

Illnesses Associated with Non-Point Source Contamination of Recreational Water and Potential New Management Tactics to Minimize Health Risk

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Abstract

The timely and accurate detection of contamination events that may pose a risk to public health is a critical aspect of recreational water management. Currently, regular microbial monitoring of fecal indicator bacteria species *Escherichia coli* and *Enterococcus* is standard procedure for detecting changes in water quality and establishing the need to implement beach advisories or closures. In locations where predominant sources of pollution are those originating from agricultural or urban runoff as well as other animal waste however, the detection of these fecal indicator bacteria species may not consistently or accurately predict the presence of a human health risk. Furthermore, factors such as increased precipitation, elevated temperatures and more frequent extreme weather events associated with climate change will likely result in the increased prevalence of these types of contamination events and the need for them to be more immediately addressed in water management. A review of literature addressing recreational water management strategies and microbial monitoring procedures has been conducted in order to establish current knowledge gaps in the field, opportunities for future research, as well as potential alterations of the current management system that may be able to provide more effective public health protection. A number of limitations are associated with the reliance on indicator species detection to predict a public health risk. The establishment of additional or alternative species to monitor, as well as more efficient technologies to perform tests on water samples may eventually be able to address some of these issues. The incorporation of predictive modelling strategies into water management systems, which will allow beach managers to implement advisories or closures following likely contamination events prior to human exposure, may be an effective alternative to microbial monitoring, especially in locations where contamination results mainly from runoff and animal waste.

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1.0 Introduction

The use of coastal marine water and inland freshwater bodies for recreational activities has become increasingly popular globally. Monitoring these waters for microbial, chemical and physical factors that may pose a risk to public health is of great importance. Organizations such as the World Health Organization (WHO), Natural Resource Defense Committee (NRDC), and government bodies at multiple levels including Health Canada and Public Health Ontario, research and review scientific literature, and in conjunction with epidemiological studies involving water related illnesses, create safe water criteria for maximizing public health protection. At the forefront of these criteria is a set of microbial quality parameters which dictate an acceptable concentration of fecal indicator bacteria (FIB) considered tolerable from a public health perspective; that is, whether or not the water can be considered safe for public exposure. Guidelines for Canadian Recreational Water Quality (GCRWQ) (2012), from the Health Canada directory, outlines the recommended guideline values of *Escherichia coli* in fresh water, and *Enterococci* in marine water that are to be used as indicators of the presence of fecal contamination. These indicators have been selected because comprehensive epidemiological studies have reported significant correlations between these FIB and the presence of organisms which are pathogenic to humans. They are also relatively easy and economical to detect, so it is feasible to use them as regularly monitored indicator species (Dorevitch *et al.* 2010; Wade 2003; GCRWQ 2012).

Pathogens that have been observed to cause adverse human health effects in the majority of these studies are associated with human waste contamination, and sewage treatment plant effluent, otherwise known as *point-source* contamination. Illnesses associated with this type of contamination are most often mild self-limiting gastrointestinal illnesses (Fleisher *et al.* 1996;

Pond 2005). Pond, in a report published by the WHO (2005), addresses the concern that more severe illnesses caused by recreational water contamination, such as acute respiratory illnesses (ARIs), and other adverse skin, eye and ear infections, although less frequently observed than self-limiting gastrointestinal illnesses, may be of greater concern to public health than is currently recognized. A model translating these water related illnesses into Daily Adjusted Life Years (DALY's), a unit created by the WHO to quantify the burden of individual diseases on the global population, supports Pond's hypothesis, presenting the estimated total global DALY for gastro-enteric infections in a year as 66,000, whereas ARIs and related respiratory infections are almost double that, at 114,000 (Shuval 2003). These types of illnesses are often attributed to pathogens associated with contamination sources known as *non-point* sources, which include urban, agricultural and stormwater runoff, as well as animal waste (Pond 2005; Colford *et al.* 2007; Fleisher *et al.* 1996; Dorevitch *et al.* 2010). These sources currently make up the majority of recreational water pollution (NRDC 2013), and factors such as increased urbanization and climate change will likely enhance the need to consider these non-point sources and associated illnesses more prominently in monitoring and management procedures of recreational water in the future (Rose *et al.* 2001; Turgeon 2010).

A number of knowledge gaps currently exist in recreational water management practices in Canada, especially pertaining to the reliance of FIB detection in water samples as a measure to reduce risk exposure and maintain public health protection. Scientific research has begun to delineate the relationship between FIB and the contraction of non-enteric illnesses including the above mentioned respiratory, ear, eye and skin illnesses subsequent to recreational water exposure which may be attributable to their limited association with human associated fecal pathogens (Colford *et al.* 2007; Fleisher *et al.* 1996). Furthermore, the effectiveness of relying on

FIB to accurately predict human health risk is abated by the 24-48 hour time period following sample collection that is currently required for beach officials to acquire test results from laboratories. This allows for a significant period of potential exposure of beach users to pathogens present in the water (Boehm *et al.* 2009). Additionally, water quality has the potential to change drastically, even over short periods of time, and the implementation of an advisory or closure up to 48 hours following the collection of a contaminated sample is likely to be futile. This suggests the need for further consideration of more effective strategies for minimizing, monitoring, and predicting the presence of non-point sources of contamination in management practices.

Conducting a review of current available literature regarding recreational water quality and management will be important in highlighting areas of the field which require refinement. By summarizing recent documented recreational water illness outbreaks and attributed pathogen sources, the current public health risk that is associated with the use of natural water bodies for recreational activities may be demonstrated. Analysis of the current recreational water management legislation in Canada, in relation to both foreign management practices and most recent scientific literature pertaining to technological advances in the field, will demonstrate its current effectiveness and potential areas for improvement. With an acknowledgment of current scientific and economic limitations, recommendations will be made for future research opportunities that will potentially establish additional indicator species to monitor, as well as methods for more effectively incorporating region specific risks and predictive modelling into management. With the apparent knowledge gaps currently associated with recreational water monitoring practices and changing conditions of the environment and climate that will potentially exacerbate these issues, it is critical for researchers, policy makers, and beach

managers to consider a review of this nature for refining current management practices in order to provide more reliable and efficient public health protection.

2.0 Adverse Health Effects Attributed to Contaminated Recreational Water Use

2.1 Illnesses Associated with Exposure to Non-Point Source Contaminated Recreational Water

2.1.1 Summary of Documented Outbreaks

There are many limitations to monitoring the frequency of illness outbreaks associated with recreational water use, especially if the illness does not result in the seeking of medical attention or hospitalization. The documentation of these incidents often relies on self-reporting, and even when illnesses are reported, there may be a lack of sufficient evidence required to demonstrate a causal relationship between the presented illness and pathogen source. Characteristics contributing to these difficulties include the prolonged incubation period of some illnesses, dispersion of people presenting with illnesses and, in general, lack of available etiological data needed to link these types of illnesses to their pathogenic sources, especially when the location, nature, and timing of the contamination source may be unknown (Hlavsa *et al.* 2014).

The surveillance system for outbreaks and diseases in the United States is currently more sophisticated than the Health Canada system in the case of recreational water related illness documentation. Canada's Working Group on Beach and Recreational Water Quality (Health Canada 2011) published a fact sheet summarizing current and future directions in water management of the Great Lakes area suggesting the need for a system to be implemented for obtaining and compiling information about contamination and illness outbreak events in order to further improve management practices. It was also noted that a compilation of United States' and

Canada's relevant statistics for this area would be beneficial for both parties in communicating health and safety concerns to the public.

In the United States, the surveillance system works at a national level, through the Centers for Disease Control and Prevention (CDC) relying on individual jurisdictions within the nation to document and report cases which are then compiled into an annual national surveillance report (Hlavsa *et al.* 2014). These reports are accessible and provide detailed statistics regarding timing and sources of outbreaks. As previously mentioned, Health Canada is lacking such an integrated system for compiling interprovincial data and therefore, for simplicity in this report, United States disease outbreak statistics for untreated recreational water related illnesses incorporating both inland freshwater and coastal marine waters will be referenced. A special focus will be placed on the Great Lakes area as these water bodies are shared between American and Canadian recreational users and management systems.

This year, the 'Recreational Water-Associated Disease Outbreaks- United States, 2009-2010' report was published by Hlavsa and colleagues (2014). It is the most current document available of this nature and summarizes the reported disease outbreaks in the United States related to both treated and untreated recreational water exposures from 2009 to 2010. A total of 1,326 cases were recorded within the year encompassing 81 different outbreak events, which are considered cases in which two or more illnesses can be attributed to the same source. 30% of these outbreaks are resultant of exposures to contaminated untreated recreational water, 96% of these being associated with inland freshwater bodies including the Great Lakes. The vast majority occurred between the months of June and August (83%) when recreational water use is at peak levels. These numbers are noted to be continuously and significantly increasing from reports in past years, and predicted likely to be lower than the actual number of cases due to

incidences of un-reported illnesses. It is likely that Canadian statistics would resemble these numbers due to geographical proximity and shared freshwater bodies, as well as similarities in social behavioral patterns and management practices between the two countries. These management practices will be discussed in greater detail in Section 3.0.

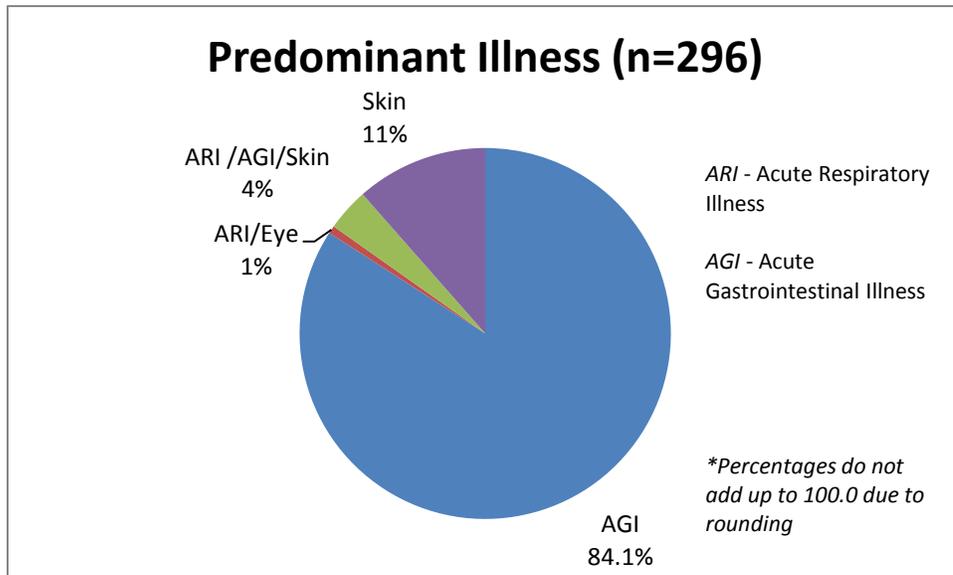


Figure 1. Recreational water-associated outbreaks; untreated water related predominant illnesses by individual case– United States, 2009-2010 (Hlvasa *et al.* 2014)

A consideration of the types of illnesses that were reported will allow for further inferences to be made regarding the sources and nature of the involved contamination events. With reference to the total number of illnesses reported as a result of contaminated untreated recreational water exposure in the United States between 2009 and 2010, the proportions of predominant types of illnesses are represented in Figure 1. Raw data discriminating between treated and untreated water related illnesses is available for further analysis, and Appendix 1 can be referenced for details pertaining specifically to the untreated water related instances (Hlvasa *et al.* 2014).. The vast majority of illnesses reported (84.1%) were acute gastro-intestinal

illnesses. The remaining approximate 16% of illnesses involved respiratory, skin or eye related symptoms, some presenting as combinations of these illnesses. The latter group of illnesses have been referred to as the more severe outcomes of exposure to recreational water contamination (Pond 2005) which are often attributed to pathogens associated with non-point sources of contamination (Colford *et al.* 2007). In terms of hospitalizations, Appendix 1 can again be referenced for specific incidences, however it is worth noting that 22 of the total 269 individual cases of illness required in-hospital treatment.

2.1.2 Pathogens Likely Associated with Documented Outbreaks

The establishment of causal relationships between pathogens and human illnesses through etiological research is critical in the field of recreational water management. Advances in this knowledge will potentially allow for health care professionals to more efficiently and certainly detect water related illness upon presentation and to initiate the appropriate protocols to protect the public from further exposure. Hlvasa *et al.* (2014) do not provide a specific set of data pertaining to non-enteric illnesses and source pathogens which appears, from Appendix 1, to be due to the fact that non-enteric illnesses were most often attributed to ‘unidentified’ pathogens. For this reason, a general depiction of the proportion of pathogens attributed to reported illnesses will be demonstrated through statistics pertaining to acute gastro-intestinal (AGI).

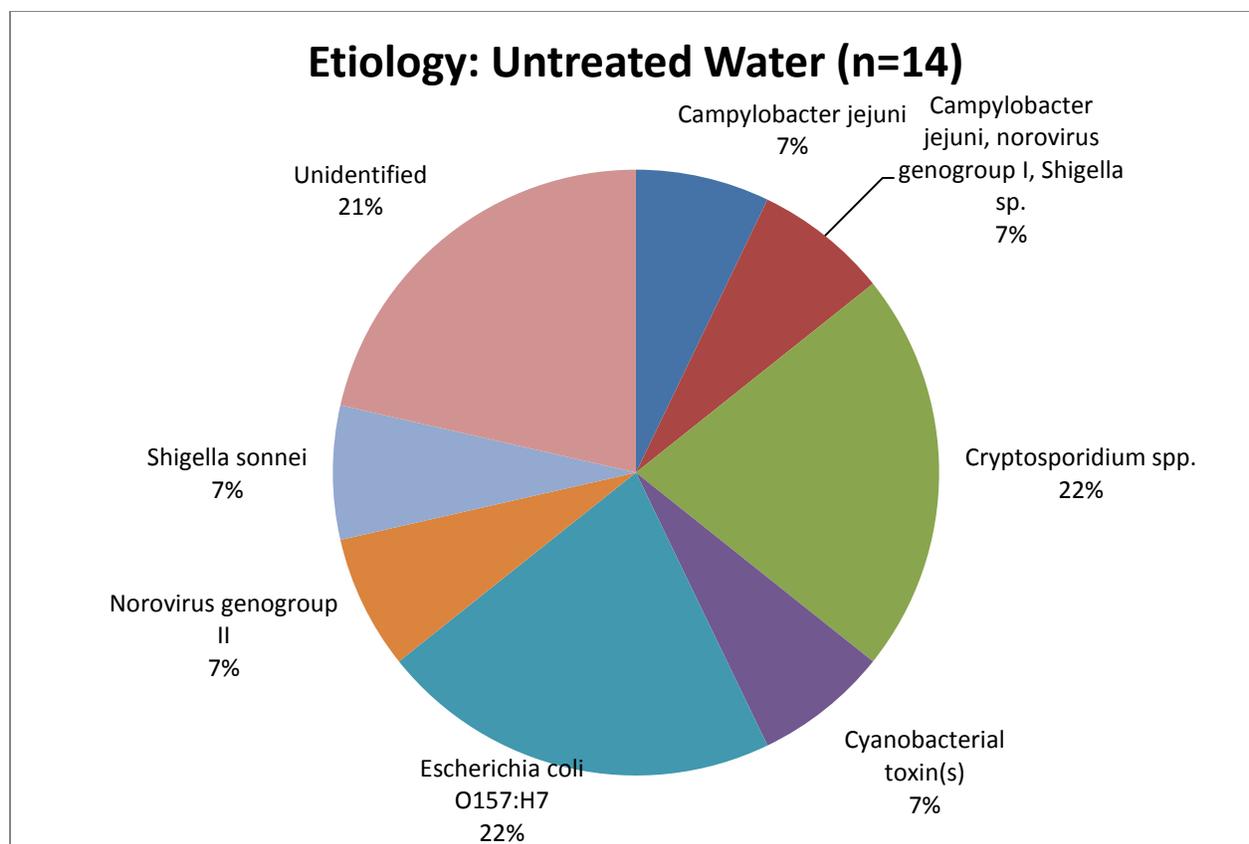


Figure 2. Recreational water-associated AGI outbreaks; untreated water related etiological statistics by outbreak event– United States, 2009-2010 (Hlvasa *et al.* 2014)

In the 14 documented AGI outbreak events which occurred in the United States between 2009 and 2010, the distribution of attributed pathogens was relatively invariable. *E. coli* O157:H7 (22%), and *Cryptosporidium* (22%), as well as a portion of unidentified species (21%) made up the majority of pathogens responsible for human illness and the remaining pathogenic species (*Shigella sonnei*, Norovirus genogroup II, Cyanobacterial toxin(s), *Campylobacter jejuni* and a combination of *Campylobacter jejuni*, Norovirus genogroup I, and *Shigella spp.*) were distributed evenly across remaining illnesses (7% each). These individual pathogens will be considered further in terms of their perceived sources in following sections.

2.2 Sources of Pathogens and Areas of High Risk

Pathogens discussed previously have been considered in terms of etiological evidence linking them to associated human illnesses. The understanding of that relationship is important in allowing health care and public health professionals, to link the symptoms of illnesses presented to possible sources of illness contraction. In order to inform the appropriate interventions, pathogens must also be considered in terms of their origin and what geographical or climate driven determinants may make them more likely to be encountered by recreational water users. This knowledge will be useful for policy makers and beach managers in establishing effective management strategies for individual beaches.

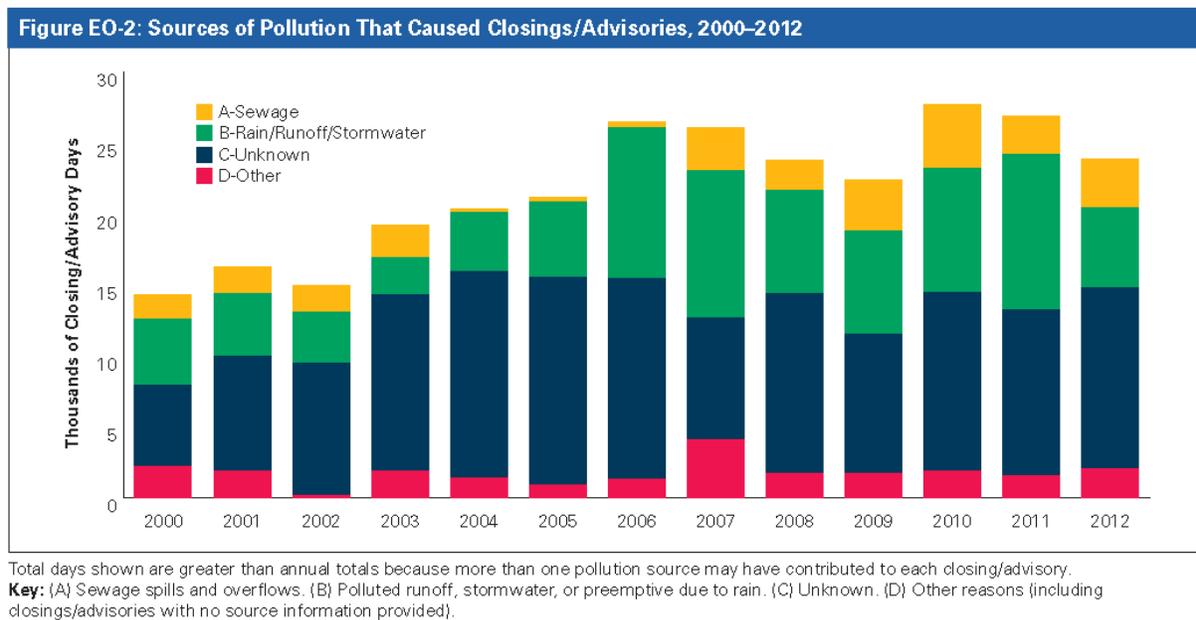


Figure 3. Sources of pollution leading to beach closures or advisories issued between the years 2000-2012. Taken from ‘Testing the Waters: Executive Overview’ (Dorfman and Haren, 2013)

The above Figure 3 was taken from the NRDC’s ‘Testing the Waters: Executive Overview’ (Dorfman and Haren, 2013) and depicts the overall contributing sources to untreated

recreational water pollution and contamination between the years 2000-2012. Notably, the contributions of human sewage (point-sources) have remained relatively steady and marginal in comparison to other sources such as unknown pollutants and runoff (non-point sources). Figure 3 depicts that point-source contamination accounts for only 10% of the total sources of pollution over the twelve years accounted for. Although epidemiological studies have proven elevated levels of point-sources of pollution are highly correlated with human illness in cases of exposure, correlations have also been made between non-point sources and adverse, sometimes severe, health effects (Colford *et al.* 2007; Fleisher *et al.* 1996; Dorevitch *et al.* 2010). Because non-point sources of pollution have consistently made up the vast majority of documented contaminant sources over the past twelve years, a greater emphasis on the detection and management of these sources should be considered.

Pond (2005) discusses pathogens associated with non-point source contamination and human illnesses, a number of which are depicted in Figure 2 as causal agents of disease outbreaks in the United States between 2009 and 2010. *E. coli* O157:H7, *Cryptosporidium* and *Campylobacter* are listed as pathogens originating from animal excreta with the potential for causing severe illnesses in exposed humans. *E. coli* O157:H7 is a bacterial species largely present in GI tracts of cattle and potentially other livestock. This species has the ability to persist in untreated water bodies and disease outbreak trends suggest that its presence peaks in summer and fall seasons, especially in freshwater ponds and other small water bodies (Pond 2003). *Cryptosporidia* are protozoan parasites which have the potential to persist in the form of oocysts in the environment and many surface water bodies. They are zoonotic pathogens which are shed by animals through excretion. The presence of this pathogen in the environment increases in the spring when rainfall levels are heightened (Pond 2005). Epidemiological evidence has indicated

a less certain association with *Campylobacter* and recreational water than the two former pathogens; however, Pond (2005) suggests that poultry and gulls are major reservoirs of this genus of bacteria, and it may be shed from their GI tracts through fecal excretion. It has been observed to cause sporadic incidents of individual illnesses related to recreational water exposure, especially in more heavily industrialized areas. This may be due to smaller water bodies in these areas experiencing higher relative densities of bird waste, or possibly due to differing levels of contaminants found in poultry and gull feces affected by industrial exposures. Each of these species have been studied in association with human illnesses and compared to the known risks of human waste associated pathogens. Soller and colleagues (2010) conclude that non-point source contaminated waters should be treated with more vigilant consideration in management and monitoring procedures, similar to the emphasis currently placed on point source contamination.

Summary

In summary, even with the current monitoring and management procedures in place to minimize human health risk associated with untreated recreational water use, a total of 14 outbreaks comprised of 296 individual cases of illness were reported in the United States between 2009 and 2010 alone. These numbers are likely to be lower than the actual number of cases that occurred due to reporting limitations (Hlvsa *et al.* 2014). The NRDC (2011) reports that pollution levels and concurrent beach closures/advisory days are steadily increasing at an estimated rate of 14% per year, suggesting that rates of illness outbreaks will likely follow this same trend. Over the past 12 years, 90% of the sources of pollution of natural recreational water bodies recorded were non-point sources. Many of the pathogens associated with these contaminants originate from animal excreta and are intensified by seasonal factors such as

increased precipitation and temperature, or other practices including agriculture and industrialization. This indicates that there is a need for management practices to more effectively address these sources of contamination and trends suggest that this need will only increase in the future.

3.0 Current Recreational Water Management in Canada

3.1 Indicator Bacteria Species

The use of indicator bacteria species for monitoring recreational water quality is a standard procedure nationwide and is currently considered the only scientific and economically feasible method for monitoring microbial water quality. Their use is also supported by sufficient epidemiological data linking their presence to gastrointestinal illness rates in water users (Wade *et al.* 2003). In an assessment of the current “quest for the ideal indicator”, Griffin and colleagues (2001) demonstrate a list of desired characteristics to be possessed by an indicator species as shown in Table 1. These qualities will contribute to the ability of a bacterial species to indicate with relative certainty that a fecal contamination event has recently occurred. These indicator bacteria need also to be distinctly and relatively easily detected, as well as representative of the scale of contamination and health risk associated with the water at that time.

Historical characteristics of the Ideal water quality Indicator
Occurs where pathogens do
Cannot grow in the environment
More resistant to disinfection than are pathogens
Easy to isolate and count
Can be isolated from all types of water
Not subject to antibiosis
Only found in sewage
Found in higher numbers than pathogens
Density of indicator should relate to degree of contamination
Density of indicator should relate to a health hazard or type of pollution

Table 1. Characteristics of ideal water quality indicator species (Griffin *et al.* 2001)

The *Guidelines for Canadian Recreational Water Quality* (GCRWQ, 2012) refers to a similar list of qualities, and states that fecal contamination of water bodies is currently considered best indicated by two species of gastro-intestinal (GI) tract associated, non-pathogenic bacteria; *Escherichia coli* (*E. coli*) and *Enterococcus*. They are shed in both human and animal feces and their presence has proven to be highly correlated with the presence of other pathogenic organisms. They are considered the closest known species to possessing all of the desired characteristics such as those outlined in Table 1 (GCRWQ, 2012).

E. coli is historically one of the first bacterial species studied that was thought to possess the qualities necessary for the use as a fecal indicator organism. Once a viable test mechanism was established in the early 1980s for confirming its presence in a water sample, it was quickly incorporated into routine water quality monitoring practices (Edberg *et al.* 2000; GCRWQ, 2012). The species is present at a concentration of approximately 10^9 cells per gram in human and animal feces. It has been observed to be capable of survival outside of its host but is unlikely

to proliferate, and therefore provides a likely indication that a contamination event is responsible for its presence. The length of time for which it is able to survive varies with environmental conditions; however, this has been reported to be an average of 4 to 12 weeks in natural aquatic environments with an average temperature of 15-18°C. Three standard methods of detection have been established which involve the utilization of substrates that will expose the unique enzymatic activity of *E. coli* and therefore indicate its presumptive presence in the sample (Edberg *et al.* 2000). Standard culture methods are commonly used in recreational water monitoring practices; however, this and alternative available methods will not be discussed in detail in this report. The GCRWQ can be referred to for further details on these methodologies.

Enterococcus has been a more recent addition to the group of indicator organisms used in recreational water management following its initial consideration as a possible substitute or co-indicator for *E. coli* (Kinzleman *et al.* 2003; Sinton *et al.* 1993; GCRWQ, 2012). There is far less consistency between concentrations of these bacteria in animal and human feces in comparison to *E. coli*; however, it is reported to be present in all fecal samples at approximately 10^5 to 10^7 cells per gram. Reports indicate that this organism is unlikely to be found in unpolluted water, but there is still a lack of clarity on its ability to survive and proliferate in marine water and soil which could potentially lead to a misinterpretation regarding how recently a contamination event may have occurred (Sinton *et al.* 1993; GCRWQ, 2012). Despite this uncertainty, studies conducted have confirmed that *Enterococcus* is currently one of the most effective known indicator species, especially for contamination of marine water, and its detection is a presumptive indication that a fecal contamination event has occurred (Wade *et al.* 2003).

3.2 Fresh Water vs. Marine Water Parameters

The *Guidelines for Canadian Recreational Water Quality* (2012) distinguish fresh water from marine water indicator bacteria monitoring standards by both type and acceptable concentrations. They also distinguish acceptable contaminant level values for water intended for primary contact, that being direct immersion in the water, from secondary contact, referring to water intended for all other recreational use. Fresh and marine water guidelines will be addressed, focusing on those in place for primary contact recreation. For further details on characteristics of coastal and inland waters which lead to differing effective management techniques, refer to the review by Dorevitch et al. (2010).

E. coli is the primary indicator microorganism used in the monitoring of freshwater quality. The Canadian standard maximum concentration acceptable to be present in a single sample before the water is considered a public health risk is ≤ 400 *E. coli*/100mL. An average of ≤ 200 *E. coli*/100 mL is considered the maximum geometric mean value over a minimum of 5 samples taken. Both values are recommended to be considered with each test; however, the geometric mean is intended to more accurately represent of the overall tendency of bacteria populations present in the water. *Enterococcus* can also be considered an indication of contamination if detected in freshwater, however it is more commonly relied on as an indicator for the contamination of marine water (GCRWQ, 2012).

Contamination of marine water has been found to be more effectively demonstrated by the presence of *Enterococcus* (Wade et al. 2003). Similar to the set of values indicated for fresh water monitoring, the presence of this bacteria at a concentration exceeding the maximum value for one single sample, or the maximum average value over a set of at least 5 individual samples

is considered a valid indication of public health risk. The maximum accepted value in an individual sample is ≤ 70 enterococci/100mL of water and the accepted geometric mean value over the span of 5 or more samples is currently ≤ 35 enterococci/100mL (GCRWQ, 2012).

There is no specific indication of required frequency of monitoring as it is suggested site-specific characteristics are taken into consideration when creating a management plan; however, it is recommended within the guidelines that monitoring in seasons of water use should not occur at a frequency lower than once per week. In terms of the location of sample extraction, the *GCRWQ* suggests that knee to chest deep water may provide a representative sample for the determination of microbial quality of water most frequently encountered by swimmers. However, consultation of further literature is recommended to determine the most effective times and locations based on site-specific characteristics, as one specific set of recommendations may not be most effective at all locations. Details on physical characteristics of freshwater and marine water which contribute to the effectiveness of different standard monitoring procedures, as well as further descriptions of indicators and other water quality parameters, can be accessed in Appendix 2 as well as the *GCRWQ* (2012).

Although the body of literature surrounding the use of indicator bacteria for water quality monitoring tends to support the use of *E. coli* and *Enterococcus* to indicate the presence of fecal associated pathogens, a number of gaps still exist, and this practice certainly cannot be considered faultless. Specific parameters outlined above have been established based on scientific research supporting these values as appropriate thresholds for safety of human exposure in most scenarios. Outside of these indicated guideline values however, the success of location and frequency of sampling in accurately predicting the occurrence of a contamination event has proven to be variable between different sites. It is also highly likely that this success

will vary, even throughout the course of a single day as environmental conditions at each specific site change. Given the reliance on time consuming culture methods to determine water quality, and the possible fluctuations in water quality over the course of time, the accuracy with which this practice can predict true water quality at any given time is questionable. Specific limitations of the reliance on indicator bacteria detection in the monitoring of recreational water quality will be discussed in Section 3.5.

3.3 Levels of Management and Control

In Canada, Health Canada, of the federal government, is responsible for reviewing scientific research and maintaining current and relevant documentation on health and safety factors for a number of different matters. Much of their resources pertaining to environmental management are acquired from documentation and recommendations of the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA). Recreational water management criteria are then recommended by Health Canada for the purpose of influencing provincial and territorial policy makers to incorporate these into their individual legislation. A sub-division of Health Canada, known as the Federal-Provincial-Territorial Working Group on Recreational Water Quality compiled the *Guidelines for Canadian Recreational Water Quality* (2012) detailing the most current set of water quality standards and management recommendations. Canadian recreational water management thus falls under provincial/territorial jurisdiction, with different aspects of management duties and responsibilities designated to municipalities and beach managers established on a regional basis (GCRWQ 2012).

The Canadian recreational water quality management plan emphasizes taking a ‘multi-barrier approach’ as opposed to solely relying on monitoring feedback and reactive strategies for public health protection. This approach is recommended by the WHO as an effective management strategy and is widely adopted by international governing bodies (USEPA 1999). It attempts to provide effective preventative methods across multiple barriers of management that will reduce the likelihood of public exposure to contaminated water. At the base of this approach, Canada’s guidelines indicate the necessity of an annual “Environmental Health and Safety Survey” (EHSS) at each beach location. This survey attempts to provide updated assessments of potential hazards that can be considered in the implementation of management plans. The GCRWQ (2012) states that results of the survey should help to “revise plan[s] as necessary”, but does not indicate that there is any form legal obligation held by beach authorities or policy makers to utilize these results and restructure plans in a timely manner. Other barriers noted include water quality protection, compliance monitoring, as well as communication and consultation at management and public levels (GCRWQ, 2012).

Precautionary and preventative measures for public health protection are ideally embedded within a barrier-like approach. The GCRWQ (2012) indicates that the Canadian management system attempts to accomplish this mainly through strategies such as “source-protection” and “hazard-control”; however, water bodies are often not able to be completely protected and contamination events may not always be controlled, such as in cases of weather induced events or unavoidable runoff subsequent to adjacent land use practices. Furthermore, compliance monitoring is still the main practice relied upon to indicate the occurrence of contamination, and this is exactly the type of reactive strategy the preferred approach attempts to avoid. In order to fulfill a fully pro-active or precautionary approach to public health protection,

a system should be considered in which compliance monitoring no longer represents the sole indication of water quality, nor dictates the necessity for advisory or closure implementations. Alternative strategies, such as risk assessment modelling or predictive modelling, should receive higher precedence in research and should adopt a more prominent role in management practices.

3.4 Comparison of Management Systems

Recreational water management guidelines of both inland freshwater and marine coastal water vary between countries and even between states or provinces within a country. Although there are more often similar, if not identical, public safety objectives between regions, individual areas will have different physical, microbial, and chemical factors to take into consideration when determining optimal practices for public health protection. Currently, however, based on recommendations made by the WHO, microbial testing is one of the central and most widely used methods for monitoring water quality throughout seasons of recreational use.

Recommended water quality criteria cover a wide range of parameters; however, this section will focus on contrasts between levels of control, recommended indicator species parameters, and other distinguishing characteristics between Canada and the United States as well as Canada and Europe.

3.4.1 United States

Recreational water quality criteria in the United States are developed at a national level by the United States Environmental Protection Agency (US-EPA). Similar to the role that Health Canada plays in the Canadian management hierarchy, this agency does not hold any binding legal power over state legislation; it simply provides current reports summarizing scientific research in the field and recommendations for appropriate management criteria. Individual states

are required to consider this information or information from other credible scientific sources and incorporate it into their legislation (US-EPA, 2012).

The most recent report produced by the US-EPA is the 2012 Recreational Water Quality Criteria (RWQC), which contains updated scientific data and epidemiological studies from the previous report published decades earlier. This document summarizes proposed indicator species and monitoring parameters with only a few minor differences from the recommendations of the Canadian guidelines. One main difference, however, is that two sets of guideline values exist for fecal indicator bacteria *E. coli* and *Enterococcus* and selection between the two is recommended to be based on individual location risk assessments and rates of illness. Additionally, a significant portion of the RWQC (2012) focuses on future research plans in line with global scientific research workshops in the field.

In comparison with Canadian recreational water management and guidelines, the United States criteria seem to possess some sophisticated qualities. The provision of two different sets of microbial parameters may not be significantly more efficient in providing public health protection than the single set of guideline values indicated in the GCRWQ (2012); however, this strategy does promote individual states and locations to thoroughly assess site specific risks when determining management strategies. This has the potential to lead to further individualization of management structures, even with respect to aspects other than microbial quality. The focus on structured goals for current and future technological advancements will also be beneficial in stimulating and directing research in the field.

3.4.2 Europe

The 28 countries affiliated with the European Union establish directives by a different hierarchy of control than both Canada and the United States. The European Commission is responsible for establishing current and effective management parameters for recreational water. These involve research contributions and recommendations from the WHO and the European Environment Agency (EEA). According to the Commission's Bathing Water Directive (BWD) (2006), member states are required to introduce parameters into their legislation within a dictated time period following their establishment. This is a legal requirement for individual countries' governments and corresponding non-compliance penalties may be designated as with all directives initiated by the union. Governments are permitted to establish their own directives as replacements for guideline procedures under the condition that they obtain approval from members of the Commission.

The Bathing Water Directive (2006) emphasizes the assessment of individual recreational water sites based on a number of different parameters over a four year period of time after which they are categorized into quality ratings. The rating helps determine the stringency with which they must monitor water quality throughout the bathing season. The microbial parameters included in this assessment involve the monitoring of *E. coli* and *Enterococcus* indicator bacteria species similar to North American standards. Guideline values are comprised of both a mandatory and an optimal value that must be met over a certain portion of samples tested in order to indicate compliance with public safety standards.

In comparison to both the Canadian and American management systems, the one in place in Europe is very distinct. The unity of a large number of member states under one governing

commission creates a unique hierarchy of control. The legal bindings associated with such union have the potential to stimulate more efficient and immediate policy changes in individual countries as research advances are made in the field. Another distinguishing factor is the large emphasis placed on categorizing water quality at specific locations. The reliance on this classification to establish site specific monitoring and management procedures is an approach that is not employed in North American systems.

Literature which may have conducted a comparative analysis between these management tactics and their actual effectiveness in application has not been referenced; however, a brief analysis suggests they each achieve some measures of success. The use of a classification system to direct microbial monitoring practices creates a sort of feed-back loop in the system that attempts to ensure efficiency. The prioritization of increased efficiency through this approach, especially when literature reiterates the economic limitations present in this field, may be an effective technique to consider incorporating into future strategies and revisions of Canadian water quality criteria.

3.5 Limitations in the Current Management System

3.5.1 Effectiveness of Current Indicators

As previously discussed, comprehensive epidemiological studies have demonstrated the abilities of bacteria species *E. coli* and *Enterococcus* to indicate the presence of fecal contamination in water (Wade *et al.* 2003). However, there has been a significant focus in the literature on the limitations of this practice and the implications this may have for public health. A number of reports address incidents of illness related to non-point source contamination of water and the failure of these indicator species to predict the presence of a public health risk

when these occurred (Colford *et al.* 2007; Fleisher *et al.* 1996). This calls attention to the need to consider specific location characteristics more thoroughly when determining appropriate indicators of contamination, as the reliance on a universal indicator species may not be completely effective in all regions (Wade *et al.* 2003). Additionally, there has been consideration of the lack of availability of specific and efficient detection methods which would enable beach officials to accurately identify risks and implement the proper public health interventions (Dorevitch *et al.* 2010).

Colford and colleagues (2007) assessed the effectiveness of standard fecal indicator bacteria in predicting illnesses contracted by recreational water users at a location where the predominant sources of contamination were non-point sources. Because the location chosen was a marine water body, the study looked specifically at detection levels of *Enterococcus* and compared these values to reported illnesses in both swimmers and non-swimmers over a 14 day study period. The results indicated that levels of illnesses in swimmers significantly exceeded those of non-swimmers, especially when water was reported to have been ingested, which allowed for the conclusion that illness may be attributed to water contact. When comparing the detection levels of indicator bacteria and illnesses, no correlation was reported. Authors acknowledged that this specific location could be an anomaly to the previous findings; however, it was reported that this beach had been targeted for extensive clean-up efforts and that there is a known lack of point-sources of contamination at this location. These factors suggests that the conclusion of this study, being that the use of standard indicator bacteria monitoring lacks efficiency in predicting non-point source related public health risk, is plausible. This disparity has also been examined in a study comparing illness rates in swimmers exposed to sub-tropical marine water settings. Similarly, authors of this study concluded that the detection of elevated

levels of *Enterococcus* did not result in a dose-response relationship with swimmer contracted illnesses (Fleisher *et al.* 1996).

The potential lack of correlation between indicator species and presence of pathogenic organisms is not the only limitation of the current water quality monitoring system that has been addressed in the literature. Dorevitch and colleagues (2010) assessed a number of current areas in which they considered knowledge-gaps to exist in this field. One of the foremost points reported in this study suggested that the standard culture method currently used for testing water samples for the presence of indicator bacteria species is not timely enough to provide total public health protection by preventing exposure. The 24-48 hour time gap between water sampling and the acquisition of results from testing laboratories allows the opportunity for a significant level of public exposure to occur to potentially contaminated water. Recent literature suggests that technologies which would reduce this time gap and provide more meaningful results to beach managers are currently being studied (Boehm *et al.* 2009). These aforementioned studies aim to establish feasible monitoring technology that will be able to provide test results within four to six hours of sampling, yet will still only be able to act as a reactive measure in management practices. Until test results are able to be confirmed and relayed to beach managers, public exposure to pathogens has the potential to occur. Furthermore, water quality can change rapidly with changing environmental conditions and even though the time gap between sampling and result acquisition may be drastically shortened, this practice remains unable to produce real time water quality indications and has the potential to result in ineffectual beach advisories or closures.

In response to some of these addressed limitations, it has been recommended that future research attempts to uncover more effective and feasible mechanisms for incorporating

alternative types of pathogens into monitoring criteria, in addition to the standard fecal indicator bacteria currently being used. The establishment of new analytical technologies which will incorporate tracking mechanisms for identifying specific sources of pathogenic bacteria (ie. animal vs. human or individual species) is currently a large focus of this movement (Boehm *et al.* 2009). Although it is acknowledged that *E. coli* and *Enterococcus* are currently the most supported indicator species in the available literature, extensive epidemiological data has indicated that the reliance on a universal fecal indicator bacteria species across all environments is not completely effective in accurately predicting public health risk (Wade *et al.* 2003). Even more importantly, their presence is not currently able to be detected in real time which, as previously discussed, results in health risks only being calculated following potential public exposure. Research should continue to focus on addressing the current limitations related to microbial water quality monitoring, as well as establishing alternative strategies that anticipate health risks prior to public exposure.

3.5.2 Potential Influence of Climate Change on the Need to Adjust Management Strategies

A number of limitations to public health protection embedded within the current water quality monitoring system have been considered based on the current general quality of natural water bodies, temporal variability and climate. An emergent discourse is beginning to circulate around how the changing climate and unpredictability of weather events may begin to affect water quality and monitoring effectiveness.

Rainfall and temperature are two key factors that play a role in the transmission and persistence of pathogens in water, especially those originating from run-off or other non-point sources of contamination. Rose and colleagues (2001) analyzed a number of individual studies

which had examined the relationship between heavy rainfall events and recreational water related disease outbreaks, and reported that consistent strong positive correlations occurred between these two variables. There were also a number of studies considered which determined that elevated levels of sunlight and temperature played a role in increasing the maturation, survival and infectivity of a number of pathogens in groundwater and other surface waters used recreationally (Rose *et al.* 2001). Models indicating current trends and predictions of future trends in climate change and variability depict the likelihood of increasing average temperatures, extreme high temperatures and intense precipitation events (Meehl *et al.* 2000). This suggests that the future may bring about increasing levels of public health risk associated with recreational water exposure and gaps in management practices and public protection may become even more prominent.

Two significant areas of the current management system highlighted as being in need of improvement are surveillance and predictive modeling (Rose *et al.* 2001). These proactive strategies increase the potential for appropriate public health measures to be initiated in response to probable contamination events prior to any swimmer exposures. Quantitative Microbial Risk Assessment (QMRA) strategies embody some of these characteristics (US-EPA 2010) and this, as well as additional methods for assessing and surveying environmental and climate related risks associated with individual water bodies (Turgeon 2012), will be considered further in commentary on future opportunities in recreational water management research and practices (Section 4).

Summary

In summary, the current recreational water management system in Canada is based on a multi-barrier risk management strategy which relies on compliance monitoring procedures established at the municipal level to indicate the presence of health risks associated with the use of individual water bodies. The *Guidelines for Canadian Recreational Water Quality* (2012) dictate guideline values for fecal indicator species levels and other quality monitoring parameters which are currently well supported in the literature by sufficient epidemiological evidence as the best possible predictors of risk (Wade *et al.* 2003). When compared with foreign recreational water management criteria, it was noted that the use of microbial monitoring of indicator species was central to all management systems, and guideline values used were not significantly different from those used in Canada. Minor differences were observed, in the structure of governance and designated responsibilities to individual jurisdictions for manipulating management procedure to best suit specific locations (BWD 2006; RWQC 2012); however, the actual success of these strategies was only speculated upon. Limitations to the current system in place in Canada are highlighted by the failure of indicator species to predict human illnesses in places where non-point sources are the predominant source of contamination (Colford *et al.* 2007; Fleisher *et al.* 1996). Moreover, when indicator species have been demonstrated to be more reliable, such as in instances of point-source contamination events of freshwater bodies, a one to two day period is still required before results are reported. Climate change has also been considered as a potential factor which will exacerbate gaps in the current management system and should be considered in the establishment of both the direction and urgency of future research (Rose *et al.* 2001).

4.0 Proposal for Improvements to Current Recreational Water Monitoring Practices

4.1 Potential Indicator Species to Additionally Monitor

Multiple studies have emerged addressing the lack of correlation between fecal indicator bacteria levels and numbers of associated human illnesses in recreational water bodies which are dominantly exposed to non-point sources of contamination (Colford *et al.* 2007; Fleisher 1996). Colford and colleagues (2007) conducted a study of this nature, concluding that indicator species currently being used are insufficient for predicting human illnesses, suggesting a need to consider additional or alternative indicators. The authors attempted to determine if the presence of an alternative bacterial species correlated more strongly with prevalence of human illnesses. Results demonstrated that one specific human coliphage virus exhibited this correlation; however, the authors were cautious to recommend this as potential alternative indicator due to the technical limitations associated with isolating viruses from marine water samples.

In a meta-analysis of the current literature conducted by Wade and colleagues (2003), specifically pertaining to indicator species' effectiveness in predicting pathogen presence and human health risks, a number of potential alternative indicators are highlighted. A number of virus and non-fecal bacteria species were considered, but it was concluded that there was a lack of sufficient evidence available to support the incorporation of any one species into current management criteria. It should be noted that each of the species considered in the analysis was looked at in terms of its correlation specifically with GI tract illnesses and other types of human illnesses were not considered. In a more recent literature review, these conclusions were reiterated (Boehm *et al.* 2013). Again, the lack of correlation between standard fecal indicator bacterial species numbers and human illness in relation to non-point source impacted waters was

highlighted, but the lack of evidence indicating a feasible alternative solution caused authors to refrain from making any immediate recommendations (Boehm *et al.* 2013).

The GCRWQ (2012) briefly addresses four microorganisms which are gaining consideration by experts and policymakers as potential alternative indicator species. These fecal-associated organisms include bacteria species *Bacteriodes* spp. and *Clostridium perfringens*, viral coliphages, and *Bacteriodes fragilis* following bacteriophage infection. The GCRWQ (2012) indicates that there are a number of necessary requirements that a species must meet in order to be considered an effective indicator, and each of the four above mentioned species currently lacks a number of these key characteristics. Moreover, none have effectively demonstrated any consistent or strong correlation between their density in the environment and pathogen presence or human health risks. Further research should attempt to determine whether they should be incorporated into monitoring criteria on a site specific or conditional basis, and their potential role as fecal source indicators.

The failure of standard fecal indicator species to unequivocally demonstrate human health risks in non-point source contaminated waters is a recurring theme in the recent literature. Simultaneously, there has been significant emergent dialogue regarding alternative fecal indicator species. Nonetheless, there remains an apparent lack of literature specifically addressing potential effective indicators of animal waste associated pathogens or even other mechanisms by which health risks associated with them might be accurately predicted. Pathogens such as *Cryptosporidium* and *Campylobacter* are reported to be responsible for causing a significant portion of human illnesses related to non-point source contamination (Hlvasa *et al.* 2014), some of which are considered to be severe, and it is becoming apparent that these health risks are often inadequately predicted by current monitoring standards (Pond 2005;

Colford *et al.* 2007; Dorevitch *et al.* 2010). Without sufficient supporting evidence, a practical recommendation is unable to be made for specific changes, or additions, to indicator species used in current microbial quality monitoring. As such, due to this persistent gap in knowledge, alterations of current management strategies, which will reduce the reliance on indicator species to demonstrate the presence of a health risk, should be considered.

4.2 Potential Improvements for Monitoring Techniques

The standard culture method currently relied upon for the detection of fecal indicator bacteria in water samples is associated with a number of limitations. Not only does it require a 24-48 hour period before results of the test are available, but tests must be conducted in a laboratory setting as it is not feasible to conduct them on-site (Wang 2013; Boehm *et al.* 2009). This creates a significant time gap between sample collection and the relaying of results from the laboratory to beach managers. Scientists are working towards improving technologies that may eventually allow for on-site sample testing to become possible through quicker and more effective detection methods. Scientific research is and has been conducted in attempts to establish more effective and rapid methods for detecting a larger variety of pathogens in water samples as well as characterizing properties of pathogens that will accurately indicate their source. These practices would ideally contribute to a more rapid and thorough understanding of microbial conditions of the water body in question.

One field of research focusing on this source identification process is that of ‘Microbial Source Tracking’ (Harwood *et al.* 2013). Microbial Source Tracking (MST) involves the detection of specific markers in fecal associated pathogens, characteristic of the individual species from which the organism originated. There are a number of ways in which this may be

accomplished with quantitative polymerase chain reaction (qPCR) assays the most commonly referenced method currently (Harwood *et al.* 2013). Through the development of markers, or specific sequences of DNA, which are unique to specific species, MST provides a mechanism for accurately identifying pathogen sources. Because different health risks have been associated with pathogens originating from different sources (Soller *et al.* 2010), the opportunity to identify the source of a contaminant may allow for health risks to be more appropriately addressed, and hazards to be more effectively and efficiently managed.

While the development of MST and incorporation of this method into microbial quality monitoring standards remains a major focus of current and future research objectives, a greater analysis of its practicality and immediate effectiveness in contributing to public health protection should be considered. According to Harwood and colleagues (2013), after summarizing the work that has been done in the field and highlighting some of the current limitations of this practice, it is apparent that a number of knowledge gaps still exist which prevent MST from being a viable strategy for current monitoring practice. Markers have yet to be developed for a large number of both domestic and wild animals whose feces are likely to play a large role in water contamination. Additionally, challenges exist with the use of qPCR methods in water samples from natural water bodies due to potentially high concentrations of other organisms or inhibitors that may be present in the water. Besides these challenges, qPCR must be conducted by trained professionals in a laboratory setting, which is a factor that would ideally be abstracted from future water quality monitoring practices (Harwood 2013). Finally, although library independent methods may currently be more frequently utilized, the standardization and compilation of data into libraries has been associated with a high level of misinterpretation of misclassification

across different laboratories (GCRWQ 2012). All of these factors greatly reduce the likelihood of this practice being incorporated into regulatory management systems in the near future.

The GCRWQ (2012) suggests that although microbiologists have held high expectations of MST, and the role it may be able to play in recreational water management in recent years, the advantages compared to the limitations associated with the practice should be considered more comprehensively in future research. In order to address the current issue of human health risks associated with non-point sources of contamination being improperly managed or inaccurately detected, it is likely that a more immediately viable and less technical solution should be given higher precedence in future research.

4.3 Predictive Modelling Strategies

Canada's emphasis on the multi-barrier approach for recreational water management (GCRWQ, 2012) indicates that research should address not only the development of improved microbial quality monitoring practices, but also more effective preventative risk assessment strategies. An emergent management strategy of this nature, which has been addressed by the US-EPA as a potential new tactic to incorporate into a revised RWQC, is predictive modelling using geophysical and climate parameters. Water quality can be estimated by combining predictive modelling estimates of short term changes in pathogen levels with human health risk estimates from Quantitative Microbial Risk Assessment (QMRA). Ideally, this system would provide a thorough characterization of risks associated with different geographic, temporal, climate, or specific pathogen source related variables. Risk assessments, on a site specific basis, would allow for individual models to be created which would be utilized to indicate the likelihood of contamination events and consequential health risks with statistical accuracy. This

system would be especially applicable to areas where non-point sources of contamination are predominant, as these are often majorly affected by temporal and climate variability (US-EPA 2010).

The US-EPA report on QMRA (2010) provides an account of a specific theoretical scenario in which this model was created to consider its practicality and effectiveness. A freshwater body impacted by non-point source contamination originating from adjacent agricultural land use as a result of an intense rainfall event was considered. Risks were calculated by formulations based on a number of assumptions including the likely volume of fecal containing materials applied to the agricultural land, density of pathogens in that material, the transmittance of that material into the water body during and immediately following a rainfall event and the contact of a swimmer via ingestion of the contaminated water. The calculation of risk is reported to account for potential variability or uncertainties in the nature of these events. The US-EPA concluded that this strategy provided an improved mechanism for determining human health risks associated with water bodies and contamination sources that are otherwise unable to be characterized (e.g. by epidemiological or observational studies) (US-EPA 2010).

The US-EPA (2010) can be referenced for further indication of how risks are assessed and how models are formulated based on these assessments. Additionally, access is provided to some software packages, such as 'Virtual Beach', which have been designed to create statistical models of pathogen indicator levels at beaches, but have yet to become popularized for routine use in management practices. Limitations to this modelling strategy indicated in the document include its limited ability to address non-enteric illnesses, as well as the possibility that confounding factors in the natural environment may introduce conditions which are unaccounted for in models and could contribute to the occurrence of inaccurate predictions. Nevertheless, this

is a pro-active strategy which will be able to act as a bridge for the current gap in sampling/result acquisition times as well as other scientific and technological limitations associated with the reliance on microbial testing to ensure public health protection. The US-EPA states that this strategy would be both a viable and valuable complement to the current monitoring system and will be especially effective in water bodies where epidemiology has been less successful in characterizing risks. The GCRWQ (2012) does not discuss any current research pertaining to this strategy, or future opportunities it would provide. Further research, revision, and adaptation of this modelling system may create an increasingly effective strategy for predicting public health risks prior to exposure and should receive consideration for incorporation into revised water quality criteria.

Summary

Although public health protection is the foremost priority when establishing water management frameworks, economic and scientific limitations exist and are unavoidable in the field. Scientific research should continue to work towards creating increasingly effective and efficient technologies which are able to detect pathogens in water samples. They must also consider incorporating simplicity and economic feasibility into their technological designs in order to increase the practicality of their use at recreational beach settings by managers or technicians who may have limited scientific backgrounds. The search for additional indicator species or specific pathogens that have the potential to increase the likelihood of confirming public health risks should continue, as it provides the opportunity for effective long term improvements to future monitoring criteria. The attempt to establish a mechanism for accurately characterizing pathogen sources has been targeted in current research; however, the effectiveness of this strategy should be critically analyzed in order to determine its practicality for future

incorporation into monitoring procedures, and its role in addressing the immediate limitations associated with these practices. Viable predictive modelling strategies are beginning to be established and should be seriously considered by policy makers for incorporation into recreational water management practices as they may be useful in compensating for current technological gaps in the field. Proposed future research opportunities which will be addressed in this report will include objectives highlighted by experts in the literature as well as areas in which potentially greater or lesser emphasis should be placed based on successes and failures of current practices indicated above.

5.0 Conclusion: The Future of Recreational Water Monitoring and Management

- Public health risks associated with recreational water use result from exposure to contamination by both point and non-point sources of pollution. The Centers for Disease Control and Prevention produces an annual surveillance report indicating trends in reported recreational water related illnesses, and over the past decade these numbers have steadily increased. Both enteric and non-enteric illnesses may be contracted as a result of pathogen exposure, the latter type having been classified as severe in some cases. The Natural Resource Defense Committee indicates that 90% of the pollution sources of recreational water over the past 12 years were non-point sources, and it is these types of pollution that have been linked to a number of the more prevalent human illnesses indicated in recent reports.

- Recreational water management in Canada, as well as a number of foreign systems relies on the microbial monitoring of two individual fecal indicator bacteria species to indicate the presence of a contamination event and consequential human health risk; namely *E. coli* and *Enterococcus*. Concentrations of these bacteria at levels higher than the indicated safe guideline values will result in beach closures or advisories being implemented. Although the monitoring of indicator species is currently considered the only scientifically and economically feasible method for obtaining regular microbial water quality information, a number of limitations exist with this practice. Most specifically, the failure of these species to consistently and accurately predict the presence of a human health risks at locations predominantly contaminated by non-point sources of pollution has been highlighted as an area of water management which needs to be addressed.
- Factors such as higher temperatures, increased levels of precipitation and more extreme weather events associated with climate change will increase the volume and rate of runoff into water bodies, and potentially alter the behaviour of pathogens in the water. This will further increase the prevalence of non-point sources of contamination in water bodies and increases the urgency with which beach managers and policy makers should address some of the above mentioned knowledge gaps associated with them in the current management system.
- Research in the field has targeted more accurate and efficient monitoring technologies, additional or alternative indicator species, as well DNA based techniques for identifying sources of pathogens. These advances will eventually contribute to a more thorough understanding of water quality and likely, more effective management systems. The current need to address uncertainties associated with microbial monitoring practices

however, may be more effectively accomplished by the utilization of predictive modelling strategies and risk assessment models.

- Risk assessment modelling will provide a pro-active approach to public health protection. It should be developed based on the effects environmental parameters such as wind, precipitation, temperatures, currents, etc. which will be compiled into libraries, allowing this system to be applied across a number of individual beach locations. Quantitative microbial risk assessment will develop models so that they will effectively characterize and address health risks associated with non-point source related pathogens. Microbial monitoring should continue to be practiced regularly; however, it should be used to inform models and provide feedback as to how successfully individual models are functioning. If a beach is closed because of adverse water quality concerns, it is also possible that microbial monitoring could be used in the decision to re-open the beach.
- This current recommended approach is similar to that applied to the food supply chain, drinking water and air pollution regulations and has proven to be a successful strategy for addressing human health risks prior to exposure. For example, if proper food storage conditions or water treatment parameters are not achieved, distribution will be halted or controlled immediately, without waiting for a microbiology test to confirm that adverse health risks had been introduced. With the health risks currently associated with recreational water use, the increasing prevalence of non-point sources of contamination in water bodies, and the lack consistent and effective detection of these risks in the current management system, researchers and policy makers should consider this approach as a viable alternative strategy for immediate incorporation into standard management practices.

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7.0 Appendices

Appendix 1 – Recreational Water-associated Outbreaks, Supplemental Data Table (Hlvasa *et al.* 2014)

Untreated Recreational Water

Jurisdiction	Month	Year	Class*	Etiology	Predominant Illness†	No. cases‡	No. hospitalizations‡	Venue	Setting
Alabama	May	2010	1	Norovirus genogroup II	AGI	69	2	Lake/Reservoir	State park
Arkansas	Jun	2010	4	<i>Escherichia coli</i> O157:H7	AGI	5	3	River/Stream	Public outdoor area
California	Jul	2010	4	Unidentified††††	Skin	9	0	Pond	Public outdoor area
Florida	Aug	2009	4	<i>Cryptosporidium</i> sp.	AGI	6	0	Lake/Reservoir	State park
Massachusetts	Jul	2009	1	<i>Shigella sonnei</i>	AGI	68	6	Lake/Reservoir	Public beach
Michigan	Jun	2010	3	<i>Campylobacter jejuni</i>	AGI	6	4	Lake/Reservoir	Public beach
Michigan	Jun	2010	4	Unidentified§§§§	Skin	3	0	Lake/Reservoir	Unknown
Minnesota	Jul	2010	2	<i>Escherichia coli</i> O157:H7	AGI	5	4	Lake/Reservoir	Public beach
Minnesota	Aug	2010	2	<i>Cryptosporidium hominis</i> 1bA10G2	AGI	3	0	Lake/Reservoir	Public beach
New York	Jun	2009	3	Unidentified¶¶¶¶	ARI; Eye	2	0	Lake/Reservoir	Unknown
New York	Jun	2009	3	Unidentified¶¶¶¶	Skin	2	0	Lake/Reservoir	Public beach
New York	Aug	2009	3	Cyanobacterial toxin(s)******	Skin	2	0	Lake/Reservoir	State park
New York	Oct	2010	4	Unidentified††††	Skin	2	0	Ocean	Membership club
Ohio	Jun	2010	3	Cyanobacterial toxin(s)†††††	AGI; ARI; Skin	8	1	Lake/Reservoir	State park
Ohio	Jul	2010	3	Cyanobacterial toxin(s)§§§§§	AGI	19	0	Lake/Reservoir	Camp/Cabin
Ohio	Jul	2010	3	Unidentified¶¶¶¶¶	Skin	7	0	Lake/Reservoir	State park
Ohio	Jul	2010	3	Cyanobacterial toxin(s)******	Skin	9	0	Lake/Reservoir	Public outdoor area
Ohio	Aug	2010	3	Unidentified*****	AGI; ARI; Neuro; Skin†††††	3	0	Lake/Reservoir	State park
Ohio	Aug	2010	3	Unidentified§§§§§	AGI	2	0	Lake/Reservoir	State park
Oklahoma	May	2009	3	<i>Campylobacter jejuni</i> ; norovirus genogroup I; <i>Shigella</i> sp.	AGI	45	0	River/Stream	Public outdoor area
Tennessee	Mar	2009	4	<i>Cryptosporidium</i> sp.	AGI	7	0	Lake/Reservoir, river/stream	Camp/Cabin
Washington	Jun	2009	4	Unidentified¶¶¶¶¶	AGI	4	1	Lake/Reservoir	State park
Washington	Jul	2009	4	Unidentified¶¶¶¶¶	AGI	3	0	Lake/Reservoir	State park
Wisconsin	Jun	2009	2	<i>Escherichia coli</i> O157:H7	AGI	7	1	Lake/Reservoir	State park

Appendix 1 cont.

Abbreviations: AGI = acute gastrointestinal illness; ARI = acute respiratory illness; Ear = illnesses, conditions, or symptoms related to the ears; Eye = illnesses, conditions, or symptoms related to the eyes; Neuro = neurologic illnesses, conditions, or symptoms (e.g., meningitis); Skin = illnesses, conditions, or symptoms related to the skin.

* Based on epidemiologic, clinical laboratory, and environmental data (e.g., water quality data) reported to CDC. For more information, refer to the [strength-of-evidence classification table](#).

† The category of illness reported by ≥50% of ill respondents. All legionellosis outbreaks were categorized as ARI.

§ No outbreak-related deaths were reported.

¶ Value was set to missing in reports when zero hospitalizations were reported and the reported number of people for whom these data were available was also zero.

** Etiology unidentified: *Pseudomonas aeruginosa* suspected based on reported venue(s) of exposure and clinical signs and symptoms.

†† *Cryptosporidium* was detected in stool specimens from multiple case-patients. Isolate from one case-patient was identified as *Cryptosporidium hominis* IaA28R4.

§§ Eleven case-patients reported earaches in addition to dermatologic symptoms.

¶¶ Etiology unidentified: chlorine (i.e., toxic chlorine gas or extremely elevated chlorine levels) suspected based on reported events.

*** Etiology unidentified: disinfection by-products (e.g., chloramines), altered water chemistry, or extremely elevated chlorine levels suspected based on reported data.

††† Isolates from stool specimens of six case-patients were identified as *C. hominis* IaA28R4; the isolate from another case-patient was identified as *C. hominis* IaA24R4; and the isolate from another case-patient was identified as *C. hominis* IdA15G1.

§§§ Etiology unidentified: norovirus suspected based on reported incubation period, symptoms, or duration of illness.

¶¶¶ Eight case-patients reported earaches in addition to dermatologic symptoms.

**** Pool is a manufactured venue that is filled with filtered but otherwise untreated hot spring water.

†††† Etiology unidentified: avian schistosomes suspected based on reported clinical diagnosis of cercarial dermatitis and environmental data.

§§§§ Etiology unidentified: copper suspected based on reported use of chemical treatment for algae.

¶¶¶¶ Etiology unidentified: cyanobacterial toxin(s) suspected based on reported clinical signs and symptoms, environmental data (e.g., confirmed algal bloom), and venue of exposure.

***** Microcystin toxin (≥20 ppb) detected in water samples collected during or within 1 day of dates of exposure. Other cyanobacterial toxin(s) suspected based on reported clinical signs and symptoms.

††††† Microcystin toxin (≥20 ppb), anatoxin-a, saxitoxin, and cylindrospermopsin detected in water samples collected during or within 1 day of dates of exposure.

§§§§§ Microcystin toxin (≥20 ppb) detected in water samples collected during or within 1 day of dates of exposure.

¶¶¶¶¶ Etiology unidentified: microcystin toxin, saxitoxin, and other cyanobacterial toxin(s) suspected based on reported clinical signs and symptoms, environmental data (e.g., confirmed algal bloom), and venue of exposure. Microcystin toxin (<20 ppb) and saxitoxin detected in water samples collected during or within 1 day of dates of exposure.

***** Etiology unidentified: microcystin toxin, anatoxin-a, and other cyanobacterial toxin(s) suspected based on reported clinical signs and symptoms, environmental data (e.g., confirmed algal bloom), and venue of exposure. Microcystin toxin (<20 ppb) and anatoxin-a detected in water samples collected during or within 1 day of dates of exposure.

†††††† One or more case-patients reported symptoms in each illness category; however, no illness category was definitively reported by ≥50% of ill respondents. Therefore, all reported illness categories have been included.

Appendix 2 – Guidelines for Canadian Recreational Water Quality

Table 1. Guidelines for Canadian recreational water quality: summary table

Guidelines		
Parameter	Considerations	Guideline
<i>Escherichia coli</i> (Primary-Contact Recreation)*	Geometric mean concentration (minimum 5 samples) Single sample maximum concentration	≤ 200 <i>E. coli</i> /100 mL ≤ 400 <i>E. coli</i> /100 mL
Enterococci (Primary-Contact Recreation)*	Geometric mean concentration (minimum 5 samples) Single sample maximum concentration	≤ 35 Enterococci /100 mL ≤ 70 Enterococci /100 mL
Pathogenic Microorganisms (bacteria, viruses, protozoa)	Testing only needed when there is epidemiological or other evidence to suggest that this is necessary	No numerical guideline value
Cyanobacteria Cyanobacterial toxins	Total Cyanobacteria Total Microcystins	≤ 100,000 cells/mL ≤ 20 µg/L
Other Biological Hazards (e.g. schistosomes causing swimmer's itch, aquatic vascular plants and algae)	Recreational activities should not be pursued in waters where the responsible authority deems the presence of these organisms poses a risk to the health and safety of the users	No numerical guideline value
pH	For waters used for primary contact recreation	5.0 to 9.0
Temperature	Should not cause an appreciable increase or decrease in the deep body temperature of swimmers	No numerical guideline value
Chemical Hazards	Risks associated with specific chemical hazards will be dependent on the particular circumstances of the area and should be assessed on a case-by-case basis.	No numerical guideline value
Aesthetic Objectives		
Parameter	Considerations	Aesthetic Objective
Turbidity	To satisfy most recreational uses	50 NTU
Clarity	Clarity should be sufficient for users to estimate depth and to see subsurface hazards	Secchi Disc visible at a depth of 1.2 m
Colour	Colour should not be so intense as to impede visibility in areas used for swimming	No numerical value

* Advice regarding waters intended for secondary-contact recreational activities is provided in Section 4.2.

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