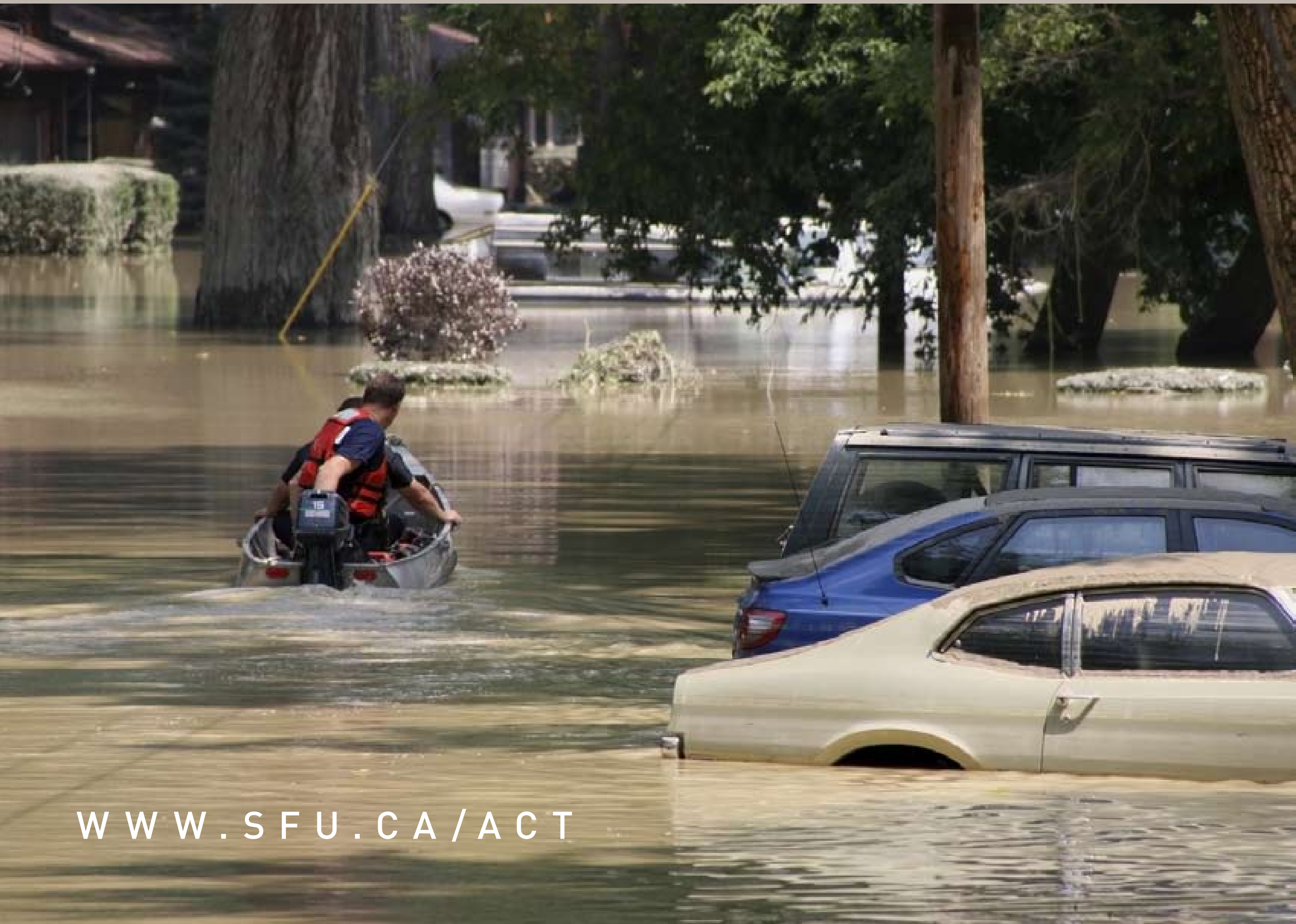
SIMON FRASER UNIVERSITY
THINKING OF THE WORLD

ACT

ADAPTATION TO CLIMATE CHANGE TEAM

BACKGROUND REPORT

CLIMATE CHANGE AND EXTREME WEATHER: DESIGNING ADAPTATION POLICY



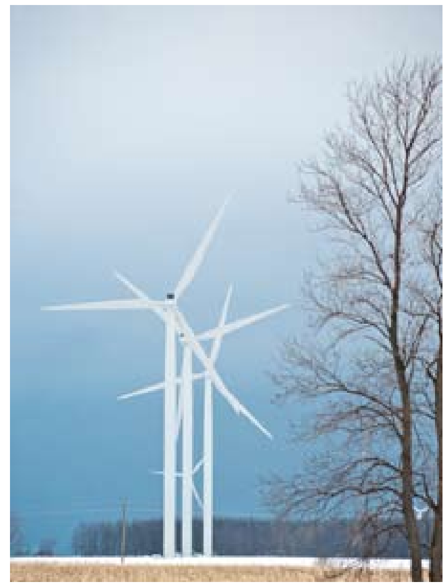
WWW.SFU.CA/ACT

PUBLICATION SPONSOR

AMEC is very pleased to support Simon Fraser University and the Adaptation to Climate Change Team to produce this comprehensive and important study.

AMEC operates in some of the world's most socially and environmentally sensitive and challenging industries and locations. Every day, our people and projects interact with a complex web of stakeholders and face highly demanding technical, commercial and environmental challenges.

We have the opportunity to live out our commitment to sustainability in several ways.



We support public and private sector initiatives like this report, aiming to improve sustainability performance in public and private sectors, and help bring to light new tools and approaches to help businesses and communities adapt to changing realities.

We govern our own sustainability performance through a comprehensive and transparent process, one that has placed us at or near the top of our sector in the Dow Jones Sustainability Index for the past five years.

And as a significant provider of environmental services, project management, management consulting and infrastructure engineering – we have an opportunity to live out our sustainability responsibilities in the services we deliver to our clients.

In Canada, AMEC employs 5,000 people operating out of about 65 offices. Wherever we work, we have been involved with projects that seek to embed sustainability principles into the fabric of our nation. We have been involved in several climate change adaptation projects, working with government agencies and industry associations to develop new understandings of the impact of climate change and what we can do to mitigate impacts and prepare businesses and communities for change.

The new energy economy is very much a part of adaptation, and AMEC is involved in the move to more sustainable energy projects. AMEC plays a major role in providing a range of innovative services to make wind power generation a reality. We have participated in more than 30 completed wind farms ranging from 10 to over 200 MW, both on land and offshore. In Canada, AMEC has constructed 20% of the nation's total wind power capacity.

Partnering in these ways – with industry, government and academic institutions – it is AMEC's aim to improve our collective understanding and ability to manage and adapt to climate change and sustainability issues. Working together, we can balance economic, environmental and social responsibilities in a manner that will meet the needs of generations of Canadians.

BACKGROUND REPORT

CLIMATE CHANGE AND EXTREME WEATHER: DESIGNING ADAPTATION POLICY

Dan Henstra and Gordon McBean

September 9, 2009

ACKNOWLEDGEMENTS

Gordon McBean, lead policy author for ACT's second set of findings, has a long involvement in climate change studies as a scientist, professor and manager. A lead author for the first and second IPCC Assessments and a review editor for the fourth, Gordon is currently Professor of Geography and Political Science at The University of Western Ontario, Director of Policy Studies of the Institute of Catastrophic Loss Reduction and Chair of the international Science Committee for the Integrated Research on Disaster Risk of the International Council for Science, the International Social Sciences Council and UN's International Strategy for Disaster Reduction. He is also Chair of the Board of the Canadian Foundation for Climate and Atmospheric Sciences, President of START International, and member of several advisory groups on climate change adaptation. Former appointments include Chair, UN Agencies International Scientific Committee for the World Climate Research Programme (1988-94), Professor of Atmospheric and Oceanographic Sciences at the University of British Columbia, and Assistant Deputy Minister, Meteorological Service of Environment Canada responsible for climate, weather, water and ice science and services. Gordon is a Member of the Order of Canada, shares in the Nobel Peace Prize for his role in IPCC, a Fellow of the Royal Society of Canada and was awarded the 1989 Patterson Medal for distinguished contributions to meteorology.

Dan Henstra, policy co-author for ACT's second set of findings is Assistant Professor of public administration and local government in the Department of Political Science at the University of Windsor. His research interests include public policy and administration, federalism and multilevel governance. Dr. Henstra has significant experience in policy research and analysis and has participated in projects funded by government departments such as Infrastructure Canada and Natural Resources Canada. His research on public policy, particularly in the field of emergency management, has been published in academic journals such as Canadian Public Administration, Canadian Public Policy and Public Administration Review.

ACT would like to thank **BC Ministry of Environment** experts Cathy LeBlanc, Intergovernmental Relations and Planning, Ministry of Community Development and Ben Kangasniemi, Acting Manager, Science and Adaptation, Climate Action Secretariat, for kindly providing a technical review of this document.

ACT (the Adaptation to Climate Change Team) is a five-year series of six-month sessions that bring leading experts together with decision-makers and experts from industry, community, academia, and government, to explore the risks posed by climate change and generate policy recommendations for sustainable adaptation. This second set of findings is partly based on information gathered during ACT's three conferences – Municipalities Adapting to Climate Change held June 2-3, 2008, Adapting Infrastructure to Climate Change held October 17, 2008, and Climate Impacts and Public Safety held November 21, 2008 – as part of the six-month session on Extreme Weather Events and adaptation to climate change.

EXTREME WEATHER SESSION PARTNERS

Zurich Canada was a key sponsor for this six-month research session and conference series. It behooves our industry to examine the role of insurance in climate adaptation for extreme weather events, and map out solutions to the challenges insurers face in developing products to support climate adaptation.

Zurich is taking an active role when considering change to the earth's climate and the associated risks it presents. We aim to help customers manage the risks associated with climate change through a dedicated climate change unit exploring approaches to help global businesses respond to this emerging risk, including solutions for customers participating in the growth carbon credit market.

Zurich is an insurance-based financial services provider with a global network of subsidiaries and offices in North America and Europe as well as in Asia Pacific, Latin America and other markets. Founded in 1872, our Group is headquartered in Zurich, Switzerland. We employ approximately 60,000 people serving customers in more than 170 countries.

BC Ministry of Environment was a key sponsor for this six-month research session and conference series. The BC Climate Action Secretariat leads and drives change to achieve the Province's greenhouse gas reduction targets by co-ordinating climate action activities across government and with stakeholders. The Secretariat has a mandate to ensure an innovative, coordinated and effective approach to climate action in British Columbia.

AMEC was the key sponsor for the background and policy recommendations reports. AMEC is a focused supplier of high-value consultancy, engineering and project management services to the world's energy, power and process industries and the public sector. With annual revenues of over Cdn $4.6 billion, AMEC designs, delivers and maintains strategic and complex assets for its customers. AMEC employs over 23,000 people in more than 30 countries globally, including about 5,000 in Canada. We are proud to trace our roots back more than 100 years in this great nation. For further information please see www.amec.com. See inside cover for publication sponsor message.

ISBN: 978-1-77287-036-7

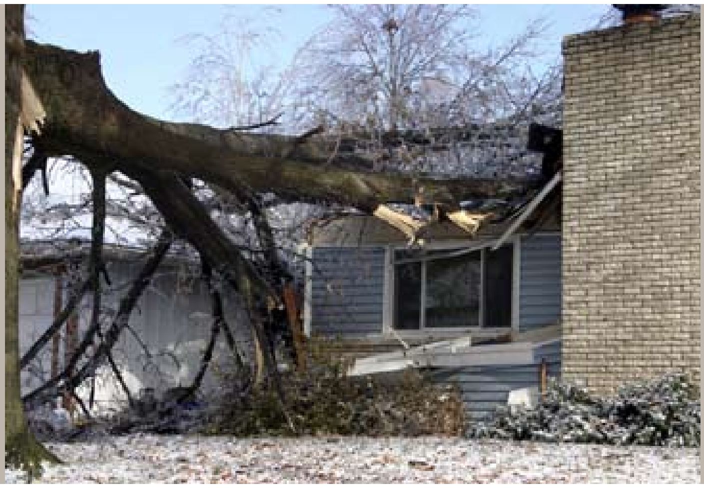
ZURICH®

BRITISH COLUMBIA
The Best Place on Earth
Ministry of Environment

amec

TABLE OF CONTENTS

1.0 INTRODUCTION



All regions of Canada experience extreme weather events of one type or another, and it is likely that they will increase in frequency and intensity as a result of climate change. The risk these hazards pose demands a purposive course of action to reduce the vulnerability of communities and to strengthen their capacity to cope with weather-related impacts.

In December 2006, British Columbia's Lower Mainland and Vancouver Island were struck by a series of storms more powerful than any experienced in the province's history.[1] Hurricane-force winds felled thousands of trees, blocking transportation routes and bringing down power transmission lines, interrupting electricity to nearly 200,000 households.[2] An early damage assessment suggested insured losses associated with the storm could reach $80 million, and the City of Vancouver faced the roughly $2 million task of cleaning up thousands of broken trees in Stanley Park.[3] The extensive damage raised questions about the region's capacity to cope with extreme weather, and prompted journalists and affected residents to offer recommendations about how vulnerability to future storms could be reduced.[4]

Extreme weather events like the 2006 B.C. windstorms periodically illustrate the susceptibility of Canadian communities to climate-related stress. All regions of Canada experience extreme weather events of one type or another, and it is likely that they will increase in frequency and intensity as a result of climate change. The risk these hazards pose demands a purposive course of action to reduce the vulnerability of communities and to strengthen their capacity to cope with weather-related impacts. Public policies designed to achieve these goals can be aggregated under the rubric of *climate adaptation*.[5] In this report, we seek to contribute to the development of Canadian climate adaptation policies targeted at extreme weather events. Our specific objective is to map out a course of action to address climate change and extreme weather at the community level, and to assess how the federal and provincial governments can facilitate and support these local actions. The report begins by examining climate change and its relationship with extreme weather in Canada. It then develops a policy framework, which identifies goals, principles and instruments associated with effective climate adaptation policy. Finally, the report analyzes two sectors that are particularly sensitive to extreme weather events—emergency management and infrastructure—and identifies specific adaptation actions in these areas. Throughout the report, recommendations are offered to support the design and implementation of climate adaptation policy.

1 Environment Canada, "The Top Ten Canadian Weather Stories for 2006," December 28, 2006, http://www.msc-smc.ec.gc.ca/media/top10/2006/topten2006_e.html (accessed 14 November 2008).

2 Jonathan Fowlie, "Traffic Snarled; 190,000 Homes Without Power," The Vancouver Sun, December 12, 2006, A1; William Boei, "Commuter Chaos on Roads, Transit," The Vancouver Sun, December 16, 2006, B4.

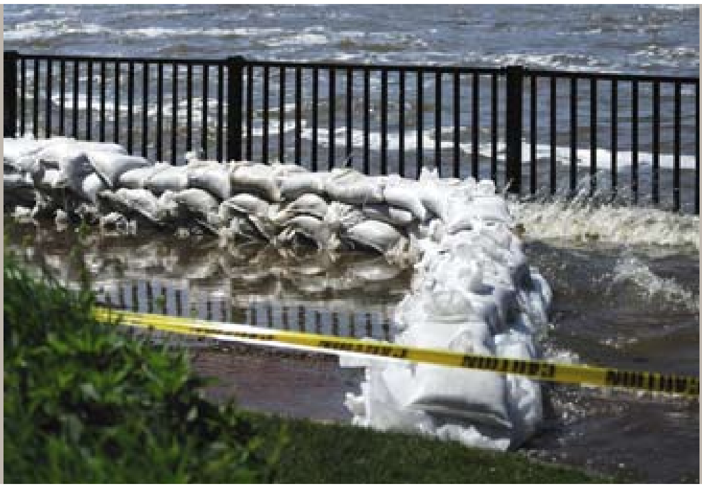
3 Ian Austin and Kent Spencer, "Insurance Claims Could Hit $80M," *The Province*, December 19, 2006, A4; Stuart Hunter, "Mayor Seeks Emergency Funds," *The Province*, December 21, 2006, A4.

4 Richard Angus, "Let Us Cut Our Trees to Protect Our Property," Letter to the Editor, *The Province*, December 20, 2006, A19; n.a., "Storm Aftermath Perfect Time to Review Power Policy," *The Province*, December 19, 2006, A20.

5 Ian Burton, "Climate Adaptation Policies for Canada?," Policy Options 19 (1998), no. 4, 6–10.

2.0 CLIMATE CHANGE, EXTREME WEATHER AND COMMUNITIES

Based on its analysis of global observations of the climate system, the IPCC concludes that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."



The global climate system involves complex interaction among a number of interconnected elements, including the atmosphere, oceans, land surfaces, sea ice, glaciers and ecosystems. In 1988, the World Meteorological Organization and the United Nations Environment Programme created the Intergovernmental Panel on Climate Change (IPCC) to study the global climate system and to undertake scientific assessments of all aspects of climate change. Findings of these IPCC assessments have been disseminated through authoritative reports in 1990, 1995, 2001 and 2007, and these reports are the primary source of the scientific information in this section.

The link between greenhouse gases, such as carbon dioxide and methane, and warming of the global climate is clear and supported scientifically.[6] The Fourth Assessment Report of the IPCC, issued in 2007, presents a thorough analysis of climate and climate change based on an assessment of the world's leading climate scientists. Working Group I, whose analysis focused on physical scientific evidence, reports that global atmospheric concentration of carbon dioxide was about 379 ppm in 2005, higher than any value previously recorded.[7] By 2008, that value had risen to 385 ppm. The report indicates that the planet has been warming at a linear rate of 0.07°C per decade over the past 100 years (0.7°C warming in the past 100 years) and that rate has increased to 0.18°C per decade over the past 25 years (0.45°C warming in the past 25 years). These are global averages including the oceanic areas, which are warming more slowly. Northern hemisphere land areas have been warming about 0.3°C per decade over the past 25 years, compared to a rate of 0.08°C per decade over the past 100 years. From 1900 to 2005 there was a general increase in precipitation over land north of 30°N, but there have been downward trends in precipitation in the tropics since the 1970s.[8] It has become significantly wetter in eastern parts of North and South America. It is also likely that there have been increases in the number of heavy precipitation events (e.g., 95th percentile) within many land regions, even in those where there has been a reduction in total precipitation. There have been changes in atmospheric circulation, such that the mid-latitude westerly winds have generally increased in both hemispheres. These are predominantly observed as 'annular modes', related to the zonally averaged mid-latitude westerlies, which strengthened in most seasons from the 1960s to

6 Andrew J. Weaver, *Keeping Our Cool: Canada in a Warming World* (Toronto, ON: Viking Canada, 2008).

7 Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon et al. (Cambridge, UK: Cambridge University Press, 2007), 2.

8 K. E. Trenberth et al., "Observations: Surface and Atmospheric Climate Change," in *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon et al. (Cambridge, UK: Cambridge University Press, 2007), 238.

at least the mid-1990s, with poleward displacements of corresponding jet streams and enhanced storm tracks. These have been accompanied by a tendency towards stronger winter polar vortices throughout the troposphere and lower stratosphere.

Based on its analysis of global observations of the climate system, the IPCC concludes that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."[9] In attributing these changes, the IPCC reports that "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."[10] In addition, Working Group II, whose focus was impacts, adaptation and vulnerability, reports evidence from all continents and most oceans, indicating that many natural systems are being affected by regional climate change. In the words of the authors, "a global assessment of data since 1970 has shown it is likely that anthropogenic warming has had a discernible influence on many physical and biological systems."[11] In essence, climate change is happening, it is affecting natural systems and human activities are the primary cause.

Extrapolating from various scenarios, The IPCC projects a warming of about 0.2°C per decade for the next two decades, due to existing accumulated greenhouse gases in the atmosphere, continuing emissions over those decades and the delayed warming of the oceans. By mid-century, the climatic warming associated with different scenarios diverge, with warming by the end of century likely ranging from 1°C to 6°C compared to 1980-1999, or about 2-7°C warmer than pre-industrial global temperature. For any scenarios, warming is projected to continue for centuries. These numbers factor in scientific uncertainty which is estimated at the end of the century to typically be +/- 1°C or more.[12]

A summary of projected regional-scale climatic changes includes:[13]

- Warming greatest over land and at most high northern latitudes and least over Southern Ocean and parts of the North Atlantic Ocean, continuing recent observed trends;
- Contraction of snow cover area, increases in thaw depth over most permafrost regions, and decrease in sea ice extent. Some emissions scenarios project that Arctic late-summer sea ice will disappear almost entirely by the latter part of the 21st century;
- *Very likely* increase in frequency of hot extremes, heat waves, and heavy precipitation;
- *Likely* increase in tropical cyclone intensity; less confidence in global decrease of tropical cyclone numbers;
- Poleward shift of extra-tropical storm tracks with consequent changes in wind, precipitation, and temperature patterns;
- *Very likely* precipitation increases in high latitudes and *likely* decreases in most subtropical land regions, continuing observed recent trends.

The IPCC report on climate change mitigation notes that longer-term efforts will be required to stabilize greenhouse gas emissions, before these ultimately decline; the lower the stabilization level, the more quickly this peak and decline

9 Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon et al. (Cambridge, UK: Cambridge University Press, 2007), 5.

10 Ibid., 10.

11 Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. M. L. Parry et al. (Cambridge, UK: Cambridge University Press, 2007), 9.

12 G. A. Meehl et al., "Global Climate Projections," in *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon et al. (Cambridge, UK: Cambridge University Press, 2007).

13 Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. M. L. Parry et al. (Cambridge, UK: Cambridge University Press, 2007).

will occur.[14] Emissions increases over the next two to three decades will have a major impact on opportunities to achieve stabilization. In October, 2007, the Global Carbon Project reported on global fossil fuel emissions up to 2006.[15] During the 1990s, global emissions had been increasing at 1.3 percent per year; for the period 2000-2006, the rate of increase was 3.3 percent per year. In 2006, global emissions were 8.4 GtC (billions of tonnes carbon or carbon equivalents), which was higher than even the most pessimistic of the earlier IPCC emission scenarios. Clearly emission reduction strategies have thus far been ineffective on a global scale.

2.1 CLIMATE CHANGE AND CANADA

Annual mean temperatures and precipitation increased in most parts of Canada during the 20th century.[16] In the future, Canada will generally warm more than the global average and the greatest warming, on an annual basis, will occur in the Arctic regions. By 2090-2099, for a medium (A1B) scenario, the global mean warming is projected to be 2.8°C. The winter warming in Canada is projected to be 7°C or more in the high Arctic, 3-4°C in Ontario and southern Quebec and about 2.5°C along the British Columbia coast. In the summer, the most warming is expected to occur over southern interior B.C. and the south-western Prairies, reaching 4oC. A summer warming of between 2.5 and 3.5°C is expected over most of the rest of Canada, with the exception of the Arctic coast (1°C), where the absence of summertime sea ice will greatly moderate the summertime warming. This warming will be a continuation of the observed warming, as summarized in Canada's National Assessment.[17]

On an annual basis, all of Canada will see more precipitation, from a 5-10 percent increase in the south to a 30-50 percent increase in the north, and more precipitation will fall as rain than snow, relative to present conditions. In the winter, the overall situation is similar, except the southern Canada increases are expected to be slightly higher (10-15 percent). However, in the summer, the southern B.C. interior and south-western Prairies will see a decrease in precipitation of about 10 percent, while most of the rest of southern Canada will see either no change or a small increase. Further north, the increases will be in the range of 10-15 percent.

2.2 CLIMATE CHANGE AND EXTREME WEATHER

Extreme weather refers to infrequent, but significant, departures from a location's normal weather conditions. This can include unusually high or low temperatures: intense summer heat, for example, poses a significant health risk, particularly for urban dwellers.[18] However, extreme weather is most often associated with specific, anomalous events that are potentially destructive because they exceed the range of weather intensity a location normally experiences.[19] In this sense, extreme weather events such as severe thunderstorms, ice storms, blizzards, windstorms, tornadoes and hail can be labelled climate hazards, meaning specific manifestations of climatic change that are potentially harmful for people and property.[20]

14 Intergovernmental Panel on Climate Change, "Summary for Policymakers," in *Climate Change 2007: Mitigation of Climate Change*, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. B. Metz et al. (Cambridge, UK: Cambridge University Press, 2007).

15 Michael R. Raupach et al., "Global and Regional Drivers of Accelerating CO2 Emissions," *Proceedings of the National Academy of Sciences* 104 (2007), no. 24, 10288–10293; Josep G. Canadella et al., "Contributions to Accelerating Atmospheric CO2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks," *Proceedings of the National Academy of Sciences* 104 (2007), no. 47, 18866–18870.

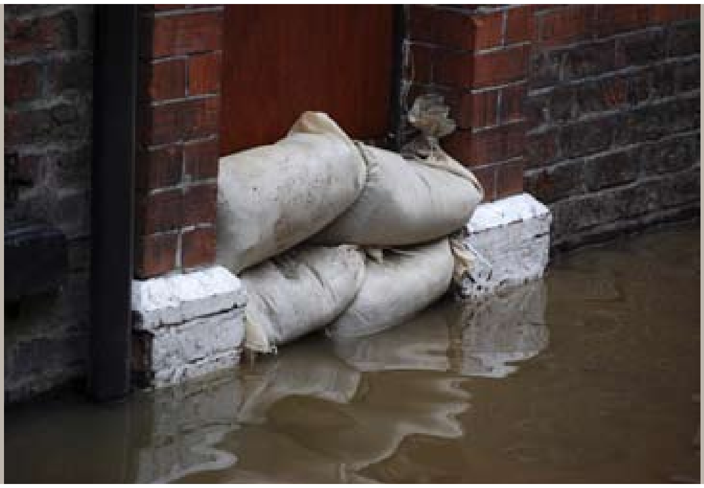
16 Xuebin Zhang et al., "Temperature and Precipitation Trends in Canada During the 20th Century," *Atmosphere-Ocean* 38 (2000), no. 3, 395–429.

17 Fiona J. Warren and Paul Egginton, "Background Information: Concepts, Overviews and Approaches," in *From Impacts to Adaptation: Canada in a Changing Climate 2007*, eds. Donald S. Lemmen et al. (Ottawa, ON: Government of Canada, 2008), 48–51.

18 Karen E. Smoyer-Tomic, Robyn Kuhn and Alana Hudson, "Heat Wave Hazards: An Overview of Heat Wave Impacts in Canada," *Natural Hazards* 28 (2003), no. 2, 463–485.

19 David Francis and Henry Hengeveld, *Extreme Weather and Climate Change* (Ottawa, ON: Environment Canada, 1998), 2; Canadian Council of Ministers of the Environment (CCME), *Climate, Nature, People: Indicators of Canada's Changing Climate* (Winnipeg, MB: CCME, 2003), 137.

20 Nick Brooks, *Vulnerability, Risk and Adaptation: A Conceptual Framework*, Working Paper 38 (Norwich, UK: Tyndall Centre for Climate Change Research, 2003), 3.



Extreme weather events pose a significant risk for communities in all parts of Canada. Flooding, for example, is among the most prominent climate hazards Canadian communities face, and has been at the root of some of Canada's worst disasters.

The global impacts of extreme weather events are enormous. Munich Re, the world's largest reinsurance company, recently reported that insured losses associated with natural disasters in 2008 totalled roughly US$45 billion, an increase of about 50 percent over the previous year.[21] Insured losses caused by weather-related disasters have increased by about two percent per year since the 1970s and, since the 1990s, total costs associated with extreme weather events have averaged around US$60 billion annually.[22] Although these figures are staggering, both insurers and scientists expect that climate change will bring more frequent and intense extreme weather events, potentially resulting in more costly disasters in years to come.

As noted above, the Fourth IPCC Assessment Report projects a number of climatic changes for North America that could contribute to more frequent and intense extreme weather events in Canada in the 21st century. Among the most likely projected changes are warmer surface air temperatures, a general increase in precipitation and more extreme precipitation events.[23] Models simulating future climate based on projected levels of greenhouse gas emissions indicate that increasing atmospheric moisture could generate more intense storm systems and a greater number of extreme rainfall events in many parts of Canada.[24] Although there is always uncertainty associated with projecting future climate values, models consistently indicate that the return period of extreme weather events—that is, the estimated interval of time between occurrences—will be shorter in the future.[25] For these reasons, it is expected that the risk posed by extreme weather events will become greater as the climate changes.[26]

2.3 EXTREME WEATHER EVENTS AND CANADIAN COMMUNITIES

Extreme weather events pose a significant risk for communities in all parts of Canada.[27] Flooding, for example, is among the most prominent climate hazards Canadian communities face, and has been at the root of some of Canada's worst disasters. In 1996, severe flooding in the Saguenay-Lac-Saint-Jean region in southern Quebec destroyed more

21 Munich Re Group, "Catastrophe Figures for 2008 Confirm Climate Agreement is Urgently Needed," December 29, 2008, http://www.munichre.com/en/press/press_releases/2008/2008_12_29_press_release.aspx (accessed 9 January 2009).

22 Nicholas Herbert Stern, *The Economics of Climate Change: The Stern Review* (Cambridge, UK: Cambridge University Press, 2007), 149.

23 J. H. Christensen et al., "Regional Climate Projections," in *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. S. Solomon et al. (Cambridge, UK: Cambridge University Press, 2007), 889–891.

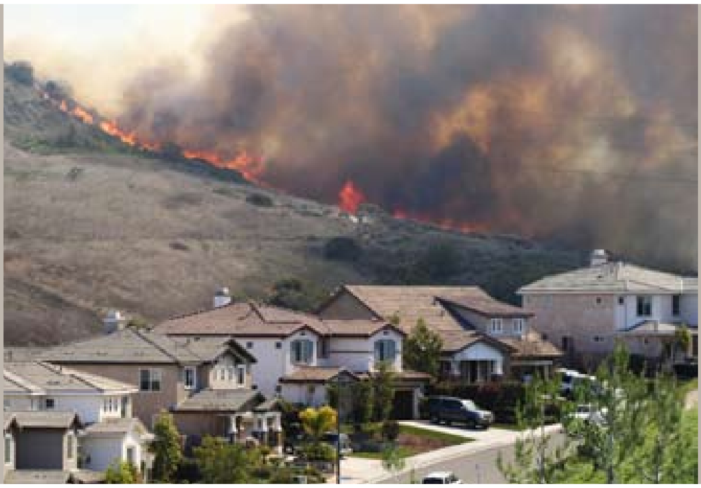
24 Francis W. Zwiers and Viatcheslav V. Kharin, "Changes in the Extremes of the Climate Simulated by CCC GCM2 under CO_2 Doubling," *Journal of Climate* 11 (1998), no. 9, 2200–2222.

25 Viatcheslav V. Kharin and Francis W. Zwiers, "Estimating Extremes in Transient Climate Change Simulations," *Journal of Climate* 18 (2005), no. 8, 1156–1173.

26 Gordon McBean, "Climate Change and Extreme Weather: A Basis for Action," *Natural Hazards* 31 (2004), no. 1, 177–190.

27 Donald S. Lemmen, Fiona J. Warren and Jacinthe Lacroix, "Synthesis," in *From Impacts to Adaptation: Canada in a Changing Climate 2007*, ed. Donald S. Lemmen (Ottawa, ON: Government of Canada, 2008), 13–14.

As the climate changes, warmer surface air temperatures could increase the frequency and areal extent of wildfires and could lengthen the wildfire season. In addition, more frequent summer thunderstorms could increase the risk of lightning-ignited wildfires.



than 1,000 homes, required the evacuation of 16,000 people and caused damages in excess of $800 million.[28] Similarly, major flooding along the Red River in Manitoba in 1997 prompted the evacuation of 25,000 residents and caused damages of approximately $800 million.[29] More rapid and extensive snowmelt associated with rising temperatures and increasingly intense rainfall associated with summer storms could heighten the flood risk in many Canadian communities.[30]

Wildfires pose a significant hazard, as evidenced in British Columbia in the summer of 2003.[31] In that year, unusually hot and dry weather created the conditions for more than 2,500 wildfires, which destroyed over 300 homes, required the evacuation of more than 45,000 people and caused total costs of roughly $700 million. At one point, Premier Gordon Campbell warned that “the wildfire risk is at the highest level in recent memory, with 85 per cent of the province facing a high or extreme fire hazard level.”[32] As the climate changes, warmer surface air temperatures could increase the frequency and areal extent of wildfires and could lengthen the wildfire season.[33] In addition, more frequent summer thunderstorms could increase the risk of lightning-ignited wildfires.[34]

Many Canadian communities are susceptible to ice storms—prolonged periods of freezing rain which cause ice to accumulate on exposed surfaces. The most serious Canadian ice storm occurred in January 1998, in which eastern Ontario, southern Quebec and parts of the Maritime provinces experienced six days of heavy freezing rain.[35] Accumulated ice caused electrical transmission lines to sag and hydro towers to buckle and collapse, interrupting electricity and leaving millions without power.[36] Lack of heat, traffic accidents, falling debris and fires were responsible for 28 deaths and over 900 injuries. Insured losses totalled over $1.4 billion—the largest loss for any single event in Canadian history—and the estimated total costs associated with the disaster exceeded $5 billion.[37] More intense winter

28 Tonia Morris-Oswald and A. John Sinclair, “Values and Floodplain Management: Case Studies from the Red River Basin, Canada,” *Environmental Hazards* 6 (2005), no. 1, 9–22.

29 Greg Brooks, “Geomorphic Effects and Impacts from July 1996 Severe Flooding in the Saguenay Area, Quebec,” January 30, 2008, http://gsc.nrcan.gc.ca/floods/saguenay1996/index_e.php (accessed 29 April 2008).

30 Athanasios Loukas and Michael C. Quick, “The Effect of Climate Change on Floods in British Columbia,” *Nordic Hydrology* 30 (1999), no. 3, 231–256; Rodney White and David Etkin, “Climate Change, Extreme Events and the Canadian Insurance Industry,” *Natural Hazards* 16, (1997), 135–163.

31 British Columbia, *Firestorm 2003: Provincial Review* (Victoria, BC: Government of British Columbia, (2004).

32 Public Safety Canada, “Tornado: Pine Lake AB, 2000,” *Canadian Disaster Database*, November 19, 2007, http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp (accessed December 15, 2008).

33 M. D. Flannigan et al., “Future Area Burned in Canada,” *Climatic Change* 72 (2005), no. 1/2, 1–16; M. D. Flannigan and C. E. van Wagner, “Climate Change and Wildfire in Canada,” Canadian Journal of Forest Research 21 (1991), no. 1, 66–72; B. M. Wotton and M. D. Flannigan, “Length of the Fire Season in a Changing Climate,” *Forestry Chronicle* 69 (1993), no. 2, 187–192.

34 C. Price and D. Rind, “The Impact of a 2×CO_2 Climate on Lightning-Caused Fires,” *Journal of Climate* 7 (1994), no. 10, 1484–1494.

35 Eugene L. Lecomte, Alan W. Pang and James W. Russell, *Ice Storm ‘98* (Toronto, ON: Institute for Catastrophic Loss Reduction, 1998).

36 Mara Kerry et al., “Glazed Over: Canada Copes With the Ice Storm of 1998,” *Environment* 41 (1999), no. 1, 6–11.

37 Public Safety Canada, “Freezing Rain: Ontario to New Brunswick, 1998,” Canadian Disaster Database, November 19, 2007, http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp (accessed December 15, 2008).

storms are anticipated for mid-latitude regions as a result of climate change, suggesting that major ice storms of this sort could become more common in the future.

Tornadoes are a concern for communities in many parts of Canada, particularly in the Prairie provinces and in southern Ontario. For instance, a tornado in Pine Lake, Alberta in 2000 killed 12 people, injured more than 140 others and caused an estimated $30 million in damages.[38] The frequency of tornadoes in the Prairie provinces appears to be related to above-normal summer temperatures, suggesting that these hazards could become more common if average temperatures rise as predicted in climate models.[39] Scientific opinion is mixed as to whether climate change will increase the frequency of tornadoes, but the destructive power of these hazards nevertheless demands strategies to reduce the risk to people and property.[40]

Climate change is expected to increase the frequency of hot days in most parts of Canada. For example, under a medium emission scenario, by 2050 the number of days with a maximum temperature above 30°C increases in Victoria from 1 to about 5; in Calgary from 5 to almost 20; in Winnipeg from 14 to nearly 50; in Toronto from 12 to 35; and in Fredericton from 8 to about 25.[41] Summer heat poses a significant risk to public health and safety, as was starkly demonstrated by the 2003 heat wave in western Europe, which was associated with more than 35,000 deaths.[42] The risk is greater for those who live in densely-populated urban neighbourhoods, in part because of the urban heat island effect, whereby heat is absorbed by asphalt surfaces and various infrastructure materials, increasing the outdoor air temperature by 0.5 to 5°C. Extreme heat events can also have indirect negative health impacts. For instance, hot summer days are usually also smoggy days. A recent report by the Canadian Medical Association projects that the annual number of deaths associated with acute effects of air pollution will increase by 2031 to almost 90,000 people.[43] Canada's National Assessment projects that both heat waves and smog episodes are likely to become more frequent under a changing climate.

As these examples illustrate, climate change is a significant threat to the health and safety of Canadians. Extreme weather events like those described above pose both direct and indirect risks to people and their property, and threaten the continuity of infrastructure systems that support life in communities. Serious disruptions to critical infrastructure such as transportation, water treatment and distribution systems, and energy generation and transmission, have already occurred and are likely to become increasingly frequent in the future. Both the current and projected impacts of extreme weather events demand a course of action designed to reduce the risk associated with these hazards. The next section examines elements of climate adaptation as a policy response.

38 Public Safety Canada, "Tornado: Pine Lake AB, 2000," *Canadian Disaster Database*, November 19, 2007, http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp (accessed December 15, 2008).

39 David A. Etkin, "Beyond the Year 2000, More Tornadoes in Western Canada? Implications from the Historical Record," *Natural Hazards* 12 (1995), 19–27.

40 G. A. McBean, "Risk Mitigation Strategies for Tornadoes in the Context of Climate Change and Development," *Mitigation and Adaptation Strategies for Global Change* 10 (2005), no. 3, 357–366.

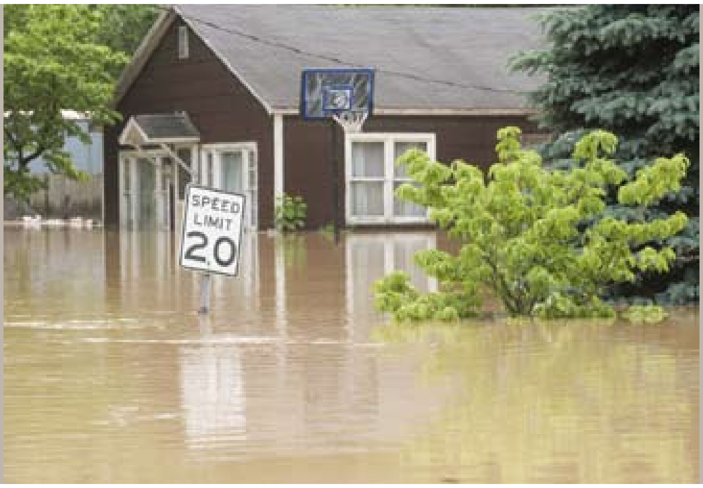
41 Henry Hengeveld, Bob Whitewood and Angus Fergusson, *An Introduction to Climate Change: A Canadian Perspective* (Downsview, ON: Environment Canada, 2005), 44.

42 Shaoni Bhattacharya, "European Heatwave Caused 35,000 Deaths," *New Scientist*, October 10, 2003; Marc Poumadère et al., "The 2003 Heat Wave in France: Dangerous Climate Change Here and Now," *Risk Analysis* 25 (2005), no. 6, 1483–1494.

43 Canadian Medical Association, *No Breathing Room: National Illness Costs of Air Pollution* (Ottawa: Canadian Medical Association, 2008), iii.

3.0 CLIMATE ADAPTATION POLICY

Every community has some inherent capacity to cope with variable weather, but extreme weather events are such significant departures from normal conditions that they threaten to exceed this "coping range."



There are two fundamental policy responses to the risk associated with climate change. The first, mitigation, involves efforts to stabilize or reduce greenhouse gas emissions to slow or stall changes in climate. Mitigation is the central focus of most national policies concerning climate change, largely driven by international agreements such as the Kyoto Protocol, which set binding emissions-reduction targets for signatory states. The second policy response, *adaptation*, recognizes that despite even the most ambitious efforts to reduce greenhouse gas emissions by Canada and other states, a significant degree of climate change is inevitable.[44] Furthermore, it acknowledges that the climate already exerts significant pressure on physical, social and economic systems, which has not been sufficiently addressed.[45] As such, in addition to a concerted mitigation effort, action is required to adapt to both existing and future climate-related stress.[46]

Although analysts define adaptation in various ways, a common thread in this work is that it involves "adjustments"—purposive changes to practices, processes, or structures undertaken to better cope with climatic stimuli and their impacts.[47] Extreme weather events are one set of climatic stimuli demanding such adjustments. Every community has some inherent capacity to cope with variable weather, but extreme weather events are such significant departures from normal conditions that they threaten to exceed this "coping range". The risk posed by extreme weather events cannot be fully resolved through autonomous actions of individuals and organizations, and thus requires state intervention through public policy. *Climate adaptation policy* refers here to a course of action chosen by public authorities to mandate or facilitate adjustments to practices, processes or structures, aimed at reducing current and future impacts of extreme weather events.

As noted above, this report is primarily concerned with *community* climate adaptation policy. This local lens has been adopted for a number of reasons. First, communities are sites where population and infrastructure are concentrated and, as such, it as at this level that the impacts of extreme weather events are felt most immediately and acutely.[48] When an ice storm occurs, for example, it is the local responders who render assistance to victims, assess damages and restore infrastructure systems disrupted during the emergency. The imperative to adapt is arguably strongest at the local level,

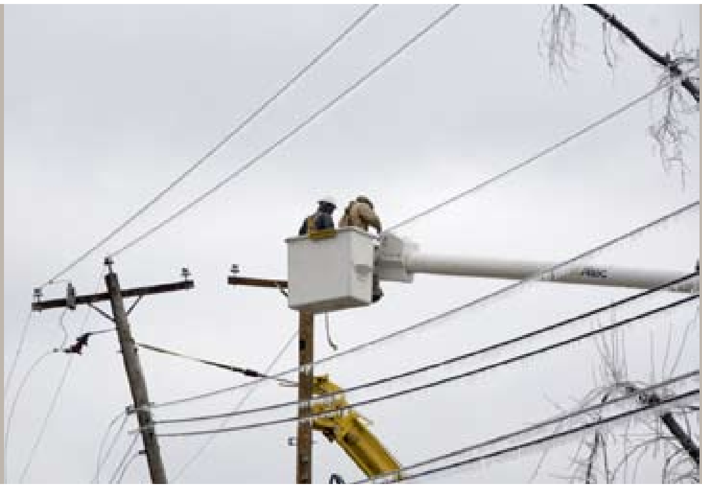
44 For example, see Bill Hare and Malte Meinshausen, "How Much Warming Are We Committed to and How Much Can Be Avoided?," *Climatic Change* 75 (2006), no. 1/2, 111–149, and T. M. L. Wigley, "The Climate Change Commitment," *Science* 307 (2005), 1766–1769.

45 James Ford, "Emerging Trends in Climate Change Policy: The Role of Adaptation," *International Public Policy Review* 3 (2008), no. 2, 8.

46 Roger A. Pielke, Jr., "Rethinking the Role of Adaptation in Climate Policy," *Global Environmental Change* 8 (1998), no. 2, 159–170.

47 M. L. Parry et al., "Technical Summary," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. M. L. Parry et al. (Cambridge, UK: Cambridge University Press, 2007), 27.

48 Gordon McBean and Dan Henstra, *Climate Change, Natural Hazards and Cities* (Toronto, ON: Institute for Catastrophic Loss Reduction, 2003).



Much of a community's exposure to extreme weather events is determined by geography: a town located adjacent to a river has a greater exposure to the risk of flooding; a village surrounded by forest is more exposed to the risk of wildfires, and so on.

where the current climate already has visible and significant impacts on people and property.[49] Second, though the broad impacts of climate change can be predicted with relative confidence, greater uncertainty surrounds projections of specific impacts on local communities. What seems certain, however, is that the nature and scope of climate hazards will vary considerably from place to place. For this reason, it is difficult and perhaps inefficient to centralize adaptation planning, as the localized impacts of climate change will demand customized adaptation responses.[50] Unique local knowledge of current climate impacts and of the community's capacity to cope with these impacts is invaluable for adaptation policy-making.

Third, despite commendable efforts by many Canadian communities to reduce greenhouse gas emissions,[51] the role that local governments can play in climate change mitigation is limited.[52] Local politicians are understandably reluctant to spend money on mitigation—the benefits of which are enjoyed outside the community's borders—or to regulate emissions of local industries for fear of putting the community at a competitive disadvantage.[53] This suggests that any major initiative to reduce greenhouse gas emissions will probably require a mandate from higher-level governments. By contrast, the benefits of adaptation are enjoyed locally, and a community that is less vulnerable to climate hazards is arguably better positioned to attract people and business. Finally, though national and regional policies may mandate or facilitate adaptation, most specific, instrumental responses must be implemented locally by government officials, private sector actors and individuals.[54]

Although communities are well-positioned to implement adaptation measures, recurrent local impacts associated with extreme weather events suggest a weak and insufficient adaptation effort—an "adaptation deficit"—which must be addressed through policy.[55] Designing effective climate adaptation policy requires a framework of goals, principles and instruments which guides the application of public authority and resources. The following sections draw upon expert knowledge to construct a framework for climate adaptation policy to address extreme weather events in communities.

49 W. Neil Adger, "Scales of Governance and Environmental Justice for Adaptation and Mitigation of Climate Change," *Journal of International Development* 13 (2001), no. 7, 921–931.

50 Nils Larsson, "Adapting to Climate Change in Canada," *Building Research & Information* 31 (2003), no. 3/4, 233.

51 For example, *Partners for Climate Protection* is an initiative of the Federation of Canadian Municipalities and ICLEI – Local Governments for Sustainability, which includes 175 municipalities committed to reducing emissions (http://www.sustainablecommunities.fcm.ca/partners-for-climate-protection/, accessed December 23, 2008).

52 Pamela J. Robinson and Christopher D. Gore, "Barriers to Canadian Municipal Response to Climate Change," *Canadian Journal of Urban Research* 14 (2005), no. 1, 102–120.

53 Andrew Sancton, "Cities and Climate Change: Policy-Takers, Not Policy-Makers," *Policy Options* 27 (2006), no. 8, 32–34.

54 Karen O'Brien, Linda Sygna and Jan Erik Haugen, "Vulnerable or Resilient? A Multi-Scale Assessment of Climate Impacts and Vulnerability in Norway," *Climatic Change* 64 (2004), no. 1, 197; A. K. Snover et al., *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* (Oakland, CA: ICLEI – Local Governments for Sustainability, 2007), 27.

55 Ian Burton, "Adapt and Thrive: Options for Reducing the Climate Change Adaptation Deficit," *Policy Options* 27 (2005), no. 1, 33–38.

3.1 GOALS

Although climate hazards pose a potential threat, their associated impacts are largely determined by a community's *vulnerability*, which is a function of its exposure to climate hazards, its sensitivity to the stresses they impose, and its capacity to adapt to these stresses.[56] Since our ability to prevent climate hazards is limited, the central goal of adaptation policy must be to reduce vulnerability.[57] The vulnerability of communities to extreme weather events is not a fixed condition, and it can be reduced through actions which minimize exposure, reduce the sensitivity of people and systems, and strengthen the community's adaptive capacity.

3.1.1 EXPOSURE

Exposure refers to the degree to which a system is subject to climate stress. As such, exposure can be defined here as the degree to which a community is subject to stress associated with extreme weather events. Defined in this way, exposure is clearly connected to a community's *physical vulnerability*, a function of both the nature of extreme weather events it faces—their frequency and magnitude, for instance—as well as the number and value of assets at risk. Much of a community's exposure to extreme weather events is determined by geography: a town located adjacent to a river has a greater exposure to the risk of flooding; a village surrounded by forest is more exposed to the risk of wildfires, and so on. Similarly, communities that contain a large number of high-value assets exposed to extreme weather events are more vulnerable to these climate hazards. For instance, a city with an extensive hydroelectric power infrastructure has a greater exposure to an ice storm and thus may be more vulnerable than a rural neighbour with a simpler network. Effective climate adaptation policy must include measures to reduce exposure to extreme weather events.

3.1.2 SENSITIVITY

Sensitivity refers to the degree to which a system will respond to a change in climatic conditions, either positively or negatively. For our purposes, a community's sensitivity can be defined as the degree to which it will suffer negative impacts associated with more frequent and intense extreme weather events. From this perspective, one important contributing factor is the coping ability of individual inhabitants. In every community there are specific "vulnerable groups"—socioeconomic or demographic subpopulations which are especially susceptible to hazard impacts.[58] For instance, low-income households, the homeless, and people who are unemployed are particularly vulnerable, because they lack the means to buy emergency supplies and usually have more difficulty in the recovery phase.[59] Women—particularly lone parents—typically have fewer resources to prepare for and recover from the impacts of climate hazards, and thus also tend to be disproportionately vulnerable.[60] Women are generally also more sensitive to psychosocial health impacts during extreme weather events, because they are more likely to bear the burden of recovering from the event, while continuing to meet multiple demands within and outside the household. Children, who make up roughly 24 percent of Canada's population, are especially vulnerable to climate hazards, because their perception of danger is not fully developed and because they require assistance to adopt protective measures. A community with a high concentration of vulnerable groups is more sensitive to climate hazards.

Community sensitivity to extreme weather events is also a function of the resilience of physical infrastructure systems. The supply of essential local services such as clean water, electrical power, communications and transportation depends on the continuity of the infrastructure which delivers them. Although these systems are designed to withstand

56 Barry Smit et al., "An Anatomy of Adaptation to Climate Change and Variability," *Climatic Change* 45 (2000), no. 1, 237.

57 Ian Burton et al., "From Impacts Assessment to Adaptation Priorities: The Shaping of Adaptation Policy," *Climate Policy* 2 (2002), no. 2/3, 154.

58 Hans G. Bohle, Thomas E. Downing and Michael J. Watts, "Climate Change and Social Vulnerability," *Global Environmental Change* 4 (1994), no. 1, 37–48; Susan Cutter, Bryan J. Boruff and W. Lynn Shirley, "Social Vulnerability to Environmental Hazards," *Social Science Quarterly* 84 (2003), no. 2, 242–261.

59 Alice Fothergill and Lori A. Peek, "Poverty and Disasters in the United States: A Review of Recent Sociological Findings," *Natural Hazards* 32 (2004), no. 1, 89–110.

60 See, for example, Elaine Enarson and Betty Hearn Morrow, *The Gendered Terrain of Disaster* (New York: Praeger 1998).

extreme weather, their age, record of maintenance and other variables affect their capacity to withstand or absorb climate-related stress. In light of these social and physical variables, some communities are clearly more sensitive to extreme weather events than others. Effective climate adaptation policy requires actions to reduce the sensitivity of people and systems to extreme weather events.

3.1.3 ADAPTIVE CAPACITY

Adaptive capacity refers to the ability to adjust practices, processes, or structures to moderate or offset potential negative impacts associated with climate change.[61] In contrast to the variables discussed above, the relationship here is inverse: a community that has a strong adaptive capacity is less vulnerable to climate hazards. Analysts have identified a number of factors associated with adaptive capacity,[62] and some of these are particularly relevant for adaptation to extreme weather events.

One factor which influences a community's adaptive capacity is access to *information*. In order to design appropriate adaptation responses, policy-makers require information regarding the nature and evolution of climate hazards, as well as the community's current and future vulnerability to these hazards and their impacts. This might include, for example, access to historical meteorological data and socioeconomic information to assess physical and social sensitivity to climatic stresses. Information is also necessary to detect trends in the frequency and intensity of extreme weather events, and to project scenarios of how they might change in the future. Second, adaptive capacity depends in part on whether or not there are those with *expertise* to collect the information noted above, to perform analyses, and to translate the information into policy. Designing adaptation policy for extreme weather events requires, for example, assessments of the effectiveness, costs and feasibility of measures to reduce vulnerability; stakeholder analyses to identify targets and beneficiaries of adaptation interventions; analyses of the consequences of inaction; and so on. Moreover, knowledge generated must be clearly communicated to political leaders and citizens, whose support is essential for effective adaptation policy. Once a course of action is chosen, expert personnel are required to effectively implement the policy and evaluate its performance over time.

Third, since effective adaptation policy involves some level of public expenditure, a community's adaptive capacity depends in part on available economic resources. *Fiscal capacity* to address adaptation is limited by competing demands on scarce economic resources, which must be met regardless of climate change. The willingness of political leaders to divert resources from other priority areas depends on their perception of the need and demand for this course of action. Thus a fourth determinant of adaptive capacity is a general recognition that it is possible and desirable to adapt, as well as the *political will* to act. For elected officials, it is rational to prioritize issues that are considered problematic by voters. Neither group is likely to assign a high priority to adaptation unless it is perceived that extreme weather events are a significant hazard and that inaction will lead to increased risk as the climate changes.

A community with a greater capacity to adapt is less vulnerable to negative impacts associated with climate change. For this reason, a specific objective of adaptation policy for extreme weather events is to implement measures which will increase the adaptive capacity of communities. The discussion above suggests several priority areas to target in pursuing this objective.

61 J. Adejuwon et al., "Overview of Impacts, Adaptation, and Vulnerability to Climate Change," in *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, eds. J. J. McCarthy et al. (Cambridge, UK: Cambridge University Press, 2001), 89.

62 See Barry Smit et al., "Adaptation to Climate Change in the Context of Sustainable Development and Equity," in *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, eds. J. J. McCarthy et al. (Cambridge, UK: Cambridge University Press, 2001), 877–912, and Gary Yohe and Richard S. J. Tol, "Indicators for Social and Economic Coping Capacity: Moving Toward a Working Definition of Adaptive Capacity," *Global Environmental Change* 12 (2002), no. 1, 25–40.

3.2 PRINCIPLES

Given the objectives identified above, it is clear that designing climate adaptation policy involves complex choices and affects the interests of many community actors and stakeholders. This section identifies key principles associated with effective climate adaptation policy and recommends actions to support community implementation.[63]

3.2.1 EFFECTIVE ADAPTATION POLICY INVOLVES INTERGOVERNMENTAL COLLABORATION

Although local actors have a central role in designing and implementing climate adaptation policy, a partnership with higher-level governments is also required. It is clearly in the interests of both the federal and provincial governments to ensure effective community-level adaptation for extreme weather events. Although local governments respond initially to emergencies triggered by extreme weather, provincial (and sometimes federal) resources must be deployed when the impacts exceed local coping capacity. If communities are sufficiently resilient to absorb the stresses associated with extreme weather events, they are less likely to need operational assistance from higher-level governments. Similarly, resilient communities are less likely to need financial support from provincial disaster recovery programs or the federal Disaster Financial Assistance Arrangements program, which compensate for damages to public infrastructure and personal property losses.

With a nationwide mandate, the Government of Canada is uniquely positioned to support community adaptation planning in all regions. The federal government produces a number of important policy resources, including research concerning climate impacts on communities, current and historical climate and weather data to support vulnerability and risk assessments, and climate change scenarios to project future impacts. Particularly noteworthy is a recent announcement by the federal government that $30 million will be allocated to Natural Resources Canada for the creation of "Regional Adaptation Collaboratives"—networks of stakeholders organized to integrate climate change risks into planning and decision-making.[64] This appears to be a promising initiative to support community-level adaptation, and these networks should be formed as soon as possible.

Provincial government support for local adaptation efforts is also important, in order to avoid "downloading" the costs of climate change onto local governments.[65] Given their constitutional jurisdiction over municipal institutions, provincial governments can use instruments ranging from exhortation and voluntary compliance to legal mandates with strict performance standards, in order to ensure that all local governments take action to adapt to climate change. For instance, Ontario, Quebec and a number of other provinces have recently passed legislation requiring local governments to undertake comprehensive emergency planning which meets rigorous standards set out in regulations. Although these mandates were met with some initial resistance, they have nevertheless compelled local officials to ensure sufficient resources are in place to respond effectively to emergencies within their jurisdiction. Creating similar legislation to mandate climate adaptation planning, or integrating this priority into existing emergency planning laws, could be a viable approach, provided that resources are available to assist in their implementation.

Mandating climate adaptation actions, however, is a coercive approach that is unlikely to secure local commitment to the goals and principles of effective climate adaptation policy. A more promising provincial strategy is to partner with local governments and provide materials to guide and support local policy design. Although the scope of their activities varies, provincial governments have begun to organize resources to support adaptation within their borders. For instance, British Columbia's Climate Action Plan incorporates an explicit commitment to adaptation, and in 2008

63 Many of the ideas in this section arise from dialogue among participants at three ACT conferences: *Extreme Events: Municipalities Adapting to Climate Change*, June 2–3, 2008, Vancouver, BC; *Extreme Events: Adapting Infrastructure to Climate Change*, October 17, 2008, Surrey, BC; and *Extreme Weather Events: Climate Impacts and Public Safety*, November 21, 2008, Vancouver, BC.

64 Environment Canada, "Canada's Government Taking Action on Adaptation and Climate Change Issues," December 10, 2007, http://www.ec.gc.ca/default.asp?lang=En&xml=91E1F38E-C53C-404B-9512-22EA69C08787 (accessed December 30, 2008).

65 Chris Rickett, Erin Shapero and Elio Di Iorio, "Downloading Climate Change: Municipalities Are Bearing the Costs," *Municipal World* 116 (2006), no. 11, 27–29.

the government committed nearly $95 million to undertake research on climate change solutions and to assess, develop and promote viable mitigation and adaptation options to better inform policies and actions in BC.[66] The Government of Ontario has formed an Expert Panel on Climate Change Adaptation to provide recommendations concerning adaptation actions, and has committed funds for further research on adaptation.[67] New Brunswick's Climate Change Action Plan recognizes the need to adapt to both current and future climate impacts on communities, and places a particular emphasis on considering climate risks in development decisions.[68] Various initiatives are underway in the province to support adaptation planning, including projects to better communicate climate risks to infrastructure managers, and measures to strengthen local and regional emergency management capacity.[69]

The federal and provincial efforts noted above are a strong foundation on which to build a comprehensive intergovernmental framework to facilitate and support community adaptation policy-making. Sustained collaboration among officials located in all levels of the state will be necessary to ensure that efforts are co-ordinated and resources are allocated effectively. A number of strategies are recommended to achieve this end. First, a permanent intergovernmental working group should be created with a mandate to share information and co-ordinate adaptation policies and programs. Second, climate adaptation for extreme weather events should be incorporated as a key policy priority in intergovernmental meetings of the Canadian Council of Ministers of the Environment (CCME) and the Canadian Councils of Resource Ministers (CCRM).[70] Third, climate adaptation should be integrated into the *National Disaster Mitigation Strategy*, a recent initiative of the federal, provincial and territorial governments, which aims to "protect lives and maintain resilient, sustainable communities by fostering disaster risk reduction as a way of life."[71] The strategy appears to be a promising vehicle for co-ordinating adaptation efforts, given the strong parallels between disaster risk reduction and climate adaptation.[72] Priority should be given to developing consistent communication messages regarding adaptation, in order to reduce confusion or uncertainty among decision-makers, which can forestall adaptation efforts. The federal and provincial governments are well-positioned to implement public education and outreach programs which could inform citizens about climate-related risks and the need to invest in resilient communities. Expansion of intergovernmental information-sharing networks is another priority, to ensure that data and materials are made available to communities pursuing adaptation actions.

3.2.2 EFFECTIVE ADAPTATION POLICY ENGAGES STAKEHOLDERS

Analysts frequently assert that adaptation planning must engage stakeholders—actors who have a role to play in adaptation or have a particular interest in the outcome of adaptation policy—as well as the general public.[73] Stakeholder engagement is necessary, because many of the systems and structures that are vulnerable to climate hazards are not under direct government control. In seeking to reduce a community's vulnerability to a major ice storm, for instance, adaptation planners must ensure that the local power infrastructure is equipped to quickly recover from a system failure. Often the power utility is a corporate entity, and though the local government may be able to influence its operations,

66 British Columbia, *Climate Action Plan* (Victoria, BC: Government of British Columbia, 2008).

67 Ontario, "Ontario Commits Climate Change Funding for Adaptation," December 12, 2007, http://www.ene.gov.on.ca/en/news/2007/121201.php (accessed December 16, 2008).

68 New Brunswick, *Climate Change Action Plan 2007–2012* (Fredericton, NB: New Brunswick Climate Change Secretariat, Department of Environment, 2007), 4.

69 New Brunswick, *Climate Change Action Plan, 2007–2008 Progress Report* (Fredericton, NB: New Brunswick Climate Change Secretariat, Department of Environment, 2008), 11.

70 The foundation for this work appears to be in place. See Canadian Intergovernmental Conference Secretariat, "Ministers Agree That Adapting to Climate Change Will Be a Policy Priority," news release ref: 830-918/004, September 12, 2007, http://www.scics.gc.ca/cinfo07/830918004_e.html (accessed 9 January 2009).

71 Public Safety Canada, *Canada's National Disaster Mitigation Strategy*, http://www.publicsafety.gc.ca/prg/em/ndms/_fl/NDMS_Web_E.pdf (accessed February 2, 2009).

72 Frank Thomalla et al., "Reducing Hazard Vulnerability: Towards a Common Approach Between Disaster Risk Reduction and Climate Adaptation," *Disasters* 30 (2006), no. 1, 39–48.

73 See Cecilia Conde and Kate Lonsdale, "Engaging Stakeholders in the Adaptation Process," in *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, eds. Bo Lim and Erika Spanger-Siegfried (Cambridge, UK: Cambridge University Press, 2004), 47–66.

this is not the same as having direct control over service provision. By incorporating private- and nonprofit-sector actors into the policy-making process, adaptation planners can draw upon a broad range of expertise and can generate support among those with an interest in policy outcomes.[74]

Public engagement is important to increase awareness of the risks associated with a changing climate, to generate support for courses of action chosen in response, and to legitimate resources allocated to adaptation.[75] In a relatively passive form, this might involve a public education campaign, which informs citizens about the current risks associated with extreme weather events and how these are expected to change in the future. A more active, participatory approach is to form a citizen advisory committee, a small group of citizens that meets periodically to discuss key issues and reports to decision-makers with recommendations. The ultimate objective of public engagement is to recruit "extension agents"—individuals who believe that adaptation is necessary and valuable, and who champion this objective in their interactions with others.

Given that analysts regard public and stakeholder engagement as a critical element of effective adaptation policy-making, it is recommended here that governments at all levels work to refine tools to support this activity within communities. This might include general guidance on opinion-gathering techniques—interviewing, surveys, focus groups, and so on—or specific analysis tools such as stakeholder assessment maps, reporting matrices, evaluation frameworks and conflict resolution procedures.

3.2.3 EFFECTIVE ADAPTATION POLICY ADDRESSES CURRENT VULNERABILITY AND RISK

Designing adaptation policy must begin with an assessment of current vulnerability to climate-related hazards and the way in which existing policies and practices contribute to, or reduce, this vulnerability.[76] The vulnerability assessment, which incorporates measures of exposure, sensitivity and adaptive capacity, diagnoses the scope of the problem and provides a rough benchmark against which future vulnerability can be measured.[77] Vulnerability assessments are intended to inform decision-making, and therefore should incorporate both scientific knowledge and local and indigenous knowledge of stakeholders, should account for actions taken at other scales, and should include both a historical and prospective lens.[78]

Information collected through a vulnerability assessment provides the basis for a risk assessment, which examines the likelihood of occurrence and the potential consequences of adverse climate-related impacts such as extreme weather events, in order to estimate the risk posed to the community by climate change.[79] Using climate change scenarios—plausible descriptions of future climate states—adaptation planners can project potential impacts associated with a changing climate. Although scenarios involve a considerable and often discomforting degree of uncertainty, they are nevertheless crucial for deliberation and learning among participants in the adaptation planning process. The risk assessment combines information on the current and projected impacts of climate change with socioeconomic information regarding the vulnerability of various groups to estimate the community's *coping range*—the limits of its ability to cope with climatic pressure.[80] Once equipped with vulnerability and risk assessments, adaptation planners can map out a course of action.

74 Pierre Mukheibir and Gina Ziervogel, "Developing a Municipal Adaptation Plan for Climate Change," *Environment and Urbanization* 19 (2007), no. 1, 147.

75 Roger Few, Katrina Brown and Emma L. Tompkins, *Public Participation and Climate Change Adaptation*, Working Paper 95 (Norwich, UK: Tyndall Centre for Climate Change Research, 2006).

76 Barry Smit and Olga Pilifosova, "From Adaptation to Adaptive Capacity and Vulnerability Reduction," in *Climate Change, Adaptive Capacity and Development*, eds. Joel B. Smith, Richard J. T. Klein and Saleemul Huq (Potsdam, Germany: Potsdam Institute for Climate Impact Research, 2003), 11.

77 Hans-Martin Füssel and Richard J. T. Klein, "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking," Climatic Change 75 (2006), no. 3, 301–329.

78 Dagmar Schröter, Colin Polsky and Anthony G. Patt, "Assessing Vulnerabilities to the Effects of Global Change: An Eight Step Approach," *Mitigation and Adaptation Strategies for Global Change* 10 (2005), no. 4, 573–595.

79 A. K. Snover et al., *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments* (Oakland, CA: ICLEI – Local Governments for Sustainability, 2007), 87–89.

80 Roger Jones and Rizaldi Boer, "Assessing Current Climate Risks," in *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures,* eds. Bo Lim and Erika Spanger-Siegfried (Cambridge, UK: Cambridge University Press, 2004), 91–117.

Preparing thorough vulnerability and risk assessments requires extensive and accurate information, which can be difficult for many communities to access. Expanding current efforts to produce and disseminate climate data and information should be a key priority for the federal and provincial governments as a means to support local adaptation. Specific priorities include hazard maps; climatic, hydrometric and socioeconomic datasets to support communities in assessing local impacts; and generic templates for vulnerability and risk assessment.

3.2.4 EFFECTIVE ADAPTATION POLICY IS STRATEGIC AND SYSTEMATIC

Due to the global scope of climate change, a common barrier to action on adaptation is that decision-makers perceive the problem as intractable, and are understandably overwhelmed by its many implications. For this reason, the early stages of adaptation planning are best spent identifying the most pressing problems and the most promising actions to address them. This information can then be used to map out a strategy which prioritizes short- and long-term adaptation actions, assigns responsibility for them to specific community officials, and sets out performance targets for implementation.[81] The adaptation strategy provides an accountability framework for monitoring progress and periodically measuring performance.

However, developing strategic priorities for adaptation is complex and can be challenging. Designing a course of action to address the many risks associated with climate change inevitably involves a wide range of decision-makers and stakeholders, and requires difficult choices about how scarce resources should be allocated. Competing objectives, conflicting values and myriad adaptation options can frustrate rational decision-making and lead to inaction. It is for this reason that analysts recommend *risk management* as a decision-support framework to identify and prioritize climate-related risks and to select appropriate responses.[82] Risk management is a logical and systematic methodology widely used by government and industry to identify, assess, communicate and manage risks. It recognizes that risk-related decisions involve considerable uncertainty and can be significantly influenced by the perceptions of participants, which are rarely congruent with objective risk.

The risk management framework offers a number of advantages which can support and strengthen the design of community climate adaptation policies for extreme weather events.[83] First, the language of risk management is familiar to both government officials and private sector actors, whose participation is imperative to an effective community adaptation strategy. For instance, framing extreme weather events as a risk to the integrity or continuity of infrastructure systems is a means to generate a positive response from owners and operators who are familiar with managing other forms of risk. Second, risk management allows for explicit consideration of the uncertainty which surrounds projections of future climate conditions. Through the use of alternative risk scenarios, analysts are forced to consider various outcomes, estimate their consequences and assess benefits and costs of taking action. Third, the risk management framework emphasizes continuous communication with stakeholders, to incorporate a broad range of interests and to ensure that proposed solutions are publicly and politically acceptable.

It is recommended that the federal and provincial governments develop and distribute tools to support communities in making strategic choices about adaptation. This might involve offering training programs for policy- and decision-makers to learn about risk management as a framework for strategic adaptation planning. It might also involve creating a central repository of decision-support frameworks for cost-benefit analysis, multi-criteria analysis, and cost effectiveness analysis. Also important are locally-appropriate climate change scenarios and downscaling tools—techniques to obtain finer-resolution scenarios from global-scale climate models—which can be used by policy-makers to raise awareness

81 Isabelle Niang-Diop and Henk Bosch, "Formulating an Adaptation Strategy," in *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, eds. Bo Lim and Erika Spanger-Siegfried (Cambridge, UK: Cambridge University Press, 2004), 83–204.

82 David Noble, Jim Bruce and Mark Egener, *An Overview of the Risk Management Approach to Adaptation to Climate Change in Canada* (Ottawa: Natural Resources Canada, 2005), 2.

83 James P. Bruce et al., *Municipal Risks Assessment: Investigation of the Potential Municipal Impacts and Adaptation Measures Envisioned as a Result of Climate Change* (Ottawa: Global Change Strategies International, 2002).

of projected risks and assess potential courses of action.[84] On this front, it is encouraging to note that the Government of Canada intends to allocate $15 million to Environment Canada for the development of improved climate change scenarios and $5 million to Natural Resources Canada to develop tools for risk assessment, economic analysis and adaptation planning.[85] It is recommended here that these programs be implemented swiftly.

3.2.5 EFFECTIVE ADAPTATION POLICY REQUIRES "MAINSTREAMING"

The final and perhaps most challenging principle of effective climate adaptation policy is that it should be integrated into all relevant policy sectors.[86] That is, adaptation is most effective when it is not only pursued in isolation, but rather is "mainstreamed" into the wide range of decisions and actions that governments take every day. For example, local development decisions—choices about land use, the location of structures, and so on—are permanent, and could contribute to the vulnerability of a community unless exposure and sensitivity to future extreme weather events are considered. Successful mainstreaming techniques used by local governments include designating an internal steering committee to integrate adaptation into existing policies and programs, and incorporating adaptation principles into the community's official plan.[87] As a specific example, in 2007 Halifax Regional Municipality developed a risk management guide to ensure developers were aware of the risks associated with climate change and their implications for proposed projects.[88]

Equally important is the need to mainstream climate adaptation into federal and provincial policies and programs, which can significantly impact on community resilience. For instance, adaptation should be incorporated into environmental assessments, in order to identify risks posed by climate change and potential impacts on proposed projects.[89] Similarly, incorporating an "adaptation lens" into the assessment of proposed projects under the current infrastructure programs is one of the most promising ways to mainstream the objective of building community resilience to extreme weather events.[90] But although federal and provincial review processes are opportunities to add adaptation into proposed projects, climate-related risks should ideally be considered by local governments during the project planning phase, before they submit applications to federal or provincial programs. Persuading local officials to adopt this adaptation lens requires a purposive information and public education campaign.

Perhaps the most effective means to mainstream climate adaptation is to integrate it into education and training programs for professionals—engineers, architects, planners and so on—who will ultimately be in a position to implement adaptation through their operational decisions.[91] Furthermore, partnering with national and regional professional associations is a way to mainstream adaptation into the work of practitioners already working in relevant fields. One such partnership between Natural Resources Canada and the Canadian Institute of Planners (CIP), a national association representing more than 7,000 professional planners, has had notable success in strengthening the capacity of planners to evaluate local vulnerability and incorporate climate change considerations into their work. CIP recently issued a policy statement on climate change, encouraging members to consider climate change in their

84 It should be noted that significant efforts to produce and disseminate these tools are already being made through Environment Canada's *Canadian Climate Change Scenarios Network* (http://www.cccsn.ca).

85 Environment Canada, "Canada's Government Taking Action on Adaptation and Climate Change Issues," December 10, 2007, http://www.ec.gc.ca/default.asp?lang=En&xml=91E1F38E-C53C-404B-9512-22EA69C08787 (accessed 30 December 2008).

86 Ian Burton et al., "From Impacts Assessment to Adaptation Priorities: The Shaping of Adaptation Policy," *Climate Policy* 2 (2002), no. 2/3, 156.

87 Eva Ligeti, Jennifer Penney and Ireen Wieditz, *Cities Preparing for Climate Change: A Study of Six Urban Regions* (Toronto: Clean Air Partnership, 2007), xii.

88 Halifax Regional Municipality, *Climate Change: Developer's Risk Management Guide* (Halifax, NS: Halifax Regional Municipality, 2007).

89 Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment, *Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners* (Ottawa, ON: Canadian Environmental Assessment Agency, 2003).

90 A recent report by Infrastructure Canada suggests that climate adaptation is already considered in the assessment of applications to the Canadian Strategic Infrastructure Fund. See Infrastructure Canada, *Adapting Infrastructure to Climate Change in Canada's Cities and Communities: A Literature Review* (Ottawa: Research and Analysis Division, Infrastructure Canada, 2006), 2.

91 For example, see Michael Mortimer and Jeff Walker, *Climate Change and Infrastructure Engineering: Moving Towards a New Curriculum* (Ottawa: Canadian Standards Association, 2007).

activities and to minimize risks associated with extreme weather events.[92] But in a recent national survey of engineers conducted by the Canadian Standards Association, fewer than ten percent of respondents indicated that they routinely consider climate change impacts in their daily work.[93] This indicates that further effort to mainstream adaptation into professional practice is required.

3.3 INSTRUMENTS

In designing a course of action based on the goals and principles identified above, policy-makers must determine not only the appropriate scope of public intervention, but also the specific means by which climate adaptation will be put into effect. Table 1 identifies a set of generic adaptation measures commonly identified in expert literature, and illustrates how these could be implemented to address extreme weather events.

TABLE 1. ADAPTATION MEASURES

Barry Smit et al., "Adaptation to Climate Change in the Context of Sustainable Development and Equity," in *Climate Change 2001: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, eds. J. J. McCarthy et al. (Cambridge, UK: Cambridge University Press, 2001), 885.

Instrument	Action	Examples
Share loss	Spread losses among wider population	Insurance Relief and rehabilitation programs
Modify events	Implement measures to control or contain hazards	Flood protection (dykes; levees)
Prevent effects	Protect people and systems from hazards	Land-use regulation Warning systems
Reduce impacts	Build resilient infrastructure; reduce demands on infrastructure to free up capacity	Increase robustness Plan for swift recovery Water or energy conservation
Change location	Relocate people and property from hazard-prone areas	Incentives to relocate Public acquisition of exposed properties
Research	Invest in research to identify new adaptation methods	Pilot projects Engineering research for code development
Education	Information and public education campaigns to encourage behavioural change	Websites; pamphlets Seminars; workshops

Governments can choose to act directly, by spending public funds or by adjusting their own operations to increase community resilience to extreme weather events. They can also choose an indirect approach by, for example, offering economic incentives to induce adaptation actions, or levying charges to dissuade individuals and firms from engaging in activities which contribute to vulnerability. The challenge for policy-makers is to choose a mix of adaptation instruments that makes the most effective use of resources and minimizes inefficiency. Although more specific measures

92 Canadian Institute of Planners, *Climate Change: A Policy Paper* (Ottawa: Canadian Institute of Planners, 2008).

93 Canadian Standards Association, *National Survey of Canada's Infrastructure Engineers About Climate Change* (Ottawa: Canadian Standards Association, 2007).

to reduce vulnerability to extreme weather events are offered later in the paper, four broad instruments are discussed below, which appear particularly promising for facilitating and supporting community-level adaptation.

3.3.1 INFORMATION

A recurring finding in studies of local adaptation is that both scientific data regarding climate change impacts and knowledge concerning adaptation measures must be better mobilized and transferred to local actors who need it to design a course of action. Moreover, policy-makers have long known that the most powerful way to change behaviour is to change the knowledge, beliefs and values on which it is based. Information-based instruments such as reports, conferences, training sessions and online databases are among the most cost-effective and least obtrusive tools that higher-level governments can use to support local adaptation. As part of an intergovernmental adaptation framework, a concerted effort should be devoted to informing and educating both local decision-makers and citizens about the importance and value of adaptation.

3.3.2 PLANNING

Most provinces require local governments to prepare official community plans, which set out policies concerning the use of land within the community's borders, project future growth and anticipate infrastructure and other service needs to support this growth. The planning function offers communities a powerful set of tools for building resilience to extreme weather events. Land use plans, for example, identify optimal uses of land within a community, and zoning bylaws and regulations are used to control the location, type and density of development. Given that climate change will affect the frequency and magnitude of extreme weather events, this increasing risk must be incorporated into the planning process, so that decisions made today do not increase community vulnerability to future climate hazards. For instance, local land use plans can be used to prohibit or restrict development in hazard-prone areas such as floodplains, thereby limiting the exposure of people and property. In hazardous areas, zoning regulations can be used to prohibit inappropriate development, such as residential construction, and instead can designate the land for low-risk uses, such as recreation. Decisions concerning the location of infrastructure components or transportation routes can limit the exposure of key assets, thus reducing vulnerability to extreme weather events.

3.3.3 INSURANCE

Insurance has long been an effective instrument to share the risk associated with climate variability and extremes, and the insurance sector will play an increasingly important role as the climate changes.[94] Insurers have begun to design innovative climate-related products that will be a valuable complement to other adaptation instruments. For instance, when structures are damaged by extreme weather events, the rehabilitation stage offers a unique opportunity to incorporate components which contribute to both climate change mitigation and adaptation. Flexible insurance products that support "green" and climate-resilient rebuilding could provide an effective vehicle to reduce greenhouse gas emissions and to increase the capacity of communities to cope with extreme weather events. Given that historical records are decreasingly useful for projecting future risks, a primary challenge facing insurers is the need to compile accurate hazard data and use simulation models to price insurance premiums.[95] This will require closer partnerships between insurers and public sector organizations, such as government research laboratories and universities. Pricing of insurance products is important from a community perspective, as it can prompt households and businesses to implement protective actions or to relocate from high-risk areas. From a public policy standpoint, governments must assess whether there is sufficient insurance coverage available to citizens, and to what extent citizens are taking it up.

94 See, for example, Paul Kovacs et al., *Understanding the Significance of Insurance, Alternative Risk Spreading Mechanisms, and Related Public Policy for the Risk Management of Physical Infrastructure in the Face of Climate Change in the Yukon, Northwest Territories and Nunavut*, report prepared for the National Round Table on the Environment and the Economy (Toronto, ON: Institute for Catastrophic Loss Reduction, 2007).

95 Samuel Fankhauser et al., "Economic and Policy Instruments to Promote Adaptation," in *Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments*, eds. Shardul Agrawala and Samuel Fankhauser (Paris: Organisation for Economic Co-operation and Development, 2008), 100.

Insurance is a valuable tool for managing climate-related risks, as it offers a means to finance the repair or replacement of assets that suffer infrequent, unforeseeable losses. However, its effectiveness as an adaptation instrument will be undermined if the exposure and sensitivity of insured assets to more frequent and intense extreme weather events leads to chronic, catastrophic losses. It is for this reason that insurance must be incorporated into a broader course of action, complementing other measures aimed at reducing losses associated with climate hazards.

3.3.4 CODES AND STANDARDS

Regulatory instruments are a primary means by which governments can prevent or reduce hazard losses. Provincial governments have constitutional authority to regulate building construction in Canada, and each province has a building code which sets out design and performance criteria for new construction.[96] Building codes hold promise as an adaptation tool, provided that projected climate change impacts are incorporated as a risk factor during code development. Moreover, to effectively support adaptation, building codes must be sufficiently flexible to allow for innovations which contribute to community resilience. For instance, a green roof system—a building roof which is partially or completely covered with vegetation and soil—can reduce stormwater runoff by absorbing water during heavy rainfall events. Existing building codes provide little in the way of technical standards to guide green roof design and construction, leaving local building officials, designers, architects and engineers to determine whether these structures meet general roof system performance criteria.

Although building regulation is a provincial responsibility, Canada has a centralized system of code development based around the National Building Code, and periodic revisions provide a crucial opportunity to mainstream climate adaptation into the construction process. The development and maintenance of the National Building Code is overseen by the Canadian Commission on Building and Fire Codes, an arms-length agency funded by the National Research Council, which draws on a number of expert committees to establish the content. It is recommended here that the Canadian Commission on Building and Fire Codes establish a working group to examine whether and how building codes can be adapted to ensure buildings are resilient to cope with extreme weather expected to accompany climate change.

Standards are detailed specifications promulgated by public- or private-sector organizations which serve as guidelines for the design, construction and maintenance of structures such as buildings and infrastructure systems. Testing and improving construction standards requires engineering research, such as that of the Insurance Research Lab for Better Homes, a large-scale research facility which tests the effects of extreme weather conditions on buildings, for the purpose of "improving construction techniques to make our communities more resilient to natural hazards and more energy efficient in the coming decades."[97] Standards are developed through a lengthy process involving expert committees, stakeholders and the general public, and are periodically reviewed and updated. These development and review processes present opportunities to incorporate adaptation into standards governing the design and construction of physical systems.[98]

Given that climate change will increase the frequency and intensity of extreme weather events in the future, it is imperative that codes and standards which guide the production of the built environment today be sufficiently robust to ensure the resilience of communities and their lifelines to these climate hazards. Here we endorse the recommendation of other analysts, who suggest that new-generation codes and standards incorporate an explicit "climate change adaptation factor"—an adjustment in climatic design values to account for climate change.[99]

96 Some provinces have adopted the National Building Code of Canada, a model code published by the National Research Council of Canada. Others use provincial variants based on the National Building Code.

97 Insurance Research Lab for Better Homes, University of Western Ontario, http://www.eng.uwo.ca/irlbh/ (accessed February 12, 2009).

98 Michel Girard and Michael Mortimer, *The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change* (Ottawa: Canadian Standards Association, 2006).

99 Heather Auld, Don MacIver and Joan Klaassen, Adaptation Options for Infrastructure Under Changing Climate Conditions, Occasional Paper 10 (Toronto: Environment Canada, 2007), 7.

4.0 EMERGENCY MANAGEMENT

Emergency management involves the design and implementation of policies and procedures to prevent or avoid hazards, to reduce vulnerability, and to cope with the impacts of emergencies and disasters.

Emergencies are triggered when hazards interact with community vulnerability.[100] The negative social and economic impacts of emergencies sometimes exceed the coping capacity of a community, and this is normally referred to as a disaster. *Emergency management* involves the design and implementation of policies and procedures to prevent or avoid hazards, to reduce vulnerability, and to cope with the impacts of emergencies and disasters.[101] Climate change poses a challenge for emergency management: faced with the prospect of increasingly frequent and intense extreme weather events, emergency managers must implement courses of action which reduce the risk posed by these climate hazards.

Over the past several decades, the central focus of emergency management has shifted from preparedness and response to risk reduction.[102] Modern emergency management doctrine explicitly recognizes that, since most hazards cannot be prevented, resources must be allocated to reducing vulnerability, as a proactive means to mitigate the impacts of emergencies.[103] The primary objectives are to protect people and property from hazards, to minimize losses associated with emergencies, and to ensure a swift and effective recovery from disasters. At the United Nations World Conference on Disaster Reduction in 2005, Canada was one of many states that committed to these objectives through the *Hyogo Framework for Action*, a strategic and systematic approach to vulnerability and hazard risk reduction aimed at building disaster-resilient communities.[104]

4.1 CLIMATE ADAPTATION AND EMERGENCY MANAGEMENT

As a part of community climate adaptation policy, emergency management is clearly a "no-regrets" investment.[105] Since extreme weather events pose a current risk to Canadian communities, better emergency planning accrues immediate

100 David A. McEntire, "Triggering Agents, Vulnerabilities and Disaster Reduction: Towards a Holistic Paradigm," *Disaster Prevention and Management* 10 (2001), no. 3, 189–196; Douglas Paton and David Johnston, "Disasters and Communities: Vulnerability, Resilience and Preparedness," *Disaster Prevention and Management* 10 (2001), no. 4, 270–277.

101 Ronald John Hy and William L. Waugh, Jr., "The Function of Emergency Management," in *Handbook of Emergency Management*, eds. William L. Waugh, Jr., and Ronald John Hy (Westport, CT: Greenwood, 1990), 11–26.

102 Dan Henstra and Gordon McBean, "Canadian Disaster Management Policy: Moving Toward a Paradigm Shift?," *Canadian Public Policy* 31 (2005), no. 3, 303–318.

103 See, for instance, David A. McEntire, "Why Vulnerability Matters: Exploring the Merit of an Inclusive Disaster Reduction Concept," *Disaster Prevention and Management* 14 (2005), no. 2, 206–222.

104 United Nations International Strategy for Disaster Reduction, *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters* (Geneva: United Nations, 2005).

105 T. J. Wilbanks et al., "Industry, Settlement and Society," in *Climate Change 2007: Impacts, Adaptation and Vulnerability*, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, eds. M. L. Parry et al. (Cambridge, UK: Cambridge University Press, 2007), 378.

benefits, regardless of the scope and degree of climate change in the future. There are many practical measures that communities can take to address current disaster risk and to ensure plans and procedures are adequately adapted to cope with changing risk into the future. This section identifies a number of adaptation actions to reduce community vulnerability to extreme weather events.

4.1.1 REDUCING EXPOSURE

One of the specific objectives of community adaptation policy concerning extreme weather events is to reduce the exposure of people and property to these hazards. For emergency managers, an important first step is to undertake a hazard and risk assessment, which involves identifying hazards the community is likely to face, assessing physical and social vulnerability to these hazards, and estimating the likely injuries, damages and costs associated with the hazards over a specified period of time.[106]

In order to undertake comprehensive hazard and risk assessments, communities require detailed climate and weather data. This in turn requires a high-quality observation and monitoring network. Indeed, the *Hyogo Framework for Action* calls on all states to invest in "the technical and scientific capacity to develop and apply methodologies, studies and models to assess vulnerabilities and the impact of geological, weather, water and climate-related hazards, including the improvement of regional monitoring capacities and assessments."[107] Although Canada has world-class expertise in the collection and analysis of weather and climate data, as a recent report of the Commissioner of the Environment and Sustainable Development points out, due to chronic under-investment Canada's monitoring network is "nearing the breaking point."[108] It is recommended here that Canada's observation and monitoring network be evaluated to ensure comprehensive and high-quality climate and weather information is collected, analyzed and disseminated to communities seeking to build resilience to extreme weather events.

The information generated through a hazard and risk assessment should be used to adjust local practices that might contribute to disaster risk. For instance, the information can be immensely valuable if it is integrated into land use planning and regulation, which are perhaps the most powerful local tools for vulnerability reduction.[109] Where development cannot be blocked entirely, regulations should limit building intensity, in order to minimize the number of people and amount of property at risk. But although these measures can significantly reduce the exposure of people and property to extreme weather events, at one time or another every community is bound to face an event which threatens public safety. As such, local emergency managers should also plan and test procedures to evacuate people from areas at risk, in order to minimize the exposure of residents during an emergency.

4.1.2 REDUCING SENSITIVITY

Local emergency managers have several means by which to reduce the sensitivity of people and systems to extreme weather events. First, communities can establish a warning system to inform residents about impending hazard events, so that they can take protective actions.[110] Local hazard warning systems vary in sophistication, ranging from website notices to sirens to "reverse-911" telephone systems, which deliver recorded warning messages directly to residents.[111] But although there are various local mechanisms for disseminating warnings, communities generally receive warning information through the media, which the media obtain from a number of different federal, provincial, regional, or

106 Robert E. Deyle et al., "Hazard Assessment: The Factual Basis for Planning and Mitigation," in *Cooperating with Nature: Confronting Natural Hazards with Land-use Planning and Sustainable Communities*, ed. Raymond J. Burby (Washington, DC: Joseph Henry Press, 1998), 119–166.

107 United Nations International Strategy for Disaster Reduction, *Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters* (Geneva: United Nations, 2005), 10.

108 Office of the Auditor General of Canada, "Managing Severe Weather Warnings: Environment Canada," in *Report of the Commissioner of the Environment and Sustainable Development* (Ottawa, ON: Minister of Public Works and Government Services Canada, 2008), 9.

109 Raymond J. Burby et al., "Creating Hazard Resilient Communities Through Land-Use Planning," *Natural Hazards Review* 1 (2000), no. 2, 99–106.

110 John H. Sorensen, "Hazard Warning Systems: Review of 20 Years of Progress," *Natural Hazards Review* 1 (2000), no. 2, 119–125.

111 David A. McEntire and Amy Myers, "Preparing Communities for Disasters: Issues and Processes for Government Readiness," *Disaster Prevention and Management* 13 (2004), no. 2, 141.

local agencies. For example, weather warnings come from the Meteorological Service of Canada, part of Environment Canada; flood (and usually smog) warnings come from either a provincial or local agency; snow slide warning information is generated by a local, or perhaps even volunteer, authority; and volcano or earthquake warnings, if issued at all, usually come from a federal agency or a university monitoring facility. This fragmented collection of sources can impede the ability of emergency personnel to receive and relay hazard warnings in a timely and effective manner.[112] In keeping with the priorities of the *Hyogo Framework*, it is recommended here that the Government of Canada work with public and private sector partners to develop an integrated, multi-hazard early warning system.

In the United States, an "All-Channel-Alert" system permits hazard warnings to be broadcast on all television screens during regular programming. Despite efforts by Environment Canada and others, Canada has not yet implemented a similar system capable of "pushing" warning information to end users. Such a system would communicate warnings over all radio and television stations and through mobile devices such as cellular phones. Although the technology has been available in Canada for at least a decade, regulatory barriers have thus far prevented its effective use in broadcasting hazard warnings to the public. Public Safety Canada, the federal department with primary responsibility for emergency management, is currently tasked with developing a National Public Alerting System. This system could perhaps be grafted onto the Meteorological Service's current weather warning system, which is widely used by government agencies, business firms, citizens and the media, and is generally regarded as one the most valuable federal services. Alternatively, the system might be established through a partnership with private firms. For instance, Pelmorex Communications Inc., the parent company of The Weather Network and MétéoMédia, is seeking regulatory approvals from the Canadian Radio-television and Telecommunications Commission (CRTC) to establish "a 24/7 alerting operations centre that would aggregate and authenticate alerts from all three levels of government and make them available on a voluntary basis to broadcasters, distributors and media outlets using non-proprietary technology."[113]

No matter how a national public alerting system is structured, hazard warnings are of little use unless people know what action they are expected to take when they are notified. For instance, a recent study analyzes the facts surrounding a series of winter storms in the Montreal area in early March 2008, which caused 18 roofs to collapse, resulting in the deaths of three people and the closure of more than 200 schools.[114] It finds that, despite warnings of severe winter weather, key decision-makers did not adequately perceive the risk posed by the hazard, and thus failed to take protective measures. The report recommends that predictions of hazardous weather be better linked with information about its possible consequences. Communities should devote resources to educating the public about extreme weather events, so that they are better equipped to prepare for and respond to these emergencies when they occur. Public education raises general awareness of emergency planning and fosters a sense of individual responsibility for preparedness.[115] Local emergency managers should also engage the business community in adaptation planning for extreme weather events. Major emergencies can have direct impacts on business, such as physical damage to structures, but can also have a number of operational impacts, such as service disruptions, severed shipping routes and extended employee absences.[116] A large number of failed businesses as a result of a disaster can have a significant negative impact on local employment and tax revenues, so it is critical that the local business community be involved in emergency planning.

Finally, emergency managers can reduce sensitivity to extreme weather events by formulating targeted measures

112 Nova Scotia Emergency Management Office, "Nova Scotia Calls for National Public Alert System," January 11, 2007, http://www.gov.ns.ca/news/details.asp?id=20070111002 (accessed February 6, 2009).

113 See CRTC, "Broadcasting Notice of Consultation CRTC 2009-2-2," February 12, 2009, http://www.crtc.gc.ca/eng/archive/2009/2009-2-2.htm (accessed February 12, 2009).

114 Jacques Descurieux, *Post-hoc Study of Severe Weather: Snow Storms in the Montréal Area, 3–9 March 2008* (Kelowna, BC: Meteorological Service of Canada, 2009).

115 David King, "You're on Your Own: Community Vulnerability and the Need for Awareness and Education for Predictable Natural Disasters," *Journal of Contingencies and Crisis Management* 8 (2000), no. 4, 223–228.

116 Rodney C. Runyan, "Small Business in the Face of Crisis: Identifying Barriers to Recovery from a Natural Disaster," *Journal of Contingencies and Crisis Management* 14 (2006), no. 1, 12–26; Gary R. Webb, Kathleen J. Tierney and James M. Dahlhamer, "Businesses and Disasters: Empirical Patterns and Unanswered Questions," *Natural Hazards Review* 1 (2000), no. 2, 83–90.

to protect vulnerable groups—people within the community who are especially susceptible to hazard impacts.[117] For instance, people with disabilities are particularly vulnerable: special transportation needs complicate evacuation; vision or hearing impairments prevent people from receiving hazard warnings; and emergency shelters and other facilities are often inaccessible to those who are mobility-impaired.[118] Similarly, elderly residents often have mobility constraints which complicate evacuation, are more likely to suffer injuries, and generally take longer to recover after hazard events.[119] Specific preparedness measures, such as providing targeted education programs and arranging emergency transportation, are required to ensure that the special needs of citizens are met in the event of an emergency.

4.1.3 INCREASING ADAPTIVE CAPACITY

In addition to actions targeting exposure and sensitivity, communities can reduce vulnerability to extreme weather events by strengthening adaptive capacity. In the emergency management sector, this involves designing and implementing measures which enhance the community's ability to respond effectively to extreme weather events and to recover quickly from their impacts. One of the greatest challenges local governments face following a major emergency or disaster is an often dramatic increase in citizen demand for routine services, such as waste collection, public transit and social services.[120] As such, emergency managers should plan for the continuity of operations, which involves identifying critical government functions and services, and developing strategies to quickly restore them if they are interrupted in an emergency. Practical measures include, for example, preparing an inventory of personnel, equipment and records, and a strategy to relocate services to alternate buildings in the event that their headquarters sustain terminal damage.

Secondly, in any emergency response resources can quickly become depleted, so it is prudent for communities to establish mutual aid agreements with neighbouring communities, whereby they can borrow equipment and personnel if their own capacity is overwhelmed. Although spontaneous assistance may be offered by other jurisdictions in an emergency, formal agreements are advisable, as they clarify the legal authority under which the agreement is undertaken, set out procedures for requesting and providing resources, and specify whether and how the assisting jurisdiction will be compensated.[121] Third, communities should augment their capacity to respond to extreme weather events by organizing teams of volunteers, which can be mobilized as needed. Groups of trained volunteers can be a valuable auxiliary resource for official personnel, performing a number of important response functions, such as providing first aid assistance to victims and conducting light search and rescue.[122]

Fourth, emergency managers should plan ahead for important recovery-related activities such as damage assessment and debris management, to ensure that resources are allocated effectively in the recovery phase.[123] Rebuilding or rehabilitating structures that have sustained damage in an emergency offers an opportunity to incorporate resilience to cope with future extreme weather events. However, this requires thought and planning before an emergency, as the immediate interest in the recovery phase tends to be returning the community to normal as rapidly as possible. Finally, following an emergency or disaster, officials should collect information and report to decision-makers on "lessons learned", which can be used to identify adaptive strategies, and can also be useful for other communities facing similar risks. Since the willingness of both elected officials and citizens to invest in emergency management depends on the level of risk they perceive from environmental hazards, accounts of real emergencies in real places are a powerful tool to convince people of the need to adapt to both current and future extreme weather events.

117 Betty Hearn Morrow, "Identifying and Mapping Community Vulnerability," *Disasters* 23 (1999), no. 1, 1–18.

118 Keith M. Christensen, Martin E. Blair and Judith M. Holt, "The Built Environment, Evacuations, and Individuals with Disabilities: A Guiding Framework for Disaster Policy and Preparation," *Journal of Disability Policy Studies* 17 (2007), no. 4, 249–254; Vincent T. Wood and Robert A. Weisman, "A Hole in the Weather Warning System: Improving Access to Hazardous Weather Information For Deaf and Hard of Hearing People," *Bulletin of the American Meteorological Society* 84 (2003), no. 2, 187–194.

119 Ehren B. Ngo, "When Disasters and Age Collide: Reviewing Vulnerability of the Elderly," *Natural Hazards Review* 2 (2001), no. 2, 80–89.

120 Ronald W. Perry and Lawrence D. Mankin, "Preparing for the Unthinkable," *Public Personnel Management* 34 (2005), no. 2, 176–177.

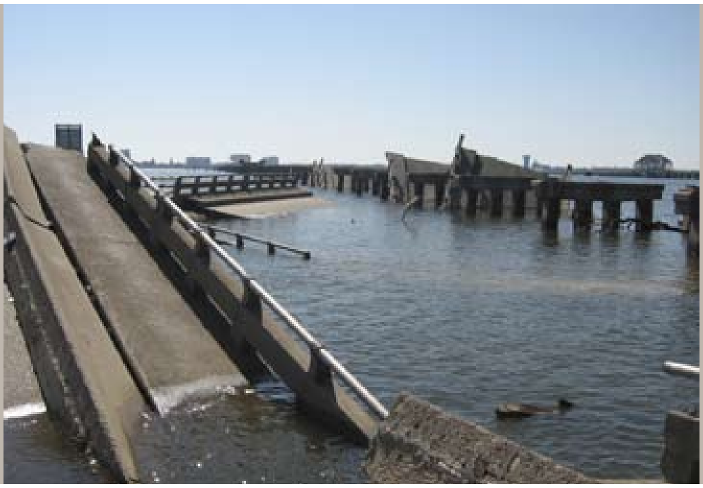
121 Alan D. Cohn, "Mutual Aid: Intergovernmental Agreements for Emergency Preparedness and Response," *Urban Lawyer* 37 (2005), no. 1, 1–52.

122 David M. Simpson, "Community Emergency Response Training (CERTs): A Recent History and Review," *Natural Hazards Review* 2 (2001), no. 2, 54–63.

123 Gabriela Y. Solis et al., *Disaster Debris Management* (Ottawa, ON: Emergency Preparedness Canada, 1995).

5.0 INFRASTRUCTURE

Extreme weather events are one source of stress on infrastructure systems, posing risks ranging from temporary interruption of services to permanent damage and destruction of exposed facilities.



Life in every Canadian community is supported by a complex network of infrastructure. Roads and bridges facilitate movement of people and goods and link the community to others in the surrounding area. Power distribution networks and telecommunications systems are crucial supports for the digital, knowledge-based economy, connecting people and businesses across community borders. A vast network of water and wastewater lines connects households and organizations to central processing facilities. The reliability of these critical infrastructure systems and the continuity of the services they support are essential for the health and safety of residents and for the social and economic activities they engage in. Infrastructure is normally dependable, delivering services to users with few interruptions. Over their long life cycle, however, infrastructure assets are subject to many stresses, which occasionally trigger system failures.

Extreme weather events are one source of stress on infrastructure systems, posing risks ranging from temporary interruption of services to permanent damage and destruction of exposed facilities.[124] For instance, a recent national assessment of the vulnerability of public infrastructure reveals that water resource systems are vulnerable to both heavy precipitation events and drought conditions; power supply systems are vulnerable to ice storms and windstorms; and most buildings are vulnerable to increased loads from snow and wind.[125] Heavy rainstorms in urban areas overwhelm stormwater drainage infrastructure, causing flooding. Ice storms coat exposed surfaces with a layer of ice, causing electrical transmission lines to sag and hydro towers to collapse. Windstorms cause structural damage to building components, block transportation routes with debris and sever telephone, television and other communication lines.

There are a number of reasons to expect that damages to infrastructure associated with extreme weather events will increase in the future. First, Canada's existing stock of physical infrastructure is aging and many structures and facilities are approaching or have exceeded their normal service life.[126] Due to deferred maintenance and underinvestment in replacement, infrastructure assets such as storm and sanitary sewer lines have deteriorated significantly, leaving them increasingly susceptible to failure under heavy loads brought on by extreme events. Although all infrastructure assets are designed to withstand pressures associated with weather extremes, "margins of safety" built into structures 50 years

124 Public Safety Canada, *Threats to Canada's Critical Infrastructure*, Threat Analysis TA03-001 (Ottawa, ON: Government of Canada, 2003).

125 Engineers Canada, Adapting to Climate Change: *Canada's First National Engineering Vulnerability Assessment of Public Infrastructure* (Ottawa, ON: Canadian Council of Professional Engineers, 2008).

126 M. Saeed Mirza and Murtaza Haider, *The State of Infrastructure in Canada: Implications for Infrastructure Planning and Policy* (Ottawa, ON: Research and Analysis Division, Infrastructure Canada, 2003), 2.

ago may not be appropriate for the current climate, and are almost certainly inadequate to cope with future climate conditions.[127]

Second, Canada is a highly urbanized nation: more than 80 percent of the population lives in urban areas of 10,000 people or more.[128] Urbanization concentrates large numbers of people and complex infrastructure in relatively small geographic areas, increasing the exposure of people and property to localized climate hazards. Urban development can also significantly affect weather-related stresses on infrastructure systems. For instance, an increase in the proportion of surfaces impervious to water (such as concrete) can alter local hydrology and lead to a higher volume of surface runoff, potentially overwhelming drainage systems with stormwater from even relatively modest precipitation events.[129] Urban population growth also increases demand and dependence on water infrastructure systems, thus contributing to the sensitivity of these facilities to drought which constricts supply.[130]

Third, it is believed that even a small increase in the magnitude or intensity of extreme weather events could bring about a major increase in damage to infrastructure systems. The sensitivity of infrastructure to extreme weather events appears to be nonlinear, as damage can increase dramatically when weather conditions exceed a system's "critical threshold", or the edge of its coping range.[131] For instance, physical damage associated with a windstorm is significantly influenced by wind speed, whereby a small increase in peak gust velocity can cause an exponential increase in damage.[132] In designing climate adaptation policy for infrastructure, planners must consider critical thresholds, particularly since future climatic conditions are expected to differ significantly from those experienced historically.

Finally, increasing interdependence of infrastructure systems creates the potential for complex failures.[133] Interdependence of parts of one infrastructure system can be problematic, as illustrated by the massive electrical power blackout experienced by Ontario and large portions of the Midwest and Northeast United States on August 14, 2003. Triggered by a site-specific incident which cascaded into a wider regional failure, the blackout affected roughly 50 million people for up to a week and had a significant negative impact on economic productivity.[134] Interdependence among different infrastructure systems also contributes to vulnerability. For instance, the failure of power transmission infrastructure has direct negative impacts on end users, but also diminishes the capacity of other infrastructure systems to deliver the services they normally provide.[135] Such was the case during the August 2003 blackout: lack of power interrupted thousands of Internet communications portals, leaving millions of individual users and organizations such as banks, educational institutions, government units and hospitals without connectivity for hours or days.[136] For these reasons, interdependencies among infrastructure systems must be considered in planning climate adaptation responses.[137]

---

127 Heather Auld and Don MacIver, *Changing Weather Patterns, Uncertainty and Infrastructure Risks: Emerging Adaptation Requirements*, Occasional Paper 9 (Toronto, ON: Environment Canada, 2007).

128 Statistics Canada, "Portrait of the Canadian Population in 2006: Highlights," March 17, 2008, http://www12.statcan.ca/english/census06/analysis/popdwell/highlights.cfm (accessed December 30, 2008).

129 Joong Gwang Lee and James P. Heaney, "Estimation of Urban Imperviousness and Its Impacts on Storm Water Systems," *Journal of Water Resources Planning and Management* 129 (2003), no. 5, 419–426.

130 Reid Kreutzwiser et al., "Drought Sensitivity of Municipal Water Supply Systems in Ontario," *The Great Lakes Geographer* 9 (2003), no. 2, 59–70.

131 Heather Auld and Don MacIver, *Changing Weather Patterns, Uncertainty and Infrastructure Risks: Emerging Adaptation Requirements*, Occasional Paper 9 (Toronto, ON: Environment Canada, 2007), 4–5.

132 Paul Freeman and Koko Warner, *Vulnerability of Infrastructure to Climate Variability: How Does This Affect Infrastructure Lending Policies?* (Washington, DC: Disaster Management Facility of The World Bank, 2001), 18–19.

133 Stephanie E. Chang et al., "Infrastructure Failure Interdependencies in Extreme Events," *Natural Hazards* 41 (2007), no. 2, 337–358.

134 United States–Canada Power System Outage Task Force, *Interim Report: Causes of the August 14th Blackout in the United States and Canada* (U.S.–Canada Power System Outage Task Force, 2003).

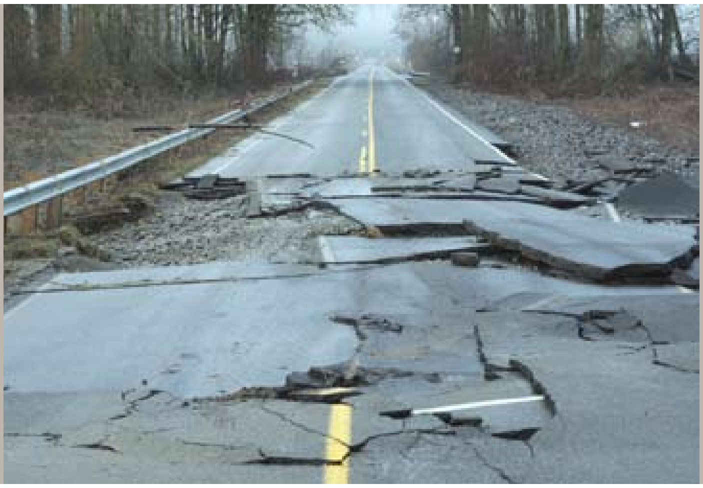
135 Richard G. Little, "Toward More Robust Infrastructure: Observations on Improving the Resilience and Reliability of Critical Systems," in *Proceedings of the 36th Hawaii International Conference on System Sciences* (University of Hawaii at Mānoa, 2002).

136 James H. Cowie et al., *Impact of the 2003 Blackouts on Internet Communications* (Hanover, NH: Renesys Corporation, 2003).

137 See, for example, Paul Kirshen, Matthias Ruth and William Anderson, "Interdependencies of Urban Climate Change Impacts and Adaptation Strategies: A Case Study of Metropolitan Boston USA," *Climatic Change* 86 (2008), no. 1/2, 105–122.

5.1 INFRASTRUCTURE AND CLIMATE ADAPTATION POLICY

Throughout the life cycle of an infrastructure asset—design, build, operate, refurbish, decommission—there are many opportunities for managers to build resilience to extreme weather events.



In light of the risks posed by extreme weather events, reducing the vulnerability of infrastructure systems must be a central objective of community climate adaptation policy. Throughout the life cycle of an infrastructure asset—design, build, operate, refurbish, decommission—there are many opportunities for managers to build resilience to extreme weather events. However, the costs of adaptation are lowest when measures are implemented during new construction. For this reason, adaptation must be mainstreamed into the design and construction of infrastructure, in order to reduce the risk of damage or failure due to extreme weather into the future.[138] Spending on infrastructure has become an increasingly important policy objective of both the federal and provincial governments. Large-scale projects to build or replace infrastructure in the coming years present a tremendous opportunity to ensure these physical systems are resilient to cope with a changing climate.[139]

5.1.1 REDUCING EXPOSURE

Decisions regarding the location of infrastructure components can significantly affect the exposure of these systems to extreme weather events. For instance, in west central British Columbia, linear infrastructure such as electrical transmission lines and pipelines are sometimes located on unstable ground, making them vulnerable to disruption in the event of a landslide triggered by heavy rainfall or rapid snowmelt.[140] Infrastructure exposure to extreme weather events can thus be reduced chiefly by locating (or relocating) critical facilities, such as electrical power generation and transmission structures, away from hazard-prone areas like floodplains or hillsides.[141]

There are limitations here, of course, depending on the type of infrastructure under consideration: changing the location of buildings, for instance, is generally not a feasible means of adapting them to climate change.[142] Where relocation is not feasible, measures should be taken to shield infrastructure components from hazard impacts. For instance, sewage treatment plants are generally built along waterways, and are thus vulnerable to flooding due to heavy rainfall events. Although new facilities can be built on higher ground to reduce the flood risk, protecting existing facilities may require the use of dykes or other floodproofing measures to prevent damages.

138 Monirul Mirza, "Mainstreaming Climate Change for Extreme Weather Events and Management of Disasters: An Engineering Challenge," in *Proceedings of the Engineering Institute of Canada Climate Change Technology Conference* (Ottawa, ON, May 10–12, 2006).

139 Steven Chase, Daniel Leblanc and Brian Laghi, "Tories to Pump $7-Billion into Public Works," *Globe & Mail*, January 26, 2009.

140 M. Geertsema et al., "Landslides Impacting Linear Infrastructure in West Central British Columbia," *Natural Hazards* 48 (2008), no. 1, 59–72.

141 Terrain Group, *Government Roles in Climate Change Adaptation for Urban Infrastructure* (Ottawa, ON: Natural Resources Canada, 2007), 68.

142 Takahiko Hasegawa, "Climate Change, Adaptation and Government Policy for the Building Sector," *Building Research & Information* 32 (2004), no. 1, 62.

5.1.2 REDUCING SENSITIVITY

In seeking to reduce the sensitivity of infrastructure systems to extreme weather events, a high priority should be given to measures which increase their resilience—that is, their ability to withstand stresses without suffering a loss of function, and to recover quickly in the event that a failure occurs.[143] To ensure that new infrastructure components are robust enough to withstand stresses associated with more frequent and intense extreme weather events, it may be necessary to design and build these systems to higher standards than are currently used. For example, design standards for drainage infrastructure based on historical hydrometric records are likely to be inadequate to cope with a more active hydrological cycle. One practical approach might be to design infrastructure systems for present climatic conditions, while building in flexibility to add additional capacity when required. Alternatively, infrastructure components might be built with a shorter design life, and then retrofitted or replaced as changing climate conditions require.[144] Both strategies have economic implications, and will thus require innovative solutions developed through partnerships between government and industry.

Integrating resilience to extreme weather into new infrastructure requires engagement with key actors such as engineers and contractors at the pre-construction stage.[145] Given that many new infrastructure projects are contracted out to private firms, local governments have an opportunity to incorporate resilience by including adaptation criteria in requests for proposals. Although local governments have an important role in monitoring and enforcing standards at the construction stage, changes to design requirements for new infrastructure will require action by provincial governments. Furthermore, the Government of Canada also has a central role here in supervising the development of industry-wide codes and standards for new construction.

In addition to incorporating resilience into the design and construction of new infrastructure, action is required to make existing infrastructure systems more resilient to climate hazards. As an example, experts offer a number of practical measures to adapt existing stormwater management infrastructure to cope with extreme weather.[146] Roof rainwater leaders that currently discharge directly into the community storm sewer system could be disconnected, and the water could be allowed to drain onto lawns, into underground cisterns, or into rain barrels. Alternatively, berms could be constructed around large open spaces such as parks in order to use the areas for temporary water storage during heavy rainfall events. Retrofitting options exist for other types of infrastructure as well. For instance, the technology is available to make existing communication systems virtually "disaster-proof", in order to ensure their continued functionality in the aftermath of extreme weather events.[147] Although such adaptation measures might be implemented voluntarily by infrastructure managers or business firms, governments must be prepared to mandate standards and practices in order to increase community resilience to extreme weather events. Forums for dialogue between governments and private sector infrastructure managers should be used to discuss climate change and extreme weather events, with the objective of identifying effective and efficient adaptation measures.

5.1.3 INCREASING ADAPTIVE CAPACITY

In addition to specific actions to reduce the exposure and sensitivity of infrastructure systems to extreme weather events, equally important is the need to enhance adaptive capacity. One practical strategy is to embed into infrastructure planning a longer-term time horizon, in order to anticipate future climate impacts and to plan adequate responses. Long-term planning exercises can be immensely valuable, as they force participants to think about the ways in which

143 Timothy McDaniels et al., "Fostering Resilience to Extreme Events Within Infrastructure Systems," *Global Environmental Change* 18 (2008), no. 2, 310–318.

144 Hans Arisz and Brian C. Burrell, "Urban Drainage Infrastructure Planning and Design Considering Climate Change," in *Proceedings of the Engineering Institute of Canada Climate Change Technology Conference* (Ottawa, ON, May 10–12, 2006), 1–9.

145 Lee Bosher et al., "Built-in Resilience to Disasters: A Pre-Emptive Approach," *Engineering, Construction and Architectural Management* 14 (2007), no. 5, 434–446.

146 Darren Waters et al., "Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting from Climate Change," *Journal of Environmental Planning and Management* 46 (2003), no. 5, 755–770.

147 William Webb, "Protecting Phone Systems: Making Telecommunications Networks Disaster-Proof," *Ingenia* 26 (2006), 13–17.

climatic conditions could change over several decades, and to map out strategies to cope with these changes. Knowledge generated through a long-term planning process can provide the basis for adaptive management of infrastructure assets in response to actual changes in climatic conditions over time. At the community level, this involves forming a planning team composed of decision-makers, infrastructure managers and operators, climate researchers and applied scientists such as planners and engineers, who can work with climate scenarios to develop practical adaptation strategies.

A high priority for any community climate adaptation strategy must be to raise awareness among public and private-sector actors and to encourage them to integrate an adaptation lens into their operations. An awareness campaign is necessary to convey the importance and value of adaptation, but also to communicate to stakeholders that their participation is necessary in order for community-level adaptation to be effective. For instance, although it seems sensible to increase the capacity of stormwater transmission pipes to accommodate a greater peak flow and volume created by more frequent extreme precipitation events, Watt, Waters and McLean note, "there has been and continues to be a great deal of inertia in urban stormwater policy and design. It remains a challenge to encourage all Canadian provinces and municipalities to use the existing historical rainfall database in their design guidelines, let alone accommodate potential shifts in climate."[148] Although technological adaptation solutions are available, those in a position to implement them must first perceive the need to take action.

Climate-related risks to infrastructure range from gradual changes in temperature and moisture which can increase weathering effects on structures, to more frequent extreme events, which subject systems to heavy loads and threaten to exceed their design capacity. Interdependence heightens the risk of cascading failures which can cripple community activities and pose a serious threat to public health and safety. As noted above, the risk management framework offers a logical and systematic approach to assess these climate risks, and map out strategies to address them. It is recommended here that local governments implement a comprehensive risk management approach to identify, assess and manage risks to infrastructure systems as a central element of community climate adaptation policy. Since many local officials may be unfamiliar with using risk management to facilitate adaptation planning,[149] higher-level governments can make a valuable contribution to this initiative by offering training for local officials.

Finally, regardless of other actions taken to increase the capacity of infrastructure to adapt to more frequent and intense extreme weather events, all communities should plan for infrastructure failures and exhort citizens to prepare to be self-sufficient in the recovery period.[150] Although some citizens prefer to ignore risks, most want to be informed about potential threats so that they can choose whether and how to take action to cope with them.

148 W. Edgar Watt, D. Waters and R. McLean, *Climate Change and Urban Stormwater Infrastructure in Canada: Context and Case Studies* (Toronto, ON: Toronto–Niagara Region Study on Atmospheric Change, 2003), 5.

149 Federation of Canadian Municipalities, *Final Report on Federation of Canadian Municipalities Municipal Infrastructure Risk Project: Adapting to Climate Change* (Ottawa, ON: Natural Resources Canada, 2002), 24.

150 Arjen Boin and Allan McConnell, "Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience," *Journal of Contingencies and Crisis Management* 15 (2007), no. 1, 50–59.

6.0 CONCLUSION

Extreme weather poses a significant risk to public health and safety, and thus demands a purposive and co-ordinated course of action to reduce the vulnerability of communities and to increase their capacity to cope with hazard impacts.

Communities in all parts of Canada are susceptible to extreme weather events, and it is projected that these hazards will increase in frequency and severity due to climate change. Extreme weather poses a significant risk to public health and safety, and thus demands a purposive and co-ordinated course of action to reduce the vulnerability of communities and to increase their capacity to cope with hazard impacts. Although this report focuses primarily on local adaptation measures in the policy fields of emergency management and infrastructure, these must be part of a broader public policy strategy to increase community resilience, which will require co-ordinated action among all levels of government. The goals, principles and instruments examined here offer guidance for the development of community climate adaptation policy, and provide a blueprint for an intergovernmental framework to support local climate adaptation.

SOURCES

Adejuwon, J. et al. (2001). "Overview of Impacts, Adaptation, and Vulnerability to Climate Change," in McCarthy, J. J. et al. (eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, 77-103.

Adger, W. Neil. (2001). "Scales of Governance and Environmental Justice for Adaptation and Mitigation of Climate Change," *Journal of International Development* 13 (7), 921-931.

Arisz, Hans and Brian C. Burrell. (2006). "Urban Drainage Infrastructure Planning and Design Considering Climate Change," in *Proceedings of the Engineering Institute of Canada Climate Change Technology Conference*, Ottawa, May 10-12, 2006, 1-9.

Auld, Heather, Don Maclver and Joan Klaassen. (2007). *Adaptation Options for Infrastructure under Changing Climate Conditions*. Occasional Paper 10. Toronto: Environment Canada.

Auld, Heather and Don Maclver. (2007). *Changing Weather Patterns, Uncertainty and Infrastructure Risks: Emerging Adaptation Requirements*. Occasional Paper 9. Toronto: Environment Canada.

Austin, Ian and Kent Spencer. (2006). "Insurance Claims Could Hit $80M," *The Province*, 19 December, A4.

Angus, Richard. (2006). "Let us Cut our Trees to Protect our Property," Letter to the Editor, *The Province*, 20 December, A19.

Bhattacharya, Shaoni. (2003). "European Heatwave Caused 35,000 Deaths," *New Scientist*, 10 October 2003.

Boei, William. (2006). "Commuter Chaos on Roads, Transit;" *The Vancouver Sun*, 16.

Bohle, Hans G., Thomas E. Downing and Michael J. Watts. (1994). "Climate Change and Social Vulnerability," *Global Environmental Change* 4 (1), 37-48.

Boin, Arjen, and Allan McConnell. (2007). "Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience," *Journal of Contingencies and Crisis Management* 15 (1), 50-59.

Bosher, Lee et al. (2007). "Built-in Resilience to Disasters: A Pre-Emptive Approach," *Engineering, Construction and Architectural Management* 14 (5), 434-446.

British Columbia. (2004). *Firestorm 2003: Provincial Review*. Victoria: Government of British Columbia.

British Columbia. (2008). *Climate Action Plan*. Victoria, BC: Government of British Columbia.

Brooks, Greg. 2008. "Geomorphic Effects and Impacts from July 1996 Severe Flooding in the Saguenay Area, Quebec." 30 January 2008. <http://gsc.nrcan.gc.ca/floods/saguenay1996/index_e.php> (accessed 29 April 2008).

Brooks, Nick. (2003). *Vulnerability, Risk and Adaptation: A Conceptual Framework*. Working Paper 38, Norwich, UK: Tyndall Centre for Climate Change Research, 3.

Bruce, James P. et al. (2002). *Municipal Risks Assessment: Investigation of the Potential Municipal Impacts and Adaptation Measures Envisioned as a Result of Climate Change*. Ottawa: Global Change Strategies International.

Burby, Raymond J. et al. (2000). "Creating Hazard Resilient Communities Through Land-Use Planning," *Natural Hazards Review* 1 (2), 99-106.

Burton, Ian. (1998). "Climate Adaptation Policies for Canada?," *Policy Options* 19 (4), 6-10.

Burton, Ian. (2005). "Adapt and Thrive: Options for Reducing the Climate Change Adaptation Deficit," *Policy Options* 27 (1), 33-38.

Burton, Ian et al. (2002). "From Impacts Assessment to Adaptation Priorities: The Shaping of Adaptation Policy," *Climate Policy* 2 (2-3), 145-159.

Canadella, Josep G. et al. (2007). "Contributions to Accelerating Atmospheric CO2 Growth from Economic Activity, Carbon Intensity, and Efficiency of Natural Sinks," *Proceedings of the National Academy of Sciences* 104 (47), 18866-18870.

Canadian Council of Ministers of the Environment (CCME). (2003). *Climate, Nature, People: Indicators of Canada's Changing Climate*. Winnipeg: CCME.

Canadian Institute of Planners. (2008). *Climate Change: A Policy Paper*. Ottawa: Canadian Institute of Planners.

Canadian Medical Association. (2008). *No Breathing Room: National Illness Costs of Air Pollution*. Ottawa: Canadian Medical Association.

Canadian Standards Association. (2007). *National Survey of Canada's Infrastructure Engineers about Climate Change*. Ottawa: Canadian Standards Association.

Chang, Stephanie E. et al. (2007). "Infrastructure Failure Interdependencies in Extreme Events," *Natural Hazards* 41 (2), 337-358.

Chase, Steven, Daniel Leblanc and Brian Laghi. (2009). "Tories to Pump $7-Billion into Public Works," *Globe & Mail*, 26 January.

Christensen, Keith M., Martin E. Blair and Judith M. Holt. (2007). "The Built Environment, Evacuations, and Individuals with Disabilities: A Guiding Framework for Disaster Policy and Preparation," *Journal of Disability Policy Studies* 17 (4), 249-254.

Christensen, J.H. et al. (2007). "Regional Climate Projections," in Solomon, S. et al. (eds.), *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, 847-940.

Cohn, Alan D. (2005). "Mutual Aid: Intergovernmental Agreements for Emergency Preparedness and Response," *Urban Lawyer* 37 (1), 1-52.

Conde, Cecilia and Kate Lonsdale. (2004). "Engaging Stakeholders in the Adaptation Process," in Lim, Bo and Erika Spanger-Siegfried (eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, Cambridge, UK: Cambridge University Press, 47-66.

Cowie, James H. et al. (2003). *Impact of the 2003 Blackouts on Internet Communications*. Hanover, NH: Renesys Corporation.

Cutter, Susan, Bryan J. Boruff and W. Lynn Shirley. (2003). "Social Vulnerability to Environmental Hazards," *Social Science Quarterly* 84 (2), 242-261.

Descurieux, Jacques. (2009). *Post-hoc Study of Severe Weather: Snow Storms in the Montréal Area*, 3-9 March 2008. Kelowna, BC: Meteorological Service of Canada.

Deyle, Robert E. et al. (1998). "Hazard Assessment: The Factual Basis for Planning and Mitigation," in Burby, Raymond J. (ed.) *Cooperating with Nature: Confronting Natural Hazards with Land-use Planning and Sustainable Communities*, Washington, DC: Joseph Henry Press, 119-166.

Ehren B. Ngo. (2001). "When Disasters and Age Collide: Reviewing Vulnerability of the Elderly," *Natural Hazards Review* 2 (2), 80-89.

Enarson, Elaine and Betty Hearn Morrow. (1998). *The Gendered Terrain of Disaster*. New York: Praeger Publishers.

Engineers Canada. 2008. *Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure*. Ottawa: Canadian Council of Professional Engineers.

Environment Canada. (2007). "The Top Ten Canadian Weather Stories for 2006." 28 December 2006 <http://www.msc-smc.ec.gc.ca/media/top10/2006/topten2006_e.html> (accessed 14 November 2008).

Etkin, David A. (1995). "Beyond the Year 2000, More Tornadoes in Western Canada? Implications from the Historical Record," *Natural Hazards* 12, 19-27.

Fankhauser, Samuel et al. (2008). "Economic and Policy Instruments to Promote Adaptation," in Agrawala, Shardul and Samuel Fankhauser (eds.), *Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments*, Paris: Organisation for Economic Co-operation and Development, 85-133.

Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment. (2003). *Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners*. Ottawa: Canadian Environmental Assessment Agency.

Federation of Canadian Municipalities. (2002). *Final Report on Federation of Canadian Municipalities Municipal Infrastructure Risk Project: Adapting to Climate Change*. Ottawa: Natural Resources Canada.

Few, Roger, Katrina Brown and Emma L. Tompkins. (2006). *Public Participation and Climate Change Adaptation*. Working Paper 95. Norwich, UK: Tyndall Centre for Climate Change Research.

Flannigan, M.D. and van Wagner, C.E. (1991). "Climate Change and Wildfire in Canada," *Canadian Journal of Forest Research* 21 (1), 66-72.

Flannigan, M. D. et al. (2005). "Future Area Burned in Canada," *Climatic Change* 72 (1-2), 1-16.

Ford, James. (2008). "Emerging Trends in Climate Change Policy: The Role of Adaptation," *International Public Policy Review* 3 (2), 1-16.

Fothergill, Alice and Lori A. Peek. (2004). "Poverty and Disasters in the United States: A Review of Recent Sociological Findings," *Natural Hazards* 32 (1), 89-110.

Fowlie, Jonathan. (2006). "Traffic Snarled; 190,000 Homes Without Power," *The Vancouver Sun*, 12 December, A1.

Francis, David and Henry Hengeveld. (1998). *Extreme Weather and Climate Change*. Ottawa: Environment Canada.

Freeman, Paul and Koko Warner. (2001). *Vulnerability of Infrastructure to Climate Variability: How Does This Affect Infrastructure Lending Policies?* Washington: Disaster Management Facility of The World Bank.

Füssel, Hans-Martin and Richard J. T. Klein. (2006). "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking," *Climatic Change* 75 (3), 301-329.

Geertsema, M. et al. (2008). "Landslides Impacting Linear Infrastructure in West Central British Columbia," *Natural Hazards* 48 (1), 59-72.

Girard, Michel and Michael Mortimer. (2006). *The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change*. Ottawa: Canadian Standards Association.

Halifax Regional Municipality. (2007). *Climate Change: Developer's Risk Management Guide*. Halifax, NS: Halifax Regional Municipality.

Hare, Bill and Malte Meinshausen. (2006). "How Much Warming are We Committed to and How Much can be Avoided?," *Climatic Change* 75 (1-2), 111-149.

Hasegawa, Takahiko. (2004). "Climate Change, Adaptation and Government Policy for the Building Sector," *Building Research & Information* 32 (1), 61-64.

Hengeveld, Henry, Bob Whitewood and Angus Fergusson. (2005). *An Introduction to Climate Change: A Canadian Perspective*. Downsview, ON: Environment Canada.

Henstra, Dan and Gordon McBean. (2005). "Canadian Disaster Management Policy: Moving Toward a Paradigm Shift?," *Canadian Public Policy* 31 (3), 303-318.

Hunter, Stuart. (2006). "Mayor Seeks Emergency Funds," *The Province*, 21 December, A4.

Hy, Ronald John and William L. Waugh, Jr. (1990). "The Function of Emergency Management," in William L. Waugh, Jr. and Ronald John Hy (eds.), *Handbook of Emergency Management*. Westport, CT: Greenwood Publishing Group, 11-26.

Infrastructure Canada. (2006). *Adapting Infrastructure to Climate Change in Canada's Cities and Communities*: A Literature Review. Ottawa: Research & Analysis Division, Infrastructure Canada.

Intergovernmental Panel on Climate Change. (2007). "Summary for Policymakers," in Metz, B. et al. (eds.), *Climate Change 2007: Mitigation of Climate Change*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2007). "Summary for Policymakers," in Parry, M.L. et al. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change. (2007). "Summary for Policymakers," in Solomon, S. et al. (eds.), *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press.

Jones, Roger and Rizaldi Boer. (2004). "Assessing Current Climate Risks," in Lim, Bo and Erika Spanger-Siegfried (eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, Cambridge, UK: Cambridge University Press, 91-117.

Kerry, Mara et al. (1999). "Glazed Over: Canada Copes With the Ice Storm of 1998," *Environment* 41 (1), 6-11; 28-32.

Kharin, Viatcheslav V. and Francis W. Zwiers. (2005). "Estimating Extremes in Transient Climate Change Simulations," *Journal of Climate* 18 (8), 1156-1173.

King, David. (2000). "You're on Your Own: Community Vulnerability and the Need for Awareness and Education for Predictable Natural Disasters," *Journal of Contingencies and Crisis Management* 8 (4), 223-228.

Kirshen, Paul, Matthias Ruth and William Anderson. (2008). "Interdependencies of Urban Climate Change Impacts and Adaptation Strategies: A Case Study of Metropolitan Boston USA," *Climatic Change* 86 (1-2), 105-122.

Kovacs, Paul et al. (2007). *Understanding the Significance of Insurance, Alternative Risk Spreading Mechanisms, and Related Public Policy for the Risk Management of Physical Infrastructure in the Face of Climate Change in the Yukon, Northwest Territories and Nunavut*. Report prepared for the National Round Table on the Environment and the Economy. Toronto: Institute for Catastrophic Loss Reduction.

Kreutzwiser, Reid et al. (2003). "Drought Sensitivity of Municipal Water Supply Systems in Ontario," *The Great Lakes Geographer* 9 (2), 59-70.

Larsson, Nils. (2003). "Adapting to Climate Change in Canada," *Building Research & Information* 31 (3/4), 231-239.

Lecomte, Eugene L., Alan W. Pang and James W. Russell. (1998). *Ice Storm '98*. Toronto: Institute for Catastrophic Loss Reduction.

Lee, Joong Gwang and James P. Heaney. (2003). "Estimation of Urban Imperviousness and its Impacts on Storm Water Systems," *Journal of Water Resources Planning and Management* 129 (5), 419-426.

Lemmen, Donald S., Fiona J. Warren and Jacinthe Lacroix. (2008). "Synthesis," in Lemmen, Donald S. (eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007*, Ottawa: Government of Canada, 1-20.

Ligeti, Eva, Jennifer Penney and Ireen Wieditz. (2007). *Cities Preparing for Climate Change: A Study of Six Urban Regions*. Toronto: Clean Air Partnership.

Little, Richard G. (2002). *Toward More Robust Infrastructure: Observations on Improving the Resilience and Reliability of Critical Systems*. Proceedings of the 36th Hawaii International Conference on System Sciences: University of Hawaii at Mãnoa.

Loukas, Athanasios and Michael C. Quick. (1999). "The Effect of Climate Change on Floods in British Columbia," *Nordic Hydrology* 30 (3), 231-256.

McBean, G. A. (2005). "Risk Mitigation Strategies for Tornadoes in the Context of Climate Change and Development," *Mitigation and Adaptation Strategies for Global Change* 10 (3), 357-366.

McBean, Gordon. (2004). "Climate Change and Extreme Weather: A Basis for Action," *Natural Hazards* 31 (1), 177-190.

McBean, Gordon and Dan Henstra. (2003). *Climate Change, Natural Hazards and Cities*. Toronto: Institute for Catastrophic Loss Reduction.

McDaniels, Timothy et al. (2008). "Fostering Resilience to Extreme Events Within Infrastructure Systems," *Global Environmental Change* 18 (2), 310-318.

McEntire, David A. (2001). "Triggering Agents, Vulnerabilities and Disaster Reduction: Towards a Holistic Paradigm," *Disaster Prevention and Management* 10 (3), 189-196.

McEntire, David A. (2005). "Why Vulnerability Matters: Exploring the Merit of an Inclusive Disaster Reduction Concept," *Disaster Prevention and Management* 14 (2), 206-222.

McEntire, David A and Amy Myers. (2004). "Preparing Communities for Disasters: Issues and Processes for Government Readiness," *Disaster Prevention and Management* 13 (2), 140-152.

Meehl, G.A. et al. (2007). "Global Climate Projections," in Solomon, S. et al. (eds.), *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, 747-845.

Mirza, M. Saeed and Murtaza Haider. (2003). *The State of Infrastructure in Canada: Implications for Infrastructure Planning and Policy*. Ottawa: Research and Analysis Division, Infrastructure Canada.

Mirza, Monirul. (2006). "Mainstreaming Climate Change for Extreme Weather Events and Management of Disasters: An Engineering Challenge," in *Proceedings of the Engineering Institute of Canada Climate Change Technology Conference*, Ottawa, May 10-12, 2006.

Morris-Oswald, Tonia, and A. John Sinclair. 2005. "Values and Floodplain Management: Case Studies from the Red River Basin, Canada." *Environmental Hazards* 6 (1), 9-22.

Morrow, Betty Hearn. (1999). "Identifying and Mapping Community Vulnerability," *Disasters* 23 (1), 1-18.

Mortimer, Michael and Jeff Walker. (2007). *Climate Change and Infrastructure Engineering: Moving Towards a New Curriculum*. Ottawa: Canadian Standards Association.

Mukheibir, Pierre and Gina Ziervogel. (2007). "Developing a Municipal Adaptation Plan for Climate Change," *Environment and Urbanization* 19 (1), 143-158.

New Brunswick. (2007). *Climate Change Action Plan 2007-2012*. Fredericton, NB: New Brunswick Climate Change Secretariat, Department of Environment.

New Brunswick. (2008). *Climate Change Action Plan 2007-2008 Progress Report*. Fredericton, NB: New Brunswick Climate Change Secretariat, Department of Environment.

Niang-Diop, Isabelle and Henk Bosch. (2004). "Formulating an Adaptation Strategy," in Lim, Bo and Erika Spanger-Siegfried (eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, Cambridge, UK: Cambridge University Press, 183-204.

Noble, David, Jim Bruce and Mark Egener. (2005). *An Overview of the Risk Management Approach to Adaptation to Climate Change in Canada*. Ottawa: Natural Resources Canada.

O'Brien, Karen, Linda Sygna and Jan Erik Haugen. (2004). "Vulnerable or Resilient? A Multi-Scale Assessment of Climate Impacts and Vulnerability in Norway," *Climatic Change* 64 (1), 193-225.

Office of the Auditor General of Canada. (2008). "Managing Severe Weather Warnings: Environment Canada," in *Report of the Commissioner of the Environment and Sustainable Development*, December 2008. Ottawa: Minister of Public Works and Government Services Canada.

Ontario. (2007). "Ontario Commits Climate Change Funding For Adaptation." 12 December 2007. <http://www.ene.gov.on.ca/en/news/2007/121201.php> (accessed 16 December 2008).

Parry, M.L. et al. (2007). "Technical Summary," in Parry, M.L. et al. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 23-78.

Paton, Douglas and David Johnston. (2001). "Disasters and Communities: Vulnerability, Resilience and Preparedness," *Disaster Prevention and Management* 10 (4), 270-277.

Perry, Ronald W. and Lawrence D. Mankin. (2005). "Preparing for the Unthinkable: Managers, Terrorism and the HRM Function," *Public Personnel Management* 34 (2), 175-193.

Pielke Jr., Roger A. (1998). "Rethinking the Role of Adaptation in Climate Policy," *Global Environmental Change* 8 (2), 159-170.

Poumadère, Marc et al. (2005). "The 2003 Heat Wave in France: Dangerous Climate Change Here and Now," *Risk Analysis* 25 (6), 1483-1494.

Public Safety Canada. (2007). "Freezing Rain: Ontario to New Brunswick, 1998." *Canadian Disaster Database*. 19 November 2007. <http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp> (Accessed 15 December 2008).

Public Safety Canada. (2007). "Tornado: Pine Lake AB, 2000." *Canadian Disaster Database*. 19 November 2007 < http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp> (accessed 15 December 2008).

Public Safety Canada. (2003). *Threats to Canada's Critical Infrastructure*. Threat Analysis TA03-001. Ottawa: Government of Canada.

Public Safety Canada. (2008). *Canada's National Disaster Mitigation Strategy*. <http://www.publicsafety.gc.ca/prg/em/ndms/_fl/NDMS_Web_E.pdf) (accessed 2 February 2009).

Price, C. and Rind, D. (1994). "The Impact of a 2×CO_2 Climate on Lightning-Caused Fires," *Journal of Climate*, 7 (10), 1484-1494.

Raupach, Michael R. et al. (2007). "Global and Regional Drivers of Accelerating CO_2 Emissions," *Proceedings of the National Academy of Sciences* 104 (24), 10288-10293.

Rickett, Chris, Erin Shapero and Elio Di Iorio. (2006). "Downloading Climate Change: Municipalities are Bearing the Costs," *Municipal World* 116 (11), 27-29.

Robinson, Pamela J. and Christopher D. Gore. (2005). "Barriers to Canadian Municipal Response to Climate Change," *Canadian Journal of Urban Research* 14 (1), 102-120.

Runyan, Rodney C. (2006). "Small Business in the Face of Crisis: Identifying Barriers to Recovery from a Natural Disaster," *Journal of Contingencies and Crisis Management* 14 (1), 12-26.

Sancton, Andrew. (2006). "Cities and Climate Change: Policy-Takers, not Policy-Makers," *Policy Options* 27 (8), 32-34.

Schröter, Dagmar, Colin Polsky and Anthony G. Patt. (2005). "Assessing Vulnerabilities to the Effects of Global Change: An Eight Step Approach," *Mitigation and Adaptation Strategies for Global Change* 10 (4), 573-595.

Simpson, David M. (2001). "Community Emergency Response Training (CERTs): A Recent History and Review," *Natural Hazards Review* 2 (2), 54-63.

Smit, Barry and Olga Pilifosova. (2003). "From Adaptation to Adaptive Capacity and Vulnerability Reduction," in Smith, Joel B, Richard J.T. Klein and Saleemul Huq (eds.), *Climate Change, Adaptive Capacity and Development*, Potsdam: Potsdam Institute for Climate Impact Research, 1-20.

Smit, Barry et al. (2000). "An Anatomy of Adaptation to Climate Change and Variability," *Climatic Change* 45 (1), 223-251.

Smit, Barry et al. (2001). "Adaptation to Climate Change in the Context of Sustainable Development and Equity," in McCarthy, J.J. et al. (eds.), *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 877-912.

Smoyer-Tomic, Karen E., Robyn Kuhn and Alana Hudson. (2003). "Heat Wave Hazards: An Overview of Heat Wave Impacts in Canada," *Natural Hazards* 28 (2), 463-485.

Snover, A.K. et al. (2007). *Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments*. Oakland, CA: ICLEI – Local Governments for Sustainability.

Solis, Gabriela Y. et al. (1995). *Disaster Debris Management*. Ottawa: Emergency Preparedness Canada.

Sorensen, John H. (2000). "Hazard Warning Systems: Review of 20 Years of Progress," *Natural Hazards Review* 1 (2), 119-125.

Stern, Nicholas Herbert. (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Terrain Group. (2007). *Government Roles in Climate Change Adaptation for Urban Infrastructure*. Ottawa: Natural Resources Canada.

Thomalla, Frank et al. (2006). "Reducing Hazard Vulnerability: Towards a Common Approach Between Disaster Risk Reduction and Climate Adaptation," *Disasters* 30 (1), 39-48.

Trenberth, K.E. et al. (2007). "Observations: Surface and Atmospheric Climate Change," in Solomon, S. et al. (eds.), *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK: Cambridge University Press, 235-336.

United Nations International Strategy for Disaster Reduction. (2005). *Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters*. Geneva: United Nations.

United States-Canada Power System Outage Task Force. (2003). *Interim Report: Causes of the August 14th Blackout in the United States and Canada*. U.S.-Canada Power System Outage Task Force.

Warren, Fiona J. and Paul Egginton. (2008). "Background Information: Concepts, Overviews and Approaches," in Lemmen, Donald S. et al. (eds.), *From Impacts to Adaptation: Canada in a Changing Climate 2007*. Ottawa: Government of Canada, 48-51.

Waters, Darren et al. (2003). "Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting from Climate Change," *Journal of Environmental Planning and Management* 46 (5), 755-770.

Watt, W. Edgar, D. Waters and R. McLean. (2003). *Climate Change and Urban Stormwater Infrastructure in Canada: Context and Case Studies*. Toronto: Toronto-Niagara Region Study on Atmospheric Change.

Weaver, Andrew J. (2008). *Keeping Our Cool: Canada in a Warming World*. Toronto: Viking Canada.

Webb, Gary R., Kathleen J. Tierney and James M. Dahlhamer. (2000). "Businesses and Disasters: Empirical Patterns and Unanswered Questions," *Natural Hazards Review* 1 (2), 83-90.

Webb, William. (2006). "Protecting Phone Systems: Making Telecommunications Networks Disaster-Proof," *Ingenia* 26, 13-17.

White, Rodney and David Etkin. (1997). "Climate Change, Extreme Events and the Canadian Insurance Industry," *Natural Hazards* 16, v135-163.

Wigley, T.M.L. (2005). "The Climate Change Commitment," *Science* 307 (5716), 1766-1769.

Wilbanks, T.J. et al. (2007). "Industry, Settlement and Society," in M.L. Parry et al. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 357-390.

Wood, Vincent T. and Robert A. Weisman. (2003). "A Hole in the Weather Warning System: Improving Access to Hazardous Weather Information For Deaf and Hard of Hearing People," *Bulletin of the American Meteorological Society* 84 (2), 187-194.

Wotton, B.M. and Flannigan, M.D. (1993). "Length of the Fire Season in a Changing Climate," *Forestry Chronicle 69* (2), 187-192.

Yohe, Gary and Richard S. J. Tol. (2002). "Indicators for Social and Economic Coping Capacity: Moving Toward a Working Definition of Adaptive Capacity," *Global Environmental Change* 12 (1), 25-40.

Zhang, Xuebin et al. (2000). "Temperature and Precipitation Trends in Canada During the 20th Century," *Atmosphere-Ocean* 38 (3), 395-429.

Zwiers, Francis W. and Viatcheslav V. Kharin. (1998). "Changes in the Extremes of the Climate Simulated by CCC GCM2 under CO_2 Doubling," *Journal Of Climate* 11 (9), 2200-2222.

ACT (ADAPTATION TO CLIMATE CHANGE TEAM)

SFU Vancouver
515 West Hastings Street
Vancouver, BC V6B 5K3
TEL: (604) 671-2449
E-MAIL: adapt@sfu.ca

WWW.SFU.CA/ACT