CHAPTER 7:
HUMAN HEALTH

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KEY FINDINGS

- Stronger evidence has emerged since 2008 that a wide range of health risks to Canadians are increasing as the climate continues to change. For example, climate-sensitive diseases (e.g. Lyme disease) and vectors are moving northward into Canada and will likely continue to expand their range. In addition, new research suggests climate change will exacerbate air pollution issues in some parts of Canada, although further reductions of air contaminant emissions could offset climate change impacts on levels of ground-level ozone and particulate matter.
- A range of climate-related natural hazards continue to impact communities and will pose increasing risks to health in the future. For example, recent flood and wildfire events have severely impacted communities through destruction of infrastructure and displacement of populations.
- Many adaptation activities are being taken from local to national levels to help Canadians prepare for the health impacts of climate change. Adaptation planning should consider the important differences in factors responsible for health vulnerability among urban, rural, coastal and northern communities.
- Provincial, territorial, and local health authorities are gaining an increasing knowledge of climate change and health vulnerabilities through assessments and targeted research, and some jurisdictions have begun mainstreaming climate change considerations into existing health policies and programs. Greater efforts are also being made to increase public awareness about how to reduce climate-related health risks.
- Addressing key knowledge gaps and strengthening adaptation efforts would reduce the growing risks from climate change, which leave some individuals and communities highly vulnerable to associated impacts. Adaptation tools and measures, such as heat alert and response systems, projections of vector-borne disease expansion and greening urban environments can help protect Canadians from the effects of climate change being felt now and from future impacts.

1. INTRODUCTION

Climate change poses significant risks to human health and well-being, with impacts from extreme weather events and natural hazards, air quality, stratospheric ozone depletion and water-, food-, vector- and rodent-borne diseases (Seguin, 2008; Costello et al., 2009; WHO, 2012b) (*see* Table 1). Vulnerability is a function of the exposure to hazards associated with changing weather and climate patterns, the sensitivity of specific populations, and the ability of individuals and communities to take protective measures (Seguin, 2008; WHO, 2012b). For example, some populations or regions, such as Canadians living in the North, face particular health challenges related to high exposure to climate hazards (Seguin and Berry, 2008). The extreme heat events in Europe in 2003 and more recently in Russia in 2010, which together caused an estimated 125 000 deaths (Robine et al., 2008; Barriopedro et al., 2011) show that countries not well prepared for climate-related events can be severely impacted. The economic costs of climate change on communities is expected to increase (Stern, 2006; NRTEE, 2011) and the costs of weather-related disasters in Canada have been rising rapidly for decades (*see* Figure 2, Chapter 5). Previous Canadian assessments indicate that Canada is vulnerable to the health impacts of climate change as a result of changing health, social, demographic and climate conditions (Lemmen et al., 2008; Seguin and Berry, 2008; Commissioner of the Environment and Sustainable Development, 2010).

In recent years, greater efforts have been taken by public health and emergency management officials and non-governmental organizations to better prepare Canadians for climate change impacts on health (Berry, 2008; Paterson et al., 2012; Poutiainen et al., 2013). Health adaptation is defined in this chapter as actions taken by health sector officials, in collaboration with those in related sectors, to understand, assess, prepare for and help prevent the health impacts of climate change, particularly on the most vulnerable in society. Adaptation is a planned and comprehensive approach to address climate change risks that supports broader goals of sustainability and resiliency, while coping is concerned primarily with minimizing immediate damages associated with a climate-related impact. Adaptation actions include raising awareness of health risks and the need for adaptive actions, as well as the provision of information and tools to help address current and projected future vulnerabilities (Pajot and Aubin, 2012; Paterson et al., 2012; Poutiainen et al., 2013; OCFP, 2011).

This chapter reports on the findings of recent research (post-2006), focusing on health outcomes from current climate-related impacts, how risks to health could increase as the climate continues to change, and what adaptation options and tools are available to public health and emergency management officials. Regional vulnerabilities are highlighted where data permits and case studies of impacts and adaptation initiatives are included. New research findings regarding characteristics and circumstances that increase the vulnerability of some individuals or certain groups are highlighted to help address barriers to action. Analysis in this chapter draws from information in Chapter 2 – An Overview of Canada's Changing Climate, and also builds upon findings from previous Government of Canada assessments (Lemmen et al., 2008; Seguin, 2008) that reported on health vulnerabilities (*see* Table 2).

Health Impact Categories	Potential Changes	Projected/Possible Health Effects
Temperature extremes	• More frequent, severe and longer heat waves • Overall warmer weather, with possible colder conditions in some locations	• Heat-related illnesses and deaths • Respiratory and cardiovascular disorders • Possible changed patterns of illness and death due to cold
Extreme weather events and natural hazards	• More frequent and violent thunderstorms, more severe hurricanes and other types of severe weather • Heavy rains causing mudslides and floods • Rising sea levels and coastal instability • Increased drought in some areas, affecting water supplies and agricultural production, and contributing to wildfires • Social and economic changes	• Death, injury and illness from violent storms, floods, etc. • Psychological health effects, including mental health and stress-related illnesses • Health impacts due to food or water shortages • Illnesses related to drinking water contamination • Effects of the displacement of populations and crowding in emergency shelters • Indirect health impacts from ecological changes, infrastructure damages and interruptions in health services
Air quality	• Increased air pollution: higher levels of ground-level ozone and airborne particulate matter, including smoke and particulates from wildfires • Increased production of pollens and spores by plants	• Eye, nose and throat irritation, and shortness of breath • Exacerbation of respiratory conditions • Chronic obstructive pulmonary disease and asthma • Exacerbation of allergies • Increased risk of cardiovascular diseases (e.g. heart attacks and ischemic heart disease) • Premature death
Contamination of food and water	• Increased contamination of drinking and recreational water by run-off from heavy rainfall • Changes in marine environments that result in algal blooms and higher levels of toxins in fish and shellfish • Behavioural changes due to warmer temperatures resulting in an increased risk of food- and water-borne infections (e.g. through longer BBQ and swimming seasons) • Increased economic pressures on low income and subsistence food users	• Sporadic cases and outbreaks of disease from strains of water-borne pathogenic micro-organisms • Food-borne illnesses • Other diarrheal and intestinal diseases • Impacts on nutrition due to availability of local and traditional foods
Infectious diseases transmitted by insects, ticks and rodents	• Changes in the biology and ecology of various disease-carrying insects, ticks and rodents (including geographical distribution) • Faster maturation for pathogens within insect and tick vectors • Longer disease transmission season	• Increased incidence of vector-borne infectious diseases native to Canada (e.g. eastern & western equine encephalitis, Rocky Mountain spotted fever) • Introduction of infectious diseases new to Canada • Possible emergence of new diseases, and re-emergence of those previously eradicated in Canada
Stratospheric ozone depletion	• Depletion of stratospheric ozone by some of the same gases responsible for climate change (e.g. chloro- and fluorocarbons) • Temperature-related changes to stratospheric ozone chemistry, delaying recovery of the ozone hole • Increased human exposure to UV radiation owing to behavioural changes resulting from a warmer climate	• More cases of sunburns, skin cancers, cataracts and eye damage • Various immune disorders

TABLE 1: Key health concerns from climate change in Canada *(Source: Adapted from Seguin, 2008)*.

	Key Findings
Risks to Health	• Climate change will bring increased risks to health from extreme weather and other climate-related events such as floods, drought, forest fires and heat waves • Air quality is already a serious public health issue in a number of Canadian communities and is likely to be impacted by increased smog formation, wildfires, pollen production and greater emissions of air contaminants due to changed personal behaviours • Climate change is likely to increase risks associated with some infectious diseases across the country, and may result in the emergence of diseases that are currently thought to be rare in or exotic to Canada • With climate change, it is expected that the number of high to extreme ultraviolet radiation (UV) readings could increase, even in the far North
Regional Vulnerabilities	• Climate change will impact regions across Canada differently. For example, cities tend to experience higher temperatures and tend to have higher levels of air pollution than do rural areas • Northern communities are already reporting environmental changes and corresponding risks to health and well-being (e.g. food spoilage, sunburns, dangerous travel) associated with a changing climate, and are taking many actions to adapt • Coastal regions may be impacted by sea level rise due to climate change which can increase the risk of storm-surge flooding in these regions
Adaptive Capacity	• The combined effects of projected health, demographic and climate trends in Canada, as well as changes related to social conditions and infrastructure, could increase the vulnerability of Canadians to future climate-related health risks in the absence of effective adaptation strategies • Concerns exist about the effectiveness of current adaptations to mitigate health risks from climate variability. Existing gaps in public health and emergency management activities that are not addressed will reduce our ability to plan and respond to climate change in Canada • Actions are being taken to adapt to the health impacts of climate change but barriers to adaptation exist. These include an incomplete knowledge of health risks, uneven access to protective measures, limited awareness of best adaptation practices to protect health, and challenges in undertaking new adaptive actions
Future Needs	• Further adaptation to reduce health risks is needed. Measures should be tailored to meet the needs of the most vulnerable Canadians – seniors, children and infants, the socially disadvantaged, and the chronically ill • The health sector needs to maintain current efforts to protect health from climate-related risks, incorporate climate change information and engage other sectors in their plans for future programs • Regional and community-level assessments of health vulnerabilities are needed to support adaptation through preventative risk reduction • Multi-disciplinary research and collaborations across all levels of government can build the knowledge base on vulnerabilities to climate change to address existing adaptation gaps

TABLE 2: Summary of health risks and vulnerabilities facing Canadians from climate change *(Sources: Lemmen et al., 2008; Seguin and Berry, 2008)*.

2. OVERVIEW OF KEY HEALTH RISKS FROM CLIMATE CHANGE

Since the release of previous Government of Canada assessments (Lemmen et al., 2008; Seguin, 2008), stronger evidence has emerged that a wide range of climate-related impacts are of public health concern in Canada. The following sections draw from recent research findings from peer-reviewed publications and technical and government reports.

2.1 AIR QUALITY

The direct and indirect influence of climate on air quality in Canada is substantial and well established (McMichael et al., 2006; Lamy and Bouchet, 2008; IOM, 2011; Union of Concerned Scientists, 2011). Recent studies increase confidence that climate change will exacerbate existing health risks associated with poor air quality through heat and other meteorologically-related increases in ambient air pollutants (e.g. O_3 and PM) (Frumkin et al., 2008; Bambrick et al., 2011), aeroallergens, and biological contaminants and pathogens (Greer and Fisman, 2008; Schenck et al., 2010). Climate change may also impact ambient air quality by increasing wildfires (*see* Section 2.4.3), while indoor air quality can be affected by climate extremes and efforts to reduce the carbon footprint of buildings.

2.1.1 AIR POLLUTANT TRENDS IN CANADA

Air pollution poses significant risks to the health of Canadians (*see* Box 1). While Canadians have experienced better air quality since monitoring began in the 1970s (Environment Canada, 2013b), some air pollutants that pose risks to human health are increasing and are spatially variable. Average levels of ground-level ozone (O_3) increased by 10% between 1990 and 2010 (Environment Canada, 2012a), although peak O_3 levels are declining (Health Canada, 2012e). Climate is an important factor in the formation of some air pollutants (e.g. ozone) that cause harm to health (IPCC, 2007), but the degree to which air pollutant levels in Canada are attributed to climate change is unclear. Ambient concentrations of fine particulate matter ($PM_{2.5}$) showed no significant national trend in Canada between 2000 and 2010. Some urban locations experience high ambient levels of $PM_{2.5}$ due to their proximity to large point sources of emissions (Environment Canada, 2012b). Furthermore, residential wood burning may contribute to local $PM_{2.5}$ pollution in Canada (Larson et al., 2007; Smargiassi et al., 2012).

BOX 1

HEALTH IMPACTS OF GROUND-LEVEL OZONE (O_3) AND PARTICULATE MATTER (PM)

The Canadian Medical Association (CMA) estimated that air pollution was responsible for the death of 21 000 Canadians in 2008 (CMA, 2008). Exposure to O_3 is associated with premature mortality (especially acute exposure-related) and a variety of morbidity effects. Evidence is especially persuasive in terms of the effects of O_3 on lung function, respiratory symptoms, inflammation, and immunological defenses (Government of Canada, 2012). Significant associations exist between short-term exposure to ozone and respiratory emergency room and hospital visits (especially asthma-related), and premature mortality (Government of Canada, 2012). Recent evidence increasingly links ozone to some cardiac effects, adverse long-term respiratory impacts and chronic-exposure mortality (Gauderman et al., 2004; Islam et al., 2009; Jerrett et al., 2009; Salam et al., 2009; Zanobetti and Schwartz, 2011).

Particulate matter also poses significant health risks to Canadians. PM is usually categorized as coarse ($PM_{10-2.5}$), fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$). Fine particulate matter can form as a result of reactions involving other air pollutants and can be emitted directly from vehicles, industrial sources, forest fires, and wood and waste burning (Environment Canada, 2012b). Recent epidemiologic evidence confirms earlier observations of significant harm from PM, especially, but not confined to, the fine fraction. This includes confirmation of mortality from long-term exposure to PM, and the linkage to adverse cardiac outcomes, both from acute and chronic exposures. Additionally, there is a robust relationship between fine PM and lung cancer mortality (Krewski et al., 2005). Research suggests that PM is linked to morbidity through a range of adverse effects including restricted activity days, respiratory symptoms, bronchitis (both acute and chronic), asthma exacerbation, as well as respiratory and cardiac impacts, which result in increased emergency room visits, hospital admission, and premature mortality (Government of Canada, 2012).

Certain population groups are particularly susceptible to adverse effects following exposure to PM and O_3 including healthy and asthmatic children, the elderly (especially those with a pre-existing respiratory or cardiac condition), individuals who hyper-respond to respiratory irritants, and those who are more active outdoors. It is possible that thresholds for population-level health effects do not exist or exist at very low levels (Government of Canada, 2012).

2.1.2 AIR POLLUTION PROJECTIONS

While uncertainty still exists regarding the potential impacts of climate change on air quality in Canada, regional-scale modeling of climate change and air quality has evolved considerably since the first studies appeared approximately ten years ago. Simulations now better account for inter-annual variability in meteorology and include both ozone and particulate matter (e.g. Tagaris et al., 2007). Simulations of ten summer seasons of current (circa 2000) and future (ca. 2045) air quality in North America by Kelly et al. (2012) suggest that O_3 concentrations are expected to increase by up to 9 to 10 parts per billion by volume (ppbv) with climate change, when anthropogenic air pollutant emissions are kept constant (*see* Figure 1a, b). Changes across Canada are generally smaller than those found in the U.S., with local increases of 4 to 5 ppbv in parts of southern Ontario and 1 to 2 ppbv in various regions across the rest of the country. In contrast, if anthropogenic air pollutant emissions are reduced, decreases of 5 to 15 ppbv in O_3 concentrations could occur for much of Canada and the U.S. even with the effects of climate change (*see* Figure 1c).

The same simulations forecast lower magnitude increases of $PM_{2.5}$ (< 0.2 µg m^{-3}) over much of North America (*see* Figure 2a and b). Large increases (> 1.0 µg m^{-3}) over Hudson's Bay will be driven by increases in natural sea-salt aerosol emissions as a result of decreased sea ice cover combined with increased regional winds. Overall, in most cities, $PM_{2.5}$ is seen to increase with climate change, but decrease when the effects of climate change are offset by possible future reductions in anthropogenic emissions (*see* Figure 2c) (Kelly et al., 2012).

These results suggest that while climate change negatively affects air quality, the impact can be modulated through reductions in air pollutant emissions. Reducing air pollution would contribute to reductions in acute air-quality episodes, acidifying deposition and ozone deposition, and their associated impacts (e.g. increased mortality, damage to buildings and crops, etc.) (Kelly et al., 2012). Where greenhouse gas (GHG) mitigation actions have associated 'co-benefits' in the form of air pollutant emission reductions, some of the costs associated with reducing GHGs would be offset (Kelly et al., 2012).

Changes at the global scale, including inter-continental transport of pollutants and changes in wildfires, can be expected to impact air quality over Canada and were not addressed in the study by Kelly et al. (2012). A regional study projected future air pollution and extreme heat events under different climate change scenarios in four Canadian cities: Toronto, Calgary, Montreal, and Vancouver. Results indicated increased O_3 concentrations due to warming, suggesting climate change would bring increased risks to health in these cities (NRTEE, 2011). The increased use of bio-fuels may also have implications for health (e.g. respiratory disease, cardiovascular disease, cancer), although recent analysis suggested that use of E10 (a mixture of gasoline with 10% ethanol), and of low level bio-diesel blends would be associated with minimal incremental health impacts in Canada (Health Canada, 2013a; 2013b).

Black carbon, a component of fine particulate matter formed from the incomplete combustion of fossil fuels, biofuels, and biomass, has been linked to premature mortality and morbidity. Diesel exhaust, which contains black carbon, is now recognized as a human carcinogen (WHO, 2012a). Black carbon is a short-lived climate forcer with roughly one million times the heat trapping power of carbon dioxide (Schmidt, 2011). The pollutant is able to travel long distances on air currents, and in northern regions accelerates the melting of ice and snow once it is deposited (Schmidt, 2011), with potential health and safety concerns for First Nations and Inuit communities. Recent studies suggest potentially large GHG mitigation benefits and significant health co-benefits from efforts aimed at reducing black carbon emissions (Anenberg et al., 2012; US EPA, 2012; Shindell et al., 2013).

2.1.3 AEROALLERGENS AND HUMAN PATHOGENS

Aeroallergens such as pollens from trees, grasses or weeds, molds (indoor and outdoor), and dust mites are air-borne substances that once inhaled trigger allergic responses in sensitized individuals. Increased aeroallergen formation has been associated with exacerbation of respiratory diseases (Frumkin et al., 2008), such as asthma and chronic obstructive pulmonary disease (COPD) leading to increased hospital admissions (Hess et al., 2009).

Climate change is expected to impact aeroallergens by leading to an earlier onset of the pollen season in temperate zones, increasing the amount of pollen produced and the allergenicity or severity of allergic reaction (US EPA, 2008 *as cited in* Ziska et al., 2009; Rosenzweig et al., 2011; Ziska et al., 2011). In North America, the ragweed season is becoming longer, a pattern most prevalent in northern latitudes. Ragweed is pervasive in highly populated areas of Canada and the leading cause of seasonal allergic rhinitis in north-eastern North America, responsible for approximately 75% of seasonal allergy symptoms (Ziska et al., 2011). Between 1995 and 2009, the length of the ragweed season increased by 27 days in Saskatoon and increased by 25 days in Winnipeg (Ziska et al., 2011).

O_3

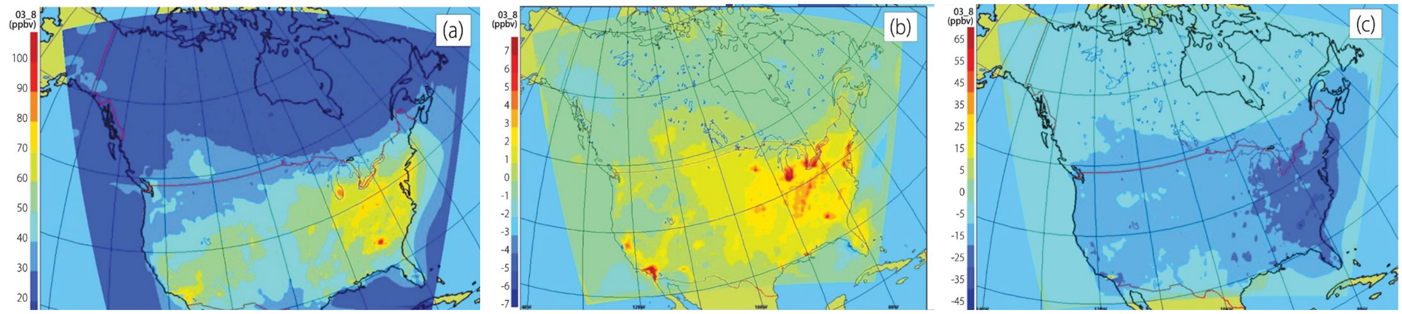

FIGURE 1: **a)** The ten year average "current" mean summer (June-July-August) daily maximum 8-hour average O_3 concentration; **b)** projected changes in the summer average daily maximum 8-hour O_3 between the "current" case and the "future" case with climate change using constant air pollutant emissions; and the **c)** "current" case and "future" case with possible reductions in future air pollutant emissions *(Source: Kelly et al., 2012)*. Note the different contour intervals used in each panel.

$PM_{2.5}$

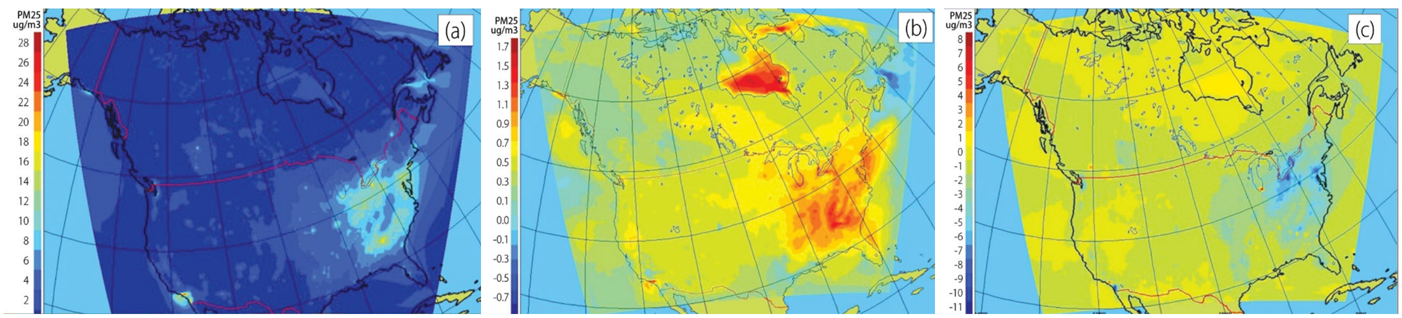

FIGURE 2: **a)** The ten year average "current" mean summer (June-July-August) 24-hour average $PM_{2.5}$ concentration; **b)** projected changes in the summer 24-hour average $PM_{2.5}$ concentration due to climate change with constant air pollutant emissions; and **c)** projected changes to $PM_{2.5}$ for the future with the combined effects of climate change and possible future decreases in air pollutant emissions *(Source: Kelly et al., 2012)*. Note the different contour intervals used in each panel.

In Canada, higher temperatures and drier conditions due to climate change could facilitate the establishment of fungal pathogens in new locations (Greer et al., 2008). For example, *Cryptococcus gattii*, a fungal pathogen typically found in tropical and sub-tropical regions, was identified on Vancouver Island in 1999 and has since spread to the British Columbia mainland. Its prevalence may be linked to warmer and drier summers in western Canada (Kidd et al., 2007; BC CDC, 2012). Sensitive populations who are exposed to this fungus may become sick with cryptococcal disease (cryptococcosis) which can be serious and result in pneumonia or meningitis (BC CDC, 2012).

2.1.4 INDOOR AIR QUALITY

Efforts to reduce the greenhouse gas footprint of buildings or adapt to climate change impacts may have unanticipated effects on health. Changes in the design of buildings (residential or commercial) and their building methods and materials in order to improve energy efficiency may affect health through reductions in indoor air quality (IOM, 2011). For example, some actions to weatherize buildings can reduce airflow, lower ventilation and trap pollutants that enter from outdoors (e.g. particulate matter, and volatile organic compounds or VOCs) or that are emitted indoors (e.g. tobacco smoke, radon, or various chemicals from building materials) (Potera, 2011).

An increase in the frequency of intense precipitation events (*see* Chapter 2) could also create indoor health risks to Canadians. Moisture in buildings from infiltration of rain or flooding, poorly designed ventilation and air-conditioning systems, and poor building maintenance can lead to growth of biological contaminants, such as fungi and infectious bacteria, which may impact health (e.g. respiratory disease) (Değer et al., 2010; Schenck et al., 2010; Potera, 2011). Dampness in buildings may increase emissions of VOCs and semi-volatile organic compounds (SVOCs) from building materials or products that may increase risks of asthma and allergies (Tuomainen et al., 2004; Jaakola and Knight, 2008). Inadequate or inappropriate remediation measures after a disaster may also contribute to poor indoor air quality (Chew et al., 2006).

In addition, power outages associated with extreme weather events (e.g. ice storms) lead to the indoor use of portable gas-powered or electric generators (which emit carbon monoxide), oil and gas furnaces, fireplaces, or candles. When used improperly, these devices are a fire hazard and can lead to high levels of indoor air pollutants, toxicity, hospitalization or even death. For example, the ice storm in Eastern Canada in 1998 resulted in 28 deaths, mostly due to carbon monoxide poisoning (Berry et al., 2008b).

2.2 FOOD AND WATER QUALITY

2.2.1 FOOD-BORNE ILLNESSES AND FOOD SECURITY

While surveillance systems are in place to identify food-borne illnesses and reduce the burden of these diseases within communities, there are still a large number of unreported cases. It has been estimated that approximately 4 million episodes of food-borne illness occur in Canada annually (Thomas et al., 2013). Every summer, reports of food-borne bacterial illness peak in Canada (Isaacs et al., 1998) and this peak is due in part to increased replication rates and persistence of pathogens with increased temperature, as well as to seasonal changes in eating behaviour, with barbeques and picnics providing greater opportunities for bacteria to survive cooking or to produce harmful toxins.

In Canada, human cases of salmonellosis have been associated with higher temperatures, and occurrences of acute gastrointestinal illness (AGI) have been shown to increase with both high and very low precipitation levels, especially during the summer and fall (Febriani et al., 2010; Ravel et al., 2010). A study evaluating the impact of temperature on food-borne illness in the United Kingdom from 1981 to 2006 (Lake et al., 2009) found that food-borne infections continue to be associated with temperature, but that there was a significant reduction in the association between temperature and food-borne illness over time that could be a result of improved food safety and increased food safety measures. Warmer temperatures due to climate change may also impact other pathogens and result in increased outbreaks of food-borne diseases such as botulism in Arctic communities (Parkinson and Evengard, 2009).

There are only a limited number of studies on the impacts of climate change on food security and subsequent impacts on human health in Canada, with most of the studies focused on the Canadian Arctic (Lemmen et al., 2008; Seguin, 2008). Climate change and weather variability (e.g. flooding, drought, temperature) can impact agriculture and fisheries in Canada (*see* Chapter 4 – Food Production). In addition, almost all Canadians depend on imported food to supplement their diet. Climate change could affect the availability of some foods, potentially increasing food costs and reducing accessibility for people with low incomes or living in isolated communities (Meakin and Kurvits, 2009).

2.2.2 WATER-BORNE DISEASES AND WATER SECURITY

Water-borne illnesses result from exposure to chemicals or microbes in contaminated drinking water supplies, recreational water and/or food. In Canada, there are guidelines in place to protect water quality and drinking water, although water can still become contaminated and result in people becoming ill (Health Canada, 2012b). Small drinking water systems can be more vulnerable than larger systems to climate change due to infrastructure and financial, technological and training constraints (Moffatt and Struck, 2011; Brettle et al., 2013). A recent study among Canadian water utility officials found that over half of those surveyed do not envisage drinking water challenges from climate change and have no plans to address future climate change impacts (CWWA, 2012).

In Canada, water-borne disease outbreaks have been linked to weather events, particularly heavy rains and drought, and to increasing temperatures (Thomas et al., 2006; Seguin, 2008; Moffatt and Struck, 2011). Heavy rainfall two to four weeks prior to illness was found to increase the number of gastrointestinal illness-related clinic visits in two Inuit communities in Nunatsiavut, Canada (Harper et al., 2011). While most research focuses on the impacts of climate on microbiological contamination, climate change could also affect the pathways by which chemical contamination occurs. Flooding, storms and precipitation can all transport chemical contaminants such as pesticides, nutrients, heavy metals and persistent organic pollutants into water bodies (Hilscherova et al., 2007; Harmon and Wyatt, 2008; Noyes et al., 2009). Pesticide concentrations in water supplies have been found to increase with the effects of greater storm intensity, such as water runoff and flooding (Chiovarou and Siewicki, 2007). Therefore, more frequent and intense storms, increased precipitation, and increased flooding associated with climate change may increase chemical contamination of water bodies and watersheds.

Climate change could increase the proliferation of cyanobacteria, also known as blue-green algae, in Canada (Barbeau et al., 2009; DesJarlais and Blondlot, 2010). Cyanobacteria can result in unacceptable taste and odours and some also produce various toxins (cyanotoxins) that taint drinking and recreational water and that contaminate fish and shellfish. Some cyanotoxins can impact the health of people and animals if contaminated water is ingested or becomes airborne and is inhaled. In other cases, skin contact with the algal cells may result in an allergic-type reaction (Health Canada, 2000). Blue-green algae blooms have been reported in every province of Canada and in the Yukon (Orihel et al., 2012). Blooms of cyanobacteria and filamentous green algae have increased in Ontario in the last 15 years (Winter et al., 2011). Globally, increases in algal blooms are attributed to nutrient enrichment and warming weather (Heisler et al., 2008; Paerl and Huisman, 2008). Water management strategies to reduce harmful cyanobacterial blooms include decreasing nutrient input in water sources (Paerl and Huisman, 2009) and utilizing processes such as adsorption with powdered activated carbon or oxidization treatments which are effective for treating drinking water (Barbeau et al., 2009).

2.3 ZOONOSES AND VECTOR-BORNE DISEASES (VBDS)

Climate change may affect health risks from both zoonoses (diseases transmitted from animals to humans) and vector-borne diseases (VBD – diseases transmitted either human-to-human or animal-to-human by arthropod vectors). Four main outcomes that may occur in isolation or in concert may increase health risks including: i) changes to the geographic footprint of the occurrence of transmission cycles; ii) changes in the abundance of pathogens and vectors where zoonosis/VBD transmission cycles already occur; iii) changes in evolutionary pressures on pathogens with potential consequences for their transmissibility to humans and capacity to cause disease; and iv) changes to human activities that alter the frequency with which humans are exposed to zoonoses/VBDs (Ogden et al., 2010).

There are few quantitative assessments of the current and future risks of zoonoses and VBDs in Canada. In 2007, Lyme disease (*see* Box 2) was considered to be, for the most part, a risk that may emerge in the future. However, maps developed by Ogden et al. (2008a) (*see* Figure 3) highlighting current and projected future risk of Lyme disease based on the geographic distribution of the tick vector *Ixodes scapularis* (the blacklegged tick) have now been validated in the field. These validation studies (Ogden et al., 2010; Bouchard et al., 2011; Koffi et al., 2012; Public Health Agency of Canada, 2014) reveal that the emergence of Lyme risk in the Canadian environment is underway, with the annual incidence of Lyme disease having increased from approximately 30 cases a year to 315 in 2012.

Surveillance data indicates that Lyme vectors (as a proxy for Lyme disease risk) are spreading into Canada at a rate of 35-55 km per year and are following climate-determined geographic trajectories (Leighton et al., 2012), further supporting the validity of the risk maps (*see* Figure 4).

BOX 2

THE SYMPTOMS OF LYME DISEASE

(Source: Public Health Agency of Canada, 2013a)

Lyme disease is a serious illness that usually begins with a characteristic rash at the site of the tick bite. The disease can be treated with antibiotics. If untreated in the early stages it may progress to 'disseminated Lyme disease' with symptoms of weakness, multiple skin rashes, painful, swollen or stiff joints, abnormal heartbeat, central and peripheral nervous system disorders including paralysis, and extreme fatigue.

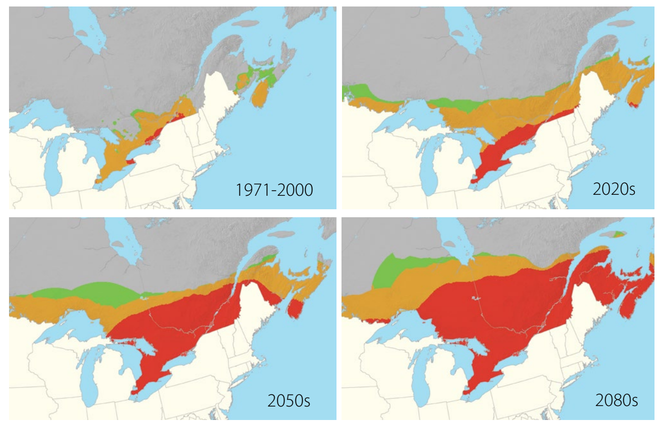

FIGURE 3: Risk maps for establishment and spread of the Lyme disease vector Ixodes scapularis under (1971-2000) and projected future climate (2020s to 2080s) after Ogden et al., 2008a. The green zone indicates the main extent of locations where *I. scapularis* may become established. The orange and red zones indicate areas with increasingly high risk for *I. scapularis* population emergence. The grey zone indicates areas where the risk of *I. scapularis* population emergence is very low *(Source: Ogden et al., 2008a)*.

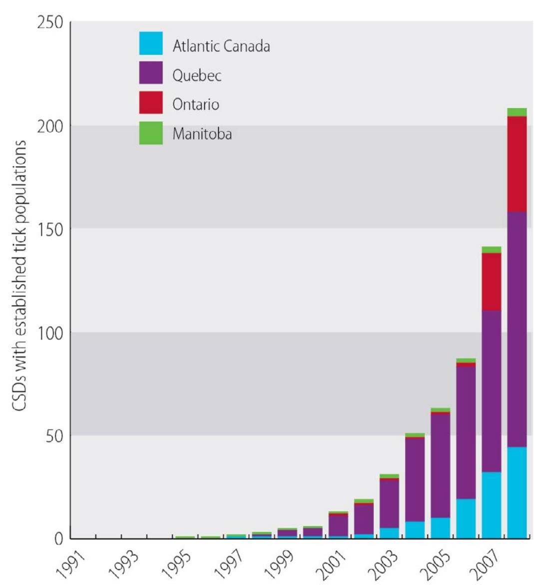

FIGURE 4: Expansion of *I. scapularis* populations in Canada, 1991-2007 *(Source: reproduced from Leighton et al., 2012)*. CSD = Census Sub-Division.

Similar studies have assessed the range expansion of West Nile Virus (WNV) risk with climate change within Canada (Hongoh et al., 2012), Lyme disease risk in British Columbia (Mak et al., 2010) and expansion of Tularaemia and plague risk in Canada, and spread from the U.S. (Nakazawa et al., 2007). More qualitative approaches have been taken to assess changing risk from zoonotic VBDs caused by viruses (arboviruses) due to climate and other environmental changes. For example, Hongoh et al. (2009) predicted a northward expansion of zoonotic VBD risks into Canada from their current range in the U.S., and a northwards spread within Canada for those arboviruses already endemic here as the climate continues to change. The recent spread of Eastern Equine Encephalitis virus (EEEV) into Canada may be evidence of this expansion (unpublished data by L.R. Lindsay). Like WNV, this mosquito-transmitted arbovirus uses wild birds as its reservoir hosts, and has spread from the U.S. to locations in Nova Scotia, Quebec and Ontario in recent years. It has caused a number of fatal cases in horses and emus; although, no human cases have occurred to date.

Risks of other diseases transmitted by blacklegged ticks (Human anaplasmosis caused by *Anaplasma phagocytophilum*, Human babesiosis caused by *Babesia microti*) are also beginning to emerge in Canada (Cockwill et al., 2009; unpublished data by L.R. Lindsay). It is not clear as to whether the increasing environmental risk is resulting in an increased number of cases in humans because these diseases are not under national surveillance.

2.3.1 WILDLIFE-BORNE ZOONOSES

Only a limited number of recent studies on the occurrence of climate-sensitive wildlife-borne zoonoses in southern Canada are available (e.g. Wobeser et al., 2009; Jardine et al., 2011). Studies targeted to specific aspects of zoonosis ecology, such as Lyme dispersion (Ogden et al., 2008b; 2011), Hantavirus risk (Safronetz et al., 2008) and toxoplasma risk (Simon et al., 2011) have provided data that have been, or will be, useful for assessing the effects of climate change on zoonosis risk. More effort has been expended on understanding the risk from zoonoses in northern Canada via studies of wildlife (Simon et al., 2011), domesticated animals (Salb et al., 2008; Himsworth et al., 2010a, b) and humans (Messier et al., 2009; Gilbert et al., 2010; Campagna et al., 2011; Sampasa-Kanyinga et al., 2012). These studies highlight zoonoses as a public health issue in the North and provide qualitative assessments of how the risk from these diseases may be affected by climate change. However, our knowledge of the ecology of these diseases remains too limited to confidently predict the extent to which climate change will impact risks to people in northern communities (Jenkins et al., 2011). Recent studies have also identified that known endemic wildlife diseases in Canada, particularly arboviruses such as the Snowshoe Hare virus, can be pathogenic in humans and are likely to be sensitive to climate change. As a result, they could emerge as significant, public health risks in the future in terms of number of cases and case severity (Meier-Stephenson et al., 2007).

2.3.2 EXOTIC ZOONOSES/VBDS

A number of studies have begun to assess Canada's vulnerability to 'exotic' zoonoses/VBDs such as malaria, chikungunya, dengue, Japanese encephalitis, and Rift Valley Fever imported from countries further afield than the United States. These studies suggest that as temperature increases, southern Canada will become increasingly suitable for malaria transmission, where competent vectors already exist (Berrang-Ford et al., 2009) (*see* Figure 5).

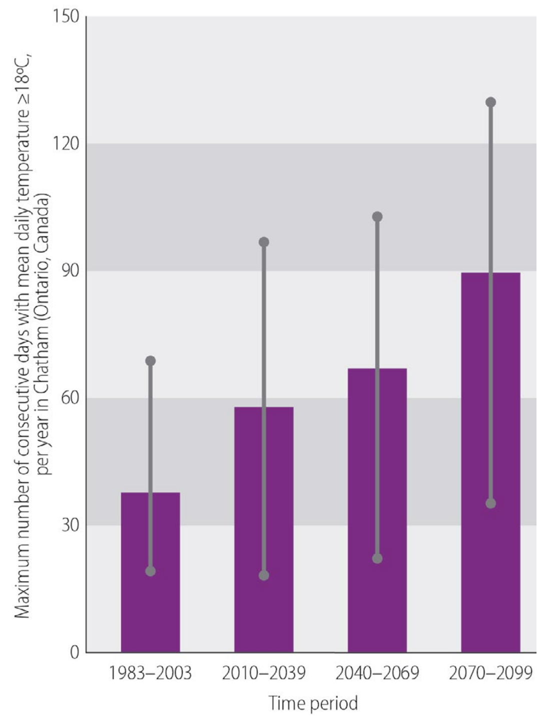

FIGURE 5: Recent and projected (for 2010-2099) annual number of consecutive days ≥18˚C for Chatham, Ontario. 18˚C is the threshold temperature condition for transmission of the malaria parasite *Plasmodium vivax*. At 18˚C development in the vector takes 30 days, a duration which is the limit for survival of the mosquito *(Source: Berrang-Ford et al., 2009).*

As would be expected, current risk of malaria transmission in southern Canadian communities is highest in those communities with high proportions of immigrants from malaria-endemic parts of the world (Eckhardt et al., 2012). Studies have also identified the ability of mosquito species present in Canada to acquire and transmit Rift Valley Fever virus (Iranpour et al., 2011). Models that use multi-criteria decision analysis (MCDA) identify the potential for emergence of exotic vector-borne diseases in Canada due to both climate warming and import by infected migrants (Jackson et al., 2010; Cox et al., 2012). Recent epidemics of imported chikungunya in Italy (Angelini et al., 2008) and dengue in Florida (Bouri et al., 2012) have raised awareness of the threat of imported/invasive VBDs. Increasing climatic suitability in Canada is expected to increase the likelihood of these events (Berrang-Ford et al., 2009). Infected mosquitoes can be readily imported via global trade and travel (Medlock et al., 2012). Exotic VBD incidence is likely to increase with climate change, especially in developing countries (Ermert et al., 2012), and economic/disaster-driven migration of infected people from developing countries is anticipated to increase with climate change (McMichael et al., 2012). Thielman and Hunter (2006) have identified the establishment of exotic mosquitoes and mosquito vectors in Canada.

Tools to allow risk-based decision-making for the management (i.e. surveillance, prevention and control) of emerging/re-emerging zoonoses/VBDs include MCDA (*see* Case Study 1). Research continues to develop improved methods of surveillance for zoonoses/VBDs (e.g. Pabbaraju et al., 2009; Vrbova et al., 2010), as not all potential methods end up being useful in the field (Millins et al., 2011).

Diagnostic delays, due to a lack of expertise and diagnostic capacity within the medical profession for unexpected and emerging exotic zoonoses/VBDs, mean that disease severity can be very high (Berrang-Ford et al., 2009). Efforts to address VBDs are also faced with a lack of trained personnel, as well as uneven public health and clinical measures in place (Public Health Agency of Canada, 2013b).

CASE STUDY 1

DESCRIPTION OF USES OF MULTI-CRITERIA DECISION ANALYSIS (MCDA)

(Source: Cox et al., 2012)

Multi-criteria decision analysis is a powerful tool that allows integration of multiple considerations in risk-based decision making. In the context of the selection of surveillance and control methods for emerging infectious diseases, these considerations can include health and environmental impacts, performance, acceptability and cost-benefit. MCDA allows weighting of the importance of a given consideration to align with the needs and priorities of different jurisdictions and end users. It supports consensus-building among multiple jurisdictions and integrates public perception of risk with expert-driven analyses. MCDA also ensures that decisions are made in an open and transparent fashion, with due diligence applied to documented consultations with experts, stakeholders and end users. Officials with the Québec Public Health Program have tested this approach in the decision-making process for methods of surveillance for Lyme disease.

2.4 NATURAL HAZARDS

Climate change is affecting extreme weather and climate events around the world (WMO, 2013) and is expected to make weather more variable, affecting the frequency, intensity, spatial extent, duration, and timing of these events (IPCC, 2012). The IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (2012) notes that these changes can result in "unprecedented" extreme events that can have severe impacts on individuals and communities in both developed and developing countries. Projections suggest that Canada can expect an increase in the intensity of heavy rain events and storms, and in the occurrence of wildfires and droughts. Climate change is also expected to increase the frequency of extreme heat events in many Canadian communities (Lemmen et al., 2008; Seguin, 2008; Health Canada, 2011a) (*see* Chapter 2).

The Canadian Disaster Database (CDD) provides information on the frequency of disasters, including hydrometeorological disasters in Canada.[1] However, published literature documenting trends in the frequency of extreme weather events and the resulting impacts is scarce. There is limited surveillance of direct and indirect health impacts from extreme weather-related events in Canada, and data at the national level are often sparse and not systematically collected. The following sections discuss recent evidence related to the health impacts of extreme weather events which are projected to increase from climate change in Canada.

2.4.1 STORMS AND FLOODING

Canadians across the country can be vulnerable to the health impacts of thunderstorms and lightning, snow storms, freezing rain, tornadoes, hurricanes, and hailstorms – particularly when widespread power outages occur (Environment Canada, 2007) and where health, social, and emergency services are insufficiently robust to handle large or concurrent events (Berry, 2008). Recent evidence from the U.S. indicates that storms that produce wind damage

[1] Disasters are events that result in broad environmental, health or economic impacts that disrupt the everyday functioning of a community which may require the help of other partners for recovery (IPCC, 2012).

and flooding, such as hurricanes, are often associated with physical injuries sometimes causing death (Cretikos et al., 2007; Brunkard et al., 2008; Frumkin et al., 2008; English et al., 2009; Hess et al., 2009), drowning (the most common cause of death during Hurricane Katrina; Brunkard et al., 2008; Frumkin et al., 2008), the aggravation of chronic diseases (e.g. through lack of food and potable water; English et al., 2009; Hess et al., 2009; Bethel et al., 2011), hypothermia (Cretikos et al., 2007) and mental illness such as post-traumatic stress disorder (PTSD) (*see* Section 2.4.5). Storm events have also been associated with an exacerbation of heart conditions (English et al., 2009) and gastrointestinal illness resulting from the failure of refrigerators and freezers and the inability to prepare hot food (Cretikos et al., 2007). Rainstorms have been observed to worsen asthma symptoms (Hess et al., 2009).

Storms can also affect health through the disruption of medical care (Cretikos et al., 2007; Brunkard et al., 2008; Frumkin et al., 2008) and other social services due to building, infrastructure and medical vehicle damage, and effects on staff resulting from physical impacts (e.g. blocked roadways) or event-related stress (Cretikos et al., 2007). Hospitals, for example, may be affected directly (Cretikos et al., 2007; Brunkard et al., 2008; Clarke, 2009) and ongoing medical care such as routine laboratory testing, newborn screening, dialysis, provision of oxygen, and home intravenous therapy can be disrupted, putting patients at increased health risk (Cretikos et al., 2007; Frumkin et al., 2008). Many hospitals in Canada have limited capacity to deal with the surge in patients due to public health emergencies (Gomez et al., 2011).

An increase in freezing rain events has been observed and is expected to continue into the future (Ebi and Paulson, 2010; Cheng at al., 2011). Evidence from the U.S. suggests that the health effects of freezing rain can include slips and falls (Frumkin et al., 2008; Du et al., 2010), injury or illness resulting from critical infrastructure and building failure (Du et al., 2010; Auger et al., 2011), challenges regarding access to health care services (Auger et al., 2011), and an increase in motor vehicle accidents due to poor road conditions (Frumkin et al., 2008).

Cheng et al. (2011) project that days with freezing rain between December and February will increase from averaged historic conditions for Ontario communities by 35% to 100% for the period 2046-2065, and by 35% to155% for the period 2081-2100. The more northern the community, the greater the projected increase. For example, by 2046-2065, days with freezing rain are projected to increase by 35% to 55% for Toronto and Windsor, by 50% to 70% for Montreal and Ottawa, and by 70% to 100% for Kenora, Thunder Bay, and Timmins.

Cunderlik and Ouarda (2009) found evidence of increasing intensity of rainfall events between 1974-2003 in Canada as well as weak evidence that floods are occurring earlier in the year, particularly in southern Canada. The number of flood disasters has increased in Canada throughout the 20th century with about 70% occurring after 1959 (Laforce et al., 2011). Floods remain one of the costliest and most frequent types of natural disaster in Canada (Public Safety Canada, 2013a). Population growth, a continued trend of people settling on flood plains, and urbanization, which generally reduces the capacity of watersheds to absorb storm water run-off, are expected to exacerbate risks of floods. Studies of recent flood events have increased knowledge of primary and secondary (including mid-to-long term) impacts on health (*see* Table 3).

There are a number of ways in which climate change is expected to increase flooding, including earlier spring runoff (Bedsworth and Hanak, 2010), increasing storm surges (Bedsworth and Hanak, 2010) and increases in heavy precipitation (Cunderlik and Ouarda, 2009; DesJarlais and Blondlot, 2010; Ostry et al., 2010). Projections of future flood events in specific regions of Canada are limited. The City of Toronto recently completed a Climate Drivers Study that predicts significant increases in heavy rainstorms in the summer by 2040-2049 (City of Toronto, 2012). Flooding due to heavy rainfall in Southern Ontario (Grand, Humber, Rideau and Upper Thames River Basins) from April to November is expected to increase 10 to 35% by 2046-2065, and 35 to 50% by 2081-2100 (Cheng et al., 2011). Future flooding from climate change has also been identified as a key risk in British Columbia (Ostry et al., 2010) and in Quebec (DesJarlais and Blondlot, 2010).

Primary Health Impacts from Floods	
Impact	**Cause**
Mortality	Drowning or acute trauma (e.g. debris or building collapse) (Acharya et al., 2007; Fundter et al., 2008; Jonkman et al., 2009), usually attributable to motor vehicle accidents or inappropriate behavior in flooded areas (e.g. swimming, surfing) (Haines et al., 2006; English et al., 2009; Du et al., 2010; Fitzgerald et al., 2010)
Shock, hypothermia	Exposure to floodwater which is often below human core body temperature (Acharya et al., 2007; Carroll et al., 2010; Du et al., 2010)
High blood pressure, heart attacks and strokes	Exertion and stress related to the event (Acharya et al., 2007; Jonkman et al., 2009; Carroll et al., 2010; Du et al., 2010)
Physical injuries such as lacerations, skin irritations, bruises, wound infections	Direct contact with flood water (Acharya et al., 2007; Fundter et al., 2008; Carroll et al., 2010; Du et al., 2010)
Infection, pulmonary swelling, lung irritation, fungal infection	Aspiration of water into lungs (Robinson et al., 2011)
Sprains, strains and orthopedic injuries	Contact with water-borne debris, attempts to escape from collapsed structures, falls from ladders, attempts to rescue people or possessions, etc. (Acharya et al., 2007; Fundter et al., 2008; Carroll et al., 2010; Du et al., 2010)
Electrical injuries	Contact with downed power cables/lines, circuits and electrical equipment in contact with standing water (Du et al., 2010)
Burns (fire-related or chemical) and explosion-related injuries	Disturbed propane and natural gas lines, tanks, power lines and chemical storage tanks; toxic gas emissions; rescue boats coming in to contact with power lines (Du et al., 2010)

Secondary Health Impacts from Floods	
Impact	**Cause**
Exacerbation of existing illnesses, including chronic diseases	Disruption/decreased availability of emergency and ongoing health services, especially if health infrastructure is affected, including: decreased ability to provide/access care; displacement of patients and staff; impaired surveillance of illness, injury, toxic exposure; loss of medical records; loss/impairment of medication and medical devices (Haines et al., 2006; Du et al., 2010; Ebi and Paulson, 2010)
Carbon monoxide poisoning	Inappropriate use of unventilated cooking tanks (e.g. barbeques), pressure washers and gas powered generators (Du et al., 2010)
Burns/smoke inhalation	House fires started by candles (Du et al., 2010)
Dehydration, heat stroke, heart attack, stroke	Exposure of vulnerable populations to environmental stresses in days following event (Jonkman et al., 2009)
Water- and food-borne diseases – upset stomach/gastrointestinal problems, infectious diseases with longer incubation periods including *Legionella pneumophila* (Marcheggiani et al., 2010) *Norovirus, Rotavirus, Hepatitis A* and *C*	Water and food contamination (e.g. from sewage overflows, flooding of agricultural areas and transport of sediment, fertilizers, pesticides, etc., leakage from tanks holding petroleum products, landfill materials)(Haines et al., 2006; Acharya et al., 2007; Du et al., 2010; Ebi and Paulson 2010; Ostry et al., 2010; ten Veldhuis et al., 2010), chemical contamination of water (e.g. from flooding of industrial sites) (Du et al., 2010)
Respiratory problems/symptoms	Respiratory contaminants from mold[2], bacteria[3], fungal growth on damp structures (Carroll et al., 2010; Du et al., 2010; Robinson et al., 2011; Taylor et al., 2011). Also, due to *Legionaella, Chlamydia, pneumonia, Burkholderia cepacia*, and *Mycobacterium avium* (Taylor et al., 2011)

TABLE 3: Primary, secondary and mid- to long-term health impacts of floods.

[2] *Cladosporium, Aspergillus, Penicillium, Alternaria* and *Stachybotrys* have been observed in damp and flooded buildings (Taylor et al., 2011).
[3] *Streptomycetes, Caulobacter* and *Agrobacterium* have been observed (Taylor et al., 2011).

2.4.2 EXTREME HEAT

Internationally, recent events have demonstrated the catastrophic impacts that extreme heat can have on communities in developed countries (Robine et al., 2008; Barriopedro et al., 2011). Extreme heat events pose serious health risks to Canadians; for example, they are associated with sudden, short-term increases in mortality, especially among older adults, people who are chronically ill, people on certain medications and the socially disadvantaged (Kovats and Hajat, 2008; Hajat and Kosatsky, 2010; Kenny et al., 2010; CIHI, 2011; Health Canada, 2011a). A 2009 extreme heat event in British Columbia contributed to 156 excess deaths in the province's lower mainland area (Kosatsky, 2010) and in 2010 an extreme heat event in Quebec resulted in an excess of 280 deaths (Bustinza et al., 2013). The National Drowning Report (Drowning Prevention Research Centre Canada, 2011) suggests that increases in drowning deaths in 2005 (492 deaths), 2006 (508 deaths), and 2007 (480 deaths) are a departure from the long-term trend toward fewer fatalities from drowning and are partly due to the warmer and drier conditions in those years resulting in more people participating in aquatic activities.

Studies of the association between daily maximum temperatures and excess mortality in select Canadian cities (*see* Figure 6) indicate that high temperatures are a health risk. Latitude, elevation, proximity to bodies of water, urban heat islands, access to air conditioning, population demographics and local acclimatization, among other factors, influence how each city experiences a heat event and the severity of the health impacts (Martel at al., 2010). Some cities, including Toronto, ON, Windsor, ON and Winnipeg, MB have undertaken heat-health vulnerability assessments to inform the development or revision of heat alert and response systems (HARS) (Berry et al., 2011a; City of Toronto, 2011).

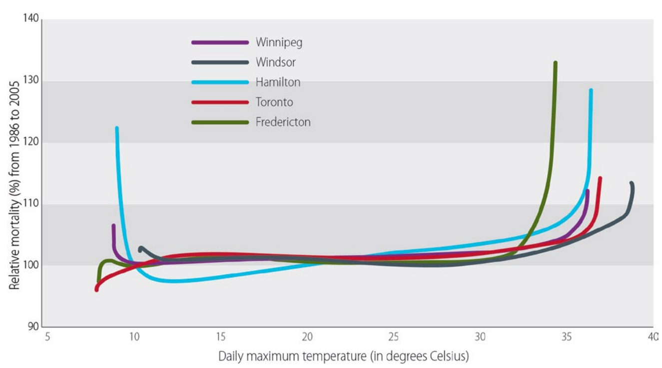

FIGURE 6: Relationship between daily maximum temperatures in June, July and August and all non-traumatic deaths for selected Canadian cities, 1986-2005 *(Source: Casati et al., in press)*.

Extreme heat can cause skin rashes, cramps, dehydration, syncope (fainting), exhaustion, and heat stroke. It can also exacerbate many pre-existing conditions such as cardiovascular, cerebrovascular and respiratory diseases, and neurological disorders (Kenny et al., 2010; Health Canada, 2011b; Lowe et al., 2011). These conditions are not normally coded as heat-related in the International Classification of Diseases (ICD); therefore, measures of the impact of extreme heat events on health are often underestimated (Kravchenko et al., 2013). Extreme heat events are associated with greater utilization of health care services (Vida et al., 2012; Anderson et al., 2013). In Toronto, a significant positive correlation was found between heat and utilization of emergency medical services for various groups of heat-related adverse health outcomes during the summer of 2009-2011 (Bassil, 2012). The 2010 extreme heat event in Quebec resulted in an extra 3400 emergency department admissions with significant variation among regions (Bustinza et al., 2013).

Canada can expect an increase in the length, frequency, and/or intensity of warm spells or heat waves; a 1-in-20 year hottest day is likely to become a 1-in-2 year event by the end of the 21st century (IPCC, 2012)[4]. Temperature projections indicate that the number of days with temperatures above 30°C in cities such as Toronto, ON, Winnipeg, MB and Windsor, ON (*see* Figure 7) are expected to double between 2011-2040 and 2071-2100. In many communities, the projected increase in warm nights will limit nighttime relief from the heat (Health Canada, 2012c). Ebi and Mills (2013) suggest that heat-related mortality associated with warmer temperatures from climate change is likely to be higher than reductions in cold-related mortality.

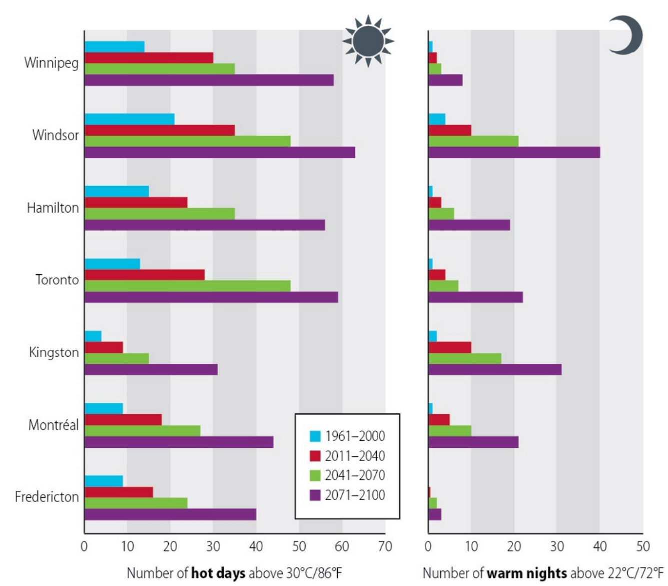

FIGURE 7: Historical and projected number of hot days and warm nights for selected cities in Canada *(Source: Casati and Yagouti, 2010)*.

[4] Based on the A1B and A2 emissions scenarios (IPCC, 2012)

2.4.3 WILDFIRES

Wildfires or forest fires are a common occurrence across Canada (*see* Chapter 3 – Natural Resources) and present risks to thousands of private homes and businesses (Seguin, 2008). On average, 5500 people are evacuated from 10 communities, and twenty communities with a total of 70 000 people are threatened by large fires in Canada each year (Flannigan and Wotton, 2010) (*see* Case Study 2).

Immediate health consequences of wildfires include increased respiratory complaints (Künzli et al., 2006; Moore et al., 2006; Bambrick et al., 2011) such as smoke inhalation, respiratory tract burns and injury, and impaired oxygenation (Hess et al., 2009; Robinson et al., 2011; Johnston et al., 2012). Other health impacts such as radiant heat injury, dehydration and heat exhaustion (Johnston, 2009) have been reported with overall increases in mortality (Künzli et al., 2006; Johnston, 2009). Wildfires are also often associated with increased physician and emergency room visits (Henderson et al., 2011), reduced access to health and community services, and health concerns associated with emergency/temporary shelters (Johnston, 2009). Mid- to long-term health impacts of wildfires may include mental exhaustion, anxiety, depression and post-traumatic stress disorder (PTSD) related to loss of friends, relatives, homes and livelihoods (Johnston, 2009; Ostry et al., 2010). Significant challenges may arise for health and emergency services when whole communities are affected by wildfires and need to be evacuated.

Wildfires can significantly impact air quality in nearby communities and also contribute to the long-range transport of pollutants in North America (Committee on the Significance of International Transport of Air Pollutants, 2009). This may exacerbate chronic diseases such as asthma (especially in children), COPD, ischaemic heart disease, and other chronic lung diseases leading to increased hospital admission rates (Künzli et al., 2006; Johnston, 2009; Robinson et al., 2011). Increased rates of infant mortality have also been associated with wildfires due to an increased risk of cardiovascular and respiratory mortality (Robinson et al., 2011). Wildfires in Canada have affected air quality in the past; average levels of $PM_{2.5}$ in 2010 in Canada exceeded those of 2009 by 24% due to wildfires in British Columbia, Saskatchewan and Quebec (Environment Canada, 2012b). There is an expected increase in wildfires in much of Canada's forest cover due to projected increases in temperature and seasonal reductions in precipitation (Flannigan et al., 2009; Bambrick et al., 2011; *see also* Chapter 3 – Natural Resources).

CASE STUDY 2

HEALTH IMPACTS OF FOREST FIRES IN NORTHERN ONTARIO, JULY 2011

On July 6, 2011, a lightning storm sparked a series of forest fires that rapidly spread across northwestern Ontario, lasting from July 6 to 23 (120 fires were reported on July 20). Many First Nations communities were directly threatened by the fires and those at increased risk of suffering from smoke inhalation were ordered to evacuate, as were communities suffering from power outages, food shortages, and a lack of food storage capacity (Public Safety Canada, 2013a). In total, 3292 people were evacuated from 8 First Nations communities (Public Safety Canada, 2013a), in addition to the entire communities of Keewaywin and Koocheching First Nations. Residents were relocated to 14 communities as far away as Southern Ontario and Manitoba.

2.4.4 DROUGHT

Droughts can have significant impacts on human health (Wheaton et al., 2008) by lowering groundwater levels and streamflows, increasing wind erosion of soils, and causing cracking of cisterns and septic tanks, creating the potential for increased sediment levels in water. They can also result in an increase in water-borne pathogens and water contamination (English et al., 2009; Ostry et al., 2010; Wittrock et al., 2011) leading to gastroenteritis (US CDC et al., 2010). Certain vector-borne diseases may spread more easily during periods of drought (Frumkin et al., 2008) and health can be impacted through wind erosion and dust storms (Wheaton et al., 2008). Droughts can decrease agricultural and crop production (Wheaton et al., 2008; *see* Chapter 4 – Food Production) leading to suboptimal nutrition due to food shortages, lack of food availability, and high costs (Horton et al., 2010), particularly for low income people and those relying on fishing or agriculture for their livelihoods (US CDC et al., 2010). Increased stress and mental health issues, particularly among farmers, have been linked to drought conditions (US CDC et al., 2010; Polain et al., 2011; Wittrock et al., 2011). Summer continental interior drying, drought risk and areas impacted by drought are all projected to increase in Canada (Wheaton et al., 2008; Wittrock et al., 2011, *see also* Chapter 4 – Food Production).

2.4.5 PSYCHOSOCIAL AND MENTAL HEALTH IMPACTS

An increase in the frequency, severity, and duration of extreme weather may adversely affect mental health, creating psychosocial impacts (Fritze et al., 2008; Berry et al., 2009; Kjellstrom and Weaver, 2009; Vida et al., 2012). The term "psychosocial" relates to the psychological, social and livelihood aspects of an individual's life, and acknowledges the interplay and co-dependencies that exist between individual and community well-being. Natural hazards can affect psychosocial and mental health by exposing people to distressing conditions and events that influence their physical health (e.g. asthmatic attacks triggered by forest fire smoke; injury from flying debris; disruption of medical care) (Brunkard et al., 2008; Auger et al., 2011). They may also negatively affect mental health and stress levels through, for example, the disruption of daily life and livelihoods as a result of evacuations and limited access to medical services (Bethel et al., 2011). Similarly, such impacts may result from alterations in the natural and social environment (e.g. loss of sense of place and belonging through extensive damage to community spaces and altered patterns of social interaction) (Higginbotham et al., 2007). The causal pathways by which climate change affects mental health are depicted in Figure 8.

Symptoms of psychosocial impacts from an extreme weather event or disaster may take various forms such as alterations in mood, thoughts, behaviour, an increased level of distress, and a reduction of one's ability to function in everyday life (Berry et al., 2008a). Disaster-induced cognitive and emotional issues may manifest in the form of concentration and memory loss, learning disorders, anxiety, acute stress disorders, PTSD, depression, sleep difficulties, aggression, substance abuse, and high risk behaviour in adolescents (Somasundaram and Van De Put, 2006; Boon et al., 2011).

Numerous studies have examined the relationship between specific natural hazards and negative mental health outcomes (Salcioglu et al., 2007), including drought (US CDC et al., 2010; Polain et al., 2011; Wittrock et al., 2011), heat waves (Nitschke et al., 2007; Hanson et al., 2008; Bambrick et al., 2011), wild fires (Johnston, 2009; Ostry et al., 2010), storms and hurricanes (Cretikos et al., 2007; Bethel et al., 2011; Boon et al., 2011), and ice and snow (Auger et al., 2011). Floods, for example, have been associated with a range of mental health problems, including PTSD (Adhern et al., 2005; Acharya et al., 2007; Carroll et al., 2009; Ebi and Paulson, 2010; Carnie et al., 2011), increased social disruption, violent behaviour (e.g. assaults) and substance abuse (Ebi and Paulson, 2010), and increased suicide risk (Du et al., 2010).

Knowledge of effective measures to reduce psychosocial impacts from extreme weather events and disasters has increased (Berry et al., 2009; Clarke, 2009). For example, a number of lessons were gained as a result of responding to and recovering from the unprecedented flood that impacted the province of Manitoba in 2011 (*see* Case Study 3).

2.5 ULTRAVIOLET RADIATION

Ambient ultraviolet radiation (UVR) levels vary with geographic location, season, time of day, altitude, cloud cover, and atmospheric pollution (Thomas et al., 2012). A range of short-term health effects (e.g. DNA damage, immune suppression) (Norval and Halliday, 2011; Thomas et al., 2012) and long-term health effects (e.g. skin cancer, cataracts) (de Albuquerque Alves, 2011; Thomas et al., 2012) have been associated with UVR exposures, along with some benefits (e.g. production of vitamin D) (Dixon et al., 2012). It was estimated that 81 000 cases of non-melanoma and 5 800 new cases of melanoma skin cancer would occur in Canada in 2012 (Canadian Cancer Society, 2012).

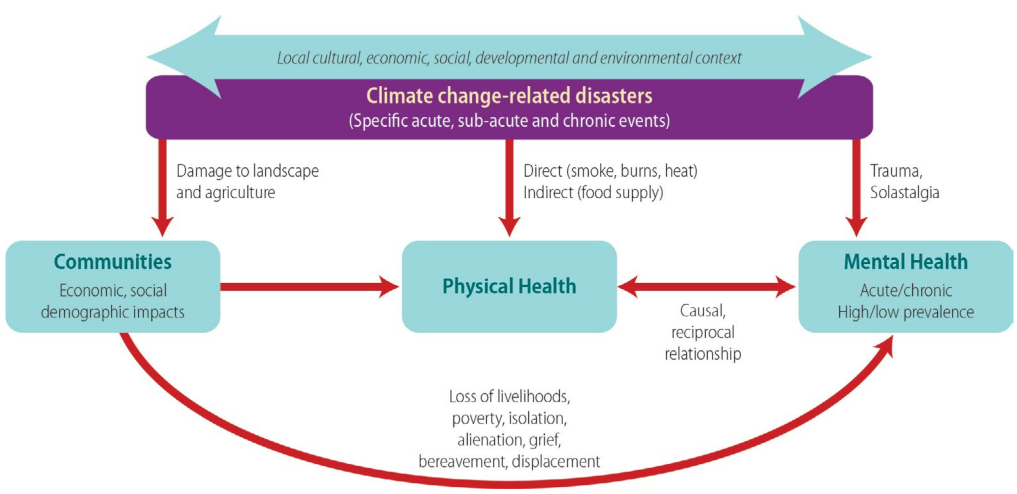

FIGURE 8: Framework showing the causal pathway linking climate change and mental health *(Source: Berry et al., 2009)*.

CASE STUDY 3

MANITOBA FLOOD 2011: IMPETUS FOR A PROVINCIAL APPROACH TO PSYCHOSOCIAL ADAPTATION TO NATURAL HAZARDS

The 2011 flood in Manitoba lasted roughly four months, and many small communities, including a large number of First Nations, were evacuated for varying lengths of time. Some 1932 people remained displaced eighteen months later, and a proportion of evacuees are unlikely to ever return to their homes. Psychosocial impacts identified among individuals and families included increases in alcohol and drug use and family violence, along with other general symptoms of high levels of stress such as depression, anxiety, sleep disruption, and an increase in physical ailments (pers. comms., Gerry Delorme).

Manitoba Health's Office of Disaster Management worked with provincial emergency social services to identify and map locations and communities where psychosocial impacts were anticipated to be greatest. Key organizations (e.g. Emergency Social Services, Emergency Measures Organization, Aboriginal Affairs and Northern Development Canada, Manitoba Agriculture, Food and Rural Initiatives, Manitoba Family and Rural Support Services, Conservation and Water Stewardship) quickly established a *Provincial Psychosocial 2011 Flood Recovery Table* which formalized a structure for planning and response, and provided the leadership and funding required to address the multiple scales of psychosocial impacts (individual, community and provincial). Four regional recovery teams of 3 to 4 staff members were deployed to the most severely impacted areas of the province. Through this experience, the following challenges and lessons learned were identified:

- *Leadership* – Effective responses to the flood event required both centralized coordinated leadership and community-based actions.
- *Building capacity to address psychosocial impacts* – Psychosocial considerations must be routinely included in risk assessment and disaster management planning and response.
- *Tailoring communication and messaging* – Communications staff should be cognizant of, and trained in, the psychosocial aspects of messaging to affected citizens so as to reduce, rather than attenuate distress.
- *At-risk populations* – The most vulnerable people suffered disproportionately from psychosocial and other health impacts (e.g. elderly people, children, those with chronic medical conditions, the poor, and First Nations communities). More specific planning is required to identify and enhance the capacity of these people.
- *Psychosocial impacts and response personnel* – Emergency responders, psychosocial recovery workers, and decision makers suffered from psychosocial impacts, ranging from fatigue to extreme stress reactions. Targeted psychosocial support is required for health care workers, emergency management and other responders during an event.
- *Evaluating responses* – Evaluating the success of psychosocial interventions was limited by the capacity to plan for and collect data in the midst of response and recovery activities.

The flood of 2011 highlighted the need to plan more effectively to address the psychosocial impacts of climate-related events and disasters. As a result of the flood, a *Provincial Interagency Psychosocial Planning Table* (per comms. Gerry Delorme) has been established to increase the provincial capacity to respond to future disasters.

Warmer temperatures associated with climate change may result in increased exposure by the population to UVR in Canada due to higher levels of ambient UVR along with changes in human behaviour (e.g. more outdoor activities, limited use of personal protective measures) (Thomas et al., 2012). The Canadian National Sun Survey conducted in 2006 revealed that children aged one to 12 years use regular sun protection infrequently and heavily rely on sunscreen, indicating that other measures such as seeking shade and wearing protective clothing need to be promoted (Pichora and Marrett, 2010).

Ozone depletion has stabilized and started to recover since the 1990s (Bais, 2011; WMO, 2011). Recent projections of erythemally-weighted solar irradiance (UV-Ery) – a widely used metric to describe "sunburning" properties of UVR that is directly proportional to the UV Index – suggest that by the 2090s UV-Ery will be approximately 12% lower at high altitudes, 3% lower at mid-latitudes and 1% higher at the tropics (Bais, 2011).

The projected values take climate change into consideration and are dependent on an increase in cloud cover at high latitudes and full recovery of column ozone,[5] which absorbs the UV-B band known for its negative health effects. Other projections suggest that under a clear-sky scenario, by 2095 the UV Index will decrease by 9% in northern high latitudes, increase by 4% in the tropics, and increase by up to 20% in southern high latitudes in late spring and early summer (Hegglin and Shepherd, 2009). Many uncertainties exist about projected levels of UVR and its spectral composition because of uncertainties associated with future levels of precipitation, cloud cover, aerosols, and loss of snow and sea ice (Thomas et al., 2012). Recent animal models demonstrate that an increase in temperature could increase UVR-induced carcinogenesis (van der Leun et al., 2008). However, predicting how climatic changes will affect UVR-related health impacts remains a challenge.

[5] The effects of climate change on ground-level ozone are discussed in Section 2.1.

3. REGIONAL AND COMMUNITY VULNERABILITIES

Exposure to climatic events that can affect health is highly dependent on geography, topography, and land use. Health impacts resulting from climate and weather-related exposures are either modulated or compounded by population sensitivities and adaptive capacity at sub-regional, local, and individual levels (Berry, 2008). Canadian communities and regions differ greatly in terms of key vulnerability factors that underpin threats to health from climate change. Urban, rural, coastal and northern communities have unique attributes that make them differentially vulnerable to health impacts. The availability of health, weather, climate, and socio-economic data is not uniform across the country which makes measurement and comparison of regional climate change health risks and vulnerabilities challenging. Some examples of regional variations in health risks and vulnerabilities are presented in Table 4.

Climate Risk Category	Examples of Regions At Highest Risk	Examples of Climate-related Risk Factors and Health Impacts
Extreme Temperatures	**Extreme Heat** Windsor to Quebec corridor (e.g. Windsor, Hamilton, Toronto, Kingston, Montreal), regions along Lake Erie, Lake Ontario and St. Lawrence River, Prairies (e.g. Winnipeg), Atlantic Canada (e.g. Fredericton) and British Columbia (e.g. Vancouver) **Extreme Cold** Arctic, Prairies, Ontario, eastern Canada	More frequent and severe heat waves and longer periods of warmer weather, possible colder conditions in some locations Increase in annual heat-related mortality in Quebec projected for 2020, 2050 and 2080 to be 150, 550, and 1400 excess annual deaths respectively, based on mean temperature increase[6]
Extreme Weather Events and Natural Hazards	**Thunderstorms, Lightning, Tornadoes, Hailstorms** Canada wide, low-lying areas of southern Canada, Saskatchewan, Manitoba , Nova Scotia, Ontario, Quebec, Alberta **Freezing Rain , Winter Storms** Atlantic Canada, Ontario, southern Saskatchewan, southern and northwestern Alberta, southwestern interior British Columbia **Hurricanes, Storm Surges, Sea-Level Rise** Eastern Canada (particularly Atlantic Canada), Arctic, British Columbia **Mud-Rock and Landslides, Debris Flows, Avalanches** Rocky Mountains, Alberta, British Columbia, Yukon, southern and northeastern Quebec and Labrador, Atlantic coastline, Great Lakes, St. Lawrence shorelines **Floods** New Brunswick, southern Ontario, southern Quebec and Manitoba **Drought** Prairies, southern Canada **Wildfires** Ontario, Quebec, Manitoba, Saskatchewan, British Columbia, Northwest Territories, Yukon	More frequent and violent extreme weather events, land-shifts, rising sea levels, increased floods, drought and wildfires In January 2012, a freezing rain event in Montreal resulted in 50 road accidents that included 1 fatality[7] and followed a similar event a few weeks earlier which led to several traffic accidents, hospitalizations and road closures[8] Between 2003 and 2011, there were 60 extreme flood events in Canada which resulted in the evacuation of 44 255 people. A June 2012 flood event in British Columbia resulted in 1 fatality, at least 350 evacuations, treacherous travel conditions and road closures[9] 34 wildfires occurred from 2003-2011 resulting in 113 996 evacuations, and in one event, 2 fatalities[10]; wildfires in Kelowna BC in 2003 were implicated in increased physician visits for respiratory disease up to 78% relative to previous years[11]

Table 4 continued on next page

6 Gosselin, P., Belanger, D., and Doyan, B. (2008b): Health impacts of climate change in Quebec; *in* Human health in a changing climate: A Canadian assessment of vulnerabilities and adaptive capacity; Health Canada, Ottawa, Ontario.

7 CBC News (2012). Snow, freezing rain causes accidents across Quebec. Accessed on August 21, 2012 from: <http://www.cbc.ca/news/canada/montreal/story/2012/01/13/weather-montreal.html>

8 CBC News (2012). Freezing rain causes havoc on Montreal roads. Accessed on August 21, 2012 from: <http://www.cbc.ca/news/canada/montreal/story/2011/12/21/freezin-rain-causes-accidents-in-montreal.html>

9 CBC News (2012). Deadly B.C. flooding prompts more evacuations, highway closures. Accessed on August 21, 2012 from: <http://www.theglobeandmail.com/news/british-columbia/deadly-bc-flooding-prompts-more-evacuations-highway-closures/article4368207/>

10 Public Safety Canada (PSC) (2012). The Canadian Disaster Database. Retrieved August 19, 2012 from: <http://www.publicsafety.gc.ca/prg/em/cdd/index-eng.aspx>

11 Ostry A. et al. (2010). Climate change and health in British Columbia: Projected impacts and a proposed agenda for adaptation research and policy. International Journal of Environmental Research and Public Health, v. 7, no. 3, p. 1018-1035

Air Quality	**Outdoor Air Pollutants (Ozone and Particulate Matter)** Ontario (Great Lakes Region), particularly urban areas of southern Ontario (Toronto), southern Quebec (e.g. Montreal) British Columbia (Vancouver, Lower Fraser Valley), Alberta (Calgary, Edmonton, Fort McMurray) and Manitoba (Winnipeg) **Aeroallergens (Ragweed) and Fungal Pathogens** Southern Quebec and southern Ontario, central and southern Saskatchewan (e.g. Saskatoon) and Manitoba (e.g. Winnipeg), British Columbia	Higher ground-level ozone levels, airborne dust, increased production of pollens and spores by plants Increased average temperature in Canada could lead to an increase in ozone concentration and could result in an overall increase of 312 premature deaths.[12] On the Island of Montreal, nearly 40 000 children suffer from ragweed-related allergic reactions[13]
Contamination of Food and Water and Food Security	**Water Contamination** Canada wide, marine or freshwater coastal regions or watersheds vulnerable to sea-level rise and/or exposure to toxic or pathogenic surface run-off (West Coast, East Coast, Arctic, Great Lakes), regions that are vulnerable to drought (e.g. Prairies), overland flow or flooding leading to surface or groundwater contamination (e.g. rural agricultural areas, urban centers) **Food Contamination** Canada wide, agricultural regions (e.g. Prairies, Ontario, Quebec), regions with communities that are vulnerable to power outages and heat waves (e.g. urban centers such as Toronto), are exposed to toxic marine biota (coastal regions of British Columbia and Atlantic Provinces), are reliant on outdoor cold temperatures for food storage (e.g. Arctic) **Food Security** Arctic and agricultural regions	Contamination of drinking and recreational water due to run-off from heavy rainfall, and coastal algal blooms in coastal regions 4 million people suffer from food-related illnesses each year in Canada[14]; 7 provinces were implicated in the 2008 Canadian listeriosis outbreak that, of the 57 confirmed cases, lead to 23 deaths (75% occurring in Ontario)[15] In 2006, 30% of Inuit children in Canada had experienced hunger at some point because the family had run out of food or money to buy food[16]. In 2007-2008, 9.7% of Canadian households with children experienced food insecurity[17]
Infectious Diseases Transmitted by Insects, Ticks and Rodents	**Lyme Disease** Southern and southeastern Quebec, southern and eastern Ontario, and southeastern Manitoba, New Brunswick and Nova Scotia, southern British Columbia **West Nile Virus** Urban and semi urban areas of southern Quebec and southern Ontario, rural populations in the Prairies, rural and semi-urban areas of British Columbia **Eastern Equine Encephalitis** From Ontario to Nova Scotia **Rodent-borne Diseases (e.g. Hantavirus)** British Columbia, Alberta, Saskatchewan and Manitoba, Northwest Territories, Ontario, Quebec	Changes in the biology and ecology of various disease-carrying insects, ticks and rodents, faster maturation for pathogens within insect vectors and longer disease transmission season Range expansion of the tick vector for Lyme disease is expected in the coming decade at an increased rate with climate change; this is expected to increase human Lyme disease risk, particularly in eastern Canada[18]
Stratospheric Ozone Depletion	Canada wide, in particular regions: at high altitudes; with highly reflective surfaces (e.g. Arctic); with limited natural or built-form shade or air particulates (i.e. smog) that may block UV radiation (e.g. rural areas), in southern Canada (i.e. lower latitude regions closer to the equator)	Increased human exposure to UV radiation owing to behavioural changes resulting from a warmer climate In 2008, the estimated number of new cases of non-melanoma skin cancer among men was 40 000 and 33 000 among women. The estimated number of deaths was 160 among men and 100 among women in that year[19]

TABLE 4: Regional variations in climate change health risks and impacts *(Sources: Lemmen et al., 2008; Seguin, 2008; ICLR, 2012; Public Safety Canada, 2013a)*.

12 Lamy, S., and Bouchet, V. (2008): Air quality, climate change and health; in Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity; Health Canada, Ottawa, Ontario.

13 See<http://www.santemontreal.qc.ca/en/healthy-living/healthy-environment/ragweed/>

14 Thomas, M. K., Murray, R., Flockhart, L., Pintar, K., Pollari, F., Fazil, A., Nesbitt, A and Marshall, B. (2013). Estimates of the burden of foodborne illness in Canada for 30 specified pathogens and unspecified agents, Circa 2006. Foodborne Pathogens and Disease. July 2013, 10(7): 639-648 < http://www.phac-aspc.gc.ca/efwd-emoha/efbi-emoa-eng.php>

15 Public Health Agency of Canada (2013): Evaluation of food-borne enteric illness prevention, detection and response activities at the Public Health Agency of Canada. <http://www.phac-aspc.gc.ca/about_apropos/evaluation/reports-rapports/2011-2012/feipdra-pdimeoa/app-ann-c-eng.php>

16 Meakin, S. and Kurvits, T. (2009): Assessing the impacts of climate change on food security in the Canadian Arctic; <http://www.grida.no/files/publications/foodsec_updt_LA_lo.pdf>

17 Health Canada (2013): Household Food Insecurity In Canada in 2007-2008: Key Statistics and Graphics; <http://www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/insecurit/key-stats-cles-2007-2008-eng.php#b>

18 Leighton, P. et al. (2012): Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector Ixodes scapularis in Canada, v. 49, no. 2, p 457-464.

19 Public Health Agency of Canada (2013): Non Melanoma Skin Cancer; <http://www.phac-aspc.gc.ca/cd-mc/cancer/non_melanoma_skin_cancer-cancer_peau_non_melanique-eng.php>

The following sections discuss populations at higher risk to the health impacts of climate change and regional-level vulnerability factors important for planning and implementing adaptations to protect health.

3.1 VULNERABLE POPULATIONS

All Canadians are at risk from the health impacts of climate change. However, seniors, children and infants, the socially and economically disadvantaged, those with chronic diseases and compromised immune systems, Aboriginal people, and residents of northern and remote communities have been identified as being more vulnerable (Lemmen et al., 2008; Seguin, 2008; Bernstein and Myers, 2011). Evidence supports earlier findings that people with existing respiratory conditions are more vulnerable to air pollution and that seniors (Frumkin et al., 2008; Balbus and Malina, 2009) and children (Frumkin et al., 2008; Ebi and Paulson, 2010) are at higher risk from extreme heat events. Individuals who rely on untreated water systems may also be at higher risk from extreme weather events (both heavy rainfall and drought).

Climate change also poses special challenges to the health of Aboriginal populations and residents of northern and remote communities due to impacts on traditional food sources and diets, their dependence on the land, reliance on reasonably predictable and stable weather patterns and cultural impacts (Furgal and Seguin, 2006; Furgal, 2008; Ford et al., 2010a). Aboriginal Canadians living in the North, on reserve in southern communities and off reserve may be differently impacted by climate change. Research on the vulnerabilities faced by Aboriginal people in southern communities is sparse and further research is needed to inform adaptation actions.

Studies of the health impacts of extreme weather events (*see* Section 2.4) confirm that some groups are more impacted by these events and expand knowledge on the nature of existing vulnerabilities (Costello et al., 2009; IPCC, 2012; WHO, 2012b). For example, recent evidence suggests that seniors are more vulnerable to storms and floods because they are less likely to leave their homes in an emergency due to prior experience with false alarms, fear that their homes will be looted, or of the possible disruption of medical or other routines (Brunkard et al., 2008). In addition, people with lower socioeconomic standing who have poor quality housing, an inability to replace damaged property (e.g. lack insurance), and less access to legal and other services often suffer greater impacts from floods (English et al., 2009; Carroll et al., 2010). Home renters are less likely to be prepared for emergencies and have been found to be more vulnerable to flood events (Coulston and Deeny, 2010). There is also growing recognition of the heightened vulnerability of people whose job it is to help those in distress during emergencies, including support workers (Carroll et al., 2010), police and first responders (Neria et al., 2008), and health care and social service providers (Hess et al., 2009; Health Canada, 2011b).

Protecting the most vulnerable in society from climate change requires understanding individual sensitivity and exposure to current hazards, adaptation challenges (*see* Table 5) and knowledge of, and ability to communicate with, the most vulnerable populations (Maibach et al., 2011).

Innovative ways have been developed to locate vulnerable populations before and during emergencies and disasters so that they can be assisted. Bernier et al. (2009) used spatial online analytical processing (SOLAP) to investigate climate change and health vulnerability data in Québec City. SOLAP allows decision makers to combine the spatial views of geographic information systems (GIS) with complex and temporal analysis needed to understand and adapt to climate change impacts on health (Bernier et al., 2009). The City of Toronto has developed heat vulnerability maps (*see* Figure 9) to assist in the implementation of their heat alert and response system by, for example, providing information to ambulance services to prepare for heat alert days, supporting targeted door-to-door outreach to assist people in need, informing the creation of heat registries and identifying the best locations for cooling centres (Toronto Public Health, 2011a).

Heat-Vulnerable Groups	Examples of Challenges

Older adults	• Physiological characteristics that may contribute to increased vulnerability to heat:
	    • reduced thirst sensation
	    • reduced fitness level
	    • reduced sweating ability
	    • increased susceptibility to chronic dehydration
	• Visual, cognitive, and hearing impairments
	• Agility and mobility challenges
	• Differing perceptions of risks and vulnerabilities based on life experiences
	• Reduced literacy
	• Social isolation

Infants and young children	• Physiological and behavioural characteristics that may contribute to increased vulnerability to heat:
	    • increased body heat production during physical activity
	    • faster heat gain from the environment if air temperature is greater than skin temperature due to greater surface-area-to-body-weight ratio
	    • inability to increase cardiac output
	    • reduced sweating
	• Dependence on caregiver to recognize heat impacts and take recommended actions

Socially disadvantaged individuals and communities: • Low income • Homeless • Living alone	• Limited financial resources to adequately take protective actions • Reduced access to clean water and cool places • Limited access to health care and social services • More environmental exposures (e.g. homeless, living on higher floors with no air conditioning) • Higher rates of alcohol and drug dependency • Social isolation

TABLE 5: Examples of heat-vulnerable groups and challenges they may face in adapting to extreme heat events *(Source: Adapted from Health Canada, 2012c)*.

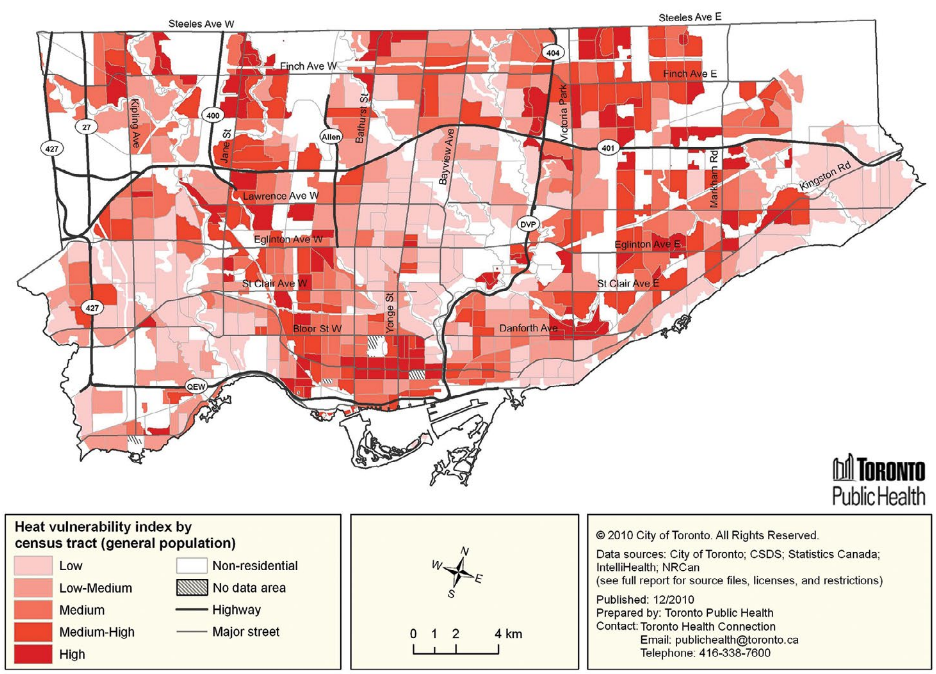

FIGURE 9: Vulnerability to heat in Toronto *(Source: Toronto Public Health, 2011a)*.

3.2 URBAN AND RURAL COMMUNITIES

Urban Canada has unique vulnerability attributes that predispose residents to health impacts from specific climate-related hazards; for example, large-scale population exposure to extreme heat and air pollution due to high population densities and the nature of the built environment. Cities have a high proportion of heat-retaining asphalt, high density living, tall towers, and limited green-space, which makes urban centres vulnerable to extreme heat events (Hess et al., 2009; Ostry et al., 2010; Bambrick et al., 2011; Gabriel and Endlicher, 2011; Huang et al., 2011a; Toronto Public Health, 2011a). Some Canadian cities are taking action to reduce climate-related health risks. For example, Montreal has implemented measures to reduce the urban heat island through regulations for newly constructed and renovated roofs and by developing green spaces to reduce solar reflectivity and heat retention in urban areas (Marsden, 2011).

Flood risks are increased in cities because water flows more rapidly on land that has been built over. Storms can lead to damaged or flooded roadways, combined sewer system overflows and floods in buildings, all of which can result in unsafe transport conditions, compromised critical infrastructure, and poor indoor air quality (Rosenzweig et al., 2011). Risks are higher in cities with drainage systems (e.g. combined sewer overflow systems) that are not adapted accordingly (McGranahan et al., 2007). Exposure to multiple extreme weather events occurring at the same time and in the same location may result in cumulative impacts that increase risks to health. During the summer of 2012 in the United States, very hot temperatures, drought conditions and stormy weather buckled highways, softened airport runways, kinked railway tracks, affected nuclear facilities due to warming of cooling water, and downed power lines, knocking out power to millions of people (Wald and Schwartz, 2012).

In rural regions where livelihoods are closely tied to natural resources, climate change may contribute to economic decline, social disruption, population displacement and/or similar challenges (Battisti and Naylor, 2009; Friel et al., 2009; Holden, 2009; McLeman et al., 2011; Clarke, 2012). Rural communities may be more exposed to certain types of extreme weather events and/or have more limited response capacity or access to services that help protect people (Berry, 2008; Ostry et al., 2010). For example, there is an increased risk of wildfires and floods in parts of western Canada affected by the Mountain Pine Beetle, which could have significant health implications for people living in these rural areas (Ostry et al., 2010). Evidence also suggests that flooded farmlands and surface run-off can contaminate local water sources and create health risks for populations located around or downstream of agriculture feedlots (Haines et al., 2006; Acharya et al., 2007). Fecal-oral cycling in such situations poses health risks to farmers, farm workers, farm families, and outdoor workers (Acharya et al., 2007; Du et al., 2010). In general, communities dependent on small and private drinking water systems that service populations of 5000 or less may be more vulnerable to water-borne disease outbreaks (Moffatt and Struck, 2011).

The capacity of rural populations to respond to climate change is influenced by unique sensitivities related to reductions in public services, changing demographics and dependency on natural resources (Wall and Marzall, 2006). Relative strengths relating to capacity include the social capital, networks and diverse skill sets of rural communities (Clarke, 2012). Table 6 highlights some of the health vulnerability risk factors stemming from climate change and climate-related impacts that can be prevalent in rural and urban communities.

Key Vulnerability Factors	Examples of Urban Characteristics	Examples of Rural Characteristics
Exposure • Geography • Land use • Climate	• Complex infrastructure, high density buildings and landscape dominated by impervious surfaces • Higher population density • Higher air pollutant levels	• Increased health risks from water contamination due to a high reliance on small drinking water systems • More people employed in outdoor occupations • Higher risk of exposure to land-shifts, wildfires, vector borne diseases and floods
Individual Sensitivity • Age and Gender • Health status	• Ageing population • Cardiovascular and respiratory conditions in large urban centers from air pollution and extreme heat	• High elderly population and high incidence of chronic illnesses, smoking and obesity
Key Adaptive Capacity Factors • Socio-economic status • Public services and risk communication programs • Employment	• Greater prevalence of high risk population groups, with limited adaptive capacity (e.g. low socio-economic status) • Higher prevalence of social isolation and limited access to services (e.g. immigrants, First Nations, homeless or persons of low income or with mental illnesses) • High reliance on critical infrastructure for health care and emergency service provision that are vulnerable to extreme weather	• Limited access to services during extreme events (e.g. power, water, food, medical) • Limited availability and accessibility of public services and programs and communication venues to deliver health and emergency messages • High dependency on natural resources that are vulnerable to disruption from extreme weather • Lower proportion of population highly educated • Limited livelihood and economic diversification • Limited resources and services to respond to extreme weather events and associated health burdens • Limited service access in remote communities

TABLE 6: Urban and rural characteristics that increase vulnerability to climate change and climate-related impacts.

3.3 ABORIGINAL AND NORTHERN COMMUNITIES

Climate change impacts contribute to transformative social, ecological, and economic changes in Canada's north and present significant health risks to Aboriginal communities (Parkinson 2010a,b; Downing and Ceurrier, 2011; Rylander et al., 2011; The Aspen Institute, 2011; Health Canada, 2012a). Exposure to rapid climate change means that northern communities face increasing risks related to reduced duration and thickness of sea and lake ice, thawing permafrost, sea level rise and storm surges, erosion and landslides, more unpredictable weather, freezing rain and wildfires, shorter winter conditions, and hotter summers (Ford et al., 2009; Boulton et al., 2011). Such impacts create health risks by threatening food safety and security, drinking water supplies, water and ice safety, the availability of traditional medicine and the stability of infrastructure (Health Canada, 2012a). Northern residents report that environmental changes are impacting their livelihoods, their relationship with the land, their culture, and their mental health and well-being (Ford et al., 2010b; Lemelin et al., 2010; Morse and Zakrison, 2010; Downing and Cuerrier, 2011; Andrachuk and Smit, 2012; McClymont and Myers, 2012).

Traditional food practices such as hunting and gathering are threatened by climate change. For example, the shifting abundance and distribution of resources, threats to transportation safety when accessing resources and warmer temperatures are compromising the safety of food storage practices (Ford, 2009). In the Ross River First Nations (Yukon Territory), earlier spring thaw, warmer and extended summers, and increasing wildfires are affecting the feeding grounds, distribution and abundance of caribou populations, which are a vital traditional food source (Health Canada, 2012f). Impacts to caribou herds are also exacerbated by resource development, which is also influenced by climate change (*see* Chapter 3 – Natural Resources). These cumulative impacts can affect habitat suitability and lead to bioaccumulation of contaminants, ultimately threatening food safety (Health Canada, 2012a). One investigation of food security in Northern Manitoba found that weaker ice conditions related to winter warming have affected the transportation of goods, resulting in a shorter supply of healthy groceries for many of the province's 25 northern communities (Centre for Indigenous Environmental Resources, 2006). In Iqaluit, Nunavut, many people prefer traditional methods of collecting drinking water from rivers, streams, ponds, lakes, icebergs and sea ice versus relying on tap water. However, freshwater resources are at risk of possible contamination from thawing permafrost that could contain toxins, as well as from the northward migration of plants and animals harbouring water-borne pathogens (Health Canada, 2012d).

Characteristics that increase the vulnerability of Aboriginal health systems to climate change include the reliance on subsistence food supply, high rates of poverty, limited surveillance and early warning capacity, less access to health information, diagnosis and treatment of climate-sensitive diseases, jurisdictional and resource constraints and inequality (Ford et al., 2010a). Adaptive capacity challenges relate to the young population (the median age of Inuit is 22 years) and their relatively lower education levels, as only 25% of students graduate from high school (Statistics Canada, 2011). Furthermore, increased housing availability has not accommodated population growth in parts of the North (Owens et al., 2012) and unstable land from permafrost degradation and coastal erosion contributes to deterioration of a wide range of infrastructure in this region (Allard and Lemay, 2012).

3.4 COASTAL COMMUNITIES

Despite one third of Canada's coastline being moderately to highly vulnerable to sea-level rise (Shaw et al., 1998), relatively little research has been done on health-related impacts and adaptation to climate change in coastal areas in Canada (Dolan et al., 2005; Dolan and Walker, 2006). Unique health hazards and vulnerabilities exist in coastal areas; the combined effects of sea level rise, more severe and frequent storm surges, changing sea ice conditions and thawing permafrost are anticipated to cause a series of socioeconomic and environmental stresses that can impact health. Some coastal communities reside in the North or are small and isolated, and so share some of the specific factors that make these other types of communities vulnerable.

Climate change affects health in coastal regions through population displacement and social disruption due to land loss from sea-level rise, flooding and erosion, as well as changes in biodiversity, which affect use of natural resources and cultures. Storms and changing ice conditions that affect water security, occupational safety and economic opportunities, and landscape changes that affect the distribution and amounts of biotic and abiotic pollution in the environment can also threaten the health and safety of populations (Dolan and Walker, 2006; Hess et al., 2008; Rosenzweig et al., 2011; Government of British Columbia, 2012).

Exposure to extreme weather increases the vulnerability of coastal communities to climate change (Dolan and Ommer, 2008). For example, in 2010, Hurricane Igor stressed emergency response and acute health care services and displaced families in Newfoundland and Labrador (Public Safety Canada, 2013b). Ninety communities were isolated, 22 declared states of emergency, 300 families were evacuated, and 1 person died (Public Safety Canada, 2013b). High tides coupled with heavy rains have increased flood risk in communities in delta regions; as was seen on Vancouver Island in 2009 when extensive flooding resulted in a local state of emergency, with 50 homes destroyed and approximately 900 residents (300 homes) evacuated (Public Safety Canada, 2013c).

Environmental resource dependence and changing socio-economic conditions may make some coastal communities more vulnerable to the health impacts of climate change (Dolan and Ommer, 2008). For example, production of Fraser River sockeye salmon appears to be declining due to trends in water temperatures (*see* Chapter 4 – Food Production). This may have significant economic and cultural implications for Canadians, especially in British Columbia (Hinch and Martins, 2011)[20].

Some west coast towns that were previously dependent on forestry and fisheries have grown more dependent on tourism and aquaculture to provide employment and tax revenues. Others have endured population declines as people move away to find work (Dolan and Ommer, 2008). In remote coastal communities, vulnerability is further increased by social isolation and shrinking human capital, resulting in part from trends toward urban migration (Frumkin et al, 2008). Future impacts may be exacerbated by pressures linked to migration and coastal development (McGranahan et al., 2007; Rosenzweig et al., 2011; IPCC, 2012). Climate change may also bring benefits for coastal communities if changes related to access and use of natural resources create new economic opportunities in fisheries, tourism, and agriculture (Bigano et al., 2008; Lemmen et al., 2008; World Tourism Organization, 2008; Sumaila et al., 2011; *see also* Chapter 4 – Food Production and Chapter 5 – Industry).

Specific adaptation plans for coastal regions that are being considered, implemented and/or researched are typically led by Ministries or organizations outside of public health (e.g. Ministries of Environment). Such initiatives tend to lack a health lens, but exceptions exist, such as in northern Canada where programs dealing with country food security and health have been implemented (Government of Northwest Territories, 2008).

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[20] Between 1988 and 1998 the total landed value of the commercial salmon fishery in British Columbia declined from $410 million to $55 million which impacted the standard of living of some people reliant on this resource (Dolan and Ommer, 2008).

4. ADDRESSING CLIMATE CHANGE RISKS TO HEALTH

"Much of the potential health impact of climate change can [...] be avoided through a combination of strengthening key health system functions and improved management of the risks presented by a changing climate." (WHO, 2012b, page V)

As the climate continues to change and impacts on health are increasingly evident (Costello et al., 2009), adaptation is needed to reduce growing risks to vulnerable populations and communities (McMichael et al., 2008; WHO, 2008; Ebi, 2009; Paterson et al., 2012). The Canadian Medical Association (2010) called for action by health authorities to address climate change in Canada in five main areas:

- education and capacity building;
- surveillance and research;
- reducing the burden of disease to mitigate climate change impacts;
- preparing for climate emergencies; and
- advocacy to combat climate change.

Successful adaptation requires intersectoral collaboration (e.g. health, environment, planning, transport, infrastructure) on monitoring and surveillance of climate change health outcomes, addressing root causes that limit preparedness (e.g. poverty), identification of vulnerable populations, reducing uncertainty through increased research on impacts, educating the public and decision makers about potential disasters and the benefits of preparedness, and the financing of needed measures (Seguin, 2008; WHO, 2010; Ebi, 2011; Frumkin, 2011). Adaptations are most effective when they maximize co-benefits (e.g. increase social capital, improve urban design) (Cheng and Berry, 2012) that address related health concerns, and when they are mainstreamed into existing programs and planning.

4.1 ADAPTATION MEASURES AND STRATEGIES TO PROTECT HEALTH

Understanding of adaptation options that can be taken by public health and emergency management officials to build resilience has increased (Ebi et al., 2012; Paterson et al., 2012) although information about adaptation success is limited (Lesnikowski et al., 2011). Table 7 highlights measures identified in recent literature that are available to address climate change risks to health, and builds upon the list of public health adaptations presented by Seguin (2008)[21]. New adaptation areas of focus by public health officials and researchers include:

- vulnerability assessments of high risk populations (*see* Section 4.2.1);
- actions to address secondary health effects of climate hazards such as psychosocial impacts (*see* Case Study 3);
- use of new technologies to facilitate adoption of individual adaptive behaviours (e.g. use of automated devices in cars to warn of water depth (Fitzgerald et al., 2010) or landslide early detection systems);
- advice to health care providers about actions they can take to reduce climate-related health risks;
- emergency management planning measures tailored to increase the resiliency of health care facilities from climate change; and
- identification of preventative measures to reduce harmful exposures before negative health outcomes occur (e.g. infrastructure development such as green roofs to reduce the urban heat island).

[21] See pages 426-427 in "Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity" (Seguin, 2008) available at <http://publications.gc.ca/collections/collection_2008/hc-sc/H128-1-08-528E.pdf>

Extreme Heat and Air Pollution	
Impact	**Adaptation Measures**
Health impacts from higher temperatures, increased frequency and severity of heat waves, increased air pollution	• Air conditioning (Frumkin et al., 2008; Balbus and Malina, 2009; Bedsworth and Hanak, 2010; Bambrick et al., 2011), with the caveat that other solutions should be explored first, as air conditioning may contribute to climate change and air pollution through greater use of fossil fuels (Ayres et al., 2009; Maller and Strengers, 2011; Health Canada, 2012c) • Better quality housing stock, appropriate infrastructure (Frumkin et al., 2008; Ayres et al., 2009; English et al., 2009) with the ability to capture energy and recycle water (Bambrick et al., 2011) • Infrastructure development such as green roofs, reflective road and building surfaces, urban green spaces, interior air sealing, use of elastomeric roof coating (Huang et al., 2011a; Maller and Strengers, 2011; Health Canada, 2012c) • Public awareness and education campaigns to promote personal protection from air pollution (e.g. Air Quality Health Index – AQHI) (Haines et al., 2006; Seguin, 2008; Bedsworth and Hanak, 2010) • Vulnerability assessments of high risk regions/populations (Ostry et al., 2010; Health Canada, 2011a; Health Canada, 2012c) • Physician attention to vulnerable patients, pre-summer vulnerability assessments, advice on routine care, education of health risks and appropriate behaviours (Ayres et al., 2009; Ebi and Paulson, 2010; Health Canada, 2011b) • Development and use of vulnerability maps to allow targeting of vulnerable populations (Hess et al., 2009; Health Canada, 2011a) • Promotion of social capital development (Bambrick et al., 2011; Huang et al., 2011b)
Wildfires	
Impact	**Adaptation Measures**
Increased contact with fire/fire front and evacuations	• Avoid building in vulnerable locations (Bedsworth and Hanak, 2010) • Access to appropriate clothing, fire shelters (e.g. bunkers), and equipment (e.g. particle filtering masks) for high risk areas (Künzli et al., 2006; Johnston, 2009) • Infection control, disease surveillance and appropriate emergency accommodation (Johnston, 2009)
Increase in air pollution	• Relocation to clean air locations such as office, libraries, etc. (Johnston, 2009) • Use of air conditioners (Künzli et al., 2006), especially reverse cycle air conditioners set to recycle mode to filter air particles (Johnston, 2009) (*see caveat above*) • Avoidance of exercise in affected environments (Johnston, 2009) • Spending less time outdoors (Künzli et al., 2006) • Use of air masks (Künzli et al., 2006)
Drought	
Impact	**Adaptation Measures**
Decreased availability and quality of water	• Distribution of public awareness materials/public service announcements, public education programs (Morrissey and Reser, 2007; Wheaton et al., 2008; Bonsal et al., 2011; Wittrock et al., 2011) • Physical relocation of individuals/families to non-drought affected areas (Wittrock et al., 2011) • School-based mental health programs in rural areas, participation of trusted adults who understand drought, early identification of mental health problems and referral (Carnie et al., 2011; Hart et al., 2011) • Training in coping mechanisms (Morrissey and Reser, 2007)
Decreased availability and higher costs for fresh fruits and vegetables (for consumers)	• Technological advances to increase production in new climate conditions (Frumkin et al., 2008) • Improved food delivery systems (Frumkin et al., 2008)
Increase in water-borne pathogens and water contamination	• Boil water advisories (Wittrock et al., 2011) • Monitoring of gastroenteritis (Horton et al., 2010)
Increase in drought and temperature enabled vector-borne disease	• Public education (Frumkin et al., 2008) • Vector control (e.g. mosquito spraying) (Frumkin et al., 2008) • Medical prophylaxis and treatment (Frumkin et al., 2008) • Vaccination (Frumkin et al., 2008)

Table 7 continued on next page

Floods	
Impact	**Adaptation Measures**
Physical and mental health impacts from increased flood incidence rates and severity	• Flood-appropriate building and infrastructure construction standards for vulnerable areas (e.g. higher level bridges and causeways, water resistant emergency power) (Fundter et al., 2008; Du et al., 2010; Fitzgerald et al., 2010) • Early warning systems based upon weather predictions of flooding, landslides, river flooding and coastal flooding (Alfieri et al., 2012) • Flood evacuation plans, especially for nursing homes, hospitals, schools (Hayes et al., 2009; Jonkman et al., 2009; Bedsworth and Hanak, 2010) • Proper design and siting of health infrastructure (Du et al., 2010) • Assessment of the resiliency of health care facilities to climate change (Paterson et al., 2013) • Education of health risks and appropriate behaviours by physicians (Ebi and Paulson, 2010) • Mapping of high risk populations with 100- and 500-year flood zones (English et al., 2009) • Post-flood disease surveillance (Fewtrell and Kay, 2008) • Use of automated devices in cars to warn of water depth (FitzGerald et al., 2010), landslide early detection systems • Disaster mental health services that are sensitive to socioeconomic status, livelihood patterns, local traditions, cultures and languages (Du et al., 2010) • Immediate family reunion and support (for families that have been separated) (Ebi and Paulson, 2010)
Increased mold and respiratory contaminants from mold, bacteria, fungal growth on damp structures	• Inspection of heating, ventilating and air conditioning system (HVAC) by a professional after a flood (US, CDC, 2012) • Drying out homes using fans or dehumidifiers when safe to do so, or by opening doors and windows (US CDC, 2012)

Zoonoses and Vector-borne Diseases	
Impact	**Adaptation Measures**
Spread of vector-borne and zoonotic diseases including exotic diseases	• Development of new surveillance methods (e.g. Ogden et al., 2011; Koffi et al., 2012) • Dissemination of information for public health officials and the public (Public Health Agency of Canada, 2013a) • Tools for risk-based decision making on management (i.e. surveillance, prevention and control) of emerging/re-emerging zoonoses/VBDs (e.g. Multi-Criteria Decision Analysis) (e.g. Hongoh et al., 2011), prioritization of zoonoses/VBDs for public health action (Cox et al., 2012; Ng and Sargeant, 2012), and weather-based forecasting of West Nile Virus (Wang et al., 2011)

Food and Water Quality	
Impact	**Adaptation Measures**
Increased water contamination and water-borne diseases, contamination of food	• Protocols for chemical and contaminant risk management (Du et al., 2010) • Monitoring of harmful algae bloom outbreaks (Haines et al., 2006; English et al., 2009) • Boil water advisories (Haines et al., 2006) • Expanding water reuse systems to offset reduced supply, increased demand, or both (Water Research Foundation, 2013) • Improving or expanding water treatment regimes (Water Research Foundation, 2013) • Adopting alternative energy sources at treatment plants (e.g. diversifying power sources, adding energy-efficient water pumps) (Water Research Foundation, 2013) • Establishing collaborative management regimes with power suppliers (Water Research Foundation, 2013) • Abandoning or enhancing water infrastructure at risk (Water Research Foundation, 2013)

TABLE 7: Adaptation measures to reduce health risks from climate change impacts.

4.2 HEALTH ADAPTATION IN CANADA

An international comparison of health adaptation activities among developed countries[22] listed in Annex 1 of the United Nations Framework Convention on Climate Change (UNFCCC) reported that Canada is further ahead of many countries in efforts to protect health from climate change. Specifically, it is one of the leading countries with respect to the depth of research being led on vulnerability to the impacts of climate change and adaptation options within the health sector. It is also one of the few countries to recognize and develop specific adaptation options around vulnerabilities of Indigenous groups (Lesnikowski et al., 2011). For development of this chapter, health adaptation efforts at federal, provincial, territorial and local levels related to assessing vulnerabilities, preparing for the impacts and communicating health risks to Canadians were examined. This review did not provide a comprehensive inventory of all local and regional adaptations (e.g. infectious disease surveillance, emergency management programs), nor did it comprehensively assess the state of health adaptation in Canada. However, it did highlight information that communities can draw from in order to set priorities, select appropriate strategies and implement them in a sustainable manner as a complement to existing programs, to protect and enhance health in their respective jurisdictions. The remainder of this section describes key findings of this review.

4.2.1 ASSESSING IMPACTS AND VULNERABILITIES

Climate change and health vulnerability assessments help public health officials to identify populations in their community or region who are vulnerable to the impacts, gauge the effectiveness of existing interventions and programs, identify additional measures necessary to respond to climate change, strengthen capacity to take action, and provide a baseline of information to monitor adaptation progress (Clarke and Berry, 2011; Health Canada, 2011a; WHO, 2012b). The World Health Organization recently released new guidelines for assessing health vulnerabilities to climate change and adaptation options (WHO, 2012b) and Health Canada released guidelines for assessing the vulnerability of communities and individuals to extreme heat (Health Canada, 2011a) (*see* Figure 10).

Such assessments rely on monitoring and surveillance data illustrating health impact trends associated with climate variability and change. Gaps in data exist for many climate change impacts of concern to Canadians (*see* Section 2.0). Cheng and Berry (2013) have identified a key basket of climate change and health indicators that can be used by health authorities to track impacts on health over time.

At present, few health authorities at regional and local levels have conducted full climate change and health vulnerability assessments. Analysis of possible health impacts from climate change have been undertaken in British Columbia (Ostry et

FIGURE 10: Steps for conducting an extreme heat and health vulnerability assessment *(Source: Health Canada, 2011a)*.

[22] For a list of UNFCCC Annex 1 countries see: http://unfccc.int/parties_and_observers/parties/annex_i/items/2774.php

al., 2010) and Quebec (Gosselin, 2010). Ontario's Adaptation Strategy and Action Plan 2011-2014 recognized extreme heat events as a key health concern and committed to the creation of a heat vulnerability assessment tool (Government of Ontario, 2011). At the local level, Peel Public Health (Ontario) used the new WHO guidelines to conduct a health vulnerability assessment (Pajot and Aubin, 2012) that will contribute to implementation of the Region of Peel Climate Change Strategy (Region of Peel, 2011). In addition, some public health authorities and their partners are currently undertaking or have undertaken research projects that contribute to knowledge of local vulnerability to specific health impacts (e.g. Gosselin, 2010; Kosatsky, 2010; Toronto Public Health, 2011a; Toronto Public Health, 2011b). Expertise on climate change and health issues is growing and many universities and organizations across Canada are undertaking research in this area.

4.2.2 PREPARING FOR THE IMPACTS

Protecting health from climate change impacts requires "mainstreaming" climate change considerations into existing risk assessment and management activities (Kovats et al., 2009; Clarke and Berry, 2011). Mainstreaming is based on "flexible" adaptation and institutional learning, which is responsive to changing risks to health, climate surprises, and individual- and community-level vulnerabilities (New York Panel on Climate Change, 2010; Ebi, 2011; Hess et al., 2011). Mainstreaming aims to reduce duplication and contradictions between existing public health interventions and new adaptations developed in response to climate change (Haq et al., 2008).

Evidence of mainstreaming in provincial and territorial policies, regulatory instruments and planning tools includes Strategic Direction 1 in the *"Quebec In Action – Greener by 2020: Government Strategy for Climate Change Adaptation"* that integrates climate change adaptation into government administration by modifying, where needed, the content of laws, regulations, strategies, policies, and planning tools (Government of Quebec, 2012). In Nunavut, the climate change adaptation plan requires all departments and agencies to "[…] integrate climate change projections, impacts, and best practices in all levels of their decision-making in order to implement a comprehensive response to climate change" (Government of Nunavut, 2011). One study in Ontario found evidence of adaptation through the mainstreaming of climate change into existing public health programs (Paterson et al., 2012). Outside of government, the Insurance Bureau of Canada is developing a municipal risk assessment tool that can help community decision makers use climate change information to address infrastructure vulnerabilities to projected flood events (IBC, 2013; *see also* Case Study 2, Chapter 5).

Other initiatives also contribute to reducing health risks from climate change. Many health authorities utilize HARS (heat alert response systems), air pollution monitoring activities, and programs to raise awareness of vector-borne diseases, which helps to manage a range of climate-related impacts (Berry, 2008). For example, the provinces of Manitoba, Quebec, and Nova Scotia have provincial HARS systems in place while Alberta is initiating one, and health authorities in Ontario are collaborating to maximize the effectiveness and integration of local systems. In addition, some activities that were not developed with the primary purpose of protecting health – for example, the development of a Drought Response Plan by the British Columbia Inter-Agency Drought Working Group (Government of British Columbia, 2010) – can indirectly help to improve health and well-being and thereby reduce the impacts of climate change.

New approaches and tools have been developed that could facilitate efforts to assist vulnerable groups in Canada and improve understanding of adaptation options at the individual and community levels. One example is the *"Building Community Resilience to Disasters: A Roadmap to Guide Local Planning"* (*see* Table 8). It provides examples of activities that public health and emergency management officials can undertake to help communities recover from disasters more quickly and withstand more severe events in the future.

Lever	Activities
Wellness	Ensure pre-health incident access to health services and post-health incident continuity of care
Access	Provide "psychological first aid" or other early post-disaster psychological or behavioural health interventions
Education	Bolster coping skills and psychological wellness by developing public health campaigns focused on these messages
Engagement	Build the capacity of social and volunteer organizations (i.e. nongovernmental organizations) to engage citizens in collective action to address an issue or problem (e.g. a community development or service project)
Self-sufficiency	Develop programs that recognize the vital role citizens can and must play as "first responders" to help their own families and neighbours in the first hours and days of a major disaster
Partnership	Engage established and local organizations (e.g. cultural, civic, and faith-based groups, schools, and businesses) and social networks to develop and disseminate preparedness information and supplies
Quality	Ensure that all disaster plans have identified common data elements (e.g. benchmarks for disaster operations) to facilitate seamless monitoring and evaluation of health, behavioural health, and social services before, during and after an incident
Efficiency	Develop policies for effective donation management and provide the public with clear guidance on donations

TABLE 8: Examples of activities for building community resilience to disasters *(Source: Rand, 2011)*.

Warming temperatures in some areas may contribute to air pollution, thereby hindering efforts to improve air quality (Kleeman et al., 2010; Union of Concerned Scientists, 2011). Findings in this chapter suggest this could be the case for Canada (*see* Section 2.1.2). Significant "health co-benefits" can be achieved through properly designed efforts to both reduce GHG emissions (Frumkin and McMichael, 2008; Haines et al., 2009; Kjellstrom and Weaver, 2009) and adapt to climate change impacts (Rosenzweig et al., 2011). For example, immediate health benefits can be achieved through the adoption of active transport and rapid public transit measures that reduce GHG emissions, air contaminants and the urban heat island effect, which helps to reduce a range of diseases associated with physical inactivity and exposure to air pollution in a population (Environment Canada, 2002; Frumkin and McMichael, 2008; Haines et al., 2009; Cheng and Berry, 2012; WHO, 2012b).

Several provinces and territories are linking efforts to mitigate GHGs with efforts to adapt to climate change by improving air quality. For example, the New Brunswick Climate Change Action Plan 2007-2012 sets out actions to reduce GHGs through public education efforts aimed at reducing vehicle idling to protect health and the environment (Government of New Brunswick, 2007). Nova Scotia's climate change action plan highlights actions to reduce and monitor GHGs and includes the Air Quality Health Index (AQHI) to help protect human health from air pollution (Government of Nova Scotia, 2009). Some efforts to reduce GHGs in Canada are being driven explicitly, at least in part, to maximize co-benefits to health (e.g. City of Calgary, 2011).

Many interventions that have been implemented and may help reduce risks to health from climate change have not had their effectiveness evaluated (CMA, 2010; WHO, 2012b). A review by the Canadian Institute for Health Information (CIHI) of interventions in the urban environment to mitigate health inequalities that can be exacerbated by extreme heat and air pollution found that 86% had not been evaluated (CIHI, 2012). Building evaluation measures into adaptation planning to reduce climate change-related health risks is important (Kovats et al., 2009).

4.2.3 COMMUNICATING HEALTH RISKS TO THE PUBLIC

Individuals have a primary role to play in adapting to the health impacts of climate change. Psychological factors such as risk perception and perceived adaptive capacity may be important influences in determining levels of climate change adaptation (Grothmann and Patt, 2005; Osberghaus et al., 2010). Appropriate and targeted climate change and health education and awareness activities can encourage people to adopt protective behaviours (Maibach et al., 2011). A survey of Canadians in 2008 revealed that while most people are aware and concerned about climate change, they have little knowledge of specific risks to health (Berry et al., 2011b). Public health and emergency management authorities are providing the public with more information about how to reduce existing health risks from specific climate-related impacts, including those examined in this chapter (*see* Case Study 4).

There are few formal evaluations of public education efforts to reduce health risks associated with climate change (National Collaborating Centre for Environmental Health, 2008). Those that have been completed show mixed results. A study of the education campaign in Montreal, Quebec indicated that people who have been exposed to education materials were more likely to take protective measures against heat through, for example, the use of lightweight clothing, avoiding strenuous exercise, taking a shower or bath to cool down, and hydration (Gosselin et al., 2008a). However, other studies suggest that while knowledge of heat warnings is very broad (>90%), protective actions taken by individuals are inadequate (Sheridan, 2006) or that perceptions of health risks are generally low and the adoption of preventative actions is not widespread (Gower and Mee, 2011). Research on levels of public awareness and the effectiveness of health promotion campaigns related to air quality advisories (Heart and Stroke Foundation, 2008; The Lung Association, 2008), food safety (Mancini, 2008) and reducing risks from vector-borne diseases (Region of Peel, 2006) show similarly mixed results. Public awareness messaging on climate-related risks can be contradictory (e.g. exercising later in the day to avoid extreme heat versus not going outdoors at night to avoid contracting West Nile Virus). To maximize effectiveness, health promotion programs should develop consistent messaging across health issue areas (Hill, 2012).

CASE STUDY 4

MANAGING RISKS TO HEALTH FROM POOR AIR QUALITY WITH THE AIR QUALITY HEALTH INDEX (AQHI)

Climate change is expected to increase risks to the health of Canadians from poor air quality (*see* Section 2.1). Local AQHI data is now available and used in over 60 communities in all 10 provinces. The AQHI is a health management tool that provides information via the Internet (www.airhealth.ca) that allows people to make informed decisions about reducing their exposure to air pollution. Health messages are provided to the general public and are also tailored for vulnerable groups – parents with children and infants, seniors and those with cardiovascular and respiratory diseases (Environment Canada, 2013a). Local AQHI values are also available through The Weather Network, both on-line and through local television weather forecasts. The Asthma Society also makes local, real-time AQHI values available through their desktop widget, which can be downloaded from their website.

This review of health adaptation activities in Canada suggests that a range of actions are being taken from local to national levels to reduce health risks from climate change, including many of the activities highlighted in previous Government of Canada assessments (Lemmen et al., 2008; Seguin, 2008) and by the WHO (2010) and international experts. Some Canadian health authorities have assessed potential health vulnerabilities. Efforts, programs, and actions to mainstream climate change considerations into existing policies are underway to increase the public's understanding of climate-related health risks. However, adaptation activities are not consistent across Canada, leaving some communities and individuals more vulnerable than others. Efforts to protect Canadians from climate change will benefit from actions to strengthen effective health adaptation. The impacts of climate change on the health system or on the resiliency of individuals may reduce the ability of communities and regions to take such actions in the future.

4.2.4 RESEARCH NEEDS

Over the last 15 years, calls for expanded research efforts on climate-related health risks (Duncan et al., 1997; Riedel, 2004; Seguin, 2008) have resulted in a growing body of research to help guide actions to protect the health of Canadians (Berrang-Ford et al., 2011; Gosselin et al., 2011). Strides have been made in the areas of air quality, extreme heat, and the understanding of some climate-related infectious diseases. Although it is important to understand and recognize how far Canada has come, knowledge development has not been uniform among issue areas nor across regions of Canada (Berrang-Ford et al., 2011). Research needs identified in this chapter to better inform adaptation to climate change impacts on health are presented in Table 9.

Health Concern	Research Needs
Air Quality	• Estimates of the contribution of black carbon emissions in Canada originating from sources such as open biomass burning and wood stove burning • Identification of the extent of proliferation, impact and allergenicity of aeroallergen-producing plants as warming continues • Identification and monitoring of potentially invasive fungal diseases that could establish with climate change • Understanding of the effects of various GHG mitigation and adaptation activities (e.g. energy efficiency trade-offs, green roofs) on ambient and indoor air quality and associated health impacts • Understanding of how heat and poor air quality interact to impact health and adaptive strategies to reduce health risks • Identification of how dampness and temperature affect degradation of materials in buildings and how indoor material product design may affect human exposure to chemicals
Food and Water Quality	• Understanding of the impact of water contaminants on human health and monitoring of illnesses • Monitoring of food-borne illness cases to reduce underreporting, including attention to emergence or re-emergence of specific diseases • Knowledge of the impacts of climate change on food and water security in northern and southern Canada • Understanding of the capacity and preparedness of water utilities to adapt to climate change • Defining the characteristics of resilient water and food management systems
Zoonoses and VBDs	• Surveillance for zoonoses, vectors and vector-borne diseases, including attention to emergence of novel diseases • Basic and applied research studies to inform the development of surveillance, prevention and control methods, vaccines and licensed products for vector control • Enhanced capacity to train highly qualified personnel for both research and public health activities
Natural Hazards	• Improved projections of extreme weather events due to climate change and modelling of possible health impacts • Surveillance of direct and indirect health impacts from extreme weather-related events • Interdisciplinary (psychology, social work, community development, health promotion, emergency management) research on the effects of natural hazards on psychosocial health • Understanding of climate-resilient infrastructure that is protective of human health
Vulnerable Populations	• Definition of robust environmental health indicators of climate change to monitor impacts on individuals and communities and develop adaptive measures • Understanding of how the nature of vulnerabilities to the health impacts of climate change for specific groups are changing in order to inform new protective measures for such populations • Understanding how current perceptions and attitudes about climate change and health risks influence the adoption of adaptations • Longitudinal studies across different demographic groups (children, elderly, urban, rural and outdoor workers) to identify health impacts from slow developing hazards (e.g. drought) and cumulative effects of climate change (e.g. extreme heat, drought and wild fires)

TABLE 9: Climate change and health research needs in Canada.

5. CONCLUSIONS

Since 2008, stronger evidence has emerged that health risks related to weather variability and climate change are increasing in Canada. For example, further evidence has emerged of the effects of air pollution and extreme heat events on health. Recent studies suggest impacts on ambient air pollution associated with increases in aeroallergens, O_3, PM, and wildfires will increase as the climate continues to change. Projections of future air quality in 2050 suggest that without further reductions in anthropogenic air contaminants, air pollution in many Canadian communities will worsen due to increased concentrations of O_3 and PM. Indoor air quality may be affected because of more extreme weather events affecting indoor environments (e.g. mold growth after floods).

Climate change is expected to increase risks from food-borne diseases as temperatures rise and extreme precipitation events increase. How the food security of Canadians will be affected is less certain, although evidence suggests Aboriginal populations in the North are already being impacted and would benefit from early adaptation measures. There is also evidence of a link between climate change and impacts on water quality in Canada through microbial contamination, the introduction of hazardous materials (e.g. pesticides) via extreme weather and the growth of cyanobacteria.

Projections in 2008 suggesting the expansion in Canada of the tick vector that causes Lyme Disease have been validated in the field and human cases are on the rise. The spread of Eastern Equine Encephalitis virus into Canada is also evidence of the expansion of a vector-borne disease that could be due, at least in part, to a changing climate. In addition, researchers are beginning to examine the vulnerability of Canadians to 'exotic' zoonoses/vector borne diseases (e.g. malaria, chikungunya, dengue, Japanese encephalitis, Rift Valley fever) imported from countries further afield than the U.S., noting that a warming southern Canada will become increasingly suitable for malaria transmission.

An increase in the number of extreme weather events continues to affect the health of Canadians, although the extent and severity of the impacts on health is difficult to determine from existing surveillance systems. Expanded monitoring of the health impacts from extreme weather events will benefit future adaptation efforts. Improved understanding of health risks from floods, extreme heat and other extreme weather events highlights the need to build resiliency among vulnerable populations to these events, particularly given the expected impacts of climate change in most parts of the country. Analysis of recent natural disasters in Canada and the U.S. has increased knowledge of the psychosocial impacts on health that may result from these events and of the measures that can be taken to protect health.

Canadians across the country are affected by the health impacts of current climate and weather variability, but vulnerability factors that predispose people to increased risks differ significantly by region and population. Greater exposure to rapid climate change and more limited capacity to adapt makes Canada's North one of the most vulnerable regions to health impacts. Important differences in infrastructure, community design, health care and social service delivery, community resources, and demographic and health trends require the adoption of local or regionally planned public health adaptation strategies for urban, rural, northern, and coastal communities (e.g. mitigating the urban heat island effect in cities, improving access to traditional foods in the North, protecting drinking water from sea level rise on the coast).

Government authorities at the federal, provincial, territorial, and local levels in Canada are taking action to prepare for climate change health impacts by including health risks in climate change plans and by mainstreaming climate change considerations into a range of policies and programs that help protect health. However, adaptation efforts need strengthening as growing risks from climate change leave some individuals and communities highly vulnerable to associated impacts. An expanded range of measures and tools to adapt to the health impacts of climate change, including vulnerability assessment guidelines, vulnerability mapping, and decision support tools are now available to public health and emergency management officials in Canada. Increased collaboration and information sharing among governmental, non-governmental, and academic partners will enhance efforts to protect Canadians from the health impacts of climate change.

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