GUIDELINES FOR

# CANADIAN RECREATIONAL WATER QUALITY

## MICROBIOLOGICAL PATHOGENS AND BIOLOGICAL HAZARDS

Guideline Technical Document

Health Canada Santé Canada

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*Recommandations au sujet de la qualité des eaux utilisées à des fins récréatives au Canada: Agents pathogènes microbiologiques et dangers biologiques, document technique.*

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Publication date: November 2023



Cat.: 978-0-660-68002-6
ISBN: H144-118/2023E-PDF
Pub.: 230433

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# FOREWORD

**The *Guidelines for Canadian Recreational Water Quality* comprise multiple guideline technical documents that consider the various factors that could interfere with the safety of recreational waters from a human health perspective. This includes technical documents on understanding and managing risks in recreational waters, fecal indicator organisms, microbiological methods for monitoring fecal contamination, cyanobacteria and their toxins, physical, aesthetic, and chemical characteristics, and microbiological pathogens and other biological hazards. These documents provide guideline values for specific parameters used to monitor water quality hazards and recommend science-based monitoring and risk management strategies.**

Recreational waters are any natural fresh, marine or estuarine bodies of water that are used for recreation. This includes lakes, rivers, and human-made constructions (for example, quarries, artificial lakes) that are filled with untreated natural waters. Jurisdictions may choose to apply these guidelines to natural waters where limited treatment is provided (for example, short-term application of disinfection for an athletic event), although applying the guidelines in these scenarios should be done with caution as indicator organisms are easier to disinfect than other disease-causing microorganisms (for example, protozoan pathogens). Recreational activities that could present a human health risk through intentional or incidental immersion and ingestion include primary contact activities (for example, swimming, bathing, wading, windsurfing and waterskiing) and secondary contact activities (for example, canoeing and fishing).

Each guideline technical document has been established based on current, published scientific research related to health effects, aesthetic effects, and beach management considerations. Since responsibility for recreational water quality generally falls under provincial and territorial jurisdiction, policies and management decisions may vary across Canada. The guideline technical documents are intended to guide decisions by the responsible authorities for the management of recreational waters.

For a complete list of the guideline technical documents available, please refer to the *Guidelines for Canadian Recreational Water Quality* summary document available on the Health Canada website (in publication).

# MANAGEMENT OF MICROBIOLOGICAL PATHOGENS AND BIOLOGICAL HAZARDS IN RECREATIONAL WATERS

This document outlines potential health risks from exposure to pathogenic microorganisms and other biological hazards associated with natural recreational waters. This document does not apply to constructed recreational water facilities such as swimming pools, splash parks or other similar settings.

It is intended as background information for those interested in recreational water quality and safety. Implementing a preventive risk management approach that focuses on the identification and control of water quality hazards and their associated risks before the point of contact with the recreational water user represents the best strategy for protecting public health from these hazards. This approach consists of an integrated system of procedures, actions, and tools that are applied across all identified areas of management (that is, source protection, monitoring, hazard identification and control, communication, consultation) to reduce the risk of human exposure to recreational water quality hazards. More details on risk management of recreational water quality are available in the technical document *Guidelines for Canadian Recreational Water Quality - Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023b).

# 1.0 GUIDELINE VALUES AND THEIR APPLICATION

Guideline values are not established for the microbiological pathogens or other biological hazards described in this document. A preventive risk management approach that incorporates procedures, actions, and tools to collectively reduce the risk of human exposure to these hazards is the preferred approach to protecting public health. Further information on this approach can be found in the *Guidelines for Canadian Recreational Water Quality - Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023b)

The challenges associated with the detection of pathogenic microorganisms in recreational waters are currently too great to recommend a routine monitoring program. Testing for the presence of pathogens or biological hazards in recreational waters should be performed only when there is epidemiological or other types of evidence (for example, visible signs of deterioration) suggesting that this may be necessary. To protect public health, and as part of a risk management approach, recreational waters are instead monitored for fecal indicators (for example., *E. coli,* enterococci), as they indicate possible fecal contamination and potentially elevated risk from enteric pathogens. Guideline values have been established for both *E. coli* and enterococci and published in *Guidelines for Canadian Recreational Water Quality - Indicators of Fecal Contamination* (Health Canada, 2023a). Although *E. coli* and enterococci concentrations below the guideline values indicate an acceptable level of risk, this does not mean that all pathogenic microorganisms are absent. Further information on fecal indicators can be found in the guideline technical document on fecal indicators (Health Canada, 2023a). Non-enteric pathogens (for example, naturally occurring or free-living organisms) are not related to fecal contamination and therefore the presence of fecal indicator organisms is not associated with the presence of non-enteric pathogens. Fecal pathogens are a more common cause of human illness than non-enteric pathogens in recreational water settings.

In general, areas used for recreational water purposes should remain as free as is practical from pathogenic microorganisms and other biological hazards. Engaging in recreational activities, including swimming, splashing and other water activities, will always involve some level of risk. Public health decisions should balance the potential increased health risks with the enjoyment and exercise that is associated with these activities. Primary contact recreational activities should not be pursued in waters where the responsible authority deems that the presence of pathogenic microorganisms and other biological hazards poses an unacceptable risk to health and safety.

The purpose of this guideline technical document is to provide regulatory and management authorities with information on some of the microbiological pathogens and biological hazards that may exist in natural fresh, marine or estuarine bodies of water in Canada that are used for recreation. It is based on current knowledge. However, the detection and characterization of known and emerging pathogens is a rapidly evolving field. In addition, many enteric illnesses are under reported. For those that are recorded, the source of exposure is often not reported making it difficult to assess the magnitude of waterborne illnesses in Canada (Murphy et al., 2016). The list of pathogens presented is also not intended to be exhaustive, and responsible authorities may wish to provide information on other organisms depending on regional interests. The listed pathogens are not present in all recreational settings, nor are they present on a continuous basis. Water quality in most natural recreational environments varies from day to day, but also within any given day. The changing climate in Canada may also influence the types and quantities of pathogens present in some water sources.

Information on cyanobacteria (also known as blue-green algae) is not included in this document but can be found in the *Guidelines for Canadian Recreational Water Quality – Cyanobacteria and their Toxins* technical document (Health Canada, 2022b). Additional information on many of these organisms can also be found in the technical documents for the *Guidelines for Canadian Drinking Water Quality* (Health Canada, 2019a, b, 2022a).

# 2.0 PATHOGENIC MICROORGANISMS

Numerous pathogenic microorganisms can potentially be found in natural recreational environments. The three main types are bacteria, viruses and protozoa. Many occur as a result of contamination from human or animal wastes, whereas some are free-living microorganisms that exist naturally in the recreational water environment. A fourth type that may be of concern at some beaches, particularly associated with beach sand, are fungi. It should be noted, however, that research to characterize the potential risks from fungi is ongoing (Brandão et al., 2021; Novak Babič et al., 2022).

Enteric pathogens are a common cause of illness associated with recreational water exposures. The principal route of entry for human-infectious enteric pathogens in recreational waters is sewage-contaminated wastes (WHO, 2021). Point sources of pollution such as municipal sewage discharges or combined sewer overflows are the primary sources of sewage contamination. Non-point sources that may contribute to fecal loads in environmental waters include storm drains, river discharges (which capture runoff from urban and rural areas), and malfunctioning or improperly designed septic waste systems. Swimmers themselves, particularly young children, may contribute to contamination through fecal shedding and the accidental release of fecal material. Animal wastes may also harbour many bacterial and protozoan pathogens; however, they are considered to be of low risk for the transmission of enteric viruses to humans (Cliver and Moe, 2004; Percival et al., 2004; Wong et al., 2012; Health Canada, 2019a).

Beach sand can also be a reservoir for many of the same pathogenic microorganisms that can be present in the recreational waters. Fecal and non-fecal pathogenic species of bacteria, viruses, protozoa and fungi have been isolated from the sand environment (WHO, 2021; Solo-Gabriele et al., 2016; Whitman et al., 2014; Shah et al., 2011). Pathogens are deposited in beach sand through various routes, such as direct contamination from bird and animal feces, land runoff and wave action. Individuals who spend time playing in beach sand have higher rates of gastrointestinal illness compared to those who do not (Solo-Gabriele et al., 2016; Heaney et al., 2009, 2012).

The probability that pathogens will be present in recreational water bodies may also increase in some areas due to climate change. Canada is expected to see intensification of some weather extremes, including more intense rainfalls along with an increase in average temperatures (Bush and Lemmen, 2019; Berry & Schnitter, 2022). Rainfall events, for example, may result in more enteric pathogens entering recreational waterbodies through combined sewer overflows into waterways or more intense land run-off. Increases in average air temperatures can lead to warmer waters. In turn, this can promote the growth of temperature-sensitive pathogens. Responsible authorities should work to identify the pathogens that may impact the recreational water areas in their jurisdictions. This includes those pathogens that may become of greater risk to health due to the changing climate.

Information on managing the risks from pathogenic microorganisms can be found in the *Guidelines for Canadian Recreational Water Quality* technical document on *Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023b).

## 2.1 Enteric bacterial pathogens

Enteric pathogenic bacteria from human or animal fecal wastes can enter recreational water through numerous potential pathways and can be influenced by climatic events. Transmission to humans occurs through the fecal-oral route, through incidental or accidental ingestion of contaminated waters or sand. Gastrointestinal symptoms are the most common manifestation of illness following infection with enteric bacterial pathogens, although some pathogens can cause illness with more severe outcomes. Summary information on select enteric bacterial pathogens can be found in Appendix B. *E. coli* and enterococci are the primary fecal indicator bacteria used to indicate the risk of enteric illness (Health Canada, 2023a) from enteric pathogens.

### 2.1.1. *Campylobacter* species (spp.)

*Campylobacter* bacteria (Class: Epsilonproteobacteria) are Gram-negative, motile, non-spore-forming, spiral, curved or S-shaped rods. They are thermophilic (growing optimally at 42°C and incapable of growth below 30°C) and microaerophilic (surviving best under partially anaerobic conditions) organisms. The genus *Campylobacter* is composed of over 30 species (LPSN, 2019); however, *C. jejuni* and *C. coli* are the major species of human concern in the water environment.

*Campylobacter* spp. are predominantly considered to be zoonotic pathogens (Fricker, 2006) but can also be transmitted through human fecal wastes. They are part of the normal intestinal flora of a wide range of domestic (for example, poultry, cattle, sheep, pets) and wild animals, particularly waterfowl (Moore et al., 2002; Pond, 2005; Fricker, 2006; Wagenaar et al., 2015; Backert et al., 2017). Important sources of fecal contamination include surface runoff contaminated with livestock waste or feces from wild animals (for example, waterfowl), direct deposition from waterfowl (for example, gulls and geese) overnighting on water bodies, and human sewage sources.

Symptoms of *Campylobacter* enteritis include a profuse, watery diarrhea (with or without blood), cramps, abdominal pain, chills, and fever. The incubation period is generally between 1 and 5 days and illness is typically self-limiting, requiring up to 10 days for recovery (Backert et al., 2017). Antibiotics should only be prescribed in serious cases (Wagenaar et al., 2015). *Campylobacter* spp. are resistant to some antibiotics and have been classified as a "serious threat" by the Centers for Disease Control and Prevention (CDC, 2019a). Asymptomatic infections (those in which symptoms of disease are not exhibited) with *Campylobacter* spp. are also possible (Percival and Williams, 2014b). Dose-response information for *Campylobacter* infection and illness is not fully understood, but evidence suggests a dose-dependent illness response among infected subjects (Teunis et al., 2005; 2018). A high probability of infection and illness was found at doses of 500 to 800 *C. jejuni* in a human feeding study (Medema et al., 1996). Information from a foodborne outbreak suggests that the infectious dose may be even lower for certain strains or for children (Teunis et al., 2005; 2018). Some severe infections may lead to hospitalization and can be life-threatening, but fatalities are uncommon and are usually restricted to infants, the elderly or patients with other underlying illnesses (Pond, 2005).

Certain post-infection complications have been associated with *Campylobacter* enteritis, including Guillain-Barré syndrome and reactive arthritis; however, these are considered rare (Backert et al., 2017; Percival and Williams, 2014b). Evidence also suggests that *Campylobacter* spp. infection may be associated with the development of inflammatory bowel diseases such as Crohn's disease, ulcerative colitis and irritable bowel syndrome (Backert et al., 2017; Huang et al., 2015).

Despite the fact that *Campylobacter* spp. have been isolated from fresh and marine waters in North America (Hellein et al., 2011; Khan et al., 2013a,b; Oster et al., 2014; Guy et al., 2018), there have been few recorded outbreaks of *Campylobacter*-associated gastrointestinal illness as a result of recreational water activity. Between 2000 and 2014, *Campylobacter* spp. were implicated as the sole causative agent in one recreational water outbreak of gastroenteritis in the United States, as well as one outbreak where multiple pathogens were involved (Graciaa et al., 2018). Outbreaks have also been linked to drinking water (Health Canada, 2022). No outbreaks of campylobacteriosis have been identified in Canada related to recreational waters. Cases of campylobacteriosis in Canada and abroad are mostly sporadic, with most illnesses linked to consumption of contaminated food (Huang et al., 2015; Wagenaar et al., 2015; Pintar et al., 2017). However, recreational water contact is a potential exposure risk (Denno et al., 2009; Pintar et al., 2017; Ravel et al., 2017) and has been linked to sporadic cases internationally (McBride et al., 2002; Schönberg-Norio et al., 2004).

### 2.1.2. Pathogenic *Escherichia coli/Shigella* spp.

*Escherichia coli* (Family: *Enterobacteriaceae*; Class: Gammaproteobacteria) are Gram-negative, motile or non-motile, facultatively anaerobic, non-spore-forming rod-shaped bacteria that are natural inhabitants of the intestinal tract of humans and animals. They can grow over a broad temperature range (7°C to 45°C), with optimal growth at 37°C (Ishii and Sadowsky, 2008; Percival and Williams, 2014c). The vast majority of *E. coli* strains are harmless and are used as indicators of fecal contamination; however, several serotypes or strains possess virulence factors enabling them to act as human pathogens. Pathogenic enteric strains causing gastrointestinal infection can be separated into six functional groups according to their serological or virulence characteristics: enterohemorrhagic *E. coli* (EHEC), enterotoxigenic *E. coli* (ETEC), enteroinvasive *E. coli* (EIEC), enteropathogenic *E. coli* (EPEC), enteroaggregative *E. coli* (EAEC), and diffusely adherent *E. coli* (DAEC) (Croxen et al., 2013; Percival and Williams, 2014c). Some *E. coli* strains, such as uropathogenic *E. coli* (UPEC), can also cause extra-intestinal infections (Abe et al., 2008).

Advanced molecular typing and sequencing analyses have demonstrated that *Shigella* spp. are also members of the EIEC pathotype (Croxen et al., 2013; Robins-Browne et al., 2016). The genus name *Shigella* spp. and the disease name shigellosis (that is, disease caused by *Shigella* spp.) are still used for historical purposes (Croxen et al., 2013). *Shigella* spp. has traditionally been composed of four major species: *S. sonnei* (1 serotype), *S. flexneri* (6 serotypes), *S. boydii* (15 serotypes) and *S. dysenteriae* (10 known serotypes). Two species, *S. sonnei* and *S. flexneri*, account for the vast majority of *Shigella*-associated illness in North America (CDC, 2005a), representing 95% of reported *Shigella* cases in Canada (Government of Canada, 2020). Other *Shigella* spp. are uncommon but remain important causes of disease in developing countries (CDC, 2005a).

The main sources of pathogenic *E. coli* vary between *E. coli* groups. EHEC are zoonotic pathogens, and cattle are considered the primary reservoir with human waste also recognized as an important source (Croxen et al., 2013; Percival and Williams, 2014c). For the remaining major pathogenic *E. coli* groups, including *Shigella* spp., human sewage is the principal source of contamination. In recreational waters, sources of human sewage may include obvious sources such as municipal sewage discharges as well as less obvious sources, such as fecal shedding by infected swimmers (Kramer et al., 1996; Levy et al., 1998). As EHEC are zoonotic pathogens, surface runoff contaminated with livestock waste is an important source of fecal contamination. *E. coli* that have been linked to extra-intestinal infections are usually strains that are part of the commensal flora of the human intestines, but cause adverse health impacts when they are deposited in non-intestinal systems, such as in the urinary tract (Shah, 2019).

Enteric pathogenic *E. coli/Shigella* spp. cause diseases that range in severity from mild and self-limiting to severe and life-threatening depending on the group and strain involved. The main symptoms are watery or bloody diarrhea, accompanied by abdominal pain and fever. The incubation period ranges from 1 to 3 days, with the duration of infection lasting from 1 to 2 weeks (Percival and Williams, 2014c, 2014g). In most cases, diarrheal infections are self-limiting. Treatment generally involves oral rehydration to maintain fluid and electrolyte balance. With some infections, individuals can become asymptomatic carriers capable of shedding the organisms in their feces for weeks to months after infection (Croxen et al., 2013; Percival and Williams, 2014c, 2014g). Extra-intestinal *E. coli,* such as UPEC, are associated with urinary tract infections.

Some infections can progress to more serious and potentially life-threatening conditions. *S. dysenteriae* serotype 1, which produces Shiga toxin, is a major cause of dysentery in developing countries, but is uncommon in North America. EHEC (synonyms: shiga toxin-producing *Escherichia coli*/STEC and verotoxin-producing *Escherichia coli*/VTEC) is also able to produce Shiga-like toxins similar to those produced by *S. dysenteriae. E. coli* O157:H7 is the most prevalent EHEC serotype. EHEC infection causes haemorrhagic colitis, marked by grossly bloody diarrhea, severe cramping and abdominal pain with a general lack of fever. An estimated 4% to 17% of all cases of EHEC infection progress to what is known as hemolytic uremic syndrome (HUS)—a life-threatening condition involving large-scale destruction of red blood cells and kidney failure (Croxen et al., 2013; Keithlin et al., 2014). Children, the elderly and immunocompromised persons are at increased risk for developing HUS.

The dose of pathogenic *E. coli/Shigella* spp. that is likely to cause infection is estimated to range from less than 100 to 1,000 organisms for EHEC and EIEC/*Shigella* spp. to greater than 1 million to 10 billion organisms for the other groups (Kothary and Babu, 2001; Croxen et al., 2013; Percival and Williams, 2014c, 2014g).

EHEC and *Shigella* spp. are among the leading causes of bacterial gastrointestinal illness in Canada, the United States and Europe and are frequently related to food and travel-related exposures in North America (Health Canada, 2022a). They are also the members of the pathogenic *E. coli/Shigella* spp. group most often implicated in illness associated with recreational waters. According to surveillance data published by the United States Centers for Disease Control and Prevention (US CDC) for 2000 to 2014, pathogenic *E. coli* were associated with 14% (19 out of 140) and *Shigella* spp. with 10% (14 out of 140) of the total number of outbreaks of gastrointestinal illness reported for natural waters (Graciaa et al., 2018; CDC, 2020). The majority of the *E. coli* related outbreaks were caused by *E. coli* O157:H7. The majority of *Shigella*-related outbreaks were caused by *S. sonnei*. Outbreaks have also been associated with drinking water (Health Canada, 2022).

In Canada, very few *E. coli/Shigella* spp. related outbreaks associated with recreational waters have been reported to date. In August 2001, an outbreak of *E. coli* O157:H7-associated illness involving four children was linked to swimming at a public beach in Montreal (Bruneau et al., 2004). Weekly water samples collected around the time of the outbreak were shown to be within the recreational water quality limits specified by the Province of Quebec. It was suggested that a high swimmer population and the shallow depth of water encountered in the swimming area contributed to the transmission of the organisms. More recently, in September of 2020, seven confirmed cases of *E. coli* infection were linked to a swimming area of a conservation area. Most cases were reported in individuals under the age of 12 (City of Hamilton, 2020).

### 2.1.3. 2.1.3 *Salmonella* spp.

*Salmonella* bacteria (Family: *Enterobacteriaceae*; Class: Gammaproteobacteria) are Gram-negative, facultatively anaerobic, motile, non-spore-forming rods that grow at temperatures from 5°C to 47°C, with optimum growth between 35°C and 37°C (Graziani et al., 2017). The genus *Salmonella* is comprised of two species: *S. enterica* and *S. bongori* (Percival et al., 2004). *S. enterica* is further subdivided into six subspecies (*S. enterica* subsp.): *enterica*, *salamae*, *arizonae*, *diarizonae*, *houtenae*, and *indica*, and contains over 2,500 serotypes (Percival and Williams, 2014f; Andino and Hanning, 2015). Most of the serotypes encountered in cases of human gastroenteritis belong to the subspecies *S. enterica* subsp. *enterica* (Lightfoot, 2004). When referring to *Salmonella*, it is common to use the serotype name in place of the species name. Thus, *Salmonella* serotype Enteritidis (or *Salmonella* Enteritidis) is used instead of *S. enterica* subsp. *Enterica* serotype Enteritidis.

*Salmonella* bacteria of human importance are broadly categorized into two main groups according to the type of disease they cause. The typhoidal *Salmonella* (*S. enterica* serotype Typhi and *S. enterica* serotype Paratyphi) are the causative agents of enteric fever, a serious and life-threatening illness (Sanchez-Vargas et al., 2011). Humans are the only known source of the typhoidal *Salmonella* species (Percival and Williams, 2014f). The non-typhoidal *Salmonella* are a large group containing the rest of the *S. enterica* serotypes which cause gastrointestinal illness of varying severity (Sanchez-Vargas et al., 2011). Non-typhoidal *Salmonella* are considered zoonotic pathogens. Poultry, swine, birds, cattle, rodents, tortoises and turtles, dogs and cats can act as a reservoir for these bacteria (Percival et al., 2004; Graziani et al., 2017). Humans recovering from illness can be a source of *Salmonella*, and asymptomatic infections among humans are possible (Percival and Williams, 2014f; Graziani et al., 2017).

Gastroenteritis is by far the most common *Salmonella*-associated illness. The main symptoms of non-typhoidal *Salmonella* are mild to severe diarrhea, nausea and vomiting. Symptoms usually appear between 12 and 72 hours from the time of infection, but this time lag may be reduced in cases where large quantities of cells have been consumed (Percival and Williams, 2014f). Children have the highest incidence of *Salmonella* infections (Christenson, 2013; PHAC, 2018b). Illness is generally mild and self-limiting, lasting 4 to 7 days on average. In severe cases, infection can spread to other parts of the body (for example, blood, urine, joints, brain) and can be life-threatening (Percival and Williams, 2014f; Sanchez-Vargas et al., 2011). Severe infections and fatal cases are rare and are more commonly reported among the very young, the very old and those with compromised immune systems or underlying illness (Sanchez-Vargas et al., 2011; Dekker and Frank, 2015). Treatment for infections with non-typhoidal *Salmonella* involves fluid and electrolyte replacement, with antibiotics only prescribed in severe cases. Some *Salmonella* have shown resistance to antibiotics. The Public Health Agency of Canada, the U.S. CDC, and the World Health Organization have categorized non-typhoidal *Salmonella* resistant to ciprofloxacin, ceftriaxone or multiple classes (that is, >3) of drugs as public health threats of serious to critical importance (CDC 2013a; WHO, 2017, PHAC, 2018a). Reports on the infectivity of *Salmonella* spp. Have suggested that the median dose for the non-typhoidal species may range from less than 100 organisms to a high of 100,000 to 10 billion organisms (Hunter, 1997; Pond, 2005; Kothary and Babu, 2001).

Enteric fever (also known as typhoid or paratyphoid fever) is a more severe and often fatal form of salmonellosis caused by *Salmonella* Typhi and *Salmonella* Paratyphi. Symptoms of the illness are prolonged high fever, vomiting, headaches, and numerous potentially fatal complications (Sanchez-Vargas et al., 2011). Waterborne outbreaks of enteric fever are more prevalent in developing countries where crowded living conditions and poor hygiene practices exist and are often associated with improperly treated drinking water supplies. Cases of enteric fever are rare in North America.

*Salmonella* spp. are the second-leading cause of bacterial gastrointestinal illness in Canada with most cases being sporadic or associated with consumption of contaminated food, person-to-person contact, or direct contact with animals (Health Canada, 2022a). Ingestion of contaminated water is a recognized route for infection of non-typhoidal *Salmonella* (Graziani et al., 2017). Although *Salmonella* spp. have been isolated from surface waters in Canada, the United States of America, and elsewhere (Levantesi et al., 2012; Jokinen et al., 2015; Kadykalo et al., 2020), US CDC surveillance data for 1992 to 2014 indicate that *Salmonella* was not cited as a causative agent for any of the recreational waterborne outbreaks of gastroenteritis reported over that period (Garciaa et al., 2018; CDC, 2020). There have also been no documented *Salmonella*-associated outbreaks in Canadian recreational waters.

## 2.2 Naturally occurring pathogenic bacteria

Naturally occurring pathogenic bacteria are free-living microorganisms that are found in the environment. Unlike many enteric pathogens, they can thrive in the natural environment under favourable conditions. If these microorganisms are present in high enough numbers in a body of water, they may be transmitted to humans through inhalation, ingestion, or direct body contact with water, depending on the microorganism. Some can also be found in beach sands. The impacts of climate change on the presence of these microorganisms in the natural environment is likely to vary with location and pathogen. These naturally occurring pathogenic bacteria are diverse, causing a range of illnesses including gastrointestinal and respiratory illnesses and infections of the eyes, ears or skin. A summary of naturally occurring bacterial pathogens can be found in Appendix B. As these organisms are not enteric pathogens, fecal indicators are not expected to correlate well with their presence. There is no recognized microbiological indicator for these pathogens.

### 2.2.1. *Legionella* spp.

The bacterial genus *Legionella* (Family: *Legionellaceae;* Class: Gammaproteobacteria) comprises 61 species and 3 subspecies (LPSN, 2019). *Legionella* are Gram-negative, obligately aerobic, thermotolerant, motile, short, rod-shaped bacteria that have strict nutrient requirements when grown in culture.

Pathogenic *Legionella* spp. are opportunistic pathogens that cause respiratory illness in two main forms: Legionnaires' disease and Pontiac fever (Percival and Williams, 2014d; NASEM, 2020). Legionnaires' disease is a more severe and sometimes fatal form of respiratory illness that requires treatment with antibiotics (Fields et al., 2002; Edelstein and Roy, 2015, Castillo et al., 2016; Wilson et al., 2018). Pontiac fever is a milder illness causing flu-like symptoms but not pneumonia. Most individuals with Pontiac fever do not become ill enough to seek medical attention, and antibiotic treatment is generally not required (Edelstein and Roy, 2015, Castillo et al., 2016). Legionnaires' disease is more likely to occur in older adults or in individuals who are immunocompromised or have underlying health conditions. Further information on the health impacts of *Legionella* spp. can be found in Health Canada's *Guidelines for Canadian Drinking Water Quality: Guidance on Waterborne Pathogens* (2022a).

Illnesses caused by *Legionella* spp. are collectively known as legionellosis. *Legionella pneumophila* (mainly serogroup 1) is the most common and virulent pathogen of the genus, responsible for 65–90% of all cases of Legionnaires' disease (Fields et al., 2002; Edelstein and Roy, 2015; Percival and Williams, 2014d, Prussin II et al., 2017). It is suspected that all *Legionella* spp. may be capable of causing illness, and at least 30 of the identified species have been implicated in human disease (Hall, 2006).

The main route of transmission for *Legionella* spp. is the inhalation of aerosols containing the bacteria. Person-to-person transmission generally does not occur (Percival and Williams, 2014d; Edelstein and Roy, 2015). Although many individuals are exposed to *Legionella* bacteria, few develop illness (Castillo et al., 2016) There is no consensus on whether there is a threshold of detectable *Legionella* below which there is no risk of infection (NASEM, 2020).

*Legionella* bacteria have two habitats—a primary reservoir in the natural environment and a secondary habitat in engineered water systems (NASEM, 2020). In the natural environment, *Legionella* spp. occur in freshwater systems. *Legionella* typically grows at temperatures between 25°C and 45°C (optimum temperature range between 25°C to 35°C) but can survive at much higher temperatures (up to 70°C) (Allegra et al., 2008; Cervero-Aragó, 2015; 2019). They can be isolated from a wide range of freshwater habitats, including sediments, lakes, rivers, and natural thermal pools at temperatures as high as 60°C (Percival and Williams, 2014d; Burillo et al., 2017; NASEM, 2020). Marine environments typically do not provide appropriate growth conditions for *Legionella* spp. The growth of *Legionella* spp. is predominantly within free-living protozoa that reside within biofilms (Devos et al., 2005; NASEM, 2020). *Naegleria* or *Acanthamoeba* are free-living freshwater protozoa that are natural hosts for *Legionella* spp., providing a protective environment against adverse conditions (such as elevated temperatures), along with nutrients and a means of transport (Thomas and Ashbolt, 2011; Bartrand et al., 2014; Percival and Williams, 2014e; Siddiqui et al., 2016; NASEM, 2020). Passage in free-living protozoa may also increase the virulence of amoebae-resisting microorganisms, such as *Legionella* (Visvesvara et al., 2007; Thomas and Ashbolt, 2011; Chalmers, 2014a). Human and animal feces are not considered a source of *Legionella*, although they can be detected in the feces of infected individuals experiencing diarrhea symptoms. Animals can be infected by *Legionella* spp., but zoonotic transmission of the organism has not been documented (Surman-Lee et al., 2007; Edelstein and Roy, 2015).

*Legionella* spp. are typically encountered in low numbers in the aquatic environment. A review of outbreaks linked to recreational waters (including treated and natural waters) concluded that the risk related to natural rivers and lakes appear negligible (Leoni et al., 2018). Some systems that use natural waters supplied through constructed systems, such as hot springs or other hydrothermal spas, can provide favourable conditions for the survival and spread of *Legionella*. They have been linked to cases of legionellosis (Leoni et al., 2018) and water management plans are suggested for these types of facilities (James et al., 2022). Engineered water environments (for example, cooling towers, premise plumbing in buildings and residences) are typically where *Legionella* spp. can reach high concentrations, under the right conditions, resulting in an increased risk of human exposure and disease (NASEM, 2020). Warmer weather associated with climate change may facilitate *Legionella* growth in these systems (MacIntyre et al., 2018).

Even though *Legionella* spp. are thought to be ubiquitous in bodies of water, no outbreaks of legionellosis have been reported in Canada or the United States as a result of recreational activity in natural waters. This may be due to the low concentrations found in most natural waters as well as the lack of aerosolization. All reported outbreaks of legionellosis associated with human contact with recreational waters have been linked to the use of treated water facilities, such as hot tubs and spas (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004; Hlavsa et al., 2018), which are outside the scope of this document.

### 2.2.2. *Mycobacterium* spp.

The genus *Mycobacterium* (Class: Actinobacteria) contains over 200 recognized species of mycobacteria. They are aerobic to microaerophilic, non-motile, non-spore-forming, rod-shaped bacteria. Mycobacteria can grow at temperatures ranging from 15°C to 45°C (George et al., 1980; Cangelosi et al., 2004; Kaur, 2014). Optimal growth temperatures for individual species vary between 30°C and 45°C (De Groote, 2004; Stinear et al., 2004); however, mycobacteria are relatively heat-resistant and capable of surviving at temperatures greater than 50°C (Schulze-Robbecke and Buchholtz, 1992; Falkinham, 2016a). All mycobacteria possess a thick and lipid-rich cell wall that makes the microorganisms relatively impermeable to hydrophilic compounds. This provides the bacteria with increased resistance to acid/alkaline conditions, disinfectants and antibiotics.

Mycobacteria vary in their ability to cause disease in humans. Some are strict pathogens, whereas others cause opportunistic infections or are non-pathogenic. The mycobacteria commonly isolated from the environment are collectively referred to as the non-tuberculous mycobacteria (NTM) and are considered opportunistic pathogens (Falkinham, 2016a, b). NTM need to be distinguished from *M. tuberculosis* (causative agent of tuberculosis) and *M. leprae* (causative agent of leprosy), which are strict pathogens. Neither *M. tuberculosis* nor *M. leprae* is a concern for recreational waters.

The NTM species most described as having relevance for recreational water exposures belong to the *Mycobacterium avium* complex (*M. avium* and its subspecies, *M. intracellulare* and *M. chimaera*), which are known to cause respiratory illness; and *M. marinum* and *M. kansasii*, which can cause skin infections. The main routes of infection are inhalation of mycobacteria contained in aerosols and direct water contact or ingestion of contaminated water (Percival and Williams, 2014e; Falkinham, 2015; Falkinham et al., 2015). There is little evidence of person-to-person transmission. Illness is more commonly observed in individuals with some underlying condition that predisposes them to infection (abraded or traumatized skin; or a weakened or compromised immune system). The infective doses of NTM species are not known (Stout et al., 2016; Hamilton et al., 2017; Adjemian et al., 2018).

Non-tuberculous mycobacteria are considered ubiquitous in natural waters. They can be found in virtually every medium, including soils, wastewater, lakes, rivers, ponds, streams, groundwater, and treated water supplies. However, few NTM are encountered in marine waters (Pond, 2005; LeChevallier, 2006; Falkinham, 2016b; Percival and Williams, 2014e). NTM are capable of survival and growth within certain species of phagocytic protozoa, specifically members of the genus *Acanthamoeba*, as well as in biofilms (Percival and Williams, 2014e).

Like *Legionella,* NTM can survive in hot springs or other hydrothermal spas because of the elevated water temperatures. A Japanese study reported that both *Legionella* and NTM had been detected in these types of environments (Kobayashi et al., 2014). Exposures to NTM have been most strongly linked to swimming pool and hot tub use, and typically resulted in cases of skin and soft tissue infections and hypersensitivity pneumonitis (inflammation of the lungs). Discussions regarding swimming pool and hot tub use are outside the scope of this document. Although environmental mycobacteria are considered ubiquitous in most types of water, to date there have been no recorded outbreaks of mycobacterial-associated illness through contact with natural recreational waters in either Canada or the United States. For healthy individuals, the risk of acquiring a mycobacterial infection from recreational activity in natural waters is considered to be extremely low.

### 2.2.3. *Pseudomonas* spp.

*Pseudomonas* spp. (Family: *Pseudomonadaceae*; Class: Gammaproteobacteria) are Gram-negative, motile, strictly aerobic oxidase-positive, non-spore-forming, slightly curved rod-shaped bacteria that grow at temperatures from 4°C to 42°C (optimum range is 28°C to 37°C) (Moore et al., 2006; Chakravarty and Anderson, 2015). The genus *Pseudomonas* includes over 200 species (LPSN, 2020). *P. aeruginosa* is an opportunistic pathogen capable of causing a variety of infections and is the most significant species of human concern. Other species (*P. fluorescens*, *P. putida*, *P. stutzeri*) have been infrequently reported in human infections (Chakravarty and Anderson, 2015).

*P. aeruginosa* is widely distributed in the aquatic environment and can be frequently isolated from fresh water, seawater and soils (Hunter, 1997). These bacteria are considered part of the natural aquatic flora (WHO, 2003). The microorganism has minimal growth requirements and can proliferate in waters with low nutrient levels. *P. aeruginosa* is infrequently isolated from human feces (Geldreich, 2006) but it can be recovered from sewage and wastewater (Degnan, 2006). If *P. aeruginosa* are present in high enough numbers in recreational waters, they may be transmitted to humans through direct body contact with the contaminated water. Ingestion is not considered to be a significant route of infection.

*P. aeruginosa* can cause respiratory, skin, eye, and ear infections as well as skin rashes, with the latter three conditions being the most common. Ear infections occur when *P. aeruginosa* enters and colonizes the outer ear canal. A few days after swimming, the swimmer's ear may become itchy and painful, and discharges of pus may be observed. Skin irritations (dermatitis) present as a red, itchy rash, which occurs roughly 18 to 24 hours after water contact. Infection can progress to folliculitis (inflammation of the hair follicles of the skin), which is marked by an increased tenderness of the infected area and the presence of pus-filled blisters or pimples surrounding the hair follicles. Localized skin infections are easily treatable. Invasive infections are very difficult to treat because of increasing antibiotic resistance (Falkinham et al., 2015; George et al., 2022). Some strains have been found to be resistant to all or nearly all antibiotics and have been identified as a "serious threat" and priority for risk management attention (CDC, 2019a; Garner et al., 2015).

Several epidemiological studies have shown a link between *Pseudomonas* in natural waters and the incidence of eye and skin infections among swimmers (Seyfried and Cook, 1984; Springer and Shapiro, 1985; Ferley et al., 1989; Marino et al., 1995; van Asperen et al., 1995). Reported outbreaks of *Pseudomonas* dermatitis have virtually all been associated with treated water venues such as hot tubs, swimming pools or hotel whirlpool or spa baths (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004; Hlavsa et al., 2018). The incidence of *P. aeruginosa* infections from contact with natural recreational waters is not known, as illnesses are usually mild and are typically not reported.

### 2.2.4. *Aeromonas* spp.

*Aeromonas* spp. (Family: *Aeromonadaceae*; Class: Gammaproteobacteria) are Gram-negative, facultatively anaerobic, non-spore-forming, variably motile, rod-shaped to coccoid-like bacteria. They are thought to share many morphological and biochemical characteristics with members of the Enterobacteriaceae family, which includes *E. coli.* The genus *Aeromonas* consists of approximately 30 species (Moyer, 2006; US EPA, 2006; Janda and Abbot, 2010; Percival and Williams, 2014a; LPSN, 2019). Strains associated with human infections grow optimally at temperatures between 35°C and 37°C, although many strains can grow at temperatures between 4°C and 42°C (Janda and Abbott, 2010; Percival and Williams, 2014a). *Aeromonas* spp. are opportunistic pathogens and to date, 14 species have been implicated in human illness. Most human infections (85%) are caused by strains of 4 species: *A. hydrophila*, *A.caviae*, *A. veronii* (biotype sobria) and *A. trota* (Percival and Williams, 2014a; Bhowmick and Battacharjee, 2018).

*Aeromonas* spp. are natural inhabitants of the aquatic environment. They are frequently found in fresh, marine and estuarine waters, sediments, as well as sewage and wastewater effluents. Aeromonads have also been found in high concentrations in foreshore sands (Khan et al., 2009). Aeromonads are not commonly found in significant numbers in the feces of healthy individuals; however, some individuals may carry the organisms in their intestinal tract without showing outward signs of illness. Aeromonads are recognized animal pathogens and have been isolated from the intestinal tract of a number of animal species, including fish, reptiles, amphibians, birds and domestic livestock, with and without evidence of illness (Percival and Williams, 2014a). The occurrence of the bacteria in recreational waters is not dependent on fecal pollution as they can survive and reproduce in the natural environment. However, the microorganisms are present in high numbers in sewage and thus can be detected at significant levels in sewage-contaminated waters. Aeromonads can reach relatively high concentrations in eutrophic (nutrient rich) waters (Moyer, 2006). Since these microorganisms achieve optimal growth at elevated temperatures, the highest concentrations in natural waters are observed during the warmer months.

Ingestion of contaminated food and water are the main routes of gastrointestinal-related *Aeromonas* infections. Contaminated water can also cause wound infections. Gastrointestinal illness is typically mild and self-limiting, although certain strains may cause a dysentery- or cholera-like illness, marked by severe abdominal cramps, vomiting, diarrhea (including bloody stools) and fever (Janda and Abbott, 2010). In recreational water users, *Aeromonas* infections are most often associated with wound infections. Typically, skin trauma such as an open wound or a penetrating injury is needed for an infection to occur. Wound infections are characterized by pain, swelling, redness and fluid accumulation around the infected area. Cellulitis (severe inflammation) is frequently observed with wound infections, and septicemia is also a fairly common outcome (Percival et al., 2004; Janda and Abbott, 2010), largely arising through the transfer of bacteria from the gastrointestinal tract or from wound infections. Common features associated with these infections are fever, jaundice, abdominal pain and septic shock (Janda and Abbott, 2010). Other, rarer complications include necrotizing fasciitis, meningitis, pneumonia, peritonitis and endocarditis (Percival et al., 2004; Janda and Abbott, 2010; Bhowmick and Battacharjee, 2018).

The dose of *Aeromonas* spp. necessary to cause infection is not clear. The single available challenge study used ingestion as the route of exposure and showed that only two out of five strains produced infection (14 out of 57 individuals shed the test strain without symptoms of illness) and diarrhea (2 out of 57 individuals) at high doses ($10^4$ to $10^{10}$ colony forming units, or CFU) (Morgan et al., 1985).

Despite their widespread occurrence, there have been no reported outbreaks of *Aeromonas*-associated illness as a result of recreational water activities in North America. Marino et al. (1995) reported a positive correlation between *A. hydrophila* concentrations and skin infections at two swimming beaches in Malaga, Spain. Currently, however, there is no evidence of a link between Aeromonad concentrations and the risk of acquiring swimming-associated gastroenteritis. *Aeromonas*-associated infections are not reportable illnesses in Canada or most countries worldwide. Consequently, an estimate of the likely incidence of *Aeromonas*-associated infections due to recreational water exposures in Canadian waters is not available.

## 2.3 Other pathogenic bacteria

In addition to enteric and naturally occurring bacteria, other pathogenic bacteria may enter recreational environments by way of urine or through direct contamination from bathers. If these microorganisms are present in high concentrations, they may be transmitted to humans, typically through direct contact with body surfaces and mucous membranes. The types of human illness observed range from wound infections to life-threatening conditions. A summary of these bacterial pathogens can be found in Appendix B. As these bacteria are not of fecal origin, fecal indicators are not expected to correlate well with their presence. There is no recognized microbiological indicator for these pathogens at the present time.

### 2.3.1. 2.3.1 *Leptospira* spp.

*Leptospira* spp. are spirally coiled or corkscrew-shaped bacteria. They are Gram-negative, aerobic, long, thin and motile organisms that can live at temperatures ranging from 4°C to 40°C (Barragan et al., 2017). The genus *Leptospira* (Class: Spirochaetes) contains more than 20 known species, and over 200 pathogenic serotypes have been described. The more severe forms of leptospirosis are attributed to serovars (syn. serotypes) of *L. interrogans* (Pond, 2005; Wynwood et al., 2014; Levett, 2015).

The genus *Leptospira* are divided into pathogenic, environmental non-pathogenic (saprophytic) and indeterminate (genetically distinct from pathogenic and saprophytic) species. They are encountered worldwide and are predominantly associated with freshwater environments. Pathogenic leptospires are important zoonotic pathogens that are carried in the renal tract (kidney) of infected animals and excreted in the urine. Small mammals, such as rats, mice and voles, are considered the most significant source of pathogenic *Leptospira*. These microorganisms can also be spread by domestic animals, such as cattle, pigs, dogs and cats, sheep, goats and horses (WHO, 2003; CDC, 2005b; Barragan et al., 2017). Heavy rainfall facilitates their spread, as runoff from contaminated soils can affect surface waters (Pond, 2005).

Human infection can occur following direct contact with the urine of infected animals or indirectly through contact with contaminated water, soil or mud. Leptospirae gain access through cuts or abrasions in the skin or through the mucous membranes of the eyes, nose and mouth. The incubation period in humans is approximately 10 days but may range from 2 to 30 days (CDC, 2008). Infections associated with *Leptospira* spp. can range in severity from a mild, influenza-like illness to more severe, and possibly fatal disease. Early symptoms include fever, chills, headache, muscle pains, vomiting and reddening of the eyes (PHAC, 2004). Recovery from mild illness is usually complete, but can take months to years (WHO, 2003). If left untreated, the disease can progress to more serious illness, also known as Weil's disease. Severe cases of leptospirosis can be fatal, with death occurring as a result of kidney failure, cardiorespiratory failure or extensive hemorrhaging. The reasons for the differences in the severity of infection are not fully understood; however, it is believed that each pathogenic serovar possesses the capacity to cause either mild or severe disease (WHO, 2003). Illness associated with *Leptospira* spp. can be difficult to diagnose, as it may be mistaken for other infections or illnesses that produce similar symptoms. Mild forms of the illness may not be reported. Ingestion of as few as 1 to 10 microorganisms may lead to human illness (Pond, 2005).

Leptospirosis is a greater concern in developing countries, where poor housing standards and local infrastructure can result in exposure to rodent reservoirs, as well as in tropical climates. Incidental contact with contaminated water, such as through occupational or recreational activities in endemic areas, is also a source of exposure (Haake and Levett, 2015). A systematic review of waterborne disease related to extreme weather events worldwide identified *Leptospira* spp. as one of the more commonly reported pathogens associated with environmental exposure routes (for example, wading in flood waters) (Cann et al., 2013). However, it is unclear whether any of these exposures were related to recreational water activities. In the United States, three outbreaks of leptospirosis linked to recreational waters were reported between 1991 and 2002 (Moore et al., 1993; Barwick et al., 2000; Lee et al., 2002). Between 2000 and 2014, *Leptospira* spp. were implicated in six outbreaks in the United States (Graciaa et al., 2018). Most of the outbreaks were associated with participation in adventure races/triathlons or exposure to drought impacted waters. Currently, the prevalence of *Leptospira* spp. in Canadian waters is not known, and leptospirosis in not a reportable illness in Canada. There have been no documented cases of *Leptospira* -associated infection linked to recreational water activity in Canada.

### 2.3.2. *Staphylococcus aureus*

Members of the genus *Staphylococcus* (Class: Bacilli) are Gram-positive, non-motile cocci. *S. aureus* is considered the species of greatest human health concern in the genus and is the species of most significance for recreational water use. This includes the antibiotic resistant strain known as methicillin-resistant *Staphylococcus aureus* (MRSA). MRSA infections are classified as community-acquired MRSA infections or hospital-acquired MRSA infections, depending on where the infection was acquired. Hospital-acquired infections are more common and have resulted in outbreaks in these facilities (Government of Canada, 2022c). MRSA infections acquired from recreational water exposures would be classified as community-acquired MRSA.

*S. aureus* is not considered to be a natural inhabitant of environmental waters. The major reservoirs for this microorganism are the skin, nose, ears and mucous membranes of warm-blooded animals (Baptiste et al., 2005; Boost et al., 2008; Abdullahi et al., 2021; Silva et al., 2023). The presence of *S. aureus* in recreational waters is predominantly due to releases of the microorganism from the mouths, noses and throats of swimmers and to discharges from existing infections (Plano et al., 2011). However, the microorganism can be isolated from human feces (Percival et al., 2004), and other sources, such as sewage and stormwaters, have been identified (Economy et al., 2019).

Transmission of *S. aureus* in recreational waters occurs through direct contact with waters containing a high enough number of microorganisms to cause an infection. Infection occurs through cuts or scratches on the skin and, to a lesser extent, through contact with the eyes and ears. Person-to-person spread of the microorganism is also possible. Ingestion is not considered to be a significant route of exposure. Concentrations of a few hundred cells per millilitre may be sufficient to initiate infection in injured or distressed skin (Percival et al., 2004).

*S. aureus* is predominantly associated with skin infections in recreational water users (Charoenca and Fujioka, 1995). Common infections include infected cuts and scratches, boils, pustules, dermatitis, folliculitis and impetigo (WHO, 2006). Infections are most often pus-forming, with symptoms often not becoming apparent until 48 hours after contact. The microorganism has been linked to other illnesses including eye infections, ear infections and urinary tract infections (WHO, 2006). *S. aureus* infections can become severe or life-threatening, especially when they are caused by MRSA (David and Daum, 2010). MRSA has been isolated from natural recreational water environments. Although up to 20% of *S. aureus* have been identified as MRSA from natural waters (Levin-Edens et al., 2012), studies usually report that less than 5% of isolates are methicillin-resistant (Goodwin et al., 2012; Plano et al., 2013).

Some epidemiological studies have explored the possibility of using staphylococci as an indicator of adverse health impacts from recreational activities. Several authors have demonstrated possible connections between staphylococci in recreational waters and gastrointestinal illness and skin conditions in swimmers (Seyfried et al., 1985; Calderon et al., 1991; Griffith et al., 2016). However, this finding is not consistent (Plano et al., 2013; Griffith et al., 2016). A link between the concentrations of staphylococci and bather density has also been found (Calderon et al., 1991; Plano et al., 2013). However, no consistent relationship has been reported between the concentrations of staphylococci and the quality of recreational waters as indicated by the presence of *E. coli* or enterococci (Calderon et al., 1991; Haack et al., 2013; Fogarty et al., 2015).

## 2.4 Enteric viral pathogens

Viruses are much smaller than bacteria, ranging in size from 20 nm to 350 nm. They have a nucleic acid core composed of either RNA or DNA which is surrounded by an external protein shell called a capsid. Some viruses (enveloped viruses) may also have a lipoprotein envelope surrounding the capsid. Non-enveloped viruses lack this external layer. Viruses are obligate intracellular parasites and must infect a host cell to replicate. Although they are incapable of replicating outside of their host environment, they can survive for extended periods outside a host. Most viruses of concern for transmission through water are non-enveloped viruses (for example, enteric viruses). Non-enveloped viruses are more resistant to environmental conditions than enveloped viruses. Some enveloped viruses are shed in feces (for example, coronaviruses including SARS-CoV-2); however, a fecal-oral route of transmission has not been documented and they are therefore considered low risk for transmission through water environments (La Rosa et al., 2020).

Enteric viruses—viruses that infect the human gastrointestinal tract and are shed in human feces—are thought to pose the greatest risk of infection to swimmers in recreational waters (Schoen and Ashbolt, 2010; Soller et al., 2010; Dufour et al., 2012; McBride et al., 2013; Eregno et al., 2016; Vergara et al., 2016). Sources of enteric viruses include municipal sewage, combined sewer overflows and septic tanks as well as shedding by infected bathers. As with sources of enteric bacteria (section 2.1), these sources can be impacted by climatic events (Levy et al., 2016; Jofre et al., 2021).

Enteric viruses are considered to have a narrow host range, meaning that enteric viruses that infect animals do not generally infect humans and vice versa. Exposure to enteric viruses in recreational waters occurs through the fecal-oral route, through the accidental ingestion of contaminated water. Some viruses, like the adenoviruses, have additional routes of infection, such as inhalation or contact with mucosal membranes of the eyes.

Gastrointestinal symptoms (nausea, vomiting, diarrhea) are the most common symptoms of enteric viral illness. Some virus infections can result in more serious health outcomes, although these are considered to be much rarer.

There are more than 200 recognized enteric viruses that can be excreted in feces (Haas et al., 2014), including 140 serotypes known to infect humans (AWWA, 1999; Taylor et al., 2001). Enteric viruses are shed in high numbers in the feces of infected individuals and can reach concentrations as high as $10^{10}$ to $10^{12}$ particles per gram of feces (Gerba, 2000; Bosch et al., 2008). Even asymptomatic individuals can excrete large numbers of viruses. The total viral load of sewage can be quite constant; however, the types and numbers of individual viruses are strongly influenced by the rates of epidemic and endemic illness within the population contributing to the sewage. As a result, the viral composition of sewage can vary considerably, often demonstrating strong seasonal trends (Krikelis et al., 1985; Tani et al., 1995; Pina et al., 1998; Lipp et al., 2001). The presence of viruses in surface waters is expected to vary regionally and is dependent upon (among other factors) the degree and type of fecal contamination and the rates of environmental inactivation. Numerous studies have reported the presence of enteric viruses in surface waters around the world, including Canada. Further information can be found in the *Guidelines for Canadian Drinking Water Quality – Enteric Viruses* guideline technical document (Health Canada, 2019a).

The enteric viruses most commonly associated with waterborne illness include noroviruses, enteroviruses, rotaviruses, adenoviruses and Hepatitis A virus, and they have been detected in marine and fresh waters used for recreational purposes in Canada, the United States, and Europe (Payment, 1984; Puig et al., 1994; Pina et al., 1998; Griffin et al., 1999; Chapron et al., 2000; Payment et al., 2000; Schvoerer et al., 2001; Denis-Mize et al., 2004; Jiang and Chu, 2004; Laverick et al., 2004). These enteric viral pathogens are briefly described in Appendix B. Outbreaks have been linked to many of these enteric viruses (see sections 2.4.1 to 2.4.6). As pathogenic viruses are difficult to detect in water, outbreaks of acute gastrointestinal illness of unknown etiology have also been attributed to viral infections. In the United States, 23% (14 out of 64) of documented outbreaks from 1991 to 2002 (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004), and 26% (37 out of 140) of documented outbreaks between 2000 and 2014 (Graciaa et al., 2018) had an unknown etiology.

*E. coli* and enterococci are used as indicators of fecal contamination and thus the possible presence of enteric viruses. However, the absence of indicator organisms does not necessarily indicate that enteric viruses are also absent. Fecal source tracking methods (for example, qPCR for human-specific fecal markers) can be used to supplement monitoring and assessment tools to identify risks posed by enteric viruses. Further information on managing risks in recreational waters and fecal indicator organisms can be found in the *Guidelines for Canadian Recreational Water Quality* technical documents on *Understanding and Managing Risks in Recreational Waters* and *Indicators of Fecal Contamination* (Health Canada, 2023a, b).

### 2.4.1. 2.4.1 Noroviruses

Noroviruses are small (35 to 40 nm in diameter), non-enveloped RNA viruses belonging to the Caliciviridae family. Noroviruses are currently subdivided into seven genogroups (GI to GVII) of which genogroups GI, GII and GIV contain the genotypes usually associated with human illnesses (Verhoef et al., 2015). The incubation period associated with norovirus infection is 12 to 48 hours (CDC, 2013b; Government of Canada, 2022a). Health effects associated with norovirus infections are self-limiting, typically lasting 24 to 48 hours. The primary symptoms of illness are diarrhea, nausea, vomiting, abdominal pain and fever. The onset of projectile vomiting is considered a characteristic trait of norovirus infection. Asymptomatic infections with norovirus can occur (Graham et al., 1994), and some individuals are resistant to infection (Hutson et al., 2003; Lindesmith et al., 2003; Cheetham et al., 2007). In healthy adults, illness rarely progresses to more serious concerns (for example, dehydration), but more serious infections may occur in vulnerable groups such as the elderly.

Noroviruses are the etiologic agent of primary concern to swimmer's health (Schoen and Ashbolt, 2010; Soller et al., 2010; Dufour et al., 2012; McBride et al., 2013; Eregno et al., 2016; Vergara et al., 2016). Between 1991 and 2002, the US CDC reported that 13% (8 of 64) of disease outbreaks reported in natural waters in the United States were caused by noroviruses (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004). More recent US CDC reports indicate that between the years 2000 and 2014, 22% (21 of 95) of outbreaks in untreated recreational water (with known etiology) were caused by norovirus, which accounted for 47% (1,459 of 3,125) of the cases of illness (Graciaa et al., 2018). Data on norovirus outbreaks related to recreational waters is not available for Canada, but it is likely that cases of norovirus infections have occurred but were not detected or reported. Exposure to noroviruses in recreational areas results from contamination by human fecal matter, such as through municipal sewage discharges and combined sewer overflows (McBride et al., 2013; Eregano et al., 2016; Wade et al., 2018) or through fecal shedding by infected beachgoers (Schets et al., 2018).

### 2.4.2. Enteroviruses

Enteroviruses are a large group of small (20 to 30 nm), non-enveloped RNA viruses belonging to the genus *Enterovirus* and the Picornaviridae family. Within the genus, four species designated *Enterovirus A, Enterovirus B, Enterovirus C* and *Enterovirus D* have been associated with human illness (EV-A to EV-D). Members of the EV-A to EV-D species include enteroviruses, polioviruses, coxsackieviruses and echoviruses (Simmonds et al., 2020).

The incubation period for enteroviruses ranges from 2 to 35 days (AWWA, 2006) and the symptoms and severity of illness vary considerably among the individual virus types. Many enterovirus infections are asymptomatic. Mild symptoms may include fever, malaise, sore throat, vomiting, rash and upper respiratory tract illness. Acute gastroenteritis is less common. More serious outcomes have been associated with individual virus groups, including myocarditis (coxsackievirus), aseptic meningitis (coxsackievirus, poliovirus), encephalitis (coxsackievirus, echovirus), poliomyelitis (poliovirus), and non-specific febrile illnesses of newborns and young infants. However, these illnesses are not considered to be common (Rotbart, 1995; Roivainen et al., 1998). Other complications include myalgia, Guillain-Barré syndrome, hepatitis and conjunctivitis. Enteroviruses have also been implicated in the etiology of chronic diseases, such as inflammatory myositis, dilated cardiomyopathy, amyotrophic lateral sclerosis, chronic fatigue syndrome and post-poliomyelitis muscular atrophy (Pallansch and Roos, 2007; Chia and Chia, 2008). There is also some research supporting a link between enterovirus infection and the development of insulin-dependent (Type 1) diabetes mellitus (Nairn et al., 1999; Lönnrot et al., 2000; Laitinen et al., 2014; Oikarinen et al., 2014).

Enteroviruses are endemic worldwide and have been detected in water sources in Canada and the United States (Health Canada, 2019a). However, few enterovirus outbreaks have been reported around the world. No recreational water-related outbreaks were reported in the United States from 2000 to 2014 and only one case was reported prior to the year 2000 (Sinclair et al., 2009; Graciaa et al., 2018). No outbreaks related to enteroviruses in recreational areas have been reported in Canada. It is likely that cases of enterovirus infections have occurred but were not detected or reported.

### 2.4.3. Rotaviruses

Rotaviruses are larger (60 to 80 nm), non-enveloped, double-stranded RNA viruses which belong to the Reoviridae family. These viruses have been divided into eight serological groups, designated as A to H (Marthaler et al., 2012); three of the groups (A, B and C) infect humans, with group A being the most common and widespread (Estes and Greenberg, 2013).

In general, rotaviruses cause gastroenteritis, which is characterized by vomiting and diarrhea. Gastroenteritis can range from mild, lasting less than 24 hours, to severe infection, which can become life-threatening because of dehydration and electrolyte imbalance. Groups considered vulnerable to severe disease and illness-induced mortality include young children, immunocompromised individuals and the elderly. Rotavirus infection has been identified as the number one cause of infantile gastroenteritis worldwide. The vast majority of rotavirus infections are believed to result from person-to-person transmission (Butler et al., 2015). As a result of the immunity acquired during childhood, infections among healthy adults are often asymptomatic (Percival et al., 2004). In young children, extra-intestinal manifestations, such as respiratory symptoms and seizures, can also occur (Candy, 2007).

Group A rotavirus is endemic worldwide; however, a rotavirus vaccine is available. Rotaviruses have been isolated from surface water sources in Canada and the United States (Rose et al., 1987; Corsi et al., 2014; Pang et al., 2019) and from individual stool samples after recreational water exposures (Dorevitch et al., 2012; Hintaran et al., 2018). Nonetheless, no outbreaks of rotavirus associated with recreational water have been reported.

### 2.4.4. Adenoviruses

Adenoviruses are large (70 to 100 nm) non-enveloped, double-stranded DNA viruses belonging to the Adenoviridae family. Over 60 individual serotypes have been identified as being capable of causing human illness, with the clinical features and severity of illness varying considerably among the individual types (Percival et al., 2004). Most adenovirus serotypes cause respiratory illness, which presents with pharyngitis and cough and cold-like symptoms. Conjunctivitis can also occur as a result of infection of the eye. The majority of waterborne isolates are types 40 and 41 and cause gastrointestinal illness (Mena and Gerba, 2009), which may last a week (PHAC, 2010). Adenoviruses are thought to be second only to rotaviruses as a cause of childhood gastroenteritis (Crabtree et al., 1997), with most illnesses believed to be associated with person-to-person transmission (Butler et al., 2015). Infections are generally confined to children less than five years of age (FSA, 2000; Lennon et al., 2007) and are rare in adults. Adenoviruses have been detected in surface water sources around the world (Xagoraraki et al., 2007; Sassoubre et al., 2012; Lee et al., 2014; Marion et al., 2014; Vergara et al., 2016; Steele et al., 2018) but very few outbreaks linked to recreational waters have been recorded worldwide (Sinclair et al., 2009; Graciaa et al., 2018). No adenovirus outbreaks associated with recreational waters have been reported in Canada. It is likely that cases of adenovirus infections have occurred but were not detected or reported.

### 2.4.5. Hepatitis viruses

Six types of hepatitis viruses have been identified (A, B, C, D, E and G), but only two types, hepatitis A and hepatitis E, appear to be transmitted through the fecal-oral route and may therefore be associated with waterborne transmission. Hepatitis viruses are very stable in the environment, but their survival time is temperature dependent (van der Poel and Rzezutka, 2017). Although hepatitis viruses may survive in the environment, no outbreaks related to recreational waters have been recorded in Canada.

Hepatitis A virus (HAV) is a small (27 to 32 nm), non-enveloped single-stranded RNA virus belonging to the genus *Hepatovirus* within the Picornadiridae family. The major target organ for HAV is the liver. The incubation period of HAV infection is between 15 and 50 days (CDC, 2015). The majority of HAV infections are asymptomatic. Illness is most frequently reported among adults, with the severity of illness increasing with age. Children usually have mild or no symptoms (Yayli et al., 2002). Symptoms of HAV infection may include anorexia, malaise and fever, followed by nausea, vomiting, abdominal pain and jaundice. Infection is typically self-limiting, but in some cases HAV can cause liver damage leading to death. Convalescence may also be prolonged (8 to 10 weeks), and in some cases, individuals may experience relapses for up to six months (CDC, 2015). In Canada, the incidence of HAV has declined significantly since the introduction of the HAV vaccine in 1996 (PHAC, 2022). Most cases of HAV occur in contacts of infected individuals, in travellers returning from countries were HAV is common and in communities with inadequate sanitation (PHAC, 2022).

Hepatitis E virus (HEV) is a small (27 to 34 nm), non-enveloped, single-stranded RNA virus belonging to the Hepeviridae family. Human-infectious HEV are classified into four genotypes. Genotypes 1 and 2 have been found only in humans, whereas genotypes 3 and 4 appear to be zoonotic (transmitted to humans from deer, pigs and wild boars) (Smith et al., 2014). The incubation period for HEV varies from 15 to 60 days. Symptoms include malaise, anorexia, abdominal pain, arthralgia, dark urine, fever and jaundice, usually resolving in 1 to 6 weeks, although cases with a weakened immune system may develop long-lasting illnesses that can lead to more advanced liver disease (Government of Canada, 2022b). Infection is more often reported in young to middle-aged adults and can lead to death in rare cases. In pregnant women, the fatality rate can approach 20% to 25% (Matson, 2004). Illnesses associated with HEV are rare in developed countries, with most infections being linked to international travel.

### 2.4.6. Astroviruses

Astroviruses are small (28 to 30 nm), non-enveloped, single-stranded RNA viruses belonging to the Astroviridae family. Genotypes A and B are capable of infecting humans (Carter, 2005). Of the viral agents known to cause enteric illness, the significance of astroviruses as a cause of waterborne illness is perhaps the least well characterized (Percival et al., 2004). Illness in infected individuals appears to be similar to rotaviral illness, although it is markedly less severe (diarrhea lasting 2 to 3 days that does not lead to significant dehydration). Other symptoms include headache, malaise, nausea, vomiting and mild fever (Percival et al., 2004; Méndez and Arias, 2007). Infections caused by serotypes 1 and 2 are commonly acquired during childhood (Palombo and Bishop, 1996), and those caused by other serotypes (4 and above) may not occur until adulthood (Carter, 2005); however, infection in adults is uncommon (Oishi et al., 1994; Caul, 1996; Gray et al., 1997). Re-infection is rare, as healthy individuals generally acquire protective immunity to the disease (Gofti-Laroche et al., 2003).

Astroviruses can be transmitted through food, water, fomites and person-to-person contact (Bosch et al., 2014; Butler et al., 2015). The degree of transmission that occurs through water, particularly recreational water, is unknown. Person-to-person contact is believed to be the main route of transmission (Butler et al., 2015). No outbreaks of astroviruses associated with recreational waters have been recorded in Canada. Although there have been no outbreaks, astroviruses have been recovered from surface water sources in Canada (Jones et al., 2017; Pang et al., 2019). This suggests exposure to surface waters may cause astrovirus cases that have just not been detected or reported.

## 2.5 Enteric protozoan pathogens

Pathogenic protozoa that are of significance in relation to recreational environments include both enteric and free-living species. Enteric protozoa are common parasites that infect the intestinal tract of humans and other animals. They are obligate parasites, meaning that they must infect a host to replicate and are incapable of growth outside the host environment. The most important stage of their life cycle involves the production of cysts or oocysts, which are shed in large numbers in the feces. These cysts or oocysts are extremely resistant to environmental stresses and wastewater disinfection (Adeyemo et al., 2019), and can survive for long periods in the environment. Sources of enteric protozoa that can impact recreational waters include those that contain human or animal feces (for example, wastewater discharges, agricultural runoff, direct deposition of feces). These sources can also impact beach sands. Similar to enteric bacteria and enteric viruses, climatic conditions may impact the load of enteric protozoa in recreational waters.

Transmission to humans occurs through ingestion of contaminated water or sand. The most common enteric protozoa of concern in recreational waters are *Giardia* and *Cryptosporidium*, which cause illness that typically manifests as gastrointestinal symptoms (for example, diarrhea). A summary of the enteric protozoan pathogens can be found in Appendix B. *E. coli* and enterococci are the primary microorganisms used to indicate the presence of fecal contamination in water and thus the possible risk of enteric illness, including the risk of illness from enteric protozoa. Enteric protozoa can survive longer in the environment than the bacterial indicators and may be present after *E. coli* and enterococci have died off.

### 2.5.1. *Giardia*

*Giardia* spp. are flagellated protozoan parasites. They have a two-stage life cycle consisting of a trophozoite (feeding stage) and an environmentally resistant cyst stage. Six *Giardia* species are recognized at present. *G. lamblia* (syn. *G. intestinalis* and *G. duodenalis*), found in humans and a wide range of other mammals, is the only human-infective species. Other species (*G. muris*, *G. agilis*, *G. microti*, *G. psittaci* and *G. ardea*) have been reported in animals, including rodents, birds and amphibians. Molecular characterization of *G. lamblia* has identified eight genetically distinct assemblages (designated A through H) which differ in their host range (Boarato-David et al., 2017). Assemblages A and B infect humans and other mammals, whereas the remaining assemblages (C, D, E, F and G) have not yet been isolated from humans and appear to have restricted host ranges (Plutzer et al., 2010).

The most common symptoms associated with *Giardia* infection (also known as giardiasis) include sudden explosive, watery, pale, greasy and foul-smelling diarrhea, nausea, intestinal upset, fatigue, low-grade fever and chills. The severity of *Giardia* infection can range from no observable symptoms (asymptomatic infections) to severe gastrointestinal illness requiring hospitalization. *Giardia* infection can also lead to lactase deficiency (that is, lactose intolerance) and general malabsorptive syndrome, and some research suggests that it could also lead to irritable bowel syndrome or chronic fatigue syndrome in some individuals (Cotton et al., 2011; Wensaas et al., 2012; Hanevik et al., 2014). The median dose for infection is around 50 cysts (Hibler et al., 1987), although subjects have shown infection at much lower doses (Rendtorff, 1978). The time between ingestion and the excretion of new cysts (prepatent period) ranges from 6 to 16 days. Infection is usually self-limiting, clearing within 1 to 3 weeks on average; however, some patients may be asymptomatic carriers for longer periods. In other cases, individuals (particularly children) may experience recurrent bouts of the disease, persisting for several months to a year. Persistent illness can be treated using a number of antiparasitic drugs.

Human and animal feces (especially cattle feces) are major sources of *G. lamblia*. Other recognized animal hosts include pigs, beavers, muskrats, dogs, sheep and horses. Many of these animals can be infected with *G. lamblia* originating from human sources (Davies and Hibler, 1979; Hewlett et al., 1982; Erlandsen et al., 1988; Traub et al., 2004, 2005; Eligio-Garcia et al., 2005). Epidemiological and molecular data suggest that it is only these human-source strains that have been significantly associated with human illness (Hoque et al., 2003; Stuart et al., 2003; Berrilli et al., 2004; Thompson, 2004; Hunter and Thompson, 2005; Ryan et al., 2005). *Giardia* is commonly encountered in sewage and surface waters. In general, concentrations in raw and treated domestic wastewater typically range from 5,000 to 50,000 cysts/L and from 50 to 500 cysts/L, respectively (Medema et al., 2003; Pond et al., 2004). Surface water concentrations typically range from < 2 to 200 cysts/100 L (Gammie et al., 2000). Canadian studies have found that the majority of *Giardia* isolates in surface water were assemblages A and B (Edge et al., 2013; Prystajecky et al., 2015).

Surveillance data published by the US CDC for 1992 to 2002 indicate that *Giardia* was responsible for 9% (6 out of 64) of the total number of outbreaks of gastroenteritis reported for natural recreational waters (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004). More recently, for 2000 to 2014, *Giardia* was found to be responsible for 3% (9 of 140) of these outbreaks (Graciaa et al., 2018). Locations included recreational lakes, a recreational river and a pond setting. Although *Giardia* has not been linked to outbreaks in natural recreational waters in Canada, it is likely that cases have occurred but were not detected or reported.

### 2.5.2. *Cryptosporidium*

*Cryptosporidium* are small, non-motile protozoan parasites. These organisms possess a complex, multi-stage life cycle, which includes the production of a round, thick-walled, environmentally stable oocyst. Twenty-nine species are currently recognized as belonging to the genus (Ryan et al., 2014; Zahedi et al., 2016). Two predominant genotypes have been linked to human illness: *C. hominis* (genotype 1), reported only in humans, and *C. parvum* (genotype 2), reported in humans, calves and other ruminants. Other species and genotypes have been identified from human infections, but much less frequently. Humans and cattle are the most significant sources of *Cryptosporidium*. Sheep, pigs and horses are also considered to be reservoirs (Olson et al., 1997). Rodents are not a significant source of human-infective *Cryptosporidium* (Roach et al., 1993).

*Cryptosporidium* infection can result in illness varying in severity from asymptomatic carriage to severe, life-threatening illness in immunocompromised individuals. The primary characteristic of illness is profuse, watery, non-bloody and sometimes mucoid diarrhea. Other symptoms include cramping, nausea, vomiting, abdominal pain, weight loss, dehydration, anorexia and low-grade fever (CDC, 2021c).

As is the case with other pathogens, although a variety of median infective doses have been reported for *Cryptosporidium*, a single organism is theoretically sufficient to initiate infection. Volunteer feeding studies suggest that the median infective dose of *Cryptosporidium* is between 9 and 2,066 oocysts (DuPont et al., 1995; Okhuysen et al., 1998, 1999, 2002; Chappell et al., 1999, 2006; Messner et al., 2001). The prepatent period is roughly 4 to 9 days. Most healthy individuals experience a complete recovery, with the disease resolving itself in about 1 to 2 weeks. Oocysts may continue to be shed in feces for a short period following recovery. In most reports of individuals with severely weakened immune systems (that is, AIDS patients), the infection is never completely cleared, and may develop into an infection with long bouts of remission followed by mild symptoms. Extraintestinal cryptosporidiosis (that is, in the lungs, middle ear, pancreas, etc.) and death have been reported, primarily among persons with AIDS (Farthing, 2000; Mercado et al., 2007), but these cases are considered rare.

*Cryptosporidium* oocysts are commonly found in water affected by human or livestock wastes. Contamination may occur through sewage discharges, fecal shedding by swimmers and stormwater runoff. Waterfowl (ducks, geese) may pick up oocysts from their habitat and deposit them elsewhere through discharge in their feces. Typical concentrations in raw wastewater are on the order of 1,000 to 10,000 oocysts/L (Guy et al., 2003). In Canadian surface waters, concentrations generally range from 1 to 100 oocysts/100 L (Gammie et al., 2000).

Surveillance data in the United States for 1992 to 2002 show that 6 (9%) of the 64 outbreaks of gastrointestinal illness reported as being linked to natural recreational waters were caused by *Cryptosporidium* (Moore et al., 1993; Kramer et al., 1996; Levy et al., 1998; Barwick et al., 2000; Lee et al., 2002; Yoder et al., 2004). More recently, from 2000 to 2014, 12 (9%) of 140 recreational outbreaks were attributed to this pathogen (Graciaa et al., 2018). Recreational lakes were the setting for most of the outbreaks. A large outbreak at a New Jersey lake in 1994 involving 418 cases was the first recorded US outbreak of cryptosporidiosis related to recreational water use (Kramer et al., 1996). Treated recreational water venues (which are outside the scope of this document), such as water parks and community and motel swimming pools, have provided the setting for most outbreaks of cryptosporidiosis (Hlavsa et al., 2018). Surveillance in Canada has been limited. To date, there have been no reported outbreaks of cryptosporidiosis associated with natural recreational waters. As with *Giardia*, it is expected that cases have occurred but have not been detected or reported.

### 2.5.3. Other enteric protozoa of potential concern

Other enteric pathogenic protozoa of potential concern include *Entamoeba*, *Toxoplasma* and *Cyclospora*. Humans are the only significant reservoir of *Entamoeba*. Most infections occur through person-to-person contact, but they can also be acquired through ingestion of fecally contaminated water and food. *Entamoeba* infections can range from being asymptomatic to causing gastrointestinal illness, which may be serious or life-threatening (Kucik et al., 2004). *Toxoplasma* affects almost all warm-blooded animals, including humans, and can be shed in human and animal feces. It is usually transmitted through the ingestion of raw or undercooked infected meat, through contaminated foods or water, or through handling of contaminated soil or cat feces. Most *Toxoplasma* infections cause mild, flu-like symptoms; however, infection can be life-threatening for immunocompromised individuals and cause serious fetal health impacts (including neonatal death) if contracted during pregnancy. It can also significantly reduce the quality of life in children who survive a prenatal infection (Tenter et al., 2000). *Cyclospora* is like *Entamoeba* in that it only occurs in humans. Transmission is thought to occur through the ingestion of food or water contaminated with human feces. In Canada, most reported cases of illness are linked to contaminated food and travel (Ortega and Sanchez, 2010). *Cyclospora* infection causes symptoms similar to those associated with *Cryptosporidium*.

*Entamoeba, Toxoplasma* and *Cyclospora* can conceivably contaminate recreational waters. *Toxoplasma* has been linked to a drinking water-associated outbreak in Canada, which indicates that surface waters can be contaminated with this pathogen (Isaac-Renton et al., 1998). However, no recreational waterborne outbreaks have been reported for *Toxoplasma*, *Entamoeba* or *Cyclospora* in Canada. Consequently, based on current evidence, recreational water activity is not considered to be a significant risk factor for illness caused by these organisms.

## 2.6 Free-living protozoa

Free-living protozoa, unlike enteric protozoa, occur naturally in recreational waters and do not need a host organism to complete their life cycle. Transmission to humans can occur in waters containing sufficient quantities of the organisms, through mechanisms such as inhalation or through direct contact with mucous membranes (for example, those of the eye). Some free-living protozoa are temperature sensitive and increases in recreational water temperatures may be beneficial to their growth. Free-living protozoa can cause various types of illness, including infections of the central nervous system and eye infections. A brief description of the free-living protozoan pathogens can be found in Appendix B. As these protozoans are not of fecal origin, fecal indicators are not expected to correlate well with their presence. Currently, there is no recognized microbiological indicator for these pathogens.

The free-living protozoa recognized as being the most significant from the perspective of natural recreational waters are *Naegleria* and *Acanthamoeba*.

### 2.6.1. *Naegleria fowleri*

*Naegleria* are thermophilic, free-living freshwater amoebae. The genus *Naegleria* is composed of over 40 species; however, only *N. fowleri* is a pathogen in humans (Marciano-Cabral and Cabral, 2007; Yoder et al., 2010). *N. fowleri* are thermophilic organisms that grow well at temperatures between 25°C and 40°C (optimum: 37°C) and can tolerate temperatures exceeding 50°C to 60°C (Hallenbeck and Brenniman, 1989; Visvesvara et al., 2007; Zaongo et al., 2018). The organism has a multi-stage life cycle consisting of a motile feeding trophozoite stage, a non-replicating flagellate stage and an environmentally resistant cyst stage. The cysts are the most resistant form of the organism and can survive under adverse environmental conditions.

*N. fowleri* has been found around the world in warm fresh water and soil. The organism has been isolated from both natural and artificial warm water supplies, including lakes, rivers, hot springs, swimming pools, hydrotherapy baths and tap water. It is most commonly detected in tropical and subtropical fresh waters and in hot springs. While survival of *N. fowleri* in northern waters is less common, the pathogen has been found in lake water in states as far north as Minnesota (Yoder et al., 2010, 2012). No human or animal reservoirs have been identified.

*N. fowleri* causes a disease of the central nervous system called primary amoebic meningitis (PAM), which is almost always fatal. Human infection occurs when water containing the amoeba enters the nasal passages (for example, during diving, jumping, falling or swimming underwater). Following entry into nasal passages, the organism travels to the brain, where it damages the cells of the olfactory system and cerebral cortex. The onset of illness is rapid with symptoms occurring 1 to 7 days after exposure. The disease progresses rapidly, with death generally occurring within 5 days (Visvesvara et al., 2007; Chalmers, 2014b). Symptoms include severe headache, high fever and vomiting, followed by a stiff neck, altered mental status, seizures, coma and ultimately death. PAM has an extremely high fatality rate (greater than 97%) (Capewell et al., 2015). Successful treatment requires prompt diagnosis and aggressive antimicrobial therapy (CDC, 2019b).

Cases of PAM are extremely rare. It is estimated that in the United States, one case occurs among approximately every 2.5 million swimmers (Visvesvara and Moura, 2006). From 1962 to 2015, 138 cases of PAM were reported in the United States, with between 0 and 8 cases reported annually (Cope and Ali, 2016). Most exposures have occurred at lakes and ponds; exposures at rivers or streams have been less frequently reported (Yoder et al., 2010). There have been some cases of illness where improperly maintained swimming pools were the probable sources of exposure (Yoder et al., 2010; Cope and Ali, 2016). Cases are more common in the southern United States. However, with climate warming, cases have been identified farther north, for example, in Minnesota, Kansas, and Indiana (Cope and Ali, 2016). To date, there have been no recorded cases of PAM linked to recreational water contact in Canadian waters. The bulk of the evidence suggests that amoebic meningoencephalitis is an unlikely health concern in Canada. However, researchers have suggested that increasing lake temperatures brought on by climate change could result in this organism extending their distribution (Rose et al., 2001; Schuster and Visvesvara, 2004). This could impact Canadian surface waters if they become sufficiently warmed.

### 2.6.2. *Acanthamoeba*

*Acanthamoeba* are free-living amoebae. Approximately 20 different genotypes of *Acanthamoeba* have been identified (Juárez et al., 2018). *Acanthamoeba* genotype T4 is the predominant type encountered in cases of illness and in the environment; however, other genotypes have also been associated with disease (Chalmers, 2014a; Juárez et al., 2018).

*Acanthamoeba* are considered ubiquitous in the environment. They can be found in fresh, estuarine and marine waters, hot springs, soils and sewage. *Acanthamoeba* spp. have low nutrient requirements and grow at temperatures from 12°C to 45°C (optimum: 30°C) (Chalmers, 2014a). Their life cycle consists of two stages: a feeding trophozoite (25 to 40 μm) and a resistant cyst (10 to 30 μm) that can withstand temperatures between -20°C and 56°C and resist desiccation and disinfection (Chalmers, 2014a; Juárez et al., 2018).

*Acanthamoeba* are opportunistic pathogens that can cause rare but severe human diseases affecting the eye, skin, lungs, brain and central nervous system (Visvesvara et al., 2007; Chalmers, 2014a; de Lacerda and Lira, 2021). The most common form of illness is amoebic keratitis (AK), a painful, vision-threatening disease of the cornea (Juárez et al., 2018). Infection occurs through direct contact with the mucous membranes of the eye. AK is usually associated with poor hygiene practices in contact lens wearers (use of contaminated solutions and inadequate disinfection). In rare cases, *Acanthamoeba* can also cause disseminated infections, which originate in the skin and lungs and then spread to other areas of the body. One such example is granulomatous amoebic encephalitis, a fatal disease of the central nervous system. The rare cases of disseminated illness, which are not thought to be waterborne, primarily occur in individuals with weakened immune systems or underlying disease (Chalmers, 2014a). Despite the widespread occurrence of *Acanthamoeba* in environmental waters, recreational water contact is not considered to be a significant risk factor for acquiring illness. As mentioned above, most cases are linked to the use of contact lenses (de Lacerda and Lira, 2021), some of which could be a result from wearing contact lenses while swimming in lakes or ponds. To reduce this risk, contact lenses should be removed before engaging in primary contact water activities (CDC, 2021b).

As mentioned in section 2.3.2, *Acanthamoeba* may also host certain free-living bacterial pathogens, namely *Legionella* and *Mycobacterium* (Visvesvara et al., 2007; Juárez et al., 2018). Survival within *Acanthamoeba* can provide these organisms with an environment suitable for replication, as well as protection from environmental stresses.

# 3.0 OTHER BIOLOGICAL HAZARDS

This section provides guidance on other organisms that may affect the recreational value of natural waters by rendering them unsafe, aesthetically objectionable or otherwise unusable, and thus interfering with users' health, physical comfort and enjoyment. These organisms are free-living species that occur naturally in recreational waters. Guidance is provided here so that authorities responsible for managing recreational waters and the general public have information on the possible hazard posed by these organisms and steps for reducing potential exposure. This list is not intended to be exhaustive. The responsible authorities may wish to provide information on other organisms of regional or local significance.

## 3.1 Schistosomes

Swimmer's itch (cercarial dermatitis) is caused by human reaction to dermal penetration by parasitic flatworms or "schistosomes" which belong to the *Schistosomatidae* family and may infect certain waterfowl and aquatic rodent species (Manitoba Water Stewardship, 2007). The species known to cause swimmer's itch include members of the genera *Austrobilharzia, Trichobilharzia, Dendritobilharzia, Gigantobilharzia* and *Schistosomatium* (Levesque et al., 2002; CDC, 2004a; Gordy et al., 2018). Cercarial dermatitis should be clearly distinguished from human schistosomiasis, a far more serious human infection caused by species of the genus *Schistosoma* which is typically restricted to tropical regions of the world (WHO, 2003).

The species of schistosome that cause swimmer's itch have a two-host life cycle, consisting of a definitive host (waterfowl or aquatic rodents) and an intermediate host (certain species of aquatic snails). It is the aquatic snails that produce the form of the parasite (that is, the cercariae) that can impact humans. Once a snail is infected (for example, in late spring by migrating waterfowl), it generally takes up to 1.5 months for the cercariae to emerge. Water temperature can affect the release of mature cercariae by infected snails, with higher concentrations occurring in warmer waters (Verbrugge et al., 2004). Warmer waters and the parasite life cycle may partially explain why infections are encountered more frequently during the summer months. Summer is also a time when recreational water activities increase in Canada, increasing potential exposure to this parasite. Warm waters as a result of climate change could lead to increased infections with this parasite

(Gordy et al., 2018; Kaffenberger et al., 2016). Schistosome cercariae are encountered in areas with dense snail beds. Outbreak data indicate that dense beds are typically found in shallow waters along the shoreline, particularly where there are large numbers of aquatic plants (Levesque et al., 2002; Leighton et al., 2004; Verbrugge et al., 2004). Onshore winds can also direct cercariae towards shorelines where snails are absent (Rudko et al., 2018; Sckrabulis et al., 2020).

Humans are an accidental or dead-end host for the cercariae. When cercariae come in contact with humans in the water, they may penetrate the outer layer of skin but then quickly die as they cannot develop any further. The presence of the cercariae beneath the skin causes an allergic reaction (that is, cercarial dermatitis) with symptoms such as an initial tingling, itching or burning sensation. Small, reddish pimples typically appear within 12 hours after infection. These can progress to larger secondary blisters or rashes, which can be accompanied by an even stronger itching sensation. The effects of swimmer's itch may be felt shortly after swimming, in some cases in as little as a few minutes. Although the infection is self-limiting, typically lasting from 2 to 5 days, symptoms can persist for as long as 2 weeks. Swimmer's itch is not contagious and cannot spread from person to person. However, individuals who develop an allergic reaction to cercariae can experience an increased sensitivity to subsequent infections. The symptoms become more intense and develop much more rapidly in these instances (British Columbia Ministry of Health, 2018). Sensitivity can vary considerably between different individuals; some may show a strong allergic reaction, whereas others show no signs of infection. Individuals who have a severe reaction are advised to seek medical treatment from a health professional. Treatments suggested for alleviating itching symptoms include bathing in Epsom salts, baking soda or colloidal oatmeal; and using cold compresses; anti-itch medications such as corticosteroid creams or calamine lotion; or oral antihistamines (Manitoba Water Stewardship, 2007; British Columbia Ministry of Health, 2018). Affected individuals should refrain from scratching because it increases the potential for secondary bacterial infection (CDC, 2004b).

A review of reported episodes of swimmer's itch across Canada found very few documented cases (only 280) over more than 60 years, and indicates that only one or two outbreaks of swimmer's itch occur every decade (Gordy et al., 2018). However, many cases of swimmer's itch go unreported because the symptoms are typically benign and users may not seek medical attention. To better capture the amount of underreporting and assess the real incidence of swimmer's itch, Gordy et al. (2018) used swimmer's itch case reports from 2013 to 2017, gathered through a voluntary, online survey every summer. The survey captured 3,882 cases of swimmer's itch over the five summers. The reported cases occurred in every province in Canada except for Prince Edward Island. Recent studies in Quebec analysed waterborne disease outbreak data for the years 2005 to 2018; 11 outbreaks impacting approximately 160 people were related to schistosomes (Huppé et al., 2019; Dubé and Lebel, 2022). These studies confirm that schistosomes are a risk at some beaches and recreational users should be made aware of the potential risks in impacted areas.

### 3.1.1. Managing health risks from schistosomes

The species of schistosomes that cause swimmer's itch are considered to occur naturally in Canadian surface waters. They are not related to fecal contamination. As a result, their presence is not detected during standard water quality testing for the recommended indicators of fecal contamination. The presence of these organisms in natural waters is dependent upon a number of factors, both biological and environmental. This makes it very difficult to predict when and where swimmer's itch might become a problem. Certain areas may report a problem where none appeared to exist previously. Areas in which swimmer's itch has been reported will not necessarily always remain a problem. Propagation of the parasites responsible for causing swimmer's itch requires that both the primary and intermediate host be present in sufficient numbers.

A management strategy combining actions to control the extent of the water quality hazard and steps to limit exposure during periods or in areas perceived to be at greater risk is recommended to reduce the probability of human exposure to these schistosomes in recreational waters. Actions that may help control the presence of schistosomes include not feeding waterfowl, and where possible, removing organic wastes within the main snail habitat.

Warning signs that clearly notify the public of the risk of exposure should be posted in recreational water areas where cases of swimmer's itch have been reported. A swimming advisory may be issued at the discretion of the responsible authority. Further details on the posting of information in recreational water areas can be found in *Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023b).

Another risk reduction approach can include distributing educational materials outlining steps that the public can take to reduce their personal risk of exposure and the severity of symptoms in the event of infection. Guidance provided in communication materials intended for the general public could include the following:

- avoiding the use of recreational waters in areas where warning signs are posted or suspected schistosome locations;
- towelling down briskly after leaving the water and showering after a recreational water activity;
- if experiencing health effects, consulting a medical professional and alerting the appropriate authorities (if necessary); and
- taking other actions to help mitigate the potential risk in recreational water areas (for example, not feeding waterfowl

## 3.2 Aquatic vascular plants and algae

Aquatic vascular plants (macrophytes) and algae can affect recreational water use. It is difficult to estimate the magnitude of their impact in terms of their degree of interference with recreational pursuits and the potential risks to the health of recreational water users.

The presence of these aquatic vascular plants and algae can present a safety risk to recreational water users. Swimmers may become entangled in the fronds of aquatic plants. Dense growths can obstruct the view of the bottom and of underwater hazards and may impair the ability of safety personnel to see persons in distress. Algal mats attached to rocks and other substrates (that is, periphyton) can cause slippery conditions that may lead to unintentional immersions or injuries.

Excessive growth of aquatic plants and algae can also create aesthetic problems for recreational water areas. Macrophytes can reach high population densities and make nearshore and shallow regions unsuitable for any recreational activity (Priyadarshi, 2005). Dislodged rafts or mats of plants and algal material can be washed ashore and left to rot, fouling beaches. In addition to being unsightly, these masses can further detract from user enjoyment by producing offensive odours and restricting access to shorelines. They may also pose a public health hazard because they can attract undesirable animals to the area and provide breeding grounds for a variety of species of insects and bacteria (Whitman et al., 2003). The most notorious organism in this respect has been the green algal species *Cladophora* (Priyadarshi, 2005). It can be found in both fresh and marine environments (Whitman et al., 2003). There have been many accounts of beaches and shorelines in the Great Lakes fouled by rotting, stinking masses of this alga. *Cladophora* mats can also provide a secondary habitat for bacteria that can adversely impact the water quality in affected swimming areas (Whitman et al., 2003; Ishii et al., 2006; Englebert et al., 2008; Verhougstraete et al., 2010) and for bacteria linked to bird die-offs (avian botulism) (Lan Chun et al., 2015). Blooms of other non-toxic algal species can also cause aesthetic problems and potentially be mistaken for cyanobacteria blooms. Cyanobacteria blooms are a public health concern as they can contain cyanobacterial toxins, which can have adverse effects on the kidneys, liver, and neurological tissues, and contact with bloom material may also cause skin irritation and gastrointestinal upset. Further information on cyanobacteria can be found in the *Guidelines for Canadian Recreational Water Quality – Cyanobacteria and their toxins* technical document (Health Canada, 2022b).

The presence of excess nutrients in the water may increase plant and algae growth; this is known as eutrophication. Various nutrient sources, including agricultural runoff, domestic sewage and industrial effluent, contribute phosphorus and nitrogen to aquatic systems and can lead to eutrophication. Impaired water quality due to eutrophication can reduce recreational opportunities (Chambers et al., 2001; Watson et al., 2017). Canadian water quality guidelines have been developed for both phosphorus and nitrogen to protect the aquatic environment from the buildup of these nutrients and their effects on aquatic organisms (CCME, 1999).

### 3.2.1. Managing health risks

Recreational water activities should not be pursued in areas where there are such large quantities of aquatic plants and algae that the responsible authorities consider that their presence poses a potential health or safety risk to recreational water users. An environmental health and safety survey should be conducted at the start of each swimming season to identify potential health and safety hazards in a given recreational water area. If problems are identified, signs may be posted to warn users of potential visibility or entanglement risks from these organisms. Further information on the posting of warning signs can be found in *Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023b).

Improved beach clean-up procedures to remove masses of plants and algal material that have washed up on shorelines can be effective in reducing potential risks to recreational users. Management actions that involve trying to remove these organisms from natural waters or to treat them using pesticides are discouraged and, depending on the jurisdiction, may also be considered illegal. Removal may be harmful to the aquatic environment and is generally not effective from the perspectives of practicality (plants quickly grow back) and financial resources (many hours of paid labour). Many aquatic plants and algae also provide an important habitat for fish and other aquatic biota. The application of pesticides to combat these organisms may create a health hazard for recreational water users if the products are used incorrectly. Furthermore, the application of pesticides could cause the release of cyanobacterial toxins if toxin producing cyanobacteria are present (Zastepa et al., 2014). Longer-term actions that may reduce the impact of these organisms may include identifying the major nutrient inputs within the watershed and implementing strategies for their control.

## 3.3 Additional organisms

Numerous other organisms can interfere with the safe and enjoyable use of recreational waters in Canada. For example, at some coastal beaches, jellyfish can cause painful and possibly serious stings to recreational water users who encounter them. Similarly, leech "bites" can occur in leech-infested areas, and sea urchins and mussel shells can cause painful injuries when stepped on by users of recreational waters. As these organisms are often of local or regional significance, it is recommended that the responsible authority provide appropriate guidance to recreational water users on these subjects where necessary. This may include providing information on the potential risks posed by these organisms and on steps for reducing the risk of exposure for individuals.

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# APPENDIX A
# LIST OF ABBREVIATIONS

| | |
|---|---|
| **AIDS** | acquired immunodeficiency syndrome |
| **AK** | Acanthamoeba keratitis |
| **CDC** | Centers for Disease Control and Prevention |
| **DNA** | deoxyribonucleic acid |
| **E. coli** | Escherichia coli |
| **EHEC** | enterohemorrhagic *Escherichia coli* |
| **EIEC** | enteroinvasive *Escherichia coli* |
| **HAV** | hepatitis A virus |
| **HEV** | hepatitis E virus |
| **HUS** | hemolytic uremic syndrome |
| **MRSA** | methicillin-resistant *Staphylococcus aureus* |
| **NTM** | non-tuberculous mycobacteria |
| **PAM** | primary amoebic meningoencephalitis |
| **PCR** | polymerase chain reaction |
| **RNA** | ribonucleic acid |
| **spp.** | species |
| **UPEC** | uropathogenic *E. coli* |

# APPENDIX B

## Microbial pathogens in recreational water areas

**Table B.1:** Bacterial pathogens of potential concern for recreational water areas

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Campylobacter**<br>**(C. jejuni,**<br>**C. coli)** | Diarrhea, abdominal pain, chills, fever; can be life threatening; may lead to inflammatory bowel diseases | Young children, the elderly, persons with weakened/ compromised immune systems | Poultry, cattle, sheep, pets, waterfowl, human sewage | Ingestion | Potential risk in fresh and marine waters; no recorded Canadian outbreaks but have been found in surface waters; outbreaks reported in the USA. |
| **Pathogenic Escherichia**<br>**(Entero-haemorrhagic E.coli (EHEC) group, includes E. coli O157:H7)** | Diarrhea, abdominal pain, fever; some cause severe illnesses such as haemorrhagic colitis that can lead to hemolytic uremic syndrome | Young children, the elderly, persons with weakened/ compromised immune systems | Cattle, human sewage | Ingestion | Potential risk in fresh and marine waters; outbreaks in Canada and the USA. |
| **Shigella**<br>**(S. sonnei, S. flexerni)** | Diarrhea, abdominal pain, fever | Young children, the elderly, persons with weakened/ compromised immune systems | Human sewage | Ingestion | Potential risk in fresh and marine waters; no outbreaks reported in Canada but common cause of outbreaks in the USA. |

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|---|---|---|---|---|---|
| **Salmonella**<br><br>**(Non-typhoidal serotypes)** | Diarrhea, nausea, vomiting | Young children, the elderly, persons with weakened/ compromised immune systems | Poultry, swine, birds, cattle, pets, human sewage | Ingestion | Potential risk in fresh and marine waters; no recorded outbreaks in Canada or USA but have been found in surface waters. |
| **Legionella**<br><br>**(L. pneumophila)** | Legionnaires' disease (severe respiratory illness involving pneumonia) and Pontiac fever (flu-like symptoms) | Older adults, persons with weakened/ compromised immune systems or underlying health conditions | Naturally present at low concentrations in fresh waters; rare in marine waters; can grow to high numbers in engineered systems | Inhalation | No outbreaks from natural waters in Canada or the USA, risk is considered extremely low; hot springs and hydrothermal spas may present a risk. |
| **Mycobacterium**<br><br>**(Non-tuberculous mycobacteria (NTM))** | Respiratory illness, skin infections | Persons with underlying conditions (weakened/ compromised immune systems, abraded or traumatized skin) | Naturally present in fresh waters, soils, wastewaters; less common in marine waters | Inhalation, ingestion, direct water contact | No outbreaks from natural waters in Canada or the USA, risk is considered extremely low; hot springs and hydrothermal spas may present a risk. |
| **Pseudomonas**<br><br>**(P. aeruginosa)** | Skin, eye, and ear infections, skin rashes | None listed for recreational water exposure routes | Naturally present in fresh and marine waters | Direct water contact | Potential risk in fresh and marine waters; no outbreaks from natural waters in Canada or the USA but studies have linked *P. aeruginosa* in natural waters to eye and skin infections. |

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Aeromonas**<br><br>**(A. hydrophila, A. caviae, A. veronii (biotype sobria), A. trota)** | Gastrointestinal illness, wound infections; can lead to serious outcomes (septicemia, fever, jaundice, septic shock) | Persons with open wounds or penetrating injuries | Naturally present in fresh and marine waters, human and animal fecal material | Direct water contact, ingestion | Potential risk in fresh and marine water; no reported outbreaks in North America; has been linked to skin infections but not to gastrointestinal illness from recreational exposures. |
| **Leptospira** | Mild-flu like symptoms; if left untreated can progress to severe illness (Weil's disease). | Persons with cuts or abrasions in the skin | Urine of infected rats, mice, voles, domestic animals usually thru runoff to water sources | Direct water contact | Potential risk in freshwater; no cases linked to recreational water activity in Canada; outbreaks in the USA linked to adventure races and drought impacted waters. |
| **Staphylococcus**<br><br>**(S. aureus)** | Infected cuts, scratches; boils, pustules, dermatitis, folliculitis, impetigo; can be life threatening if caused by methicillin-resistant *S. aureus* (MRSA) | Persons with cuts or abrasions in the skin | Mouths, noses and throats of swimmers; discharges from existing infections; human sewage | Direct water contact | Potential risk in fresh and marine waters; has also been investigated as an indicator of water safety but study results did not consistently link the bacteria to adverse health impacts. |

**Table B.2:** Viral pathogens of potential concern for recreational water areas

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Noroviruses**<br><br>**(Genogroups GI, GII and GIV)** | Diarrhea, nausea, vomiting, abdominal pain, fever | The elderly may develop more serious illness | Human fecal matter (sewage sources and bather shedding) | Ingestion | Common cause of outbreaks in the USA; outbreak data not available for Canada but noroviruses are considered a significant risk in fresh and marine waters. |
| **Enteroviruses**<br><br>**(Enterovirus A, B, C, and D)** | Fever, sore throat, vomiting, malaise; some can cause more serious illnesses (myocarditis, meningitis, poliomyelitis, encephalitis) | None listed for recreational water exposure routes | Human fecal matter (sewage sources and bather shedding) | Ingestion | Potential risk in fresh and marine waters; very few outbreaks have been reported worldwide and no recorded Canadian outbreaks; the viruses have been found in surface waters in Canada. |
| **Rotaviruses**<br><br>**(Group A)** | Vomiting, diarrhea; can be life threatening from dehydration and electrolyte imbalance | Young children, the elderly, persons with weakened/ compromised immune systems | Human fecal matter (sewage sources and bather shedding) | Ingestion | Potential risk in fresh and marine water; no outbreaks have been reported in Canada; the viruses have been found in surface waters in Canada. |

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Adenoviruses**<br><br>**(Types 40 and 41)** | Gastrointestinal illness | Young children | Human fecal matter (sewage sources and bather shedding) | Ingestion | Potential risk in fresh and marine waters: very few outbreaks have been reported worldwide and no recorded Canadian outbreaks; the viruses have been found in surface waters in Canada. |
| **Hepatitis viruses**<br><br>**(Types A and E)** | Anorexia, malaise, fever followed by nausea, vomiting, jaundice, liver damage | Adults | Human fecal matter (sewage sources and bather shedding) | Ingestion | Potential risk in fresh and marine waters; no outbreaks have been reported in Canada; hepatitis A has been found in surface waters in Canada; hepatitis E infections are rare in developed countries. |
| **Astroviruses**<br><br>**(Genotypes A and B)** | Vomiting, diarrhea, mild fever | Young children | Human fecal matter (sewage sources and bather shedding) | Ingestion | Potential risk in fresh and marine waters; no outbreaks have been reported in Canada; viruses have been found in surface waters in Canada. |

**Table B.3:** Protozoan pathogens of potential concern for recreational water areas

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Giardia**<br><br>**(G. lamblia - syn. G. intestinalis and G. duodenalis)** | Diarrhea, nausea, fatigue, fever; can lead to more serious illnesses | Young children are at risk for longer illness | Human and animal feces | Ingestion | Potential risk in fresh and marine waters; common cause of outbreaks in the USA. No outbreaks have been reported in Canada but cases have likely occurred but were not detected or reported. |
| **Cryptosporidium**<br><br>**(C. hominis, C., parvum)** | Diarrhea, nausea, vomiting, anorexia, fever | Immuno-compromised individuals at risk of more severe outcomes | Human and animal feces | Ingestion | Potential risk in fresh and marine waters; common cause of outbreaks in the USA. No outbreaks have been reported in Canada but cases have likely occurred but were not detected or reported. |
| **Naegleria**<br><br>**(N. fowleri)** | Primary amoebic meningitis, almost always fatal | None listed for recreational water exposure routes | Naturally present in tropical and subtropical fresh waters | Water enters through the nasal passages | Extremely rare; no reported cases in Canada. Most reported cases are associated with warm climates. |
| **Acanthamoeba**<br><br>**(Genotype T4)** | Amoebic keratitis (disease of the cornea) | People using contact lenses while swimming | Naturally present in fresh and marine waters | Direct water contact with mucus membrane of the eye | Ubiquitous in the environment; recreational water activity is not considered to be a significant risk factor illness. |

| Pathogen (members commonly associated with illness in Canada) | Main health effects | Groups at higher risk for illness/ severe illness | Sources of contamination | Routes of exposure for recreational waters | Significance as a recreational water pathogen |
|---|---|---|---|---|---|
| **Entamoeba** | Gastrointestinal illness, sometimes serious or life-threatening | None listed for recreational water exposure routes | Human feces | Ingestion | No outbreaks have been reported in Canada; recreational water activity is not considered to be a significant risk factor for illness. |
| **Toxoplasma** | Flu-like symptoms, but can be life-threatening | Immuno-compromised, pregnant individuals | Human and animal feces | Ingestion | No outbreaks have been reported in Canada; recreational water activity is not considered to be a significant risk factor for illness. |
| **Cyclospora** | Diarrhea, nausea, vomiting, anorexia, fever | None listed for recreational water exposure routes | Human feces | Ingestion | No outbreaks have been reported in Canada; recreational water activity is not considered to be a significant risk factor for illness. |