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Small Drinking Water Systems Project

Water-borne Disease Outbreaks in Canadian Small Drinking Water Systems

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Report Highlights

- Information about Canadian drinking water systems and past water-borne disease outbreaks is incomplete and non-standardized. Standard definitions and coordinated surveillance systems for water-borne disease outbreaks would help inform policy and practice.
- A relatively high proportion of past water-borne disease outbreaks in Canada are estimated to have occurred in small drinking water systems serving populations of 5,000 people or less.
- Water-borne disease outbreaks in small drinking water systems are often the result of a combination of water system failures; contributing factors often include a lack of source water protection and inadequate drinking water treatment.
- Analyses suggest small drinking water systems face challenges associated with infrastructure, technology, and financial constraints. Investments in drinking water systems and operator training have the potential to reduce the burden of water-borne disease in Canada.

Summary
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Executive Summary

Generally, Canadians have access to safe and secure drinking water. However, as demonstrated by the events of Walkerton in 2000, the exception can be tragic. Outbreaks of water-borne disease are preventable, yet evidence-informed policy and practice is hampered, in part, by our limited knowledge of drinking water systems that experience outbreaks and the factors that contribute to outbreaks in Canada. There is no national surveillance system for systematic collection of water-borne disease outbreak data. Investigating past water-borne disease outbreaks is a valuable approach to collect information to inform practice and policy.

Investigations of water-borne disease outbreaks are challenging because the outbreak events are rare, the pathogenic agents involved may be transmitted via multiple routes (e.g., person to person, food-borne, as well as water-borne), and gastrointestinal illnesses are frequently under-reported. For this report, evidence about past water-borne disease outbreaks in Canada was obtained from two retrospective research studies (Wilson et al, 2009[1]; Schuster et al, 2005[2]) and a case history analysis exploring recurring themes and patterns in Canadian and international settings (Hrudey and Hrudey, 2004)[3]. The two retrospective studies are not comprehensive and differ in their categorization of water systems.

Trends suggest that small and private drinking water systems, serving populations of 5,000 or less, may be more vulnerable to water-borne disease outbreaks. The Novometrix research study[a] found that the majority (75%) of water-borne disease outbreaks occurred with Small Drinking Water Systems (SDWS). Among the definitely, probably, and possibly water-borne disease outbreaks reported by Schuster et al., a high proportion of events occurred in SDWS classified as semi-public (48%) and private (18%) water systems.[2] Approximately 34% of the enteric disease outbreaks reported by Schuster occurred in public water systems; reanalysis of this data suggests about half of the public outbreaks reported occurred in systems serving populations of 5,000 people or less.

Water-borne disease outbreaks in small drinking water systems are often the result of a combination of water system failures. Factors shown to contribute to water-borne disease outbreaks are identified as:

- *Lack of source water protection:* Animals in the watershed were identified as the most common source of contamination in surface water outbreaks; human septic contamination was the most common source among groundwater outbreaks. Optimal management and protection of watersheds reduces the potential for surface water contamination by pathogens.
- *Precipitation, spring thaw/run-off and high turbidity:* Weather events tend to exacerbate underlying vulnerabilities created by inadequate water protection or inadequate treatment. The majority of infectious water-borne disease outbreaks occurred in spring and summer. This is likely related to the survival of pathogens and weather variables, such as snow melt, rainfall or increased human and animal activity in watershed areas. Climatic factors, such as heavy precipitation prior to an event, have been shown to increase risk of water-borne outbreaks.
- *Inadequacy or failure of water treatment:* The majority of disease outbreaks occurred in unprotected groundwater systems with no water treatment. When outbreaks were associated with surface water systems some type of water treatment method was more likely to have been in place; yet, inadequacy or failure of treatment systems were often associated with the outbreaks. Treatment practices in SDWS are influenced by challenges associated with lack of funding, infrastructure, and/or training opportunities for SDWS operators.
- *Malfunctioning water distribution systems:* Main breaks (e.g., broken pipes) and cross-connections (e.g., back siphonage and back flow) are common causes of outbreaks traced to water distribution systems. Water quality hazards within distribution systems are challenging because they are difficult to anticipate and detect; thus, field investigations and monitoring of water quality at its destination are required.
- *Other factors:* Ongoing maintenance work (including repairs and replacements) in the water system was associated with three outbreaks reported in the Schuster study. Human error was a reported factor in water-borne disease outbreaks described by the Novometrix study.

Recent investigations provide information about characteristics and factors associated with outbreaks in Canadian water systems. Prevention of water-borne disease outbreaks requires multiple, robust, and effective barriers for source water protection and treatment practices. SDWS face various challenges, for example, the unit cost of operating small water systems may be higher when economies of scale cannot be realized. Lack of investment, financial considerations, and limited training opportunities for small system operators are suggested to have an important role in the occurrence of past water-borne outbreaks in Canada.

Many practitioners and researchers have described the surveillance of water-borne disease in Canada as inadequate. It is unknown how many water-borne disease outbreaks, as well as sporadic illnesses, are not detected or reported. Standardized definitions of water-borne disease outbreaks and drinking water systems would improve our understanding of factors associated with water-borne disease in Canada. Coordinated provincial and national surveillance systems for reporting water-borne disease outbreaks are needed to capture data about types of water systems, size of population serviced, and contributing factors associated with waterborne illnesses and outbreaks.

Introduction

Generally, Canadians have access to safe and secure drinking water. However, the tragic water-borne disease outbreak that occurred in Walkerton, Ontario in 2000 was a notable exception. Drinking water systems can cause considerable harm as large numbers of consumers may be simultaneously exposed to disease-causing agents. Outbreaks of water-borne disease are preventable; however, evidence-based policy and practice is hampered, in part, by our limited knowledge of the factors and water system characteristics that contribute to outbreaks in Canada. Investigating past outbreaks is a valuable approach to inform practice and policy.

This report synthesizes the findings from three publications which assess water-borne disease outbreaks in Canada; two retrospective research studies and a case history analysis exploring recurring themes and patterns in Canadian and international settings. The available information about Canadian water-borne disease outbreaks is imperfect. Surveillance of water-borne disease is challenging because the pathogenic agents involved may be transmitted via multiple

a Authored by Wilson et al.,[1] referred to as Novometrix in this report.

routes (e.g., person to person, food-borne, as well as water-borne) and gastro-intestinal illnesses are frequently under-reported. Nonetheless, this review provides insight regarding overall trends of Canadian water-borne disease outbreaks. The objectives of this report are to:

(i) provide a brief overview of Canadian drinking water systems;
(ii) describe trends of past water-borne disease outbreaks;
(iii) describe characteristics and factors contributing to outbreaks in small drinking water systems;
(iv) discuss practices for preventing water-borne disease outbreaks in small drinking water systems.

An overview of Canadian drinking water systems

Drinking water systems process and distribute water and can be characterized with respect to their ownership and type of population serviced, for example, Schuster et al.[2] describe three categories:

- Private water systems: privately owned systems that provide drinking water to individuals owning the systems and to their guests;
- Semi-public systems: privately owned systems that provide drinking water to the visiting general public - often seasonal (e.g., camping grounds); and
- Public water systems: publicly owned municipal systems.

However, this type of classification of drinking water systems with respect to ownership can be problematic. For example, there is no clear distinction for systems that are publically owned but privately operated. For example, some privately operated systems provide drinking water to permanent residents, industry locations, mobile home parks, schools, nursing homes or hospitals.

Drinking water systems can also be characterized by the number of connections, output, or people serviced by the system. Health Canada defines Small Drinking Water Systems (SDWS) as systems serving 5,000 people or less.[4,5] This is the definition used in this paper. In 2006, the number of Canadian census subdivisions (i.e., communities) with a population of 5000 or less was approximately 4,315.[6] Unfortunately, accurate estimates of the number of actual SDWS, or population served by these systems in Canada, are not currently available.

The best estimates for general information about drinking water systems are available from Statistics Canada.[7] In 2007, approximately 28 million Canadians received their water from drinking water treatment plants that serviced communities of 300 people or more and the remaining 5 million Canadians (about 15%) received drinking water from plants serving less than 300 people or from their private water supply.[7]

The various definitions of drinking water systems can be confusing. Generally, private and semi-public systems serve small populations (5,000 people or less) and may be classified as SDWS. Public systems may serve large communities or city populations but may also serve smaller communities and be classified as SDWS. These distinctions are important as data regarding the type of water system associated with recent water-borne disease outbreaks are limited, yet there is evidence, discussed in this report, suggesting that small drinking water systems may be more vulnerable or susceptible to water-borne disease outbreaks.

Source water

Drinking water systems draw source water from either groundwater, surface water or sometimes a mix of both. Groundwater, if drawn from a confined aquifer, is generally considered a safer drinking water source, as it is less vulnerable to microbial contamination (especially protozoal – e.g., *Giardia* and *cryptosporidium* – contamination) than surface water. However, groundwater may still be susceptible to water-borne disease pathogens, for example, groundwater under the direct influence of surface water may be at risk to infiltration from surface sources, such as agricultural runoff or contamination by nearby septic sources. The majority (92%) of Canadians, with a private water supply, collect water from groundwater sources.[8] In contrast, the majority (about 85%) of Canadians, with drinking water from public water supplies, receive water from surface water sources.[7]

Treatment practices

The type of water treatment is influenced by the type and quality of source water, number of people served by the drinking water plant and available financial and human resources. Statistics Canada[7] estimates that in 2007 just over half (55%) of treated water produced came from conventional or direct filtration drinking water plants, serving about half the Canadian population. Conventional plants apply coagulation, flocculation, sedimentation, and granular media filtration while direct filtration plants have a similar treatment process, without the application of sedimentation. Other plants use a variety of filtration systems, disinfection, or some combination of treatment processes. Statistics Canada estimates that approximately 8.7% of Canadian drinking water plants, servicing communities of 300 people or more, do not utilize any water treatment processes.[7]

Trends in disease outbreaks and surveillance

Water-borne disease outbreaks in Canada

Investigations of water-borne disease outbreaks are challenging because the outbreak events are rare, the pathogenic agents involved may be transmitted via multiple routes (e.g., person to person, food-borne, as well as water-borne), and gastro-intestinal illnesses are frequently under-reported.[9] Despite such challenges, useful information about water-borne disease outbreaks may be obtained from in-depth case studies and analysis of drinking water system failures. Information pertaining to outbreaks may be collected, assessed, and reported at the local and regional level. However, in Canada there is no national surveillance system for systematic collection of water-borne disease outbreak data.[b] National surveillance is fragmented because each province and territory has different lists of reportable diseases, case reports, investigation practices, and mechanisms for assessing outbreaks.

Two water-borne disease outbreaks, in Walkerton, Ontario in May-June 2000 and in North Battleford, Saskatchewan in April 2001, brought considerable attention to water quality issues in Canada. In-depth assessments of these high profile water-borne disease outbreaks are available in the form of government publications and reports.[10-14] These publications describe the findings of epidemiological investigations and include personal narratives and description of events leading to the water-borne disease outbreaks. These case studies provide particularly insightful accounts of drinking water system failures and their consequences. Increased awareness of water quality has led to a renewed interest in understanding the burden of water-borne disease and factors contributing to disease outbreaks in Canada.

Recent investigations of water-borne disease outbreaks

In an attempt to inform practice and policy, this report aims to review available information about past Canadian water-borne disease outbreaks. In the absence of national surveillance data, two recent investigations and one case history analysis inform this report. These publications were selected for inclusion as they provide the most recent and comprehensive information about Canadian water-borne disease outbreaks.

(1) In 2009, the National Collaborating Centre for Environmental Health (NCCEH) commissioned Novometrix Research Inc[c] to explore the characteristics of water-borne disease outbreaks in Canada. In their retrospective investigation, Novometrix contacted representatives from public health regions across Canada for a voluntary telephone interview. Representatives responded to a standardized questionnaire about water-borne disease events (suspected or confirmed) that had occurred between 1993 and 2009, based on recall and their review of available reports. Project objectives included:

(i) Defining the characteristics of water-borne disease events;
(ii) Describing factors contributing to water-borne disease events;
(iii) Describing current water-borne disease event detection and prevention practices;
(iv) Identifying information needs of front-line public health staff.

Novometrix identified a number of limitations to the data collected. The retrospective design may have resulted in recall bias. Interviewees may have provided information on larger, more significant or more recent outbreaks. As well, interviewees may not have been aware of water-borne disease events that occurred, either due to personnel turnover during the study period or incomplete reporting and documentation. The investigation also reported a degree of non-response (29%) that may have biased the results. Novometrix characterized drinking water systems by the number of people serviced by the system, but did not report whether the system was public, semi-public or private.

The final Novometrix report provided details about 47 water-borne disease events between 1993 and 2008. An additional event (not previously captured in the final report, because of its late survey response) has been included here. Additionally, five of the original events reported did not include information regarding the number of people served by the drinking water system. Information about the population served was not previously available for the Walkerton, Ontario 2000 outbreak, but has been included here; informed by the O'Connor10 investigative report. Thus, included in this report are details about 48 water-borne disease events (a total of 44 events contain information about the population served by the drinking water system).

For a full description of the methodology, limitations, and results please see the final report Retrospective surveillance for drinking water-related illnesses in Canada.[1]

(2) In 2005, Schuster and colleagues[2] (referred to as Schuster in this report) analyzed information about Canadian infectious disease outbreaks related to drinking water. Their investigation relied on documented outbreak summary reports accessed from Health Canada and the province of Quebec, as well as information from academic and grey literature sources. The study's objective was to gain a better understanding of public health and disease burden of drinking water quality. The investigation described 288 *definite, probable,* and *possible* water-borne disease outbreaks between 1974 and 2001.

b The National Enteric Surveillance Program (NESP) collects and reports on the national incidence of enteric pathogens, see http://www.nml-lnm.gc.ca/NESP-PNSME/index-eng.htm.
c Authored by Wilson et al.,[1] referred to as Novometrix in this report, as noted in Executive Summary.

Schuster included a broad list of infectious disease outbreaks, based on epidemiological evidence and classified as *definitely, probably,* and *possibly* water-borne, including events that may not have been truly water-borne. Schuster described a greater number of outbreaks over a longer period of time; however, their analysis captured fewer event details and did not include specific information about population size served by the water system.

(3) In 2004, Hrudey and Hrudey[3] (referred to as the Hrudeys in this report) published in-depth case reviews of numerous water-borne disease outbreaks in Canada and other industrialized countries. Their review summarized important themes for drinking water provision and has been included to provide a broader context for trends of water-borne disease outbreaks.

Defining water-borne disease outbreaks

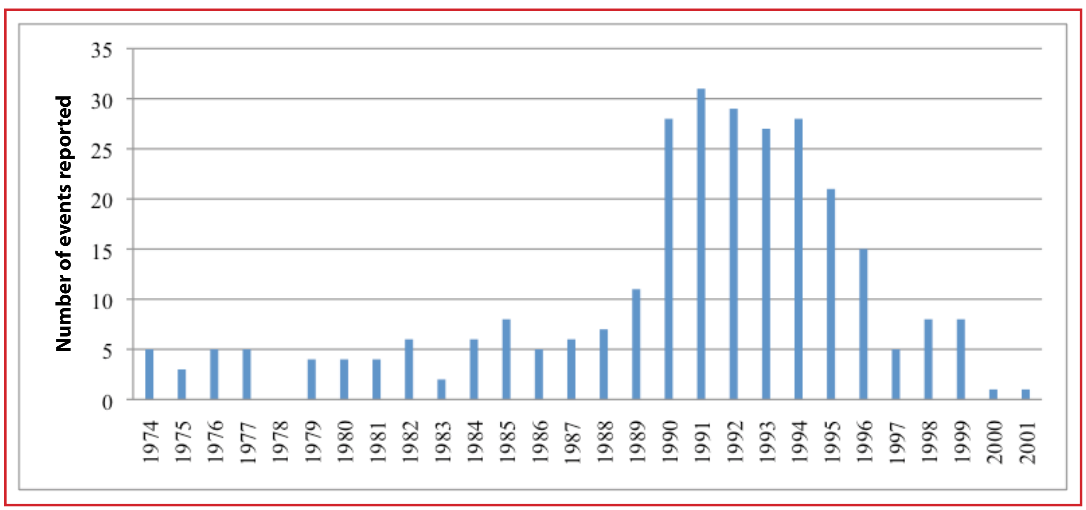
Each of the research investigations, described above, define water-borne disease outbreaks somewhat differently. Schuster defined a water-borne infectious disease outbreak as an incident in which more than two cases of illness occurred after the ingestion of water from the same potable source. Novometrix defined waterborne disease events as cases of a suspected or confirmed acute illness related to exposure to biological, chemical or radiological agents from drinking water and involving two or more individuals. Additionally Novometrix included events involving a single individual where a clear point source (e.g., a private well) could be identified.

Trends of all Canadian water-borne disease outbreaks

There are a number of challenges to water-borne disease surveillance, including under-reporting of gastrointestinal illnesses and multiple routes of transmission of pathogenic agents (e.g., person to person, food-borne, as well as water-borne). Yet, it is possible to overcome these challenges with resources designated for surveillance. The investigations by Novometrix and Schuster describe a high proportion of outbreaks reported from the province of Québec. The increased reporting is an outcome of the province's enhanced surveillance program through the Institut national de santé publique du Québec (INSPQ).

The temporal distribution of all Canadian water-borne disease outbreaks, as summarized by Schuster, is illustrated in Figure 1. The Schuster study reports consistently low numbers of outbreaks between 1974 and 1988, with a significant peak in the early 1990s. This is perhaps due to the identifications of new water-borne pathogens (e.g., *Giardia* and *cryptosporidium)*, increased surveillance, and/or improvements in case identification and outbreak detection. A subsequent decrease in the number of outbreaks reported through the late 1990s may be partly due to improvements in water quality management (e.g., filtration systems to prevent outbreaks), following increased awareness and/or subsequent efforts to control outbreaks. Under-reporting of outbreaks between 2000 and 2001 is highly suspected, as only two highly publicized water-borne disease outbreaks are included in the Schuster dataset.

Figure 1: Number of "definitely", "probably", and "possibly" water-borne disease outbreaks reported by Schuster (1974-2001)



Source: Schuster et al. Reproduced with permission of the Canadian Public Health Association

Novometrix investigated 48 water-borne disease events between 1993 and 2008. As illustrated in Table 3, they report a decline in reported events following 2000. One possible explanation is improvements in drinking water awareness and quality following the Walkerton, ON outbreak in 2000. During the year of the Walkerton outbreak, public awareness of water quality was likely heightened and following the outbreak considerable efforts were made to control water-borne disease and improve water quality management.

Table 3: Number of water-borne disease events investigated by Novometrix (1993-2007)

Year	Number of water-borne disease events
1993	5
1994	5
1995	8
1996	5
1997	2
1998	5
1999	0
2000	7
2001	2
2002	1
2003	0
2004	1
2005	1
2006	2
2007	2
No date reported	2
Total	**48**

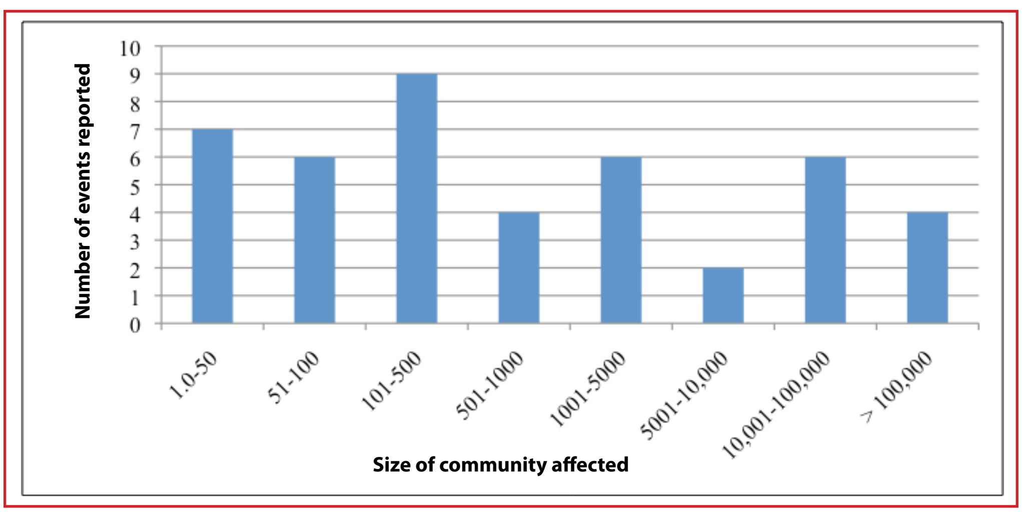
Source: Data from Novometrix Research Inc.

The decreasing trend since the mid-1990s may also be partly due to a shift in risk exposure in the Canadian population. Studies from British Columbia and Ontario, 2001-2002 and 2004 respectively, describe increased use of in-home water treatment methods and increased consumption of bottled water as a primary drinking water source.[15,16] Alternative water sources make the detection and identification of water-borne illnesses more difficult, as they create multiple, geographically diffuse sources of drinking water. As well, shifts in exposure may also include changes in urbanization and the coverage of public water systems over time.

Drinking water systems affected by water-borne disease outbreaks

As illustrated in Figure 2, Novometrix found that the majority (75%) of water-borne disease events occurred among SDWS serving communities with populations of 5,000 or less. A total of 33 water-borne disease events in SDWS were reported between 1993 and 2008; of these, 26 events occurred in water systems serving less than 1,000 people and 7 events affected water systems serving 30 people or less (likely associated with private or semi-public systems).

Figure 2: Distribution of water-borne disease events investigated by Novometrix (1993-2007), according to size of population served



Source: Data from Novometrix Research Inc.

In their analysis of Canadian infectious disease outbreaks related to drinking water between 1974 and 2001, Schuster found that almost half (48%) of outbreaks were reported in semi-public systems, 34% in public systems, and 18% in private systems (Table 4). Of outbreaks that could be categorized as definitely water-borne, the majority (60%) were in public systems. Outbreaks in the semi-public and private systems were less likely to be categorized as definitely water-borne. The authors suggest that public system outbreaks are more likely to be reported and investigated because a larger number of people are affected.

Table 4: Number of infectious disease outbreaks reported by Schuster (1974-2001); categorized by type of drinking water system and by strength of evidence for a water-borne source

Source	Public	Semi-public	Private	Total
Definitely water-borne	59	28	12	99
Probably water-borne	17	25	19	61
Possibly water-borne	23	85	20	128
Total	**99**	**138**	**51**	**288**

Source: Schuster et al. Reproduced with permission of the Canadian Public Health Association

The original investigation by Schuster did not thoroughly explore the population size of communities affected by infectious disease outbreaks. It is likely that the outbreaks reported in semi-public and private water systems (total of 189 outbreaks) serviced populations of less than 5,000 people.

To obtain general information about trends in public SDWS, the current population of communities affected were queried and added to the Schuster dataset. Of the 99 outbreaks that occurred in public drinking water systems between 1974 and 2001, current population data was available for 87 of the outbreaks. Due to the broad time period (1974-2001), population estimates have likely resulted in some error. As described in Table 5, 43 outbreaks occurred in public water systems with populations of 5,000 or less and/or described their *population at risk* as less than 5,000. The findings suggest that about half the public outbreaks (including those that were *definitely, probably,* and *possibly* water-borne) described by Schuster, occurred in communities serviced by SDWS.

Table 5: Distribution of infectious disease outbreaks in public water systems reported by Schuster (1974-2001) by size of population served

Population size	Number of outbreaks
100 – 999	6
1,000 – 1,999	15
2,000 – 2,999	9
3,000 – 3,999	7
4,000 – 5,000	6
5,001 or more	44
Total	**87**

Source: Data from Schuster et al.
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Burden of disease

The water-borne *E. coli* outbreak in Walkerton, Ontario in May 2000 caused more than 2,200 cases of gastrointestinal illness and resulted in 65 hospitalizations and 7 deaths. This outbreak occurred in a municipal water system servicing a population of 4,800 and an in-depth investigation (described in detail by O'Connor[10]) provided information about the burden of disease following the tragedy. For the other water-borne disease outbreaks explored in this analysis, far fewer illnesses were reported; the majority reported less than 50 illness cases and only a few events were associated with hospitalizations of a small number of patients. The low number of reported cases is likely due to high under-reporting of gastro-intestinal illness cases.[3,9]

Characteristics and factors contributing to outbreaks in small drinking water systems

Limited available data suggests that a high proportion of water-borne disease outbreaks, captured in recent investigations, have occurred in SDWS. Novometrix found that the majority (75%) of water-borne disease events occurred among SDWS (described in Figure 2). Reanalysis of the Schuster data (including all *possible, probable,* and *definite* outbreaks) finds that about half of the public outbreaks occurred in communities serviced by SDWS. Additionally, it is likely that the outbreaks reported in semi-public and private water systems serviced populations of less than 5,000 people.

The remainder of this report will focus on characteristics and factors contributing to water-borne disease outbreaks affecting those systems servicing populations of 5,000 people or less. Information about these rare events is limited; details are available about the 33 events reported in the Novometrix investigation and incomplete information is available about the 43 infectious outbreaks in public SDWS and 189 outbreaks in semi-public and private water systems investigated by Schuster.

Appendix A describes characteristics and factors contributing to outbreaks investigated by Novometrix and Schuster: Table A provides details about the 16 groundwater SDWS events reported by Novometrix; Table B provides details about the 14 surface water SDWS events described by Novometrix; Table C describes the known characteristics of 30 public SDWS infectious disease outbreaks reported by Schuster. (Note: 13 outbreaks reviewed by Schuster did not have any information about water source, treatment process or factors contributing to the outbreak). Details about the 189 outbreaks in semi-public and private water systems investigated by Schuster are not listed in the Appendix but are discussed below.

Etiological agents

The majority of SDWS events investigated by Novometrix were associated with a variety of microbial disease agents; only two events were associated with a chemical (nitrate-copper) agent. Schuster's investigation focused only on biological agents, due to their importance in water quality management. Many (47%), of the all the reported cases investigated by Schuster, failed to identify a responsible disease agent. This trend was most obvious among private and semi-public water system events where resources for agent identification were likely limited. Both investigations found that the majority of infectious water-borne disease outbreaks occurred in summer and spring. This is consistent with findings in other investigations and is likely related to the survival of pathogens and weather variables, such as snow melt and rainfall or increased human and animal activity in watershed areas.

Source water

Most public water systems service larger populations and obtain source water from surface water sources. The majority of public system outbreaks investigated by Schuster occurred in surface water systems. Novometrix described 14 outbreaks associated with surface water sources, with *Giardia* being the most common etiological agent identified.

The majority (92%) of Canadians who use a private water supply, collect their water from groundwater sources.[8] As expected, the majority of outbreaks in private drinking water systems reported by Schuster were from groundwater sources (28 events in groundwater, 1 surface water, and 17 no reported water source). Novometrix described six outbreaks associated with private groundwater wells. The disease agents most often associated with groundwater outbreaks were bacterial and/or viral.

Semi-public systems include restaurants, campgrounds, and other privately operated, yet publically accessed, systems. The investigation by Schuster found that among semi-public system outbreaks the majority (71%) of systems obtained water from groundwater sources and about a quarter (26%) obtained water from surface water sources. A few of the outbreaks, involving a mix of surface water and groundwater, were often associated with public and semi-public water systems. The low number of reported events likely reflects the small number of systems that obtain water from mixed sources.

Water treatment

Novometrix found that 15 outbreaks occurred in SDWS that lacked water treatment. Excluding the two chemical outbreaks, Table 6 describes the water treatment process during the reported infectious disease outbreaks. The majority of outbreaks occurred in unprotected groundwater systems with no water treatment. When outbreaks occurred in surface water systems, some type of water treatment method was more likely to have been in place but inadequacy or failure of the treatment systems were often associated with the outbreaks. When disinfection was applied, chlorine was the most common disinfectant used. Similarly, inadequacy or failure of water treatment was a characteristic of many outbreaks reviewed by Schuster.

Table 6: Type of water treatment by water source at time of SDWS infectious disease outbreaks reported by Novometrix (1993-2007)

Type of treatment	Groundwater	Surface water	Mixed	Total
None	10	5	0	15
Disinfection only	5	8	1	14
Disinfection and filtration	0	1*	1	2
Total	**15**	**14**	**2**	**31**

Source: Data from Novometrix Research Inc.
*Failure of the filtration system was reported as a causative factor in this *Giardia* outbreak

Factors contributing to disease outbreaks

Water-borne outbreaks are often the result of a combination of failures in a water system.[3] Those interviewed by Novometrix identified numerous environmental and technical factors that may have contributed to the disease event in their SDWS. Schuster's investigative review described a number of factors associated with the reported disease outbreaks (although the terminology in outbreak reports can be vague). The factors contributing to water-borne disease outbreaks are summarized as:

Lack of source water protection: Animals (agricultural or wildlife) in the watershed were the most commonly identified source of contamination in surface water outbreaks and human septic contamination was the most common source identified for groundwater outbreaks. Optimal management and protection of watersheds reduces the potential for surface water contamination by pathogens.[17] Yet, these findings indicate that watershed protection within SDWS is currently weak and requires improvement.

Precipitation, spring thaw/run-off, and high turbidity: Weather events tend to exacerbate underlying vulnerabilities of a drinking water system that has been created by inadequate water protection or inadequate treatment. For example, precipitation may lead to increased turbidity, due to soil and debris intrusion in the water source. In absence of a filtration system, soil particles may carry pathogens into water; the effectiveness of water disinfection (e.g., chlorination) may be reduced because of the presence of organic matters in the water and consequently some microorganisms might be able to bypass or survive the water treatment process. Climatic factors, such as heavy precipitation prior to an event, have been shown to increase risk of water-borne outbreaks. These are expected to increase under global climate change scenarios.[18,19]

Inadequacy or failure of water treatment: Treatment practices in SDWS are influenced by challenges associated with lack of funding, infrastructure, and/or training opportunities for SDWS operators.[3] The Hrudeys emphasize the importance of operators in the management and maintenance of local drinking water systems. Operators with adequate training and understanding of their water system, including knowledge of their system's capacity to cope with hazards and recognition of how changes in treatment impact water quality, can take action and respond to unusual or potentially hazardous events. Additionally, the Hrudeys describe select cases of community resistance to water chlorination, due to taste and aesthetic preferences as well as concerns of disinfection byproducts (DBPs).

Malfunctioning water distribution systems: Main breaks (e.g., broken pipes) and cross-connections (e.g., back siphonage and back flow) are common causes of outbreaks traced to water distribution systems. Water-borne disease outbreaks associated with problems within distribution systems are challenging because they are difficult to anticipate and detect, thus requiring field investigations and monitoring of water quality at its destination. The Hrudeys suggest that operators undertake an inspection program to recognize and repair potential hazards within their water distribution systems.

Other factors: Ongoing maintenance work (including repairs and replacements) in the water system was associated with three outbreaks reported in Schuster. Human error was a reported factor described by Novometrix. Details and terminology about the predisposing circumstances of an outbreak were often vague or not available.

Current water-borne disease event detection and prevention practices

In addition to identifying key characteristics of systems with WBE, Novometrix sought to describe current WBE detection and prevention practices and identify information needs of front-line public health staff. In an effort to obtain this information, Novometrix interviewed system operators about their past and current water-borne disease prevention and detection practices.

Event detection

Novometrix[1] reported various channels of SDWS disease event detection, including identification by patients and phone inquiries as well as local public health unit, physician, and laboratory reports. The water-borne outbreaks of SDWS investigated were also identified through water quality monitoring, epidemiological investigations, laboratory confirmation or a combination of these methods.

The majority of Novometrix participants relied on a variety of external expert resources and information during the SDWS outbreak investigations, including water treatment personnel, regional epidemiologists, and epidemiologists from the Canadian Public Health Agency field epidemiology program. However, a number of outbreak investigations did not consult additional expert resources. Access to specific experts and support for local authorities to seek appropriate advice, either during water-borne outbreaks or during protocol planning and water system development, may be an important aspect of water-borne disease prevention.

Drinking water advisories

Novometrix found that in the majority of cases a drinking water advisory was issued in response to a SDWS disease outbreak. When an advisory had not been issued it was because one was already in place or they chose to close the facility. It is important to note that drinking water advisories are often not effective in protecting people from contaminants.[3] Many advisories are issued late or not until after an outbreak is already over.[3] Furthermore, people may be non-compliant to water advisories because they did not learn of the advisory, did not adequately understand the meaning or the intent of the advisory, did not remember or were disbelieving.[3]

Changes to water system management

Several Novometrix participants described improvements to their water system following the disease event. A small number of systems closed and five of the water providers altered their source water from one more likely to be associated with water-borne pathogens (i.e., surface water) to a source less likely to be associated with water-borne pathogens (i.e., groundwater). Nine interview participants reported improved water treatment processes following the outbreak. These results indicate that water-borne outbreaks prompted some water providers and communities to invest in and improve water quality management practices.

Monitoring drinking water quality

A number of the SDWS outbreaks reported by Novometrix did not have water monitoring programs. Monitoring programs were defined broadly by Novometrix, including water sampling for pathogens and other indicators of water quality (e.g., turbidity, chlorine residual). As illustrated in Table 7, when a water monitoring program was in place and operating, the responsible agency was more likely to be a government body than a private person or business. When a monitoring program was not in place, the designated responsible agency was always private.

Table 7: Monitoring program in SDWS reported by Novometrix (1993-2007)

	Number of events reported			
Water monitoring program in place?	**Private responsibility (alone)**	**Governement responsibility (alone or in combination with private)**	**Unknow**	**Total**
Yes	5	11	0	16
No	11	0	1	12
Unknown	1	3	1	5
Total	**17**	**14**	**2**	**33**

Source: Data from Novometrix Research Inc.

System owners are responsible for water quality and monitoring of private water systems, yet the literature indicates many private owners are not monitoring their water quality.[20] Statistics Canada found that only 35% of households, with non-municipal water supplies, reported testing their drinking water in 2007 and in 2006.[8] A survey by Jones et al.[15] found 21% of private water operators had never tested their water supply and only 8% had tested their water supply 3 times or more each year, as guidelines suggest. Explanations for limited testing included inconveniences associated with visiting the testing facility, lack of apparent health problems or noticeable changes to water from their supply, and a tendency for past results to dictate future testing behavior (i.e., when past results indicated no problem, no further testing occurred).

Results suggest that SDWS monitoring programs stand a better chance of being implemented and maintained when government bodies are responsible or involved. Information regarding the actions and responsibilities of private businesses and water purveyors is limited and requires further investigation. Furthermore, Novometrix reported that seven SDWS outbreaks occurred when monitoring of drinking water was shared between agencies. Research may be useful to investigate whether shared monitoring of drinking water systems increases risk (e.g., due to diffusion of responsibility or unclear roles of system operators).

Monitoring water quality for pathogens does not prevent water-borne disease outbreaks.[3] Water quality test results can take days, even weeks, to yield results and throughout this time water ingestion has already taken place. However, water quality monitoring does indicate that contamination has occurred and this information is particularly useful if contamination is still occurring.[3] The Novometrix results indicate that water quality monitoring is a primary tool in outbreak identification, therefore an important tool during the investigative process. Furthermore, even if a pathogen is no longer present in a water system, a good water monitoring program will help record disruptions to water quality and help guide future activities.

Themes of drinking water provision

Hrudey and Hrudey's[3] case history analysis provides evidence that supports the findings from Novometrix and Schuster. The Hrudeys concluded that the majority of water-borne outbreaks occurred in small water systems (due to the international scope of the publication these systems were not defined) and emphasized that operators of SDWS face various challenges. For example, the Hrudeys note that the unit cost for operating small water systems may be higher where economies of scale cannot be realized. The authors also describe the lack of investment and financial considerations associated with past water-borne outbreaks in Canada, including Walkerton, Ontario in 2000 and North Battleford, Saskatchewan in 2001. Researchers conclude that ensuring drinking water safety will require that consumers value safe drinking water, hold their government officials accountable, and ultimately pay for system investments. The Hrudeys summarize six reoccurring themes of drinking water provision:

1. ***Pathogens pose the greatest and most tangible risk to drinking water safety.***
   The majority of water-borne outbreaks are associated with microbiological pathogens. Ultimately, transmission of pathogens is oral-fecal; thus, sources of pathogens follow human and animal activity.[3] Under-reporting of gastrointestinal symptoms can conceal the presence of water-borne pathogens. Additionally, prevention and detection of outbreaks can be difficult because pathogens are often heterogeneously distributed in water and consumer exposure to infectious doses of agents is non-uniform.[3] Protozoa pathogens, like *cryptosporidium* and *Giardia* cysts, pose an additional challenge to disease prevention because they are resistant to chemical disinfection; thus, treatment systems require fine particle removal and alternative disinfection processes.[3]

2. ***Robust, effective, multiple barriers to drinking water contamination are needed to suit the level of contamination challenge facing raw water sources.***
   To prevent disease the Hrudeys describe the importance of multiple and robust barriers within water systems to accommodate errors and changes in the system. The Hrudeys describe a surprisingly large number of outbreaks associated with water drawn from untreated sources accessible by humans and animals.

3. ***Trouble is usually preceded by change, so change should be taken as a warning to be on alert for trouble.***
   Many past outbreaks of water-borne disease were associated with changes or events within a drinking water system, often extreme or unusual weather or modifications of system operations. The Hrudeys suggest it is important for operators to know and understand normal operations of their water system plants and be able to recognize the potential impact of unusual conditions and associated operational changes. As each water system plant operates uniquely, understanding the behaviour of a system under unusual or challenging conditions can provide information to prevent future illness. Additional lessons learned can also come from close calls that do not escalate into a disease outbreak.

4. ***Operators must be capable and responsive.***
   Events, reviewed by the Hrudeys, describe the importance of capable and responsive water system operators. Operators with enhanced knowledge of their water system can identify problems and take protective action prior to water-borne disease outbreaks. The authors recommend efforts to increase awareness, training, and understanding among system operators.

5. ***Drinking water professionals** (providers, regulators, and health officials) **must be accountable to drinking water consumers.*** As water quality has a direct impact on public health, the Hrudeys suggest that water system operators, regulators, politicians, and health officials have a full appreciation of their responsibility. The Hrudeys describe a number of Canadian cases where municipal politicians lack concern for drinking water safety or provide ill-informed statements to the public. The authors further note that good communication and strong relationships between water utilities, local health authorities, and public health inspectors is important for prevention and early detection of water-borne disease outbreaks.
6. ***Ensuring safety is an exercise in risk management, requiring sensible decisions in the face of uncertainty.*** Identifying and detecting water-borne disease outbreaks can be challenging, as the evidence is often unclear while events are unfolding.[3] It is difficult to gather evidence of water-borne illnesses because there may be a lag time between water system contamination, distribution of pathogens, ingestion, incubation period prior to symptom onset, reported symptoms to health practitioners, and laboratory confirmation. Outbreak and pathogen detection through laboratory testing is limited because of asymptomatic infections and persons not seeking medical attention. Following positive laboratory tests, the epidemiological investigation of an outbreak requires additional time and resources. As well, the pathogens involved may be spread via other routes, including person-to-person contact and food-borne illnesses, often complicating the water-borne disease investigation. The investigation of possible water-borne disease outbreaks is an exercise in risk management as water system operators and public officials attempt to make sensible decisions in the face of uncertainty.[3]

Unanswered questions

The outbreak investigations reviewed in this report do not provide information describing underlying or sporadic illnesses associated with water quality. There is preliminary evidence that populations served by private water systems have an increased risk of sporadic gastrointestinal illnesses.[21, 22] People may be able to develop a resistance or tolerance to enteric pathogens. In a prospective study of rural drinking water quality, people who had lived 10 years or more at their current address were less likely to report symptoms of acute gastrointestinal illness.[23] Resistance, adaptation, and tolerance among residents may conceal local water quality concerns, but leave visitors vulnerable to infection.[24]

Investigations of water-borne disease are challenging because outbreaks are rare events, the pathogenic agents involved may be transmitted via multiple routes (e.g., person to person, food-borne, as well as water-borne) and gastro-intestinal illnesses are frequently under-reported. It is unknown how many water-borne outbreaks, as well as sporadic gastro-intestinal illnesses, are not being detected or reported. Are illnesses, originating from SDWS, less likely to be reported?

The Hrudeys comment on unique challenges faced by operators of SDWS. Further information regarding actual infrastructure, technology, and financial constraints is required. What role does community size and financial constraints play in the operation of SDWS? What financial, infrastructural, and training challenges do operators of SDWS face? What role does public opinion play in inadequate treatment practices (i.e., lack of chlorination due to taste preferences)? How does the collaborative management of systems (i.e., possible diffusion of responsibility or unclear roles) affect system operations?

Conclusions

Recent investigations provide information about the characteristics and factors associated with disease outbreaks in Canadian water systems. Based on available data, a relatively high proportion of water-borne disease outbreaks have occurred in SDWS. Estimates are based on limited data and utilize various definitions of water-borne disease outbreaks and classifications of Canadian drinking water systems. The Novometrix research study found that the majority (75%) of water-borne disease outbreaks occurred among SDWS. Among the *definitely, probably,* and *possibly* water-borne outbreaks reported by Schuster, a high proportion of events occurred in SDWS classified as semi-public (48%) and private (18%) water systems. Approximately 34% of the enteric disease outbreaks reported by Schuster occurred in public water systems. Reanalysis of the data suggests about half of the public outbreaks reported by Schuster occurred in systems serving populations of 5,000 people or less. The Hrudeys' analysis of water-borne disease outbreaks in affluent nations provides further context. The themes and discussions suggest small drinking water systems face challenges associated with infrastructure, technology, and financial constraints. Investments in drinking water systems and operator training have the potential to reduce the burden of water-borne disease in Canada.

While the best estimates about drinking water systems are available from Statistics Canada,[7] information about the number of SDWS and the population serviced by these systems is limited. Standardized definitions of drinking water systems and reporting of operational variables would improve our understanding of factors associated with water-borne disease outbreaks. Inconsistent and fragmented data is one factor impeding evidence-informed policy and practice. While there are a number of challenges to water-borne disease investigation and detection, enhanced reporting from the Institut national de santé publique du Québec (INSPQ) illustrates improved surveillance is possible. Coordinated provincial and national surveillance systems for reporting water-borne disease outbreaks are required to inform policy and practice and to ensure safe drinking water for Canadians.

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APPENDIX

Table A: Groundwater disease SDWS outbreaks described in the Novometrix investigation (n=16)

Distribution	Disease agent	Types of treatment	Precipitation	Thaw	No source water protection	Septic system contami-nation	Water treatment failure	Inadequate or lack of treatment	Broken pipe during distribution	Water turbidity	Human error
Private well	Giardia	None						√			
Private well	Unknown	Disinfection	√	√			√	√			
Private well	norovirus /norwalk	Disinfection	√					√			√
Private well	Norovirus /norwalk	None				√			√		
Private well	Salmonella	None			√	√		√			
Private well	E.Coli	None				√			√		
Pipe	Ecoli/coliform	None				√					
Pipe	HepA	None	√				√			√	
Pipe	HepA	None	√		√			√			
Pipe	Norovirus /norwalk	None			√			√			
Pipe	Ecoli/coliform	None			√			√			
Pipe	Ecoli/coliform	Disinfection	√					√		√	√
Pipe	Unknown	Disinfection	√				√				
Pipe	Unknown /infectious	None		√				√		√	
Pipe	Unknown	Disinfection	√								
Pipe	Nitrate/copper	Disinfection									

Table B: Mixed and Surface water disease SDWS outbreaks described in the Novometrix investigation (n=17)

Type of water system	Disease agent	Surface water protection	Types of treatment	Precipitation	Run-off	No source water protection	Animals in watershed	Human contami-nation	Treatment failures	Inadequate or lack of treatment	Post treatment contami-nation	Water turbidity	Human error
Mixed	Nitrate/ copper	None	Disinfection & filtration							√	√		
Mixed	Legionaella	None	Disinfection & filtration								√		
Mixed	Campy	None	Disinfection			√	√		√				√
SW	Campy	None	None			√	√	√		√			
SW	Campy	None	None										
SW	Ecoli/ coliform	None	Disinfection			√	√			√		√	
SW	Ecoli/ coliform	Partially	Disinfection	√		√				√		√	√
SW	Giardia	Partially	Disinfection		√		√			√			
SW	Giardia	Fully	Disinfection				√						
SW	Giardia	None	None	√		√	√			√		√	
SW	Giardia	None	Disinfection & filtration		√		√		√				
SW	Giardia	None	Disinfection							√			
SW	Giardia	Unknown	Disinfection				√			√			
SW	Giardia	Unknown	None							√			
SW	HepA	None	Disinfection			√	√			√		√	
SW	Norovirus/ norwalk	None	Disinfection						√	√			
SW	Unknown/ infectious	None	None			√				√			

Table C: Water disease SDWS outbreaks of public systems described in the Schuster et al. investigation (n=30)

Water source	Disease agent	Treatment	Lack of source protect’	Animal	Septic	Flood/ thaw/ run-off	Inadequate treatment	Treatment failure	Post contami-nation	Water ongoing in the system	No info about causation
GW	Escherichia coli	Disinfection		√		√	√		√		
GW	Salmonella typhi	None									√
GW	Unknown	None									√
SW	Norwalk virus	None				√	√				
SW	Campylobacter jejuni	None		√						√	
SW	Campylobacter jejuni	None		√						√	
SW	Salmonella typhi	Unknown									√
SW	Giardia	Unknown									√
SW	Giardia	unknown		√							
SW	Giardia	unknown									√
SW	Giardia	unknown									√
SW	Giardia	Disinfection		√							
SW	Giardia	Disinfection									√
SW	Giardia	Disinfection		√							
SW	Giardia	Disinfection & filtration			√	√		√			
SW	Giardia	None									√
SW	Unknown	None				√	√				
SW	Unknown	Disinfection						√			
Unknown	Giardia	Unknown	√	√			√				
Unknown	Campylobacter	Unknown		√							
Unknown	Salmonella	Unknown		√							
Unknown	Salmonella; campylobacter	Unknown							√		
Unknown	Hepatitis A	Unknown			√						
Unknown	Unknown	None					√				
Unknown	Unknown	None									
Unknown	Unknown	None					√				
Unknown	Unknown	None							√		

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