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VULNERABILITY OF WATERBORNE DISEASES TO CLIMATE CHANGE IN CANADA: A REVIEW

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This project addresses two important issues relevant to the health of Canadians: the risk of waterborne illness and the health impacts of global climate change. The Canadian health burden from waterborne illness is unknown, although it presumably accounts for a significant proportion of enteric illness. Recently, large outbreaks with severe consequences produced by E. coli *O157:H7 and* Cryptosporidium *have alarmed Canadians and brought demands for political action. A concurrent need to understand the health impacts of global climate changes and to develop strategies to prevent or prepare for these has also been recognized. There is mounting evidence that weather is often a factor in triggering waterborne disease outbreaks. A recent study of precipitation and waterborne illness in the United States found that more than half the waterborne disease outbreaks in the United States during the last half century followed a period of extreme rainfall. Projections of international global climate change scenarios suggest that, under conditions of global warming most of Canada may expect longer summers, milder winters, increased summer drought, and more extreme precipitation. Excess precipitation, floods, high temperatures, and drought could affect the risk of waterborne illness in Canada. The existing scientific information regarding most weather-related adverse health impacts and on the impacts of global climate change on health in Canada is insufficient for informed decision making. The results of this project address this need through the investigation*

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of the complex systemic interrelationships between disease incidence, weather parameters, and water quality and quantity, and by projecting the potential impact of global climate change on those relationships.

Waterborne disease and drinking-water safety—believed previously by most Canadians to be a problem only in tropical countries—have become, post-Walkerton, among Canada's most pressing health concerns. In retrospect, waterborne disease outbreaks are not uncommonly reported in Canada, with over 200 credible or suspected waterborne events recorded nationally since 1975 (Health Canada, 2002). It has become apparent that urban growth, aging sewage and water treatment infrastructure, and fiscal reform of public services in recent years may have contributed to a decline in water safety nationwide. New pathogens are emerging, such as *Escherichia coli* O157:H7 and *Cryptosporidium* (WHO, 1996), with sometimes severe clinical implications and, in the latter case, resistance to traditional water disinfection (Office of Laboratory Security, PPHB, Health Canada, 2000). Weather has also played a significant historical role in triggering a number of reported waterborne disease events in Canada (Hrudey et al., 2003). The weather, always a challenge to predict, is undergoing significant alterations from historical patterns.

Although a separate concern to many Canadians, the potential health impacts of global climate change are increasingly being weighed by policymakers and national decision makers. Perhaps a few are aware of the potential water-related health implications of pronounced climate change. Existing wells and water and sewage treatment systems were designed to operate within expected levels of precipitation, ambient temperature, snow cover, snow melt, water levels, sea level, and coastal dynamics. The frequency and severity of drought, flood, sea-level rise, extreme rainfall, and changes in snow cover and timing of snowmelt may change in some parts of Canada under conditions of climate change. As a result, pathogen entry and behavior in source and finished water will also be subject to change. Public health professionals and water managers need to know as much as possible about these potential changes, in order to take the necessary steps now to protect public health now and in the future. A project at the University of Guelph, in collaboration with Health Canada and Environment Canada, has been funded by Health Canada's Health Policy Research Programme to investigate this issue.

WATERBORNE ILLNESS IN CANADA

The Canadian burden of waterborne illness is thought to account for a significant proportion of enteric illness. Payment and colleagues (1991) estimated that 35% of enteric disease in Montreal was due to preventable waterborne illness. There were 4200 cases of giardiasis and 1600 cases of cryptosporidiosis reported in Canada in 2001, but the proportion of cases that was waterborne is not known (Health Canada, 2002). The incidence of these diseases is probably much higher than what is captured by these data (Majowicz et al., 2001; Frost et al., 1996). Infective *Giardia* cysts have been shown to be widespread in raw surface waters for some time in Canada (Wallis et al., 1996). Although many cases are known or presumed waterborne, other cases are not. For example, persons with HIV are overrepresented among the cases of cryptosporidiosis, for reasons including compromised immunity, community and zoonotic exposure, and behavioral factors (Hunter & Nichols, 2002). Nonetheless, Hunter and Nichols (2002) suggest unboiled tap water is an important source of exposure for this group. Majowicz et al. (2001) found that 5% of cases of cryptosporidiosis reported in Ontario occurred in persons with HIV. Both giardiasis and cryptosporidosis are more frequently reported in children (Majowicz et al., 2001; Greig et al., 2001), in whom community exposure and behavioral factors likely play a role. Payment et al. (2000) found *Cryptosporidium*, *Giardia*, and enteric viruses in samples taken at each of 45 water treatment plants along the St. Lawrence River. They were able to model a measurable risk of giardiasis in some of these communities, depending on water temperature and treatment practices.

Waterborne cases and outbreaks have been associated with *E. coli* O157:H7, *Campylobacter*, enteric viruses of the genus *Norovirus* (*Norovirus* is the genus of caliciviruses that includes the Norwalk-like viruses as cited in Oliver et al., 2003), occasionally *Shigella*, and a number of other enteric pathogens (Lee et al., 2002; BruceGrey-Owen Sound Health Unit, 2000; Levy et al., 1998). Of cases of enteric illness that are reported, often the source is not identified and may be any of travel, waterborne, food-borne, or person-to-person transmission. A few cases of cholera are reported in Canada annually, including three indigenous cases (Health Canada, 2002; WHO, 2001, 2002). Other pathogens, such as hepatitis A (404 cases reported nationally in 2001, Health Canada, 2002), leptospirosis (rare, not notifiable), and Legionnaire's disease (41 cases reported nationally in 2001; Health Canada, 2002), can be waterborne but do not produce gastrointestinal illness. Some cases of enteric illness may have been acquired outside Canada. Canada's native peoples may be at particularly increased risk of waterborne enteric illness due to poor availability of safe drinking water in remote areas (Rosenberg et al., 1997).

Occasionally, outbreaks of gastrointestinal illness occur where, by epidemiological investigation, water is unquestionably implicated; these events provide a reasonable starting point for assessing the scope of the Canadian waterborne illness problem. Preliminary results from an analysis of a subset of near 40 Canadian historical reported waterborne disease events include outbreaks reported from 7 provinces and 1 territory. It is of note that outbreaks have been reported from all provinces and territories during this period, but not all were included in this initial subset of confirmed outbreaks. *Giardia* was the most frequent cause of these outbreaks, followed by C*ryptosporidium* (diagnosed since 1993 only) and C*ampylobacter*. Most involved a surface-water source (usually a rural watershed). Mechanical problems with treatment were implicated in many of the outbreaks where water treatment information was known (in less than half of all outbreaks in this subset). Outbreaks in this subset frequently occurred in the spring. Snowmelt and heavy spring rainfall may be significant factors contributing to the many of such spring outbreaks. In Ontario, four outbreaks were linked to heavy snowfall, snowmelt, or heavy rainfall along with resulting turbidity. British Columbia and Quebec each had two outbreaks linked to heavy rainfall.

An analysis of passive surveillance data in the National Notifiable Disease Records (1987–2001; see www.hc-sc.gc.ca/pphb-dgspsp/dsol-smed and Health Canada, 2002), which capture laboratory confirmed endemic cases and those linked to outbreaks, suggests there has been a distinct drop in both the rate and the number of reported cases of giardiasis and campylobacteriosis in recent years. Cases of verotoxigenic *E. coli* have peaked and fallen twice since reporting began in 1990 (mean near 1400 cases per year). Cryptosporidiosis has only been captured in this database since 2000 (573 cases in 2000, 1643 cases in 2001, including the Battleford, SK, outbreak; Health Canada, 2002). Majowicz and colleagues (2001) found the mean incidence of cryptosporidiosis in Ontario in 1996–1997 to be 2.13 per 100,000 people, but suspected substantial underreporting of the disease due to sporadic testing for the pathogen. In Ontario, males, children under 5 yr of age, and rural residents were at elevated risk. Of the cases where a suspected source was reported, 48% listed water, livestock exposure was a factor in 21% of cases, person-to-person transmission in 15% of cases, and travel outside of the province a factor in 22% of cases. In a similar study of *Giardia* reported in Ontario, Greig et al. (2001) found a mean annual age- and gender-adjusted rate of 26 cases per 100,000 population. Again, higher rates were found in males and children, and in urban populations. Incidence peaked in late summer or early fall.

HOW DO PEOPLE BECOME ILL FROM WATER?

Waterborne pathogens are spread through contaminated drinking water, exposure to contaminated water while swimming or other activities, or secondarily through food contaminated with bad water (Rose et al., 2001). All of these transmission patterns may be affected by climate variability and thus potentially by climate change.

For drinking water to be a source of illness, the water must first become sufficiently contaminated, escape treatment, or treatment must fail. Water may become contaminated by animal or human waste at source. Human sewage, leaking septic systems, manure runoff from agricultural lands, and wild animal wastes may all contaminate surface water later used for drinking water. Groundwater may become contaminated by surface contamination of wells, subsurface inflows, improperly situated septic fields, or leaking dumps (chemical contamination). Drinking water may also become contaminated during or after the treatment process. A persistent threat to public health, antiquated combined sewer systems (CSS) carry both storm water and raw sewage to the sewage treatment plant. When the flow of water is too great for the system (heavy rainfall, snowmelt, etc.), the sewers overflow directly into a surface water body (river, lake). Thus pathogens, industrial wastes, and city street contaminants run untreated into water, contaminating downstream drinking water sources, beaches, and fish and shellfish. For example, more than 67 municipalities in Ontario have CSS (at least since 1956), providing service to millions of people. Seventy-five percent of residents of large cities in Ontario are served by these systems (Tufgar et al., 2001).

Waterborne pathogens generally have a human or animal reservoir. A study of sewage effluent found that *Cryptosporidium* oocysts were present in sewage effluent and surface waters, with likely sources including septic tank leakage, recreational bathing, and agricultural runoff (Madore et al., 1987). Human waste is often a source of water contamination (Hafliger et al., 2000; Stirling et al., 2001; Ljungstrom & Castor, 1992). *Cryptosporidium* is found in a wide range of mammals, particularly cows (Howe et al., 2002; Jellison et al., 2002; Kistemann et al., 2002; Rose, 1997). In the Walkerton, Ontario, spring 2000 outbreak, *E. coli* O157:H7 and *Campylobacter* originated from cattle manure on a nearby farm (O'Connor, 2002). Deer and elk were thought to be the source of *E. coli* O157:H7 in an outbreak in Alpine, WY, in 1998 (Olsen et al., 2002). In a toxoplasmosis outbreak associated with a municipal water supply in Victoria, British Columbia, in 1995, both cougars and domestic cats were implicated (Aramini et al., 1999). Thus, there are many sources of contamination in Canadian watersheds.

Weather is often a factor in triggering waterborne disease outbreaks. The impact of heavy rainfall on waterborne illness may be widespread. Curriero et al. (2001) found that more than half the waterborne disease outbreaks in the United States during the last half century followed a period of extreme rainfall, with 68% of the outbreaks following storms of a severity that ranked in the top 20% for that region. Excess rainfall resulted in surface contamination of groundwater and contributed to the Walkerton outbreak of *E. coli* O157:H7 (Auld et al., 2001), drought followed by heavy rainfall preceded a large waterborne outbreak of *E. coli* O157:H7 in New York in 1999 (Patz et al., 2001). Extreme precipitation preceded the massive outbreak of *cryptosporidium* in Milwaukee in 1993 (MacKenzie et al., 1994) and preceded several other outbreaks of waterborne illness (Rose et al., 2001). A study of the Delaware River found a positive association between amount of rainfall and concentrations of *Cryptosporidium* oocysts and *Giardia* cysts (Alterholt et al., 1998). A large waterborne outbreak of toxoplasmosis in Victoria, BC, was associated with extreme precipitation (Bowie et al., 1997). Elevated turbidity caused in part by rainfall has been associated with a significant proportion of physician visits and hospitalizations for nonspecific gastroenteritis in some urban areas (Aramini et al., 2000; Schwartz et al., 2000). Kistemann et al. (2002) found that floods make extremely large contributions to the bacterial and parasite loads of drinking water reservoirs. Their results showed that substantial shares of the total microbial loads in watercourses and in drinking-water reservoirs result from rainfall and extreme runoff events. The dynamics of floods during runoff events correspond well with drastic increases in turbidity. Peak occurrences of leptospirosis have been associated with high precipitation levels (Vinetz et al., 1996), and outbreaks of leptospirosis have been linked to recreational exposure to infected water (rafting, boating, swimming; Morgan et al., 2002; Trubo, 2001).

If weather is a determinant of waterborne disease outbreaks, it is likely also a contributing factor to endemic cases of disease. As the weather changes in the coming decades, we may be faced with new public health challenges.

CLIMATE CHANGE IN CANADA

Projections of global climate change models suggest that the globally averaged surface temperature will increase by 1.4 to 5.8°C over the period 1990 to 2100 due to the accumulation of greenhouse gases in the atmosphere (IPCC, 2001). Some climate models project more extreme weather, such as intense rainstorms, thunderstorms, high winds, tornadoes, and ice and snowstorms (Francis & Hengeveld, 1998; Groisman & Easterling, 1994). Increased precipitation frequency and intensity have been noted in recent years in North America (Karl et al., 1995). The risk of waterborne illness in Canada could hypothetically be affected by excess precipitation, floods (increased runoff, decreased effectiveness of treatment), and drought (water availability, water pressure, and compaction contributing to runoff when rain eventually does fall). There may be increased risk that heavy rain or snowmelt may flush manure, human sewage, and wildlife and pet droppings into surface drinking-water reservoirs or groundwater, leading to contamination of drinking water sources. In truth, the future risk to Canadians of waterborne illness will be the result of highly complex interactions between changing weather, ecosystem changes, microbial and parasitic evolution, and technological and societal adaptations. A first step in understanding these potential impacts is the identification of existing vulnerabilities to climate variability.

Climate change projections for Canada are summarized in Table 1. Most of Canada may expect longer summers, milder winters, and increased summer drought (Government of Canada, 2002). Canada is likely to experience a higher than average increase in temperature and a decrease in summer soil moisture, due to its northern latitude. Northern areas are expected to have a greater increase in winter temperatures and more precipitation than now, especially in the winter.

Although national summaries have some use, climate change projections vary regionally. The Pacific coast has greater densities of human settlement in low-lying areas vulnerable to sea-level rise than the Atlantic coast. Low-lying coastal areas would be threatened, and this, combined with increased precipitation, may lead to an increase in flooding and erosion, and may affect the location and effectiveness of water treatment plants.

The Prairies frequently experience periodic drought; projected higher temperatures and evapotranspiration would propagate drought conditions. Irrigation may become more widely necessary, with potential increases in soil salinity

TABLE 1. A Summary of Climate Change in Canada

The greatest increases in temperatures will occur in high latitudes in winter and over land.
Changes in precipitation will vary according to region, but could triple in the far north.
Increased precipitation frequency and intensity has been noted in recent years in North America (Karl et al., 1995).
Sea level will likely rise by an average of 5 cm per decade for the next 100 years; however, this is susceptible to regional variation.
Extreme weather events will be more frequent and more severe.
There will be a global mean increase in precipitation and evaporation between 3% and 15% (but the location and timing is still unknown).
The mid-latitude rain belt currently in place would shift northward.
Spring runoff and snowmelt would occur earlier in the year.
Evapotranspiration (combination of effects caused by water evaporation and transpiration by plants) would start earlier and continue longer.
Interior continental region of Northern Hemisphere will experience drier summers.

Note. From Government of Canada (2002).

and degradation of soil quality. Warmer temperatures and low-flow/low-volume situations will create brackish conditions that favor the survival and sometimes the growth of some pathogens. Large accumulations of contaminants may pose a risk to surface water during extreme precipitation following drought. Available surface water will become scarcer, and groundwater levels may drop.

The projected average temperature for the densely populated Great Lakes–St. Lawrence Basin region could increase by up to 4.5°C by 2055, with a higher increase in the winter than in the summer. Great Lakes water levels could decrease by 0.5 to 1.0 m, which may necessitate dredging, and outflow of the St. Lawrence River could decrease by 20%. This would have detrimental effects on water quality and quantity, affect water treatment plant intake, and potentially require the relocation of treatment plants. This region will also experience more unpredictable winters with an overall decrease in snowfall. Warmer temperatures favor bacterial and algal growth in lakes, which contribute to water quality problems. New demands may be placed on the Great Lakes, for example, to supply New York City if increasing sea level adversely affects its current source of drinking water.

Floods associated with increasing sea level would threaten the low-lying areas of the Atlantic coast. Saltwater intrusion can contaminate groundwater aquifers, disturb estuaries, and displace fresh-water fish populations. Such intrusions may have impacts on drinking-water supply and on sewage and water treatment in the Maritimes. The effects of warmer climate on ocean circulation, wave patterns, and frequency of tropical storms are still unknown.

A rise in sea level would flood northern coastal regions of Canada. The gradual melting of permafrost will alter water runoff and destabilize the land. An increase in precipitation mostly in the fall and winter would result in a great accumulation of snow, which may lead to increased runoff and flooding with spring thaw.

CLIMATE CHANGE: IMPLICATIONS FOR WATERBORNE ILLNESS

Every region of Canada is likely to be affected by climate change. Alterations in risk of waterborne illness, in particular, may be associated with heavy precipitation, drought, flooding, and coastal erosion. Increases in precipitation could intensify flooding and increase erosion, with potential for surface and groundwater contamination by enteric pathogens, and decreased effectiveness of water treatment. During flood events, contamination of wells and surface water is widely assumed, and boil water advisories are generally issued (for example, southeastern Manitoba, June 2002; Manitoba Health, 2002). Drought increases the demand for water when the supply is significantly reduced and vulnerable. Heavy rain following drought can lead to more severe runoff and risk of water contamination. The rise in sea level may displace Canadians in coastal communities, resulting in temporary disruptions in water supply and a need for new fresh water sources.

Climate change may affect the worldwide distribution of cholera and other waterborne diseases, altering risk of disease to visitors to and from Canada. Cases of illness acquired elsewhere but necessitating treatment in Canada add to the overall burden on the health care system, and may pose a public health threat unless a resilient and adaptive public health infrastructure is maintained within the country.

MEASURING THE IMPACT IN CANADA

Our understanding of the links between waterborne illness and climate change will always be fraught with uncertainty, reflecting an uncertainty in the knowledge base as well as inherent uncertainties in the complex socioecological systems within which these events happen. Science for policymakers requires us to reduce the level of uncertainty in the basic knowledge base as well as to identify the boundaries of the inherent uncertainty.

Since the occurrence of several high-profile outbreaks in Canada (Walkerton, Victoria, North Battleford) and the prospect of new agreements on climate change internationally, there is some urgency for this scientific agenda. Generating new knowledge within a short time frame of the potential impacts of climate change on waterborne illness requires a broad interdisciplinary approach and a departure from traditional scientific research methods. Ongoing dialogue with decision makers and policymakers is also needed. The formation of teams of researchers with the required skills is facilitated by national research networks, such as the climate change and health issues networks coordinated by the Climate Change and Health Office, Health Canada.

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