GUIDELINES FOR

CANADIAN RECREATIONAL WATER QUALITY

INDICATORS OF FECAL CONTAMINATION

Guideline Technical Document

Health Canada Santé Canada

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Foreword

The *Guidelines for Canadian Recreational Water Quality* are comprised of 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, indicators of fecal contamination, microbiological sampling and analysis, 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 used for recreational purposes; this includes lakes, rivers, and human-made systems (e.g., stormwater ponds, artificial lakes) that are filled with untreated natural waters. Jurisdictions may choose to apply these guidelines to other natural waters for which limited treatment is applied (e.g., short-term use of disinfection for an athletic event). Applying the guidelines in these scenarios should be done with caution. Some disease-causing microorganisms (e.g., protozoan pathogens) are more difficult to disinfect than fecal indicator organisms and may still be present even if disinfection has reduced the fecal indicators to acceptable levels.

Recreational activities that could present a human health risk through intentional or incidental immersion and ingestion include primary contact activities (e.g., swimming, wading, windsurfing and waterskiing) and secondary contact activities (e.g., canoeing, boating or fishing).

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

This document focuses on the indicators of fecal contamination. 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 Canada.ca website (in publication). For issues related to drinking water, please consult the Guidelines for Canadian Drinking Water Quality – Guideline Technical Document on *Escherichia coli* (Health Canada, 2020b) and *Guidance on the use of Enterococci as an Indicator in Canadian Drinking Water Supplies* (Health Canada, 2020a).

Using indicators of fecal contamination for recreational water quality management

This document outlines how indicators of fecal contamination can be used as one component of a preventive risk management approach alongside other activities, such as environmental health and safety surveys (EHSS) and, in some cases, microbial source tracking (MST) investigations. Recreational waters may be impacted by fecal material containing enteric pathogens from numerous sources, including discharged sewage, treated wastewater effluent, stormwater runoff from agricultural or urban areas, industrial processes, wild or domesticated animals, and even fecal shedding by swimmers. The degree of risk from enteric pathogens varies between sources of fecal contamination, with sewage sources generally considered the most significant (in terms of the highest concentrations of infectious enteric viruses, bacteria and parasitic protozoa). Routine testing of recreational waters for pathogens is generally impractical, due to the variability in the types and quantities of pathogens present at any one time and the degree of difficulty associated with many of the detection methods. Consequently, as part of a risk management approach for recreational waters, authorities monitor for fecal indicators that are present in high numbers in both human and animal feces. Elevated numbers of these indicators in the aquatic environment are used to indicate fecal contamination and an elevated risk of illness.

Guideline values have been developed for *Escherichia coli* (*E. coli*) and enterococci. The values consider both the potential health risks associated with recreational activities and the benefits of recreational water use in terms of physical activity and enjoyment. These guideline values are considered to represent an acceptable level of risk for recreational activities for the general public.

E. coli and enterococci are recommended as primary indicators of possible fecal contamination and of potentially elevated gastrointestinal illness (GI) risk in recreational waters impacted by human enteric pathogens. Quantitative microbial risk assessment studies have shown that, similar to waters contaminated with human sewage, waters impacted by ruminants (e.g., cattle feces) may also present a significant risk to human health. Recreational areas that are not impacted by human or ruminant fecal sources generally contain lower levels of human pathogens, compared to those impacted by human and ruminant feces, at similar levels of *E. coli* and enterococci. Detection of *E. coli* and enterococci at the guideline levels, in water sources that are not impacted by human and ruminant feces, may therefore represent a lower level of risk to human health. Alternative water quality criteria may be developed for these potentially lower risk recreational waters on a site-specific basis. However, care is needed to ensure that the risk of illness associated with any new criteria does not exceed the acceptable level of risk. Recreational area managers are encouraged to determine the sources of fecal contamination impacting a recreational water site. A variety of options are available, such as EHSS and MST methods, as well as alternative indicators, to determine the sources of contamination and the remediation priorities to improve the water quality for recreators.

More details on risk management of recreational water quality are available in the *Guidelines for Canadian Recreational Water Quality – Guideline Technical Document on Understanding and Managing Risks in Recreational Waters* technical document (Health Canada, 2023).

1.0 GUIDELINES FOR PRIMARY CONTACT RECREATION

Guidelines for the fecal indicator bacteria *Escherichia coli* (*E. coli*) and enterococci have been developed for recreational areas used for primary contact activities (see Table 1 and Table 2). These values consider both the potential health risks and the benefits of recreational water use in terms of physical activity and enjoyment and are considered to represent an acceptable level of risk for recreational activities (see section 6.5).

Fecal indicator bacteria are used to indicate a potential increased risk to human health and are one component of a preventive risk management approach. Both culture-based methods (*E. coli* and enterococci) and polymerase chain reaction (PCR) based methods (enterococci) can be used for analysis. The choice of analytical method may depend on source water characteristics, the laboratory capacity and the necessity for same-day results. Further information on methods, including their advantages and limitations, can be found in the guideline technical document on *Microbiological Sampling and Analysis* (Health Canada, in publication). Further information on developing a sampling plan using fecal indicator bacteria can be found in the guideline technical document on *Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023)

Table 1. Guideline values[1,2] using culture-based methods

Indicator	Beach Action Value (BAV)[4]
E. coli-fresh water[3]	≤ 235 *E. coli* cfu[5]/100 mL
Enterococci-marine and fresh water	≤ 70 enterococci cfu[5]/100 mL

[1] Jurisdictions may develop alternative criteria for recreational areas that have very low risk of impacts from human fecal pathogens;

[2] Values from United States Environmental Protection Agency (U.S. EPA) (2012) for 36 illnesses/1000 primary contact recreators;

[3] *E. coli* can be adopted for marine waters if it is shown to adequately demonstrate the presence of fecal contamination;

[4] BAV concentrations are applied to each individual sample result (single or composite), rather than to averages or means;

[5] Methods with a most probable number (MPN) estimate are assumed equivalent to the cfu values given; cfu – colony-forming units

Table 2. Guideline values[1,2] using PCR-based methods

Indicator	Beach Action Value (BAV)[3]
Enterococci-marine and fresh water	< 1000 enterococci cce/100 mL

[1] Jurisdictions may develop alternative criteria for recreational areas that are very low risk for impacts from human fecal pathogens;

[2] Values from U.S. EPA (2012) for 36 illnesses/1000 primary contact recreators;

[3] BAV concentrations are applied to each individual sample result (single or composite), rather than to averages or means; cce – calibrator cell equivalent

The epidemiological link between *E. coli* or enterococci concentrations and increased risk of adverse human health outcomes is based on an assessment of sites impacted to varying degrees by human sewage. Recreational areas that are not impacted by human or ruminant fecal sources, such as those only impacted by wildlife/birds, may contain fewer human pathogens. At these sites, higher levels of indicator bacteria may be present before the risk of gastrointestinal illness (GI) exceeds the acceptable level of risk. Microbial source tracking methods, along with EHSS, can be used to determine the probable source(s) of fecal contamination to help characterize the potential associated human health risks (see Box 1 and Health Canada, 2023). Recreational waters that have a very low risk of human or ruminant fecal contamination may benefit from the development of alternative criteria on sa site-specific basis.

2.0 APPLICATION OF THE GUIDELINES

Monitoring for *E. coli* or enterococci can provide a benchmark for public health decisions and provide valuable information on water quality changes that may be occurring at the beach. The guideline values recommended in this document are beach action values (BAV) for both culture-based (*E. coli* and enterococci) and PCR-based (enterococci) monitoring methods. Jurisdictions may choose to implement culture-based methods, PCR-based methods, or both (e.g., during side-by side testing of method performance), depending on their recreational water quality monitoring plan. Quantitative and digital PCR-based methods have the advantage of providing same-day results for decision making purposes, when water quality samples are collected and received by the laboratory in a timely fashion. Further information on the advantages and limitations of monitoring methods is included in guideline technical document on *Microbiological Sampling and Analysis* (Health Canada, in publication). Decisions regarding the frequency of monitoring, the number of samples to be collected, the areas to be monitored, the choice of indicators, and the monitoring program design will be made by the appropriate regulatory and management authorities. Further guidance on these topics can be found in the guideline technical document on *Understanding and Managing Risks in Recreational Waters* (Health Canada, 2023).

The BAVs in this document are based on the water quality distributions observed in epidemiological studies and calculated by the United States Environmental Protection Agency (U.S. EPA) (see section 6.5, Appendix B, and U.S. EPA, 2012). These are recommended for informing day-to-day beach management decisions; however, they should not be the sole measure used for determining the acceptability of an area for recreational activities. EHSS data should also be considered by the responsible authorities and used as part of a preventive risk management approach to protect the health of recreational water users (see Health Canada, 2023). Public health decisions should balance the potential of increased health risks with the enjoyment and exercise that is associated with these activities.

If *E. coli* or enterococci concentrations exceed the established BAVs, this should trigger further actions by the responsible authorities. The actions required will depend on site-specific considerations, such as the sources of fecal contamination and the extent of the exceedance. Actions may include issuing a swimming advisory, immediate resampling of the site(s), and conducting a shortened EHSS. Further information on EHSS can be found in

Health Canada (2023). A swimming advisory may be particularly warranted if the area is prone to impacts from human sewage (and therefore likely enteric pathogens), the beach is poorly characterized and therefore the source of the fecal indicator bacteria is unknown, or there is evidence of illness in the community suspected to be associated with the recreational area. It should be noted that other approaches, such as using predictive beach water quality models, may also be used to trigger beach management actions (Health Canada, 2023).

At beaches where the fecal sources impacting the water quality are unknown, beach managers may use various methods to test for human and ruminant fecal sources (see Box 1). In recreational waters where the fecal indicator bacteria levels exceed current guideline values, but the fecal sources are not human or ruminant, the appropriate regulatory authority can assess whether developing alternative criteria may be beneficial for informing and supporting beach management decisions at these sites. Alternative criteria could include modified guideline values for the current indicator bacteria or the inclusion of alternative or supplementary indicators. Guidance on developing alternative recreational water quality criteria is beyond the scope of this document. However, an overview of the types of information and site considerations needed prior to developing alternative criteria has been published elsewhere (U.S. EPA, 2014).

In addition to public health decisions, fecal indicator monitoring data can help determine a location's overall suitability for recreation. Summarizing fecal indicator data using geometric means is recommended for looking at water quality trends and for comparison to the geometric mean associated with the water quality distribution used to calculate the BAVs. Further information on using geometric mean concentrations is included in section 6.5.

An approach to determining the source(s) of fecal material in fresh and marine waters used for primary or secondary contact recreation

Multiple lines of evidence should be used to identify the fecal source(s) impacting recreational waters. Much can be learned from EHSS and from expanding *E. coli* or enterococci surveillance in the immediate area around a beach or recreational water location. Techniques like smoke or dye cross-connection testing of wastewater infrastructure or microbial source tracking methods may assist in identifying likely fecal input sources or unsuspected sources of fecal inputs.

These techniques have been used to identify sources of fecal inputs at beaches across Canada. For example, multiple lines of evidence were used to identify the cause of frequent beach postings at Bluffers Park Beach in Toronto, Ontario (Edge et al., 2018). Beach observations, expanded *E. coli* surveillance, and microbial source tracking results consistently indicated the importance of reducing local impacts from bird fecal droppings and runoff from a parking lot and marsh inland of the beach. A bird management program and a berm engineered to reduce parking lot and marsh runoff led to immediate water quality improvements. The beach was subsequently awarded a Blue Flag certification (https://www.blueflag.global/all-bf-sites). Similarly, studies in Alberta (Beaudry, 2019) and Ontario (Staley et al., 2018) applied advances in microbial source tracking (quantitative and digital PCR techniques) to identify sewage cross-connections into stormwater systems and bird excreta as the important fecal sources in some recreational waters.

It is important to recognize, however, that the predominant source of fecal matter may not be the most important source of human-infectious pathogens. Hence, if birds are the predominant fecal source, it is still critical to ensure that there is no human or ruminant fecal contamination. This is key because of the higher likelihood that these latter two sources may contribute the majority of human-infectious pathogens even when they contribute as little as 15% to 20% of the fecal load (Schoen et al., 2011; Soller et al., 2015).

3.0 SIGNIFICANCE OF *E. coli* IN RECREATIONAL WATER AREAS

Indicators can be used for various purposes as part of a recreational water quality management plan. Fecal indicators signal the likely presence of fecal contamination. Common fecal indicators include *E. coli* and enterococci, as well as source-specific fecal indicators, such as the HF183 *Bacteroides* genetic marker for detecting human sewage (Harwood et al., 2014). *E. coli* or enterococci are used as the primary indicators of fecal material in fresh waters, with enterococci the preferred indicator for marine waters. Source-specific fecal indicators are used when microbial source tracking is recommended.

3.1 Description

E. coli is a member of the coliform group of bacteria and part of the family *Enterobacteriaceae*. It is a facultative anaerobic, Gramnegative, nonspore-forming, rodshaped bacterium that can ferment lactose and grow over a broad temperature range (7–45°C) with an optimal growth temperature of 37°C (Ishii and Sadowsky, 2008; Percival and Williams, 2014). Coliform bacteria are also often defined by their ability to express the enzymes β-galactosidase and β-glucuronidase. *E. coli* is found in high numbers in the intestinal tract and feces of humans and warm-blooded animals. It can also be found in numerous cold-blooded animal species (Tenaillon et al., 2010; Gordon, 2013; Frick et al., 2018). Some strains of *E. coli* can adapt to live independently of fecal material and become naturalized members of the microbial community in environmental habitats. Naturalized strains can grow and maintain their population if favourable conditions exist (Ashbolt et al., 1997; Ishii and Sadowsky, 2008; Jang et al., 2017).

E. coli is present in human feces at a concentration of approximately 10^7 to 10^9 cells per gram and comprises about 1% of the total biomass in the large intestine (Edberg et al., 2000; Leclerc et al., 2001). In two separate studies, it was detected in 94% and 100% of the human subjects tested (Finegold et al., 1983; Leclerc et al., 2001). These values are significantly higher than those reported for other members of the coliform group and were matched or exceeded only by enterococci and certain species of anaerobic bacteria (*Bacteroides*, *Eubacterium*). *E. coli* comprises about 97% of the coliform organisms in human feces, with *Klebsiella* spp. comprising 1.5% and *Enterobacter* and *Citrobacter* spp. together comprising another 1.7%. In raw sewage, *E. coli* generally declines relative to other coliforms, representing less than 30% of coliforms at sewage plant influents

(Ashbolt et al., 2001). Nonetheless, there are stress-resistant *E. coli* that appear to persist, if not grow, within sewage treatment works and are released in treated effluent (Zhi et al., 2016). Sewage effluents may also contribute antibiotic resistant bacteria in surface waters downstream of wastewater treatment plants (Day et al., 2019; Logan et al., 2020). In animal feces, *E. coli* numbers can vary considerably, but typically fall within the range from 103–109 cells per gram (Ashbolt et al., 2001; Tenaillon et al., 2010; Yost et al., 2011; Ervin et al., 2013). In domestic animals, *E. coli* has been shown to represent between 90% and 100% of all coliforms in feces (Dufour, 1977).

Although the vast majority of *E. coli* types are harmless, some strains of this bacterium can cause GI, as well as more serious health complications (e.g., hemorrhagic colitis, hemolytic uremic syndrome, kidney failure) and urinary tract infections. Nonetheless, even during outbreaks, fecal concentrations of the typical non-pathogenic *E. coli* will be greater in water sources than those of the pathogenic strains (Degnan, 2006; Soller et al., 2010a).

E. coli can be rapidly and easily enumerated in recreational waters and epidemiological studies have demonstrated a link between *E. coli* in fresh waters and the risk of GI among swimmers (Dufour, 1984; Wade et al., 2003; Wiedenmann et al., 2006; Marion et al., 2010). In Canada, most recreational water quality guidelines for natural fresh waters use *E. coli* as a fecal indicator for making public health decisions. Enterococci are also beginning to be used more frequently.

3.2 Occurrence in the aquatic environment

Once shed from a human/animal host, survival of *E. coli* in the recreational water environment is dependent on many factors, including temperature, exposure to sunlight, available nutrients, water conditions such as pH and salinity, and competition from and predation by other microorganisms (Korajkic et al., 2015). Numerous authors have reported on the ability of beach sand, sediments, and aquatic vegetation to prolong the survival, replication, and accumulation of fecal microorganisms (Whitman and Nevers, 2003; Whitman et al., 2003; Ishii et al., 2006; Olapade et al., 2006; Kon et al., 2007a; Hartz et al., 2008; Byappanahalli et al., 2009; Heuvel et al., 2010; Verhougstraete et al., 2010; Whitman et al., 2014; Devane et al., 2020). These environments are thought to provide more favourable conditions of temperature and nutrients than the adjacent waters and to offer protection from certain environmental stressors such as sunlight. As mentioned earlier, some strains of *E. coli* can become naturalized and grow in environmental habitats (Power et al., 2005; Byappanahalli et al., 2006; Ishii et al., 2006; Kon et al., 2007b; Byappanahalli et al., 2012b). Growth of *E. coli* in the environment is a limitation to its use as an indicator of fecal contamination. However, although *E. coli* is not exclusively associated with recent fecal wastes, it is accepted that *E. coli* is predominantly of fecal origin and remains a valuable indicator for determining recreational water quality.

3.3 Association with pathogens

The occurrence of fecal pathogens in recreational waters, including enteric bacteria, enteric viruses and parasitic protozoa, is strongly dependent on the fecal sources that impact the swimming area. The presence and numbers of fecal pathogens in the environment can be sporadic and highly variable. Therefore, monitoring for fecal indicators is used in place of directly monitoring for pathogens. The presence of *E. coli* in water indicates the potential for the presence of fecal pathogens that could result in an increased health risk to swimmers.

The association between *E. coli* and individual enteric pathogens is highly variable. Several early studies found that the survival rate for *E. coli* was similar to the survival rate for enteric bacterial pathogens (Rhodes and Kator, 1988; Korhonen and Martikainen, 1991; Chandran and Mohamed Hatha, 2005). In addition, one study reported that the probability of detecting *Salmonella* or Shiga-toxin producing *E. coli* (STEC) steadily increased as the concentration of *E. coli* increased, although no single sample could provide absolute assurance of the presence or absence of these pathogens (Yanko et al., 2004). Other studies have reported increased odds of detecting enteric pathogens (*Campylobacter, Cryptosporidium, Salmonella* and *E. coli* O157:H7) when densities of *E. coli* exceed 100 cfu/100 mL (Van Dyke et al., 2012; Banihashemi et al., 2015; Stea et al., 2015). In agricultural watersheds across Canada, Edge et al. (2012) generally found that higher numbers of waterborne pathogens were associated with higher levels of *E. coli*. However, they cautioned against using low levels of *E. coli* to infer no waterborne pathogen occurrence. Numerous studies have also reported on the lack of a correlation between *E. coli* concentrations and the presence of enteric viruses and protozoa in surface waters, reflecting different fecal sources and long persistence of these pathogens over fecal indicator bacteria (Griffin et al., 1999; Denis-Mize et al., 2004; Hörman et al., 2004; Dorner et al., 2007; Edge et. al., 2013; Prystajecky et al., 2014). Overall, although *E. coli* is limited in that it does not reliably predict the presence of specific fecal pathogens (Wu et al., 2011; Edge et al., 2013; Lalancette et al., 2014; Banihashemi et al., 2015; Krkosek et al., 2016), it can be used to indicate an increased potential for pathogens to be present.

4.0 SIGNIFICANCE OF ENTEROCOCCI IN RECREATIONAL WATER AREAS

Like *E. coli*, enterococci are used as a primary indicator of fecal contamination. Elevated numbers detected in either fresh or marine waters indicate the potential presence of fecal material and thus the possible presence of fecally sourced pathogenic bacteria, viruses and protozoa.

4.1 Description

Enterococci are members of the genus *Enterococcus.* The genus was created to include the more fecal-specific species of the genus *Streptococcus*, formerly considered as group D streptococci. In practice, the terms enterococci, fecal streptococci, *Enterococcus* and intestinal enterococci have been used interchangeably (Bartram and Rees, 2000). Enterococci are Gram-positive, round-shaped bacteria that meet the following criteria: growth between temperatures of 10 °C and 45 °C, resistance to heat exposure at 60 °C for 30 minutes, growth in the presence of 6.5% sodium chloride and at pH 9.6, and the ability to reduce 0.1% methylene blue (Bartram and Rees, 2000; APHA et al., 2017). They are also often defined by their ability to express the enzyme β-glucosidase.

The genus *Enterococcus* is thought to comprise more than 30 species classified into 5 to 6 major groups (*E. faecalis*, *E. faecium*, *E. avium*, *E. gallinarum*, *E. italicus,* and *E. cecorum*) (Svec and Devriese, 2009; Byappanahalli et al., 2012a). *E. faecalis* and *E. faecium* occur in significant quantities in both human and animal feces and are the species most frequently encountered in fecally polluted aquatic environments (Bartram and Rees, 2000). Other species commonly isolated from fecal material, but in lower numbers include *E. durans*, *E. hirae*, *E. gallinarum*, and *E. avium* (Pourcher et al., 1991; Moore et al., 2008; Staley et al., 2014). Enterococci are present in high concentrations in human and animal feces, with concentrations reported on the order of 10^6/g to 10^7/g (Sinton, 1993; Edberg et al., 2000). Human fecal microbiota studies reported by Leclerc et al. (2001) demonstrated that *Enterococcus* species were present in 100% of the subjects tested.

Enterococci have been used to indicate fecal contamination in fresh and marine waters and have been associated with the risk of GI among swimmers (Cabelli, 1983; Kay et al., 1994; Pruss, 1998; WHO, 1999; Wade et al., 2003, 2006, 2008; Napier et al., 2017).

4.2 Occurrence in the aquatic environment

Enterococci have been detected in water samples from diverse environmental habitats (Yamahara et al., 2009; Byappanahalli et al., 2012a; Staley et al., 2014). They are also routinely isolated from marine and fresh recreational waters known to be impacted by human and animal fecal sources. In general, enterococci tend to be present at concentrations approximately one-fold to three-fold lower than those of *E. coli* in feces and municipal wastes (Sinton, 1993; Edberg et al., 2000). Compared with other indicator microorganisms (e.g., *E. coli*, thermotolerant coliforms), enterococci may have greater resistance to certain environmental stresses in recreational waters, such as conditions of sunlight and salinity. They have also demonstrated greater resistance to wastewater treatment practices, including chlorination, and prolonged survival in marine and freshwater sediments (Davies et al., 1995; Desmarais et al., 2002; Ferguson et al., 2005). The source of the enterococci may also affect their persistence, with enterococci from cattle out-persisting those from sewage (Korajkic et al., 2013). Enterococci has also been reported to survive and grow in organic-rich environments, such as on mats of the green algae species *Cladophora* (Byappanahalli et al., 2003; Whitman et al., 2003; Verhougstraete et al., 2010) and in some environmental habitats (e.g., sand, sediments, soils) (Ran et al., 2013; Staley et al., 2014).

As in the case of *E. coli*, the existence of environmental habitats as potential sources of enterococci is a limitation when interpreting monitoring data (Whitman et al., 2003; Byappanahalli et al., 2012a), but it is accepted that enterococci detected in water samples are predominantly of fecal origin and they remain a valuable indicator for determining recreational water quality.

4.3 Association with pathogens

Direct correlations between fecal indicator concentrations and the concentration of any specific pathogen should not be expected. Within a watershed, indicators and pathogens may come from multiple different sources, and once discharged into water sources, they experience different dilution, transport, and inactivation rates (Wilkes et al., 2009). Although individual studies have occasionally observed a correlation between the presence of enterococci and the detection of a specific pathogen, the relationships are generally weak (Brookes et al., 2005, Wilkes et al., 2009). In one study, a survey of surface waters collected from various watersheds in southern California, showed a good predictive ability with

PCR detection of STEC and enterococci using culture-based methods (Yanko et al., 2004). It was reported that above an enterococci concentration of 100 most probable number (MPN)/100 mL, the probability of detection of STEC was approximately 60% to 70%. Like *E. coli*, enterococci are not predictive of the presence of viruses and protozoa (Griffin et al., 1999; Schvoerer et al., 2000, 2001; Jiang et al., 2001; Jiang and Chu, 2004).

The presence or absence of enterococci in an individual sample should not be interpreted to mean that specific enteric pathogenic microorganisms are also present or absent in the same sample. Enterococci are regarded as general indicators of fecal contamination and are routinely monitored, as epidemiological studies have shown that increased concentrations in recreational areas indicate an increased risk of adverse health impacts.

5.0 ALTERNATIVE INDICATORS OF FECAL CONTAMINATION

No single microorganism is able to fill all of the roles of what might be considered a perfect indicator of recreational water quality—one that models all of the known pathogens, provides information on the degree and source of fecal pollution and communicates the potential risk of illness for recreational water users. This would require multiple indicators, each with unique characteristics that enable them to perform specific roles (Ashbolt et al., 2001). Although *E. coli* and enterococci are the indicators routinely used for monitoring recreational beaches, there are limitations to the information provided by these microorganisms (see section 3.0 and 4.0). Other microorganisms have been widely discussed as alternatives to monitoring *E. coli* and enterococci or as supplementary indicators to better characterize potential risks. These include *Bacteroides* spp., spores of *Clostridium perfringens*, male-specific and somatic coliphages (bacteriophages infecting *E. coli*) and bacteriophages infecting *Bacteroides fragilis*. A summary of the characteristics of the recommended and potential indicator microorganisms is presented in Table 3.

The potential roles of these alternative indicators vary. For example, enteric viruses represent the most significant health risk in many recreational waters impacted by human fecal sources, and although *E. coli* and enterococci are good indicators of fecal contamination, they alone may not be adequate indicators of human enteric pathogenic viruses. Alternative indicators, such as the coliphages, bacteriophages of *Bacteroides* spp., or human sewage markers can provide additional information on the potential human health risks associated with a beach area (Nelson et al., 2018; Boehm et al., 2020). In addition, the fecal sources may not be known at many beaches and therefore the potential human health risks may not be fully assessed. As suggested in section 2.0, the use of microbial source tracking markers from microorganisms such as the *Bacteroides* spp. can help provide valuable information on the sources of fecal contamination (Boehm et al., 2018). They may also help determine whether site-specific alternative guideline values would be beneficial. Risk-based threshold values have been proposed for fecal markers (e.g., HF183) that target *Bacteroides* spp. (Boehm et al., 2018; Boehm and Soller, 2020). Further information on microbial source tracking and understanding and managing risks in recreational areas can be found in the guideline technical document on *Understanding and Managing Risks in Recreational Areas* (Health Canada, 2023).

Table 3. Characteristics of recommended and potential indicator microorganisms

	Indicator microorganism					
	Recommended		Potential			
Characteristics	***E. coli***	**Enterococci**	***C. perfringens***	***Bacteroides* spp.**	**Coliphages**	**Bacteriophages of *Bacteroides* spp.**
Brief description	Gram-negative, non-spore forming bacteria	Gram-positive, non-spore forming bacteria; comprised of >30 species, *E. faecalis* and *E. faecium* more frequent in aquatic environments	Gram-positive, spore-forming, anaerobic bacteria	Gram-negative, non-spore-forming, anaerobic bacteria; dominant species - *B. fragilis*, *B. vulgatus*, *B. distasonis* and *B. thetaiotaomicron*	Two main types (1) somatic – diverse group that can infect various members of *Enterobacteriaceae* family, and (2) male-specific (F^+) coliphages	Bacteriophage host strains most often used are for *B. fragilis* and *B. thetaiotaomicron*; crAssphage is a member of this group of bacteriophages
Includes members that are not human pathogens	Yes	Yes	Yes	Yes	Yes	Yes
Includes human pathogenic members	Yes	Yes	Yes	No	No	No
Found within the intestinal tract of humans and warm-blooded animals	10^7–10^9 cfu/g feces in humans; 10^3–10^9 cfu/g feces in animals	human and animals feces contain 10^3–10^7 cfu/g	In humans: 10^3–10^8 cells/g feces; In dogs, cats, sheep: 10^5–10^8 cells/g feces; always found in human sewage collection systems	10^{11} cells/g feces (except in some birds)	In humans: 10^1–10^4 PFU/g feces; animals: <10–10^7 PFU/g feces; raw sewage 10^6 PFU/g,	In human feces: 10–10^2 PFU/g feces, variable isolation; sewage: < 10–10^5 phages/100 mL; not detected in animals
Present in waters with recent fecal contamination at higher numbers than enteric pathogens	Yes	Yes	Dependent upon source of contamination	Insufficient data	Dependent upon source of contamination	Dependent upon source of contamination
Capable of growth in the aquatic environment	Yes, under specific conditions	Yes, under specific conditions	No	No	Somatic may grow if host bacteria is growing in the environment; F^+ not likely to grow; appreciable regrowth is not expected for either	No
Capable of surviving longer than pathogens	Similar to bacterial pathogens	Similar to bacterial pathogens	Yes	Insufficient data	Similar to enteric viruses	Similar to enteric viruses

	Indicator microorganism					
	Recommended		**Potential**			
Characteristics	***E. coli***	**Enterococci**	***C. perfringens***	***Bacteroides* spp.**	**Coliphages**	**Bacteriophages of *Bacteroides* spp.**
Applicable to fresh, estuarine and marine waters	Yes[1]	Yes	Yes	Yes	Yes	Yes
Exclusively associated with animal and human feces	No	No	No	Insufficient data.	Yes	Yes
Association between GI and the indicator	Yes	Yes	Yes, although association weak in some studies	Weak associations, more studies with human-specific marker (HF183) needed	Yes	No
Host-specific characteristics for microbial source tracking	No	No	No	Yes	Maybe (for F+ coliphages)	Maybe (some cross-reactivity reported)
Rapid, easy, inexpensive, culture-based method available	Yes	Yes	Yes	No	Yes	No
Well-established molecular method available	No[2]	Yes	Yes	Yes	No	Yes
Currently suggested role	Primary indicator	Primary indicator	Secondary indicator (e.g., sewage inputs)	Microbial source tracking; secondary indicator	Secondary indicator (human fecal inputs); microbial source tracking	Secondary indicator (human fecal inputs)
References	Dufour, 1984; Edberg et al., 2000; Solo-Gabriele et al., 2000; Ashbolt et al., 2001; Leclerc et al., 2001; Wade et al., 2003; Marion et al., 2010; Byappanahalli et al., 2012b; Ervin et al., 2013	Bartram and Rees, 2000; Edberg et al., 2000; Ashbolt et al., 2001; Wade et al., 2003; Wade et al., 2006; Wade et al., 2008; Verhougstraete et al., 2010; Byappanahalli et al., 2012a; Ervin et al., 2013; Staley, et al., 2014	Fujioka and Shizumura, 1985; Ashbolt et al., 2001; Lipp et al., 2001; Hörman et al., 2004; Fernandez-Miyakawa et al., 2005; Wiedenmann et al., 2006; Carman et al., 2008; Mueller-Spitz et al., 2010; Wade et al., 2010; Viau et al., 2011; Vierheilig et al., 2013; Jacob et al., 2015	Bernhard and Field, 2000a, 2000b; Wade et al., 2006; Hong et al., 2008; Ballesté and Blanch, 2010; Wade et al., 2010; McQuaig et al., 2012; Cao et al., 2016; Lloyd-Price et al., 2016; Hughes et al., 2017; Napier et al., 2017	Cole et al., 2003; Muniesa et al., 2003; Luther and Fujioka, 2004; Nappier et al., 2006; Colford et al., 2007; Wade et al., 2010; Lee and Sobsey, 2011; Wu et al., 2011; Haramoto et al., 2012; Plummer et al., 2014; U.S. EPA, 2015; Griffith et al., 2016; Jofre et al., 2016; Benjamin-Chung et al., 2017; Jebri et al., 2017; Nappier et al., 2019	Puig et al., 1999; Mocé-Llivina et al., 2005; Payan et al., 2005; McLaughlin and Rose, 2006; Ebdon et al., 2012; Harwood et al., 2013; McMinn et al., 2014; Sirikanchana et al., 2014; Stachler and Bibby, 2014; Diston and Wicki, 2015; McMinn et al., 2017; Dias et al., 2018; Korajkic et al., 2020

[1] *E. coli* should only be used in estuarine and marine waters if it has been demonstrated to provide comparable results to enterococci;

[2] A molecular method is in development; PFU – Plaque-forming units

6.0 EPIDEMIOLOGICAL STUDIES FOR PRIMARY CONTACT ACTIVITIES

Over the last several decades, numerous epidemiological studies have been conducted in fresh and marine water recreational environments primarily to investigate an association between *E. coli*/enterococci fecal indicators and GI. Studies have included recreational water environments impacted by point sources of contamination (i.e., the source is identifiable and stationary) and non-point sources of contamination (i.e., the sources are diffuse). Most epidemiological studies have been conducted at beaches with known point sources of human fecal contamination. Fewer studies have been conducted on recreational beaches impacted by non-point sources of fecal contamination (see Table 4). Non-point source impacted areas, particularly those with only non-human impacts, may present a lower level of risk to recreational water users at the established guideline levels. However, due to the limited information, additional studies at non-point source impacted beaches are needed to further characterize the potential human health risks at these sites. Studies at sites with both point and non-point sources are important for understanding the variability in the levels of risk to human health and the utility of fecal indicator microorganisms as part of managing recreational water quality. A smaller number of studies have focused on other health endpoints, such as respiratory or skin ailments. The most recent studies have been broadened to include a range of indicators (e.g., coliphages, fecal source markers such as HF183) and qPCR detection methods (Sánchez-Nazario et al., 2014; Griffith et al., 2016; Napier et al., 2017). Several reviews of the available epidemiological studies in fresh and marine water recreational environments have also been published (Pruss, 1998; U.S. EPA, 2002; Wade et al., 2003; Fewtrell and Kay, 2015).

The previous edition of this guideline document, published by Health Canada in 2012, reviewed the epidemiological studies published prior to 2009. Since that time, additional epidemiological studies and statistical reanalyses of older datasets have been conducted (Table 4), and the definition used to characterize GI has been expanded (see Section 6.1). The guideline values for primary contact recreational activities in this document consider all the studies published in Table 4 and balance the potential human health risks and the benefits of recreational water use in terms of physical activity and enjoyment.

Table 4. Epidemiological studies investigating the association between GI and bacterial fecal indicators during primary contact recreational activities in fresh and marine waters (1984–2016)

Source Water	Main Conclusions	References
Fresh water – impacted by human sewage (and non-point sources)	Association between GI symptoms and fecal indicator bacteria	Dufour, 1984; Ferley et al., 1989; Van Asperen et al., 1998; Wade et al., 2006; Wiedenmann et al., 2006; Wade et al., 2008
Fresh water – impacted by non-point sources (e.g., urban runoff, agriculture; forested watershed), minimal risk of human sewage impacts	Association between GI symptoms and fecal indicator bacteria	Marion et al., 2010
	Swimmers at increased risk over non-swimmers No statistically significant association between fecal indicator bacteria and GI risk	Calderon et al., 1991
Marine water – impacted by human sewage (and non-point sources)	Association between GI symptoms and fecal indicator bacteria	Cabelli, 1983; Cheung et al., 1990; Alexander et al., 1992; Corbett et al., 1993; Kay et al., 1994; Prieto et al., 2001; U.S. EPA, 2010; Wade et al., 2010; Colford et al., 2012; Yau et al., 2014; Lamparelli et al., 2015; Griffith et al., 2016; Benjamin-Chung et al., 2017
	Swimmers at increased risk over non-swimmers No statistically significant association between GI symptoms and fecal indicator bacteria	von Schirnding et al., 1992; Harrington et al., 1993; Marino et al., 1995; McBride et al., 1998; Colford et al., 2012; Papastergiou et al., 2012
Marine water – impacted by non-point sources (e.g., urban runoff, agriculture; forested watershed), minimal risk of human sewage impacts	Swimmers at increased risk over non-swimmers No association between GI symptoms and fecal indicator bacteria	Colford et al., 2007; Fleisher et al., 2010; Sinigalliano et al., 2010; U.S. EPA, 2010; Arnold et al., 2013

[*] Exposure based on incidental contact as opposed to swimming

6.1 Definition of gastrointestinal illness (GI) and associated risk of illness

In earlier studies, the association between illness and indicator values was based on a definition of GI that included symptoms of highly credible gastrointestinal illness (HCGI). HCGI was defined as either vomiting, diarrhea with a fever, or stomach ache/nausea with a fever (Cabelli, 1983). However, many enteric viruses do not present with fever, and recent studies have shown that enteric viruses are a significant cause of GI among swimmers (Sinclair et al., 2009; Soller et al., 2016). For that reason, in more recent studies a broader definition of GI is used that includes illness with or without fever (see section 6.2.1). This broader definition means more cases of GI would be recorded at a recreational area compared to cases of HCGI. Therefore, it has been necessary to determine the number of cases of GI that is equivalent to the human health risk of HCGI. Recent epidemiological studies in the United States showed that the risk of illness at fresh and marine water beaches was similar at comparable levels of enterococci, and this risk of illness was similar to the freshwater illness rates from previous studies (8 HCGI per 1000 exposed) (U.S. EPA, 2012). Using data on the rates of GI and HCGI in non-swimmers from the available epidemiological studies, it was calculated that a factor of 4.5 must be applied to the rate of HCGI to determine the rate of GI without a fever that corresponds to the same human health risk (Wymer et al., 2013). Applying this factor, the risk of illness in fresh and marine waters at the guideline values in this document are equivalent to 36 GI per 1000 exposed people.

6.2 Human sewage impacted beaches

Epidemiological studies have been conducted worldwide at recreational beaches that are impacted by raw and treated human sewage. Table 4 provides an overview of various studies conducted to date and their main conclusions with respect to the link between fecal indicators and GI.

6.2.1 U.S. studies

In the United States, numerous studies have been conducted to support the development of the U.S. EPA's recreational water quality criteria. In the 1980s, two large studies—one in fresh waters and one in marine waters—found statistically significant rates of GI among swimmers and were able to derive regression equations to relate increasing fecal indicator microorganism concentrations to increased risk of HCGI (Cabelli, 1983; Dufour, 1984). For symptoms unrelated to GI, no statistically significant differences were observed (Cabelli, 1983; Dufour, 1984). These studies were used to support the U.S. EPA's 1986 recreational water quality criteria and are the basis for the risk of illness in previous editions of the Health Canada guideline. Between 2003 and 2009, additional epidemiological studies were conducted at freshwater and marine beaches under the National Epidemiologic and Environmental Assessment of Recreational (NEEAR) Water Study (U.S. EPA, 2010; Wade et al., 2006, 2008, 2010). Similar to the studies conducted in the 1980s, the results from the NEEAR studies are applicable to the general human population, including children. Other vulnerable sub-populations (e.g., immune-compromised) were not addressed in these studies. The studies monitored sites for enterococci using qPCR and culture-based methods. *E. coli* data are not available for the study sites. These studies were used to develop the U.S. EPA's 2012 recreational water quality criteria (see Table 6) (U.S. EPA, 2012) and have been used as the basis for the updated values in this document (see section 6.5). Two main findings from the NEEAR studies were, first, that enterococci qPCR results had a stronger association with GI than the enterococci culture-based methods, and second, unlike the earlier epidemiological studies, no linear regression equation fit the NEEAR culture-based data. A linear regression equation could be fit to the qPCR enterococci data. Since qPCR detects DNA (as opposed to viability), the enterococci signal may persist longer in the water sources and give a better relationship with risk of illness. The lack of linear regression using culture-based methods may be due to the fact that the wastewater discharges impacting the recreational water quality areas were disinfected, as opposed to the earlier studies, where the wastewater was less treated (U.S. EPA, 2012). However, a cut-point analysis showed that the rate of GI between swimmers and non-swimmers was significantly different when the geometric mean concentration of enterococci exceeded 30 or 35 cfu/100 mL, corresponding to a risk level of 32 or 36 GI (i.e., 7 or 8 HCGI) per 1000 swimmers, respectively. For enterococci qPCR, a regression model was possible using the NEEAR studies. Using the regression model, geometric mean concentrations of 300 and 470 cce of enterococci per 100 mL (corresponding to a risk level of 32 or 36 GI per 1000 swimmers) provide the level of health protection comparable to that of the culture-based guideline (U.S. EPA, 2012). As *E. coli* were not measured during these studies, the equivalent thresholds for *E. coli* concentrations were determined using the regression analysis from Dufour (1984). Geometric mean concentrations of 100 and 126 cfu of *E. coli* per 100 mL would correspond to the same risk levels of 32 or 36 GI per 1000 swimmers, respectively. This approach was possible because the rates of illness in the NEEAR studies for both fresh and marine water were similar to the illness rates observed in fresh water in the earlier epidemiological studies. Using the NEEAR study data, the U.S. EPA's 2012 criteria also included accompanying statistical threshold values (STVs) (see Table 6). The STVs approximate the 90th percentile of the distribution of the water quality results and should not be exceeded by more than 10% of the samples used to calculate the associated geometric mean. Using the same water quality distribution, BAVs corresponding to the 75th percentile are included for use in beach management decisions (see Table 6) (U.S. EPA, 2012). These BAVs are the basis for the guideline values in this document (see section 6.5).

6.2.2 European studies

In Europe, numerous epidemiological studies have also been conducted to investigate links between illness and fecal indicator organisms. Randomized controlled trials were conducted in marine waters in the United Kingdom in the 1990s (Kay et al., 1994; Fleisher et al., 1996). These studies reported significant dose-response relationships between fecal streptococci (considered synonymous with enterococci) and the incidence of both GI and respiratory illness among swimmers. Possible thresholds for an increased risk of gastroenteritis at a concentration of 32 fecal streptococci/100 mL (Kay et al., 1994) and an increased risk of respiratory illness at a concentration of 60 fecal streptococci/100 mL (Fleisher et al., 1996) were reported. At freshwater swimming areas in Germany, Wiedenmann et al. (2006) conducted a randomized controlled prospective cohort study. The authors reported a relationship between the observed rates of illness and measured concentrations of *E. coli*, enterococci, *Clostridium perfringens* and somatic coliphages. No-observed-adverse-effect levels (NOAELs) were reported for several definitions of gastroenteritis, ranging from 78 to 180 *E. coli*/100 mL and from 21 to 24 enterococci/100 mL. The authors proposed guidelines by combining all of the data derived from the different definitions of GI investigated and suggested values of 100 *E. coli*/100 mL, 25 enterococci/100 mL, 10 somatic coliphages/100 mL and 10 *C. perfringens*/100 mL. Although the authors propose a value of 100 *E. coli*/100 mL, it is important to note that the NOAEL reported for GI that most closely fits the criteria of HCGI was 180 *E. coli*/100 mL and that the definition that most closely fits the broadened GI definition (i.e., fever is not required) was 167 *E. coli*/100 mL. In addition, the quartile and quintile breakdown of the data for the United Kingdom's definition of GI indicated that the rates of swimmer illness compared to those of the control group were not statistically significant until *E. coli* concentration ranges approached or exceeded 245 *E. coli*/100 mL and until enterococci concentration ranges approached or exceeded 68 enterococci/100 mL. In a separate study, concentrations of *E. coli* needed to exceed a geometric mean of 355 *E. coli*/100 mL before the risk of gastroenteritis was significantly higher in swimmers compared to non-swimmers (Van Asperen et al., 1998).

Another large randomized control study in Europe was conducted over two summers (2006 and 2007) and investigated both marine beaches (Spain) and freshwater beaches (Hungary) to determine links between health endpoints (GI, respiratory, skin ailments) and the concentration of either *E. coli* or enterococci (Epibathe report, 2009). Across all study locations, the risk of GI was higher in swimmers than in non-swimmers. Additionally, the risk of becoming ill was higher in marine waters than in fresh waters at similar levels of indicator microorganisms. This may be due to the shorter lifespan of enterococci than the pathogens in marine waters (Epibathe report, 2009). All beaches investigated met the "excellent" water quality criteria as defined in the EU bathing directive (see Table 6). Both the marine and freshwater beaches lacked strong evidence of positive dose-response relationships between *E. coli* or enterococci and GI. However, the illness levels at both beaches were quite low in comparison to previous studies and therefore, although they enrolled a high number of participants, the study had very low statistical power. To give the study more power, the Epibathe results were combined with previous results from the United Kingdom (marine waters) and Germany (fresh waters) (Kay et al., 1994; Fleisher et al., 1996; Wiedenmann et al., 2006) and a meta-analysis and regression analysis were conducted. Although the meta-analysis was unable to find any dose-response relationship, it did show an increased risk of illness in swimmers versus non-swimmers. The logistic regression, on the other hand, showed an increased risk of GI in marine waters when the enterococci concentrations exceeded 28 cfu/100 mL. No link between microorganism numbers and illness was found in fresh waters with enterococci, but *E. coli* concentrations exceeding 336 cfu/mL at the freshwater sites were linked with an increased risk of GI in swimmers.

6.3 Non-point source impacted beaches

6.3.1 Epidemiological studies

There have been a limited number of epidemiological studies at beaches impacted only by non-point sources of contamination (i.e., no human sewage outfalls so minimal risk of human feces) (see Table 4). An early study by Calderon et al. (1991) investigated a freshwater beach with no human contamination sources; only non-point contamination sources (from a forested watershed) were impacting the beach. No relationship between the risk of GI and the concentrations of *E. coli* or enterococci was observed. Swimmer illness was associated with high swimmer density and high densities of total staphylococci. Marion et al. (2010) conducted a beach cohort study at a freshwater inland lake in the United States with only non-point source contamination. Municipal wastewater discharges were permitted in tributaries but not directly into the reservoir. *E. coli* was the only indicator bacteria measured. The results showed that the odds of contracting a GI were 3.2-fold greater for beachgoers entering the water compared to those who did not. The risk of GI was also significantly higher for individuals who consumed food at the beach, potentially related to longer beach exposure times and food-related illnesses. The study also suggested an increased risk of GI or HCGI with *E. coli* concentrations in the highest two quartiles (i.e., > 11.3 to 59 cfu/100 mL and > 59 to 1551 cfu/100 mL). Although the increase was not always statistically significant, the trend is suggestive of increased odds of illness. A large study in Florida (Fleisher et al., 2010; Sinigalliano et al., 2010) investigated marine non-point source contaminated beaches. The authors used a prospective randomized exposure study where participants were randomly assigned to water exposure or beach-only exposure. The study reported an increased risk of health impacts in swimmers compared to the beach-only exposure group, but did not find any link between enterococci concentrations and GI. They did, however, report an association between skin ailments and enterococci concentrations.

6.3.2 Quantitative microbial risk assessment studies

Quantitative microbial risk assessment (QMRA) has been used in numerous research studies to better understand the potential health impacts from human pathogens in recreational settings and to investigate the relative risks from different fecal sources. QMRA modelling has generally shown that human and ruminant feces pose the highest risk of human health impacts, while feces from other animals poses a lower risk (Schoen and Ashbolt, 2010; Soller et al., 2010b, 2015). These studies estimate that at similar levels of *E. coli* or enterococci, the risk to human health from other animals (e.g., gulls, pigs, chickens) ranges from 10 to 6000 times lower than the risks associated with municipal sewage. These data support the recommendation that site-specific alternative recreational criteria be developed by jurisdictional or management authorities for recreational areas at very low risk of human pathogens. In Canada, the Province of Alberta, in its most recent safe beach protocol, has included separate benchmark values for waters with no evidence of human or ruminant fecal contamination (Government of Alberta, 2019). Further information on QMRA, including its use for developing MST targets of health significance, is included in the recreational water quality technical guideline document on *Understanding and Managing Risks in Recreational Water Quality* (Health Canada, 2023).

6.4 Non-swimming primary contact activities

While most epidemiological studies have focused on swimming as the exposure route, there are many other primary contact activities, some of which have undergone limited investigation. In fresh water, a few epidemiological studies have investigated the health effects associated with whitewater canoeing and rafting (Fewtrell et al., 1992; Lee et al., 1997). In marine recreational waters, several epidemiological studies have investigated the health effects of surfing (Harrington et al., 1993; Gammie and Wyn-Jones, 1997; Dwight et al., 2004; Stone et al., 2008; Tseng and Jiang, 2012). The conclusions of these studies are that GI is the most frequently reported—but not the only—adverse health outcome of these types of activities and that factors related to the risk of illness include the water quality and the frequency of immersion and water ingestion.

6.5 Rationale for primary contact guidelines

The goal of the primary contact guidelines set out in this document is to protect the health of Canadians during recreational water activities. Numerous studies have shown that individuals have an increased risk of illness when engaging in primary contact recreational water activities in comparison to non-participants (see section 6). A risk management approach, which includes using the fecal indicator guideline values provided in this document, aims to keep the health risk to a level that is deemed acceptable. The guideline values correspond to a potential risk of 36 GI (equivalent to 8 HCGI) for every

1000 people engaged in primary contact activities. The 2012 *Guidelines for Canadian Recreational Water Quality* included an acceptable level of risk of 10 – 20 HCGI (equivalent to 45 – 90 GI) / 1000 individuals engaged in primary contact activities. The current guideline, therefore, provides a consistent level of public health protection equivalent to the lower range of the acceptable risk levels from the previous guideline.

The guideline values provided in this document for primary contact activities (referred to as BAVs) are adopted from U.S. EPA (2012), based on epidemiological studies conducted in the United States (see section 6.2). The study participants represented the general public, with a greater weighting to children ten years of age or younger. Children were over-represented in these studies as they may be more susceptible, or have a higher level of exposure (e.g., longer time in the water, ingest greater volumes of water), to potential pathogens at recreational water areas. Based on the U.S. EPA analysis, the illness rates in children (aged less than ten) were not significantly different from the general population, so the study results are considered applicable to the general population, including children. These studies reported GI associations with enterococci concentrations for both culture- and PCR-based methods, with the PCR-based methods having a stronger association with the risk of GI. Based on this research, the guideline values in this document now include the use of PCR-based methods for monitoring recreational water quality. The use of PCR-based methods can provide more rapid results for beach management decisions, particularly at high-use beaches where monitoring is conducted daily.

The BAVs shown in Tables 1 and 2 represent the 75th percentile value of the recreational water quality distribution as reported in U.S. EPA (2012). Often, the 90th or 95th percentile values are used for developing benchmark values. However, the 75th percentile value is a more conservative approach as the 75th percentile value is a lower number, meaning beach actions are triggered when fewer fecal indicator organisms are present. Implementing conservative BAVs helps in improving protection of children's health at beaches (U.S. EPA, 2012). Depending on the jurisdictional requirements, BAVs may trigger activities to investigate water quality issues, issue beach notifications, and initiate corrective actions (where applicable). The 75th percentile value for enterococci also aligns with the previous single-sample maximum for this indicator, maintaining a consistent level of public health protection with the 2012 guidelines for enterococci. The BAVs for *E. coli* are lower than in the 2012 guidelines, but are based on the same epidemiological studies as the enterococci values. Further information on the updated guideline values can be found in Appendix B.

Although the BAVs are recommended for making day-to-day beach management decisions, the overall suitability of an area for recreational use, including an analysis of the long-term trends in water quality, can be assessed using the geometric mean of the sample results. The greater the number of samples included in the calculation of the geometric mean, the more reflective it will be of the water quality. For example, geometric mean concentrations that include samples collected over numerous months (or seasons) can help determine whether the water quality is changing or remaining stable. The geometric mean of the water quality distributions used for the BAVs, which were calculated by the U.S. EPA (2012), are shown in Table 5. By comparing the long-term geometric mean trends with the fecal indicator geometric mean values listed in Table 5, responsible authorities can determine if the water quality is expected to result in the same predicted risk of illness as exposure to water with fecal indicator concentrations corresponding to the BAV provided in Tables 1 and 2. This comparison should not be used for making day-to-day beach decisions, but is recommended for determining a recreational areas overall suitability for recreational activities. Recreational water areas where the geometric mean is consistently higher than the values listed in Table 5 may represent a greater level of risk to human health and may not be suitable for primary contact recreation.

Table 5. Geometric mean values associated with the water quality distributions used to calculate the BAVs

Fecal Indicator Bacteria	Culture-based Methods	PCR-based Methods
E. coli	126 cfu/100 mL	N/A
Enterococci	35 cfu/100 mL	470 cce/100 mL

cfu – colony forming units; cce – calibrator cell equivalent; N/A – not available

Although this guideline technical document recommends generally applicable BAVs, regulatory authorities can develop site-specific alternative values for areas that are at a low risk for human fecal contamination. QMRA data indicates that the risk of human pathogens varies with the source of the fecal matter, with human and ruminant sources being higher risk (see section 6.3.2). The epidemiological studies used as the basis for the BAVs were conducted in recreational areas with known human fecal sources. In the absence of human fecal sources, the BAVs may represent a risk lower than 36 illnesses per 1000 individuals (i.e., less than 8 HCGI). Therefore, the appropriate regulatory authorities may choose to develop alternative values, to help balance the benefits of engaging in recreational activities with the potential associated health risks associated with these activities.

6.6 Guidelines used by other countries/organizations

The guideline values for fecal indicator microorganisms established by international organizations are presented in Table 6. These values are applicable to both fresh and marine waters (unless otherwise indicated).

Table 6. Guideline values for fecal indicator concentrations in fresh and marine recreational waters established by other countries or organizations

Country/ organization	Indicator	Guideline Values		Basis of the Guideline Values	Reference
U.S. EPA		NGI – 36[a]	NGI – 32[a]	Cabelli, 1983; Dufour, 1984; NEEAR Studies: U.S. EPA, 2010; Wade et al., 2006, 2008, 2010	U.S. EPA, 2012
	E. coli - Using culture methods	GM[b]: 126 cfu/100 mL BAV[c]: 235 cfu/100 mL STV[d]: 410 cfu/100 mL	GM[b]: 100cfu/100 mL BAV[c]: 190cfu/100 mL STV[d]: 320cfu/100 mL		
	Enterococci- Using culture methods	GM[b]: 35 cfu/100 mL BAV[c]: 70 cfu/100 mL STV[d]: 130 cfu/100 mL	GM[b]: 30cfu/100 mL BAV[c]: 60cfu/100 mL STV[d]: 110cfu/100 mL		
	Using qPCR methods[e]	GM[b]: 470 cce/100 mL BAV[c]: 1000 cce/100 mL STV[d]: 2000 cce/100 mL	GM[b]: 300 cce/100 mL BAV[c]: 640 cce/100 mL STV[d]: 1280 cce/100 mL		
WHO*	Intestinal enterococci[f]	95th percentile/100 mL: A: ≤ 40 B: 41–200 C: 201–500 D: > 500		Kay et al., 2004	WHO, 2021
Australia*	Intestinal enterococci[f]	95th percentile/100 mL: A: ≤ 40 B: 41–200 C: 201–500 D: > 500		Kay et al., 1994; Fleisher et al., 1996; Kay et al., 2001	NHMRC, 2008
European Union	Fresh Water Intestinal enterococci	95th percentile/100 mL: Excellent: 200/100 mL Good: 400/100 mL 90th percentile/100 mL: Sufficient: 330/100 mL		Kay et al., 1994; Wiedenmann et al., 2006	EU, 2006
	E. coli	95th percentile/100 mL: Excellent: 500/100 mL Good: 1000/100 mL 90th percentile/100 mL: Sufficient: 900/100 mL			
	Marine Water Intestinal enterococci	95th percentile/100 mL: Excellent: 100 /100 mL Good: 200/100 mL 90th percentile/100 mL: Sufficient: 185/100 mL			
	E. coli	95th percentile/100 mL: Excellent: 250 /100 mL Good: 500/100 mL 90th percentile/100 mL: Sufficient: 500/100 mL			

[a] NEEAR Gastrointestinal Illness (NGI)-36 and NGI-32 refer to the estimated illness rate (36 or 32 illnesses) per 1000 primary contact recreators associated with swimming in water with the indicated bacteria levels

[b] GM – geometric mean

[c] BAV – Beach action values (75th percentile of the water quality distribution) are not recommended criteria but are a precautionary tool that can be used for making beach notification decisions.

[d] STV – statistical threshold value (90th percentile of the water quality distribution)

[e] Prior to using qPCR methods, evaluation of method performance in the ambient waters is recommended.

[f] Recommends guidelines for coastal waters be used until more freshwater data is available.

[*] Guidelines require two aspects: a sanitary survey for likelihood of sewage contamination as well as a microbiological evaluation of the bathing water to determine the bathing water classification.

7.0 WATER INTENDED FOR SECONDARY CONTACT RECREATIONAL ACTIVITIES

The *Guidelines for Canadian Recreational Water Quality* are intended to be protective for those activities that involve intentional or incidental immersion in natural waters. Recreational water activities that have been traditionally considered secondary contact activities (e.g., canoeing, kayaking, and fishing) involve different exposures from those associated with primary contact uses. A recent meta-analysis found a significant increase in GI associated with primary contact activities (swimming, sports-related water activities), but a non-significant increase in risk with secondary contact activities involving minimal water contact (Russo et al., 2020). Secondary contact activities are presumed to result in a lower ingestion of water and therefore a lower risk of GI. Although secondary contact activities are associated with lower risk, inadvertent immersion can result in whole body contact, and splashing can lead to a variety of water exposure scenarios. Illnesses affecting the skin and perhaps the mucous membranes of the eyes and ears may be of relatively greater importance for secondary contact uses (U.S. EPA, 2002). Inhalation may also be an important route of exposure during primary and secondary contact activities in areas where splash, spray or aerosols are generated.

7.1 Exposure

There has been limited research on the differences in exposures between primary and secondary water contact activities. A study by Dorevitch et al. (2011) estimated that the average volume of water ingested during secondary contact activities was approximately 3 to 4 mL/h, in comparison to primary contact activities with ranges between 10 and 40 mL/h (Dorevitch et al., 2011; Dufour et al., 2017; U.S. EPA, 2019). In addition to swallowing a lower volume of water, only 1% of the individuals engaged in secondary contact activities reported swallowing water (compared to 51% of primary contact participants) (Dorevitch et al., 2011). This translates into fewer individuals being exposed during secondary contact activities. In a follow-up analysis of the Dorevitch study (2011), data on numerous human waterborne pathogens were collected and QMRA was utilized to estimate the potential human health effects during secondary contact activities like fishing, canoeing, and boating. The waterway analyzed was a man-made canal system where primary contact activities were prohibited but secondary contact activities were allowed. The risk assessment model results estimated the health risks from these activities to range from 0.10 to 2.78 HCGI per 1000 incidental exposure events, which is lower than the acceptable illness risk (8 HCGI per 1000 exposures) associated with the U.S. EPA's primary contact recreational water guidelines (Rijal et al., 2011). This is consistent with an earlier study that found no significant risk of GI in individuals engaged in canoeing or rowing (Fewtrell et al., 1994). In contrast, a companion prospective cohort epidemiological study compared the health impacts of secondary contact recreation activities on the same man-made waterway (where the water quality does not meet guidelines for primary contact recreation) to the health impacts of secondary contact activities on a lake with acceptable water quality for primary contact activities. An increased risk of GI (13.7–15.1 illnesses per 1000 exposures) was found in both water types (Dorevitch et al., 2012). This risk is higher than that calculated by Rijal et al. (2011) using their risk assessment model, which had several limitations associated with the pathogen datasets. Although the risk of illness was similar for the canal system and for the general-use area, the exposures for these sites were different. Recreators in the man-made canal system were less likely to report head/face submersion than their counterparts in the general-use waters. There were also more individuals fishing in the general-use waters, which is associated with a longer exposure time compared to canoeing and kayaking. Fishing has been reported elsewhere as a significant contributor to the overall risk of GI owing to the extended potential exposure time and possible routes of exposure other than ingestion (e.g., hand-to-mouth transfer of pathogens) (Sunger et al., 2015).

7.2 Recommendations

To date, there are insufficient epidemiological data available to derive health-based fecal indicator limit values for secondary contact recreational water activities. However, because a lower degree of water exposure occurs at most times during the majority of secondary contact recreational water activities, separate secondary contact water quality values may be developed using the primary contact guidelines combined with the level of water exposure. The type of secondary contact recreational water activity and the duration of exposure will affect the level of water exposure. This approach may be considered reasonable and acceptable to local and regional authorities where a secondary contact designation is desired.

When contemplating the establishment of separate fecal indicator values for water areas used entirely for secondary contact recreation, a clear understanding of the types of activities that would fit under this description is required. The World Health Organization (WHO), in its *Guidelines for Safe Recreational Water Environments: Volume 1—Coastal and Fresh Waters* (WHO, 2003), has proposed a scheme for the classification of recreational water activities according to their degree of water exposure. The following descriptions (adapted from WHO, 2003), may be used as an initial guide when determining whether a specific recreational water activity would be considered primary or secondary contact:

- *Primary contact*: Recreational activity in which the whole body or the face and trunk are frequently immersed or the face is frequently wetted by spray, and where it is likely that some water will be swallowed. Inadvertent immersion, through being swept into the water by a wave or slipping, would also result in whole body contact. Examples include swimming, surfing, waterskiing, whitewater canoeing/rafting/kayaking, windsurfing and subsurface diving.
- *Secondary contact*: Recreational activity in which only the limbs are regularly wetted and in which greater contact (including swallowing water) is unusual. Examples include rowing, sailing, canoe touring, and fishing.

Even if these classification criteria are used, it remains a significant challenge to discern which activities constitute primary contact and which constitute secondary contact. The classification of certain recreational water activities will be clear, whereas that of others may be less obvious and more open to interpretation. Water activities considered potential candidates under a secondary contact use designation should be evaluated on a case-by-case basis.

Other factors to consider before assigning a secondary contact use designation to a recreational water area include the following:

- The water area should first be subject to an assessment of existing uses, water quality and the potential for improvement as well as any other relevant factors, such as health or environmental considerations.
- The secondary contact designation should not be applied where an assessment has shown primary contact recreation to be a significant use.
- Where the water area has a shared use (e.g., swimming and canoeing), it is the primary contact values that should apply.
- When an area is posted as suitable only for secondary contact recreational uses, communication material should clearly convey that accidental immersion (through falls, canoe spills, etc.) can lead to whole body exposure; under such circumstances, water ingestion may result in an increased risk of illness.

- Users should be reminded to take the precautions necessary to ensure that these types of exposures are avoided as much as possible; the skill of the person performing the activity may strongly influence the degree of water exposure.

In some instances, a responsible authority may choose to use a validated predictive water quality model to determine the types of water activities allowed at a site on a given day (i.e., primary or secondary contact activities), as opposed to designating the site specifically for primary or secondary contact use. Clear, consistent, and up-to-date risk messaging for recreational users would be necessary for these areas to ensure public health protection is maintained.

If it is determined that a water area is intended to be used for secondary contact recreation, a direct multiplier based on the assumed ratio difference between the primary contact exposure volume and the desired secondary exposure scenario volume can be applied to the fecal indicator guideline values. For example, using average ingestion volumes, the ratio between low ingestion activities, such as boating, fishing, and canoeing/kayaking without capsizing (3.8 mL/h; Dorevitch et al., 2011), and swimming (10 mL/h to 40 mL/h; Dorevitch et al., 2011; Dufour et al., 2017; U.S. EPA, 2019) is approximately 3 to 8. The choice of multiplier should consider the sources of fecal contamination in the waters, as human fecal sources are more likely to contain human pathogens than other non-point sources of contamination. For example, in a water system that is impacted by human or ruminant fecal sources, the responsible authority may want to apply the conservative assumption of 3 times higher than the primary guideline value. This would result in a BAV of 705 cfu *E. coli*/100 mL for the secondary contact values. Any value calculated would represent a risk management decision based on a thorough assessment of the expected exposure scenarios and potential health risks for the recreational water user. In considering both the potential health risks and the benefits of recreational water use, it was concluded that this is a tolerable and reasonable approach to protect users engaged in a voluntary activity.

There is insufficient information available to develop secondary contact guidelines for other parameters in the Guidelines for Canadian Recreational Water Quality. Therefore, for all other parameters, the primary contact values should be applied. The development of secondary contact values should not be used as a mechanism for downgrading the status of an area in response to poor water quality issues. This is particularly important where an assessment has shown that the primary contact guideline values could be achieved.

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APPENDIX A: ABBREVIATIONS

BAV	Beach action value
cce	Calibrator cell equivalent
cfu	Colony-forming units
E. coli	*Escherichia coli*
EHSS	Environmental health and safety surveys
GI	Gastrointestinal illness
GM	Geometric mean
HCGI	Highly credible gastrointestinal illness
MPN	Most probable number
MST	Microbial source tracking
NEEAR	National epidemiologic and environmental assessment of recreational water
NOAEL	No-observed-adverse-effect level
PCR	Polymerase chain reaction
QMRA	Quantitative microbial risk assessment
STEC	Shinga-toxin producing *E. coli*
STV	Statistical threshold value
UK	United Kingdom
U.S. EPA	United States Environmental Protection Agency
WHO	World Health Organization

APPENDIX B: DEVELOPMENT OF THE UPDATED GUIDELINES

B.1 Primary contact guideline values

B.1.1 Historical guideline values for fecal indicators

The previous *Guidelines for Canadian Recreational Water Quality*, published in 2012, recommended guideline values for the fecal indicators *E. coli* and enterococci. *E. coli* values were recommended primarily for freshwaters whereas enterococci values were primarily applied to marine waters. The guidelines noted that the values for *E. coli* could be applied in marine waters, and enterococci in fresh waters, if it was adequately demonstrated at a given site that they were associated with the presence of fecal contamination in these water matrices.

The guideline values comprised a geometric mean (GM) value and a single sample maximum (SSM) value for each indicator (Table B1). The geometric mean values were calculated based on a minimum of five samples, collected at times and sites as to provide representative information on the water quality likely to be encountered by users. If either guideline value was exceeded, the minimum action taken was immediate resampling. Only culture-based methods were included.

Table B1: Comparison of primary contact guideline values

	2012 Guidelines		Current Guidelines	
	GM	SSM	BAVs	
	(cfu/100 mL)	(cfu/100 mL)	(cfu/100 mL)	(cce/100 mL)*
E. coli	200	400	235	N/A
Enterococci	35	70	70	1000

* using PCR-based methods

The GM values were based on U.S. EPA's regression analysis of epidemiological data (Dufour, 1984; Cabelli, 1983) relating *E. coli* or enterococci concentrations to the incidence of swimming-associated gastrointestinal illness. The SSM values were set at a factor of 2 times the recommended geometric mean values. The resultant SSMs were consistent with the maximum allowable indicator densities reported in U.S. EPA (1986). Using the regression analysis, the *E. coli* and enterococci guideline values corresponded to seasonal gastrointestinal rates of approximately 10–20 HCGI per 1000 swimmers.

B.1.2 Current guideline values for fecal indicators

The current guideline values, as presented in Table B1, continue to recommend the use of *E. coli* and enterococci as indicators of fecal contamination. *E. coli* continues to be used primarily for fresh waters. However, enterococci is now recommended for both fresh and marine waters. Similar to the 2012 guidelines, *E. coli* can be used for marine waters if it is adequately demonstrated that they are associated with the presence of fecal contamination in the marine environment.

The guideline values are comprised of beach action values (BAVs) for each indicator. The results from each individual (or composite) sample should be compared to the BAVs. An exceedance of a BAV should trigger further actions by the responsible authorities, such as resampling or issuing beach notifications. Both culture-based methods (*E. coli* and enterococci) and PCR-based methods (enterococci) can be used for analysis.

The BAVs are adopted from U.S. EPA (2012) and represent the 75th percentile value of the water quality distribution corresponding to a potential risk of 36 GI for every 1000 people engaged in primary contact activities. As noted in section 6.1, based on a change in the definition of gastrointestinal illness used in the epidemiological studies, 36 GI is considered equivalent to 8 HCGI.

The current guidelines also acknowledge that the sources of fecal contamination are important for determining the potential risk to human health. Therefore, recreational waters that have a very low risk of human or ruminant fecal contamination may benefit from the development of alternative guideline values.

B.1.3 Rationale for the change in approach

Several significant changes have been included in the current fecal indicator guidelines. This includes moving away from using GM and SSM's to using BAVs for day-to-day beach management (based on data from the most recent epidemiological studies); recommending PCR-based monitoring methods in addition to culture-based methods; and encouraging the use of MST and the development of alternative criteria (where appropriate).

In the 2012 *Guidelines for Canadian Recreational Water Quality*, dual limits (i.e., GM and SSMs) were included as each limit provided different information on water quality. The single-sample limit was intended to alert management to any immediate water quality issues, whereas the GM limit was intended to alert authorities to chronic contamination problems. A minimum of 5 samples were recommended for calculating the GM. However, the greater the number of samples included in the GM, the better the calculated value reflects the water quality. As many locations are sampled infrequently (e.g., once a week), collecting enough samples to calculate a representative GM could take a significant portion of the swimming season. Therefore, although the GM is recommended for understanding longer-term water quality trends, and for determining an area's overall suitability for recreation (e.g., does the water quality meet the GM associated with 36 GI cases/1000 individuals engaged in primary contact activities), it is less useful for making day-to-day beach management decisions. Consequently, the BAV approach has been adopted. BAVs are similar to SSMs in that they alert management to any immediate water quality issues that need to be investigated.

The BAVs also reflect the most recent epidemiological studies conducted in the United States. Unlike earlier studies, the new epidemiological studies did not show a linear relationship between GI illnesses and increasing concentrations of *E. coli* and enterococci (detected using culture-based methods). They did determine that at a GM concentration of 30 or 35 enterococci per 100 mL, the risk between exposed and unexposed individuals was significantly different. *E. coli* data were not available for these studies. However, the *E. coli* values that represent a similar level of health risk were calculated and have been adopted for this guideline document. This harmonizes the risk levels associated with both fecal indicators. The BAVs are based on the 75th percentile of the water quality distribution associated with the GM concentrations calculated from the new studies. Using the 75th percentile (as opposed to the 90th or 95th percentile) is a more conservative approach as the 75th percentile value is a lower number, meaning beach actions are triggered when fewer fecal indicator organisms are present. This provides better protection of sensitive sub-populations such as children.

PCR-based methodologies for monitoring water quality are now included as the science of PCR-based monitoring is well-established and more accessible to responsible authorities. Access to PCR-based monitoring also makes MST research more accessible, as many MST methods use PCR-based technologies for determining the fecal sources impacting a water body. It is also well established that the level of human pathogens varies between fecal sources, with human and ruminant sources representing the greatest risk. As the methods for determining fecal impacts at a recreational area are more accessible, it is possible to better characterize the potential risk at a recreational site and allow for the development of alternative recreational water quality criteria (where appropriate). Any alternative values developed need to maintain the same level of public health protection (i.e., no more than 36 GI illness /1000 individuals engaged in primary contact activities).

B.2 Secondary contact guideline values

B.2.1 Historical guideline values

The *Guidelines for Canadian Recreational Water Quality* (published in 2012) provided advice for secondary water contact activities. It was recognized that these activities resulted in a lower degree of water exposure at most times. However, there was limited research available on the potential risks of acquiring illness during secondary contact activities so a precise health-based fecal indicator limit could not be derived. Instead, based on the available information, it was recommended that a factor of 5 be applied to the GM fecal indicator concentrations used to protect primary recreation users as a means to establish a fecal indicator limit for secondary contact activities.

B.2.2 Current guideline values

There is still insufficient epidemiological data to derive health-based fecal indicator limits for secondary contact recreation. However, there has been some additional research on the differences in exposures between primary and secondary contact activities. Research has shown that fewer individuals report swallowing water and individuals swallow a lower volume of water, compared to primary contact activities. This means exposure is lower. To establish a fecal indicator limit for secondary contact activities, a direct multiplier can be applied to the BAV based on the difference in ingestion volumes between primary and secondary contact activities. The multiplier is the decision of the responsible authority but it is suggested this value should be between 3 and 8, based on the studies available. The choice of multiplier should consider the sources of fecal contamination in the recreational areas.

B.2.3 Rational for the change in approach

Since the publication of the 2012 Guidelines, additional research investigating the risks to human health through secondary contact recreation provides additional data on the difference in exposures between primary and secondary contact activities. It has also been established that recreational areas that are not impacted by human or ruminant feces, such as those only impacted by wildlife/birds, may contain fewer human pathogens, and could benefit from the development of alternative guideline values. Based on these two advancements, a single universal multiplier and a range of multipliers were considered. It was determined that a set multiplier, applied to all recreational areas, was too limited as it does not allow site-specific considerations. Instead, a range of potential multipliers is provided that can be used by responsible authorities to make decisions on secondary contact guideline limits that consider both the potential health risks (based on site-specific considerations) and the benefits of recreational water use in terms of physical activity and enjoyment.