Infrastructure Canada

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ADAPTING INFRASTRUCTURE TO CLIMATE CHANGE IN CANADA'S CITIES AND COMMUNITIES

A Literature Review

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Adapting Infrastructure to Climate Change in Canada's Cities and Communities

A Literature Review

Section 1: Introduction

Due to climate change Canada's infrastructure is increasingly forced to withstand more frequent and extreme weather events, more climate variability, and changes in climate norms (average conditions).[1] Numerous climate changes have already occurred, such as a one degree Celsius increase in the Canadian mean temperature, increased rainfall intensity, and increased intensity and frequency of severe winter storms.[2] These changes are all projected to worsen over time, including an increase of 2 to 4 degrees Celsius in the Canadian mean temperature by 2040-2060.[3] The changes will impact infrastructure in a number of ways,[4] but the impacts will vary regionally. For example, in northern Canada permafrost is thawing, causing pipeline, road, and building instabilities.[5] Thawing permafrost could also cause the rupture of drinking water and sewage lines, the rupture of sewage storage tanks, and seepage from sewage storage lagoons.[6] In other areas, changes such as declines in river flows and water levels, higher water temperatures, storm surges, and heavier short duration rainfalls are expected to cause impacts such as a decline in hydroelectric power, declining water supplies, water quality problems, flash floods and overtaxing of drainage facilities.[7] In order to ensure that public infrastructure such as roads, bridges, communications structures, water and wastewater infrastructure, border crossings, energy transmission networks, and public buildings can safely provide essential services and support economic activities, they must continually be adapted to the impacts of climate change.[8]

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[1] Concerns related to climate change originally focused only on long-term changes in temperature means or norms (hence the term "global warming"). Climate change, however, includes not only an increase in global mean surface temperature, but also changes in climate variability and changes in extreme climate events.

[2] Noble, D., J. Bruce and M. Egener, *An Overview of the Risk Management Approach to Adaptation to Climate Change in Canada,* A report prepared for the Climate Change Impacts and Adaptation Directorate, Natural Resources Canada (Ottawa: Global Change Strategies International, 2005).

[3] Noble *et al.*

[4] It is important to note that small increases in weather and climate extremes are expected to have the potential to bring large increases in damage to existing infrastructure: "Studies indicate that damage from extreme weather events tends to increase dramatically above critical thresholds, even though the high impact storms associated with damages may not be much more severe than the type of storm intensity that occurs regularly each year." (Auld, H. and D. MacIver, *Changing Weather Patterns, Uncertainty and Infrastructure Risks: Emerging Adaptation Requirements,* (Toronto: Environment Canada, Adaptation and Impacts Research Group, 2006).)

[5] Noble *et al.*

[6] Lemmen, D.S., and F.J. Warren, eds., *Climate Change Impacts and Adaptation: A Canadian Perspective* (Ottawa: Natural Resources Canada, 2004).

[7] Noble *et al.*

[8] The definition of climate change used in this report is taken from the Intergovernmental Panel on Climate Change (IPCC), which defines climate change as "any change in climate over time, whether due

Canada is a global leader in climate change adaptation.[9] In fact, according to a global vulnerability assessment conducted in 2001, Canada has the highest resiliency to climate change, followed by Australia.[10] In addition to Infrastructure Canada (INFC), numerous federal government departments and agencies are involved in research on climate change adaptation for infrastructure: Natural Resources Canada, Environment Canada, Fisheries and Oceans Canada, Transport Canada, Industry Canada, Agriculture and Agri-Food Canada, Parks Canada, Health Canada, the National Research Council, Indian and Northern Affairs, and Public Safety and Emergency Preparedness Canada are either leading, or partners in, research projects related to climate change adaptation for infrastructure.

More specifically, INFC considers adaptation in its various funding programs. For example, proponents applying to the Canadian Strategic Infrastructure Fund (CSIF) for funding are required, under the program's policy leveraging framework, to demonstrate how their project addresses climate change impacts and adaptation. Proponents may be required to take certain measures to address these issues.[11] Also, most CSIF projects, except for some broadband projects, trigger an environmental assessment under the *Canadian Environment Assessment Act*. For example, a sewer distribution project will be required, under the Act, to reflect the impacts of projected future precipitation and wet weather flows in its design.

An example is the Red River floodway expansion project, which was funded by INFC and triggered the requirement for an environmental assessment under the CEAA. As part of the assessment, the proponent considered both the design requirements to provide the City of Winnipeg with 1 in 700 year protection from spring floods and

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to natural variability or as a result of human activity." (McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken and K.S. White, 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 (IPCC), (Cambridge: Cambridge University Press, 2001). Available online at http://www.grida.no/climate/ipcc_tar/wg2/index.htm . Accessed November 2006.)

[9] Address by Dr. D. Lemmen at the Conference *Adapting to Climate Change in Canada 2005: Understanding Risks and Building Capacity, May 2005.* http://adaptation2005.ca/may4_don_lemmen_e.html (Accessed November 2006).

[10] Richard Moss of the Pacific Northwest National Laboratory conducted the vulnerability assessment. The results were cited in United Nations Environment Programme, *Vulnerability Indices for Planning Climate Change Adaptation*. Training Workshop on National Adaptation Programme of Action (NAPA) 6-8 March, Apia, Samoa. see http://www.unitar.org/ccp/samoa/UNEP%20VA%20Indices.pdf (Accessed November 2006). The Government of Australia released a significant adaptation report in 2005: Government of Australia, *Climate Change Risk and Vulnerability: Promoting an efficient adaptation response in Australia, Final Report*. A report prepared by the Allen Consulting Group for the Australian Greenhouse Office, Department of the Environment and Heritage. (Canberra: Department of the Environment and Heritage, 2005). Available online at http://www.greenhouse.gov.au/impacts/publications/risk-vulnerability.html (Accessed November 2006). In addition to the report, the Australian Government allocated $14.2 million for a National Climate Change Adaptation Programme, which is assisting governments, industry, and communities with the development of adaptation plans. (Media Release, Minister for the Environment and Heritage, Senator the Hon. Ian Campbell 26 July 2005, A Changing Climate: Planning our response. Available online at http://www.deh.gov.au/minister/env/2005/mr26jul05.html (Accessed November 2006).)

[11] Personal communication, Oct.24, 2006.

operations requirements to manage projected increases in the intensity and frequency of major storm events at other times of the year. Another example is the consideration that was given to the possible impact of rising sea levels resulting from climate change during the federal-provincial environmental assessment of the Vancouver Convention Centre Expansion Project (VCCEP). Funded in part by INFC, the VCCEP footprint covers over 4.5 hectares, of which 56% is located on existing land and the remaining 44% over the near-shore waters of Coal Harbour in downtown Vancouver.[12]

These two requirements – to demonstrate climate change impacts and adaptation under the policy leveraging framework of CSIF and to address climate change impacts and adaptation for INFC projects that trigger the CEAA – are two ways that the department currently recognizes climate change adaptation.

With the goal of facilitating an examination of this recognition, the Research and Analysis Division of INFC prepared this report, *Adapting Canada's Infrastructure to Climate Change*, to provide an overview of literature related to climate change adaptation and infrastructure in Canada. In addition to providing such an overview, the report's objectives also include: improving knowledge and understanding around climate change adaptations for infrastructure in Canadian cities and communities and presenting key research findings.[13] It focuses on anticipatory and planned adaptation, which includes activities taken before impacts are observed and resulting from deliberate policy decisions.[14]

Context and overview of the report

The concept of climate change *adaptation* is relatively new.[15] Research and concern regarding climate change and its potential impacts gained momentum only slowly during the 20th century, finally capturing the world's attention in the 1980s when scientists, government agencies, and politicians repeatedly warned that climate change was not a theoretical problem, but was occurring and that serious impacts were already apparent.[16] During the 1990s, the impacts of climate change became more obvious, and scientists and policy makers realized that mitigation[17], though necessary for reducing impacts, would not prevent climate change from occurring.[18] Climate change research

[12] Personal communication, Nov.2, 2006.
[13] This report is focused on adaptations for public infrastructure. It also includes adaptations for cities and communities, including urban planning, coastal management and disaster management. While it does cover engineering changes needed for buildings and other infrastructure, it does not include adaptive changes to architectural design, which are not yet well documented and are beyond the scope of this paper.
[14] The IPCC distinguishes anticipatory adaptation from reactive adaptation, and autonomous from planned adaptation. (See Lemmen and Warren for a good explanation of the differences.)
[15] Smit, B., Burton, I., Klein, R.J.T. and R. Street, "The science of adaptation: a framework for assessment," *Mitigation and Adaptation Strategies for Global Change*, 4 (3/4) (1999): 199-213.
[16] For examples, see http://www.aip.org/history/climate/Internat.htm#L_M052 . (Accessed November 2006).
[17] The IPCC defines mitigation as "an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases." (McCarthy *et al*.)
[18] Lemmen and Warren.

evolved rapidly and its focus transitioned from impacts and mitigation to also include adaptation. In contrast to mitigation, which involves addressing the causes of climate change, adaptation refers to activities "that minimize the negative impacts of climate change, and/or position us to take advantage of new opportunities that may be presented."[19]

Canada produced its first national assessment of climate change impacts and adaptation, *The Canada Country Study*, in 1998.[20] Based on a review of the existing scientific and technical literature, the study includes eight volumes: six regional volumes, a national sectoral volume (including sectors such as built environment, energy, insurance, transportation, and water resources) and a cross-cutting issues volume. Natural Resources Canada (NRCan) followed up with an updated examination of the impacts of climate change and potential adaptive responses in 2004: *Climate Change Impacts and Adaptation: A Canadian Perspective*.[21] NRCan manages for the federal government a horizontal government program on climate change adaptation, the Climate Change Impacts and Adaptation Program. Through this program, the federal government has sponsored numerous research projects and a conference in 2005 on climate change adaptation.[22] To date, however, little action has been taken at the federal level to implement infrastructure adaptation measures or to facilitate adaptation in other jurisdictions; however, interest is growing within government and the private sector.

The Commissioner of the Environment and Sustainable Development concluded in her 2006 Report, "the government has not yet put in place key measures to support Canadians in adapting to a changing climate. Nor has it clarified how it intends to manage its own adaptation efforts."[23] The report explains that although federal departments have "made limited progress in using available information about the changing climate to assess potential implications on federal policies and programs… there is a lack of up-to-date climate information for use in adapting the design of infrastructures…"[24] Challenges faced in adapting to climate change are not only at the federal level. According to a report produced by Natural Resources Canada in 2006, Canadian municipalities have demonstrated leadership in their mitigation efforts but have given far less attention to adaptation.[25] Much work is needed on climate change adaptation in Canada, and particularly adaptation for infrastructure.

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[19] *Ibid.*, p.9.

[20] Environment Canada. *The Canada Country Study: Climate Impacts and Adaptation* (Ottawa: Environment Canada, 1998).

[21] Lemmen and Warren.

[22] For more information on the Climate Change Impacts and Adaptation Program, see http://adaptation.nrcan.gc.ca/index_e.php (Accessed November 2006).

[23] Government of Canada, *The 2006 Report of the Commissioner of the Environment and Sustainable Development to the House of Commons*, "Chapter 2: Adapting to the Impacts of Climate Change" (Ottawa: Office of the Auditor General, 2006). Available online at http://www.oag-bvg.gc.ca/domino/reports.nsf/html/c2006menu_e.html (Accessed November 2006).

[24] *Ibid.,* chapter 2, p.2.

[25] Mehdi, B, ed., *Adapting to Climate Change: An Introduction for Canadian Municipalities* (Ottawa: Natural Resources Canada, Canadian Climate Impacts and Adaptation Research Network, 2006).

The report is divided into four sections. This first section serves as an introduction and identifies the objectives of the report. Section two describes the challenges associated with, and processes used for, assessing adaptation responses. Section three reviews literature and research related to infrastructure and climate change adaptation in Canada. Section four provides a summary of the key observations found in the literature.

Section 2: Adaptation Processes

To some extent, communities have always adapted to climate and weather by making adjustments for existing climate variability and extremes. With climate change, adaptation requires both adjustments to present climate as well as to future climates. Climate change research involves innumerable uncertainties and estimations. Our incomplete understanding of climate processes, the interacting scientific and socio-economic variables that influence climate change, and the unknown future societal responses to climate change, make it extremely difficult to predict future climate scenarios and the impacts of those conditions on infrastructure. Due to these uncertainties, determining climate change adaptation strategies is a difficult and complex exercise. Furthermore, climate change impacts and adaptation are dynamic, changing over time. Consequently, adaptation necessitates an iterative process.

Researchers have developed numerous tools and approaches for assessing adaptation options. In the past, impact assessments used climate scenarios as the starting point for determining potential impacts and adaptive responses. Today, experts prefer a new approach for adaptation policy development – the vulnerability approach.[26] The vulnerability approach is an iterative process involving five steps:

- engage stakeholders;
- assess current vulnerability;
- estimate future conditions;
- estimate future vulnerability; and
- assess and implement options.[27]

Whereas the starting point for an impact assessment is average climate conditions as determined by climate scenarios, the starting point for a vulnerability assessment is the system (e.g., community, region or sector).[28] The vulnerability approach builds a strong foundation of knowledge regarding an area and its vulnerability before laying future climate scenarios over that matrix, and in this way the high degree of uncertainty associated with the old approach is reduced. Another advantage is the issue of scale.

[26] Besides NRCan's Climate Change Impacts and Adaptation Program, many international organizations and initiatives now use the vulnerability approach. (Smit, B. and O. Pilifosova, "From adaptation to adaptive capacity and vulnerability reduction," *in Climate Change, Adaptive Capacity and Development*, (ed.) J.B. Smith, R.J.T. Klein and S. Huq (London, UK: Imperial College Press, 2003) p. 9–28.)
[27] Lemmen and Warren, p.17.
[28] Smit and Pilifosova.

Climate scenarios often provide information on a global or large regional scale, while vulnerability assessments can be done on a much smaller scale.[29]

The vulnerability approach is based on the concept of vulnerability, which is defined by the Intergovernmental Panel on Climate Change (IPCC) as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes."[30] In other words, the vulnerability approach takes into consideration not only the impacts predicted by climate scenarios[31] and socio-economic scenarios, but also a system's capacity for coping with those impacts. A city that is able to adapt to serious climate change impacts may be less vulnerable (i.e., more resilient) than a city that experiences lesser impacts but has no capacity to implement change. The ability to adapt is often dependent upon social and economic factors including the *will* to adapt,[32] which is one reason why stakeholder participation is a key element in the vulnerability approach: by engaging stakeholders, researchers gain a better understanding of what adaptation options may or may not be implemented successfully within a given system.[33] The vulnerability approach provides a comprehensive and systematic framework for climate change adaptation that enables decision-makers to establish priorities and manage risks despite the uncertainties associated with climate change.[34]

Certain attributes of infrastructure influence its adaptability to change. For example, most infrastructure is built to last for several decades: bridges, housing, commercial buildings, seaports, and rail infrastructure typically require reconstruction or major upgrades every 50-100 years; dams, water supply infrastructure, sewers, and airports have an expected lifecycle of 50 years; and roads and waste management facilities require major upgrades every 20-30 years.[35] These life spans create a significant hurdle for climate change adaptation, since the replacement of such structures is economically and logistically impossible. For infrastructure with long life spans "expected changes in climate may occur considerably earlier during the expected service life, possibly forcing expensive reconstruction, retrofit or relocation."[36] Most infrastructure, however, requires upgrades or major refurbishment or, in the case of roads, resurfacing, on a regular basis. Roads need resurfacing every 5-10 years; rail,

[29] Burton, I. , S. Huq, B. Lim, O. Pilifosova, E. L. Schipper. "From Impacts Assessment to Adaptation Priorities: the shaping of adaptation policy." *Climate Policy,* 2 (2002): 145-159.
[30] McCarthy *et al*.
[31] According to the Canadian Institute for Climate Studies, "climate scenarios are descriptions of the future climate that are based on computer models of the atmosphere-ocean system. Each scenario is based on specific assumptions as to how the human socio-economic system will evolve in the future." http://www.cics.uvic.ca/scenarios/primer.cgi?037 (Accessed October 2006).
[32] Burton *et al.*
[33] Lemmen and Warren, p.17.
[34] *Ibid.*
[35] Auld, H., D. MacIver, and J. Klaassen, *Adaptation Options for Infrastructure under Changing Climate Conditions* (Toronto: Environment Canada, Adaptation and Impacts Research Group, 2006).
[36] Mills, B. and J. Andrey, "Climate Change and Transportation: Potential interactions and impacts," in *Conference Proceedings of The Potential Impacts of Climate Change on Transportation*, October 2002. (Washington, D.C.: US Department of Transportation, 2003), p.2. Available online at http://climate.dot.gov/workshop1002/mills.pdf (Accessed November 2006).

airports, and seaports need major refurbishments every 10-20 years; and dams/water supply and waste management infrastructure need major refurbishment every 20-30 years.[37] These timelines are not always followed. Much municipal infrastructure in Canada is in need of maintenance, rehabilitation or replacement. In 2003, Mirza and Haider estimated that the infrastructure deficit in Canada exceeded $100 billion.[38] This is the cost of bringing all municipal infrastructure up to an acceptable level (approximately $44 billion), plus the cost of rehabilitation of all infrastructure under the provincial and federal jurisdictions and the private sector. Clearly, there are limited funds for maintaining our infrastructure and building new infrastructure, let alone researching, re-designing and retrofitting infrastructure for climate change impacts. On the other hand, if so much of our infrastructure is in need of replacement or rehabilitation, then this may be an opportune time for climate change adaptation to become an element of infrastructure design.

According to scientist Heather Auld, climate scientists have not fully tapped our potential for projecting future climate, and the uncertainty associated with climate modelling and projected climate change impacts could diminish substantially in the future.[39] In the mean time, improvements in downscaling methodologies and the development of climate change analyses techniques more appropriate for climate extremes (e.g., statistical map typing methodologies, decision modeling) will no doubt improve confidence in projections of climate change impacts and their implications for climatic design values.[40] Furthermore, new methodologies such as the vulnerability approach will help to make obstacles such as uncertainty surmountable. Although there will always be some uncertainty in climate change research: “Uncertainty regarding the nature of future climate change should not be a basis for delaying adaptation to climate change, but rather serve to focus on adaptation measures that help to address current vulnerabilities through expanding coping ranges and increasing adaptive capacity.”[41]

Section 3: Adaptation Responses

This section reviews the literature on climate change adaptation and infrastructure according to four categories: literature focused on a particular type of infrastructure; literature focused on a specific geographic area such as a region or a province; literature focused more generally on climate change adaptation for cities and communities; and literature related to engineering needs.

The literature emphasizes the importance of “mainstreaming” climate change mitigation and adaptation measures into other decision-making processes rather than creating new policies or policy instruments. Engineers and municipal governments have begun to “mainstream” climate change adaptation. Some adaptation measures are not

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[37] Auld, H., D. MacIver, and J. Klaassen.
[38] M.S. Mirza and M. Haider, *The State of Infrastructure in Canada: Implications for Infrastructure Planning and Policy* (Montréal, QC: McGill University, 2003).
[39] Personal communication, Oct.27, 2006.
[40] Auld and MacIver, 2006.
[41] Lemmen and Warren, p. 28.

explicitly considered "climate change adaptations." They are considered to be measures to reduce vulnerabilities or manage risks; therefore, the literature does not always refer to "climate change adaptation." Some adaptation options are instead discussed within the context of risk management or some other process or function that has "mainstreamed" climate change adaptation into its practice.

3.1 Literature by Type of Infrastructure

Most literature on climate change adaptation that is focused on a particular type of infrastructure deals with water infrastructure or transportation infrastructure. Some literature also includes details on port infrastructure adaptation, and adaptations in the energy sector such as changes to oil and gas pipelines and hydroelectric power generation facilities.[42] This section includes a discussion of water and wastewater infrastructure, and transportation infrastructure. Other types of infrastructure such as electrical distribution structures, buildings, and communications structures are not yet well enough represented in the literature to warrant a discussion here.

3.1.1 Water Supply and Wastewater Infrastructure

In terms of climate change adaptation, water resources are frequently cited as one of the highest priority issues in Canada.[43] Water infrastructure is perhaps the most vulnerable of all types of infrastructure to climate change, and the importance of water to human health, the economy and the environment also make it one of the most critical types of infrastructure. Furthermore, this type of infrastructure has the potential to suffer the greatest damages or losses associated with climate change unless proactive adaptation actions are taken.[44] The impacts of climate change on water infrastructure could result in a myriad of problems such as increased water demand, water apportionment issues, loss of potable water, increased water quality problems, increased risk of flooding, and sewer overflows. One reason for the vulnerability of Canada's water infrastructure to climate change is the fact that municipal infrastructure is increasingly unable to meet adequately local water demands.[45]

Adaptation measures for water infrastructure are controversial because of the uncertainties surrounding climate change impacts and the significant environmental, economic, and social costs associated with building new infrastructure: "many experts advocate avoiding or postponing the construction of large-scale [water] infrastructure until there is greater certainty regarding the magnitude of expected hydrological changes."[46] Instead, much of the literature on water infrastructure adaptation stresses

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[42] For examples, see the project database at NRCan's Climate Change Impacts and Adaptation Program website, http://adaptation.nrcan.gc.ca/projdb/index_e.php . (Accessed November, 2006).
[43] Lemmen and Warren.
[44] Personal communication, October 27, 2006.
[45] Brandes, O.M. and K. Ferguson, *The future in every drop : the benefits, barriers and practice of urban water demand management in Canada* (Victoria, BC: POLIS Project on Ecological Governance, University of Victoria, 2004).
[46] Lemmen and Warren, p.43. Also, according to Dore and Burton: "it is difficult to plan for and justify expensive new projects when the magnitude, timing, and even the direction of the changes at the basin

the importance of implementing "no-regrets" measures. "A "no-regrets" climate change adaptation provides benefits to the community whether anticipated climate changes materialize or not."[47] Examples of "no-regrets" options for water supply and wastewater infrastructure include water conservation and demand management measures, education and awareness to change attitudes about climate change, long-term planning and preparedness for droughts and severe flooding, enhanced water quality protection, renewal of water monitoring efforts, and improved procedures for equitable allocation of water.[48] Many cities and rural communities are already using "no-regrets" adaptations such as watershed planning to respond to water stresses such as low water levels.[49]

In addition to "no-regrets" measures, there are opportunities for mainstreaming climate change into infrastructure planning processes. One example is the Ontario Government's proposed Bill 43, the *Clean Water Act, 2006.* The Act would require municipalities, conservation authorities and other local stakeholders to develop source protection plans at the watershed scale. Source protection plans involve, among other things, the development of a water budget, which would require a water manager to answer questions such as: How much water is available within this watershed, and how much is being used?[50] Including climate change considerations into these practices would mainstream climate change into water management, and, consequently, water infrastructure planning, in Ontario.[51]

The literature explains that the design phase of water infrastructure needs to change to accommodate climate changes. Vulnerability and risk assessments should replace the current dependence on historical climate data. Regularly updated climate design values that reflect the latest changes in regional climate, including precipitation variables, are required for the updating of design codes and standards. Currently, engineers use historical climate records when designing most urban water drainage systems. If precipitation patterns change, urban drainage systems could fail, causing problems such as sewer backups and basement flooding. This has already happened in Stratford, Ontario, where the sewer system failed after an intense rainfall event in 2001. Local residents' basements flooded after that storm and again in 2002 after another intense storm. The municipality is now spending $70 million to retrofit its infrastructure with a 250-year storm design and facing a $250 million class action lawsuit from local

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and regional levels are unknown." (Dore, M.H.I. and I. Burton, *The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions.* A report prepared for the Climate Change Action Fund (Ottawa: Natural Resources Canada, 2001).)

[47] Mehdi, B., p.9.

[48] Lemmen and Warren; Bruce *et al*.

[49] Ivey, J., J. Smithers, R. de Loë, and R. Kreutzwiser. *Strengthening Rural Community Capacity for Adaptation to Low Water Levels.* Report prepared for Natural Resources Canada and the Climate Change Action Fund (Guelph: Department of Geography, University of Guelph, 2001); Mehdi.

[50] Cataraqui Region Conservation Authority. http://www.cataraquiregion.on.ca/management/sourcewaterprotection.htm (Accessed October 2006).

[51] de Loe, R.C. and A. Berg. *Mainstreaming Climate Change in Drinking Water Source Protection in Ontario*. Prepared for Pollution Probe and the Canadian Water Resources Association, Ontario Branch (Ottawa, ON: Pollution Probe, 2006). Available online at http://www.pollutionprobe.org/Publications/Water.htm (Accessed November 2006).

residents who experienced basement flooding.[52] In another example, an extremely heavy thunderstorm event (with rainfall intensity greater than that experienced during Hurricane Hazel[53]) hit northern Toronto on August 19, 2005, resulting in the failure of a culvert under Finch Avenue. "As a result, the entire roadbed of Finch Avenue West at Black Creek was washed downstream, affecting all of the City and utility infrastructure within the road allowance."[54] To date, the storm has cost some $500 million in insured losses due to flooding, collapsed roadways, and lost "buried" infrastructure, not to mention the extreme traffic disruptions caused by the loss of a section of the entire roadbed on Finch Avenue West.[55] In these two examples, the failure of water infrastructure to withstand intense weather events cascaded into multiple infrastructure losses and demonstrates the need for new infrastructure designs that are able to resist a changing climate.

The expense of adapting water infrastructure is a key issue. For example, one study estimated the cost for wastewater treatment adaptation in Canada and found that Niagara region's costs may range from $8 to $24 million, while Toronto's costs may range from $633 million to $9 billion.[56] Rather than costly adaptations such as changes to pipe size, changes and modifications such as increases in reservoir capacity may be sufficient in some cases.[57] A study in North Vancouver found that drainage infrastructure could be "adapted to more intense rainfall events by gradually upgrading key sections of pipe during routine, scheduled infrastructure maintenance."[58] When changes to infrastructure such as pipe size *are* necessary, it is predicted to be less costly than the possible losses due to failed infrastructure.[59] One report recommends that a sliding index anchored to a reference year, much like the Consumer Price Index, should be explored as a useful adaptive instrument for determining appropriate design criteria over a long time period.[60]

In conclusion, although municipalities are beginning to implement some "no-regrets" adaptations for water supply and wastewater infrastructure, more data needs to be collected, more research needs to be conducted, engineering designs need to change, climatic design values need regular updates, and actions need to take place to mainstream climate change adaptation in order to adapt our water infrastructure.

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[52] C. Rickett, Shapero, and E. Di Iorio, "Downloading Climate Change: Municipalities are Bearing the Cost." *Municipal World*, November 2006, pp.27-29.
[53] Toronto and Region Conservation Authority. *Nature Talks Back: 2005 Annual Report*, http://www.trca.on.ca/corporate_info/pdf/AnnualReport2005.pdf (Accessed November 2006).
[54] Crowther, William G., Executive Director, Technical Services and Gary Welsh, General Manager, Transportation Services. Toronto Staff Report to Works Committee regarding Finch Avenue West Culvert Replacement at Black Creek, November 1, 2005.
[55] *Ibid*.; and Personal communication, October 27, 2006.
[56] Dore and Burton.
[57] Lemmen and Warren.
[58] *Ibid*., p.44.
[59] Lemmen and Warren.
[60] Kije Sipi Ltd, *Impacts and Adaptation of Drainage Systems, Design Methods and Politics*, Report prepared for Natural Resources, Canada Climate Change Action Fund (Ottawa: Kije Sipi Ltd, 2001), p.103. Available online at http://adaptation.nrcan.gc.ca/projdb/pdf/43_e.pdf (Accessed Nov. 2006).

3.1.2 Transportation Infrastructure

The current and potential impacts of climate change on transportation infrastructure include both beneficial and detrimental impacts.[61] Beneficial impacts include, for example, reduced winter road maintenance costs as a result of milder winters and the opening of the Northwest Passage.[62] Detrimental impacts are already felt in the North, where warmer temperatures are degrading northern roads and runways, and reducing the usefulness of ice roads and ice bridges.[63] Some elements of Canada's transportation system most vulnerable to climate change include infrastructure such as roads and runways located in permafrost areas, coastal infrastructure, Great Lakes shipping (water levels could drop significantly in the Great Lakes / St. Lawrence Seaway system),[64] roads in southern Ontario, and transportation operations and public safety in the face of increased frequency and severity of storms and flooding.[65]

In contrast to climate change impacts and mitigation, significantly less research has been completed on climate change adaptation for transportation,[66] nor has climate change adaptation been incorporated into most transportation infrastructure decisions (except in permafrost regions).[67] In terms of cost and the total amount of infrastructure that may be affected, the effect of increased freeze-thaw cycles on roads is one of the most imperative concerns.[68] Some adaptation measures for increased freeze-thaw cycles include reconstruction and use of less frost-susceptible foundation materials, retrofitting side drains on road structures, increasing the frequency and intensity of maintenance, and issuing spring weight restrictions for roads earlier in the season to prevent damage.[69] Several technical adaptations to climate change have been developed, including technologies for increasing the ability of roads to withstand increased frost heave cycles. Such technologies, however, are used only when

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[61] Potential impacts include: increased Arctic shipping in the Northwest passage, damage from permafrost degradation and increase in freeze-thaw cycles in northern Canada, changes to maintenance and design practices, increased flooding of coastal and inland infrastructure, increased costs of shipping in the Great Lakes-St. Lawrence Seaway system, port transportation and navigational problems from decreased depth, stranded docks and harbours, increased maintenance costs from increased landslide/avalanche activity, changes in winter maintenance costs of surface and air transport, and decreased damage from fewer freeze-thaw cycles in southern Canada. (Lemmen and Warren, p.135)

[62] Transport Canada, *Impacts of Climate Change on Transportation in Canada*, Final Report from the Canmore Workshop. March 2003. Report prepared by Marbek Resource Consultants (Ottawa: Transport Canada, 2003).

[63] *Ibid.*

[64] Lemmen and Warren.

[65] Andrey, J., B. Mills, with B. Jones, R. Haas and W. Hamlin, *Adaptation to Climate Change in the Canadian Transportation Sector,* Report submitted to Natural Resources Canada, Adaptation Liaison Office. (Ottawa: Natural Resources Canada, 1999); Transport Canada; Lemmen and Warren.

[66] Transport Canada; Project database at NRCan's Climate Change Impacts and Adaptation Program website, http://adaptation.nrcan.gc.ca/projdb/index_e.php. Some new projects in progress include the work of Dr. Michel Allard of Laval University who is conducting research to determine the vulnerability of Nunavik's airports to the potential impacts of climate change. His research will result in proposed solutions for the long-term maintenance and functional capacity of Nunavik's airports and related structures.

[67] Lemmen and Warren; Transport Canada.

[68] Andrey *et al.*, 1999.

[69] *Ibid*.

requested by clients.[70] An example of infrastructure design that included climate change adaptation is the Confederation Bridge, which required an environmental assessment under the *Canadian Environmental Assessment Act.*[71] The bridge incorporated design specifications to withstand potential climate change impacts such as a one-metre rise in sea level.[72]

The literature on transportation infrastructure does not share the same urgency as the literature on water infrastructure. Perhaps this is because some vulnerable regions (in the North) are already beginning to adapt or because more research is needed. Many examples of transportation adaptation relate to the North where problems are already evident. The literature suggests that potential impacts on transportation may be manageable, "providing that Canadians are prepared to be proactive and include climate change considerations in investment and decision making."[73]

3.2 Regionally Specific Literature

One of the challenges of adapting to climate change in a country such as Canada is the vast difference in climate conditions and in climate change impacts across the country. For example, in the western Arctic and sub-Arctic, average annual temperatures have already increased 1.5 – 2 degrees Celsius, while on the eastern coasts of Labrador and Newfoundland, annual temperatures have decreased slightly and are expected to continue to cool (due to changes in ocean circulation and ice transport).[74] Regional and local vulnerability to climate change ranges significantly across Canada because of the diversity of climate change impacts and the range of economic, environmental, and geographic characteristics across the country.[75] Climate change vulnerability is determined by three factors – the nature of climate change, the climatic sensitivity of a region, and the capacity of the region to adapt to the changes.[76] When all three factors are considered, it becomes obvious that northern Canada is one of the most vulnerable regions in the country.[77] The North has experienced the most severe impacts to date, and it has limited adaptive capacity. Not surprisingly, several reports on infrastructure adaptation focus on northern adaptation.

Despite its population density and economic significance to Canada, southern Ontario has garnered few reports or research on climate change adaptation for infrastructure in this region. The Great Lakes – St. Lawrence Seaway is another economically and demographically significant region that has received little attention. The literature points to the need for a more regional or local approach to climate change adaptation, and

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[70] Transport Canada.
[71] Canadian Environmental Assessment Agency, http://www.ceaa-acee.gc.ca/012/014/c_e.htm . (Accessed Nov. 2006).
[72] Lemmen and Warren.
[73] *Ibid.*, p.145.
[74] Noble, Bruce and Egener.
[75] Lemmen and Warren, p.vii.
[76] *Ibid.*
[77] Girard, M and M. Mortimer, *The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change.* (Mississauga: Canadian Standards Association (CSA), 2006).

although there exists some studies on the potential impacts of a changing climate on infrastructure such as electrical transmission structures, communications structures and water intake infrastructure in other regions, the North is the only region that has amassed sufficient literature to warrant a discussion here.

In the past few decades, the average temperature in the Arctic has increased almost twice as fast as the rest of the world. Rising temperatures are causing a myriad of problems – glaciers are melting, sea-ice thickness and extent is declining, permafrost is thawing, and sea levels are rising.[78] One of the greatest climate change concerns regarding infrastructure is the thawing permafrost in the North. In many parts of northern Canada, infrastructure including airstrips, pipelines, roads, railways, water and wastewater facilities, and building foundations are built over permafrost and rely upon its stability, yet "permafrost will disappear partly or completely over large areas of the North should predicted climate change occur."[79]

In the North, examples of infrastructure adaptation needs abound. The Yellowknife airport runway required extensive restoration after the permafrost below began to thaw. A new insulating liner was installed four metres beneath a 100 metre section of the runway.[80] The warming necessitates a whole range of adaptations such as new bridges where ice crossing are no longer possible and the conversion of ice roads to all-weather roads.[81] The Manitoba government normally relies on a 2,000 km network of ice roads each winter to transport necessities such as food, fuel and building supplies to remote communities.[82] In 1997-98 the province spent $15 to $16 million to airlift supplies to communities normally served by winter roads because the extremely warm winter temperatures prohibited winter road use.[83] The Government of the Northwest Territories faces numerous infrastructure adaptation needs: "The trend of warmer than normal temperatures has delayed the opening dates of ice bridges on the all-weather highways and reduced the operating window of the winter road system. It has also accelerated permafrost degradation, which has led to the deterioration of road and runway surfaces. There will be increased pressures to mitigate the effects by improving poor surface

[78] Hassol, Susan Joy, *Impacts of a Warming Arctic: Arctic Climate Impact Assessment* (Cambridge: Cambridge University Press, 2004).

[79] Couture, R, S.D. Robinson, and M.M. Burgess, *Climate change, permafrost degradation, and infrastructure adaptation: preliminary results from a pilot community case study in the Mackenzie valley.* (Ottawa: Natural Resources Canada, 2000), p.2. Available online at http://dsp-psd.communication.gc.ca/Collection-R/GSC-CGC/M44-2000/M44-2000-B2E.pdf (Accessed Nov. 2006).

[80] *Ibid*.; Weber, B, "Climate Change threatens Mackenzie Valley Project." *Calgary Herald* 15 February 2060: D4.

[81] Couture, R., S. Smith, S.D. Robinson, S.D, M.M. Burgess, and S. Solomon, "On the hazards to infrastructure in the Canadian North associated with thawing of permafrost." *Proceedings of the Third Canadian Conference on Geotechnique and Natural Hazards* (Edmonton, June 2003).

[82] Stern, N., *The Stern Review: The Economics of Climate Change,* Report to the Prime Minister and the Chancellor of the Exchequer. (London: Government of the United Kingdom, 2006). Available online at http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

[83] Bergman, K., "Roads At Risk: Assessing Potential Impact On Winter Roads," *Weathering Change*. Newsletter of the Northern Climate Exchange, Fall 2002, p.7. Available online at http://Yukon.Taiga.Net/Knowledge/Initiatives/NCE_Newsletter_Fall2002.Pdf

condition and realigning winter roads and building permanent bridges to extend and stabilize winter road seasons."[84]

Climate change impacts and adaptation options for infrastructure in the North have garnered a fair bit of attention and research already. Many Canadian researchers are working on adaptation issues related to permafrost such as specialized mapping in permafrost regions in support of transportation decision-making. Couture *et al* outline adaptation options for reducing the effects of thawing permafrost, including the use of different foundation materials and site selection based on more detailed permafrost information.[85] Canadian researchers have also conducted studies to assess the current and future permafrost conditions and infrastructure sensitivity in Norman Wells and Tuktoyaktuk.[86] Several federal government departments including NRCan, INFC,[87] Transport Canada, Environment Canada, and Indian and Northern Affairs (INAC) are involved in work on northern infrastructure adaptation.

Through the Aboriginal and Northern Community Action Program (ANCAP), INAC is beginning to fund projects that increase the adaptive capacity of communities.[88] One of the program's objectives is to assess the vulnerability of community infrastructure in the North and develop options and action plans to incorporate climate considerations in future infrastructure planning. INAC is also developing an adaptation strategy.[89]

Although much research has been completed on infrastructure adaptation in northern Canada, little work has been completed on other regions. In addition, research and analysis on climate change adaptation is needed at the level of cities and communities. A handful of researchers have begun this work. For example, John Parkins of the Canadian Forest Service developed a framework for assessing climate change vulnerability in rural and resource-based communities.[90] It is becoming increasingly

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[84] Government of the Northwest Territories, *2006-2009 Business Plans* (Yellowknife: Government of the Northwest Territories, 2006) Available online at http://www.gov.nt.ca/FMBS/documents/2006-2009busplans/Section12TRANS.pdf (Accessed October 2006).

[85] Couture *et al.*

[86] More information on this project, "Climate change, permafrost degradation and infrastructure adaptation: community case studies in the Mackenzie Valley," is available at NRCan's Climate Change Impacts and Adaptation Program website, http://adaptation.nrcan.gc.ca/projdb/index_e.php in the "Communities" category. The project is led by Stephen Robinson at St. Lawrence University.

[87] Infrastructure Canada, *Planning For a Soft Landing: Non-Renewable Resource Development and Community Infrastructure in the Northwest Territories.* A Research Backgrounder Prepared for the Experts Workshop on Northern Communities: Boom, Bust and the Role of Infrastructure, November 15-17, 2005, Norman Wells, Northwest Territories.

[88] For example, INAC is a partner, along with Transport Canada and Transports Quebec, in the project titled, "Determining the vulnerability of Nunavik's airports to the potential impacts of climate change and developing an adaptation strategy," which is led by Michel Allard at Université Laval.

[89] Indian and Northern Affairs Canada, Aboriginal and Northern Community Action Program. http://www.ainc-inac.gc.ca/clc/cp/cp2_e.html

[90] Wall, Ellen, Marcia Armstrong, and Sawngjai Dear Manityakul, *Climate Change and Canadian Society: Social Science Research Issues and Opportunities.* C-CIARN Symposium Report. (Ottawa: Canadian-Climate Impact and Adaptation Research Network, 2006). Available at http://www.c-ciarn.uoguelph.ca/documents/June_symposium.pdf (Accessed November 2006).

clear that assessments and adaptation strategies at the regional, city or community level are essential for effective adaptation in Canada.

3.3 Literature on Climate Change Adaptation for Cities and Communities

While all jurisdictions of government share some responsibility for various aspects of public infrastructure, municipalities carry the greatest responsibility for adapting infrastructure to climate change.[91] For instance, municipalities hold responsibility for approximately two thirds of all roads in Canada.[92] Within the climate change adaptation literature are reports and studies specifically on climate change adaptation for cities and communities. This literature includes studies focused on a particular city or community such as the "Climate Change Impacts and Adaptation Strategies for Urban Systems in Greater Vancouver"[93] and more general reports such as the NRCan report, "Adapting to Climate Change: An Introduction for Canadian Municipalities."[94] Although few of these studies are strictly about infrastructure adaptation, most include sections related to infrastructure adaptation.

Some municipalities are beginning to mainstream climate change adaptation for infrastructure into local planning procedures. For example, the Halifax Regional Municipality's ClimateSMART Initiative was developed to "help mainstream climate change mitigation and adaptation into municipal planning and decision-making."[95] Halifax has experienced a number of extreme climate events in the last few years. In 2003, the extensive damage to infrastructure, property and the environment caused by Hurricane Juan was estimated to be in excess of $100 million. In response, a collaboration of partners from the public and private sectors are developing risk and vulnerability assessments, and adaptation management tools to facilitate the mainstreaming of climate change.[96]

Community disaster management is another method to incorporate climate change adaptation into local planning procedures. For example, Ontario's *Emergency Management and Civil Protection Act* requires that municipal and regional governments develop disaster management plans.[97] Municipalities are required to undertake a Hazard Identification and Risk Assessment (HIRA) process to identify priority risks to

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[91] Mehdi, p.9.
[92] Dore and Burton, 2001.
[93] Sheltair Group, *Climate Change Impacts and Adaptation Strategies for Urban Systems in Greater Vancouver Volume 1: Preliminary Assessment* Report prepared for Natural Resources Canada (Vancouver: The Sheltair Group, August 2003). Available online at http://www.sheltair.com/library/VOL%201%20citiesplus%20Climate%20Chg%20I%20and%20A%20Strategies%20by%20Urban%20System%20for%20Gtr%20Van%20Aug%202003.pdf (Accessed November 2006).
[94] Mehdi.
[95] *Ibid.*, p.18.
[96] Mehdi.
[97] Canadian Legal Information Institute, "Emergency Management and Civil Protection Act," http://www.canlii.org/on/laws/sta/e-9/20060718/whole.html ; Auld, H. and D. MacIver. *Cities and Communities: The Changing Climate and Increasing Vulnerability of Infrastructure*. Occasional Paper 3. (Toronto: Environment Canada, Adaptation and Impacts Research Group, 2005).

infrastructure and public safety and develop prioritized emergency response plans for each of the prioritized hazards.[98] The legislation creates an opportunity for governments to mainstream climate change adaptation for infrastructure into its disaster management plans. In November 2006, intense rainfall in British Columbia caused mudslides, water quality problems, and in-land flooding, reminding us that communities -- particularly those in vulnerable areas such as the Georgia Basin -- require disaster management planning to adapt to climate change impacts.[99] Local and provincial governments are not the only players in disaster management. The federal government has a role to play, and according to a 2004 Research and Analysis Division report, further research is needed to "examine the nature of intergovernmental relationships in the context of disaster management, analyze how federalism influences the outcome of disaster policies,…assess alternatives to the current approach to disaster management and propose alternative arrangements that would provide for adaptation and enhance the disaster resilience of Canada's cities."[100]

Disaster management is important for areas at risk of in-land flooding and for coastal zones because potential climate change impacts are not infrastructure specific. Furthermore, adaptation options for coastal zones "are more acceptable and effective when they are incorporated into coastal zone management, disaster mitigation programs, land-use planning, and sustainable development strategies."[101] Annapolis Royal, a community at risk of experiencing coastal erosion and flooding, is an interesting example of a coastal community that reduced its vulnerability to climate change through completing a vulnerability assessment. The vulnerability assessment led to the adoption of some "no-regrets" adaptation actions: "the adaptations recommended by this vulnerability assessment (raising the dykes, relocating emergency equipment, rising and practicing emergency response plans, etc.) will provide benefits regardless of impacts brought on by climate change."[102]

Land use planning is another important adaptation measure for coastal communities, as well as permafrost areas, flood zones, and areas facing potential water shortages. The

[98] In response to growing demands from municipalities seeking atmospheric hazards information for the HIRA process and legislation, Environment Canada developed an initial website containing data, documentation and peer-reviewed maps for atmospheric and changing climatological hazards in Ontario (www.hazards.ca). Environment Canada intends to gradually expand this web based information to all regions of Canada, as budgets allow, and to include changing climate trends and projections of hazardous climate change conditions in all documentation. (Personal communication, November 14, 2006.)

[99] Fong, Petti, with a report from Oliver Moore, "Boil-water advisory hits two million in Vancouver: Residents warned not to use tap water for drinking, brushing teeth and rinsing food after rain triggers mudslides across region," *Globe and Mail,* 17 November 2006: A1.

[100] Henstra, D., P. Kovacs, G. McBean, R. Sweeting, *Background Paper on Disaster Resilient Cities.* Prepared by the Institute for Catastrophic Loss Reduction for Research and Analysis Division. (Ottawa: Infrastructure Canada, 2004), p.26.

[101] Smit, B., Pilifosova, O., Burton, I., Challenger, B., Huq, S., Klein, R.J.T. and Yohe, G. (2001): "Adaptation to climate change in the context of sustainable development and equity," in McCarthy *et al*, Chapter 18 section 7. Available online at http://www.grida.no/climate/ipcc_tar/wg2/654.htm#187 (Accessed Nov. 2006).

[102] Mehdi, p.25.

Canadian Institute of Planners is participating in an NRCan led project, *Municipal Case Studies: the planning process and climate change*. The project's goal is to help planners "evaluate the vulnerability of Canadian municipalities to climate change and determine the appropriate adaptation and mitigation strategies"[103] and to produce a best practices guide on incorporating climate change impacts and adaptation into land use planning. The project will include five municipal case studies focusing on water resource depletion, coastal erosion, and melting permafrost.[104]

Many land use planning methods, including the strategies used in New Urbanism and Smart Growth, incorporate sustainable design elements and can be used to reduce the impact of climate change.[105] The use of landscape architecture – a discipline within the field of land use planning – offers landscaping solutions that can reduce flash floods, desertification, the heat island effect, and landslides; and water management strategies that can reduce potential flooding due to inefficient or inadequate storm drains, water supply or waste management systems. For example, green rooftops can reduce the impacts of the heat island effect in cities: a study conducted at Ryerson University in 2005 demonstrated that using green roof technology for 8% of Toronto reduced the city's heat island effect by up to two degrees Celsius. The study also found that green roofs could slow runoff of rainfall at peak times, reducing the risk of sewer overflows.[106] Landscaping adaptation measures such as changing farming practices and changing the topography of the land have already been identified for the Canadian prairies.[107]

Most of the literature focuses on adaptation for cities or municipalities, but rural communities face some different challenges and warrant special mention. For example, in the face of climate change, rural communities face the double challenge of balancing the need to protect water for natural systems with the need to provide water for human purposes. According to Ivey *et al*, in Ontario, it is questionable whether rural communities have the capacity to implement adaptation strategies: "Whereas some confidence may be warranted in the case of large urban communities' ability to implement [climate change adaptation] measures, the ability of small rural communities in Ontario to manage their water resources effectively is not certain."[108]

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[103] Canadian Institute of Planners, http://www.cip-icu.ca/english/aboutplan/nrc_intro.htm (Accessed November 2006).
[104] *Ibid*.
[105] Klein, R.J.T., Alam, M., Burton, I, Dougherty, W.W., Ebi, K.L., Fernandes, M, Huber-Lee, A, Rahman, A.A., and C. Swartz. *Application of environmentally sound technologies for adaptation to climate change.* United Nations Framework Convention on Climate Change (UNFCCC) Technical Paper. (Geneva: United Nations, 2006).
[106] Geoff Wilson. "A Great Way to Respond to Climate Change." *Urban Design Forum*, 76 (2006). Available online at: http://www.udf.org.au/archives/2006/12/a_great_way_to.php (Accessed December 2006).
[107] McCarthy *et al*.
[108] Ivey *et al*, 2001, p.3.

3.4 Literature Related to Engineering Needs

The vulnerability of different types of infrastructure and the potential impacts that new engineering requirements, codes and standards will have on climate change vulnerability are largely unknown. Further study is needed to determine the correlation between climate change impacts, building materials, maintenance schedules, and the lifespan of infrastructure.[109] Few methodologies integrate climate change scenario information into infrastructure design.[110] Several reports emphasize the importance of modifying engineering practices and codes and standards for infrastructure to incorporate climate change impacts. According to the Canadian Standards Association, high priorities for climate change adaptation are those without existing national standards and include storm water management, rehabilitation of existing infrastructure, northern infrastructure, and coastal regions.[111]

Our existing infrastructure has been adapted to the variable climate conditions of the past using a set of climatic design values in building codes and other infrastructure standards. Climatic design values such as 100 year wind storm speed or 50 year flood are estimations of the probability that a severe weather event will occur in any given year. For example, in any given year, a 20 year return period value indicates that there is on average a one in 20 chance that this 20 year wind storm speed could be reached or exceeded.[112] At present, almost all infrastructure has been designed using climatic design values that have been calculated from historical climate data under the assumption that the average and extreme conditions of the past will represent conditions over the future lifespan of the structure.[113] With climate change, these climatic design values will need to be assessed regularly, improved, updated and probably changed to reflect changing climate extremes (e.g., a one-in a century storm may occur much more frequently, or the weight of snow or amount of rain that a structure is designed to endure may change). Structures designed using climatic design values that are based on sparse climate data or previously short dataset records are particularly vulnerable.

Existing Canadian climatic design values are in need of upgrades and regular updates. In Canada, as in other countries of the world, “current long-standing gaps and deficiencies in the determination of climatic design values prevent optimum decisions from being made on infrastructure reliability and safety.”[114] The Auditor-General of Canada noted in the 2006 Report of the Commissioner of the Environment and Sustainable Development that “there is a lack of up-to-date climate information for use in adapting the design of infrastructures such as storm sewers.”[115] Because the process of changing structural codes and standards is a lengthy one, Auld recommends the use of a “Climate Change Adaptation Factor” to facilitate a continuous process of

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109 Auld and MacIver, 2005.
110 *Ibid.*, p.12.
111 Girard and Mortimer.
112 Auld and MacIver, 2005, p.6.
113 Auld and MacIver, 2006.
114 Auld and MacIver, 2005, p.11.
115 Government of Canada, chapter 2, p.2.

updating climatic design values over time as the climate changes.[116] To ensure effective "no regrets" adaptation to current and expected climate variability, it would be important that such uncertainties and deficiencies in climatic design values be addressed .

There are many reasons why climate change adaptation options are not yet regularly incorporated into infrastructure design and why climatic design information does not include climate change projections. These include uncertainties in climate change projections, uncertainties and gaps in existing climatic design values, and a shortage of sufficient climate station records.[117] Climate monitoring and analyses programs provide the essential raw information needed for climate change adaptation, including improved and new codes and standards.[118] One of the federal government's key roles related to climate change is to maintain climate monitoring, data collection, analyses, and other scientific activities essential for adaptation (e.g., developing climate change scenarios and research on impacts). As noted in the 2006 Report by the Commissioner for the Environment and Sustainable Development, budget reductions have constrained these monitoring networks, as well as the archiving and analyses of the data in support of infrastructure design.[119] Furthermore, although climate data must be analysed before it can be useful, "key analysis of climate data to support infrastructure design was not conducted."[120] According to Heather Auld, while engineers have come knocking on government's door to ask for new or updated climatic design values for codes and standards for infrastructure, progress has been slow in spite of best efforts.[121]

The engineering community in Canada is beginning to work on climate change adaptation options for infrastructure. The Engineering Institute of Canada held a Climate Change Technology Conference in May of 2006. The conference drew participants from around the globe, and papers presented included topics such as engineering adaptations for urban drainage infrastructure planning and design considerations, municipal infrastructure decisions and incorporating climate change adaptation into InfraGuide type decision making.[122] The Canadian Council of Professional Engineers (CCPE) began a climate change adaptation program in 2004. According to the CCPE: "climate change will, over the years, necessitate changes to building codes, engineering practices and standards, and will affect the way facilities are designed, ultimately altering the economic lifespan of infrastructure and thereby impacting commerce and industry."[123] As part of its program, CCPE formed the Public Infrastructure Engineering Vulnerability Committee (PIEVC) with the task of facilitating a national assessment of the vulnerability of Canada's public infrastructure to climate change impacts. The

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[116] Auld and MacIver, 2005, p.8.
[117] Auld and MacIver, 2006.
[118] Personal communication, November 14, 2006.
[119] Government of Canada, chapter 2.
[120] *Ibid*., p.17.
[121] Personal communication, October 27, 2006.
[122] Engineering Institute of Canada, http://ccc2006.ca/eng/index.html (Accessed November 2006).
[123] Lemay, M., "Statement on the Public Infrastructure Engineering Vulnerability Committee (PIEVC) by Marie Lemay, Chief Executive Officer of the Canadian Council of Professional Engineers (CCPE)." Available online at http://www.ccpe.ca/e/pub_ceo_marapr_06.cfm (Accessed November 2006).

committee is comprised of representatives from key non-governmental organizations and senior-level representatives from three orders of government. The Director General for the Issues Management Directorate – Program Operations Branch is the current INFC representative on the PIEVC. INFC's Research and Analysis Division is funding an engineering initiative through its Knowledge-building, Outreach and Awareness Program. The Canadian Standards Association is conducing the project -- *Developing Engineering Curriculum Needs: Climate Change and Infrastructure* -- to develop engineering curriculum on climate change and infrastructure. The climate change adaptation work of the Canadian engineering community is significant, but in terms of engineering design changes, work is still at an early stage.

Section 4: Conclusion

The main findings from this literature review can be summarized as follow:

1. Adaptation is a relatively new concept and work in this area is in its infancy in Canada. Mainly research -- not implementation of adaptation actions -- has been completed to date. This is particularly true at the federal level. The federal government is supporting research on climate change adaptation for infrastructure, but it has made little progress on implementing changes: most examples of adaptation efforts are at the provincial, territorial, or local level.

2. Adaptation is expensive; however, the costs of not adapting infrastructure will be greater in many cases. Uncertainty and cost should not be barriers to implementing adaptation options. "No-regrets" adaptations provide cost-effective benefits regardless of future climate changes. "No- regrets" adaptations for infrastructure include actions such as analyses of infrastructure failures; regular infrastructure maintenance; community disaster management planning; updating climatic design values and engineering codes and standards; and improving the quality and length of climate data records.[124]

3. The vulnerability approach, which is based on the concepts of vulnerability and adaptive capacity, is the best method for determining and choosing adaptation options. This approach is used and promoted by Natural Resources Canada and many international organizations.

4. There are specific challenges related to infrastructure adaptation such as the long life spans of some infrastructure; however, due to the need for rehabilitation or replacement of existing infrastructure and current federal funding commitments, this may be an opportune time for climate change adaptation to become an element of infrastructure design.

5. Rural and agricultural communities face specific challenges related to adaptation for infrastructure.

[124] Auld and MacIver, 2005, p.22.

6. Most research on climate change adaptation for infrastructure relates to the water and transportation sectors. More research on adaptation is needed in all sectors, including infrastructure such as energy, communications, buildings, and solid waste management.

7. Although much research has been completed on infrastructure adaptation in northern Canada, more work is needed in other regions. As the climate change adaptation literature becomes more regionally specific, it becomes increasingly clear that regional or local assessments and adaptation strategies are essential for effective adaptation in Canada.

8. We do not have a good understanding of the vulnerability of different types of infrastructure, nor do we know what potential impacts new engineering requirements and codes and standards will have on climate change vulnerability.

9. Infrastructure design must change. Engineers need new and updated climatic design values, revised codes and standards, and new methodologies to incorporate potential climate changes into engineering procedures. More current climate data and its analyses are needed for this work. The federal role in areas such as monitoring and reporting is essential.

10. There is a need for more communication (information sharing and training) between climate change researchers, policy makers, engineers, architects, operators or asset managers in order to mainstream climate change adaptation into design, maintenance and restoration of infrastructure.