EXECUTIVE SUMMARY

This document provides a summary of recent materials developed for the International Joint Commission (IJC) on waterborne microbial pathogens in the Great Lakes region. These materials include reports to the Scientific Advisory Board on waterborne pathogens as well as four white papers that discuss societal influences on microbial pathogens, monitoring of pathogens, and management tools. Although some of the information in this summary has been excerpted from these source documents, I have tried to provide a comprehensive view of the issues concerning waterborne microbial pathogens in the Great Lakes.

Although diseases such as typhoid and cholera are no longer major problems in the Great Lakes basin, waterborne microbial pathogens still warrant considerable attention. Recent outbreaks in Milwaukee, WI and Walkerton, ON illustrate that waterborne microbial pathogens still pose a threat to human health. Most of these pathogens are transmitted by the fecal-to-oral route in which people are exposed to the pathogens when they ingest or come into contact with water contaminated with human or animal feces. Although attention and management efforts have focused on treating water and wastewater to prevent microbial contamination, human activities and advancements in technology continue to contribute directly and indirectly to contamination of surface and ground water with microbial pathogens. For example, irrigation increases agricultural production but the water returned to aquatic systems after agricultural use is often contaminated with nutrients and pathogens. In order to manage microbial contamination, we must be able to effectively monitor pathogens in the environment and understand their fate and transport. In the early 1900s, the IJC commissioned a bacteriological monitoring study that examined cross-boundary pollution. This study was revolutionary in its day and can inform current monitoring programs. In addition, new technologies and approaches can be used to not only determine the presence of pathogens but provide information on their fate in the environment. The Global Ocean Observation system, which has been used to track harmful algal blooms, can be used as a model for tracking waterborne pathogens in the Great Lakes. This would provide managers with accurate, real-time information on microbial contamination and can be used in determining if beaches should be closed or remain open. Finally, Hazard Analysis
and Critical Control Point (HACCP) planning provides a framework for developing a comprehensive plan for managing microbial contamination in the Great Lakes basin.

**INTRODUCTION**

The Great Lakes basin is home to approximately 30 million people, many of whom drink and recreate in the waters of the basin without any thought to microbial pathogens. However, in the US there has been an increase in the number of disease outbreaks due to waterborne pathogens since the late 1990s. The CDC estimates that there are 300,000 infections per year caused by waterborne pathogens. The largest outbreak in US history occurred in the Great Lakes region (Milwaukee, Wisconsin) where 400,000 people became ill and 100 people died due to a *Cryptosporidium* outbreak in the drinking water supply. Outbreaks have also occurred in Canada, most notably the Walkerton outbreak in 2000. Seven people died as a result of *E. coli* O157:H7 contamination of the drinking water supply.

In addition to contamination of drinking water, microbial pathogens also pose a risk for contact recreation. In 1996, U.S. Great Lakes beaches were closed 3,700 times due to the presence of pathogens or indicator organisms. Globally, the cost of human disease caused by sewage pollution of coastal waters is estimated at 4 million lost ‘man-years’ annually, which is roughly equivalent to an annual economic loss of approximately $16 billion U.S. For one Lake Michigan beach, net economic losses due to beach closures have been estimated to range from $1,274 to $37,030 per day depending value assumptions used (Rabinovici et al. 2004).

Attention given to microbial pathogens has been increasing because of an increase in the size of sensitive populations, global transportation networks that can spread pathogens worldwide, antibiotic resistance, and zoonotic transmission. Of particular interest are new findings which suggest that pathogens may be linked to diseases where their influence was never suspected such as hardening of the arteries (Ismail et al. 1999) and cancer (Goedert 2005). In addition, chemical contamination and microbial contamination may interact to exacerbate their effects. Improved estimates of land-based inputs and models of water circulation patterns and water quality will be needed to reduce risks of human exposure, provide the data and information needed for more effective control of anthropogenic inputs, and maximize recreational income (Cheves, 2003).

**MICROBIAL PATHOGENS**

Many microbial pathogens are not native to the waterbodies in which they are now found; most have been introduced by human activities via point and nonpoint sources of pollution (NRC 2004). Few studies exist on the ecology and evolution of microbial pathogens in comparison to research investigating pathogenicity. It is vital to understand the autecology of the pathogens

The NRC (2004) identifies five critical questions for studying pathogens:

1. What is the distribution and abundance of pathogens?
2. Are the reservoirs for the pathogen biotic or abiotic?
3. What are the fates of freshwater pathogens in coastal or marine waters?
4. Is the resident time of a pathogen sufficient to allow genetic exchange or change to occur?
5. What biotic and abiotic factors influence the viability and survivability of waterborne pathogens?

The NRC (2004) identifies five critical questions for studying pathogens:

1. What is the distribution and abundance of pathogens?
2. Are the reservoirs for the pathogen biotic or abiotic?
3. What are the fates of freshwater pathogens in coastal or marine waters?
4. Is the resident time of a pathogen sufficient to allow genetic exchange or change to occur?
5. What biotic and abiotic factors influence the viability and survivability of waterborne pathogens?
6. Are there environmental conditions that promote genetic exchange or the acquisition of genetic elements that confer selective advantage under clinical conditions?
7. What effect do sampling and environmental variations have on the efficacy of indicators?
and their indicators in order to gain a real understanding of their abundance, distribution, and fate in the environment (see box).

Diseases such as cholera and typhoid are no longer a major concern, mainly due to disinfection processes instigated since the early 1900s. Currently, pathogens of concern include bacteria, toxic algea, protozoa, and viruses; these are briefly described below.

**Types of Waterborne Microbial Pathogens**

Bacterial pathogens include *Escherichia coli (E. coli)*, *Campylobacter*, *Salmonella sp.*, and *Shigella sp.* Bacterial waterborne pathogens can be divided into two groups, those that are native and those that have been introduced and are not typically found in a particular water system (NRC 2004). In aquatic systems, pathogenic bacteria are a small component of a diverse microbial community. An important consideration for bacteria is that some can form endospores, specialized cells with no metabolic activity that can survive extended periods of time in harsh environmental conditions. Some bacteria, such as *Shigella* are found exclusively in humans, whereas others have multiple animal hosts. These bacteria with multiple hosts can transmit pathogens from one host to another. For example, *Campylobacter* is found in a wide range of mammalian and avian hosts, including cows, sheep, pigs, chickens, and crows. *Campylobacter* is a major cause of bacterial diarrheal illness in developing countries and was also present in the water during the Walkerton outbreak. *Campylobacter* caused 16 cases of illness during the summer of 2004 on South Bass Island (Ohio, US) where 1,450 cases of gastrointestinal illness in residents and visitors were reported (Ohio Department of Health 2005). During the outbreak, 9 cases of illness due to norovirus, 3 cases due to *Giardia* species and one case due to *Salmonella typhimurium* were also reported.

The main source of pathogens was widespread contamination of ground water and several water supplies remain closed (see figure above). In addition to having a variety of hosts, *Campylobacter* cells are viable for months and outbreaks have been associated with treated and untreated water sources. Other bacteria that have large environmental reservoirs include *Aeromonas*, *Salmonella*, and *E. coli*. Bacterial pathogens that are widespread in aquatic systems are *Pseudomonas*, *Enterobacter*, *Acinetobacter*, *Klebsiella*, and *Stenotrophomonas*. These pathogens commonly cause outbreaks in hospitals and recreational settings and are of particular concern because many are now resistant to antibiotics. Bacteria can share genetic information in several ways which allow them to rapidly respond to environmental change.

---

*Source: Ohio EPA, www.epa.state.oh.us/ddapw/SB1web/SB1_WaterUseStatus.pdf*
Toxic algae, commonly cyanobacteria or blue-green algae, produce several toxins harmful to humans and wildlife. The most well-known toxic alga is Microcystis. Concerns about harmful algal blooms (HABs) have increased over the last decade largely because of the perceived increase in the number and duration of events (Malone and Rockwell 2005). The toxins produced by these species cause finfish and shellfish poisoning, a variety of human pathologies that can lead to death, and mass mortalities of marine organisms including fish, mammals and birds. Recently, the economic impacts of HAB outbreaks along Chinese coast have been estimated to be > $1.2 billion US. A HAB outbreak in 1987-88 closed more than 400 km of North Carolina coastline for shellfishing during the peak harvesting season, causing economic losses estimated at $25 million (Malone and Rockwell 2005).

Protozoans are single-celled eukaryotes, some of which are obligate parasites that cause disease in humans. These pathogenic protozoans are often transmitted via the fecal-to-oral route (NRC 2004). The enteric protozoans of concern are Giardia lamblia, Cryptosporidium parvum, Toxoplasma, and Microsporidia. Because animals and humans are hosts to these enteric protozoans, there is the possibility of transmission between humans and other animals (zoonotic transmission). Populations of protozoans are influenced by both density-dependent and density-independent factors (NRC 2004). The density dependent factors include the population dynamics of the host, survival and reproductive success of the parasite while density-independent factors include abiotic factors such as temperature and climate. Parasitic protozoans form cysts or oocytes, which for enteric protozoa are the only form of the parasite that can survive outside its host. Giardia, one of the more common enteric protozoans, is an obligate parasite which causes diarrhea and abdominal pain in infected humans. Approximately 2.8 people worldwide, in both developed and developing countries, are infected with Giardia (Ali and Hill 2003). Microsporidia, which form spores rather than cysts, infect all animals and therefore have a large biotic reservoir. Thirteen species of Microsporidia are known to infect humans and two are associated with gastrointestinal disease (NRC 2004). Very little is known about the sources of Microsporidia and there are minimal data on its occurrence in surface waters (NRC 2004). Cryptosporidium and Toxoplasma are obligate parasites that require a host to reproduce. Cryptosporidium is an intestinal parasite and Toxoplasma is a tissue parasite. Cryptosporidium infections are ubiquitous and up to 30-50% of the US population has antibodies to C. parvum (Frost et al. 2002; Isaac-Renton et al. 1999). The primary host for Toxoplasma gondii is the domestic cat; however, oocytes have been found in freshwaters and coastal waters. Aside from humans, sea otters and marine mammals reportedly have become infected. In addition to these protozoan obligate parasites, two free-living protozoans can also cause illness. These are Naegleria and Acanthamoeba, both of which are common in aquatic ecosystems. Naegleria is found in stagnant bodies of freshwater while Acanthamoeba is found in more types of aquatic environments, including ocean sediments. The mode of infection for both forms is introduction to the nasal passages via swimming rather than the anal-to-oral route. Naegleria infections can be serious and involve the central nervous system rather than the gastrointestinal system.

Viruses are obligate intracellular parasites and several are among the emerging microbial pathogens receiving increased attention. The viruses of concern as waterborne pathogens include enteroviruses, norovirus, hepatitis A and E, parvovirus, and adenoviruses. Many human viruses infect the gastrointestinal or respiratory systems. Viruses persist in the environment and
are readily transmitted by water; viruses have been shown to persist 10 years, or more, in groundwater. In addition, the most common indicators for microbial pathogens, fecal coliform bacteria, are generally not a good measure of risk from viral pathogens (Payment and Rose 2005).

Sources
Pathogens are introduced to water systems by a variety of sources, although most are related to transporting human or animal waste into surface or ground water. The most obvious route is the direct discharge of untreated sewage into waterways. This may be the result of combined sewer overflows, separate sewer overflows, or failing septic systems. Nonpoint source pollution is also a vehicle for pathogen contamination, carrying pathogens from wildlife, livestock or humans to waterbodies via agricultural or urban runoff. Domestic cattle and sewage discharges are the primary sources of Cryptosporidium and Giardia (NRC 2004). Tile drainage and irrigation systems can have major impacts on receiving water quality. Pharmaceuticals are a growing concern in institutional septic systems (see Chapter #5 page 18) and raw septage is commonly spread on farmland which may be tile drained (see Chapter #5 page 18). Ballast is also a source of pathogens, of particular concern is the introduction of exotic algal species that may cause harmful blooms.

Methods of Detection and Monitoring
Indicators, rather than the pathogens themselves, are commonly used to monitor for microbial pathogens. These indicators are used instead of the actual pathogens because the indicator organisms are easier and less costly to sample and in many cases standard methods have been developed (NRC 2004). NRC (2004) identified important characteristics of indicator organisms (see box). Coliforms are the most common type of indicator used, many communities use fecal coliforms or E. coli as an indicator of human fecal contamination. In addition to coliforms, Enterococci have also been used because they are of fecal origin and have been strongly correlated with gastrointestinal illness from contact recreation (NRC 2004). Clostridium, a spore-forming bacterium, is a potential indicator for protozoan parasites such as Giardia and Cryptosporidium because the spores of Clostridium may behave similar to oocytes or cysts of the protozoans (NRC 2004). Bacteriophages, viruses that infect bacteria, are used as an indicator of viral pathogens.

The use of indicators is not without complications. The relationship between the indicator organisms currently used and health risks are poorly developed. Also, the use of indicators assumes that the indicator organisms occur at a constant ratio with the pathogens which is not always valid (NRC 2004). Indicators and pathogens also vary in space and time, complicating sampling and detection of the organisms. Payment and Rose (2005) illustrate the difficulties with indicators with the example of Helicobacter pylori. Studies in Pennsylvania have shown that H. pylori was found in wells that were free of the indicator, coliform bacteria. Thus, fecal
coliforms are a questionable indicator for *H. pylori*. More research on pathogens and indicator organisms is required to improve detection of pathogens and understand their ecology.

Several emerging techniques and approaches are improving the ability to detect and track pathogens. PCR techniques enable researchers to identify the actual pathogens rather than rely solely on indicators. PCR techniques can be time consuming and expensive, although new techniques such as real-time PCR have reduced the amount of time necessary to process samples. Also, micro-arrays have been developed using genomics technology. The micro-arrays, or biochips, can immobilize up to thousands of DNA probes for waterborne pathogens. Thus there is potential to identify a variety of microbes in a water sample. However, these tools are still being developed and need to be evaluated.

**SOCIAL FACTORS AFFECTING PATHOGENS**

Although we may think of humans as a direct source of pathogens by generating waste, the actions of society from water use to power generation also influence microbial pathogens. Sattar and Tetro (2005) discuss how social factors, such as advancements in technology, have unforeseen consequences on water quality. For example, drinking water treatment and disinfection practices drastically reduced the number of illnesses of common waterborne infections (Sargeant 2005). Several other advancements discussed by Sattar and Tetro (2005) include the development of antibiotics, agricultural uses, and municipal uses.

**Pharmaceuticals and Antibiotic Resistance**

Increasingly, antibiotics have been found in freshwater systems (Halling-Sorensen 1998). Until recently, nearly 1 in 3 Americans were prescribed antibiotics even though there was no valid medical reason to do so (Nyquist et al. 1998). These antibiotics pass through wastewater treatment facilities and are discharged to receiving waters. The presence of pharmaceuticals in these waters further promotes antibiotic resistance. Hagedorn et al. (1999) found bacteria resistant to antibiotics in waters which received feces from nonpoint sources. In addition, the widespread use of antimicrobial disinfectants may contribute to the problem. For example, lab studies with triclosan (a common active ingredient in antibiotic and antimicrobial soaps) show that bacteria which become resistant to triclosan also show resistance to antibiotics that rely on the same site of action to kill pathogens (Levy et al. 1999).

**Agriculture**

Agricultural runoff has long been considered a source of pollutants to waterways; however, much of the attention has been on nutrient loads into aquatic systems. Agricultural runoff also has a high microbial load, including bacteria and parasites. Sheep and cattle harbor *Campylobacter* and the application of manure is a known source of environmental contamination (Stanley and Jones 2003). Sischo et al. (2000) demonstrated that the likelihood of water contamination with *Cryptosporidium* was positively correlated with spreading manure. Also, a public inquiry in Canada suggested that runoff due to spreading manure may have been the cause of the North Battleford outbreak, which infected up to 7,000 people (Saskatchewan Justice 2002).
and there is wide speculation that runoff was also the cause of the Milwaukee incident, which resulted in over 400,000 cases of infection.

A recent trend that can also impact water quality is the concentration of animals into a small area (Kirkorn 2002). A Concentrated Animal Feeding Operation (CAFO) is a farming operation with more than 1,000 animal units (2,500 head for swine). There were over 238,000 such CAFO farms in the United States in 2002 which produced 500 million tons (227 million kg) of manure annually. This is approximately 3 times greater than the waste generated by the entire American population (U.S. EPA 2003). Several pathogens have been identified from the manure of CAFO animals (Guan and Holley 2003). They include *Helicobacter pylori; Streptococcus suis; Brucella suis; Campylobacter sp., Yersinia enterocolitica, Salmonella sp.; Listeria monocytogenes, Cryptosporidium parvum, and E. coli*. Another pathogen that has increased in prevalence in the developed world and is linked to swine farming is the hepatitis E virus (Clemente-Casares et al. 2003). Hepatitis E causes acute, self-limited, icteric hepatitis in humans and has been classified as a zoonotic infection (Smith 2001) with swine acting as the main animal reservoir. HEV was once endemic only in developing countries, has now been identified in the sewage of many industrialized countries including Spain, France and the U.S. (Kasorndorkbua et al. 2004).

**Municipalities**

Although municipal and other human activities account for less than 15% of all freshwater withdrawals in the U.S. and Canada, they have a disproportionately large impact on human health (Sattar and Tetro 2005). Local governments provide water and wastewater treatment for communities across the United States and Canada. Whether it is the use of a rural groundwater source or a public water system, the technological advancements of the last century have put clean water into nearly all homes and built a sense of confidence in the water (Hrudey and Hrudey 2004). However, as a result of events such as the Cryptosporidium outbreak in Milwaukee, the *E. coli* outbreak in Walkerton and others (Hrudey and Hrudey 2004), the public perception of safe water may be declining. Hence, the sales of point-of-use devices and bottled water are escalating.

As water travels from the drinking water treatment plant to the water tap, the residual disinfectant levels may be depleted. Biofilms, which grow within the distribution system, are currently a large area of study and are known to incorporate various opportunistic bacteria which may cause disease in susceptible individuals. Of note is *Mycobacterium avium*, which represents a major threat to immuno-compromised individuals (Aronson et al. 1999). Other potential biofilm-based bacteria include *Pseudomonas* (associated with hospital-acquired infections), *Moraxella* (ocular and respiratory infections), *Aeromonas* (urinary tract disorders) and *Legionella* (pneumonia). (Rusin et al. 1997; Pryor et al. 2004)

Three important issues arise when dealing with wastes produced by human activities; these are wastewater, sludge, and landfills. Many large cities now have some form of wastewater treatment to reduce the discharge of potential microbial or chemical contaminants into the watershed. For those treatment facilities that do not use a tertiary process, chemical pollutants that are not contained within the solid are released back into the environment, albeit at lower concentrations. Among the chemicals that may escape the treatment systems are common types
of pharmaceuticals and microbicides, some of which are the target of current studies in the Great Lakes region (Jasim 2004). The second waste issue deals with the fate of sludge produced at wastewater treatment plants. The use of sludge or biosolids produced from normal municipal wastewater facilities and their safety is controversial. Gerba & Smith (2005) have shown that some 150 enteric pathogens may exist and thrive in sewer sludge. Additionally, various chemical pollutants, such as antimicrobials, disinfectants and heavy metals are present and may also pose an environmental risk. Depending on the process by which sludge is converted into applicable biosolids, microbial and organic chemical loads may decline. However, there is always a risk for heavy metal and residual contamination through either leaching or runoff. Furthermore, this risk may be heightened due to potential interactions of pathogens and irritant chemicals (Lewis et al. 2002). Many communities now have programs to prevent potentially harmful chemicals from entering the municipal waste stream, thus reducing contaminant loadings of soils and receiving waters. Adequate treatment of municipal sludge, its safe storage, proper selection of the land disposal site as well as the right application ratios and disposal techniques are all essential to optimize the recycling of biosolids while virtually eliminating any human health risks from pathogens in them (Gale 2005). The threat to water through landfills is the third waste issue and is a problem that has emerged in the past few decades. Initially determined to be a safe environment in which to place unwanted solid wastes, the appearance of chemical contamination through leachates and plumes has all but destroyed some communities. In terms of microbial hazards from landfills, Sobsey (1978) showed that enteric viruses were barely able to withstand the environmental pressures of landfills and that contamination through leachates was, as in the case of biosolids, quite remote.

**MONITORING MICROBIAL PATHOGENS IN THE GREAT LAKES**

Given the threat to aquatic ecosystems and human health, information on the presences, distribution, fate and transport of pathogens is critical for their management. Monitoring is essential for gaining this information. The IJC conducted a ground-breaking bacteriological study in 1913-1914. This past effort, although lost to science for some time, was more comprehensive than current efforts today. Building on lessons learned from past and current monitoring programs, traditional and new approaches can be used to increase the knowledge base required to manage microbial pathogens in the Great Lakes.

*Historical Monitoring: A Lesson from the Past*

In the early 1900s, the IJC commissioned a landmark study to examine the extent of cross-boundary pollution in the Great Lakes. The study was limited to those areas where pollution on one side of the US-Canadian border was thought at that time to affect waters on the other (IJC 1914). The study examined more than 2000 miles of sampling transects and collected over 19,000 water samples. In all, 17 laboratories were involved in the study each of which was installed, equipped and staffed by the IJC. Assistance was also given by the US Public Health Service, the Provincial Boards of Health of Ontario and Quebec, the Michigan State Board of Health, and the New York State Department of Health. Also, many municipalities cooperated by providing information about their water and wastewater treatment practices. At the time the study cost $42,138, which was divided equally between the US and Canada.
A total of 1447 locations were sampled across the Great Lakes during the summer of 1913. The investigators used the most advanced methods for detecting and culturing bacteria at the time; these techniques correspond to modern sampling techniques for total coliform bacteria. In addition to the bacteriological analyses, meteorological data were recorded at the sampling sites. For all the municipalities, the area, population, source of water supply, amount of water pumped, and an estimate of sewage discharge was recorded. Each municipality also reported the number of deaths due to typhoid per 100,000 people. For some cities, bacteriological analyses of domestic tap water were also conducted.

The results of the study showed extensive cross-boundary pollution in the Detroit River, Niagara River, Rainy River, St. Clair River, St. John River, lower Lake Erie and lower Lake Ontario (IJC 1914). The major cause of this pollution was the discharge of untreated human sewage by municipalities and vessels into the waters of the Great Lakes. Based on these results, and the advice from an advisory board, the IJC (1918) recommended that “all sewage should, before being discharged into boundary waters, receive some purification treatment, and the degree of such treatment is to be determined in a large measure by the limits of safe loading of a water-purification plant.” The IJC also recommended that the requirement for treatment balance concerns of public health and economics. It is interesting to note that many of the current treatment approaches mirror the approach outlined by the IJC in 1918, namely primary (mechanical) and secondary (biological) treatment of sewage (IJC 1918). However, the recommendations were never acted upon and the study was lost to science because the results were not published in the scientific literature.

There are several lessons to be learned from the 1914 IJC study. One of the reasons the study was so advanced for the time is that the IJC consulted scientists, engineers, and public health officials across the basin for input into the study design (an expert panel was used to give serious review of the study methods and the adequacy of the research questions posed to the IJC by Canada and the US). These advisors promoted the use of the most technologically advanced methods; at the time bacteria samples were often grown in gel rather than agar (Durfee and Bagley 1997). Also, interested parties were given a chance to comment on the study at public hearings. Stakeholder participation is one of the essential elements for a successful ecosystem management plan (Hartig et al. 1998); the design and successful completion of the 1914 IJC study shows how input from experts and stakeholders can help produce high quality research. The study also shows the need for communicating findings and continued engagement with the government to produce results.

**Current Monitoring Efforts**

The Great Lakes region has not seen another study as comprehensive as the 1914 IJC assessment (Durfee and Bagley 1997). Various agencies at all levels of government currently monitor bacteria in the basin. However, a complete investigation into the extent of bacterial contamination in the Great Lakes has not been conducted recently. Current monitoring efforts include monitoring of drinking water and wastewater treatment facilities and recreational beaches.
In the US, EPA has set both health goals and legal limits for total coliform levels in drinking water (EPA 2001). The total coliform rule also provides details on the required monitoring protocol for water treatment plants, including the frequency and number of samples to collect. Wastewater treatment plants, or publicly owned treatment works (POTW), also monitor fecal coliform. Beach monitoring programs are commonly conducted by local government health departments. Potentially, these monitoring programs can provide important information regarding trends in near-shore bacterial contamination. However, long-term trends in the bacterial indicators are difficult to identify because of inconsistencies in monitoring methods and incomplete reporting over time.

In Canada, bacterial contamination of public Great Lakes beaches is regularly assessed during the swimming season by public health authorities, who determine the numbers of *E. coli* or similar (fecal coliform) bacterial indicators in the waters near public beaches (Edsall and Charlton 1997). Beach closures indicate high levels of bacterial contamination, at least in near-shore waters off the coast of recreational beaches. However, as in the US, sampling and testing procedures have not been standardized (Edsall and Charlton 1997). Unfortunately, given the gaps and inconsistencies in the data set it is not possible to truly assess trends in bacterial contamination at a given beach or across the Great Lakes.

Currently, there are many water quality monitoring programs in the Great Lakes basin; however, many of them do not include bacterial analyses. The recent USGS National Water Quality Assessment Program conducted a comprehensive study of water quality in Lake Erie and the St. Clair River (Myers et al. 2000) but fecal coliform bacteria were not included in the parameters monitored. University research programs, such as the University of Wisconsin-Milwaukee WATERbase program (UWM 2003), do monitor bacterial levels but the focus is on free-living bacteria and bacterial production not pathogens. As human illness in the Great Lakes region due to waterborne contaminants became rare in the 20th century (Health Canada 1995a, 1995b, 1995c; Health and Welfare Canada 1980), management and monitoring efforts have shifted to focus on other environmental problems such as invasive species, eutrophication, and toxic sediments. There also seems to be a shift in focus to using ecosystem-level indicators in the Great Lakes following the start of the State of the Lakes Ecosystem Conference (SOLEC) program which began in 1994. Microbial pathogens are still a major concern in the Great Lakes basin, particularly given the number of combined sewer overflows in the basin (IJC 2004). However, new methods to detect the actual pathogens rather than the use of indicators such as total coliform or *E. coli* have been recommended by the IJC (IJC 2004).

While water quality data are gathered now at the county and state level, there is no comprehensive data base, the data are fragmented in time and space in the Great Lakes basin, and there is no consistent methodology. Thus our current lack of understanding on the extent of bacterial contamination in the Great Lakes largely is due to a lack of consistency in monitoring, lack of assessment, and lack of basin-scale planning. Future efforts can learn from these past and present successes and failures which show the importance of stakeholder engagement, long-term commitment, and communication in developing a successful strategy for managing bacterial pollution in the Great Lakes.

*The Global Ocean Observation System: A Model Monitoring Program*
The Global Ocean Observation System (GOOS) is a global network that collects and disseminates data and information (Malone and Rockwell 2005). At the United Nations Conference on Environment and Development, member nations ratified the Framework Convention on Climate Change and the Program of Action for Sustainable Development that called for the creation of a GOOS to enable effective management of marine systems. The GOOS, as it is being developed, is based on the data and information requirements of groups that depend on oceans, thus it is a multi-user (e.g., scientists, managers) and multidisciplinary (e.g., chemistry, biology, oceanography) approach.

The GOOS is designed to deliver relevant information quickly to users to achieve management goals and make informed decisions. GOOS is composed of:

- A monitoring network that comprises both in situ and remote sensing measurements.
- A data assimilation and analysis component that includes conceptual, statistical and numerical models as well as Geographic Information Systems.
- A data communications component to provide rapid access to the information gathered.

An example of how such a system can work is illustrated by the Gulf of Mexico Harmful Algal Blooms Observing System (HABSOS) (Malone and Rockwell 2005). The ultimate goal of HABSOS is to predict the probability of when and where harmful algal blooms will occur and impact humans and fisheries. The ability to make this prediction requires information on the algal species, factors that influence blooms and water currents, to name but a few examples. Based on observations of the forcing functions of blooms (e.g., wind, flow, nutrients) and ecosystem properties, models can be developed to predict blooms based on environmental conditions.

An observing system such as GOOS could be used for monitoring pathogens in the Great Lakes and used for managing public beaches (Malone and Rockwell 2005). As previously discussed, beach closings are based on monitoring data. However, given the time lag between collecting a sample and lab analysis, a beach may stay open while it is actually unsafe or closed after the fact. Thus, a way to monitor and predict exposure to pathogens at beaches could improve management efforts and be more protective of human health. A Great Lakes observing system to make more informed decisions could use the GOOS/HABSOS model in the following way. First, basic information about the pathogens are needed to characterize their transport and fate in the environment. New techniques are available for tracking. For example, pathogens introduced via stormwater runoff are concentrated in plumes that can be detected by remote sensing. The movement of this plume, combined with information on the pathogens, can be used to make predictions about the risk to bathing beaches. A regional system is currently being developed for southern Lake Michigan beaches (Whitman 2005).

In order to develop an effective Great Lakes observing system, three capabilities must be developed. These are more rapid detection of pathogens, timely predictions of where and when public health risks are unacceptable, and timely forecasts of trajectories and contaminated water masses in space and time. In order to accomplish this, more investment will have to be made in monitoring (in situ and remote sensing) and in research on pathogens. Also, the system must be
sustained (permanent) to provide continuity and to capture the variability that characterize the aquatic environment and the organisms which inhabit it.

**MANAGEMENT OF MICROBIAL PATHOGENS**

**Current Programs**

In the US, EPA has set both health goals and legal limits for total coliform levels in drinking water (EPA 2001). EPA has set the health goal for total coliforms in drinking water at zero. Also, water systems finding coliforms in more than five percent of the samples collected each month fail meet the total coliform standard. If more than five percent of the samples contain coliforms, water system operators must report the violation to the state. Positive fecal coliform tests may indicate that the system's treatment technologies are not performing properly. Systems may need to take a number of actions to avoid or eliminate contamination when coliforms are found, including repairing the disinfection/filtration equipment, flushing or upgrading the distribution system, and enacting source water protection programs to prevent contamination (EPA 2001). The only limit on coliform bacteria in the ambient water may be found in the exception to the *Surface Water Treatment Rule* (EPA 1989) to avoid filtration of surface waters which states that total coliform bacteria should be less than 100 CFU/100ml or fecal coliform should be less than 20 CFU/100 ml in 90% of the samples collected.

In the US, fecal coliform is considered a conventional pollutant under the Clean Water Act and so it is controlled through use of technology standards. POTWs must use the best available technology to minimize the amount of fecal coliform in effluent discharged to receiving waters. It is interesting to note that many of the current treatment approaches mirror the approach outlined by the IJC in 1918, namely primary (mechanical) and secondary (biological) treatment of sewage (IJC 1918).

The US BEACH Act of 2000 requires states to adopt bacteria limits as a part of their state water quality standards that are protective of human health. EPA (2004) recently published the final rule for coastal and Great Lakes waters which sets federal standards for ambient bacteria levels. EPA (2004) has recommended a criterion of 126 /100ml for *E. coli*. Michigan and Ohio have already adopted standards as protective as this new EPA criterion, the other Great Lake States are in the process of adopting similar standards (EPA 2004). In Canada, bacterial contamination of public Great Lakes beaches is regularly assessed during the swimming season by public health authorities, who determine the numbers of *E. coli* or similar (fecal coliform) bacterial indicators in the waters near public beaches (Edsall and Charlton 1997). Beach closures indicate high levels of bacterial contamination, at least in near-shore waters off the coast of recreational beaches. As with monitoring data in the basin, long-term trends in beach closings are difficult to interpret because of inconsistencies in monitoring methods and incomplete reporting over time. Another complicating factor is the use of varying guidelines for what triggers a beach closing. The new EPA rules (EPA 2004) require an *E. coli* standard of at least 126/100 ml but states are allowed to use a more stringent standard. In Canada, Ontario uses a standard of 100/100ml whereas the national standard recommended by Environment Canada is 200/100 ml (Edsall and Charlton 1997).
**A New Management Tool: The HACCP Approach**

The Hazard Analysis and Critical Control Point (HACCP) system is widely used in the management of food and water quality and safety (Martel et al. in prep). The purpose of creating a HACCP plan is to document the major sources of risk to the endpoint of concern, identify and implement the major means of controlling those risks in practice, undertake monitoring to provide early warning of the failure of those control processes and to have ready to go corrective actions that will be implemented when control processes fail (Deere and Davidson 2005).

There are six basic steps in developing HACCP plan as described by Deere and Davidson (2005). First, those involved in creating the HACCP must commit resources to developing the plan. Once the participants are identified, each chooses a representative to serve on a team to work on the HACCP. Once resources have been committed the scoping phase can begin. This step calls for the identification of all users, uses, and requirements. Because this is a risk management system, the two essential questions are to what or to who are the risks to be assessed and what are the water quality requirements to meet the uses identified. The third step is to develop a conceptual model of the sources of risks to uses and users and possible control strategies. Once these are identified, the fourth step is to conduct a risk assessment. During the step, the risks are systematically identified. This includes identifying the risk of water quality being unacceptable for uses or to users, the causes (events) and hazards (contaminants), and control measures to reduce risk. The fifth step is risk management planning in which control loops are identified. These control loops identify the controls, monitor effectiveness of controls, and attempt to correct any failures based on the monitoring. The sixth and final step is validation and verification of the HACCP. Validation is determining if the scientific and technological underpinnings of the plan are valid whereas verification determines if the plan is being implemented and requirements are met.

Once complete and implemented, the HACCP plan provides confidence that the major risks have been identified and that ongoing, operational controls are in place to manage the risks to water quality and to give early warning if water quality is likely to become impaired. Over time, the plan can be improved, using adaptive management, as well as through expansion of its scope and the rigor of its implementation.

**CONCLUSIONS**

Although a variety of topics regarding pathogens have been discussed, there are several common themes. These common themes identify research and management needs for the Great Lakes basin. First, there is a need to understand the natural history and ecology of pathogens and indicators in order to better detect and manage risks to human health. Secondly, a comprehensive strategy to monitor waterborne microbial pathogens is required. This strategy should use consistent methods across the basin, use the latest technologies, be maintained so that long-term data are collected, and be readily accessible. The GOOS can serve as a model for how a monitoring program or observation system can be used to serve a variety of users and goals. Lastly, a comprehensive management approach is needed to address the risks from waterborne pathogens. The HACCP provides a step-by-step approach for how to implement a management plan based on risk assessment.
RECOMMENDATIONS

The Scientific Advisory Board recommends to the International Joint Commission:

i. That the parties invest substantially in research and pilot studies on the removal of emerging pathogens from wastewater treatment plant effluents, environmentally friendly sludge disposal, and in strategically upgrading wastewater treatment infrastructure.

ii. That the parties create a waterborne disease registry for the Great Lakes basin.

iii. That the parties identify the role of NIEHS and other organizations in addressing these emerging research issues.

iv. That the parties create an Environmental Pathogens Program, similar to the Binational Toxics Strategy, to establish an inventory of baseline data for the United States and Canada and to undertake a complete analysis of pollution reduction scenarios for key sources and determine their effectiveness in reducing microbial contamination of the waters of the Great Lakes basin.

v. That the parties establish consistent monitoring frameworks for pathogens across the Great Lakes basin.

vi. That the parties encourage the application of new technology and approaches to detect, monitor, and control microbial contamination.

vii. That the parties invest in creating an information database for water quality, including microbial pathogens, for the Great Lakes.

viii. That the parties establish a Microbial Water Quality Network to foster collaboration among groups conducting water quality monitoring in the Great Lakes basin.

ix. That the parties explicitly address public health as a basin issue that is affected by water quality, air quality, and land use.

x. That the parties recognize the need for partnerships and programs addressing waterborne pathogens.

xi. That the parties challenge Administrator Johnson to address the development of these key programs.

xii. That the parties include the approaches for Source Water Protection supported by Ontario Minister of the Environment: Honorary Leona Dombrowsky.
SOURCE DOCUMENTS

This summation was based on the following documents prepared for the IJC:


LITERATURE CITED


International Joint Commission. 1914. Progress report of the International Joint Commission on the reference by the United States and Canada in re the pollution of boundary waters whether or not such pollution extends across the boundary in contravention of the treaty of January 11, 1909 and if so, in what manner or by what means is it possible to prevent the same. www.ijc.org/php/publications/pdf/ID35.pdf


Whitman, R.L. 2005. Progress Report Grant Project Number GL98500001, City of Chicago Department of Environment, David Rockwell Project Officer