

Drinking water quality risk management in Canada
Fact summary of microbial risks relevant to property owners

CLEAR inc.

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Executive Summary Water quality risk management is a developing science. From a review of the most recent developments, we have found a growing awareness of water quality risk which is leading to an increasing burden on risk management. The growing awareness is being driven by rapidly improving detection technologies which are advancing our knowledge of the epidemiology of waterborne pathogens. The increased burden on risk management will raise the mandated responsibilities for all levels of society, including for private property owners. Today, this is no longer just a prediction, Quebec (2013) and Vancouver (2020) have enacted legislation requiring private building owners to regularly monitor water systems for *Legionella*. Ontario will likely not be far behind, considering that the reported cases of Legionellosis in Ontario have increased every year from 2014 to 2019, representing a three-fold increase in five years. The future of water quality risk management for owners will not stop at *Legionella*. *Legionella* is only one of many biofilm-associated pathogens that have found a secondary habitat in engineered water systems, such as premise plumbing systems, evaporative condensers in buildings, and drinking water distribution systems. In recent years, the public health concerns have been growing around a host of other drinking water-associated pathogens, such as *M. avium*, *P. aeruginosa*, and *H. pylori*. We project a future where property owners are mandated to monitor a growing list of such pathogens. This will make the health-status of a building more transparent which will increase the owner's responsibility to keep it healthy.

What are the microbial risks in municipal drinking water? Some important waterborne pathogens relevant to human health are summarized in Table 1. The pathogens are very diverse, but it is useful to classify them as either enteric or free-living. Enteric pathogens multiply in human or animal gastrointestinal systems¹. They are transmitted via the fecal-oral route and can cause infections after ingestion of water contaminated by human or animal feces. The amount of exposure required for infection can be extremely low; for example, ingesting only 18 particles of norovirus² or 10 oocysts of *Cryptosporidium*³ can be sufficient to cause illness. Noroviruses are the most commonly reported enteric viruses in North America⁴, thought to cause >90% of all sporadic cases of acute gastroenteritis in children⁵. *Cryptosporidium* is one of the most commonly reported enteric protozoa in the world⁶ and was responsible for the largest waterborne outbreak in documented USA history⁷ (Milwaukee, 1993). Spontaneous weather events, such as floods, snowmelts, or rainfalls, increase the probability for cross-contamination between waste waters and source waters, and this increases the risk of almost all enteric pathogens⁸. One study suggests that *Cryptosporidium* oocysts could fluctuate from below a detectable limit to peak concentrations within three days in response to rainfall⁹. On the other hand, free-living pathogens can multiply in the environment and can cause infections when contaminated water comes in direct contact with eyes or lesions in the skin, or when the water is aerosolized and respired (water-air route)¹. *Legionella* is a free-living bacteria which has found a secondary habitat in engineered water systems such as premise plumbing systems, evaporative condensers in buildings, and drinking water distribution systems¹. It persists in accumulated biofilms and has the potential for explosive growth under the right conditions¹⁰. *Legionella* is the major cause of waterborne illness in the U.S.¹¹ and receives special attention for its high mortality rates during outbreaks¹². One study detected *Legionella* in the plumbing systems in 70% of hospitals tested¹³. Other studies have detected *Legionella* from the showerheads and faucets in anywhere from 6% to 20% of households tested^{14,15}.

How does the Canadian government manage water quality risk? In Canada, the responsibility for the quality of drinking water is shared across all levels of society^{16,17}. The federal government develops the Guidelines for Canadian Drinking Water Quality (GCDWQ) through the Federal-Provincial-Territorial Committee on Drinking Water. The provinces and territories are in charge of setting quality standards and managing drinking water systems, such as source waters, treatment plants, and distribution systems. Municipalities are responsible for the actual monitoring, treatment, and distribution of drinking water. The responsibilities for private property owners are covered by the National Plumbing Code, the National Building Code, and municipal by-laws. Canada does not enforce any guidelines on specific microorganism levels in drinking water because "setting maximum acceptable concentrations for these microorganisms remains impractical."¹ Hence, the GCDWQ recognizes that direct and continuous monitoring of specific pathogens is not feasible at this time¹⁸. The only federal monitoring guidelines are set for general indicators of water quality, such as *E. coli*, total coliforms, and turbidity¹⁹. The limitations of these monitoring guidelines were clearly apparent in the 1993 Milwaukee *Cryptosporidium* outbreak. During the outbreak, none of these measured water quality indicators surpassed USA guidelines; the water quality data raised no alarms^{7,79}. Authorities were only alerted to a problem after hospitals reported alarming levels of gastrointestinal illnesses, but by then, 880,000 individuals were already being exposed to contaminated drinking waters for approximately two weeks. It is estimated that >400,000 individuals were infected, but this could be underestimated, as researchers observed cryptosporidiosis antibodies among 80% of Milwaukee children⁸⁰.

Since water quality surveillance is limited, the GCDWQ focuses instead on treatment-based guidelines as part of a multi-barrier, source-to-tap, risk management approach^{19,20}. Local decision makers are required to undergo comprehensive site-specific risk assessments. The guidelines will then mandate the extent of water treatment in proportion to the estimated risks. To help local decision makers assess risk, Health Canada publishes a standardized methodology known as the Quantitative Microbial Risk Assessment in Drinking Water (QMRA)²⁰. Most of the parameters required for the QMRA (Figure 1) are difficult to measure directly or frequently and may be filled in by expert judgment. Essentially, the QMRA estimates the annual health impact of four reference pathogens on the average person drinking an average amount of treated water on an average day.

What are some limitations of the Quantitative Microbial Risk Assessment in Drinking Water?²⁰

- a) does not account for each important pathogen and none of the reference pathogens represent enteric viruses,
- b) does not account for variability in pathogen levels (e.g. from spontaneous weather events),
- c) does not have reliable epidemiological data from the waterborne illnesses that have only recently become reportable, or continue to be unreported,
- d) does not use demographic data to account for the total health effects on specifically susceptible subpopulations (e.g. pregnant women, children, elderly, immunocompromised),
- e) does not assess any risks originating from the distribution system, nor from premise plumbing systems,
- f) does not assess risks from showering or other forms of contact with contaminated waters.

How will improving detection technologies change water quality risk management? As one review states, "...the greatest limitation on QMRA is the lack of available data to carry out this assessment."²¹ The data for pathogen levels and public health impacts are lacking because of limitations in the current methods for pathogen detection. Currently, there is no unified method for detecting all pathogens of interest²¹, each pathogen requires its own dedicated detection method. Since most pathogens are clinically relevant at extremely low levels in large volumes of water^{1,4,6,20}, the first step for detection is to concentrate the pathogen into smaller volumes⁴. Current methods for concentrating enteric viruses from groundwater recommend filtering >1,500 L of water to get a 1-2 mL sample²², using adsorption filters or ultrafiltration systems with extremely small pore sizes (<20 nm). This highly specialized, laborious, and expensive procedure is a major reason that routine monitoring of enteric viruses in water is not currently feasible⁴. The second step for detection is the analysis of the concentrated sample, for which cell culture and molecular methods exist. Historically, cell culture-based methods are the most widely used and continue to be the recommended methods in government guidelines²⁰. In cell culture, the sample is provided conditions which encourage growth of the pathogen of interest. The extent, or lack, of growth gives a rough indication on the amount of pathogen in the sample. However, not all enteric viruses will grow in cell culture and many bacteria can be Viable But Notculturable (VBNC)²¹, meaning that they might not grow in standard growth conditions but may still be clinically relevant. Even in the best cases, the cultured pathogens will grow slowly, sometimes taking weeks to confirm a negative result⁴.

Currently, the QMRA relies almost exclusively on data obtained by cell culture-based methods²¹. This means that the federal guidelines rely on methods that are almost two decades behind the current generation of molecular methods which have already become standards in the sciences²¹; including immunofluorescence²⁴ and PCR-based methods²⁵. The molecular methods can be specific enough to measure specific strains, sensitive enough to require less concentrated samples, fast enough to provide results in real time, and some methods can even detect multiple different pathogens at once. The EPA Method 1615 is a standardized RT-qPCR method for detecting norovirus and enterovirus²³, but it has not been adopted as a federal standard because it requires specialized tools and is higher cost⁴. Fortunately, the total cost of these methods are dropping precipitously. In 1999, the per-sample cost of PCR was reported²⁶ to be US\$90, and in 2015, a review²⁷ found the per-sample cost of PCR as US\$1.58. That is a 57-fold reduction in cost over 16 years for a basic PCR, and we expect this price to continue dropping. The demand for PCR testing has exploded in the past year due to it becoming the standard method for detecting SARS-CoV-2 during the COVID-19 global pandemic²⁹. This has fueled innovation with the goals of producing cheaper, modular, portable, easy-to-use, PCR testing kits^{29,30,31}. With this in mind, it is reasonable to expect that Canada will soon begin recommending standardized PCR-based methods for waterborne pathogen monitoring, such as Method 1615²³.

Similar events have occurred before; following the 1993 Milwaukee *Cryptosporidium* outbreak, the CDC and EPA created the Working Group on Waterborne Cryptosporidiosis³² which led to the development of Method 1622/1623 for detecting *Cryptosporidium* using an immunofluorescence assay^{33,34}. Method 1622/1623 was validated in 1998 and has since been adopted as a standard by many governments. With this new standard method it became feasible to regulate *Cryptosporidium* levels and between 1998³⁵ and 2006³⁶, the EPA updated the Safe Drinking Water Act to introduce maximum level guidelines for *Cryptosporidium* in public water systems. In 1999, the UK adopted a nearly identical method to Method 1622/1623^{39,40} and amended the UK Water Supply Regulations³⁷ to become the only country requiring continuous daily monitoring of treated water for *Cryptosporidium*³⁸. In 2008, Ontario officially adopted Method 1622/1623 as an accepted protocol for testing *Cryptosporidium*⁴¹ and, in 2012, Canada introduced treatment-based guidelines for it⁴².

This shows how heightened attention following a public health crisis led to the development of a standardized molecular method which allowed governments to include a new pathogen to their water quality regulations. As new standard molecular methods are adopted, it will become feasible to monitor and regulate a growing list of pathogens. This will increase the transparency of water quality risk for regulators, researchers, and consumers, but will also increase the burden of water quality risk management on local decision makers and property owners.

Which new waterborne risks are gaining attention because of improved detection? The WHO has identified detection technologies as a limiting factor for our knowledge of the public health impacts of waterborne pathogens: "...under-appreciated pathogens continue to be recognized to be associated with the waterborne route and as being of public health significance... By increasing our capacity to concentrate and detect micro-organisms in water samples, we can recognize new pathogens and associate known micro-organisms with diseases of unknown etiology."⁴³ The fact that the causal pathogens were never identified in 40% of the reported drinking-water associated outbreaks in the USA between 1991 and 2000⁴³, highlights how much there is left to learn about waterborne pathogen epidemiology. Some of the recent advances in detection technologies have uncovered important public health impacts of waterborne pathogens which were difficult to see previously because a) they have severe impacts only on a susceptible subpopulation, or b) they have chronic or long-term health impacts that are hard to associate with specific exposures to contaminated waters.

For example, *M. avium* and *P. aeruginosa* are both free-living bacteria that are ubiquitous in the environment

and can cause respiratory infections but will very rarely lead to disease in healthy people¹. Despite infections being rare in the general population, *M. avium* and *P. aeruginosa* are some of the leading causes of death in people with HIV/AIDS⁴⁶ and cystic fibrosis⁴⁸, respectively. Both pathogens have been consistently found in engineered water systems, especially in the accumulated biofilms inside premise plumbing systems^{44,45,46,47,82}, but until recently, it has been difficult to prove these plumbing systems are the sources of disease. A gold-standard study in 2019 took place in Philadelphia and used advanced genotyping techniques to show that the genomes of *M. avium* found in 18 of 21 patients successfully matched the genomes of *M. avium* found in water samples from the patients' household plumbing system⁴⁹. This is excellent evidence that premise plumbing in municipal systems may be a substantial source of *M. avium* infections. These bio-film associated pathogens are increasing in North America^{61,65} and are being recognized as the most serious waterborne risks in developed countries. Together, *Legionella*, *M. avium* and *P. aeromonas* are costing the USA \$2.39 billion in direct health care costs annually⁵⁰.

Epidemiological links between waterborne pathogens and chronic diseases have also been growing. In 2015, *M. avium* was hypothesized to be a cause of Crohn's disease⁸³. Another recent example is the enteric bacteria, *H. pylori*¹ which can cause chronic gastritis⁵¹. *H. pylori* infections are common but most infections do not cause symptoms. The true prevalence is unknown but one study found *H. pylori* in 23% of Ontario adults with upper gastrointestinal symptoms⁵². These infections can be lifelong causing irregular symptoms and ulcers⁵³, and in 2014 the International Agency for Research on Cancer (IARC) classified *H. pylori* as carcinogenic to humans⁵⁴. It is now recognized as the single most common cause of gastric cancer worldwide^{55,56}. Contaminated drinking water from municipal systems is suspected as being the primary source for human infections, but no gold-standard study has been done to confirm this⁵⁵. In fact, the studies on the detection of *H. pylori* in municipal drinking water have been limited because *H. pylori* is VBNC and does not reliably grow in cell culture⁵⁵. Until recently, this has greatly limited the epidemiological and public health risk assessments for *H. pylori*. In 2015, a study collected water samples from public water fountains and domestic taps in Spain and by using a sophisticated qPCR technique, they detected *H. pylori* in 66% of the samples⁵⁷. Some of the *H. pylori* were proven viable and potentially infective, thus showing for the first time that *H. pylori* can survive and be potentially infective in drinking waters from municipal systems⁵⁷. These examples show how advanced detection technologies have recently uncovered new epidemiological links between previously under-appreciated pathogens in municipal water systems and the diseases of significant public health concern.

What is the future of water quality risk management in Canadian municipalities? From a review of the most recent developments in water quality risk management, we have found a growing awareness of water quality risk which will lead to an increasing burden on risk management. The growing awareness is being driven by rapidly improving detection technologies which are advancing our knowledge of the epidemiology of waterborne pathogens and making it more feasible to regularly monitor a growing list of pathogens. The increased burden on risk management will raise the mandated responsibilities for all levels of society, including for private property owners. Private property owners will be expected to manage those risks which are deemed to be under their control, such as the free-living pathogens which persist in biofilms inside premise plumbing, HVAC systems, and decorative water features. Today, this is no longer just a prediction. Following the 2012 *Legionella* outbreak in Quebec City⁵⁸, which caused 181 reported infections and 14 deaths, Quebec enacted building safety legislation which requires building owners to register their HVAC systems with a regulator, undergo a site-specific risk assessment, and implement a water management plan⁷⁶. This involves requirements for building owners to collect their own water samples and to send them to accredited laboratories, who will test for *Legionella* using a combination of cell-culture and PCR-based detection methods. Depending on the perceived risks, some buildings are required to undergo continuous monitoring. In 2020, Vancouver enacted a similar by-law and as of January 1, 2021, all new and existing cooling towers, evaporative condensers, and decorative water features are required to be regularly tested for *Legionella*⁷⁷. In both Quebec and Vancouver, if *Legionella* is detected above the maximum level guidelines, the building owners are required to take corrective actions and to immediately re-test. With Quebec and Vancouver taking the lead, Ontario should not be far behind in enacting its own building safety legislation to combat *Legionella*. In 2005, Scarborough experienced a *Legionella* outbreak that caused 112 reported infections and 23 deaths in a long-term care home⁵⁹. The reported cases of Legionellosis in Ontario has increased every year from 2014 to 2019, representing a three-fold increase in five years⁶⁰. This kind of increasing trend in disease caused by free-living pathogens in accumulated biofilms is being observed in much of North America. This is true not just for *Legionella*^{61,62} but also for *M. avium*^{63,64,65}. It should be expected that legislation continues to be introduced throughout North America mandating building owners to monitor and respond to these kinds of waterborne pathogens on their properties⁶². The future of water quality risk management for owners will not stop at *Legionella*, as detection methods continue to get cheaper, it will not be difficult for the accredited laboratories to test the same water samples for other waterborne pathogens like *M. avium*, *P. aeruginosa*, *H. pylori*, or some other emerging pathogen whose public health implications are currently underappreciated. This will make the health-status of a building more transparent which will increase the owner's responsibility to keep it healthy.

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Pathogen	Type of Organism	Size	Relevant Reservoir	Route of Infection	Reference Pathogen?	Outbreak Potential	Monitoring Responsibilities	Notable Public Health Effects	Culturable?	Resistance
Noroviruses	Enteric virus	35-40 nm	Human GI tract	Fecal-oral route	No	Common worldwide ⁴	None	>90% of all acute gastroenteritis in children ⁵	No	NA
Rotaviruses	Enteric virus	70 nm	Human GI tract	Fecal-oral route	No	Common worldwide ⁴	None	+ Leading cause of severe diarrhea in humans ⁷² + Leading cause of childhood hospitalizations from diarrhea ⁴	No	NA
Enteroviruses	Enteric virus	20-30 nm	Human GI tract	Fecal-oral route	No	Increasing in Canada and globally since 2008 ⁶⁷	None	+ Acute respiratory illness in children + Implicated in chronic diseases ⁶⁸ - Chronic fatigue syndrome ⁶⁹ - ALS ⁷¹ - Diabetes ⁷⁰	Yes	NA
<i>Cryptosporidium</i>	Enteric protozoa	Oocyst: 4-6 μm	Human GI tract	Fecal-oral route	Yes	Second most reported cause of waterborne outbreaks in North America ⁷³	Recommended continuous monitoring at water-treatment plants ⁶	+ Diarrhea, vomiting, low-grade fever + Chronic and sometimes lethal infections in immunocompromised ⁷⁵	Yes	Extremely resistant to chlorine-based disinfectants ⁷⁴
<i>Legionella</i>	Free-living bacteria	2-20 μm	Biofilms in engineered water systems ¹⁰	Water-air route	No	Increasing, high mortality outbreaks in North American cities ¹	+ Quebec (2013): Mandated monitoring of cooling towers by building owners ⁷⁶ + Vancouver(2020): Mandated monitoring cooling towers, evaporative condensers, and fountains by building owners ⁷⁷	+ Pontiac fever - 95% attack rate ¹² - Influenza-like illness + Legionnaires' disease - 5% attack rate ¹² - 25% case fatality rate ⁷⁸ - 40-80% case fatality rate in hospital patients ¹²	Yes	NA
<i>Pseudomonas aeruginosa</i>	Free-living bacteria	1.5-3 μm	Biofilms in engineered water systems ⁴⁷	Water-air route	No	Rare	None	+ Leading cause of death for Cystic fibrosis patients ⁴⁸ + High mortality infections	Yes	Carbapenem-resistant strains are critical priority ⁸¹
<i>Mycobacterium avium</i>	Free-living bacteria	1-10 μm	Biofilms in engineered water systems ⁴⁵	Water-air route ⁴⁵	No	Rare	None	+ Major cause of death for HIV/AIDS patients ⁴⁶ + Possible cause of Crohn's disease ⁸³ + \$1.5B total annual healthcare costs in USA ⁵⁰	Yes	+ Very resistant to chemical disinfectants ⁸⁴ + High antibiotic resistance ⁸⁵
<i>Helicobacter pylori</i>	Enteric bacteria	2-4 μm	Human GI tracts	Fecal-oral ⁵⁶	No	No	None	+ Most common cause of gastric cancer worldwide ^{55,56} + Chronic gastritis ⁵¹	No	Multi-drug resistant strains are high priority ⁸¹

Table 1: Summary of waterborne pathogens

Location	Year	Pathogen	Reported (Estimated) Cases	Reported Deaths	Comment	Reference
Milwaukee, USA	1993	<i>Cryptosporidium</i>	>400,000	100	Largest waterborne outbreak in USA history	79
Clitheroe, UK	2000	<i>Cryptosporidium</i>	17,252	0	Despite continuous monitoring in UK	92
Walkerton, Canada	2000	<i>E. coli</i> / <i>Campylobacter</i>	>2300	7	Walkerton Inquiry sentenced utilities operator to jail	100
North Battleford, SK, Canada	2001	<i>Cryptosporidium</i>	5800-7100	0		86
Scarborough, Canada	2005	<i>Legionella</i>	127	21	Nursing home	59
Nokia, Finland	2007	Norovirus	8453	0	Cross contamination between sewage and drinking water pipes	94
Östersund, Sweden	2010	<i>Cryptosporidium</i>	27,000	0		88
Michigan, USA	2010	<i>Legionella</i>	64	17	Cooling tower in military facility	90
Skellefteå, Sweden	2011	<i>Cryptosporidium</i>	20,000	0		87
Pennsylvania, USA	2011	<i>Legionella</i>	22	22	Hospital	91
Elassona, Greece	2012	Rotavirus	3620	0		93
Quebec City, Canada	2012	<i>Legionella</i>	180	13	Cooling towers	58
Oregon, USA	2013	<i>Cryptosporidium</i>	2780	0		89
Flint, Michigan, USA	2014	<i>Legionella</i>	87	12	Michigan Department of Environmental Quality being sued	96
Portugal	2014	<i>Legionella</i>	377	14	Cooling towers	99
Illinois, USA	2015	<i>Legionella</i>	58	13	Veterans home	97
New York, USA	2015	<i>Legionella</i>	138	16	Cooling towers in multiple buildings	98
Portugal	2020	<i>Legionella</i>	88	15		95

Table 2: Some notable modern drinking water outbreaks in developed countries

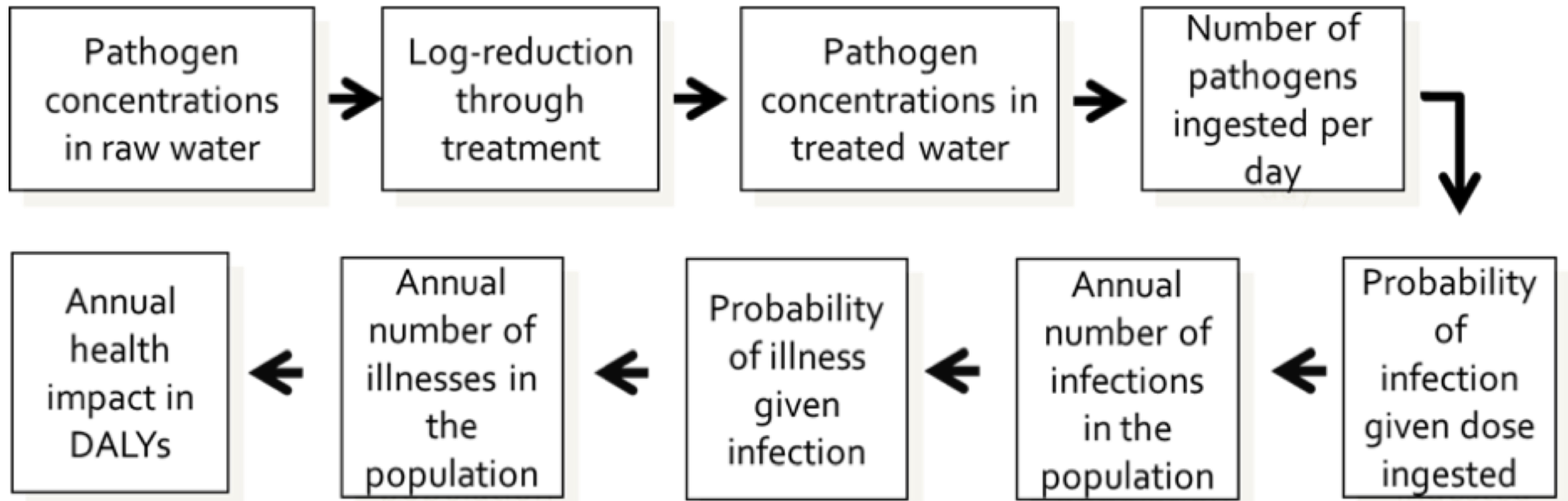


Figure 1: Overview of the key model parameters that must be estimated for the Health Canada QMRA model²⁰