Application of the Multiple Exposures, Multiple Effects Model to Four Flood Events in Canada:

Lessons Learned for Public Health Adaptation to Extreme Precipitation and Flooding in the Context of Climate Change

Final Updated Report

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Introduction

The Collaborative Approach to Testing Public Health Climate Change Adaptation Frameworks is an initiative of the Peterborough County-City Health Unit. The first phase of the project, initiated in November 2014, featured a literature review of frameworks related to public health adaptation to climate change and of the health impacts of flooding and extreme precipitation. The findings of the review were presented to the local Climate Change Working Group (CCWG) and other interested community members and representatives in December. The participants were charged with reviewing a short list of frameworks that were relevant to public health adaptation to climate change, and selecting one framework to use in the next phase of the project. After some deliberation, the Multiple Effects Multiple Exposures (MEME) model was selected by the group.

In this second phase of the project, the MEME Model is applied to four Canadian case examples in order to elucidate the public health issues, concerns and actions that are necessary to respond to future flood events and to identify the strengths and weakness of the model as it pertains to extreme precipitation events in the context of climate change. In addition, the potential application of the framework to other types of extreme precipitation (e.g. ice storms, extreme snow events) is briefly discussed.

Health Impacts associated with Flooding and Extreme Precipitation

Disasters, as defined by Goldman and Galea (2014), are large-scale events that are often unexpected and cause death, trauma and destruction of property. They are characterized by their: i) threat of harm or death to large groups of people, regardless of the actual extent of lives lost; ii) effects on social processes, and iii) secondary consequences. Extreme precipitation and flooding are natural disasters that impact natural, technical and social systems. They are not always large-scale events, however, and can be either local or regional. Different types of extreme precipitation and flooding thus require different public health responses. Figure 1 is a typology linking extreme precipitation and flood events at different spatial scales. It highlights the continuum between local and regional weather as it impacts local public health action and preparedness.

The impacts of climate change on flooding are poorly understood. Indeed, in their review of flood risk and climate change, Kundzewicz et al. (2013) state that "presently we have only *low confidence* in numerical projections of changes in flood magnitude or frequency resulting from climate change" (original emphasis, p.1). Flooding is both climate-sensitive (in that it has been linked to increases in extreme weather events), but it is also climate insensitive. It is often caused as much by human activity as by any given precipitation event. In other words, floods often have anthropogenic origins, including river bank straightening, shoreline modification, the creation of impermeable and compacted surfaces, poorly designed infrastructure, a lack of settlement planning and/or building standards and other land use changes. These changes make watershed populations more vulnerable to the impacts of severe weather. The link between ecosystem management and disaster risk reduction needs to be more explicit. For example, in their recent book on this topic, Renaud et al. (2013) state that:

> The increasing worldwide trend in disasters, which will be aggravated by global environmental change (including climate change), urges us to implement new approaches to hazard mitigation, as well as exposure and vulnerability reduction. We are, however, faced with hard choices about hazard mitigation: should we continue to build dikes and walls to protect ourselves against floods and coastal hazards – though we have seen the limits of these – or should we consider alternative, ecosystem-based solutions? Ecosystem management is a well-tested solution to sustainable development that is being revisited because of its inherent “win–win” and “no-regrets” appeal to address rising disaster and climate change issues. It is one of the few approaches that can impact all elements of the disaster risk equation – mitigating hazards, reducing exposure, reducing vulnerabilities and increasing the resilience of exposed communities. Yet, the uptake of ecosystem-based approaches for disaster risk reduction (DRR) is slow despite some very good examples of success stories. Reasons for this are multiple: ecosystem management is rarely considered as part of the portfolio of DRR solutions because the environmental and disaster management communities typically work independently from each other; its contribution to DRR is highly undervalued compared to engineered solutions and thus not attributed appropriate budget allocations; finally, there are poor science–policy interactions on ecosystem-based DRR, which have led to unclear and sometimes contradictory scientific information on the role of ecosystems in DRR.

In the 21st Century, reexamining the links between public health, watershed, ecosystem and disaster management is necessary as we are increasingly confronted with the close links between anthropogenic climate change and its impacts on social-ecological systems. These links will become more pronounced in the coming decades.

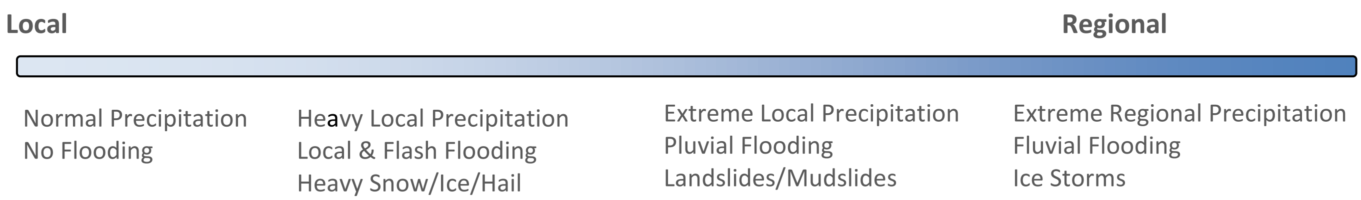


Figure 1. Typology Linking Local and Regional Scales with Different Precipitation Related Events

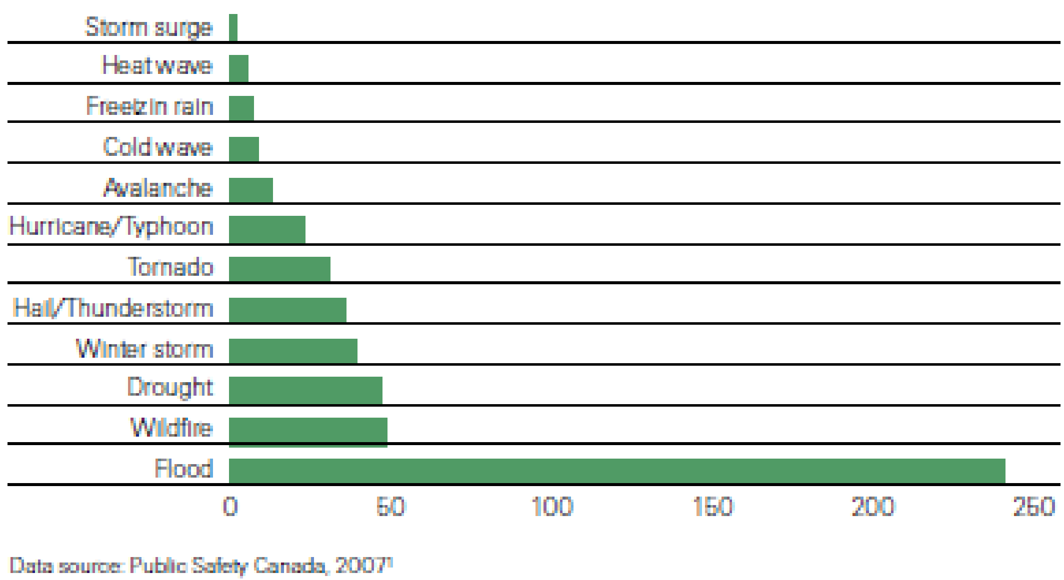
Extreme events are weather events that are rare at a particular place and time of year. They include heat waves, cold waves, heavy rain, snow, ice and hail, periods of drought as well as flooding and severe storms. By definition, one must rely heavily on the history of the locality and region in order to determine if a weather event is extreme or unusual. Regional populations respond through physiological, behavioural, cultural and technological means to the prevailing local climate. Through these adaptive measures, populations can become less sensitive to certain climatic conditions - such as heat, cold and regular weather. By definition, however, extreme events stress populations beyond their immediate coping capacity (McMichael et al., 2006).

An extreme precipitation event is an episode of abnormally high rain, ice or snow. In this case, the definition of "extreme" is a statistical concept that varies depending on location, season and the length of the historical record. The question of when extreme weather linked to climate change began to manifest itself is difficult to determine. Vineis (2010), for example, asks the question: "Was the flood in Bangladesh in 1974 the first attributable to climate change, or the last one not due to it? And what about the one in 1978?" (p.91). He reminds us that the boundaries for considering what is and what is not climate-related change are fuzzy and the causal pathways remain unclear.

Flood concerns related to climate change stem from a perceived acceleration of the hydrological cycle, which hypothesizes that flood events are likely to occur more frequently (Huntington, 2006; Trenberth et al., 2007). Precipitation intensity is expected to increase over much of the globe (Meehl et al., 2005). Whether or not they are related to global climate change, there are many different types of flooding and the categorization and definitions are used inconsistently in the literature. The Intergovernmental Panel on Climate Change report defines floods as: "the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods" (Field et al., 2012, p.559). The unique characteristics of different flood types (pluvial, fluvial, etc.) have consequences in terms of the duration of the flood event, the lead times for flood warnings, their predictability and potential impacts (Chen et al., 2010). Thus, "the suitability of each approach needs to be verified for each region under study and its specific requirements. Advocating a one-size-fits-all approach is not a recommended solution" (Theiken et al., 2014, p. 37).

Floods are the most frequently occurring natural hazard in Canada. According to Sandick et al. (2010) and data in the Canadian Disaster Database, 241 flood disasters occurred in Canada between the years 1900 and 2005. This is approximately five times as many as the next most common disaster, wildfire (Figure 2). Of these 241 flood disasters, 49 were in Ontario, where the majority of flood disasters occurred after 1970. The most common cause of flooding in Ontario is rain on snowmelt, which accounted for 47% of flood events between 1990 and 2003. Hurricane Hazel (1954) and the Timmins Storm (1961) are design storms[1] used to set the regulatory standards for floodplains in Southeastern and Northern Ontario, respectively.

In Peterborough, the 2002 flood was caused by 200mm of rainfall falling within an 11 hour period; the 2004 flood occurred after 250mm of rainfall (Klassen and Seifert, 2006).



(Source: Sandink et al., 2010)

Figure 2. Meteorological and Hydrological Disaster Occurrences in Canada, 1900 - 2005

[1] Design storms are precipitation patterns used to design hydrologic systems. Can be based on real events, or through a statistical analysis of rainfall records.

Flood types of potential relevance to the Peterborough region are described briefly below. They include: flash, pluvial, surface water (combined urban), fluvial, groundwater and catastrophic (i.e. dam breaking). Table 1 categorizes additional types of flooding. Dam breaks and canal breaching are two catastrophic flood types (Falconer et al., 2009). Each type of flooding has different potential impacts on human health and wellbeing and the built and natural environments.

Pluvial flooding is "flooding that results from rainfall-generated overland flow and ponding *before* the runoff enters any watercourse, drainage system or sewer, or cannot enter it because the network is full to capacity" (original emphasis, Falconer et al., 2009, p. 199). Pluvial flooding typically begins at the weakest part of an infrastructure system and spreads outward. This is often a combined sewer outfall draining into a river or creek where high water levels are blocking the end of the pipe. Alternatively, it could be in a low-lying road where the sewers are already full to capacity. Pluvial flooding "seldom lasts for more than one day and only affects local regions" (Chen et al., 2010, p. 1491).

Surface water or urban flooding describes combined flooding in urban areas during heavy rainfall. It includes "pluvial flooding, sewer flooding, flooding from small open-channel and culverted urban watercourses and overland flows from groundwater springs" (Falconer et al., 2009, p. 199).

Fluvial flooding is another term for riverine flooding, driven by precipitation events in a watershed. These floods typically last for days or even weeks and can generally be well-modeled. Flood hydrographs are used to predict the magnitude of a flood and the time to peak flow at a given point in a river system and can be used to guide planning. The volume of water that can be incorporated into a river system without it significantly cresting its banks depends on the stream order[2], the geology, soil characteristics and general topology of the watershed, as well as the extent of positive and negative anthropogenic influences (permeability, etc.). These characteristics will also help determine the speed of the current associated with this type of flood event.

Flash floods rise and fall quickly, usually as a result of intense rainfall over a small area and are often associated with severe thunderstorms (French and

[2] Stream order is the measure of the relative size of streams and rivers using the Strahler Stream Order system. The stream order indicates the size of a river system. Small tributaries in the headwaters of a river are first- to third-order streams, while large rivers can be fifth or sixth order streams. The Amazon River is a twelfth order stream.

Holt, 1989). They are generally associated with a specific watercourse (Falconer et al., 2009).

Groundwater flooding is caused by rising groundwater levels linked to precipitation and groundwater flows. Water enters buildings and basements through cracks in the foundation and floors and can cause significant damage.

Dam breaks are a concern with climate change. Climate models are used to predict the likelihood of dam breaks and reservoir failures under different scenarios and to predict their impacts on downstream communities (see, for example, Yerramilli, 2013). The predicted impacts of high intensity rainfall events on aging infrastructure designed using older design storm criteria is a particular concern.

Ice and snowmelt can either reduce or intensify flooding, depending on climate conditions. Climate change, and its associated general warming effect, is expected to lead to earlier snowmelt and diminished snowpacks. However, mid-winter snowfall could increase in continental regions (Trenberth, 2011).

Other forms of extreme weather related to precipitation include:

Ice storms: Ice storms are prolonged periods of freezing rain which cause ice to accumulate on exposed surfaces. They can have serious effects on built and natural infrastructure, particularly unburied power lines and trees.

Ice dams (also known as ice jams): Ice dams are "accumulations of ice forming where the slope of a river changes from steep to mild or where moving ice meets an intact ice cover—as in a large pool, at the point of outflow into a lake, or on the edge of a glacier or ice sheet. Ice jams can lead to localized and regional flooding in the area behind the blockage, and the sudden failure of an ice jam can release large quantities of water and ice that may cause damage to nearby structures, croplands, and wildlife habitat downstream. The phenomenon is commonly associated with blockages of ice that prevent the late winter or early spring drainage of rain and melting snow in colder regions or with the breakup of glaciers and ice sheets" (Encyclopaedia Britannica, 2014). They are common in the mid- to high latitudes during the spring thaw. Ice breakup regimes vary locally and with weather conditions. Midwinter thaws are expected to increase in frequency and in some instances may reduce both the snowpack and the subsequent flooding caused by ice jams (Baltaos, 2007).

Snowfall extremes: Snowfall extremes, exemplified by the November 2014 snowfall in Buffalo, USA, are important to consider because of the disruption they can cause to human society (transportation networks, health facilities, homes and businesses, etc.). They can also cause mortality and morbidity as people attempt to remove the snow from their properties, including rooftops. They tend to occur when temperatures are close to freezing. Because of that, they appear to not be temperature dependent – i.e. heavy snowfall events have occurred in both anomalously warm and cold years (Changnon et al., 2006; Kunkel et al., 2013).

Table 1. Common Types and Causes of Flooding in Canada

Type	Brief Description
Snowmelt Runoff	Linked to the spring 'freshet', or snowpack melting. When the freshet is combined with rainfall, flooding can occur.
Storm-rainfall	Flash flooding - within six hours of the precipitation event - related to extreme rainfall in small watersheds
Ice jams	Floods caused by the temporary blocking of rivers by ice; occur in spring and fall. Floods occur upstream of ice jam, and downstream when it fails.
Natural dams	Caused by landslides, moraines and glaciers blocking water flows. Floods occur upstream of dam, and downstream when it fails.
Coastal flooding	Occur in the oceans and Great Lakes. Caused by high wind and waves, high estuarine flows and tides, storm surges, seiches, rising lake levels due to wind set-up, hurricanes and tsunamis.
Urban flooding	Includes overland flows (e.g. stormwater, rivers) and infrastructure flooding (e.g. sewer backups).
Structure failure	Failure of engineered flood management structures, such as dams and levees.
Groundwater	Rising groundwater levels and saturated soils around homes can enter basements through cracks in the foundation.

Adapted from Sandink et al., 2010

Hailstorms: Violent hailstorms are another form of precipitation that is expected to worsen with climate change. Hailstorms are of particular concern due to their potential to cause significant crop and livestock damage in agricultural communities, as well as the damage they can inflict on the built environment (e.g. cars, windows, etc.). They can cause physical injury to people where adequate shelter is not available.

Table 2, below, outlines the wide range of potential health impacts that have been identified in the literature related to climate change and flooding. Consolidated lists such as these (see also Figure 3) provide a framework for identifying potential exposures and responding to potential health outcomes during and after a flood event. Appendix 1 (Defra/Environment Agency, 2003) includes additional information about causes of loss of life and serious harm to people after floods. Many of the parameters in this list, including: the characteristics of the flood (timing, duration); effects on infrastructure; victims' frustration and anxiety from dealing with insurance companies, etc.; and the particular impacts on those living in rental housing, are also themes in this study.

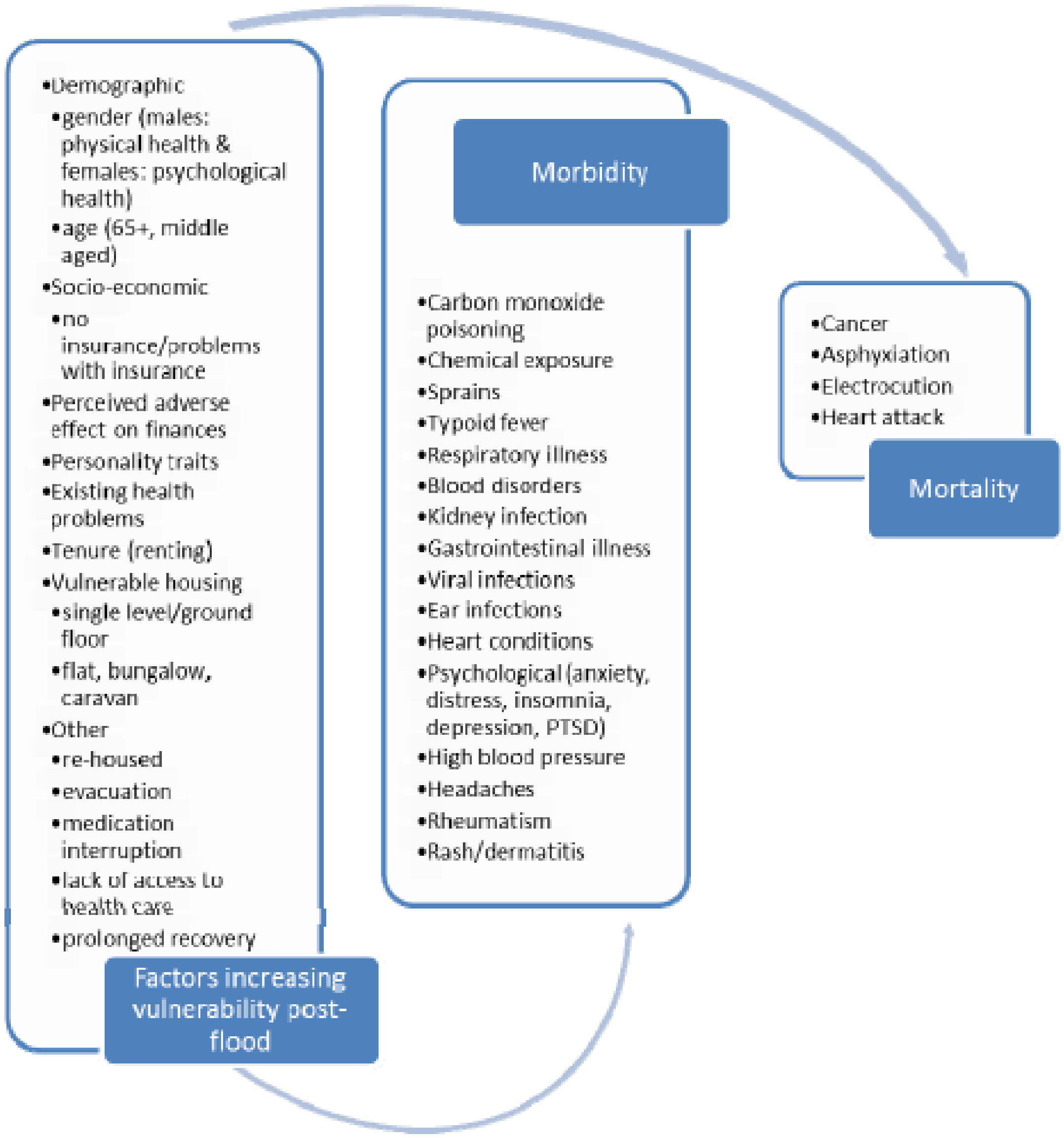
In addition to the general health impacts associated with extreme precipitation and flooding outlined in Table 2, several specific public health issues are explored in more detail in the sections below: vulnerable populations, mental health effects of disasters, flooding, and dampness and mold. A gap in the health literature, with the notable exception of the Millennium Ecosystem Assessment Framework, is the almost exclusive focus on negative health outcomes and diseases associated with climate change and a lack of attention given to the potential co-benefits of climate change adaptation for human health and wellbeing (see, for example, Patz et al., 2008; Berry, 2009; Cheng and Berry, 2013).

Table 2. Health impacts, climate-related causes and potential health effects related to extreme precipitation and flooding

Category	Climate-Related Causes	Projected/Possible Health Effects
Extreme weather events	• More frequent and violent thunderstorms, more severe hurricanes and other types of severe weather • Heavy rains causing landslides and floods • Canal breaching • Rising sea levels and coastal instability • Severe ice storms • Extreme snowfall events • Social and economic changes	• Death, injury and illness from violent storms, floods, heavy snow, landslides, ice, etc. • Injury caused by debris; • Accidents caused by extreme precipitation and damage to transportation infrastructure (including falling into hidden manholes); • Carbon monoxide poisoning from generators; • Electrocution from downed power lines and damaged household and electrical equipment; • Psychological health effects, including mental health (e.g. depression, anxiety, post-traumatic stress) and stress-related illnesses from loss of loved ones, property, livelihoods and financial concerns • Indirect health effects from damage to health care infrastructure, disruptions in treatment; • Health impacts from food or water shortages • Illnesses related to drinking water contamination (both pathogens and chemicals) • Hypothermia and frostbite from disruption of power and heating systems • Effects of displacement of populations and crowding in emergency shelters • Indirect impacts from ecological changes, infrastructure damage and interruptions to health services

Category	Climate-Related Causes	Projected/Possible Health Effects
Contamination of food and water	• Contamination of drinking and recreational water by run-off from heavy rainfall and rapid snowmelt • Cross-contamination of water mains by sewage • Changes in marine and freshwater environments, including run-off patterns and turbidity, that result in algal blooms and higher levels of toxins in drinking and irrigation water, fish and shellfish	• Outbreaks of strains of micro-organisms, such as *E. coli, Crytosporidium, Giardia, S. typhi*, amoebas and other water borne pathogens • Food-borne illnesses • Intoxication from the ingestion, dermal exposure and/or inhalation of algal toxins (several of which are also suspected carcinogens) • Other diarrheal and intestinal diseases
Vector-borne diseases	• 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 seasons	• Increased incidence of vector-borne infectious diseases, such as hantavirus and plague, including post-disaster exposure (e.g. to insects, mice and rats) • Possible emergence of new diseases, and of those previously eradicated in Canada (e.g. dengue, malaria, chikungunya)

(Sources: Health Canada, 2001; Seguin, 2008, Berry et al., 2014, PHASE, 2014 and various)



Source: Lowe et al., 2013, p. 7025

Figure 3. Factors increasing vulnerability to health effects post-flood

Vulnerable populations

The impact a disaster may have on a population depends not only on hazard exposure, but also on how capable different people and places are to anticipate, cope with, resist and recover from their impacts (Wisner et al. 2004). Climate change is expected to worsen existing health inequities and will place additional stress on poor and vulnerable groups across the globe (McMichael et al., 2006; Confalonieri et al., 2007; Berry et al., 2014). Due to its amplification of climate-sensitive health threats, and its potential to contribute significantly to social unrest (i.e. through social disorder, conflict and a breakdown in effective social institutions) and service interruptions, public health adaptations to climate change need to be tailored to a range of populations (Confalonieri et al., 2007; Scheffran and Battaglini, 2011; McMichael et al, 2012). Deciding on the best approaches is not always easy, however. Women, for example, are known to be particularly vulnerable to natural disasters, not only due to their direct effects, but also due to the increased workload placed on them in taking care of sick and injured family members (Preet et al., 2010). Nonetheless, in their review of the literature, Preet et al. (2010) found the gendered impacts of climate change to be "an underrepresented or non-existing variable both in research and studied policy documents in the field of climate change and health" (p. 6). Other vulnerable groups include: infants and children; seniors; people with underlying health disorders and/or compromised immune systems; low income and homeless people; people living off the land; First Nations Communities; disabled people and immigrant populations. The European Public Health Adaptation Strategies to Extreme Weather Events (PHASE) program created an extensive list of populations vulnerable to flooding, which is modified slightly to include First Nations populations in Table 3, below.

The impact of flooding on First Nations communities is a critical issue in Canada that requires additional attention. First Nations communities are among the most vulnerable to flooding in Canada and were affected by flooding at the watershed scale in all of the case example flood events. The issue of First Nations and flooding is an area that requires additional attention. Time and resources, however, have precluded their integration into this document.

Table 3. Vulnerable groups associated with flooding

Vulnerable Group	Factors associated with vulnerability
Children	• May become separated from their parents or caregivers • May witness the death of a close family member • May not have adequate cognitive or motor skills to move from danger or seek help if faced with a stressful event • May be unable to vocalize their symptoms • Greater risk for anxiety reactions
Elderly People	• May have reduced mobility, impaired balance or reduced strength • May have decreased physical strength and weakened physiological responses due to health conditions such as hypertension, heart disease, cancer, stroke or dementia • May have a decreased immune response • May be more susceptible to temperature extremes • May have sensory impairment • May have delayed verbal and physical responses • May have reduced ability to retain information, understand what is happening and follow rescue instructions; may become disoriented or confused in unfamiliar surroundings • May lose hearing aids, eyeglasses or dentures, which may impede recovery
First Nations	• May live off the land and have food and livelihoods disrupted; • May live in flood plains • May live in substandard housing • May have problems with dampness and mould in housing stock • May have existing health conditions that can be exacerbated by the flood • May require evacuation • May have infrastructure (roads, electricity, etc.) cut off for weeks or months • May have drinking water systems compromised by the flood
People with chronic illnesses	• Likely to rely on medications; if these are unavailable, may suffer adverse health consequences
People with physical impairments	• May rely on mobility aids, such as wheelchairs, walking canes and walkers, loss of which during a flood may result in a loss of independence • May be unable to move, and emergency personnel may not have the required skills to move them
People with sensory impairment	• May be unable to communicate aurally or visually by modes of communication commonly used in emergency responses
People with cognitive impairment	• May believe that authority figures are trying to harm them • May not have the same perception of risk as people without impairments • May be unable to express their symptoms when receiving triage health care

Vulnerable Group	Factors associated with vulnerability
Gender	• Health impacts may differ by gender and timing of exposure (before, during, after). For example, males aged 10-29 may be a greater risk for mortality during a flood
Pregnant Women	• May be reluctant to accept treatment because of possible adverse health effects on their fetus • May have a poorer immune response than non-pregnant women
Tourists	• May be unable to speak the language, perhaps resulting in difficulty in obtaining help or understanding instructions • May be unfamiliar with the local resources that can be relied on in emergency situations
Homeless	• May have a substantial rate of mental illness, which can be exacerbated by the acute stress of flooding • May have difficulty in reading or interpreting written instructions • May be at disproportionately greater risk of being disabled or persistently ill
People with cultural and language vulnerability	• May be unable to speak the language, perhaps resulting in difficulty in understanding instructions • May be unable to express their needs to health care providers, resulting in incorrect treatment or diagnosis • May be assumed to be uncooperative if they are unable to read written instructions • May lose vital components of messages • May lack trust in authority figures or members of the medical community • May express differences in gender roles or gender-appropriate behavior • May have different beliefs regarding health and treatment of illness
Housing	• People living in rented accommodation • People living in high-risk built environments • People living in vulnerable housing (caravan, bungalow, basement flat)
Insurance	• People with no insurance • People experiencing problems with insurance
Other	• Risk behavior/risk taking (for example, driving through floodwater) • Socio-economic status and educational achievement • Perception of flood risk • Prolonged recovery • Reliance on regular home care • Reliance on regular care at health facility • People who may be socially isolated

(Source: PHASE, 2014)

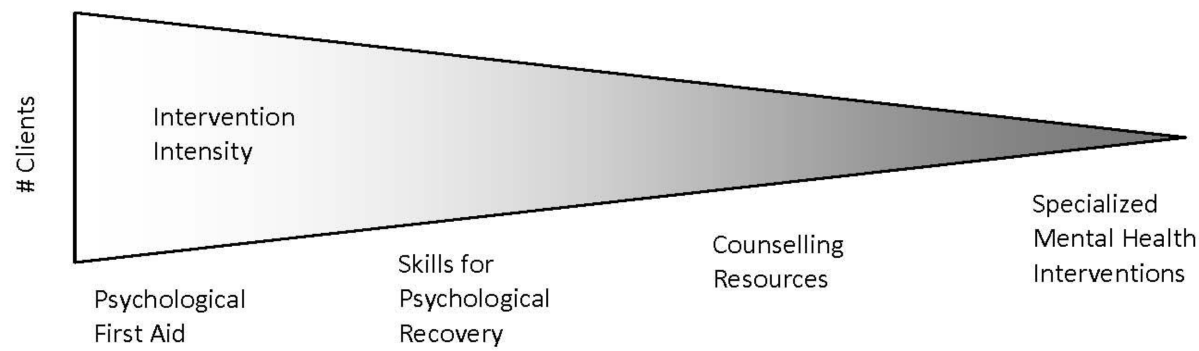
Mental Health Effects of Disasters

Climate change and increased population densities (i.e. urbanization) seem to be increasing the human health effects of natural disasters. Floods often create technological disasters, through their effects on local and regional infrastructure. Post-disaster psychopathologies include: post-traumatic stress disorder, major depressive disorder, substance use disorder and other psychological symptoms, such as generalized anxiety disorder, panic disorders and phobias. These are often present in combination (comorbidity) in affected individuals (Goldman and Galea, 2014). Norris et al., (2008) put forward four distinct post-disaster symptom trajectories: resistance (mild or no symptoms of mental illness); resilience (rapidly declining symptoms); recovery (longer period of recovery), and chronic dysfunction (moderate or severe illness for prolonged periods of time). Friel et al. (2011) note that the fear of climate change may itself threaten mental health and that "most of the psychosocial effects of climate change are likely to be gradual and cumulative" (p. 136).

Goldman and Galea (2014) found that prior mental health problems, female gender and younger age are key pre-disaster risk factors for post-disaster mental illness. PTSD and depression are generally worse for females and alcohol and other substance use disorders are worse for men. Other pre-disaster factors include low socioeconomic status, minority ethnic status and low social support or poor relationships. There are many challenges to collecting population mental health disorder data during and after disasters that make studying this issue very difficult. The authors recommend additional longitudinal studies, wide-ranging psychopathology studies, intervention studies and multi-level risk factor studies.

There is an increased recognition of the importance of addressing mental health – and in particular psychosocial health – in post-disaster situations. There is currently a great deal of work being undertaken on this topic in Manitoba, in part in response to the flooding and other natural disasters (such as wildfires) experienced in the region.

According to Manitoba Health, psychosocial recovery includes mental health, stress management, health, financial, connectedness, spiritual and vocational components (i.e. holistic health). As indicated in Figure 4, psychosocial health interventions are related to but not synonymous with psychiatric problems requiring professional mental health interventions. It is strongly linked to providing large populations with skills and support to cope with abnormal and challenging situations. Psychological First Aid is one tool that has proven effective in this area (Wooding and Rafael, n.d.; Brymer et al., 2006; Morris-Oswald, 2015).



(Source: Adapted from Morris-Oswald, 2015)

Figure 4. Psychological Support Interventions by Demand, Intensity and Distribution

FLOODING

Flooding is a natural component of riverine ecosystems. It is a function not only of precipitation amounts and rates, but also of the topography, land uses, flood control infrastructure, soil types and antecedent moisture conditions in a watershed (also called a drainage basin or catchment area). In the U.S., the majority of flood fatalities from 1959-2005 (not including data from Hurricane Katrina) were from flash floods. People between the ages of 10-29 and over 60 years of age were most vulnerable to all flood types. Human behaviour contributed to the majority of flood fatalities (such as deliberately walking or driving through flood waters), suggesting that investments in flood control infrastructure (e.g. culverts) and other technological fixes (e.g. improved bridge designs) may not reduce the number of fatalities (Ashley and Ashley, 2008). Pluvial flooding may be less detrimental to human health given that the water is generally pooled, not flowing.

DAMPNESS AND MOLD

Indoor dampness and mold are public health problems of particular concern following flood events. A meta-analysis conducted by Fisk et al. (2007) looking at the association between indoor dampness and mold contamination with adverse health effects found that such dampness and mold were associated with an increase of approximately 30-50% in a variety of respiratory and asthma-related health outcomes. These included upper respiratory tract symptoms, coughing, wheezing, and new and worsening asthma diagnoses. These symptoms have been reported in other studies of dampness and mould

(Bornehag et al, 2004; Mudarri and Fisk, 2007, World Health Organization, 2009)[3]. Following Hurricanes Katrina and Rita (2005), U.S. homes with greater flood damage (greater than three feet of indoor flooding, or water intrusion due to roof damage) had elevated levels of mold growth. While many of the molds were allergenic (e.g. *Alternaria, Aspergillus, Cladosporium, Curvularia* and *Penicillium*) a pattern of adverse health outcomes was not identified in the study population. There were a number of potential reasons for this, including the lack of access to health care of vulnerable populations. Nonetheless, the widespread diagnosis of 'Katrina Cough' had a number of potential causes, and may have been aggravated by high mold spore counts (Barbeau et al., 2010). Inhalation is the primary mode of exposure, particularly in the indoor environment. Mold exposure and lead to infectious and noninfectious illnesses. Invasive fungal infections are uncommon, particularly in health individuals. The noninfectious effects of mold include immune (primarily allergies and asthma) and non-immune responses (primarily irritation) (Barbeau et al., 2010).

Methodology

Literature Review

The flooding and extreme precipitation literature was searched by a professional librarian working with the Peterborough City-County Health Unit. The abstracts provided were reviewed for their relevance to this study, and the references of those studies, as well as other papers citing those references, also provided additional information. From the literature, it is apparent that heat waves constitute the primary focus of much of the specific public health adaptation to climate change literature. To that end, this project will contribute to the literature given its specific focus on flooding and extreme precipitation events.

Case Examples

In this study, four common flood types: pluvial, urban, snowmelt runoff and fluvial flooding were used to identify and select four case examples of flooding

[3] Where **mould** is defined as: all species of microscopic fungi that grow in the form of multicellular filaments, called hyphae. In contrast, microscopic fungi that grow as single cells are called *yeasts*, a connected network of tubular branching hyphae has multiple, genetically identical nuclei and is considered a single organism, referred to as a *colony* and **dampness** is defined as: any visible, measurable or perceived outcome of excess moisture that causes problems in buildings, such as mould, leaks or material degradation, mould odour or directly measured excess moisture (in terms of relative humidity or moisture content) or microbial growth (WHO, 2009).

(Table 4). Cases where the research team could access information in a relatively short period of time (1 month) was a key factor in the selection process. The case examples are based on a wide range of information, including semi-structured interviews with key informants. Municipal websites, news and journal articles complemented information provided by local and provincial agencies. The participating health agencies were: the Peterborough County/City Health Unit, the Haliburton, Kawartha, Pine Ridge District Health Unit, Prairie Mountain Health (formerly Assiniboine Region Health Unit), Manitoba Health and Alberta Health Services. Given the short time-frame for the study, it is a preliminary representation of the health exposures, impacts or outcomes associated with the flood for illustrative purposes only.

Table 4. Typical Canadian Flood Types and Study Case Examples

Flood Type	Case Example Location	Year of Flood Event
Pluvial/Urban	Peterborough, Ontario	2004
Snowmelt Runoff	Minden, Ontario	2013
Fluvial/Snowmelt Runoff	Wawanesa, Manitoba	2011
Fluvial/Snowmelt Runoff	High River, Alberta	2013

Multiple Exposures Multiple Effects (MEME)

The MEME model (Figure 5) was developed by the Committee for Indicators of Children's Health of the World Health Organization (WHO, 2002a; Briggs, 2003) and has been primarily applied in the field of children's environmental health. It is not a climate change adaptation framework per se, but has the potential to be modified to address climate change concerns (see sections below). One of the strengths of the model is its local context and place-based focus that is particularly applicable to local public health units where the distal causes of the problems, such as climate change, are relatively well-known. In addition, the emphasis on multiple exposures and a wide range of potential health outcomes is relevant to disaster-related planning and the design of preventive and adaptation measures. Based on the findings of this study, the model is updated to be more responsive to the need for proactive planning by local health authorities in the area of climate change, related to, for example, vulnerability, sensitivity and adaptive capacity.

The model was adapted from the Pressure-State-Response and the Health and Environment Cause and Effect (DPSEEA) approaches. These approaches are primarily descriptive and have been criticized for reflecting linear thinking and for lacking a theoretical basis for including or excluding elements of the model. A critique of the MEME model is that is does not sufficiently distinguish between proximal (exposure) and distal (pressure and state) causes, which Liu et al (2012) feel “would be particularly useful for designing and applying interventions further up the causal chain” (p.91). Another critique is that while the model recognizes the influence of context on health, it does not include the reciprocal influence of health on context. For example, people whose capacities and health have been diminished by toxic exposure are less capable of functioning, and this can affect their social, economic and demographic realities (Weiss et al., 2008).

Kyle et al., (2006) note that the MEME model emphasizes the “many-to-many relationships” that characterize how “a single environmental agent or factor may contribute to multiple health outcomes, and a single outcome may be affected by multiple environmental factors”. They stress that “it is possible to synthesize and present available data in ways that identify environmental factors relevant to health and diseases or disorders with possible or likely environmental causes and to show likely relationships in ways that are cognizant of the “many-to-many” nature of these relationships” (p. 449).

In the sections below, a summary of the results of applying the MEME model to four flood events is provided in order to better understand their impact on, and relationship to, local public health. The information about the specific case examples is included in Appendix 2. The lessons learned from the four case examples are then discussed as they relate to flooding and extreme precipitation and public health, and the strengths and weakness of the model identified. In the final section, the MEME model is updated to better represent climate change adaptation considerations.

For the purposes of this study, the ambient environment is defined as the watershed, as this is the most important ecosystem unit to consider for flooding. Indeed, the World Health Organization (2002, p.35) notes that:

> Experience has also shown that local flood protection measures can have negative effects both downstream and upstream. Therefore, a holistic approach is necessary to take into account the whole river basin. Such a holistic approach is based on multilateral cooperation, including interdisciplinary planning for the whole catchment areas. On transboundary rivers, international cooperation is needed.

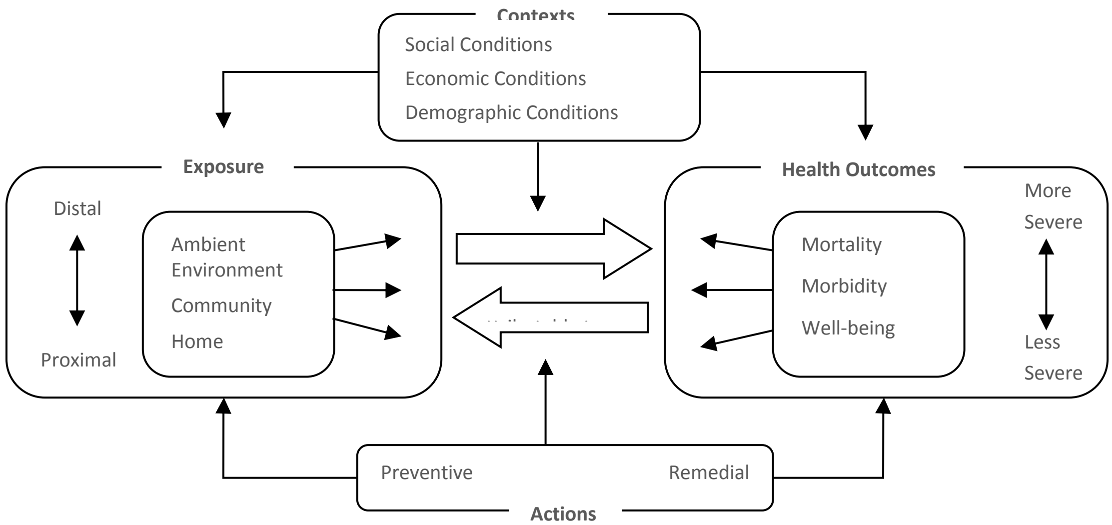


Figure 5. Multiple Exposures, Multiple Effects Model (WHO, 2002a)

Results

Table 5, below, provides a very brief summary of the findings of the study as they related to the model. The reader is directed to Appendix 2 where the results of the application of the MEME model to four Canadian case examples are included in full.

The Peterborough and Minden floods occurred as a direct result of heavy rainfall very close to the municipalities which resulted in an almost immediate flood event. In Minden, the flooding was a result of the stormwater falling on saturated, frozen ground and running off directly into the local rivers. These floods are very difficult to anticipate as they result from single precipitation events.

The High River and Wawanesa floods are also the result of precipitation in the upper watershed, combined with other factors, such as the saturation of the soil, amount of snow and the geology and topography of the watershed. To a certain extent, these floods were forecasted, providing a few days of warning in High River and several months of warning in Manitoba. Nonetheless, the predictions were exceeded by the actual flood events, requiring emergency action.

Table 5. Comparison of Case Example Findings related to the Multiple Exposure Multiple Effects Model Categories

MEME Model Headings	Peterborough, 2004	Minden, 2013	Wawanesa, 2011	High River, 2013
Context	Pluvial, Urban Flood Pop'n: 75,000	Snowmelt Runoff-Flood Pop'n: 3,000	Three fluvial, one snowmelt runoff/fluvial flood events (April, June and July): Pop'n: 300	Fluvial Flood Pop'n:30,000
Exposures	Primarily standing water contaminated with sewage and debris; damage to property; construction debris and rotting food; mould	Primarily river water, properties submerged for up to three weeks; property damage; construction debris and rotting food; potentially contaminated drinking water (pathogens and chemicals); flooded septic systems; mould	Massive regional dislocation due to flooding of roads and bridges; damage to public facilities (health care and school); potentially contaminated drinking water;	Evacuation of entire town; extensive flooding and property damage; construction debris and rotting food; potentially contaminated drinking water; mould
Health Outcomes	Concern about psychosocial health, including that of health and emergency workers Apparently limited morbidity Identification of vulnerable populations through pre-existing case files, help hotlines and initial applications for assistance	Concern about psychosocial health Apparently limited morbidity Vulnerable populations self-identified through hotline post-hoc	Concern about psychosocial health, including that of health and emergency workers, exacerbated by some colleagues dropping out of the workforce during the emergency. Also demands on psychosocial teams' own well-being Apparently limited morbidity, although pre-existing conditions likely exacerbated by length of flood and recovery periods Vulnerable populations identified through flood vulnerability screening of pre-existing case files and pre-flood planning process	Three fatalities from drowning Extensive concern about psychosocial health, including that or health and emergency workers Some evidence of morbidity, primarily injuries Vulnerable populations identified post-hoc

MEME Model Headings	Peterborough, 2004	Minden, 2013	Wawanesa, 2011	High River, 2013
Actions*	Preventive: Some information available on-line Remedial: Post-flood emphasis on assisting with access to financial assistance program Extensive reworking of emergency management system	Preventive: Some information available on-line including flood plan template Remedial: Post-flood emphasis on accessible water testing Limited changes since flood	Preventive: Extensive pre-flood planning process, although flood season much worse than expected Remedial: Post-flood emphasis on psychosocial health Significant investment in psychosocial wellbeing	Preventive: Limited information available pre-flood Remedial: Post-flood emphasis on infrastructure and housing repair and repatriation of citizens Significant investments in mental health programming, including psychosocial wellbeing

*Many additional actions at multiple scales taken by other sectors, particularly engineering and land use planning

In Peterborough, Minden and High River there is some indication that residents were not aware of the potential flood hazard or the potential for basement flooding, sewer back ups and other associated property damage. With the exception of Peterborough, accessing public support post-disaster was a cause of much stress and anxiety for the affected populations.

Discussion

The following sections outline the lessons learned in terms of the public health impacts of extreme precipitation and flooding, additional themes and regarding the application of the MEME model to four Canadian flood events.

Public Health Impacts of Extreme Precipitation and Flooding

The impacts of extreme precipitation and flooding are significant and widespread. They affect all aspects of public health, including its organization, mandate, partnerships and programming. Public health units should consider at least two different flood scenarios when making their emergency response plans: one focused on pluvial flooding (which may occur with little to no warning), and one to apply in situations where a large-scale flood of a river or lake is predicted days in advance.

Expected health outcomes at the watershed and sub-watershed scales relate primarily to the impact of floods on both downstream (typically more urban) and upstream (typically more rural) communities. Adverse mental health outcomes are noted for residents throughout the watershed, who may feel that there is either an inequitable distribution of effort (e.g. focused on urban areas), or a sacrifice of local property to meet other community's needs (e.g. in the Minden and High River floods). In all cases, clear communication about the watershed context of flood events is needed.

At the **community level**, anticipated health outcomes include outbreaks of disease such as pink eye, food and waterborne illness and potentially zoonotic diseases from increased exposure to vectors in floodwater and garbage. Novel pathogens may be present, although this was not a major issue in the cases examined. Other health outcomes may be related to the need for emergency shelter, food, water and other supplies.

Mental health is a critical concern after all of the floods. Ironically, one of the major stressors tends to be navigating the bureaucracy to obtain post-flood support from the government. This creates a perverse policy situation whereby government agencies are on the one hand trying to help residents recover their mental and physical health, while on the other hand, some government programs are actively undermining their well-being through cumbersome, slow and potentially insufficient disaster recovery programs. In the Peterborough case, the emphasis placed on assisting residents, particularly vulnerable populations, with navigating the Ontario Disaster Relief Assistance Program in the first few days after the flood, as well as the assistance provided by the staff of this provincial program (who moved to hotels in Peterborough to assist with processing the applications) provides a positive example of a potential model for improved post-disaster financial assistance in Canadian communities. Such an investment could be argued in terms of an investment in the psychosocial health of Canadians post-disaster using a health-in-all-policies lens.

At the **household level**, the following health outcomes can be anticipated:

- mortality due to exposure and/or injury. Globally, it has been found that 2/3 of deaths from flooding are from drowning, and 1/3 from physical trauma, heart attacks, electrocution, carbon monoxide poisoning and fire (Meene and Murray, 2013);
- physical health problems related to a variety of factors including:
    - injury from damage to households, roads and debris;
    - infections from exposure to sewage and flood water;

- potential illness from drinking water contaminated with pathogens and/or chemicals;
- potential illness from eating contaminated food;
- gastrointestinal and other ailments (including trouble breathing) from sewage, mould and odour.

According to Meene and Murray (2013, p. viii), "known risk factors for flood-related mortality and morbidity are: fast-flowing water, hidden hazards, water of unknown depth, driving and walking through flood-water, flood-water contamination (by chemicals, sewage and residual mud), exposure to electrical hazards during recovery and cleaning, unsafe drinking-water and food shortages and contamination, incomplete routine hygiene, CO poisoning, and lack of access to health services".

There were also commonalities in the mental health problems identified, such as depression, anxiety and post-traumatic stress syndrome, related to challenges such as:

- evacuation or rescue;
- access to services and financial concerns; and
- loss of home and/or possessions.

With regard to the loss of possessions, in Peterborough it was found that the loss of personal identification created serious challenges because the affected people could not cash a cheque or open a bank account, adding to their stress and frustration. Flood preparation materials provided by the European PHASE project (Appendix 3) explicitly mention personal documents as well as other often forgotten materials identified in the cases (such as religious material, medication, etc.) that make post-flood recovery somewhat easier.

On the positive side, neighbour-to-neighbour assistance and mutually supportive activities such as rebuilding and fundraising may strengthen feelings of trust and reciprocity between households and within the community.

The four case examples identified a very **similar suite** of exposures (sewage and contaminated water, debris and pests) and health outcomes (injury, mental health) related to flooding. The similarity of challenges faced by public health officials suggests that the framework could be used to improve pre- and post-flood planning and programming in public health and other sectors. Nonetheless, there were some differences linked to the type of flood (pluvial, fluvial, snowmelt-runoff). For example, early spring flooding increases concerns about exposure and access to adequate shelter. Fluvial flooding is more likely to cause extreme damage to property. Pluvial flooding may increase concerns over exposure to sewage and other pathogens.

In the context of climate change, **vulnerability** can be defined as "the extent to which climate change may damage or harm a system … it depends not only on a system's sensitivity but also on its ability to adapt to new climate conditions" (Watson et al., 1996:23). Thus, watersheds, communities, populations and individuals are all potentially vulnerable to climate change. The vulnerability of the watersheds in this study is difficult to assess as it is generally considered more of a biophysical issue. When the watershed is defined as a social-ecological system (Parkes et al., 2011, Morrison et al. 2012), however, in which human actions both shape and are shaped by the watershed context, it is apparent that there is the potential for harm to come from climate change on the watershed system. All of the watersheds are managed to some degree, with the reservoir lakes system in Minden having likely the most anthropocentric control and the High River watershed in Alberta with likely the least. Nonetheless, extreme precipitation and other factors can overwhelm the infrastructure in place to control water flows. Climate change may damage or harm the watershed as a social-ecological system by undermining the efficacy of the technical solutions that were devised under a different, and now uncertain, water management paradigm (i.e. design storms, return periods, etc.). New infrastructure is being built with an additional 'climate change' buffer to help address some of the systemic uncertainty over future conditions but an argument can also be made for better ecosystem management of this social-ecological system, given that many of the causes of flood are not climate sensitive but related to land use and water management decisions.

The sensitivity of the case examples to climate change is a key issue. Climate change is expected to make existing climate-related challenges more severe, and to potentially extend the range of others (infectious diseases, heat waves, etc.). Susceptibility to flooding is already a characteristic of the case example communities and thus they are less sensitive to this threat than communities that have never experienced flooding would be. For example, a British government report on flood risks (Defra/Environment Agency, 2003) identified "where there is limited or no previous flood experience and awareness of risk, and where there are no coping strategies developed following previous flooding" (p.7) as factors contributing to adverse health outcomes from flooding. Nonetheless, despite all four communities being located in known flood zones, a marked ignorance was noted in some populations related to the potential threat that living in a floodplain poses to human health and property.

Human sensitivity to flooding is an interesting question, as all humans are sensitive to the threat posed by flood waters (both quantity and quality) and are not likely to become less sensitive with time. This differentiates flooding from other climate-sensitive issues like heat and cold waves, where population-level sensitivities can change over decades as people adapt to the colder or hotter conditions through a variety of physiological and behavioral measures. Household, community and watershed sensitivity is another matter and can be addressed by a variety of adaptive measures, both behavioural and technical. In most instances, the technical issues around flooding at the household and community levels are well-known. Economics may be the most significant factor, as poverty limits adaptive capacity across the spectrum (Adger et al, 2004; OECD et al., n.d.). In addition, large fluvial flood events can overwhelm the defenses of even the most prepared communities and thus on-going training and the refining of emergency preparedness systems is required in flood-prone, and potentially flood prone, areas.

There is a role for public health in **educating** the public about what watersheds are and their influence on the health and well-being of communities. In flood prone areas, this could be done, for example, by linking flood information pages to local watershed organizations' GIS-based flood maps. Most useful are maps depicting 1, 2 and 500 year flood plains, as well as photos and illustrations of local landmarks affected by these floods (real or hypothesized). These illustrations can help the public relate to the information begin presented. Photos and histories of previous floods are also very valuable. Making the link between impermeable surface areas and faster flood returns would also be helpful. In the Souris River, a high quality, real-time, GIS-based map was available during the 2011 floods, but the public was unaware of it. Increasing the general awareness of this resource was a finding of the Souris River flood review (US Army Corps of Engineers, 2012). As indicated in the report (p.24):

> Another positive note was provided by the Souris basin map sponsored by the International Joint Commission (IJC) that was available on the [North Dakota] United States Geological Service (USGS) website. This proved to be a valuable and heavily used tool, providing convenient and useful one-stop access to all the key streamflow gauges within the Canadian and U.S. portions of the Souris basin. Availability of this tool should be continued and promoted to the public.

The results of this brief study illustrate some of the mechanisms by which **adaptive capacity** can be enhanced with respect to flooding. This includes regional watershed based flood forecasting and good communication between watershed managers, municipalities, community members and their public health colleagues. The use of a case file approach, and improving the ability to share data about vulnerable populations between agencies, seem promising as each individual is vulnerable in their own way and tailored responses are needed. The early and systematic identification of potentially vulnerable populations could be enhanced to reduce the long-term impact of the flood event on these populations and thus improve population health. A commitment to debriefing flood responses and to improving public health practices in response to the flood is an area that would benefit from additional planning and resources. An investment in emergency surveillance systems would facilitate adaptive capacity and learning by providing an improved baseline to use to monitor potential population health effects of climate change on flooding. This may include, for example, changing pathogens in the flood waters or in the post-flood mould populations, or changes in the pattern of injury due to behavior or infrastructure. Additional information about population health would have obvious benefits for improving post-flood responses in light of climate change. It would also provide a clearer sense of who the vulnerable populations are in a flood situation, and perhaps would illuminate the gendered dimensions of flooding in a way that could improve public health policy and practice. The psychosocial health team-based approach being developed in Manitoba seems to hold a great deal of promise for disaster-affected populations.

Additional Findings

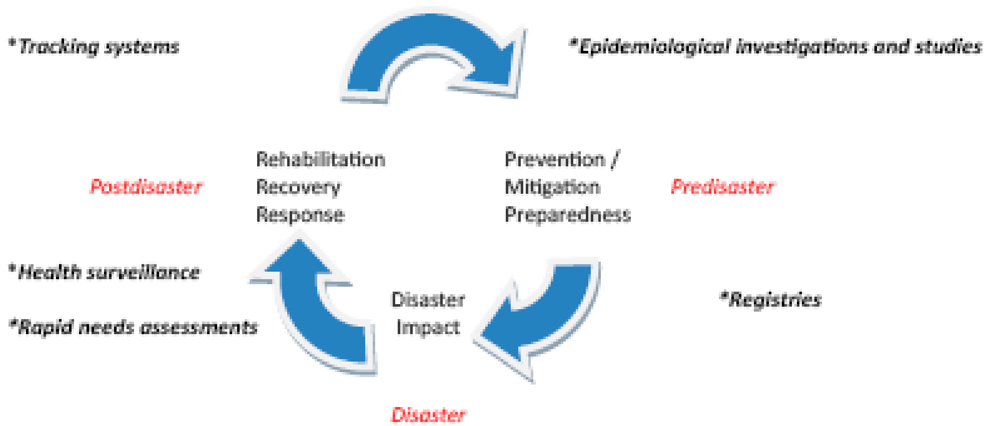
There is a constant need for vigilance with respect to infectious diseases. Possible serious water-borne infections (enterogenic E. coli, Shigella, hepatitis A, leptospirosis, giardiasis, campylobacteriosis), dermatitis and conjunctivitis may be caused by damage to water and sewage systems and insufficient supplies of clean water (WHO, 2002b). There are **new concerns** related to antibiotic and multi-drug resistance, mutations of known pathogens to new serotypes (i.e. O157:H7 and O104 E. coli) and new pathogenic organisms.

Under the rubric of climate change, flooding should **not be considered in isolation** of other forces, such as the potential for tornados, extreme wind and/or heat. These may also be associated with storm cell formation in Southern Ontario and would exponentially increase the challenges facing municipal authorities.

The model highlights the very **limited data** specific to health outcomes that feeds back to local public health authorities during an emergency situation. This gap was identified at the local level by Seguin (2008). It has repercussions for climate change adaptation, which may cause these outcomes to change as the biophysical environment changes to response to different climate signals (different habitats, pathogens, water storage capacity, etc.). The development of an emergency surveillance system tied to the expected health outcomes of a local disaster and triggered by the declaration of a State of Emergency should be explored. Currently, unless the health outcome is a reportable disease, information about population health resides with individual physicians unless a concerted effort is made to collect information, such as, for example, the emergency department syndromic surveillance program applied during the 2013 flood in Calgary.

The case examples demonstrated potential mechanisms that would enhance information sharing between physicians and public health following a disaster, such as a flood. This included the Peterborough County-City Health Unit request that physicians identify and report new clusters of disease, and prioritize asking patients for specific samples (e.g. stool samples). This approach appears to be *ad hoc*, however, and public health would benefit from a more systematic approach to surveillance, data compilation and sharing in the aftermath of an emergency. There is also a need to expand the testing of samples recovered to include potentially novel pathogens.

A key adaptive measure related to flooding and other disasters is **public health surveillance** (Samet, 2010). Surveillance – the systematic tracking of the health of a population, and the on-going use of the data for public health management (Langmuir, 1963) – is underutilized in the case examples. There are a number of different approaches that can be used, depending on the stage of the disaster management cycle they are targeting (see Figure 6, below). The relatively new field of disaster epidemiology (i.e. applied epidemiology in disaster settings) focuses on developing the tools, techniques and capacities required for post-disaster surveillance. There are a wide range of tools available. For example, the US Centre for Disease Control (CDC) has developed a Community Assessment for Public Health Emergency Response (CASPER) for rapid household-based information via surveys (CDC, 2012).

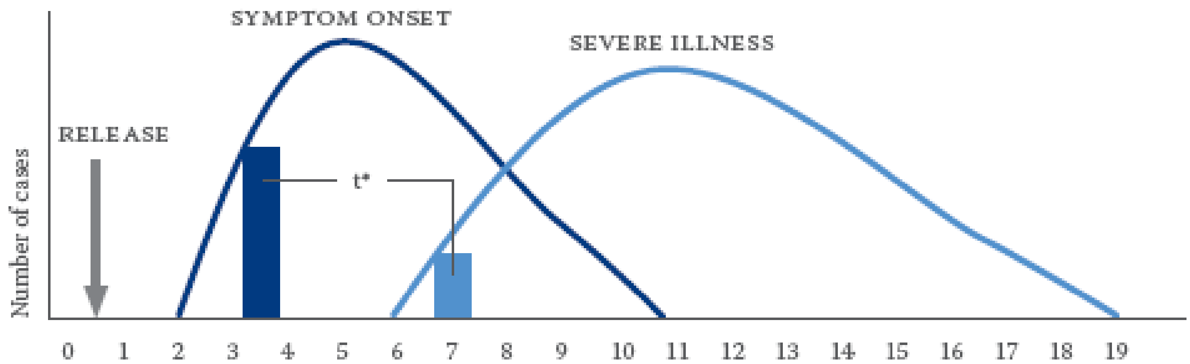


(Source: Malilay et al., 2014)

Figure 6. Disaster epidemiology actions and the disaster management cycle

Two approaches stand out from the literature: hospital-based surveillance and syndromic surveillance. **Hospital-based surveillance** was undertaken in Calgary hospitals during the 2013 floods and provides some useful insight into the health outcomes associated with this large-scale flood event.

Syndromic surveillance, where the use of surrogate data to measure a health outcome (i.e. data other than case confirmed morbidity or mortality records) (Mandl et al, 2004), can provide information about population health outcomes in a timely manner. Ziemann et al. (2011) note the strengths of this approach, including timeliness, flexibility and cost-effectiveness. They point out that following its implementation in evacuation centres following Hurricane Katrina, "it was recommended to incorporate syndromic surveillance into response plans for future disasters" (p. 14). As indicated in Figure 7, below, this approach provides early warning of a potential problem which is particularly useful during an emergency situation. Meene and Murray (2012) note that "surveillance for mortality and morbidity during and after the event is important, in order to obtain timely information for any interventions required" (p. viii).



Source: Ziemann et al., 2012, p.15

Figure 7. Ability of syndromic surveillance to detect symptom onset post-disaster

Legend: t*=time between detection by syndromic (prediagnostic) surveillance and detection by traditional (diagnostic-based) surveillance

Mental health concerns are the dominant health concern stemming from the four case examples. As with the physical health of communities, there is no systematic information being collected on which to base programming in terms of the incidence, prevalence and duration of different mental health outcomes. Anecdotal evidence is strong in all four cases to suggest a population level issue in these post-disaster communities. Alberta was the most proactive on mental health, creating a Chief Mental Health Officer position and investing significant new resources in mental health programming. Manitoba is developing a unique approach to psychosocial health using interdisciplinary intervention teams to provide support to communities after disasters.

In their study of the mental health impacts of widespread flooding in England in 2007, Paranjothy et al. (2011) were particularly concerned about psychosocial distress, anxiety, depression and probable post-traumatic stress disorder. They indicate that:

> Known risk factors for poorer mental health following natural disasters include female gender, older age, lower educational achievement, lower household income, long term health problems and lower social support in the form of networks of family and friends. Disaster specific variables such as evacuation and damage to property have also been identified as risk factors for mental ill health in some affected populations (p.1471).

They found that the prevalence of mental health problems increased with the level of flood water in the home (basement vs. first floor, etc.). The effects of the flood can last a long time. Reacher et al., 2004 found a four-fold increase in psychological distress in flooded versus non-flooded home a year after another British flood. The perception that the flood will have a detrimental effect on household finances is another key risk factor. This finding was supported by other studies that found that “problems with insurers” exacerbated psychological distress in flood victims. They also found that people evacuated from their homes were at a higher risk of psychological distress Paranjothy et al., 2011). There were evacuations in all of the cases studied, although in Peterborough and Wawanesa they were from long-term care homes and health centres, not houses. Nonetheless, this can be a significant stressor particularly where the evacuees are moved to health centres far from friends and family (as occurred in Wawanesa). A recent literature review by Stanke et al. (2012), concluded “that there is a growing body of evidence which suggests that floods can have profound effects on people’s wellbeing, psychosocial resilience, relationships and mental health, often over extended periods of time” (p. 13) and that more research is needed, based on clear and internationally accepted definitions and classifications of mental disorders.

Part of this work will also depend on recognizing the differences between a mental health and a psychosocial approach to health. Indeed, Manitoba Health has found that many people are loath to take advantage of “mental health” programming, due to the on-going stigma associated with these services. They also noted that professionals with mental health training may lack an understanding of the disaster management that is required in this situation. The lack of adequate referral services is an on-going challenge.

Norris et al., (2008) put forward four distinct post-disaster symptom trajectories: resistance (mild or no symptoms of mental illness); resilience (rapidly declining symptoms); recovery (longer period of recovery), and chronic dysfunction (moderate or severe illness for prolonged periods of time). This, or another similar, typology could be used to prioritize potentially vulnerable populations in terms of public health programming and outreach pre- and post-flood.

With regard to mental health and limited data, the WHO (2002b, p. 7) notes that:

> … the effects of flooding on mental health can be measured using standard survey instruments, can potentially be significant, and are likely to be long-term. Moreover, certain subgroups within communities may be more vulnerable to these effects than others, and may need special consideration. … there is a need for much better information, particularly of a quantitative nature, on the potential health effects of flooding, in order to improve strategies to increase adaptive capacity.

The physical health of vulnerable populations is also a concern. There is no indication, however, that changes to the current system are urgently required in that regard.

This study highlights the lack of information about **vulnerable populations** that is available to public health during emergencies, such as floods. For the most part, vulnerable populations self-identify through the use of public information lines or public services. There appears to be no systematic outreach to these populations to proactively address their concerns. There is no evidence of the disaggregation of data by gender, although being female is a known risk factor for suffering adverse public health consequences from flood events.

Planners have a good grasp of predicted changes in **socio-economic and demographic patterns** that will influence communities over time. Many trends, such as aging, are large scale and unstoppable, and drive planning and action. Others, such as the socio-economic situation, may be at the mercy of national and international processes that are beyond the control of a local government. Nonetheless, this information plays a vital role in the identification of potential vulnerable populations in a community and how they may be expected to change over time.

A critical component of exposure under the MEME model is the use of **population level data** to identify vulnerable populations. The inability of respondents to proactively identify such populations following a flood event is a critical gap in local preparedness, particularly where large populations of at-risk individuals are known to exist. There is a need to improve strategies and actions to proactively address the concerns of vulnerable populations before and after flood events. This investment in the most vulnerable will lead to population level improvements in public health. Low-income populations, the elderly and the infirm were identified in the case examples, as well as children and women. The WHO also identified people living alone as a vulnerable population in relation to floods (WHO, 2002b). The need for special programming to address vulnerable populations is clear. The vulnerable populations in the case examples had to self-identify through either a hot line or by applying for assistance. It is conceivable that the most vulnerable may not have been in a position to formally identify themselves in this way. Among the case examples, only Manitoba identified immigrant populations as a vulnerable group. Nonetheless, one suspects that there may be an issue there, for example, related to their capacity to self-identify in the face of cultural and language barriers. Creating Memoranda of Understanding with agencies who work specifically with vulnerable populations and have client lists may be useful in this regard. Access to information and privacy issues would need to be sorted out during this process. This observation is supported - albeit in the context of extreme heat - by a quote in Patterson et al. (2012, p.4), where a municipal public health official stated:

> With climate change, heat could be the big threat given our ageing population. I am concerned about knowing where vulnerable groups are and if they have social support. I am unsure if the vulnerable groups will be taken care of and of the adequacy of the current system to ensure appropriate responses to these peoples' needs to be assessed (Municipal public health official)

This concern is equally relevant for extreme precipitation and flooding.

Women are known to be particularly vulnerable to natural disasters, not only due to their direct effects, but also due to the increased workload placed on them in taking care of sick and injured family members (Preet et al., 2010). Nonetheless, in their review of the literature, Preet et al. (2010) found the gendered impacts of climate change to be "an underrepresented or non-existing variable both in research and studied policy documents in the field of climate change and health" (p. 6). In this study, some specific implications for women are alluded to in terms of increased violence, increased difficulty leaving abusive situations and concerns about families and children.

Land use changes are critical to understanding the potential impact of flood water. Land use reflects social and political choices and can be either proactive of or detrimental to the future health and prosperity of citizens. Protective land uses restore the infiltration and storage capacity of the substrate, where possible, and slow the speed of overland flow. There are a number of techniques that can be used to proactively protect people and property from flooding. The trend toward increased urbanizations and its concomitant increase in impermeable surfaces works against flood management goals and is an area that needs additional attention. Stronger linkages are needed between local land use planning and public health units, both formal (policy) and informal, for collaborative planning that protects health. There needs to be additional political awareness at the local level, of the threat to human security posed by flooding, and additional respect for changing flood regimes (such as, for example, the adoption of 200 or 500 year flood plain designations for new development). In Ontario, where Conservation Authorities have been created, their comments regarding development on flood plains should not be subject to local political manipulation.

There are many different kinds of **property damage** associated with flood events. Nonetheless, some standard messaging around food and water, mould remediation and electrical safety have been developed. Additional pre-packaged information on themes like mental health, flood occurrences and local watersheds could also be developed.

The climate change literature is very clear that the **current climate** situation is the best predictor of potential future impacts of climate change. There is also a clear indication that more extreme weather is an expected consequence of anthropogenic climate change. Thus, flood prone areas will remain that way, and flooding can be anticipated to get worse.

Despite this relative certainty, the particular parameters of these future extreme events are **difficult to predict**. Indeed, in the Peterborough flood it was noted that the storm recurrence interval is impossible to predict given that no comparable event has been recorded since monitoring began in 1866 (Buttle and Lafleur, 2007). Nonetheless, it was pegged by some commentators as a 1:290 year flood (Hammond, 2004). The whole concept of storm recurrence intervals is being undermined by the changing meteorological baselines attributed to climate change. In their review of flood risk and climate change, Kundzewicz et al. (2013) state that "presently we have only *low confidence* in numerical projections of changes in flood magnitude or frequency resulting from climate change" (original emphasis, p.1). As previously mentioned, flooding is both climate-sensitive (in that it has been linked to increases in extreme weather events), but it is also climate insensitive. It is often caused as much by human activity as by any given precipitation event. These actions, particularly at the watershed scale, can make watershed populations more vulnerable to the impacts of severe weather.

Third-party post-flood reviews were demanded by the public in all four cases. These reviews suggest widespread frustration with the community and/or watershed level flood response. It is interesting that in three of the four cases these calls were met with reviews that focused primarily on the technical/engineering aspects of the flood, and not the quality of the societal and institutional responses. In Manitoba, there appears to have been some additional focus on the social aspects, particularly in the 'what we heard' appendix of the Task Force report (Manitoba 2011 Flood Task Force, 2013). It seems that reviews of both systems are needed. Many watershed and sub-watershed scale exposure can benefit from 'hard path'[4] solutions, such as

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[4] The 'hard' and 'soft' path terminology is used in the water and energy sectors to differentiate between large-scale, centralized and technological supply management

engineered flood control structures and improved land use planning. As indicated above, however, 'soft path' solutions are also needed (Gleick, 2002).

Public health could play a more vocal role in advocating for a more holistic approach to organizational learning, that takes into account the social, technical and the environmental determinants of health during and after a disaster. This will be particularly important as we wrestle with the need for adaptive policy to deal with the changing social and biophysical baselines and context under climate change.

As always, **reductions of greenhouse gas emission**, and the protection and enhancement of carbon sinks, are "zero level"[5] investments in public health (McMichael, 2001) that are of fundamental importance to public health.

The lack of **public awareness** of the potential consequences of living in a flood plain, or more likely, the flood fringe, appears to be contributing to some of the mental health distress experienced by those affected. This seems to be particularly apparent in Minden, where the lack of the adoption of a two-zone flood planning system seems to have left many home owners in the dark about the potential risk to their properties from flooding. In Peterborough, the connection is somewhat more abstract due to the prevalence of household flooding mediated by infrastructure malfunctioning (i.e. sewage backflow). Nonetheless, the case examples suggest that there is a role for public health to help people make better connections between the state of their ecological 'setting' and their own health. This role for public health could be embedded within the policy process for municipal governments, or legislated at the provincial level for implementation at the municipal level. There is an opening for this kind of intervention in the current Ontario Public Health Sector Strategic Plan – Make No Small Plans- under Strategic Goal #4: Promote healthy environments – both natural and built. For those living by a river, this would include making the link to the potential consequences of flooding. It should be part of a more systemic shift to locating public health in the larger context of a social-ecological system, which is imperative if the sector is to deal appropriately with climate change. A WHO best practice for flood protection works along these lines. **Flood markers** are a simple tool that can help raise the awareness of community members, both new and old, of the potential for floodwaters to affect their community and their lives. This focus on raising awareness could tackle at least some of the mental health issues facing

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infrastructure and improved demand and resource management approaches, respectively.

[5] Zero-level prevention refers to preventive public health measures that underpin primary, secondary and tertiary public health prevention.

residents by normalizing flooding as a rather regular occurrence, not a surprising one. Many of these actions require partnerships with other sectors, but could be led by public health.

There are a number of areas where enhanced **post-flood-related information** and education could benefit the physical and mental health of residents. Additional pre-packaged information about flood prevention in homes (back-up valves, downspout disconnection, watershed management etc.), potential illnesses (food- and waterborne illness directing clients to submit samples) could be incorporated into the public health offerings in order to provide information and context in the event of an emergency. In Alberta, a booklet outlining all of the measures necessary for homeowners to return to their houses provided a sound basis for household decision-making. Appendix 3 includes a recently compiled resource for pre-flood preparedness in Europe. Such consolidated intersectoral resources should be developed in all high flood risk communities. Both pre- and post- flood booklets should contain information about the local watershed context for the flood. The tension between downstream and upstream communities related to the need to manage floods on a watershed basis may have been reduced if information about that larger context and its implications were available.

Flood planning and mitigation is a watershed issue. The watershed is a construct that can be defined at multiple scales. The Minden flood affected a very large managed watershed; the High River flood affected most of Southern Alberta; the Wawanesa flood large portions of Saskatchewan, North Dakota and Manitoba, while the Peterborough flood was focused more on three sub-watersheds draining through the city centre. Public health can be more proactive in helping educate the population about the relationship between ecology and health – for example, though the use of an expanded ecological model that includes watersheds at multiple scales, as well as an expanded healthy setting approach (e.g. health communities, healthy schools, healthy cities). Thinking about **watersheds as setting for health** (Parkes et al., 2010; Morrison et al, 2012) has the potential to change the paradigm as it related to the link between flooding, climate change and human health and would influence policies and programs in a variety of sectors.

The need to **engage stakeholders** in the disaster-recovery and planning process was illustrated in Peterborough, where participation in the community forums appeared to provide valuable information to the consultants while also providing a mechanism for the community to vent its stress and anger over its losses. There is a clear community-building upside to providing a formal process for people to come together to discuss the past and plan for the future that can enhance community resilience prior to the next ‘100-year’ flood - which as we know could occur at any time. The key lesson learned from the Peterborough example, is that using geographic targeting alone is not a best practice for organizing such engagement. Targeting vulnerable populations is equally, if not more, important in order for the community to gain the clearest insight into the effects of the flood on population health.

Communication during a disaster is always challenging. Flood events call for communication at the watershed as well as the local scale, particularly when upstream/downstream trade-offs have to be made. In Minden, communication was made more difficult by the complicated jurisdiction over this managed watershed. Communication to the general public regarding the management actions taken to mitigate the impact of the flood at a watershed scale were not well-communicated and resulted in increased stress and anger in the Minden population. In Peterborough, the Conservation Authority had a clear mandate to help manage and provide information about the flood at the larger scale and there is no indication of a backlash at this scale.

Within the community, communication and coordination processes in all of the case examples seemed to work well, following the lead of the Emergency Organizing Committees. Given that several of the floods seemed to gain traction during the night, there is a potential need for enhanced public warning of flood events, such as, for example, via the use of public sirens (as used during World War Two) or robo-calling to warn residents about the onset of fast-moving flood events. Such as system is also applicable for other forms of extreme weather, such as tornados.

At the community level, there is a need to ensure redundancy in the **operational response** in the event that one or more civic locations are also affected by the flood event. This entails the identification of a number of potential meeting places and spaces, as well as potential evacuation centres.

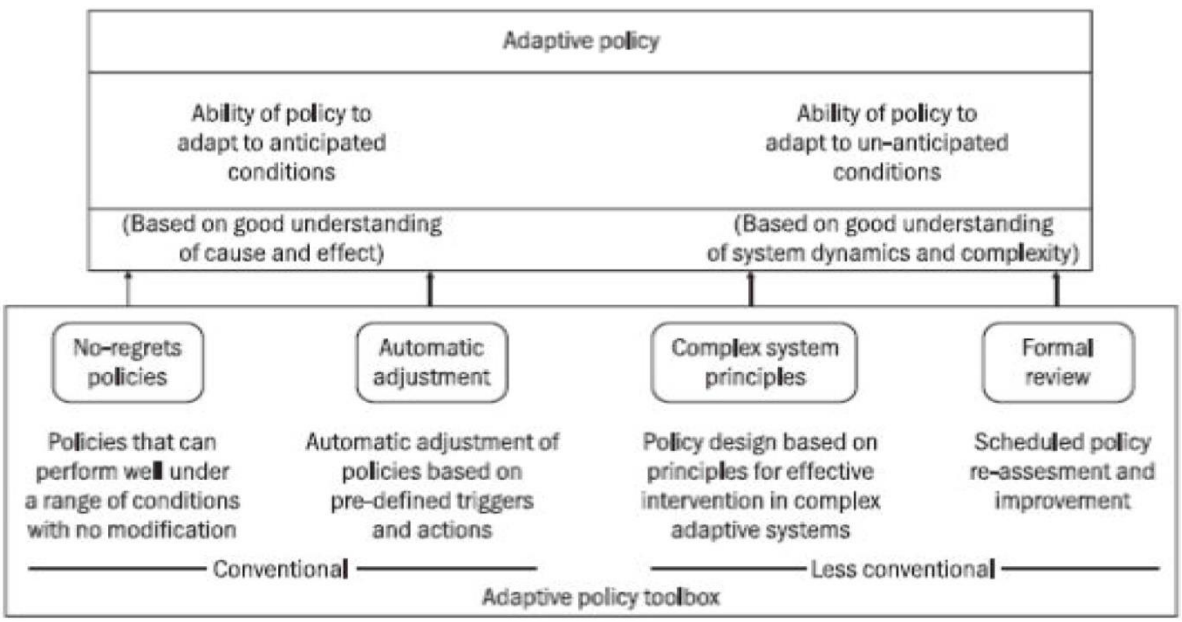
There is currently no **overland flood insurance** in Canada. The Federal Government committed to exploring this option in its 2014 budget. The major insurance companies have stated that there would be no movement on this issue until, at a minimum, flood hazard maps are updated. Updating flood plain maps is a political issue that affects real estate values. It therefore generates a great deal of resistance. In order to minimize the potential for manipulation, one technique is to create GIS maps at a low resolution so that specific properties cannot be identified. Leadership at the provincial level is required to change design storm standards. Compensation for existing property owners or some other alternative arrangements could be considered, particularly as part of an overarching climate change adaptation strategy by the government.

Both Willows and Connell (2003, on behalf of the U.K. Climate Impact Programme (UKCIP) and the International Institute for Sustainable Development (2006) have published excellent work on the topic of **adaptive policy** that is very relevant to climate change adaptation and public health. As indicated in Table 6, the UKCIP model categorizes adaptation measures in terms of: no regret, low regret, win-win and flexible or adaptive. The IISD (2006) approach fleshes out that last category (flexible or adaptive) and defines adaptive policies as those that have features that allow them to continue to adapt to both anticipated and unanticipated conditions, as illustrated in Figure 8, below. No regrets policies are defined similarly in both. Automatic adjustment, complex systems principles and formal review are all examples of adaptive policy approaches. Automatic adjustment, in the context of this study, would be, for example, when the proposed system of post-disaster syndromic (or active) surveillance is triggered by the declaration of a State of Emergency at the local level. Complex system principles would guide interventions in targeted areas based on a systemic understanding or model. This could guide interventions focused on vulnerable populations. Finally, scheduled formal review is a mechanism to ensure policy re-assessment and improvement in areas where the science is evolving. This would be relevant for the scheduled re-evaluation of emergency preparedness plans at the local level due to climate change (for example, every 10 years). There are a number of other potential applications of adaptive policy that should be considered by public health agencies as they respond and adapt to changing social and ecological baselines over the coming years.

Table 6. Generally Accepted Ranking Criteria for Adaptation Measures

Criteria	Definition	Example
No-Regret	Adaptive measures that are worthwhile (i.e. they deliver net socio-economic benefits) whatever the extent of future climate change.	Surveillance of vector populations, food- and waterborne diseases; closing beaches after heavy rain
Low Regret	Adaptive measures for which the associated costs are relatively low and for which the benefits, although primarily realized under projected future climate change, may be relatively large	Enhanced quantitative data on short-term and long-term health impacts of extreme weather events
Win-Win	Adaptive measures that have the desired result in terms of minimizing the climate risks or exploiting potential opportunities but also have other social, environmental or economic benefits.	Maintain and improve disaster management programs for local health facilities Enhance public health capacity to respond to disasters
Flexible or Adaptive	Adaptive measures are introduced through an assessment of what makes sense today, but are designed to allow for incremental change, including changing tack, as knowledge, experience and technology evolve	Delay implementing specific adaptation measures while exploring options and working with appropriate levels of government to build the necessary standards and regulatory environment

Adapted from: Willows and Connell, 2003



Source: IISD, 2006

Figure 8. The IISD Adaptive Policy Toolbox

Crises create critical opportunities for policy change. The public health sector, both locally and provincially, should position itself to take advantage of this fact to drive forward the Health in All Policies agenda. **Downs' Issue Attention Cycle** (Figure 9, below) is a useful heuristic in this regard. It focuses on the opportunity for policy change that is created during 'crises', and the different stakeholders engaged in different parts of the response process. The public is heavily involved in steps 2 and 3, and gradually loses interest and the complexity of the issues become apparent. Policy entrepreneurs and bureaucrats are more heavily involved in steps 5 and 1, as responses to crises are elaborated and the next crisis has not yet arrived. These changes make watershed populations more vulnerable to the impacts of severe weather and can be addressed by intersectoral policy changes.

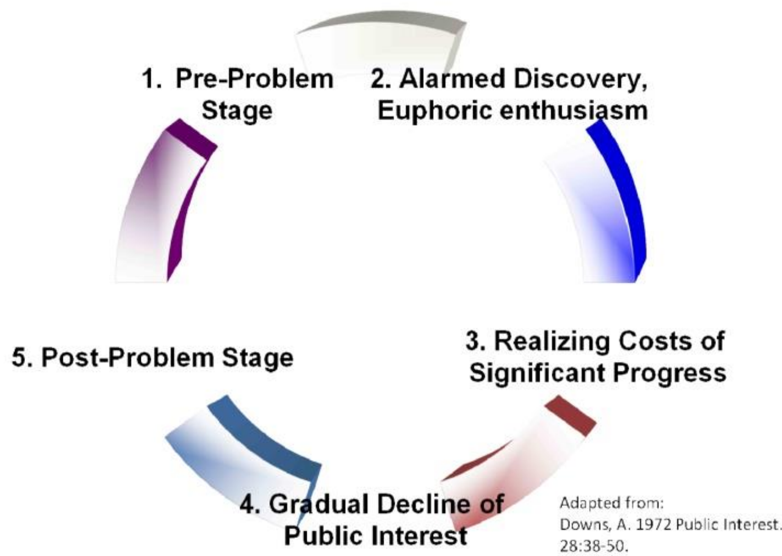


Figure 9. Downs' Issue Attention Cycle

APPLICABILITY OF THE MEME MODEL

The MEME model is very effective at drawing out the importance of taking the **local context** for a disaster, such as a flood, into account when considering potential preventive and remedial actions. Of particular importance for flooding is the overarching **watershed and sub-watershed** context - for other disasters, the appropriate focus may be a different environment (i.e. an airshed or a forest). The size of the watershed and sub-watershed units (as measured by stream order) as well as the local topology, geology and land uses are critically important to understanding the potential impacts of different kinds of floods (i.e. pluvial, fluvial, stormwater runoff, etc.).

An additional feature of the context is the importance that different forms of **housing** play in determining the population health consequences of a flood event. In areas, such as Minden, where the population is more seasonal and the homes are more likely cottages, the social disruption and displacement is more managed. In a city like Peterborough, with a relatively large low-income population living in rental housing, including basement apartments, the impacts of this population and the need for public health units to engage with landowners is significant. In a case like High River, the loss of a family's primary home has significant financial and emotional consequences. Thus, one way of characterizing potential flood responses would be to group cities, or communities within cities, according to the dominant housing type, as well as their location within the flood plain, flood fringe or in areas with the potential for infrastructure problems to occur (i.e. lacking downspout disconnections, backflow valves, located in low elevations, etc.). Best practices for each housing type could then be identified.

The model is useful in highlighting potential **exposures**. Regardless of whether or not they generate health outcomes for a particular flood event, many of these exposures require active intervention by public health or other public sector officials (gas, electricity, roads, buildings, etc.). Having a good grasp of them is essential for pre-disaster planning. The model effectively lives up to its name in reminding us that population health is affected by multiple exposures spread out over space and time - including ones that will influence the physical, mental and social health and well-being of distinct sub-populations differently, and over a potentially long time frame.

The model also highlights the potential **health outcomes** generated by the event and the associated exposures. This aspect of the model is more difficult to apply, however, based on the dearth of disaster specific health data available. One has the impression that in the absence of sound data public health officials are developing programming in response to *ad hoc* sources of information, including anecdotal reports of problems. While this may not be problematic for individual disaster events, it detracts from our ability to learn and respond to any changes in health outcomes that could be associated with climate change. Two different approaches are demonstrated in the case examples.

The vulnerability of specific populations is captured in the model by its multi-scalar emphasis. The household and community lenses capture differences among populations, and the watershed scale captures upstream and downstream tensions that are often also urban and rural and also about power and resources. As mentioned in the discussion, above, people are unlikely to become less sensitive to the threat of flood waters, both in terms of their quantity and quality. The sensitivity of specific systems and populations can, however, be understood as a component of the multiple exposures multiple effects concept, whereby the exposures related to the flood are added to the larger context of population health in an area, and thus add to the baseline of existing sensitivities from other stressors. Reducing the sensitivity of vulnerable populations requires household, community and watershed scale interventions.

The model emphasizes preventive and remedial **action**. It highlights the huge investments made by communities post-disaster, and the less evident indications of a commitment to preventive planning. This bias is not limited to disaster response, it permeates policy at all levels and strongly reflects the public health paradox: proactive success in avoiding population health problems is invisible, requires tradeoffs, is difficult to prove the effectiveness of prior to a disaster, and is thus politically unrewarding.

The model is able to identify areas where adaptive capacity is available and where it is currently lacking. This includes the capacity to learn from the flood event and to make changes to systems as a result. It covers changes to infrastructure, policies and practices that make the system more robust.

Limitations of the model are also apparent. For one, application of the model is entirely **descriptive** and the **boundaries** of what should or should not be included are not clear. These challenges are particularly apparent when it is used, as in this study, to conduct a *post hoc* evaluation of flood events - one of which was over 10 years old. It is also apparent when the ambient environment is included in the analysis. For example, how much of the pre-existing watershed-level programming is relevant to the case? Similarly, the post-disaster response is embedded in established systems and institutions. The health and social welfare programming will create the basis for the public response to vulnerable populations and their concerns. The model does not make it easy to place boundaries on how much of that system is relevant to the analysis of multiple exposures, effects and actions in a given community.

A final consideration is that the MEME model is not **dynamic.** There is no feedback between the actions taken and the exposures, outcomes or context of the community. With the caveats above, it is well-suited to elucidating key elements of an event that has occurred, but is less relevant to the demands of forecasting potential changes to exposures and effects driven by climate change. In the following section, the model is adapted to address these concerns and to be better suited to understanding the public health issues and impacts associated with climate change.

Applicability of the MEME Model to Other Forms of Extreme Precipitation

The MEME model, and the updated MEME4CC model, below, is applicable to identifying the exposures, outcomes and potential actions associated with other forms of extreme precipitation. Retrospective analysis of extreme events (such as the Buffalo snowfall of 2014) can provide useful insight into future system vulnerabilities, sensitivities and opportunities to build adaptive capacity. As with flooding, it is difficult to predict the likelihood or magnitude of extreme precipitation events with any accuracy, however.

One of the limitations of the MEME model is the lack of standardized local information about health outcomes currently available. This report suggests linking disaster surveillance to the declaration of a local (or higher level) state of emergency. This is likely more relevant to ice storms and extreme snowfall than hailstorms and rainfall induced lightening strikes, which tend to intensely affect a smaller geographic area and thus fewer people. The cost of enhanced surveillance for such events may not be worth the potential information gained. Nonetheless, there are specific lessons learned from each of the different forms of extreme precipitation that can be identified through retrospective case analysis or expert opinion and may be useful for developing policy or programs. These include, for example, developing a holistic understanding of the potential impacts of the event on the health and well-being of specific populations, and contributing to the development of preventive health messages and emergency response.

Current climatic conditions are the best predictor of future climate-change related challenges. Thus, local experiences with a variety of extreme precipitation events should be considered and the consequences of larger and more extreme occurrences forecasted. In addition, however, shifts in regional climates need to be understood. Part of a community’s sensitivity to climate change is related to its previous collective experience of weather events. Communities that are experiencing a new weather event for the first time are more vulnerable to it than others. The two MEME models are useful in organizing the public health response to such events.

Multiple Exposures Multiple Effects Model for Climate Change (MEME4CC) Adaptation

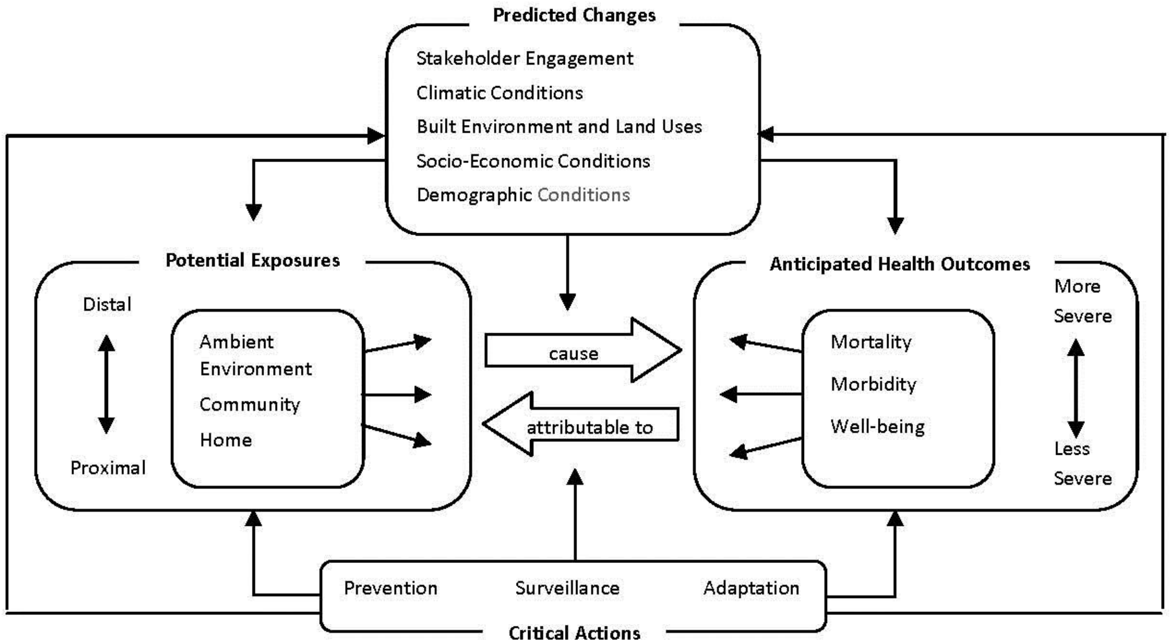


Figure 10. Multiple Exposures Multiple Effects Model for Climate Change Adaptation (MEME4CC)

The updated framework (Figure 10) guides future-decision making through its focus on defining predicted changes, potential exposures, anticipated health outcomes and critical actions. The influence of the critical actions on the predicted changes to future conditions explicitly emphasizes their role in either reducing or increasing the potential exposures and positive and negative health outcomes associate with climate change.

Predicted Changes

Predicted changes are those that are expected to occur in a given area. This information can be generated by expert opinion, for example using a conjoint choice survey (See Alberini et al., 2006), or through downscaled climate modelling approaches. Given the large amount of uncertainty in the science, both approaches should generate several potential future scenarios that can be used to identify win-win policies (Willows and Connell, 2003). Of particular importance are climatic conditions, the built environment and land uses; socio-economic conditions and demographic trends.

Stakeholder engagement is a key aspect of the predicted changes that can be influenced, positively or negatively, by public health authorities. The climate change adaptation literature is very clear that intersectoral, intersectoral and public engagement is needed to address the systemic challenges created by our changing climate. Stakeholder engagement processes are required in successive iterations and must be continually re-assessed.

Potential Exposures

Potential exposures are those that can be anticipated based on current situations and temporal analogue studies[6]. Resources for monitoring, reporting and reflection are needed in order to identify any changes, such as novel exposures, over time. Checklists and other tools can help remind local authorities of the potential breadth of exposures that they need to be planning for.

Anticipated Health Outcomes

Anticipated health outcomes are those that can be expected to occur based on current conditions and temporal analogue studies. Improved surveillance systems are required in order to capture this information. In the absence of data, local authorities will continue to make programmatic decisions based on ad hoc and anecdotal data. This may create problems in the future, as climate change modifies existing social and ecological baselines and new health challenges emerge.

Increased recognition of the psychosocial outcomes related to climate-related phenomena suggest that this element of well-being should receive additional attention.

Critical Actions

Critical actions are those that can change the anticipated future conditions, potential exposures and anticipated health outcomes at multiple scales. They can be categorized as preventive or adaptive.

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[6] Spatial analogue studies identify current climate regimes which may resemble the future climate of a given region and identify the impacts on a given variable in that context. They are a number of challenges to implementing this methodology, although it may be suitable for identifying the potential human health impacts of extreme precipitation and flooding.

Prevention

Preventive actions are those taken prior to a flood event to reduce the potentially negative, and enhance the potentially positive, consequences of a weather event or technological disaster (such as a nuclear accident). Of particular importance to all sectors, including public health, are the reduction of greenhouse gas emissions and the protection and expansion of carbon sinks.

Surveillance

Surveillance is included as a critical action for public health. Surveillance is both preventive and adaptive, but it is also very much in-the-moment, as it is a critical aspect of disaster management that is currently underdeveloped. The type of surveillance put in place will depend on the context.

Adaptation

The Intergovernmental Panel on Climate Change (2001) defined adaptation and adaptive capacity as follows:

> *Adaptation:* adjustment in natural or human systems in response to actual or expected climatic *stimuli* or their effects, which moderates harm or exploits beneficial opportunities.
>
> *Adaptive Capacity:* the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Among other actions, adaptive responses should focus on: stakeholder engagement, proactively identifying and tailoring responses to vulnerable populations, fostering adaptive capacity and adaptive policy at multiple scales, investing in ecosystem management as preventive public health, disease surveillance, communications and operations.

Conclusions

The MEME model is useful for identifying the health exposures and outcomes associated with past flood events. The updated MEME4CC model is more dynamic and better suited to anticipating future challenges and opportunities related to public health.

There are ways to reduce some of the negative health outcomes related to flood events, particularly as they relate to mental and psychosocial health. New development in the institutionalization of psychosocial health teams in Manitoba seems to be a promising approach to providing immediate post-disaster support to a large number of people, as both government personnel and NGO staff can be trained in Psychosocial First Aid. Separating this from formal mental health programming may increase uptake by the affected public by reducing stigma. The emphasis placed on mental health programming in Alberta, including the formation of a Medical Officer of Mental Health is indicative of the concern all of the case examples demonstrated for this topic. Additional study and pan-Canadian exchange of best practices in this area is needed.

People experiencing floods are living in a dynamic social-ecological system. This fact directly affects their health. Public health needs to reflect this thinking, particularly in light of the profound changes we can expect in local social-ecological systems due to climate change. A lack of understanding at the population level of the potential consequences of living in a flood plain should be addressed. Public health can be more proactive in helping educate the population about the relationship between ecology and health – for example, through the use of an expanded ecological model that includes watersheds as well as the healthy setting approach. Thinking about watersheds as setting for health (Parkes et al., 2010; Morrison et al, 2012) has the potential to change mindsets, policies and programs as they related to flood prevention and response.

The need to prioritize the identification and engagement of vulnerable populations is apparent. This is an area that requires additional programming at the local level. Although a known risk factor, gender and gendered policies continue to be "an underrepresented or non-existing variable" (Preet et al., 2010, p.6).

There is evidence of information sharing between public health agencies with experience coping with large flood events. This was particularly apparent between Peterborough, Manitoba Health and various agencies in Alberta during their 2013 flood. Enhanced opportunities for public health and other professionals to network and to exchange information and good practice would enhance pan-Canadian resilience to floods by strengthening the capacity for such informal exchanges of information and expertise.

Recommendations

Based on the findings of this small study, the following suite of preliminary recommendations is put forward for discussion:

i. a summary of the potential health outcomes associated with different flood types and/or those common to all floods should be prepared at three scales (household, community and watershed) to guide local and regional preparedness planning and programming;
ii. public health should engage with and promote a social-ecological systems approach to understanding, characterizing and acting upon health threats and opportunities related to climate change;
iii. local public health units should incorporate watershed and flood mapping information into its existing suite of flood-related information resources, particularly between floods, and should advocate for the use of larger design storms around which to plan development and infrastructure;
iv. more formal links between public health, land use planning and Conservation Authorities or other watershed agencies could be established with a view to implementing a health-in-all-policies approach to hazard protection and land use planning and to embed public health thinking as it related to current and future generations into our conceptualization of ecological settings and of social-ecological systems;
v. disaster surveillance systems should be developed and linked to communities' declaration of a State of Emergency. This could include passive syndromic surveillance through hospitals, physicians, family health centres or phone lines, or active surveillance, or a combination of the two. It may include laboratory-confirmation of pathogens and/or testing for an expanded suite of pathogens during an emergency. Improved information will be required to better understand the impacts of climate change on public health;
vi. the disruption of 'normal' health and social services should be planned for, including the evacuation of health and long-term care centres and the secondment and training of additional staff to cope with the emergency;
vii. mental and psychosocial health should be given the priority it requires post-disaster. Improvements should be made to existing programs to reflect best practices in the field;
viii. provinces should explore the idea of a Chief Officer of Mental Health position, as per the Alberta example;

ix. public health should leverage disasters to engage in post-disaster planning that is not only technical, but also social and institutional. The Health in All Policies lens in relevant in this regard;
x. disaster response plans should be critically reviewed on a regular basis to ensure that there is adequate local preparedness for concurrent multiples disasters/catastrophes;
xi. programming and specific resources for women should be improved post-disaster;
xii. vulnerable populations should be proactively identified, and not be required to self-identify through a phone line or a form after a disaster. The most vulnerable are most likely not to know about, or be able to take advantage of, these resources;
xiii. best practices in flood management including ecosystem management, should be implemented. Most flood control measures are well-known and well-tested;
xiv. improved information resources should be available to affected households post-disaster. Current ad hoc 1-2 page information sheets should be consolidated into one comprehensive booklet, perhaps by housing type;
xv. best practices in using social media during emergencies should be implemented to both provide, and potentially collect information from, the public during a crisis;
xvi. public health should be active and vocal advocates for greenhouse gas reduction policies locally, domestically and internationally;
xvii. public health should engage more frequently with other sectors and stakeholders, including those engaged in natural resource management;
xviii. proactive action is needed, despite the public health paradox. More and improved local investments in prevention (including not building in flood plains and flood fringes) should be advocated by public health agencies;
xix. the MEME4CC model should be tested for its applicability to local public health adaptation related to climate change[7];
xx. an on-going commitment to organizational learning and adaptive policy should be a priority for local public health agencies, particularly in climate-sensitive areas; and,

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[7] According to Fussel and Klein (2004, p.23), "the most suitable definition of the 'exposure to anthropogenic climate change' in terms of the variables involved, the choice of the spatial and temporal unit of analysis, and the consideration of dynamic aspects depends on the specific health outcome concerned. It is largely determined by the type of climatic hazard involved in the causation of a specific disease". For this reason, generalized studies of climate change impacts are less preferred than targeted studies focused on particular hazards or exposures.

xxi. opportunities for professional networking and knowledge exchange between public health units and other professionals in flood-prone areas should be encouraged.

Appendix 1: Causes of Loss of Life and Serious Harm to People during Floods

The following list of causes of loss of life and serious harm to people during floods is reproduced from the Defra/Environment Agency (2003) report, pages 5 & 6. The Table is from p. 10 of the report.

Risk of loss of life

The conditions which lead to a risk of injury or loss of life are summarized in this section, based on information on flood events from around the world. It should be appreciated that the number of deaths caused by flooding in the UK is relatively small compared to some other countries.

General

The flood conditions in which the risks of death are likely to be greatest are those where one or more of the following conditions exist:

- where flow velocities are high;
- where flood onset is sudden as in flash floods, for example the Linton/Lynmouth floods in 1952, Big Thompson flood, USA, in 1976 and flash floods in Southeastern China in 1996;
- where flood waters are deep;
- where extensive low lying densely populated areas are affected, as in Bangladesh, so that escape to high ground is not possible;
- where there is no warning (i.e. where there is less than, say, 60 minutes of warning);
- where flood victims have pre-existing health/mobility problems;
- where natural or artificial protective structures fail by overtopping or collapse;
- flood alleviation and other artificial structures themselves involve a risk to life;
- because of the possibility of failure, for example dam or dike failure;
- where poor flood defense assets lead to breaches or flood wall failure, leading to high velocities and flood water loadings on people in the way; where there is debris in the floodwater that can cause death or injury;
- where the flood duration is long and/or climatic conditions are severe, leading to death from exposure; and
- where there is dam failure.

Risk of loss of life: Building collapse and related circumstances

- Death rates in floods are high where buildings fail to provide a safe refuge or collapse
- Timber framed buildings, mobile homes, informal, temporary and fragile structures (including campsites and other tented dwellings) may give rise to significant loss of life or hazardous rescues.

Risk of loss of life: Being swept away

- Pedestrians, many of whom may be unaware of the power of floodwaters, can be swept away. Experimental studies suggest that the safe limit (for adults) is a product of depth (metres) times velocity (metres/sec) in the range of 0.5 to 1.0. The heavier the person the less the chance of being swept away. Eighty percent of the estimated 200 deaths in Monterrey, Mexico in 1988 were attributed to attempts to ford the flooded river.

Exposure

- People trapped in buildings or on the roofs of buildings may die from exposure. This is linked to the duration of a flood In addition to the dangers caused by debris, other types of pollution could cause risks to people, for example the release of dangerous chemicals.

Trapped in building/vehicle

- Many deaths in floods occur because people attempt to drive through or away from floodwaters and get swept away or trapped in their cars; their cars either then get swept away as a result of positive buoyancy or stuck in the floodwater. Almost half of flash flood related deaths in the US are the result of people being trapped in vehicles.
- Deaths can occur where people are trapped in single story buildings, ground floor apartments, cellars or underground structures, such as railways or car parks which can pose a particular threat to life in urban areas. Although buildings are often a safe refuge during a flood, there are other risks to consider.
- Buildings where there is a particularly high risk of people becoming trapped during a flood include schools, hospitals and old peoples' homes.

Falling down manhole or similar

- In flooded urban areas, people attempting to move about, particularly where floodwaters are turbid or discoloured, may fall down blown manholes, into excavations or into ditches.

Behaviour of individuals during floods

- An important but difficult to quantify factor is the behaviour of some individuals during floods. Deaths have occurred of people curious to see a flood, particularly on the coast where they have been swept away by wave action. "Flood tourism" is recognized as a problem elsewhere in Europe.

Factors contributing to serious and acute consequences of flooding on human health

Many of the circumstances leading to serious harm to people are the same as those which result in loss of life. They can be categorized as below:

The people, community and their property

- where the pre-existing health status is low;
- where the population at risk is elderly;
- where there are particular types of property e.g. single storey bungalows;
- where there is limited or no previous flood experience and awareness of risk;
- where there are no coping strategies developed following previous flooding;
- when it is necessary to leave home and live in temporary accommodation;
- where there are pre-existing health conditions and susceptibility; and
- where community support is poor.

The flood

- where there are certain characteristics of the flood event (high depth and velocity, long duration, unexpected timing (middle of night, etc.));
- where floods are sudden and without warning; and
- where there are no flood warnings received or they were not acted upon.

Related to damage, etc

- where the amount and type of property damage and losses is of a certain character and high;
- where there is frustration and anxiety in dealing with insurance companies, loss adjusters, builders and contractors, etc; and,
- where recovery is impeded by a range of factors beyond the control of the flood victims.

Other factors

- where there is increased anxiety over the possible reoccurrence of the event;
- where there is a loss in the level of confidence in the authorities perceived to be responsible for providing flood protection and warnings;
- where there are financial worries (especially for those not insured);
- where there is a loss of the sense of security in the home;
- where there is an undermining of people's place identity and their sense of self (e.g. through loss of memorabilia); and
- where there is disruption of community life.

Table 2.1 Factors influencing the health impacts of floods
(listed in order of decreasing significance)

Significance	Post Traumatic Stress Syndrome	General Health Questionnaire
Highly significant	1. Problems within insurers	1. Problems with insurers
	2. Gender	2. Gender
	3. Age	3. Problems with builders
	4. Warning time	4. Rented accommodation
	5. Prior health	
	6. Flood Depth	
	7. Rented accommodation	
	8. Years since flood	
	9. Evacuation	
Some significance	1. Problems with builders	Contamination
	2. Flood awareness	Age
	3. Contamination of flood waters	Prior health
		Vulnerable housing
	4. Income	Flood Depth
		Years since flood
		Flood awareness
		Warning time

Appendix 2: Application of the MEME Framework to Four Canadian Case Examples

Case Example 1. Pluvial/Urban: 2005 Peterborough, Ontario Flood

Context

On July 15, 2004, the City of Peterborough was inundated by an extreme rainfall event that set the record for the largest 24 hour total rainfall depth (>220 mm) ever recorded in Southern Ontario since monitoring began in 1866 (Buttle and Lafleur, 2007). In one hour alone, from 3:30 to 4:30 am, 78.8 mm of rain fell on the city (City of Peterborough, 2004). The rain was both intense and of long duration (approximately 6 hours). It exceeded previous maxima for Southern Ontario, including the design storms Hurricane Hazel (1954) and the 1989 Harrow Storm (Windsor). It was part of a larger system that produced heavy rain and hail in Edmonton, Alberta four days earlier (Gough and Mohsin, 2006). The storm front extended from James Bay through the Great Lakes Basin.

The rainfall event was unique in several ways. For one, the storm cell was localized over the City, with the peak of the storm located to the south east of the City. It produced the largest instantaneous peak flow ever recorded for Jackson Creek, which runs directly through the downtown area (Buttle and Lafleur, 2007). The storm caused more than 88 million dollars in flood damage (Environment Canada, 2004) and wreaked havoc on the city.

In the late evening of July 15, the rainfall was severe enough to cause the collapse of the roof of a nursing home in the City, requiring the evacuation of the residents. As conditions worsened during the night, basements flooded and fire alarms were set off. By 5:30 am the Emergency Operations Centre was operational and a Declaration of Emergency was made by the Mayor at 7:00 am. The Declaration was in place for two weeks, until July 29th (City of Peterborough, 2004).

The storm is an excellent example of a pluvial flood, given the very short delays in space and time between the rainfall over the City, the resulting strains on local water infrastructure (water, sanitation, buildings and roads), and the onset of significant public health concerns. It followed on another extreme precipitation event (considered a 1:100 year storm) and flood in June 2002, which also disrupted parts of the city. Prior to 2002, such storms were not common. Similar rainfalls have since fallen in: 2002, 2004, 2009 and 2012. The City consulted with Environment Canada, but no particular reason was identified for this change. The 2002 storm did not affect the city in the same way, nor did it receive the same level of publicity. Affected households were dealt with on a case-by-case basis. Some, but not all, of those affected in 2002 were also flooded in 2004.

Peterborough is a city of 75,000 inhabitants. Its population has a lower than average socio-economic demographic and a large student population. A large portion of the lower income residents (including students) live in rental housing. Basement apartments tend to be the least expensive housing stock. This particular feature of the community has repercussions for the analysis of the impact of the flood on public health.

EXPOSURES

This section summarizes the exposures faced by stakeholders at the household, community and watershed scales.

HOUSEHOLD

At the household scale, during and immediately after the flood event residents were exposed to elements that could affect their **physical health**, such as[8]:

- questionable structural integrity of homes and facilities, including 6 building evacuations;
- potential physical injury from collapsed roofs (2);
- downed power lines;
- potential carbon monoxide exposure (8 alarms went off);
- people trapped in and on vehicles (25 people);
- untreated sewage in flooded basements;
- extensive amounts of household garbage and contaminated building materials, including rotten food and construction debris, and the associated concerns about rodent populations (mice, rats, raccoons, etc.);
- foodborne illness;
- electrical damage to major appliances located in basements, particularly water heaters, hydro meters, washing machines and dryers;
- loss or malfunction of personal assistive devices and electrically powered devices, such as motorized scooters and oxygen tanks;
- outdoor flood waters, particularly contaminated stormwater and urban runoff on the property,
- debris;
- post-flood mould; and,

[8] Numerical information from City of Peterborough, 2004.

- lack of shelter, food, water, personal care products and clothing. Emergency clothing was provided to more than 1300 people, and emergency food to over 1000 households.

In addition, there were concerns over exposure to natural gas; approximately 1,000 homes had their gas disconnected due to the flood.

At the commercial level, one flood related fire was reported.

In the months after the flood event, the citizens of Peterborough were also exposed to elements that could affect their **mental health**:

- stress from requiring rescue (i.e. from flooded cars) and emergency evacuation;
- stress and anxiety related to the flooding of their home and/or the loss of their possessions;
- decision fatigue and attachment to possessions (making innumerable decisions about what to keep or what to get rid of, attachment to property being disposed of. The latter was manifested by homeowner outrage at scavengers taking “their things” from the curb);
- increased trust, sense of community, from neighbor-neighbour assistance.

Community

At the community level, exposures during and immediately after the flood event focused on **public health and emergency services** and included:

- lack of shelter, clothing, food, water, etc.;
- contaminated standing water and some riverine flood water;
- physical risk from garbage and rotting food (including increased exposure to vectors such as rat, mice and raccoons) with the associated problems of odour and rodents;
- household mould and debris;
- emergency release of municipal sewage;
- flooding of the downtown core;
- debris in public spaces, including roads for up to three weeks;
- unsafe road and bridge conditions - It is estimated that cleaning, repairing and inspecting City streets “consumed thousands of hours” (City or Peterborough, 2004, p. 6). 28 minor motor vehicle accidents were reported;
- flooding of businesses; and

- water damaged electrical equipment and concerns about the integrity of the natural gas system;

Following the flood event, critical exposures affected populations differently and were related to **mental health:**

- stress and anxiety related to access to services (including funding);
- worker fatigue, particularly of the social workers charged with managing the reception and evacuation centres and the City of Peterborough Emergency Control group[9];
- community-building events to raise funds; and
- stress, anxiety and/or empowerment related to stakeholder engagement components of the City's flood review process.

WATERSHED

The Peterborough flood was part of a larger storm system that contributed to elevated baseflows throughout the Otonabee watershed. The three sub-watersheds that run through the City of Peterborough were the focus of much of the flood damage in the city itself. The primary exposures at the watershed level were to flood waters, urban runoff and combined sewer overflow water. These waters tend to contain a mixture of pathogens, chemicals and debris that can affect population health.

One of the affected sub-watersheds, Jackson Creek, is a 110 km^2 sub-watershed that drains a large wetland to the west of Peterborough and runs through the downtown core before draining into the Otonabee River. Although only approximately 5% of the basin consists of suburban and urban land uses linked to the waterway by storm sewers, the concentration of the storm over the city quickly overwhelmed the drainage capacity of the waterway. The mean daily flow of the Creek was the highest on record for a rainfall-generated flood, and "resulted in the largest instantaneous discharge on record regardless of the generating mechanism" (Buttle and Lafleur, 2007, p.69). The peak of the flood hydrograph was very sharp, implying that the high flows in the Creek were short-lived and were predominately caused by the direct contribution of overland flow from the urbanized section of the sub-basin. This water flowed

[99] During the first few days of the flood, some of the City's Emergency Control Group members were working 18-20 hour days. Since the 2004 flood, this group has been expanded to include a minimum of four (and in many cases up to six) people trained for each required position. In 2004, there were only two people trained for each role. There are also 50+ people trained to work in the Public Inquiry Centre and 80+ people trained for reception and evacuation centres (information provided by Peterborough County/City Health Unit).

into the storm sewer networks and storm water retention ponds, but the system was overwhelmed by the volume of water flowing through. This led to overbank flow from the Creek and other city streams and contributed to widespread flooding in the city (Buttle and Lafleur, 2007).

Other areas of the county were also affected. The emergency response was designed to include both the city and county. Rural residents had similar exposures and outcomes as the urban residents, with additional concerns about well water contamination and the flooding of decentralized sewage systems. The Ontario Disaster Relief Assistance Program (ODRAP) program does not cover well and septic system remediation.

Health Outcomes

This section summarizes the potential health outcomes associated with the flood event at the household, community and watershed scales.

Households

There were no mortalities as a result of the flood. As indicated in the City of Peterborough (2004) report, there was some morbidity directly associated with it. Twenty-eight medical calls were performed by the fire service and there were 28 motor vehicle accidents. One person was trapped in an elevator. It is not clear, however, how much these isolated numbers differ from the fire service's regular workload.

Pink eye that may have been associated with exposure to contaminated water was reported, as was trouble breathing due to exposure to mould.

The public health unit engaged local physicians in a system to track diarrhea, vomiting, abdominal cramps, nausea, fever, cough, headache, dizziness, and other symptoms that may have been related to sewage, mould or odour. Information about the number of cases reported and the pathogens identified from the stool samples collected was not available, although anecdotal evidence suggests that no outbreaks were reported.

Community

Many residents were forced from their homes and required emergency shelter and food. Over 10,000 meals were provided by the Salvation Army.

Food and water security was a concern for those remaining in their homes. They were provided with "shower, meal and grocery supplies" (City of Peterborough, 2004, p.7).

Several city facilities were also flooded, including the ground floor of the Social Service Department, the Children's Services and Administration Office and the local library.

A Volunteer Command Centre was created to organize and manage 503 volunteers from 37 agencies over 12 days. The agencies included 30 Fire Departments, Mennonite Disaster Services, Buddhist Monk Organization, 2 Community Colleges, Amateur Radio Emergency Services, Auxiliary Coast Guard, and Ontario Volunteer Emergency Response Team. Other volunteers also came forward and needed to be managed.

Neighbour-to-neighbour assistance is also mentioned. The health outcomes associated with this could be increased autonomy and self-efficacy.

There are clear indications of adverse mental health outcomes associated with the flood, even several months afterward. This is apparent in references to the highly contested nature of the public consultations following the flood event. In interviews conducted with key informants from the Peterborough area, Oulahen and Doberstein (2007) note how "feelings of loss, pain, and sadness quickly turned to anger and frustration" (p.6). They cite interviewees using language such as "unhappy populations", an "adversarial, and at times hostile, atmosphere" and "heated, adversarial dialogue" with city officials at public meetings.

A lack of familiarity with basic hydrological principles and terminology also led to frustration. In particular, the idea of a design storm proved challenging for the population at large – particularly in a city that had experienced two "hundred year storms" in two years. Additional time and resources were required to address this issue, as the confusion it generated threatened to undermine the public's confidence in the post-flood planning and consultation process (Oulahen and Doberstein, 2007).

Vulnerable Populations

The Public Information lines played a critical role in identifying vulnerable populations, including those with mental health concerns, as well as the mobility impaired and the elderly.

The staff dealing with the public hotlines fielded calls from "many seriously distressed callers who required expert psychological and emotional support" (City of Peterborough, 2004, p. 3). Some vulnerable populations were unable to take advantage of the shelter system. For example, one client "did not want to go to Evacuation Centre, he said he had a bi-polar, anti-social disorder, and claustrophobic and did not want to go to it" (Flood Referrals document).

Where tenant/landlord relations were already stressed, some landlords attempted to use the flood as an opportunity to evict those tenants permanently. In addition, once in the emergency shelters it was difficult to persuade some residents to make other plans or to accept the subsidized housing that was available. This was eventually solved by instituting a firm deadline to shut down the emergency shelters.

Accessing the support that was available required filling out several different forms, and sharing information between health services and volunteer agencies proved difficult, primarily due to concerns over privacy.

Children are another vulnerable population. The city's day care centres offered emergency day care to the public and assisted in the remediation and reopening of other day care facilities in the City.

Early on in the emergency, the collapse of the roof of a local long-term care facility highlighted the vulnerability of infirm and elderly populations to disasters. Over 170 people were evacuated from the facility over five hours.

Organizational Learning

There is clear evidence of an institutional commitment to learning from the flood, in the form of a formal debriefing by Emergency Services and by public health. Within a month of the end of the emergency, the City hired a private consulting firm to review the flood response and to develop a Flood Reduction Master Plan. The study was primarily an engineering study, but it was also structured to support citizen participation and stakeholder engagement from the outset, and the first community meetings were held within two months of the flood event. The process was given over to a third-party, non-local consulting firm in order to preclude any impression that it was a political process. Indeed, the involvement of politicians was highly managed (Oulahen and Doberstein, 2007).

Watershed

Organizational Learning

The City of Peterborough instituted a new Flood Reduction Master Plan in 2007 to improve the ability of the local infrastructure to cope with such an extreme precipitation event. Three watershed environmental assessments were conducted and list of future capital projects approved. The key causes of flood damage were found to be: "unprecedented heavy rainfall; insufficient storm sewer capacity; poorly defined overland flow routes; and rainwater entering the sanitary sewer system" (UMA, 2005 as cited in Oulahen and Doberstien, 2007 p.6). Downspout disconnections, backflow preventers and increased pipe sizes are some of the measures proposed better prepare for future flood events.

Actions

This section summarizes the preventive and reactive actions taken at the household, community and watershed scales to address the flood risk.

Preventive

Preventive actions are those taken prior to a flood event to reduce the potentially negative, and enhance the potentially positive, consequences of the flood event.

Households

It is not clear what measures were taken at the household level to prevent or mitigate the impact of floodwaters on their property, particularly following the 2002 flood event. There was limited overlap between the areas affected in 2002 as compared to the 2004 flood. Not living in a flood prone area (flood plain or flood fringe) is the main preventive measure available to residents. Overland flow insurance is not available in Canada, and flooding caused by infrastructure can occur in a wide variety of locations without warning.

Community

It is not clear what measures were taken by the city to respond to the 2002 flood. Oulahen and Doberstein (2007), however, note a widespread feeling on the part of the general public that "the City had not taken strong enough action to mitigate the flood hazard, despite the flood damages experienced just two years earlier" (p.6).

Watershed

On the larger watershed scale, water monitoring and flood forecasting are on-going features of ORCA's programming. A synthesis of all of the Conservation Authority's flood prevention programs is beyond the scope of this review.

Remedial

Remedial actions are those taken during or after the flood event, to either reduce the negative outcomes or enhance the positive ones.

Household

The focus of remedial measures at the household level including either hiring private companies to rehabilitate properties or for the affected residents and/or landlords to undertake the work themselves. Assistance in pumping out flooded basements and properties was provided by emergency services personnel. Information was provided about best practices in cleaning up after the flood, including ways to kill off mould (chemicals, dehumidifiers) and the use of plastic tarps over dirt flooring to reduce indoor humidity. Information was also provided regarding how to deal with flood-affected food and electrical equipment.

Community

An extensive array of post-flood actions is apparent.

Public Information Lines were activated approximately one hour after the Emergency Operations Centre was operational. The lines received over 13,000 calls between July 15 and August 3. New databases were required to compile and/or monitor the dynamic situation, including one to track call inquiries, as well as one to keep abreast of the services provided to the public. The lines were transitioned to ODRAP information lines after August 3rd and still were receiving hundreds of calls.

Counseling services were set up at the Evacuation and Public Inquiry Centres and referrals were made to both the Ontario Mental Health Association and the Mennonite Disaster Services group. The Primary Command Centre at the Peterborough police station was flooded, and the downtown unreachable during the disaster. A secondary site had to be established. There are now multiple sites, each equipped with the required technology to act as command centres during a disaster.

Information was provided to the public and the information line technicians about mould. There was enough concern about the potential health effects of mould that it gained the attention of local councilors who wanted to bring in external specialists and/or institute new processes to respond to public concern. After some consultation, this was deemed unnecessary.

Prior to the flood, mould was not considered a public health issue of particular concern in the area. A broad definition was used to frame concerns about mould during the flood, and the local public health agency continued to receive thousands of calls a year about mould for several years after the flood.

Information was also provided about how to clean up after the flood, and what to do about food and water.

Local physicians (and nurse practitioners) were asked to pay particular attention to outbreaks of gastrointestinal illness that may have been associated with the flood, and in particular with contact with sewage or contaminated water. They were requested to ask for stool samples from affected individuals and to report any clusters to the local public health agency. In institutional settings, such as the evacuation centres, ill individuals were isolated[10] to decrease the threat to other residents.

Social workers were the primary staff available to help with the disasters. These staff were also case workers trying to help their vulnerable clients cope with the flood and its aftermath. There was a great deal of strain put on these front line workers during the disaster. Changes have since been made to that system, and multiple people have been trained to take over specific roles during an emergency.

Public health routinely addressed a number of specific concerns, grouped as: tenants whose landlords were not proactively cleaning up after the flood; children with access to sewage; adults and/or children complaining of illness; large amounts of mould not being cleaned up; structural concerns or violations of property standards; and commercial premises. Each of these had a specific set of actions outlined to address the concern.

Volunteers from a variety of agencies (see above) were involved in pumping basements, cleaning out houses and helping to clear city streets. Follow-up by some groups, in particular the Mennonite Disaster Services group, lasted for up to six months after the flood. It focused on helping high-need residents rebuild their homes (drywalling, etc.).

Emergency shelters were opened in several locations. These housed people affected by the flood and volunteers.

Garbage disposal services were ramped up (up to 80 garbage trucks/day), and service fees were negotiated (reduced or dropped) for services such as gas and electrical inspections.

Regular information and updates were provided about road conditions.

[10] In this case, isolation meant: clients would be located in a room near entrances to minimize casual contact with other clients in facility; meals would be provided in room; and clients were not to use common facilities with other residents.

Over 4,000 household cleaning kits and 500+ personal care kits were distributed to the community.

Building codes were changed related to the on-site water storage capacity of land (downspout disconnection, etc.) in order to require new developments to not contribute additional discharge into the city system.

ODRAP puts the onus on the affected individual and municipalities to bear the initial responsibility for their losses. If the losses are such that the individuals cannot cope on their own, the municipality and the community at large are expected to provide support. This includes through municipal fundraising (see section on community below). Once municipalities raise the funds, ODRAP covers up to 90 per cent of claims (as with all disaster relief programs across the country, there is a type of deductible that a resident has to pay) and offers a 2-to-1 ratio for every dollar raised by the community. This system has the benefit of potentially covering more of the cost of the disaster for affected individuals, as benefits tend to be capped in provinces using other systems of reimbursement. A wide range of fundraising activities were undertaken in Peterborough city and county.

Vulnerable Populations

A critical vulnerable population affected by this flood event was the elderly. A particularly dramatic example of the effect of the flood on this population was the need for an emergency evacuation of a long-term care facility where the rain caused the roof to collapse. In total, 171 long-term care residents were evacuated.

During the recovery phase, the primary mechanism for identifying vulnerable populations was through the ODRAP application process. The needs assessments completed as part of the application (both for immediate assistance and other assistance) helped flag vulnerable households for follow up. The ODRAP program, with the help of provincial ministry staff who temporarily relocated to Peterborough from Kingston, was up and running within a day of the declaration of emergency.

The Red Cross home assessment program provided over 600 home visits. These visits provided additional support for vulnerable populations (including the elderly and those on Ontario Works and the Ontario Disability Service Plan) and assisted them with cleaning up after the flood.

Housing proved to be a particularly contentious issue. The lowest income populations tend to also live in basement apartments, which charge the lowest rents. There were a number of reports of complaints to public health about delays caused by landlords. In some cases special measures (such as Orders under Section 13 of the Health Protection and Promotion Act) were required to gain the full cooperation of landlords in the remediation efforts.

The need to address the needs of low income communities and housing was illustrated by a number of measures, for example: discretionary benefits were expanded to Ontario Disability Service Program/Ontario Works clients who required a change in lodging as a result of the flood. An intensive housing retention program was run and an ODRAP Extreme Financial Hardship Committee was created (City of Peterborough, 2004).

Over the past ten years, a number of actions have been taken by the City of Peterborough to update their emergency management operations following the 2004 flood. A report of the full suite of actions is beyond the scope of this paper, but they include the formation of a specific planning group for vulnerable sectors in emergency response and planning, as well as revamped systems and technologies for locating and staffing emergency operations and reception/evacuation centres.

WATERSHED

Within a month of the July 2004 flood, the City of Peterborough instituted a process to develop a new Flood Reduction Master Plan to improve the ability of the local infrastructure to cope with such an extreme precipitation event. The specific measures taken by the Conservation Authority to respond to the flood are beyond the scope of this study.

Sewage was by-passed directly into the Otonabee River, as it is the normal practice following a severe rain event. The sewage flow rates remained elevated for more than a month after the flood. Communities downstream complained of impacts on water quality and their businesses and advocated strongly for upgrades to the sewage treatment plants capacity. The City applied for funding and the plant is in the process of increasing its capacity.

Case Example 2. Snowmelt Runoff: 2013 Minden, Ontario Flood

Context

The 2013 Gull River flood is an example of a spring snowmelt runoff flood that was exacerbated by a rainfall event. The flooding occurred between April 18th and May 15th in the Gull River sub-watershed, which includes the Township of Minden Hills and the Haliburton Lakes. The Gull River is a 'controlled' or managed watershed, which is part of the Trent-Severn Waterway. Unlike the majority of watersheds in Southern Ontario, it is not under the management or jurisdiction of a Conservation Authority, but is managed by a combination of provincial and federal interests: namely the Ministry of Natural Resources and Parks Canada. Parks Canada manages the water reserves for the Trent-Severn Waterway year-round on a system-wide basis. The flood warning was issued by the Ministry of Natural Resources.

Flood plain mapping of the Gull River was completed in 1988 under the Canada-Ontario Flood Damage Protection Program and was based on the Timmins (1961) design storm. A two-zone flood management approach was recommended for adoption by the township of Minden at that time. It was meant to allow for increased flexibility in the development of the floodplain by differentiating between the floodway (where flood depths and/or velocities are predicted to pose a threat to life and/or property), and the flood fringe, where the impacts of major flood are expected to be less severe. In fact, the township of Minden did not implement this two-zone concept and recognized only the floodway (EcoVue Consulting, n/d).

The flood event was dramatic. According to Devolin (2013), on April 17th, 2013 conditions in the watershed were relatively normal with a lighter than average snowpack. On April 18 and 19th, however, the largest 48 hour rain event in more than 50 years occurred. The combination of the rain and snowmelt flowing over frozen ground added the equivalent of 84 to 115 mm of water to the April rainfalls and doubled the water input into the reservoir lakes. There was little to no warning that such a flood was imminent.

On the technical side, the management of the flood was considered adequate. A third party review (AECOM, 2013) conducted after the event concluded that the management actions did not contribute to the flooding in Minden, and that the actions taken to hold back water in the upstream lakes on April 25th prevented further flooding in the town (mykawartha.com, 2013). Nonetheless, poor communication in the watershed was a critical issue during the flood and the source of much tension, frustration and misinformation. The third party review found that the “communication channels between dam owners/operators and levels of government are not clearly defined by law” and that there was a need to improve provincial and municipal coordination and communication, particularly when public safety is at risk (Devolin, 2013). The fact that a third party review was conducted speaks to the level of local concern about the communication with the community during the flood.

According to a local news report (Criger, 2013), the local MP Barry Devolin estimated that in the township of Minden, six to ten businesses and 100 houses were damaged, 20 to 30 of them severely. The majority were in the municipality of Minden Hills, which has a population of approximately 2,000 people.

Exposures

Residents of the community of Minden were exposed to a wide variety of potential health hazards, as summarized in the sections below:

Household

At the household level, during and immediately after the flood event residents were exposed to elements that could affect their **physical health**:

- structural integrity of homes. These required building inspections before people were allowed back in and prevented public health inspectors from entering properties, post-flood;
- contaminated piped drinking water and well water. This was a critical concern for public health not only for potential contamination by pathogens, but also the potential for chemical contamination from gasoline, diesel, pesticides and other chemicals if they were stored nearby;
- flooded on-site sewage systems. These were compromised by the flood waters and required special attention to be ready to use again following the flood;
- foodborne illness. The safe disposal of food was a key concern not only to avoid direct contamination, but also to minimize odour and to avoid attracting wildlife (raccoons, bears, wolves, coyotes, etc.) if left outside. There was particular concern about wildlife scavengers and rabies;
- electrical damage to most major appliances requiring either professional refurbishment or replacement. The concern was for electrocution and/or fire;

- flood waters, particularly contaminated water and downstream community exposure to municipal sewer releases (standard procedure after a large rain event);
- stagnant water in and around homes. This lasted for several weeks;
- debris;
- post-flood mould; and,
- lack of shelter, food, water and clothing;

In the months after the flood event, they were exposed to elements that could affect their **mental health**:

- stress and anxiety related to the flooding of their home and/or the loss of their possessions. This was particularly strong due to the length many homes were underwater (up to three weeks) and the long delays in allowing people to return to their flooded properties to inspect the damage;
- stress and anxiety related to financial pressures and the slow pace of disaster relief funding (for example, as of July 26 2013 - five weeks after the flood - the 1,000 CAD advance funding had not been released to residents (Mortillaro, 2013)); and,
- stress and anxiety related to the permanent loss of homes (150 families) due to the loss of flood insurance coverage (Maplelakeontario.com, 2013).

While no data were collected pertaining to the mental health effects of the disaster, the anger and frustration of residents was apparent during face-to-face visits from public health professionals and emergency personnel, and it was evident during the two town hall meetings held to provide information to residents about the flood and its aftermath.

These stresses affect populations differently, and vulnerable populations can be identified. Quotes from news articles after the event (Mortillaro, 2013) point to the frustration and tension some residents experienced:

- “The Ontario Disaster Relief Assistance Program or, as I call it the Ontario Disaster Relief Aggravation Program, is really an onerous, time-consuming, emotionally-draining expectation that people who have had a disaster like this,” said Gall. “You’re not covered by insurance; the province is not obligated to come in and assist,” she said. “I don’t wish this on anybody”

- For [Ms.] Peter, who suffers from a brain injury and lives on her own, it's an arduous task. "What do I know about that? I don't know one guy who can assess me," she said.

Others are on record as reporting significantly less tension - notably those empowered by the community to deal with the flood:

- Minden Hills Reeve Barb Reid said that she doesn't have a problem with Ontario's methods, specifically if there's a maximum each household can claim in other provinces. "I'd rather have the community fundraise and know that I might be able to get $50,000 to pay for the damage for my house," Reid said. "We stand to get 2 for 1, if we do a good job. So rather than bellyache and moan about the system and whether it's fair or unfair, we all just said 'It is what it is, let's make it work to our advantage.'"

- Robert Smith, Project Manager for the City of Kawartha Lakes Disaster Relief Committee, said he hasn't heard any complaints from residents. "There is a process to go through, and the process has to be followed," said Smith. "I haven't heard a great deal of negativity." When asked what will happen to residents if not enough money is raised, Smith said, "Then they're out of luck. That is the bottom line."

Community

At the community level, exposures during and immediately after the flood event focused on **public health and emergency services** and included:

- lack of shelter, clothing, food, water, etc.;
- flood water and standing water;
- by-passing of the local sewage treatment plant released sewage downstream for two weeks during the flood;
- debris in public spaces;
- unsafe road and bridge conditions. Many roads were closed and the main bridge in Minden required an engineering assessment before it could be reopened;
- well-water contamination; and
- water damaged electrical equipment;

Following the flood event, critical exposures affected populations differently and were related to **mental health:**

- stress and anxiety related to access to services (including funding);
- community-building events to raise funds; and

- neighbour-to-neighbour assistance.

The lack of incorporation of the two-zone flood management concept into Minden's official plan may have exacerbated the stress and anxiety caused by the 2013 flood. As EcoVue Consulting (n/d) note:

> The [current Official Plan for Minden] precludes development within the floodway of the Gull River, as identified on Schedule "C" to the Plan. Regrettably, the Official Plan does not include any policies for the use of lands within the balance of the floodplain (flood fringe). Schedule "C" does not identify the flood fringe areas within the floodplain. As a result, current residents and business owners within the flood fringe may not have been aware of the flood susceptibility of their properties, prior to April of 2013. When the Gull River overtopped its banks, there was shock and dismay at the destruction caused by the flood waters. Yet it should not have come as a surprise. The furthest extent of the 2013 floodwaters is very similar to the area identified on the FDRP Public Information Flood Risk Map. Minden's experience demonstrates that all lands within a floodplain are susceptible to flooding from a regional storm event – and local Official Plan policies should reflect this reality.

The report also notes some challenges to local by-laws and their potential impacts:

> The failure to identify the full extent of the flood plain leads landowners and others to believe that the extent of flooding is much less than is actually the case. That is until, the river rises.

Of particular relevance to this study, the report concludes that:

> Flooding is an unpredictable, natural event, much like tornados, grass fires and earthquakes. There is a general agreement that climate change is resulting in more storms and in increased severity of storms. Problems arise when development is permitted to continue in areas which are vulnerable to flooding.
>
> Properties within the floodplain of the Gull River and in other communities across the Province must expect that flooding will continue to occur, perhaps more often than it has in the past. Yet, it appears that few residents of flood prone areas understand the potential for damage to their homes and properties from future flood events. In the case of Minden, Members of Council, municipal staff, and local residents had little or no understanding of the extent of potential flooding in Minden prior to the 2013 flood. They were not able to rely on their Official Plan and Zoning By-law to identify this risk.
>
> By introducing flood plain policies and regulations for flood prone areas, municipalities can begin to reduce the risk to persons and property from future flood events.

Watershed

At the regional watershed scale exposures during the flood event included those related to upstream/downstream **public health and safety** and included:

- exposure to flood waters upstream and downstream; and
- flooding of septic systems and wells, release of untreated municipal sewage.

In order to prevent sewage flooding of local properties and basements, a "complete by-pass of the facility including sewage pumping station #1, treatment plant and tertiary filter was carried out from Apr 22 – May 6th, 2013 due to severe flooding of the Gull River which caused a State of Emergency within the Township of Minden Hills" (Ontario Clean Water Agency, 2013, p.4).

It appears that the lack of public understanding of the watershed context for the flood management decision-making exacerbated community stress. Those affected were primarily focused on their own properties and were either not provided enough information to be able to look at the big picture of the watershed or were not willing to do so. There was a great deal of outrage over management decisions that seemed to be keeping individual homes and properties underwater longer than they might have been.

There was also a feeling of alienation in the small and more remote areas of the watershed upstream of Minden which were equally affected but where it was felt that Minden was receiving all of the attention and support and the rural residents were left to fend for themselves.

Health Outcomes

This section summarizes health outcomes as they related to the household, community and watershed scales.

Household

No lives were lost directly due to the flood event. Any indirect mortality is unknown. No evidence of morbidity was uncovered, although this is likely due to a lack of data for this report than a complete lack of disease or injury. No specific information was found related to the presence of mould or its health effects although it is known that the flooded homes were affected by mould. Local physicians would be aware if there were health concerns, but these data are not reportable.

The mental health outcomes associated with the flood are anecdotal, as indicated above, and may not be representative of the community. No specific information was available regarding mental health morbidity related to the flood event.

Many of those affected were cottagers, not full time residents of the community. This prevented some potential adverse outcomes, such as a widespread need for emergency shelter. Such a shelter was available at the Minden Library, but was not widely used. Most people were able to stay with friends, family or in their primary home.

Community

There were no mortalities as a result of the flood. No information was found that indicted any outbreak of food, water or vector borne disease related to the flood events. Regular surveillance systems did not change during or after the flood event.

Social Capital

By all accounts, the community of Minden was able to rally itself to effectively fundraise for disaster relief, and a wide cross-section of the community and region were engaged. The community needed to raise 1.3 million CAD and it appears to have met that target although it was not enough to cover all the costs associated with the flood. On-line donation systems were established (www.mindenhills.ca and pinestone-resort.com), as was a CIBC bank account for the funds raised; golf tournaments, barbeques, concerts, and raffles were held (maplelakeonterio.com, 2013). The Minden Food Bank put out a call early on for immediate health for those displaced by the flood, including a request for toiletries.

Neighbour-to-neighbour assistance provided critical support during and after the flood event and likely contributed to trust building.

Social media was quickly harnessed by Minden residents, including a Pinterest page dedicated to capturing pictures of the 2013 flood. Some of the initiatives undertaken seem to have created lasting value. For example, the Minden Flood Centre created a Facebook forum[11] on April 24 2013 to help provide information to the community about the flood and about measures being taken to recover from the flood. It is "dedicated to helping connect the community when there is a danger of flooding" and continues to provide this service to the community.

Nonetheless, any community-level gains in social capital appear to have been short-lived, in part perhaps due to the high turnover and large seasonal population in the area.

Vulnerable Populations

Vulnerable populations self-identified as needing assistance through use of a telephone hotline. This included the elderly and those in lower socio-economic

[11] www.facebook.com/MindenFloodCentre

groups. Volunteer assistance was provided by a small number of community NGOs, including the Red Cross and a Mennonite group. The number of volunteer organizations engaged was deliberately kept small in order to make coordinating the volunteers manageable for the emergency organizers.

Organizational Learning

In addition to the third party review of the flood management system, other debriefing meetings were held, for example, by the emergency operations group to discuss the management of the flood and how it might be improved in the future.

Watershed

There are no data related to health outcomes at the watershed scale, but there are anecdotal reports of stress both upstream and downstream of the flood related to the perceived difference in support being provided and the perceived increase in the duration of the flood due to management decisions.

Actions

This section summarizes the preventive and reactive actions taken at the household, community and watershed scales to address the flood risk.

Preventive

Preventive actions are those taken prior to a flood event to reduce the potentially negative, and enhance the potentially positive, consequences of the flood event.

Household

As a result of the Minden flood, up to 150 households were reported to have lost their insurance and thus their homes/cottages.

Community

Minden Hills has a Pre-Flood Plan and template meant to help guide action during a flood event. It is rather generic, however, and includes a number of empty spreadsheets. Parks Canada conducts year-round monitoring of the Trent-Severn Waterway and drainage area to help predict and manage flood events. Public health does not have many policies related to prevention, aside from helping to provide as much warning as possible of an impending or potential flood event.

Sandbagging was used to protect property - for example by the volunteer firefighters. Over 15,000 sandbags were used to protect homes and businesses (Watt, 2013).

Halliburton County provided, among other information, bulletins related to electrical safety and water damaged electrical equipment as well as boil water advisories.

The General Public was proactive in harnessing social media (i.e. Pinterest, Facebook) to help communicate and coordinate action in the affected areas.

The level of awareness of the flood plain in Minden and how it is integrated into municipal plans requires additional investigation. In the document 'planning lessons learned for Minden', EcoVue Consulting (n/d) note that major floods of the Gull River are a fairly regular occurrence, and were documented in 1913, 1928, 1929, 1943, 1950 and 1983.

Watershed

No information about upstream mortality or morbidity associated with the flood was found.

Dam management, flood forecasting and water monitoring are on-going processes. Within the watershed there were issues related to community well-being, such as the tension between upstream and downstream communities experience when water was held back to protect the township of Minden,

There is the potential for enhanced community information regarding flood zones, the on-line provision of flood maps and the potential to require disclosure of flood risk by real estate agents are examples.

Remedial

Remedial actions are those taken during or after the flood event, to either reduce the negative outcomes or enhance the positive ones.

Household

Households with insurance hired private companies to help clean up the mess left by the floods. Some people permanently lost their houses/cottages due to the loss of insurance. The severely damaged homes required new construction.

Community

Remedial actions by the community included a State of Emergency Declaration by the Township of Minden Hills.

Proactive measures by public health included prioritizing the collection and disposal of food waste to prevent food poisoning and having rotting garbage attract wildlife into the area. They also prioritized the collection and analysis of water samples. A community drop-off centre was established at the Minden

Library to make it convenient for the community to get their water tested before they began to use it again.

Door-to-door evacuations were undertaken and neighbours assisted each other throughout the event. Emergency shelter was provided in the Minden Library. Some local businesses assisted with the provision of low cost-housing by local motels (i.e. Nobel Motel at Moore Falls offered rooms for 50 CAD/night + tax).

All available inspectors were dispatched during the recovery phase to conduct on site visits to affected businesses and residential properties that registered with the Minden Township as being flooded. Township's Recovery Coordinator provided a list of flooded roads and flood affected 911 addresses that were used to strategically identify areas to visit. PHI's brought with them information packages and water sample bottles to provide to the homeowners.

Road and bridges were closed and inspections undertaken to ensure safety before reopening them.

Boil water advisories were issued for the affected communities and information was provided about septic tank flooding.

Emergency funding was provided by the Ontario Disaster Remediation Assistance Program, but it took several months to arrive.

The community undertook extensive fundraising to help with remediation efforts.

WATERSHED

Assistance was provided by nearby towns and communities - including county staff, EMS, OPP, fire services from the surrounding communities (Algonquin Highlands and Dysart);.

A remedial step following the flood was the third party review of the flood control operation. This review stemmed from a perceived lack of communication and coordination of management options and decisions during the flood event. Additional concerns have since been raised about the delineation of the floodplain in Minden.

It is not clear if any changes to management operations were made as a result of the flood event in the watershed.

There is a difference between the amount of information available to communities, such as Kawartha Lakes, that are managed by a Conservation Authority, as compared to ones that are not. The amount of information provided by the Conservation Authorities seems to have improved dramatically in the last few years. Where there is a local CA representative, he/she sits in on emergency organizing committee meetings, and provides information about flood forecasting and whether or not protective measures, such as sandbagging, should be undertaken. This information improves public health’s messaging to the community regarding flood advisories and warnings.

There is a need to invest in community-wide flood messaging, both on-line and off-line for the elderly and low income populations who may not have regular access to a computer.

Case Example 3. Snowmelt Runoff & Fluvial: 2011 Wawanesa, Manitoba Floods

Context

In 2010, above average precipitation in Saskatchewan and western Manitoba saturated the soil prior to the winter freeze and contributed to a 1:300 year flood in the Assiniboine basin, and affected communities in Manitoba and North Dakota. This flood differs from the other cases in the amount of warning that the communities received. The first 2011 flood forecast for the province of Manitoba was issued (one month early) on January 24th. Floods were forecasted for the both Red and Assiniboine basins, although in the end the former was not as badly affected, likely due to extensive existing flood control infrastructure. The flooding in the Assiniboine basin set new records throughout the area and caused months of disruption. It is referred to in the literature as an "epic" flood:

> … resulting in more acreage under water than ever recorded. Flood talk was continuous and exhausting, lasting from October 2010 when a weather bomb soaked the southern Prairies through to late July when the military on flood patrol finally went home. Known as the flood that would never end and the spring flood that became the summer flood, it featured the highest water levels and flows in modern history across parts of Manitoba and Saskatchewan. Statistically, the flooding on the Assiniboine River in 2011 was estimated to be at levels experienced once in 330 years. And on Lake Manitoba, engineers called the flood a one-in-2,000-year event. Governments at all levels spent close to $1 billion on flood fighting and victim compensation.
>
> … On May 9, the Manitoba government declared a province-wide state of emergency, issuing evacuation notices for several municipalities along the Assiniboine River. Brandon was at the epicentre of the months-long flood battle. There, the Assiniboine reached its highest level since 1923 and kept rising. The River was nearly seven metres higher than normal and 20 to 30 times wider in some places. Flooding on the Assiniboine near Brandon lasted 120 days and was the largest on record. The fight against the flood waters along the Assiniboine involved thousands of residents, 1,800 members of the Canadian Forces, emergency measures officials and volunteers, including inmates from a local jail (Environment Canada, 2013).

The village of Wawanesa (population 300) is located approximately 50 km southeast of Brandon. The village last experienced a major flood in 1976, which caused extensive damage to low-lying areas (Village of Wawanesa, 2014).

The 2011 flood was in fact comprised of three distinct floods, the first – a snowmelt runoff flood - peaked in April and required the construction of a temporary dyke and evacuation of the Wawanesa Health Centre. The second – a fluvial flood – peaked in June. The third and largest flood peaked on July 7 and required the emergency construction of a permanent clay and sandbag dyke to protect the west side of the village of Wawanesa (Owen, 2011). All three floods were major flood events:

> All three peaks were higher than every other flood since 1913 except 1976. (West Souris Conservation District, 2011).

For public health officials in Manitoba, the floods created an exhausting and seemingly endless cycle of "prepare, respond, repair, repatriate, prepare again, start- stop, respond and repatriate" (key informant).

Exposures

Residents of the community of Wawanesa were exposed to a wide variety of potential health hazards, as summarized in the sections below:

Household

At the household level, during and immediately after the flood event residents of Wawanesa were exposed to elements that could affect their **physical health**:

- there was some basement flooding, although due to proactive interventions limited problems with mould post-flood;
- a Boil Water Order for Wawanesa was issued on June 29, 2011 and rescinded on August 16, 2011. This was for the 2nd rising of the Souris River. The community well was compromised by overland flooding.
- storm drainage was blocked off in the areas near the school, health centre and residential areas; some back flow issues were quickly caught.

In the months after the flood event, they were exposed to elements that could affect their **mental health**. In Manitoba, the four Psychosocial Flood Recovery Teams that were in place from January 2012 to January 2013 were able to provide the following insights into the longer term impacts of the flood on the psychosocial health of residents of the region. According to information provided by Manitoba Health, these included:

- the majority of people they interacted with presented emotional health concerns, such as anxiety, domestic disputes, difficulty sleeping, impacts due to loss of social networks, and addictions;

- one of the most challenging issues for evacuees (besides from the loss of homes, property and in some cases their community) focused on the issue of financial compensation (delays or lack thereof). This caused much stress and anger for folks;

- people require accurate and timely information when it comes to financial compensation, and navigating government systems posed challenges for people;

- the kinds of damages and losses experienced include: family homes, cottages, farmland and equipment, livestock, and in some cases, whole communities;

- older adults and those in lower income brackets suffered disproportionately from the flood;

- frustration, anger, disappointment, and exhaustion expressed by flood-impacted Manitobans are in part due to delayed compensation and inconsistent and untimely communication;

- it took time for some individuals to share their experiences with Psychosocial Flood Recovery Team members, given the frustration and confusion they have encountered with flood-related provincial government staff and programs;

- mould, well-water contamination, and poor road conditions continue to be a daily stressor in some areas; and

- damage to cemeteries, parks, beaches, and historic buildings and sites impacted community spirit.

COMMUNITY

The Wawanesa Health Centre was identified early on as a potential concern and advance plans were made for its evacuation if warranted. A March 25th flood risk spreadsheet noted that the 1996 flood came to facility doors and in 1976 the site was flooded. In preparation for the first flood (April 2011), super sand bags and a temporary dike were erected. It was felt that they should be sufficient to protect the facility, however in the end a planned, safe and orderly evacuation was conducted due to concerns over community access and the ability of the infrastructure to be maintained. The facility was evacuated again in anticipation of the July flood (Owen, 2011). There were two mandatory evacuations, the first lasted 5.5 weeks and the second three weeks, with six weeks in between.

The US Army Corps of Engineers (2012) reported that 35 properties received mandatory evacuation orders on June 27th. On July 12th, evacuated residents were allowed back into their homes. Property inspections and emergency social assistance assessments were conducted on a property-by-property basis.

Significant scouring of the banks of the Wawanesa Dam impacted the stability of the structure. This led to emergency repairs during (by helicopter) and after the flood (US Army Corps of Engineers, 2012).

Watershed

A critical issue in the Manitoba floods was the disruption of the transportation network due to extensive regional flooding. Access via roads and bridges were severely curtailed, at times requiring detours of a hundred kilometers or more. The lack of access due to flood waters was community and also site specific, for example affecting access to specific infrastructure and thus requiring many services to be relocated.

Since the flood, the bridge on Provincial Road 340 in Wawanesa has been permanently closed and likely to be removed. Since the flood, emergency response times have been permanently increased. For example, it can take up to 10 minutes longer when EMS is dispatched for a call as many of the casual based on-call EMS crew now have to drive an extra 7 or 8 KMs to get into town to the EMS station and then the ambulance depending on where it is headed has to take the same route out of town.

Vulnerable Populations

As indicated in preventive actions, below, vulnerable populations were proactively identified prior to the flood event using a client screening tool specifically for this purpose. The local school was closed in April 2011 due to extensive basement flooding (Martin, 2011) but classes were relocated.

Health Outcomes

This section summarizes health outcomes as they relate to the household, community and watershed scales.

Household

It is not clear what specific health outcomes at the household level can be attributed to the 2011 floods. It is known that response times for EMS and access to primary health care were both disrupted due to the flooding of regional roads.

Information about the psychosocial impacts of the 1997 Red River flood is available in Morris-Oswald (2006). It is likely that the findings would be similar if not more pronounced following the three flood events of 2011.

Community

The local water system was compromised by the high water levels, requiring a boil water order in the community. There did not appear to be any outbreaks of gastrointestinal or other illness associated with this order. It was noted that the water situation could pose a particular challenge for immunocompromised patients.

Social Capital

Staffing issues were among the major challenges facing the public health unit. Some staff objected to the demands being placed on them in terms of commuting time (due to flooded out roads) and the long days being required of them, particularly as the months went on. Staff were able to take leaves of absence and vacation days and other measures to opt out of working during this difficult time. For example, Allen (2011) noted that half of the displaced professional nursing staff chose to take leaves of absence at some point during the floods. This led to both an increased workload for the remaining staff and some resentment of the choices being made by peers in the community. These issues continued to play themselves out well after the flood ended.

Organizational Learning

The major agencies involved in the 2011 flood response all appear to have conducted debriefing exercises to take stock of their responses to the disaster and to identify areas for improvement. Ironically, the 2013 Alberta floods provided an additional opportunity for reflection as advice from Manitoban professionals was sought by Albertan health professionals as they worked to manage their own flood situation.

Watershed

The health outcomes at the watershed scale were considerable. At the height of the flood, 7100 people were evacuated, primarily from First Nations communities. As of 2013, some of the First Nations evacuees have not yet returned to their homes, as they remain uninhabitable (Manitoba 2011 Flood Task Force, 2013). A medical helicopter was transferred from Winnipeg to Brandon to assist with emergency first aid for the flooded communities.

Actions

This section summarizes the preventive and reactive actions taken at the household, community and watershed scales to address the flood risk.

Preventive

Preventive actions are those taken prior to a flood event to reduce the potentially negative, and enhance the potentially positive, consequences of the flood event.

Household

Some houses in rural areas sandbagged around their houses to keep the overland flow at bay. It is not clear if this action was taken by households in the Village of Wawanesa.

Community

Because of the unusually heavy rainfall in the fall of 2010 and the record levels of soil saturation in the Basin, the Assiniboine Regional Health Authority began planning for potential flooding early in the year. The ARHA held a Spring Flood Preparation Meeting in early February of 2011 to review the Corporate Incident Command System procedures and to discuss updates to the system, procedures and forms. On February 4, a site planning and risk review meeting was conducted with Wawanesa EMO, two Area Managers and facility department heads. Plans were made regarding the potential evacuation of hospital facilities as well as for home care patients (EMC Briefing Note, 2011). A trial run of evacuating the Wawanesa Health Centre was undertaken in 2010. During the floods, the 24 patients in the Centre were evacuated twice, on April 13th and June 27th. The length of time required for the evacuation of all personnel and necessary equipment was reduced from 2 hours, 25 minutes for the exercise to 90 minutes for the first evacuation and 45 minutes for the second, demonstrating the learning curve for these complex evacuations and the need for regular training exercises.

Plans for specific facilities and programs were developed, including for: acute care facilities, public health, mental health, disaster management, regional facilities, EMS, communication, incident command, human resources, the Wawanesa health centre, First Nation health and home care (Flood Preparedness Action Plan, 2011). At the registration and inquiry process in place at evacuation centres, evacuees were asked to sign a waiver stating that they were comfortable having their data shared between relevant agencies. This process helped facilitate tailored follow-up by different groups (such as the Red

Cross). Prior to the flood a detailed screening process was undertaken to identify clients at risk of being affected by the flood. This included, but was not limited to, whether or not they lived in the flood plain and what their coping skills were like.

Manitoba Health's mental health managers conducted regional risk assessments to identify vulnerable populations and provided a brief orientation to their staff on the topic of Psychological First Aid[12]. They were able to identify the hardest hit regions and prepare psychosocial flood recovery teams to assist communities with their post-flood recovery efforts. The province, through the Office of Disaster Management and Mental Health Branch, has established a Provincial Psychosocial Planning Table (PPPT) with a mandate:

> to coordinate among the key service providers, produce psycho-educational materials, advance training and workforce resiliency needs, and determine psychosocial needs in disaster … The PPPT met regularly in advance of the onset of flood for planning, preparation and recovery periods. Agenda topics included the development of psychosocial educational materials, including fact sheets, resource booklets, colouring books for children; discussion of workforce resiliency documents and resources; and development of appropriate training for front line staff. During the response phase, the table continued to meet to provide updates on activities and needs of individuals who were impacted by the flood.
>
> (excerpt from information provided by Manitoba Health).

Following the 2011 flood, the table met to debrief its experience and to adjourn operations until the next flood season. The province is also investing in improving the collaboration between government, NGO partners and volunteers though the Partners in Disaster Group.

WATERSHED

The Souris River is a sub-watershed of the larger Assiniboine River Basin. It is a transboundary watershed overseen by the International Joint Commission. There is a range of infrastructure in place within the watershed to control the

[12] Manitoba Health is currently developing a one-day PFA training course with the intention of providing such training throughout the health and disaster management communities in order to increase provincial capacity to manage emergencies and disasters.

water flow. The US Army Corps of Engineers (2012) report summarizes the major actions taken within the watershed and their effects on communities on both sides of the border (Saskatchewan, Manitoba and North Dakota). The upstream-downstream watershed tension is reflected at the international scale as well, for example, the report states (p.66):

> … it must be recognized that the Souris Basin Project primarily provides water supply benefits to Canada, while flood control is the primary benefit to the United States.… Canadian regulators have wide latitude to make flow release decisions from the Canadian dams to meet their objectives, but that do not always align with desired U.S. objectives … Certainly, more rigorous regulation schemes using index levels and system reservoir level balancing would likely produce better results for overall project flood control regulation, but there would need to be binational agreement to this concept.

Remedial

Remedial actions are those taken during or after the flood event, to either reduce the negative outcomes or enhance the positive ones.

Household

The extent of household flooding in Wawanesa is not clear, although it is assumed that if homes were flooded there would be a need for either private or personal remediation of the properties for water damage and mould.

Community

The regional psychosocial response teams were in operation for six months after the final flood event, helping residents cope with the aftermath of the flood. Government assistance was provided to some affected residents, although this process appears to have been rather cumbersome and stressful for those applying to it. For example, during the What We Heard consultations, the Manitoba 2011 Flood Review Task Force (2013) noted that:

> Seven out of the 10 people who responded to a Task Force survey question about the consistency of Disaster Financial Assistance information indicated that the information received since the flood was somewhat or very inconsistent. Other respondents, 80% indicated that it had taken several months for them to receive information or answers regarding claims or questions they had submitted, and 80% also rated their overall experience with DFA as poor or very poor. One municipal official who responded to the survey noted that:

> *"The forms to fill out for compensation are VERY comprehensive and time consuming. We had over 60 sites and I am still trying to work through the forms in order to get some compensation. Our bank account has been sitting at a $300,000 deficit for over a year now while we try to work through the claim forms."*

The Task Force report (2013) included a number of suggestions that were made by the public for how the Province could improve these programs, including "developing a "one stop shop" for before, during and after major events such as a flood, where different departments are brought together at a single site" (p. 15).

Other village services, such as garbage disposal, electricity and gas, appear to have been retained during the months of flooding, contributing to the resilience of the community post-flood.

WATERSHED

Several watershed-scale reviews, such as the one by the US Army Corps of Engineers (2012) were undertaken. Changes to the management of the Basin are beyond the scope of this case example, however. In Wawanesa, there is now a permanent dyke protecting the Village (and obstructing previously available views of the river).

Case Example 4. Fluvial/Snowmelt Runoff: High River, Alberta Flood 2013

Context

Three days of torrential rain preceded the catastrophic Southern Alberta floods that began in High River on June 19th. June is typically the wettest month of the year in the region, and is when the mountain snowmelt begins to reach the Prairies. In High River, one weather station recorded 325 mm of rain in less than 48 hours. Burns Creek (elevation 1400m) just west of High River, received a record 345 mm of rain in the same period. The intensity of the downpour was likened to a tropical storm.

The rain fell on saturated, frozen and snow-covered ground (with a higher than average snowpack), on the steep slopes of the eastern Rocky Mountains causing rapid flooding in the area's rivers. The Highwood River, flowing through High River, had a flood rate that was 10 times higher than its average for that time of year and included both precipitation and melted snowpack water.

As the Highwood River overflowed its banks, evacuations of high risk communities began and a State of Emergency was declared at 7:04 am on June 20th. Over 150 residents were evacuated from the rooftops of their homes. 350 Canadian Forces personnel and 80 RCMP officers assisted with the rescue efforts. Some residents were airlifted out. On June 20, all 13,000 residents were ordered to evacuate. The town remained off limits for a week after the flooding first hit.

Residents were directed to the town's website, Facebook and Twitter feeds for more information (High River, 2012d).

The estimated 1.7 billion CAD price tag for insurable losses following the 2013 Southern Alberta flood was "the largest disaster loss ever recorded in Western Canada" (Kovacs and Sandink, 2013, p. 3). The Town of High River was completely devastated by the flood. Despite all of the other things going on in the area, the seizure of guns during the initial flood response by the RCMP is one of the more significant controversies that is being played out locally.

Exposures

Residents of the community of High River were exposed to a wide variety of potential health hazards, as summarized in the sections below:

Household

At the household scale, during and immediately after the flood event residents were exposed to elements that could affect their **physical health**, such as:

- rooftop rescues of over 150 people;
- questionable structural integrity of homes and facilities,
- downed power lines;
- carbon monoxide exposure from using water pumps indoors;
- extensive amounts of household garbage and contaminated building materials, including rotten food and construction debris, and the associated concerns about wildlife populations;
- boil water orders and concern over E.coli contamination of water;
- foodborne illness;
- electrical damage to all appliances in affected homes;
- outdoor flood waters,
- debris;
- post-flood mould; and,
- lack of shelter, food, water, personal care products and clothing for the entire town of 13,000 people.

In the months after the flood event, the citizens of High River were also exposed to elements that could affect their **mental health**:

- stress from requiring rescue (i.e. from rooftops) and emergency evacuations of town, including hospitals and hospices;
- stress and anxiety related to the flooding of their home and/or the loss of their possessions;
- massive social upheaval and dislocation caused by the huge impact of the flood on the town;
- stress, depression and anxiety from living in temporary/emergency housing; and
- exacerbation of pre-existing mental health problems due to the stress of the flood on individuals and the community.

Community

At the community level, exposures during and immediately after the flood event focused on **public health and emergency services** and included:

- lack of shelter, clothing, food, water, etc.;
- fast-flowing flood water (at its peak, the speed of the Highwood River was flowing faster than that over Niagara Falls);
- standing water;
- reports of sexual assault and violence (at the Provincial level);
- by-passing of the local sewage treatment plant;
- floodwater and debris in public spaces;

- unsafe road and bridge conditions; and
- water damaged electrical equipment.

Following the flood event, critical exposures affected populations differently and were related to **mental health:**

- stress and anxiety related to access to services (including funding);
- massive population upheaval due to scale of the disaster;
- concerns about parents and children's well-being, particularly those in emergency housing;
- community-building events to raise funds;
- neighbour-to-neighbour assistance and fundraising.

The High River Hospital, hospice and two continuing care sites were evacuated during the flood, affecting more than 47 acute care and 75 long-term care residents (Alberta Health Services, 2013).

A boil water order in the communities of Hampton Hills and Sunrise was in place until July 19, 2013 (High River, 2012c).

Watershed

At the watershed level, the massive scale of the flood led to a myriad of exposures throughout Southern Alberta. This included mudslides and land subsidence. Locally, the residents of Hampton Hills (a planned neighbourhood within High River) felt that they had been 'sacrificed' in order to better de-water other neighbourhoods after the flood (Schneider and Kaufmann, 2013). Hampton Hills was turned into a kilometer wide lake by the flood and the homes were destroyed. The entire community was eventually bought out by the Alberta government to prevent rebuilding in that low-lying area.

Health Outcomes

Household

Three fatalities by drowning were reported in High River as a direct result of the flood (Canadian Press, 2013b). The following information about **physical and mental health** outcomes associated with the Southern Alberta floods was reported by Alberta Health Services and is primarily focused on Calgary emergency departments. It is difficult to know how similar or different the data for High River would be, although the hospitals treated Albertans from all the flood affected areas. Alberta Health Services (2013) monitored visits to Calgary emergency departments for 25 chief complaints following the southern Alberta floods. The list included:

"diarrhea, vomiting/nausea, redeye/discharge, eye pain, eye trauma, cardiac event, depression/suicidal, anxiety, situational crisis, laceration/puncture, localized swelling and redness, rash, sexual assault, violent behaviour, symptoms of stroke, lower extremity injury, hypertension, palpitation, tachypnea, shortness of breath, hives, allergic reaction, nasal congestion, cough congestion, and sore throat".

No statistically significant increases in visits were observed for chief complaints pertaining to gastrointestinal, respiratory, dermatological illnesses or depression/suicide.

During the first **two weeks** post-flood as compared to pre-flood, statistically significant increases in visits to Calgary emergency departments by **Albertans from flood affected areas** were observed for chief complaints related to injuries [localized swelling and redness (RR 1.57, 95%CI 1.16- 2.10) and lacerations/punctures (RR 1.37, 95%CI 1.04- 1.81)], situational crisis (RR 2.79, 95%CI 1.01- 7.66), cardiac events (RR 1.35, 95%CI 1.01- 1.80). The number of visits for all of these chief complaints returned to pre-flood levels following this time period.

During the first **month** post-flood as compared to pre-flood, statistically significant increases in visits to Calgary emergency departments by **Calgary municipality residents** were observed for chief complaints related to eye pain (RR 1.76, 95%CI 1.22- 2.53). The number of visits for this chief complaint returned to pre-flood levels following this time period.

Infectious disease was not considered an issue, although the monitoring in place was primarily syndromic and focused on the Emergency Departments, as indicated above, as well as Healthlink calls. Hospital emergency department visits were reported to have increased by 10% "for various kinds of wounds and abrasions, from stepping on a nail to being struck by falling debris". Tetanus vaccinations also increased by 10% (Lee, 2013, internet pagination). In addition, the Chief Medical Officer, Dr. James Talbot, was quoted as saying he had "seen a rise in hospital admissions for carbon monoxide poisoning, as some people have been using [pumps] indoors without proper ventilation" (Lee, 2013, internet pagination).

In terms of the mental health impacts, the province of Alberta recognized the on-going need for mental health programming. It stated that "The government understands that there is a link between a disaster like the flood experienced in June and an increase in mental health issues". They announced additional funding for mental health initiatives targeting: "enhanced-community based services, new programs targeted for Aboriginal populations, support to build mental health resilience in youth, and increased education and training for responders". The province has a Health Link hotline and a Mental Health Line available (High River, 2012).

Community

For months after the flood, the community of High River was frequently referred to as being "like a war zone" due to the magnitude of the devastation.

There was no information available to this study about health outcomes from the flood specific to High River.

Thousands of residents of High River were staying in emergency shelters following the flood. In order to begin to close them down, five months after the flood, the provincial government began to charge rent to those staying in temporary government accommodations (Canadian Press, 2013).

Watershed

Organizational Learning. Following the flood a consulting group was charged with developing a High River Emergency Management Plan (High River, 2012b).

Actions

This section summarizes the preventive and reactive actions taken at the household, community and watershed scales to address the flood risk.

Preventive

Preventive actions are those taken prior to a flood event to reduce the potentially negative, and enhance the potentially positive, consequences of the flood event.

Household

It is not clear what preventive measures were available to, or taken by, the residents of High River aside from not building in a flood zone. Overland flow insurance is not available in Canada.

Community

It is not clear what preventive measures were available to, or taken by, the community of High River.

Watershed

Alberta has missed an opportunity to take preventive action by relying on only 100-year design flood criteria to designate it protection zones. Other provinces use more stringent standards for protection beyond the floodway. British Columbia's standard is a 200-year storm, Saskatchewan uses a 500-year design storm and Manitoba protects Winnipeg from a 700-year storm (Kovacs and Sandink, 2013).

Remedial

Remedial actions are those taken during or after the flood event, to either reduce the negative outcomes or enhance the positive ones.

Household

Some households, such as those in Hampton Hills, permanently lost their homes as a result of the flood. Others had to rebuild entirely. Only 10% of those whose houses were severely affected by the flood chose to relocate to a new building site. In a controversial policy move, provincial funding was provided so that people without insurance could rebuild in the same location if they chose.

There was a combination of people hiring contractors to clean up after the flood and people doing the work themselves. The Government of Alberta put out an information booklet containing information about all of the measures necessary to be able to return safely to one's house after the flood.

Some home and business in Alberta were able to prove that sewer back-up occurred before overland flooding took place and received compensation for their losses.

Community

Mental health was a clear and early priority for the Government. A new Chief Mental Health Officer position was created at the Ministry of Health under the leadership of Dr. Michael Trew. The position was indented to "ensure that mental health priorities [were] being addressed to help those in affected communities who may be experiencing emotional or psychological distress" (High River, 2012e). As of 2014, the province had spent 25 million CAD on mental health support (White, 2014). A Government of Alberta online pamphlet, listed "warning signs" that reflect the experiences of others who have lived through a disaster:

- Having flashbacks to the event.
- Avoiding people or activities you usually enjoy.
- Using alcohol or drugs more (as cited in Henn et al., 2013).

A higher than normal number of clients in the "low to middle income category" were being received by the Peer Support Services for Abused Women program in Calgary as a result of the flood. They noticed that the financial toll it took on some families made it harder for abused women to leave their situations (White, 2014).

In High River, The Calgary Counselling Centre set up a satellite office in High River to provide services. The Parent Link Centre offered a disaster recovery Triple P Positive Parenting program targeting parents, children and youth (Henn et al., 2013). Another program provided children in temporary housing with colouring books developed by experts in mental-health recovery (Pearce, 2013). A number of other small projects were undertaken. For example, one program involved setting up a booth for residents to place Post-It notes "asking for advice, requesting items for the town, or simply expressing how they were feeling" (Lee, 2013). A year after the event, representatives from Family & Community Support Service, Alberta Health Services, the Red Cross and town officials went door-to-door to talk to residents and to see if they were receiving the emotional and financial support they needed. They underestimated the time that was required to allow each homeowner to express his or her concerns, and needed to extend the duration of the program to achieve its goals (White, 2014).

A lobby group in High River is now advocating for a case-worker based program that would help ensure that Disaster Relief funding is efficiently and effectively delivered to those who need it after a major disaster, such as the High River flood.

WATERSHED

In High River, a wide range of flood mitigation measures have been undertaken, including: installation of wall structures, installing drainage vaults and/or culverts, adding Geogrid structures that lay on top of dikes to provide erosion protection and facilitate vegetation growth, additional compaction and possible top layers, construction of pathways, general clean up, top soil and seeding where required, and additional erosion control measures, etc.

The flood mitigation measures have "the ultimate goal of the 2013 flood level plus freeboard[13] of approximately one metre for all permanent construction" (High River, 2012a - May 16 2014).

[13] Freeboard is the difference in elevation between the crest of an embankment and its reservoir water surface.

Appendix 3: U.K. Flood Leaflet

See attached file: UKflood_leaflet_2015_final

Based on the findings of this study, in addition to the kind of information provided in this booklet, a full page with an orientation to the local watershed, major flood types and pictures of well-known city intersections and other landmarks affected by previous flood events should be included in pre-flood information resources for the public.

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