.39
Filtration	2.41	1.92	1.57
Chlorine disinfection	0.03	1.05	12.00
UV disinfection			
Total	4.30	4.58	14.96
C			
Coagulation	1.86	1.61	1.39
Filtration	6.41	6.18	10.00
Chlorine disinfection	0.03	0.81	12.00
UV disinfection			
Total	8.30	8.60	23.39
D			
Coagulation	0.00	0.00	0.00
Filtration	6.41	6.18	10.00
Chlorine disinfection	0.02	0.72	12.00
UV disinfection			
Total	6.43	6.90	22.00
E			
Coagulation	1.86	1.61	1.39
Filtration	2.41	1.92	1.57
Chlorine disinfection	0.05	2.54	12.00
UV disinfection			
Total	4.32	6.07	14.96
F			
Coagulation	0.00	0.00	0.00
Filtration	6.41	6.18	10.00
Chlorine disinfection	0.00	0.30	9.47
UV disinfection	4.43	4.53	5.10
Total	10.84	11.01	24.57
G			
Coagulation	0.00	0.00	0.00
Filtration	6.41	6.18	10.00
Chlorine disinfection	0.00	0.30	9.47
UV disinfection	4.43	4.53	5.10
Total	10.84	11.01	24.57

was less than 10 CFU/100 mL. From these results, *E. coli* is an inappropriate indicator for protozoa presence for Nova Scotia source waters. This finding is consistent with the literature (Wilkes *et al.* 2009; Nieminski *et al.* 2010).

Use of a surface water vulnerability assessment as a pre-screening tool

By comparing the risk ranking of the semi-quantitative risk analysis with the results of the microbial sampling (both concentration and number of positive samples), we end up with the following risk rankings for the source waters (not taking into consideration the treatment barriers) from high to low:

- source water for Communities G, C, B, A, F, D, E (water quality data);
- source water for Communities A, G, B, D, E, C, F (semi-quantitative risk analysis).

The semi-quantitative risk analysis was a good first step toward identifying the water sources most at risk and prioritizing resources for source water monitoring. However, the differences in the bullet points demonstrate the importance for collecting actual samples from sources that may be at risk to truly assess source water quality and risk.

In this study, there was only one positive sample for *Cryptosporidium*, and 14 positive samples for *Giardia*. Based on these results, *Giardia* appears to be the protozoa of concern in source waters in Nova Scotia. However, utilities must remain vigilant against *Cryptosporidium*, as the non-detect results are dependent on the study detection limits and may not accurately reflect *Cryptosporidium* presence. Also, it is a chlorine-resistant microorganism that requires effective filtration for removal. If filtration plants are meeting turbidity limits, filtration should ensure adequate removal of both *Giardia* and *Cryptosporidium*.

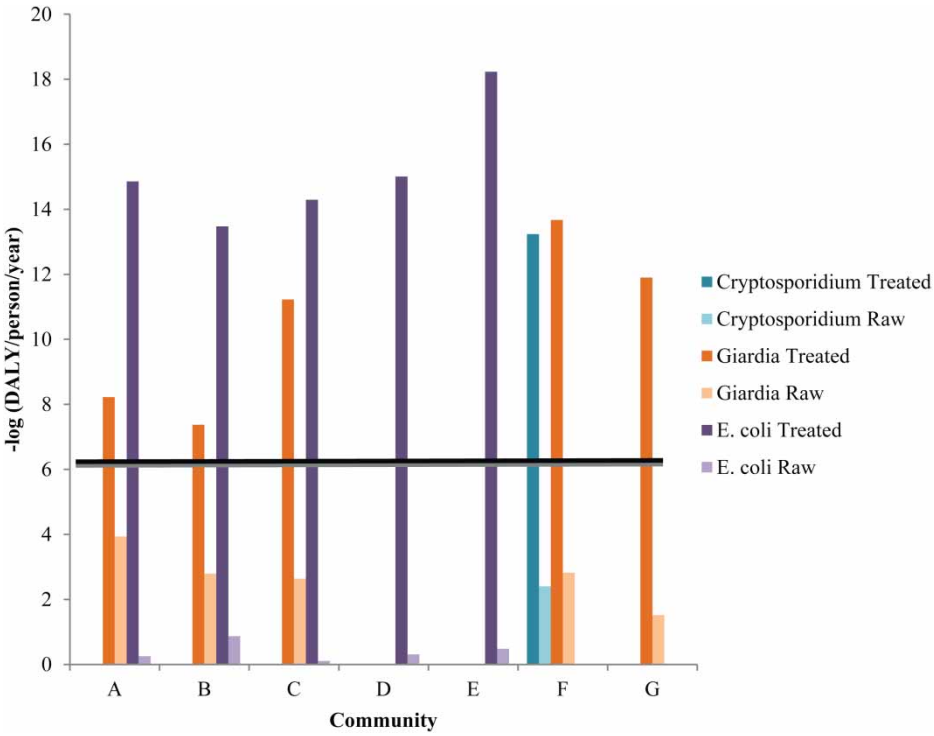

Figure 1 | Disease burden due to *Cryptosporidium, Giardia* and *E. coli* presence in source water in seven Nova Scotia community water systems. The black line in the figure represents the WHO health target and all bars that are above the black line provide an adequate barrier.

QMRA as a risk management tool

QMRA modeling was conducted on seven sites in Nova Scotia. The results revealed that only under unique 'emergency situations' (i.e., no treatment and disinfection), would human health risks be predicted (as measured by DALYs). In general, most surface water systems in Nova Scotia are anticipated to meet DALY values that would be expected through normal operating conditions. This analysis shows that as long as treatment plants are operated as designed, and managed properly, all systems should meet the required log reduction targets. As shown in Table 7, all of these systems have adequate treatment barriers in place to provide the required log reduction for both *Cryptosporidium* and *Giardia* based on averages assigned to the model. In addition, all systems have adequate protection in place to meet the health-based targets given the measured levels of pathogens as shown in Figure 1.

As mentioned above, assuming all barriers were in place and functioning as designed, all of the seven systems meet the health-based targets, largely because Communities F and G have both ultra- and nano-filtration membranes and UV disinfection, which provides additional levels of protozoan protection over conventional treatment (10–11-log reduction credits of protozoa, as shown in Table 7). In addition, three of the seven sites did not have sample results that indicated the need for a >3-log requirement for *Giardia.* It would then be likely that source waters with lower risk factors would also not require a >3-log reduction for protozoa, unless a major change occurred within the watershed increasing the risk of source water contamination.

CONCLUSIONS

Seven surface waters in Nova Scotia were evaluated for source water protozoan risks, all of which likely had the highest risk of microbial contamination in the province, based on a semi-quantitative risk analysis. The microbial sampling results in this study indicated

that some source waters in Nova Scotia are at higher risk of contamination than the current 3-log reduction requirement in the province. The semi-quantitative risk analysis is a useful pre-screening tool for directing resources toward vulnerable source waters, but is not an adequate replacement for site sampling and analysis.

The majority of regulations across Canada and in the USA require 3-log reduction for *Giardia* and either 2- or 3-log reduction for *Cryptosporidium*, unless source water protozoan concentrations dictate increased log reduction. Based on the results from this study, it would appear that *Giardia* is of larger concern in source waters in Nova Scotia than *Cryptosporidium*. Also, the frequent use of *E. coli* as an indicator organism for protozoa in small systems helps with cost reduction, but this study indicated that *E. coli* is not an appropriate indicator for protozoa in Nova Scotia.

Based on the results of this study, there is no justification to require greater than 3-log reduction for *Giardia* cysts or *Cryptosporidium* oocysts in Nova Scotia at this time. The QMRA demonstrated that existing conditions provided adequate health risk mitigation and the actual treatment reductions achieved were greater than 3-log. This was made necessary because in some cases greater health targets were required for vulnerable source waters. If these facilities were only designed to achieve 3-log reduction of protozoa, they would not meet the health targets. The use of actual water quality data and treatment performance in the model is critical to ensure that results are reflective of actual practice and site-specific conditions.

ACKNOWLEDGMENTS

The authors acknowledge the research funding provided by the NSERC/Halifax Water Industrial Research Chair program. In addition, the authors kindly acknowledge project support provided by the Nova Scotia Department of Environment. Finally, the authors thank Ms Judy MacDonald for her technical review and insight throughout the project.

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First received 6 February 2015; accepted in revised form 27 May 2015. Available online 7 July 2015