Characteristics of small residential and commercial water systems that influence their likelihood of being on drinking water advisories in rural British Columbia, Canada: a cross-sectional study using administrative data

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ABSTRACT

Health officials often lack information about characteristics that predict which water systems are most likely to be placed on and to persist on drinking water advisories (e.g. health warnings offering advice or information). This study uses data collected by the Interior Health Authority in British Columbia to characterize water systems on advisory for microbiological threats and to identify the variables associated with advisory status and length. By systematically extracting key characteristics, this study explores advisory status by examining associated variables: water systems size, administrative area, governance structure, water source, treatment level, and service type (e.g. residential or commercial systems). Results show residential and commercial water systems have different characteristics associated with advisory status and length. For residential systems, certain governance structures are more likely to be placed on and to stay on advisory, especially the cooperative governance structures not operated by local governments. For commercial systems, administrative area and system size were associated with advisory status, but not advisory length. The overall results highlight the influence of governance structure and support the need for targeted interventions to improve residential small water systems not operated by local governments or utilities. Lastly, these results show how health officials can use administrative data for program planning and evaluation.

Key words | administrative data, boil water advisories, drinking water, small water systems

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LIST OF ABBREVIATIONS

BC	British Columbia
CPCN	Certificate of Public Convenience and Necessity
CI	Confidence interval
EHO	Environmental Health Officer
DWPA	Drinking Water Protection Act
HES	Hedgehog Environmental System
IHA	Interior Health Authority
MOE	Ministry of Environment
OR	Odds ratio
POU	Point-of-use
SWS	Small water system
UV	Ultra violet disinfection
WUC	Water users community
WS1	Water system serving greater than 300 service connections
WS2	Water system serving between 15 and 300 service connections
WS3	Water system serving fewer than 15 service connections

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INTRODUCTION

The importance of safe and reliable tap water came into focus for Canadians during the 2000 *Escherichia coli* outbreak in Walkerton, Ontario, where contaminated drinking water resulted in approximately 2,300 cases of illness and seven preventable deaths (Schuster *et al.* 2005; Geldreich 2005; Hrudey *et al.* 2006; Hrudey & Hrudey 2007). Over a decade later, many parts of Canada still rely on drinking water supplies that lack proper maintenance and fall below current health standards (Geldreich 2005; Hrudey 2011). Several reports (Eggertson 2008; Hrudey 2008, 2011; Office of the Ombudsman 2008) have highlighted these shortcomings, suggesting that the high number of persistent boil water advisories (e.g. health warnings offering advice or information) indicates that certain water systems have made little progress towards providing safer drinking water.

Drinking water advisories communicate risk to the public and offer advice when conditions exist that expose individuals to health threats from their drinking water supply. Officials issue boil water advisories in emergency situations (such as bacteriological contamination, inadequate treatment, or disinfection failure) when users must boil their water or use bottled water to protect themselves from becoming ill from their drinking supply (BC Ministry of Health 2011). Other types of water quality advisories may warn certain vulnerable populations when risks from microbiological agents are modest, or may inform users not to consume their water when boiling cannot remediate an identified contaminant (BC Ministry of Health 2011). Drinking water advisories do not directly measure population health outcomes, as they do not depend on the incidence of waterborne disease. Yet persistent advisories can indicate poor risk management and can be used to examine inadequate water quality (Eggertson 2008; Hrudey 2011; Patrick 2011).

While health officials agree that the number of drinking water advisories remains a concern (Eggertson 2008), there is limited information about the characteristics that predict which water systems are most likely to be placed on advisory or persist on advisory. Long lasting drinking water advisories occur most often among small water systems (SWSs), and experts agree that SWSs face a number of challenges meeting current water quality and treatment standards compared with larger municipal systems (Grose *et al.* 1998; Jocoy 2000; AquaVic Water Solutions Inc. 2005; Geldreich 2005; Smith *et al.* 2006; Ministry of Community Services 2007; Office of the Ombudsman 2008; Hrudey 2008; Hunter *et al.* 2009; Patrick 2011; Kot *et al.* 2011).

Health Canada defines SWSs as those systems serving fewer than 5,000 people (National Collaborating Centres for Public Health 2009). However, SWS definitions vary among the provinces and territories ranging from systems serving as few as two, five, or 15 households (connection based) to serving up to 100, 500, or 5,000 people (population based). Unlike larger systems run by local governments, SWSs commonly lack access to funding, resources, and trained personnel (AquaVic Water Solutions Inc. 2005; Geldreich 2005; Ministry of Community Services 2007; Office of the Ombudsman 2008). Experts also agree that SWSs are at higher risk of enteric waterborne disease resulting from inadequate treatment and infrastructure, poor source water quality, and insufficient operations and maintenance (Geldreich 1989, 2005; Davies & Mazumder 2003; Schuster *et al.* 2005; Jones *et al.* 2006; Smith *et al.* 2006; Hrudey & Hrudey 2007; Hunter *et al.* 2009, 2011; Richardson *et al.* 2009; Uhlmann *et al.* 2009). Research also shows that spatial (location and proximity to sources of contamination) and temporal (seasonal precipitation and temperature) factors can negatively impact on water quality for small systems, challenging them further (Auld *et al.* 2004; Thomas *et al.* 2006; Richardson *et al.* 2009). Even with the recognition of SWS challenges, information about the key characteristics of drinking water systems (source, treatment, water system size, number of people served, governance structure, etc.) remains limited and not readily accessible across Canada (Schuster *et al.* 2005; Smith *et al.* 2006; Office of the Ombudsman 2008; Hunter *et al.* 2009; Moffat & Struck 2011). Although such information may exist at the local level, health officials have rarely collected and recorded it in a way that allows them to quantitatively assess system-related health risks.

In Canada, the constitutional division of powers between the provinces, territories, and federal government guides the regulatory oversight for drinking water (Hrudey 2011). Health Canada sets microbiological, physical and chemical guidelines for drinking water potability; however, the provinces and territories provide regulatory oversight and set the operational standards for water systems governed at the local level through individual provincial or territorial regulations (Hrudey 2011). British Columbia, New Brunswick and the three territories are the only jurisdictions in Canada where the departments of health are the primary regulators of all drinking water supply systems (Boettger, Provincial Drinking Water Officer, BC, personal correspondence May 2012). The other Canadian provinces rely on their respective environmental departments or equivalent to regulate drinking water supplies down to a certain size. Below this cut off, the local departments of health have varying levels of responsibility and oversight depending on the province (Boettger, personal correspondence 2012). Regardless of the jurisdictional oversight model, the medical health officers in all provinces play a role when called upon or notified that health parameters exceed guidelines or other threats to drinking water exist in public water supplies (Boettger, personal correspondence 2012).

Health officials have identified long-term (≥18 months) boil water advisories as a challenge in British Columbia (BC) (Eggertson 2008; Office of the Ombudsman 2008), particularly in the Interior Health Authority (IHA) where an estimated 737,500 of BC's 4.57 million plus residents live (BC Stats 2011). The IHA includes an immense rural and semi-rural region of the province (Figure 1). In BC, Environmental Health Officers (EHOs) employed by the regional health authorities administer the BC (2001) Drinking Water Protection Act (DWPA) and are responsible for the inspection and monitoring of regulated drinking water supplies to ensure public health standards are met. The DWPA also determines the sampling frequency for all water systems based on the number of people they serve. Ideally, systems serving fewer than 5,000 people are required to sample at least four times per month. In reality, SWSs do not often sample at this frequency. The EHO has the discretion to reduce or increase the sampling frequency after considering the system size, population served, source, location, sampling history, and whether or not the system has robust treatment (or no treatment at all).

The IHA has jurisdiction over a large majority of the approximated 4,000 plus regulated water systems (Eggertson 2008; Office of the Ombudsman 2008) in the province. The high number of water systems regulated across BC relates to the size of the province, its mountainous topography, but also to the fact that BC is the only Canadian jurisdiction that regulates and requires an operating permit for any water supply serving anything larger than a single-family residence. The BC DWPA defines water systems that must be regulated as any domestic supply with two or more connections or any commercial operation (including those with a single service connection, such as a restaurant or hotel). More water quality advisories appear in the IHA than in the other four BC regional health authorities combined, a situation which local health officials relate to the abundance of SWSs found in the BC interior. (The public can view and count current advisories for all five BC regional health authorities at: http://www.health.gov.bc.ca/protect/dwadvisories.html.) Approximately 91% of the water systems regulated under the DWPA within the IHA meet the provincial definition of a SWS (different from the federal definition), which is restricted to those systems serving up to 500 people within a 24-hour period (Office of the Ombudsman 2008).

The primary objective of this study was to use data collected by the IHA about the characteristics of residential and commercial water systems to identify the variables associated with being on advisory and being on long-term advisory. Through a systematic extraction of key characteristics from reports within the IHA database, we explore how advisory status and advisory length are associated with water system size (measured by the number of service connections and population served), administrative area (e.g. regional district), governance structure, water source, treatment level, and service type (e.g. commercial versus residential systems). The study includes type of governance structure as a variable, because BC health professionals have identified it as one of the barriers to water system maintenance and improvement. Reports from other parts of Canada support this claim. Conestoga-Rovers & Associates (2011) found governance to have an impact on infrastructure and the number of advisories in Newfoundland and Labrador. Water system governance refers to the structure and administrative processes that direct and control operations, decision-making, and finances (AquaVic Water Solutions Inc. 2005; Office of the Ombudsman 2008; Brandes & Curran 2009). British Columbia faces a greater regulatory challenge than other Canadian provinces when it comes to drinking water governance and oversight (Nowlan & Bakker 2007; Patrick 2008; Brandes & Curran 2009). This challenge emerges from the number and complexity of

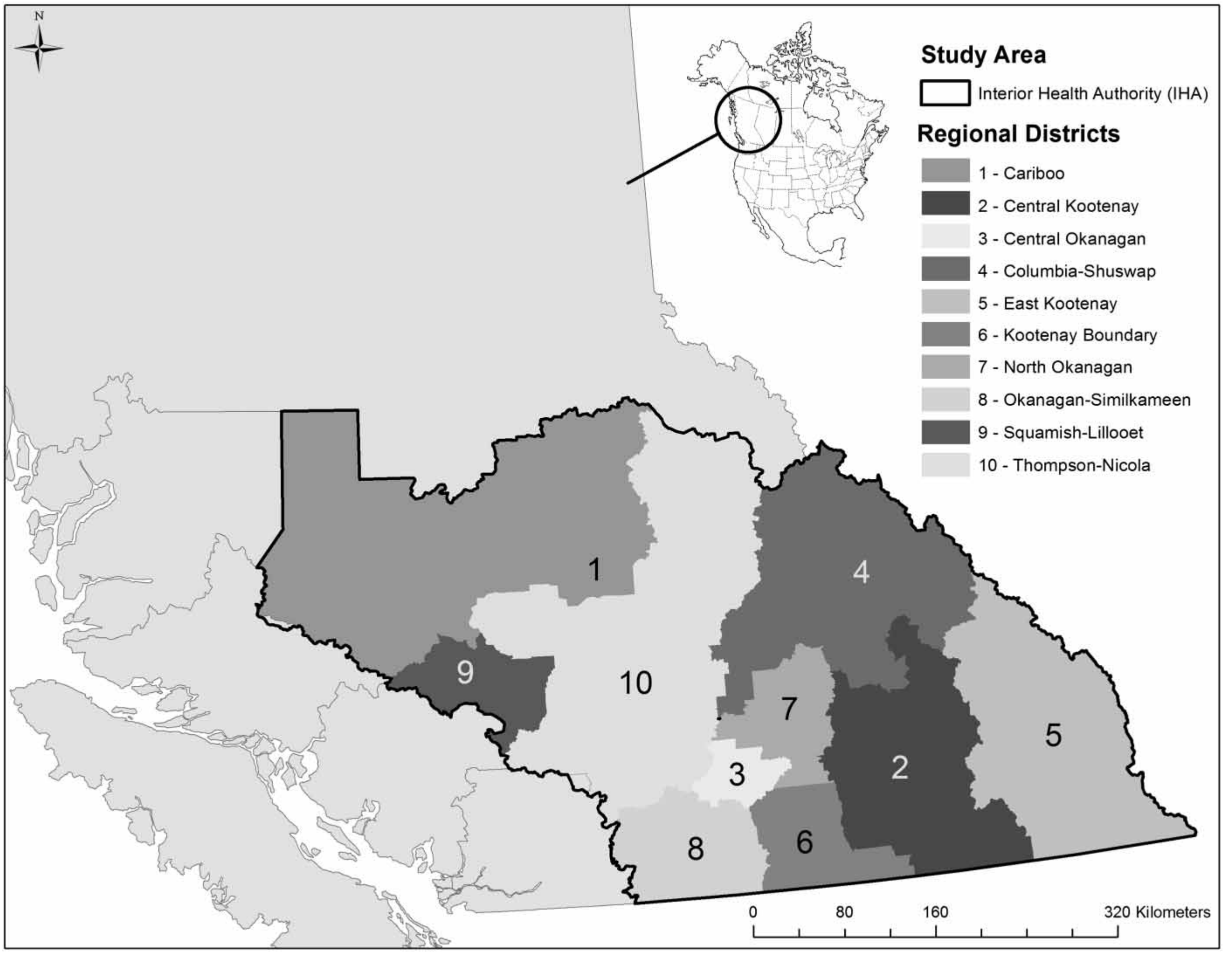

Figure 1 | Map of the study area and the 10 regional districts within the BC IHA.

governance structures (Table 1) and the amount of legislation pertaining to water under the jurisdiction of multiple branches of government. Although the governance oversight and legislation differ among the varying governance structures in BC, the DWPA determines the operational, sampling, and supply standards for all regulated drinking water supplies, regardless of their type.

Our secondary objective was to illustrate how the administrative data, which regulatory agencies routinely collect as part of their health inspection and approval processes, can be used to quantify characteristics that predict drinking water advisories. By using administrative data in this way, regulatory agencies could target interventions and policies towards water systems most likely to be on advisory.

METHODS

Data sources and extraction

This study included 1,847 residential and commercial water systems as recorded in the IHA database as of March 2011. The study excluded water systems categorized as water depots and bottlers ($n = 8$), bulk haulers ($n = 15$), those with pending applications ($n = 4$), and those on advisory due to chemical parameters exceeding the Guidelines for Canadian Drinking Water Quality ($n = 10$). The last-mentioned were excluded to focus the study on water advisories related to microbiological threats. Water systems with more than one permit ($n = 3$) were only counted once.

Table 1 | Descriptions of the various types of governance structures for water systems in British Columbia

Type of governance	Description
Municipalities	Municipalities refer to a type of local government system that owns and operates the water systems found in cities, towns, and villages. Municipal systems consist of an elected mayor and council that are governed under the *BC Local Government Act* and the *Community Charter* with oversight provided by the Ministry of Community, Sport, and Cultural Development (Office of the Ombudsman 2008). Most large water systems are municipal systems.
Regional districts	Regional districts provide regional governance and services across BC. Regional districts are often the local government type in rural areas in BC outside the boundaries of municipalities. Regional district water systems are governed under the *BC Local Government Act* by an elected board of directors who represent the various smaller electoral areas (Office of the Ombudsman 2008). The Ministry of Community, Sport, and Cultural Development provides governance oversight.
Improvement districts	Improvement districts (which include irrigation and waterworks districts) are incorporated under the *BC Local Government Act*, but are not considered an official form of local government (Office of the Ombudsman 2008). They provide limited services in rural areas, but they rely on a board of elected trustees (who are sometimes volunteers) and do not have access to the same funding as municipalities and regional districts (Office of the Ombudsman 2008). The Ministry of Community, Sport, and Cultural Development provides governance oversight.
Utilities	Utilities are water systems built by developers in areas where no existing water service is available. They are governed under the *BC Water Utility Act* and *the Utility Commission Act* with oversight provided by the Comptroller of Water Rights from the Ministry of Forests, Lands, and Natural Resource Operations. Utilities are owned and organized by an individual, a corporation, a strata corporation, or a water users society. Prior to construction, utilities must get approval from the Comptroller through a Certificate of Public Convenience and Necessity (CPCN) (Office of the Ombudsman 2008; Ministry of Environment 2010).
Strata corporations	Strata councils under the *BC Strata Property Act* can also govern water systems independent of the Comptroller of Water Rights, but they do not hold a CPCN. Strata corporations are often developed as utilities, but once the majority of lots are sold the Comptroller relinquishes oversight to the strata corporation (Ministry of Environment 2010).
Societies	Water systems can also govern themselves as a society under the *BC Society Act* independent of the Comptroller of Water Rights. Societies that are not governed as a utility under the Comptroller do not hold a CPCN. Societies are organized as either a water users society/association (residential systems) or a non-profit society (commercial systems).
Water user communities	Water users communities (WUC) are another form of incorporated cooperative governance under the *BC Water Act* that rely on surface water systems only. The Comptroller of Water Rights provides some limited oversight to WUCs, which consist of a small group of homeowners with individual water licenses who collectively share a water works system (Office of the Ombudsman 2008). Unlike utilities, WUCs do not need to prove health requirements are met prior to obtaining approval from the Comptroller to incorporate and share a water system.
Joint systems	Joint good neighbor systems are those small water systems that are not governed or incorporated under any act. They consist of a group of dwellings and individuals that share a source and water system, often lacking in clear ownership and oversight. These systems may be as small as two neighbors sharing a single source.
Private systems	Private water systems are the most abundant type of water system. Private systems are those systems owned and operated by an individual, business or corporation. Mobile home parks and trailer courts most often fall in the private category (Ministry of Environment 2010).
Provincial and federal government systems	BC also has a variety of provincial and federal government owned and operated water systems. Various ministries and agencies own and operate these systems. For provincial systems, the agencies include BC Parks; Ministry of Forests, Lands, and Natural Resource Operations; Ministry of Transportation, etc. A few federal government owned water systems, such as Canada Customs and Parks Canada, are included in this government category.
School districts	School districts owned and operated water systems are governed under the *BC School Act*. The Ministry of Education provides governance oversight.

The IHA maintains information about all regulated water systems under its jurisdiction in the Hedgehog Classic Environmental System (HES) database, created for Canadian environmental health professionals by Hedgerow Software Ltd (www.hedgerowsoftware.com/index.php/home). Information on individual water systems is manually uploaded to HES through a variety of forms completed as part of the administration and health inspection processes. These include *application forms* for operating permits, *inspection reports*, *inspection priority assessment forms*, *sample site creation forms*, and *drinking water public notifications*. Once entered in HES, information from these forms is used to generate a variety of reports including *facility listing reports*, *sample site reports*, *connected facility reports*, and *advisory listing reports*. All forms and reports used in this study are described in detail below.

Basic administrative data are collected via *application forms* for all water systems and premises that are regulated by EHOs. This information includes the legal name, ownership information, governance structure, administrative area, and number of connections. *Facility listing reports* provide lists of water systems that can be sorted by number of connections, governance structure, administrative area, inspection priority rating, and/or the overseeing EHO. *Connected facility reports* list all regulated facilities (such as restaurants) that are supplied by the same water system. EHOs complete *inspection reports* for each inspection conducted on regulated facilities. These mostly contain qualitative information about the facility or the observations of the EHO, but the reports also include codes for observed violations and actions taken. EHOs also complete *inspection priority assessment forms* after every routine inspection, which are used to determine inspection frequency and priority. These forms include information about water source, water treatment, operator training, engineering standards, maintenance, bacteriological sampling history, and water system size. *Sample site creation forms* are completed by EHOs when they set up a water system sample site location for routine or audit sampling. These forms include some general information on the water source, type of treatment, and the size of the population served. HES uses information collected from *sample site creation forms* to produce *sample site reports*, which provide a list of all sample sites for the water systems that have been set up for monitoring. Finally, *drinking water public notifications* are completed in HES when an EHO issues an advisory. The HES uses the information entered to create *advisory listing reports*. These reports provide a list of current (or past) drinking water advisories in the IHA, and include information on the type of advisory, reason for the advisory, start date of the advisory, and number of days in effect.

Cross-sectional information about each water system was extracted from HES database reports generated between 1st January 2011 and 3rd March 2011. The primary outcome of interest was advisory status taken from an advisory listing report generated on 3rd March 2011, where water systems were either on a drinking water advisory or not on an advisory that day. The secondary outcome of interest was advisory length, where the status of those systems on a drinking water advisory as of 3rd March was classified as either a short-term advisory (<18 months) or a long-term advisory (≥18 months), using the same definition of a long-term advisory found in the 2008 BC Ombudsman's report (Office of the Ombudsman 2008). This study applied this definition in response to concerns highlighted about the large number of long-term advisories that persist in BC with little action towards improvement. This dichotomization allowed the study to compare the characteristics of systems that had been on advisory for a very long time (some lasting longer than 20 years) with those that had been put on advisory more recently (within the last 18 months).

All data on advisories came from *advisory listing reports* within HES. While the IHA strives to follow clear and consistent criteria for issuing drinking water advisories, some historical and regional differences in practices do persist. Because untreated surface water should always warrant advisory status, we assessed the assumption that advisories were consistently applied across the administrative areas by comparing the number of water systems recorded as having untreated surface water, but were not recorded as being on an advisory.

Variables potentially associated with advisory status were system type, water source, water treatment, number of connections, population served, type of governance structure, and administrative area. These variables and their extraction are described below. After data extraction was complete, only one water system was missing information on water source, water treatment, and population served.

System type

Water systems were categorized as being either commercial or residential (Table 2). We defined commercial water systems as those serving food facilities, tourist sites, recreational operations, parks, golf courses, ski hills without residential developments, businesses, industrial sites, campgrounds, recreational vehicle parks, schools, day cares, care homes, resorts, lodges, hotels, inns, churches, community halls, border crossings and rest stops. Residential systems included those serving communities, subdivisions, mobile home parks, and any other residential grouping with a shared source and distribution. This distinction between commercial and residential water systems does not exist in HES. Therefore, we categorized the water systems using the water system name and owner information provided in the *facility listing report*. In cases where the correct classification did not appear to be obvious from this information, we verified the status by reviewing facility *inspection reports* and searching online for business names. When the water system name sounded like it could be a commercial facility business name, we checked the *connected facility report* to see if a regulated facility (such as a food premise) was connected to the water system with the same name. When these methods could not confirm the status of facilities, we contacted a local EHO familiar with the water system.

Water source

The water systems in our sample had a variety of surface water, groundwater, or combined sources. This study categorized them as protected groundwater, groundwater protection unknown, unprotected groundwater, or surface water (Table 2). The category 'groundwater protection unknown' included water systems categorized as having multiple wells in HES ($n = 31$). Surface water sources listed in HES included lakes ($n = 224$), springs and other flowing supplies ($n = 363$), and combined surface water sources ($n = 12$). Water systems listed as having both a

Table 2 | Proportions of water system characteristics, advisories, and long-term advisories among residential and commercial water systems

	Residential water systems (Total $n = 619$)			Commercial water systems (Total $n = 1{,}228$)[a]		
Water system characteristics/ variables	**(No.)**	**Number on advisory (No. (%))**	**Number of advisories on long-term advisory (No. (%))**	**(No.)**	**Number on advisory (No. (%))**	**Number of advisories on long-term advisory (No. (%))**
Source						
Groundwater – protected	90	13 (14.4%)	6 (46.2%)	364	17 (4.7%)	5 (29.4%)
Groundwater – protection unknown	145	23 (15.9%)	14 (60.9%)	356	42 (11.8%)	28 (66.7%)
Groundwater – unprotected	62	23 (37.1%)	22 (95.7%)	168	47 (28.0%)	34 (72.3%)
Surface water	322	132 (41.0%)	117 (88.6%)	339	114 (33.6%)	92 (80.7%)
Treatment						
Dual treatment or more	60	6 (10.0%)	5 (83.3%)	52	1 (1.9%)	0 (0.0%)
Chlorine only	176	34 (19.3%)	23 (67.6%)	76	9 (11.8%)	7 (77.8%)
Other (UV and/or filtration)	26	8 (30.8%)	8 (100.0%)	197	25 (12.7%)	13 (52.0%)
No treatment	357	143 (40.1%)	123 (86.0%)	902	185 (20.5%)	139 (75.1%)
Population served						
>5,000	28	3 (10.7%)	1 (33.3%)	4	0 (0.0%)	N/A
501–5,000	90	14 (15.6%)	8 (57.1%)	41	8 (19.5%)	4 (50.0%)
51–500	290	91 (31.4%)	77 (84.6%)	446	79 (17.7%)	54 (68.4%)
0–50	211	83 (39.3%)	73 (88.0%)	736	133 (18.1%)	101 (75.9%)

(*continued*)

Table 2 | continued

Water system characteristics/ variables	Residential water systems (Total $n = 619$)			Commercial water systems (Total $n = 1,228$)[a]		
	(No.)	Number on advisory (No. (%))	Number of advisories on long-term advisory (No. (%))	(No.)	Number on advisory (No. (%))	Number of advisories on long-term advisory (No. (%))
Number of connections						
WS1: >300	85	10 (11.8%)	5 (50.0%)	0	N/A	N/A
WS2: 15–300	348	105 (30.2%)	87 (82.9%)	163	45 (27.6%)	30 (66.7%)
WS3: <15	186	76 (40.9%)	67 (88.2%)	1,065	175 (16.4%)	129 (73.7%)
Governance structure						
Municipalities	68	6 (8.8%)	1 (16.7%)	16	3 (18.8%)	1 (33.3%)
Regional districts	62	19 (30.6%)	15 (78.9%)	30	4 (13.3%)	3 (75.0%)
Improvement districts	95	35 (36.8%)	30 (85.7%)	0	N/A	N/A
Government systems	0	N/A	N/A	132	26 (19.7%)	23 (88.5%)
School districts	0	N/A	N/A	44	5 (11.4%)	3 (60.0%)
Utilities	77	11 (14.3%)	8 (72.7%)	15	2 (13.3%)	0 (0.0%)
Strata corporations	58	20 (34.5%)	15 (75.0%)	15	3 (20.0%)	1 (33.3%)
Societies	25	11 (44.0%)	8 (72.7%)	95	16 (16.8%)	10 (62.5%)
Water users communities	46	35 (76.1%)	34 (97.1%)	0	N/A	N/A
Joint systems	48	27 (56.3%)	24 (88.9%)	0	N/A	N/A
Private systems	140	27 (19.3%)	24 (88.9%)	881	161 (18.3%)	118 (73.3%)
Administrative area (e.g. regional district)						
East Kootenay	66	15 (22.7%)	15 (100.0%)	139	12 (8.6%)	8 (66.7%)
Central Kootenay	139	59 (42.4%)	54 (91.5%)	215	22 (10.2%)	20 (90.9%)
Kootenay – Boundary	36	8 (22.2%)	7 (87.5%)	75	12 (16.0%)	9 (75.0%)
Cariboo	33	6 (18.2%)	4 (66.7%)	229	41 (17.9%)	29 (70.7%)
Columbia – Shuswap	89	19 (21.3%)	12 (63.2%)	163	19 (11.7%)	7 (36.8%)
Thompson – Nicola	84	33 (39.3%)	28 (84.8%)	200	61 (30.5%)	48 (78.7%)
Squamish – Lillooet	9	6 (66.7%)	5 (83.3%)	19	4 (21.1%)	1 (25.0%)
Central Okanagan	55	17 (30.9%)	12 (70.6%)	48	11 (22.9%)	9 (81.8%)
North Okanagan	51	12 (23.5%)	9 (75.0%)	70	11 (15.7%)	8 (72.7%)
South Okanagan – Similkameen	57	16 (28.1%)	13 (81.3%)	70	27 (38.6%)	20 (74.1%)

[a] $n = 1,227$ for water source, water treatment, and population served for commercial water systems because of missing data for one water system.

surface and groundwater source ($n = 62$) were included in the surface water category because they were considered to have the same level of vulnerability as other surface water sources.

The EHOs assess the level of groundwater protection by a number of factors, including: the depth and type of the well; the vulnerability of the aquifer to surface contamination; the adequacy of the surface seal; the location and protection of the wellhead; and the proximity to sources of contamination (BC Ministry of Health 2012). Wells that are shallow, dug, poorly constructed, or located in a zone at risk of contamination from surface run-off or flooding are considered unprotected, especially if the well has no surface seal or is located in a well pit (Geldreich 2005; Richardson *et al.* 2009; Uhlmann *et al.* 2009; BC Ministry of Health 2012). Health officials also consider groundwater sources that are hydrogeologically linked to a surface supply as being at risk of containing pathogens (BC

Ministry of Health 2012). In circumstances where EHOs lack enough information or cannot determine the level of vulnerability of the well or the aquifer from their visual observation, they classify the well as having unknown protection.

HES does not typically track the source water type. Instead, information on water sources is limited to data available from *sample site reports*, which were never intended for surveillance and reporting purposes. Unfortunately, information on source water was only available for water systems that had a sample site created in HES for routine or audit sampling, which resulted in missing information for many water systems. We found the missing information by checking other types of reports such as *inspection priority assessment forms* and individual *inspection reports* completed by EHOs. If information on water source did not appear in other reports, we consulted a local EHO who was familiar with the water system. In some cases conflicting information occurred as a result of multiple *sample site creation forms* being completed for the same water system at different times by different EHOs, who may have recorded the information on water source differently (such as the level of groundwater protection). The classification of groundwater sources as protected, unprotected, or having an unknown level of protection was based on the professional opinion of the presiding EHO. The classification is therefore somewhat subjective, and does not often link to the results of an official comprehensive hydrogeological vulnerability assessment. We clarified conflicting information as much as possible through reviewing *inspection reports* and consulting with the local EHO. Regardless, some misclassification likely remains.

Water treatment

Information on water treatment was extracted from *sample site reports*. Four categories were used to indicate the level of treatment for each water system: dual treatment or more, chlorination only, other, or no approved treatment listed (Table 2). The dual treatment or more category included water systems listed as having chlorination and filtration ($n = 46$), dual disinfection (e.g. chlorine plus ultra violet (UV) disinfection or chlorine plus ozone disinfection) ($n = 15$), or dual disinfection plus filtration ($n = 51$). The 'other' category included sites listed as having UV disinfection only ($n = 59$), filtration only ($n = 10$), or UV with filtration ($n = 154$). We grouped these three types of treatments together because there appeared to be some misclassification between UV only and UV with filtration systems. Furthermore, it is possible that these three types of treatment could refer to point-of-use (POU) treatment devices (e.g. only one tap has treatment) installed at the sample site only. Since we could not verify whether these types of treatment were POU devices or centralized treatment, we grouped them together to limit this type of potential misclassification to the 'other' category.

Population served

As with water source and water treatment, the HES only records the population served in *sample site reports*. The variable is reported in 20 broad categories, half of which indicate seasonal peak populations. We collapsed these categories into the following four groups: 0–50, 51–500, 501–5,000, and greater than 5,000 people (Table 2). There were two baseline groups for population: 0–50 people for systems with no seasonal variability ($n = 821$) and 0–100 people for those systems that experience a seasonal peak ($n = 126$). For the purpose of this study, the two baseline groups were combined. As with the water source and water treatment variables, the category for population served often had missing or conflicting information. For clarification, we consulted *inspection report*s or the presiding EHO.

Number of connections

Although BC defines water system size by the number of people served, health officials categorize and permit them by the number of service connections. The number of service connections is an alternative measure of system size that quantifies the size of the water distribution system. This study used both number of connections and population served to assess the effect of water system size because the two measures are not always correlated. For example, a commercial water system with a small distribution system may serve a large population. *Facility listing reports* in the HES record the number of connections for all water systems in three broad categories: WS3 systems have fewer than 15 connections, WS2 systems have between 15 and 300 connections, and WS1 systems have over 300 connections (Table 2).

Governance structure

The study used *facility listing reports* in the HES to categorize water systems by their governance structure (Table 1), including municipalities, regional districts, improvement districts, federal and provincial government systems, school districts, utilities, strata corporations, societies, water users communities (WUCs), joint good neighbor systems, or privately owned systems (Table 2).

Some misclassification of governance structure became apparent during data entry. In order to minimize the effects we triangulated information using ownership information from *facility listing reports* and reports from outside HES. These included a list of improvement, irrigation and water works districts for BC found online in the BC archives (www.bcarchives.gov.bc.ca/sn-50473D/arcs/appendix/improvcd.htm), the BC Ministry of Environment (MOE) website listing current and past WUCs (www.env.gov.bc.ca/wsd/data_searches/wuc/wuc_names.htm), and a list of current utilities provided by the MOE. (After the research for this study was complete, the BC MOE was reorganized and the Water Stewardship Division and the Comptroller of Water Rights were relocated to a new Ministry, called the BC Ministry of Forests, Lands, and Natural Resource Operations.) We also created the category 'joint systems', which does not currently exist in HES. We identified joint systems that had been grouped with WUCs or private systems in HES and moved them into the 'joint systems' group using the aforementioned information from MOE and consulting with local EHOs. We also reviewed the private system category for non-profit societies that had been misclassified as private and moved them to the society category. Despite these efforts, some misclassification likely remains among private, non-profit societies, strata corporations, and joint systems.

Administrative area

The geographic boundaries of regional districts were used to compare water system characteristics and predictors of advisory by administrative area. Water systems fell into 10 regional districts within the jurisdictional boundaries of the IHA (Figure 1), including Central Kootenay, Kootenay Boundary, East Kootenay, Columbia Shuswap, Thompson Nicola, Cariboo, North Okanagan, Central Okanagan, South Okanagan – Similkameen, and portions of Squamish Lillooet (Table 2). *Facility listing reports* provided the regional district information.

The 10 regional districts (e.g. administrative areas) cover large geographic regions within the interior, which includes mountain ranges, valleys, lakes, the semi-arid Okanagan Valley, orchards, farming, industry, and small- to medium-sized communities. Because of these large areas, the study was unable to examine the influence of the specific location of the water supplies such as the terrain, climate, or whether the water system was rural or near an urban center. Despite this limitation, the regional district variable allowed us to explore whether the administrative area in which the water system was located influenced the likelihood of being on advisory. This study also used the administrative areas to detect difference in the consistency in which advisories are applied between regions.

Statistical methods

All information for each water system was systematically entered into Microsoft Excel (2004). Once data entry was finished, 10 systems were randomly chosen for an audit of completeness and accuracy. No discrepancies were found after repeating the data collection methods for those 10 systems. All statistical analyses were conducted using R version 2.12.1 (R Development Core Team 2010). Analyses were stratified by system type because descriptive statistics suggested that the 619 residential systems were fundamentally different from the 1,228 commercial systems, especially with respect to governance structure (Table 2). The same analytic approach was used for both system types.

Methods for identifying predicting characteristics associated with advisory status

For the first step of this analysis, we computed frequencies to compare water systems on advisory with those not on advisory according to the population served, number of connections, water source, water treatment, governance structure, and administrative area (Table 2). We tested the significance of the association of each variable with the outcome using Chi-square statistics or a Fisher's exact test where appropriate.

The second step of the analysis used logistic regression to associate the odds of being on advisory with the predictive variables. Variables that had significant bivariate associations with being on advisory were included as potential predictors in multivariate logistic regression models. We explored the relative importance of water system size (measured by the number of connections or the population served) and governance structure by first calculating the crude odds ratio (OR) for each, and then adjusting the ORs for water source and water treatment. Base models were constructed by systematically entering the variables into the regression equation using *a priori* assumptions about important predictors and confounders. The following algorithm was used to determine the best model fit and to decide which variables should be retained: the percentage of additional variance explained by the variable had to be greater than 1% using McFadden's adjusted R^2 value; the Akaike's Information Criterion (AIC) value could not increase; and there had to be a significant difference between nested models using an analysis of variance (ANOVA). Analyses were repeated for residential and commercial systems. The treatment variable for commercial systems was collapsed into a binary variable (treatment installed or no treatment) to minimize the error caused by insufficient sample sizes in the treatment groups.

Methods for identifying predicting characteristics associated with advisory length

For the first step of this secondary analysis, we computed frequencies to compare water systems on long-term advisory with water systems on short-term advisory according to the population served, number of connections, water source, water treatment, governance structure, and administrative area (Table 2).

The second step of the analysis used logistic regression to associate the odds of being on a long-term advisory with the same predictive variables used in the primary analysis of advisory status. Small sample sizes across groups limited our ability to stratify the independent variables, requiring that we create binary categories for certain variables. Base models were constructed and tested using the same methods to determine which variables should be retained in the final model. Analyses were repeated for residential and commercial systems.

RESULTS

As of 3rd March 2011, 411 (22%) of the 1,847 water systems in the study were on advisory. Residential systems accounted for 191 (47.5%) of these advisories, and the remainder was for commercial systems. While commercial systems had more advisories, residential systems were twice as likely to be on advisory (OR = 2.0; 95%; confidence interval (CI) = 1.6–2.6).

Residential advisory status

For residential systems, the independent variables for water source, water treatment, population served, number of connections, governance structure and administrative area (e.g. regional district) were all statistically significantly associated ($p < 0.01$) with advisory status. We found that water system size (as measured by both population served or number of connections) was associated with the odds of being on an advisory for residential systems (Table 3). As the size of the water system decreased the odds of being on an advisory increased. Adjustment for water source and water treatment reduced the strength of the association and eliminated the statistical significance, but the relationship persisted (Table 3).

The final model for predicting advisory status for residential water systems included water source, water treatment, and governance structure (Table 4). Although system size was associated with the odds of being on advisory (Table 3), the model including governance structure was better fitted to the data when adjusted for source and treatment. Municipalities (which tend to be larger and better equipped with access to resources and trained personnel) acted as the reference group because they were least likely to be on advisory. The crude ORs suggest that certain governance structures (as described in Table 1), were more likely to be on advisory, especially the cooperative governance structures including WUCs, societies, strata corporations, improvement districts and joint good neighbor systems. For example, the WUCs were far more likely (OR = 32.9; 95% CI = 11.9–105.2) to be on an advisory than water systems governed by a municipality. Joint systems were similar (OR = 13.3; 95% CI = 5.1–39.8). Utilities and water systems with private owners were less likely to be on advisory than the cooperative governance structures, but significantly more likely to be on advisory than municipalities. Regional districts were approximately four and a half times more likely to be on an advisory (Table 4).

As the level of protection of the source water decreased, (moving from protected groundwater to surface water), the likelihood of being on an advisory increased. Similarly, as the level of treatment decreased (moving from two or more forms of treatment to no treatment at all), the likelihood of being on an advisory increased. The interaction of surface water and no treatment became apparent once we adjusted for source, treatment, and governance structure in the final model. This interaction created a sizeable increase in the adjusted ORs for both surface water (OR = 16.2; 95% CI = 7.3–38.2) and no treatment (OR = 22.0; 95% CI = 8.2–68.6).

Table 3 | Association between water system size (measured by both population served and number of connections) and advisory status for residential water systems

Variable	Unadjusted OR (95% CI)	OR (95% CI) adjusted for water source and water treatment
Population served		
>5,000 (*referent*)		
501–5,000	1.5 (0.5–7.1)	1.1 (0.3–5.0)
51–500	3.8 (1.3–16.3)	1.7 (0.5–7.5)
0–50	5.4 (1.8–23.2)	1.8 (0.6–8.4)
Number of connections		
WS1: >300 (*referent*)		
WS2: 15–300	3.2 (1.7–26.9)	1.8 (0.9–4.0)
WS3: <15	5.2 (2.6–11.3)	1.8 (0.8–4.3)

Table 4 | Final model for predicting advisory status for residential water systems

Independent variable	Unadjusted OR (95% CI)	OR (95% CI) adjusted for water source, water treatment, and governance structure
Source		
Groundwater – protected (*referent*)		
Groundwater – protection unknown	1.1 (0.5–2.4)	1.1 (0.5–2.4)
Groundwater – unprotected	3.5 (1.6–7.8)	4.4 (1.9–10.4)
Surface water	4.1 (2.3–8.0)	16.2 (7.3–38.2)
Treatment		
Dual disinfection or more (*referent*)		
Chlorine only	2.2 (0.9–6.0)	2.1 (0.9–6.0)
Other (UV and/or filtration)	3.4 (1.2–12.7)	4.5 (1.3–17.2)
No treatment	6.0 (2.7–16.0)	22.0 (8.2–68.6)
Governance structure		
Municipalities (*referent*)		
Regional districts	4.6 (1.8–13.4)	3.7 (1.4–11.1)
Improvement districts	6.0 (2.5–16.9)	3.1 (1.2–9.0)
Utilities	1.7 (0.6–5.3)	1.7 (0.4–4.0)
Strata corporations	5.4 (2.1–16.0)	4.4 (1.6–13.6)
Societies	8.1 (2.7–27.3)	4.9 (1.4–18.1)
Water users communities	32.9 (11.9–105.2)	3.6 (1.1–13.0)
Joint systems	13.3 (5.1–39.8)	3.0 (1.0–10.4)
Private systems	2.5 (1.0–6.9)	1.7 (0.7–5.1)

The most important explanation for the difference between the crude and the adjusted ORs for governance structure was untreated surface water. In brief, 85% of WUCs, 48% of joint good neighbor systems, and 21% of improvement districts reported having untreated surface water. After adjusting governance structure for source and treatment, the strength of the relationship of governance decreased but remained strong and significant for most governance structures. The decrease in the adjusted ORs was especially apparent among aforementioned governance structures with a high number of systems with untreated surface water, such as WUCs (Table 4).

Length of residential advisories

The final model for predicting long-term advisory status for residential water systems included source, treatment, and type of governance structure (Table 5). Because of sample size limitations across groups, the variables were collapsed into binary groups for analysis: treatment installed versus no treatment, surface water versus groundwater, and local government (e.g. municipalities and regional districts) versus non-local government systems. As before, water systems with surface water were more likely to be on a long-term advisory when compared with groundwater systems (Table 5). On the other hand, the level of treatment was not as important for predicting the length of advisory.

Table 5 | Final model for predicting long-term advisories (greater than 18 months) for residential water systems

	Unadjusted OR (95% CI)	OR (95% CI) adjusted for water source, water treatment, and governance structure
Source		
Groundwater (*referent*)		
Surface water	3.2 (1.5–7.0)	4.4 (1.9–11.0)
Treatment		
Treated (*referent*)		
No treatment	2.1 (0.9–4.6)	2.3 (0.9–5.9)
Governance structure		
Local government (*referent*)		
Non-local government	4.4 (1.9–10.8)	3.3 (1.2–9.3)

Governance and the role of local government also remained important for predicting long-term advisories. For example, non-local government systems were 3.3 times more likely to be on long-term advisories when compared to local government systems (95% CI = 1.2–9.3). Although sample size limitations restricted our ability to stratify analysis of advisory length by the type of governance structure, we can illustrate that certain types of governance structures proportionally have a much greater number of water systems that have been on advisory for extensive periods of time, many lasting longer than 12 years (Figure 2). In particular, the cooperative governance structures, especially the WUCs (the only type of water system to rely strictly on surface water supplies), had the highest proportion of advisories, and of advisories that persisted for many years.

Commercial advisory status

The variables associated with advisory status for commercial systems differed from residential systems. For commercial systems, only water source, water treatment, number of connections, and administrative area (e.g. regional district) were associated ($p < 0.01$). The final model for predicting advisory status for commercial water systems included the independent variables water source, water treatment, number of connections, and the regional district where the water system was located (Table 6). As with residential systems, the likelihood of being on an advisory increased as the level of source vulnerability increased and the level of water treatment decreased. The size of the water system had an opposite effect for commercial systems. As the size of the distribution system (measured by number of connections) increased, the likelihood of being on an advisory significantly increased. In fact, commercial water systems with fewer than 15 service connections were nearly half as likely to be on an advisory compared with systems having more than 15 connections, even after adjustment for source, water treatment, and administrative area (adjusted OR = 0.4; 95% CI = 0.3–0.7).

The administrative area in which commercial water systems are located within IHA boundaries also proved an important predictor of advisory status (Table 6). We chose the East Kootenay Regional District as the reference group because it proportionately reported the least number of

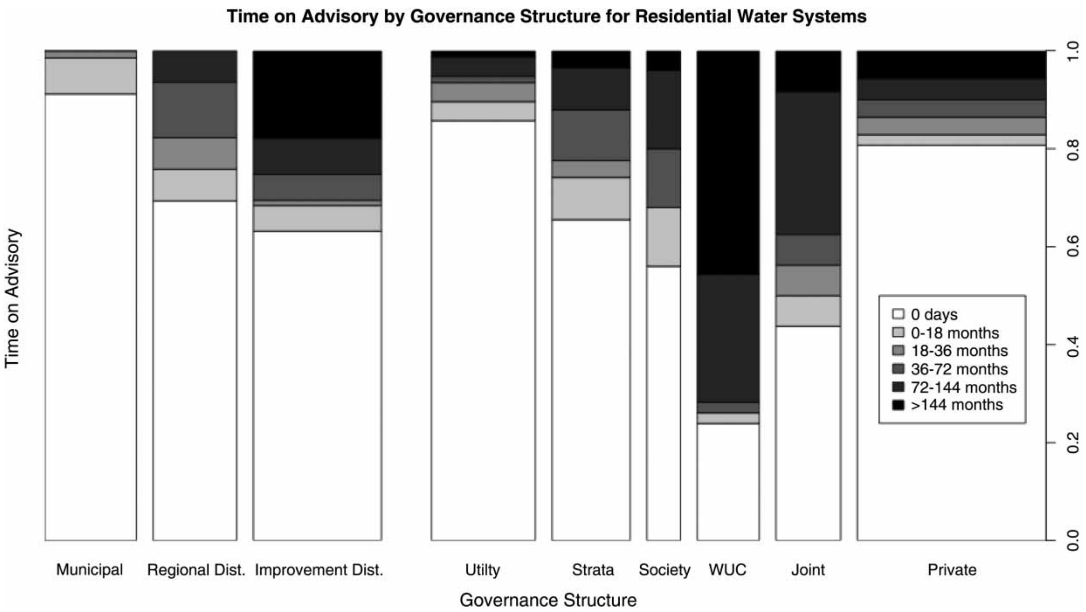

Figure 2 | Proportional representation of time spent on advisory for each type of residential water systems by governance structure. The width of each bar represents the relative proportion of water systems for each type of governance; the colors represent the length of advisory.

advisories within the HES. As our data show, water systems found within certain regional districts, such as the South Okanagan – Similkameen were more likely to be on an advisory compared with both the East and the Central Kootenay.

Length of commercial advisories

In contrast, analysis of predicting factors for commercial long-term advisories showed that administrative areas and number of connections were not important predictors, leaving source and treatment as the best predictors of advisory length. Commercial water systems with surface water were over six times more likely to be on a long-term advisory compared with those having a groundwater source (adjusted OR = 6.1; 95% CI = 2.7–15.8). Similarly, commercial water systems with no treatment were over six times more likely to be on a long-term advisory compared with systems having treatment (adjusted OR = 6.3; 95% CI = 2.3–18.0).

DISCUSSION

By extracting water system information from a variety of program reports within the HES database, this study characterized a large sample of residential and commercial water systems by water source, level of water treatment, number of connections, populations served, governance structure, and administrative area. Results confirmed that the water source and water treatment variables were significant predictors of poor water quality leading to an advisory. Our finding that surface water (and particularly untreated surface water) is the most likely water source to contain pathogens and be on advisory is both consistent with other literature (Geldreich 1989, 2005; Davies & Mazumder 2003; Uhlmann et al. 2009) and common knowledge. Surface supplies are open to the atmosphere and have a greater vulnerability to contamination from wildlife, human activity, and surface run-off caused by seasonal or extreme weather events (Thomas et al. 2006). The level of groundwater protection was also an important predictor of advisory status, with unprotected groundwater (such as shallow dug wells under the direct influence of surface water) being significantly more likely to be on an advisory compared with protected groundwater. This finding agrees with other studies reporting that poorly constructed, deteriorating, and shallow wells are most susceptible to contamination, especially those in proximity to sources of contamination such as agricultural and human wastes

Table 6 | Final model for predicting advisory status for commercial water systems

Independent variables	Unadjusted OR (95% CI)	Adjusted OR (95% CI) for water source, water treatment, number of connections, and administrative area
Source		
Groundwater – protected (*referent*)		
Groundwater – protection unknown	2.7 (1.6–5.0)	2.9 (1.6–5.6)
Groundwater – unprotected	7.9 (4.5–14.7)	8.7 (4.7–16.8)
Surface water	10.3 (6.2–18.3)	42.1 (22.9–81.5)
Treatment		
Treatment installed (*referent*)		
No treatment	2.1 (1.8–3.2)	11.4 (6.9–19.5)
Number of connections		
WS2: 15–300 (*referent*)		
WS3 < 15	0.5 (0.4–0.78)	0.4 (0.3–0.7)
Administrative area (e.g. regional district)		
East Kootenay (*referent*)		
Central Kootenay	1.2 (0.6–2.6)	1.0 (0.4–2.3)
Kootenay – Boundary	2.0 (0.9–4.8)	2.8 (1.1–7.3)
Cariboo	2.3 (1.2–4.8)	2.7 (1.3–6.3)
Columbia – Shuswap	1.4 (0.7–3.1)	1.2 (0.5–2.9)
Thompson – Nicola	4.6 (2.5–9.4)	4.4 (2.1–9.8)
Squamish – Lillooet	2.8 (0.7–9.3)	5.6 (1.1–22.9)
Central Okanagan	3.2 (1.3–7.8)	3.8 (1.3–10.8)
North Okanagan	2.0 (0.8–4.8)	3.0 (1.1–8.3)
South Okanagan – Similkameen	6.7 (3.2–14.7)	9.0 (3.8–22.3)

(Geldreich 2005; Uhlmann *et al.* 2009). Wells located in areas prone to excessive rainfall or flooding also experience a greater risk of contamination caused by pathogen transport via soil saturation or through improperly sealed wellheads (Curriero *et al.* 2001; Auld *et al.* 2004; Thomas *et al.* 2006). The literature has documented the importance of treatment in order to provide safe and reliable drinking water (Geldreich 1989, 2005; Wallis *et al.* 1996; Davies & Mazumder 2003; Krewski *et al.* 2004; Hrudey *et al.* 2006). Given that no single form of treatment can eliminate all potential health threats associated with the varying quality of source water supplies, multiple barriers of protection (such as two or more forms of treatment) are needed to reduce related health hazards (Geldreich 1989, 2005; Davies & Mazumder 2003; Uhlmann *et al.* 2009). The level of treatment required relates to the level of vulnerability and quality of the source water (Geldreich 1989, 2005; Davies & Mazumder 2003). Surface water and at-risk groundwater supplies that may not benefit from natural filtration from the soil to remove harmful pathogens benefit the most from multiple barriers of protection (Geldreich 1989, 2005; Davies & Mazumder 2003; Uhlmann *et al.* 2009).

Our results suggest that residential and community water systems are characteristically different, especially with respect to governance structures. Residential water systems had a relatively balanced distribution of the varying forms of governance structures whereas the private business models dominated the commercial systems (Table 2). In addition, some governance structures were strictly residential or commercial. We also found that residential water systems are twice as likely to be on advisory and have different predictors leading to an advisory compared with commercial water systems. This result may reflect the tendency for health officials to focus their limited resources on residential systems, especially those serving larger populations. Such program prioritization likely results in more frequent inspections of residential systems, leading to quicker identification of conditions warranting an advisory. Health officials may also be quicker to issue an advisory for residential systems as a precautionary measure to warn vulnerable populations who rely on said systems for their drinking water. In comparison, health officials may have more discretion to use a different approach before issuing advisories for small commercial systems, especially those that serve a very limited population (e.g. a private business with few employees), or in circumstances where the water is infrequently used for drinking within the commercial operation (e.g. an industrial site).

The influence of water system size on advisory status also differed between the two service types. For example, water system size results for residential systems (as measured by population served and number of connections) showed that the likelihood of being on an advisory increased as the size of the residential water system decreased. This finding supports ample evidence (Grose *et al.* 1998; Jocoy 2000; AquaVic Water Solutions Inc. 2005; Geldreich 2005; Jones *et al.* 2006; Eggertson 2008; Hrudey 2008, 2011; Office of the Ombudsman 2008; Patrick 2008, 2011; Hunter *et al.* 2009, 2011; Kot *et al.* 2011) showing that small residential water systems are more likely to be faced with persisting water quality problems due to inadequate treatment and a lack of sufficient resources and capacity to address their infrastructure needs. The role of size for commercial systems presented an opposite trend. Although only 13% of commercial systems had more than 15 connections, they were 50% more likely to have an advisory in place. This may reflect the tendency for health officials to focus their limited resources towards the commercial operations that serve the most consumers. Another possible explanation is that operational and treatment requirements increase as the size and complexity of a commercial distribution system increases, challenging systems with limited financial and operational resources. Many of the commercial operations categorized as having fewer than 15 connections have only one connection (e.g. a restaurant, a store, a lodge, etc.), which often leads to simpler systems to operate and maintain. Furthermore, many commercial systems were built prior to engineered construction permit requirements, a factor that may contribute to larger systems being on advisory as a result of flawed or ad-hoc construction as systems grew. Similarly, many small residential systems have been built without construction permits. *Inspection priority assessment reports* in HES showed that 59% of residential water systems with fewer than 15 service connections had no engineering approvals.

While water system size was an important predictor of advisory status, our results show governance structure was a better predictor for residential systems when adjusted for water source and water treatment. The relationship between governance structure and population served suggests that water users groups, strata corporations, and joint works systems contain the highest proportion of very small systems (Figure 3). Not only does the type of governance structure relate to size, it also dictates access to funding, resources, and trained personnel.

The study results also suggest that certain types of governance structure are more likely to be placed and remain on drinking water advisories. We found the cooperative governance structures (improvement districts, water users groups, strata corporations, and joint works) not run by a local government or utility were most likely to be on advisory, especially long-term advisories. These systems face similar financial and operational resource challenges in providing adequate treatment for water supplies. Not only are they ineligible for most infrastructure funding, they also often lack the ability and resources to secure a certified operator and personnel to carry out necessary administration functions. Without an economy of scale, SWSs not operated by a local government must rely on user fees from a limited number of customers to manage, operate, and improve their water systems. Although regional districts are a form of local government in the rural areas with access to funding and trained personnel, the study found them more likely to be on an advisory than municipalities. This finding may be due to regional districts often inheriting problem SWSs through default or acquisitions (Ministry of Community Services 2007).

One influence on the significance of governance structure was untreated surface water. WUCs, joint systems, and improvement districts had the highest proportion of systems with untreated surface water. These same governance

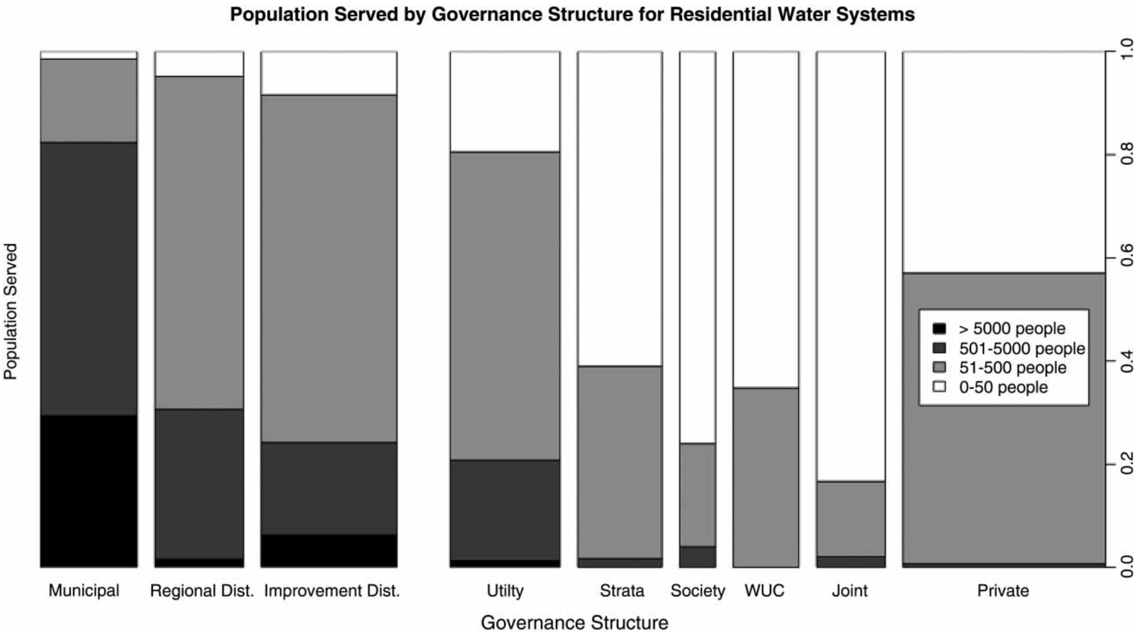

Figure 3 | Proportional representation of the number of water systems broken down by population served for the residential governance structure categories. The width of each bar represents the relative proportion of water systems for each type of governance; the colors represent the size of the population served.

structures also had the highest proportion of persistent long-term advisories lasting longer than 12 years (Figure 2). In fact, 84% of advisories in place for over 12 years had untreated surface water. This finding supports the criticisms, which the BC Ombudsman (Office of the Ombudsman 2008) and others (Eggertson 2008; Hrudey 2008) have raised about the historic use of boil water advisories as an alternative to treatment for certain types of water systems reliant on surface water or groundwater at risk of containing pathogens. One contributing factor to this situation includes a history of strong opposition to water treatment and regulatory requirements among certain types of SWS in BC (Hrudey & Hrudey 2004; Office of the Ombudsman 2008). Reasons for this objection include a fundamental opposition to chlorination resulting from taste and perceived chemical health risk concerns. Another reason stems from an inherent belief that the consequences of potential health risks posed from the untreated water supply do not outweigh the competing costs of making the required upgrades and improvements.

Governance structure was not associated with advisory status for commercial systems. The dominant governance structure for commercial system is private ownership, followed by systems owned and operated by a provincial body and those governed by a non-profit society. It is possible that the governance structures of these commercial enterprises are less complex, making administrative and financial responsibilities clearer. This does not mean that commercial systems do not face the same financial and planning challenges as residential systems.

The regional district was also a significant predictor of advisory status for commercial systems. We believe that this reflects historical differences in practice between different administrative areas, and not inherent differences in water quality. According to IHA health officials, differences in local practice surrounding advisory conditions still exist, especially for small commercial water systems. This inconsistency was not evident for advisories in residential systems, where those with untreated surface water (a condition that typically warrants a drinking water advisory) were 3.3 (95% CI = 1.7–6.4) times more likely to have an advisory in place than commercial systems with untreated surface water.

The majority of commercial systems listed as having untreated surface water but no advisory were in the Central and East Kootenay regional districts, which feature a number of very SWSs that often oppose water treatment.

It is possible that the information on source water and water treatment from sample sites is more outdated in these regions. Another explanation may be that some of the systems are on an advisory but the EHO never entered the information into the HES. In regions with fewer water systems per health officer, it is also more likely that commercial operations will receive more frequent inspections leading to a quicker identification of conditions that warrant an advisory. Furthermore, some administrative areas may use precautionary advisories more frequently than others, especially when risks are unknown.

Limitations

Any study relying on administrative data faces limitations and challenges. While the HES database holds rich and useful information, the variables used here were recorded in several different reporting formats. Information on key characteristics (such as water source, water treatment, and population served) was often missing and/or buried in *sample site creation forms* not intended for surveillance or reporting. These realities make administrative data prone to misclassification, error, and incompleteness. Some information regarding source, the level of treatment and the size of the population served may have been outdated given the method with which HES recorded it. Because *sample site creation forms* are created over various time periods and not routinely updated, some systems may have incorrect information. For example, the level of treatment variable is most likely to change over time as systems are upgraded, which could mean that our results potentially under- or over-estimated the effects of inadequate treatment. Misclassification between centralized treatment and POU treatment may have also occurred. For example, the treatment listed on a sample site may refer to a POU treatment. Therefore, it may appear that a system has centralized treatment when it does not. Alternatively, a water system may have some form of treatment, but the EHO entered the system as having received no treatment as the design does not meet regulatory standards.

Some of the data are also subjective due to the way that information was entered into the HES. For example, the level of source vulnerability most often rests on the opinion of the individual health officer who recorded the information rather than an official hydrological assessment. Very little is known about the level of consistency with which EHO officers characterized groundwater sources as either protected or unprotected. The large number of systems classified as having unknown protection suggests a degree of uncertainty and potential misclassification.

The study also faced limitations in analyzing the impact of system size, as measured by population served or number of service connections. Even though population served defines a SWS, population is not well documented and often presented conflicting or missing information. Our analysis of the true effect of water system size is limited because the HES does not record the exact number of connections or the exact size of the population served. The HES captures broad categories of size, which do not align with current definitions. This made it difficult to isolate the effect of size among the smaller systems. Having population served and number of connections as continuous variables would allow greater statistical power in future studies exploring the effect of water system size on access to safe drinking water.

The manner in which this study constructed and combined some variables also limits some of our interpretations. For example, collapsing the variables into binary categories (e.g. treatment installed versus no treatment, etc.) when exploring the characteristics associated with long-term advisories, limited our ability to explore the effect of the different levels of treatment, water sources, and governance structures.

Although HES provided the main characteristics needed for our analyses, we were limited to the available variables that we could reliably extract. Other variables available within HES relate to reasons for advisories, frequency of sample collection, as well as the classification the water system received using the *inspection priority assessment forms*. Information from these forms relates to the history of bacteriological compliance and number of previous advisories, compliance with engineering standards, and operations and maintenance of the system. We excluded these variables because they were often subjectively recorded or presented too much missing information, creating too much potential for misclassification. Although other studies show that the probability of detecting a failed bacteriological result leading to an advisory increases with the frequency of sampling (Richardson *et al.* 2009), we could not include this variable because of limitations of the available data in HES. Specifically, the majority of water systems within IHA fall under the same sampling frequency requirement of the DWPA; the information of the set frequency and compliance rates for sample submissions was not readily accessible for this analysis; and many water systems do not routinely sample. Systems that may not routinely sample include water systems on a long-term advisory for having untreated surface water as well as recalcitrant systems that remain out of compliance with the DWPA. These recalcitrant systems may be on an advisory for lacking sampling data (depending on the inherent risks of the system, the number of infractions, and the discretion of the EHO).

Another limitation is the cross-sectional design. Cross-sectional studies are limited to a snapshot in time, and do not allow the study to explore temporal relationships, such as seasonal changes that affect water quality. We used a cross-section of advisory data that occurred prior to spring freshet caused by snow melt and rainfall; therefore, to assess the effect of season we would either have to repeat the study in late spring or early summer, or use a stronger study design such as a cohort study.

CONCLUSION

Understanding water system characteristics and predictors of advisory status will assist health officials in setting priorities and targeting interventions. These results demonstrate how health officials can use existing administrative data to identify trends and challenges for program planning and evaluation. This study also highlights the importance of systematically gathering information on the basic characteristics associated with vulnerability and risk for the purposes of surveillance and reporting. It has been more than 2 years since the 2008 BC Ombudsman's report '*Fit to Drink: Challenges in Providing Safe Drinking Water in British Columbia*' drew attention to the unacceptable number of drinking water advisories. Despite this recognition, readily available information about the basic characteristics of water systems most likely to be at risk of frequent or on-going advisories remains limited. We encourage regulatory agencies to continue investing in reliable data systems to record and substantiate this characteristic information, which can be used to help fill information gaps.

We suggest a clear policy on untreated surface water, drinking water advisories and program guidelines specific to commercial systems, which often have unique challenges such as access, infrequent use, seasonal peaks, or industrial flows. Our results indicate clear differences in commercial advisory status between administrative areas, suggesting a potential gap in oversight in some regions, as well as an urgent need to update and verify existing information. Given the inherent differences between commercial and residential systems, we further recommend that health officials develop separate and flexible approaches to addressing poor water quality in both system types.

Our results suggest the need for targeted interventions and support for residential SWSs not operated by local governments or utilities. The large number of very small water systems – as small as two households – and the complexity of governance structures in BC limit some of the generalizability of our results on water systems size and governance to other parts of Canada and beyond. However, the results do provide support to other research outlining the financial and human resource challenges that SWSs across Canada and other developed countries similarly face (Davies & Mazumder 2003; Aqua Vic Water Solutions Inc. 2005; Geldreich 2005; Smith *et al.* 2006; Eggertson 2008; Hunter *et al.* 2009, 2011; Conestoga-Rovers & Associates 2011; Hrudey 2011; Kot *et al.* 2011; Moffat & Struck 2011; Patrick 2011), particularly for those that are not operated by a local government body.

Although this study was limited by administrative data and a cross-sectional design, it provides useful information to guide future research on the characteristics of residential and commercial water systems on drinking water advisories and on long-term drinking water advisories. We recommend more extensive research to verify existing information, and we suggest that future research could test the hypotheses generated here using stronger study designs. Following the sample over time would more precisely identify the reasons why water systems were put on advisory, and would capture those water systems that were placed on a short-term advisory but did not stay on advisory. Future research should also attempt to capture important characteristics and variables that were unavailable in this study, such as the age of the system, spatial factors (location, rural siting, etc.), climate, monitoring frequency, integrity of the system construction, operator capacity, as well as more detailed information on source protection. Other potential avenues for future research include exploring the risk perceptions among users and the effectiveness of drinking water advisories that persist for years if not decades. Finally, future research should report on the reasons for removing long-term advisories, so that regulatory agencies and water systems can learn from those successes.

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REFERENCES

Auld, H., MacIver, D. & Klaassen, J. 2004 Heavy rainfall and waterborne disease outbreaks: the Walkerton example. *J. Toxicol. Environ. Health, Part A* **67**, 1879–1887.

AquaVic Water Solutions Inc. 2005 Small Water Systems in BC: An Introduction to the Provision of Safe and Reliable Supplies - Part 1: Organization (Draft). Prepared for the BC Ministry of Health. Victoria, BC. Available from: www.sustainis.org/resources/.

BC Stats 2011 Population Estimates, British Columbia and Sub-Provincial – BC Stats. Province of British Columbia. Retrieved May 11, 2012 from: www.bcstats.gov.bc.ca/StatisticsBySubject/Demography/PopulationEstimates.aspx.

Brandes, O. & Curran, D. 2009 Setting a New Course in British Columbia – Water Governance Reform Options and Opportunities. POLIS Project on Ecological Governance, May. Available from: http://poliswaterproject.org/publication/272.

British Columbia Ministry of Health 2011 *Boil Water Notices/Water Quality Advisories – Drinking Water Quality*. Health Protection, Population and Public Health Branch, Province of British Columbia. Victoria, BC. Available from: www.health.gov.bc.ca/protect/dwadvisories.html.

British Columbia Ministry of Health 2012 *Guidance Document for Determining Groundwater at Risk of Containing Pathogens (GARP) Including Groundwater Under the Direct Influence of Surface Water (GWUDI) – Version 1*. Health Protection, Population and Public Health Branch, Province of British Columbia. Victoria, BC. Available from: http://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=20531.

Conestoga-Rovers & Associates 2011 Study on Operation and Maintenance of Drinking Water Infrastructure in Newfoundland and Labrador. Prepared for the Government of Newfoundland & Labrador. Worldwide Engineering, Environmental, Construction, and IT Services. Ref. No. 055425(7). St John's, Newfoundland.

Curriero, F. C., Patz, J. A., Rose, J. B. & Lele, S. 2001 The association between extreme precipitation and waterborne disease outbreaks in the United States, 1948–1994. *Am. J. Public Health* **91**, 1194–1199.

Davies, J. M. & Mazumder, A. 2003 Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources. *J. Environ. Manage.* **68**, 273–286.

Eggertson, L. 2008 Investigative report: 1766 boil-water advisories now in place across Canada. *Can. Med. Assoc. J.* **178**, 1261–1263.

Geldreich, E. E. 1989 Drinking water microbiology – new directions toward water quality enhancement. *Int. J. Food Microbiol.* **9**, 295–312.

Geldreich, E. E. 2005 Better intervention strategies are needed to reduce the risk of waterborne outbreaks. *J. Water Health* **3**, 197–208.

Grose, A. B. F., Smith, A. J., Donn, A., O'Donnell, J. & Welch, D. 1998 Supplying high quality drinking water to remote communities in Scotland. 1. *Desalination* **117**, 107–117.
Hrudey, S. E. 2008 Safe water? Depends on where you live! *Can. Med. Assoc. J.* **178**, 975.
Hrudey, S. E. 2011 Safe Drinking Water Policy for Canada - Turning Hindsight into Foresight. CD Howe Institute Commentary The Water Series (323) (February). Toronto, ON.
Hrudey, S. E. & Hrudey, E. J. 2004 *Safe Drinking Water: Lessons for Recent Outbreaks in Affluent Nations*. IWA Publishing, London.
Hrudey, S. E . & Hrudey, E. J. 2007 Published case studies of waterborne disease outbreaks – evidence of a recurrent threat. *Water Environ. Res.* **79**, 233–245.
Hrudey, S. E., Hrudey, E. J. & Pollard, S. 2006 Risk management for assuring safe drinking water. *Environ. Int.* **32**, 948–957.
Hunter, P. R., Pond, K., Jagals, P. & Cameron, J. 2009 An assessment of the costs and benefits of interventions aimed at improving rural community water supplies in developed countries. *Sci. Total Environ.* **407**, 3681–3685.
Hunter, P. R., De Sylor, M. A., Risebro, H. L., Nichols, G. L., Kay, D. & Hartemann, P. 2011 Quantitative microbial risk assessment of cryptosporidiosis and giardiasis from very small private water supplies. *Risk Analysis* **31**, 228–236.
Jocoy, C. L. 2000 Who gets clean water? Aid allocation to small water systems in Pennsylvania. *J. Am. Water Res. Assoc.* **36**, 811–821.
Jones, A. Q., Dewey, C. E., Doré, K., Majowicz, S. E., McEwen, S. A., David, W. T., Eric, M., Carr, D. J. & Henson, S. J. 2006 Public perceptions of drinking water: a postal survey of residents with private water supplies. *BMC Public Health* **6**, 94.
Kot, M., Castleden, H. & Gagnon, G. A. 2011 Unintended consequences of regulating drinking water in rural Canadian communities: examples from Atlantic Canada. *Health Place* **17**, 1030–1037.
Krewski, D., Balbus, J., Butler-Jones, D., Haas, C., Isaac-Renton, J., Roberts, K. & Sinclair, M. 2004 Managing the microbiological risks of drinking water. *J. Toxicol. Environ. Health, Part A* **67**, 1591–1617.
Ministry of Community Services 2007 Capacity Building for Small Community Water Systems: Survey of Regional Districts. British Columbia: Ministry of Community Services, Local Government Infrastructure and Finances Division, Municipal Engineering Services Branch.
Ministry of Environment 2010 Private Water Utilities: Guide to Applying for a Certificate of Public Convenience and Necessity (CPCN). British Columbia: Ministry of Environment, Water Stewardship Division, Water Utility Section. Available from: http://www.env.gov.bc.ca/wsd/water_rights/water_utilities/utilities_application_index.html.
Moffat, H. & Struck, S. 2011 *Water-borne Disease Outbreaks in Canadian Small Drinking Water Systems. Small Drinking Water Systems Project*. National Collaborating Centres for Public Health. November. Available from: www.nccph.ca/docs/SDWS_Water-borne_EN.pdf
National Collaborating Centres for Public Health 2009 Definitions – Small Drinking Water Systems. Small Drinking Water Systems Project. Available from: http://www.nccph.ca/en/index.aspx?sortcode=2.0.11.12.12
Nowlan, L. & Bakker, K. 2007 Delegating Water Governance: Issues and Challenges in the BC Context. BC Water Governance Project, University of British Columbia. Program on Water Governance, F. B Council, Canada. Dept of Fisheries, and Oceans.
Office of the Ombudsman 2008 *Fit to Drink: challenges in providing safe drinking water in British Columbia* (Special Report no. 32, June 2008, to the Legislative Assembly of British Columbia). Queen's Printer, Victoria, British Columbia.
Patrick, R. J. 2008 Source water protection for nonmetropolitan drinking water operators in British Columbia, Canada. *J. Rural Community Dev.* **3**, 64–78.
Patrick, R. J. 2011 Uneven access to safe drinking water for First Nations in Canada: connecting health and place through source water protection. *Health Place* **17**, 386–389.
R Development Core Team 2010 *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. www.R-project.org/.
Richardson, H. Y., Nichols, G., Lane, C., Lake, I. R. & Hunter, P. R. 2009 Microbiological surveillance of private water supplies in England – the impact of environmental and climate factors on water quality. *Water Res.* **43**, 2159–2168.
Schuster, C. J., Aramini, J. J., Ellis, A. G., Marshall, B. J., Robertson, W. J., Medeiros, D. T. & Charron, D. F. 2005 Infectious disease outbreaks related to drinking water in Canada, 1974–2001. *Can. J. Public Health* **96**, 254–258.
Smith, D. W., Guest, R. K., Svrcek, C. P. & Farahbakhsh, K. 2006 Public health evaluation of drinking water systems for First Nations reserves in Alberta, Canada. *J. Environ. Eng. Sci.* **5** (Suppl. 1), S1–S17.
Thomas, K. M., Charron, D. F., Waltner-Toews, D., Schuster, C., Maarouf, A. R. & Holt, J. D. 2006 A role of high impact weather events in waterborne disease outbreaks in Canada, 1975–2001. *Int. J. Environ. Health Res.* **16**, 167–180.
Uhlmann, S., Galanis, E., Takaro, T., Mak, S., Gustafson, L., Embree, G., Bellack, N., Corbett, K. & Isaac-Renton, J. 2009 Where's the pump? Associating sporadic enteric disease with drinking water using a geographic information system, in British Columbia, Canada, 1996–2005. *J. Water Health* **7**, 692–698.
Wallis, P. M., Erlandsen, S. L., Isaac-Renton, J., Olson, M. E., Robertson, W. J. & Van Keulen, H. 1996 Prevalence of *Giardia* cysts and *Cryptosporidium* oocysts and characterization of *Giardia* spp. isolated from drinking water in Canada. *Appl. Environ. Microbiol* **62**, 2789–2797.

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