Preparing for the Impacts of Climate Change on Stormwater and Floodplain Management: A Review of Adaptation Plans and Practices

A report prepared by the
Toronto and Region Conservation Authority
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Executive Summary

This study aims to summarize what has been done to date in adapting stormwater and floodplain management practices to prepare for the impacts of climate change, both in Canada and elsewhere. The specific focus of this review was on identifying adaptative approaches to the planning and design of stormwater management and drainage infrastructure, as well as changes in land use and floodplain management practices to account for the potential impact of climate change on drainage infrastructure and flood vulnerable areas. However, adaptation plans or practices from other fields were also considered where it was felt such examples provided background support and commentary on the state of climate change adaptation practice. In addition to a review of the current literature, a survey of major Canadian municipalities was also conducted to establish the current state of stormwater and floodplain management adaptation response.

Increasingly, there is general local and worldwide awareness of climate change and its potential impacts, as well as an acceptance that action is necessary in order to reduce these impacts. However, the focus of climate change response to date has been on mitigation; measures to decrease the concentration of greenhouse gases in the atmosphere to reduce the rise in global average temperatures. There has been significantly less emphasis on adaptation, despite the recognition that a significant change in climate is inevitable over the next century or longer as a result of the greenhouse gases that have already been emitted. In the current review it was ntoed that there are few examples of climate change adaptation plans by government agencies, municipalities or other sectors that are both prescriptive and detailed. Progress to date has tended towards providing strategic direction and confirming the need for adaptation planning rather than developing more detailed adaptation plans and policies. As a result, adaptation related to specific issues or areas of practice, such as stormwater and floodplain management, have generally not yet been addressed.

The lack of progress in adaptation planning can be attributed in part to the lack of climate change projections of sufficient resolution to support adaptation decisions that must made at the local and regional scales. While mitigation plans can be justified as long as climate change is accepted as occurring, adaptation plans or practices necessarily have to be developed in response to changes of definite magnitude. At this time, climate change predictions are derived from simulations on a global scale, which in many cases do not incorporate important smaller-scale processes that are important to the smaller spatial scales of regional or municipal adaptation planning.

Within Canada, the Federal government is engaged in limited partnership initiatives to research climate change impacts and practical adaptation, but it has been criticized for not providing the necessary federal guidance to support Canadians in adapting to climate change. There are many provincial climate change action plans that recommend undertaking infrastructure vulnerability studies assuming future climatic conditions will change, but there is little guidance available on how climate change impacts can be assessed or on specific adaptation. No federal or provincial initiatives were found that provide guidance or insights on climate change adaptation in stormwater or floodplain management. Only one example was located of a federally or provincially legislated requirement to consider climate change impacts in planning and design of infrastructure. The Canadian Environmental Assessment Act, (CEAA) mandates that the effect of climate change are to be evaluated on projects requiring approval under the CEAA to ensure impacts would not pose risks to the public and the environment. However, the CEAA only legislates that adaptation be considered and does not provide any specific guidance for adaptation planning or practices.

Progress in climate change adaptation varies widely between Canadian municipalities. With respect to stormwater and floodplain management, some municipalities have chosen to defer climate change adaptation planning until such time as climate projections with acceptable levels of confidence and local detail are available. In the absence of federal and provincial guidance and useful projections of future local climate, municipalities have incorporated basic or arbitrary assumptions about precipitation characteristics in a future climate and have incorporated this into policies and design practices. A common and definitive action on stormwater management is the promotion of innovative stormwater management measures, which are "no-regrets" measures that have a benefit regardless of the degree of future climate change. However, in general such programs were already being advanced to address other stormwater management issues and as such are not specific responses to climate change. No examples were found in Canada of a comprehensive impact assessment and adaptation planning process, specific to stormwater or floodplain management, that thoroughly examined the effects of a predicted future climate and recommended specific measures or practices in response.

Outside of Canada, the state of climate change adaptation planning is at a similar stage in the United States, Europe and the rest of the developed world, with most products consisting of high-level policy statements that recognize the need for specific adaptation response to climate change impacts and call for action. A notable exception related to floodplain is the Government of the Netherlands' national strategy to conduct major improvements to its flood protection works along the Rhine River, to adapt to expected flow regime changes to the river as a result of climate changes. In other locations, similar examples of definitive action on the basis of the current climate change predictions were found for other types of infrastructure, such as the construction of wastewater treatment plants at increased elevations to account for projected rise in sea levels due to climate change.

Apart from a few examples, at all scales there appears to be a tendency for efforts at adaptation planning to focus on principles and guidelines rather than detailed direction or quantitative guidance. Common to most climate change adaptation action plans are recommendations for further work as data on local climate change becomes available. In the context of stormwater and floodplain management, such recommendations include updating design storm information, modifying infrastructure design standards, and including consideration of climate change in the land use planning process to account for impacts to drainage infrastructure and floodplains. However, there is little guidance available as to how this can be accomplished. Consistent and defensible methods for the use of future climate projections to assess impacts to stormwater and floodplain management infrastructure, and wide dissemination of the methods once they are developed, are required to advance climate change adaptation practice in these fields.

1.0 Introduction and Purpose

This report summarizes a review that the Toronto and Region Conservation Authority (TRCA) has conducted on the current state of climate change adaptation in the fields of stormwater management and floodplain management.

The review focuses primarily on climate change adaptation planning and practice at the municipal and regional levels in Canada, the United States and other countries in the developed world, although some relevant developing world, applications were also reviewed. The primary objective has been to learn from the experiences of governments, agencies and other organizations involved in applicable climate change initiatives in these countries, so as to inform the development and implementation of adaptation strategies in Toronto and surrounding areas. An awareness of what is being done in this field will allow others to learn from the challenges that may have been encountered and the solutions developed as a result. This information will enhance the ability to meet challenges that may arise in policy planning, design and implementation as the impacts of climate change start to be addressed. Another objective of this initiative is to consolidate and share the resulting repository of information on climate change adaptation planning and practice in Canada and other cities around the globe.

An extensive literature search was conducted on current climate change adaptation practices for stormwater management, making use of online searches, electronic databases, and the websites of municipal, provincial and national government websites in Canada and a number of other countries. When necessary, follow-up communication was conducted to request further information or clarification of content.

To gather further information on the planning and implementation of climate change adaptation practices, a questionnaire/survey was prepared and sent to relevant departments in 21 municipalities across Canada.

Finally, sources of information consulted during this research have been collected in a bibliographic database intended for practitioners at different levels of government, who are involved in the fields of stormwater, floodplain and drainage infrastructure management. It is hoped that this database will be a useful resource for those in search of information on adaptation planning and practices. The items in this database include peer-reviewed articles, government documents, policy analysis papers, and information produced for distribution to the general public, such as pamphlets and information brochures. The focus of this bibliography is on items that were consulted during the course of this investigation, but may also include other relevant items for further review and reference. Excluded from this bibliography are papers that deal exclusively with global climate change, such as most of the Intergovernmental Panel on Climate Change papers, as the information in these types of documents is not directly applicable at the regional or local levels. TRCA will endeavour to keep the bibliography regularly updated in order to maintain its relevance and utility for managers and planners.

While there are an increasing number of organizations that dedicate time and effort to analyzing adaptation strategies in various contexts, there has been little coordination of efforts and communication between different groups. This report is an attempt to address this gap, compiling and summarizing the range of research on climate change adaptation specifically related to stormwater and floodplain management and presenting the most relevant experiences, mainly at the municipal level. We hope that this document will be useful to municipal planners, councilors, engineers, and staff of other local, provincial and federal agencies, by summarizing the current state of practice of climate change adaptation planning in these fields.

2.0 Climate Change

While generally speaking climate change refers to a "change in the state of the climate that can be identified (e.g., by using statistical tests) … and that persists for an extended period,"[1] for the purpose of this report the definition of the United Nations Framework Convention on Climate Change (UNFCCC) will be used, which states that climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."[2]

This document does not and is not intended to provide a complete summary of the state of predictive science and modelling associated with climate change. For context, the following sections provide a brief description of the causes and expected effects of climate change with some emphasis on potential impacts to the Toronto area and on stormwater and floodplain management practices.

2.1 Global Perspective

Climate change is believed to be a consequence of global warming, and examination of global temperature records indicate that the rise in global average temperature in the last century cannot be explained by internal natural variability of the climate alone, and likely has a significant anthropogenic forcing from our industrial activities[3].

According to the IPCC Climate Change Fourth Assessment Report, [4] eleven of the last twelve years (up to 2006) were the warmest recorded since 1850. As the report explains, human activities, especially since the industrial revolution (mid-1700s), "result in emissions of four long-lived greenhouse gases (GHGs): CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine)." [5] As concentrations of greenhouse gases in the atmosphere increase, higher amounts of solar energy are trapped within the atmosphere, raising the earth's surface temperature. The combined effects of present levels of CO_2, CH_4 and N_2O are very likely to bring about changes in the climate not seen in more than 10,000 years. The CO_2 radiative forcing alone has increased 20% from 1995 to 2005.[6]

2.2 Canadian Perspective

According to a study carried out by Natural Resources Canada,[7] data collected in the last century – and especially in the last fifty years – show that the overall temperature in Canada has risen more than 1.3°C since 1948, double the global average temperature rise. Temperatures are rising in all regions of Canada, including in the eastern Arctic, where a cooling trend was reversed in the 1990s. The distribution of increasing temperatures and the associated climatic changes are highly uneven both geographically and seasonally. For instance, while some parts of the eastern Arctic are seeing a cooling trend in the winter and autumn, northwest areas experience an increase in temperature of 3°C during the same seasons. Generally speaking, the most extreme changes take place in the Arctic. Precipitation patterns have also significantly changed in the last fifty years, with a national overall increase of 12% in annual precipitation levels. Regional and seasonal differences are also important: while most of Nunavut has experienced a 35% increase in annual average precipitation, most of southern Canada has experienced only a 5% increase, and in some regions even a decrease in annual average precipitation amounts. In addition to the changes in annual averages, extreme event patterns have also changed. Some of these changes include fewer extreme cold days (and nights), with fewer frost days; more extreme warm days (and nights); and more days with precipitation.[8]

2.3 Impacts of Climate Change in Ontario and the GTA

Since 1948, average temperature in Ontario has risen 1.4°C, a trend that many researchers associate with climate change.[9] The trend in increasing temperatures is projected to continue, with average temperatures during the winter expected to show a larger percentage increase than average summer temperatures. Different geographical areas will experience different types of changes and different consequences as a result of the varied economic, geographic and climatic conditions. Potential consequences of future climate change would include an increased frequency of extreme weather such as intense rainfall, droughts, freezing rain, smog events and heat waves. Other impacts include an increase in evapotranspiration associated with higher temperatures, which could dramatically impact the hydrologic cycle leading to impacts such as lower water levels in the Great Lakes and water shortages.

In 2007, in a meeting organized by the City of Toronto, experts agreed the impacts of climate change on the Greater Toronto Area (GTA) would include “more frequent and severe weather,” and “higher temperatures, extreme heat, heavy rainfalls, drought and the introduction of new and invasive species.”[10] However, it was recognized that there is significant uncertainty in the quantification of potential changes to the local climate of the GTA scale due to limitations of current climate modelling and projection tools.

2.4 Implications for Stormwater and Floodplain Management

It is generally accepted that climate change will strongly affect the frequency, magnitude, location and duration of hydrological extremes. There is little doubt that “changed hydrological extremes will have important implications on the design of future hydraulic structures, flood-plain development, and water resource management.”[11]

Given expected changes in hydrological extremes, current stormwater and floodplain management policies and practices may need to be modified so that objectives for the protection of safety, property and the natural environment will continue to be met in a changed climate. However, decisions to change approaches and design standards are challenging, because while there is a high level of certainty with respect to the likelihood of climatic changes, there is still a great deal of uncertainty about the magnitude of potential climatic changes, and their manifestation at the local scale in terms of changes in seasonal precipitation distribution and changes in the frequency and magnitude of extreme events. While confidence in climate prediction may be improved with the advancement of climate models and other predictive tools, some uncertainty will always persist, because the extent of climatic change that we will experience depends to a large degree on future emissions greenhouse gas emissions are at the global level. This presents a great political, economic and technical challenge to practitioners of stormwater and floodplain management, who must plan for climate change based on speculation about possible future scenarios. While it may be clear that design standards for stormwater infrastructure should be adapted to a changing climatic situation, it is very difficult to define new standards in the face of such high levels of uncertainty as the costs associated with upgrading or replacing infrastructure are in many cases directly correlated to the magnitude of climate change. One study has calculated that adaptation costs for the city of Toronto for wastewater treatment alone will range from a low of $633 million to a high of $9.4 billion.”[12]

Changing infrastructure design standards is a lengthy process that involves many stakeholders.[13] Design standards are usually based on historical data, which were considered to be the best resource available to predict the frequency of climatic events in the future. However, this methodology is predicated on the assumption that climatic conditions will remain stable. Climate change thus presents a new challenge, since the historical climate record can not be reliably extended to predict future conditions.

The high level of uncertainty regarding the impact and magnitude of climate change has led some municipalities to take 'no-regret' measures, i.e. implementing practices that will have a beneficial effect even in the absence of climate change. Some examples of these are: tree planting, green roofs, and disconnecting impervious areas from the sewers to reduce stormwater runoff volumes. However, conventional policies and infrastructure for floodplain and stormwater management are based on specific levels of risk and service, and require definitive standards and criteria for planning or for the retrofitting or building of new infrastructure. Today, in Ontario, there are no standard approaches for taking climate change effects into account in the stormwater management and floodplain management fields for decision making or design.

3.0 Climate Change – Adaptation vs. Mitigation

Actions taken to address climate change can be classified as mitigation measures or adaptation measures. Mitigation practices are those that are intended to reduce GHG levels in the atmosphere in order to prevent climate change from occurring, or to reduce the extent of climate change caused by human activities. According to the Intergovernmental Panel on Climate Change (IPCC), mitigation is any "anthropogenic intervention to reduce the anthropogenic forcing of the climate system" and "includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks."[14] Examples of mitigation practices include increasing the areas covered by trees, developing technologies to reduce GHG emissions from transportation or industrial activities, implementing energy conservation practices and expansion of the use of renewable energy, and development of policies to stimulate the use of cleaner forms of transportation such as public transportation and cycling.

The goal of adaptation, in contrast, is to alleviate current or future impacts of climate change and to reduce the sensitivity and exposure to its potential hazards by increasing community "resiliency to climatic and non-climatic stressors."[15] The underlying assumption is therefore that some climate change is inevitable, very likely to occur, or that it is already occurring. Defined by the IPCC, adaptation is any "adjustment in natural or *human systems* in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."[16] Adaptation practices are thus "actual adjustments, or changes in decision environments, which might ultimately enhance resilience or reduce vulnerability" to the negative impacts of climate change.[17] Examples of adaptation practices related to stormwater and floodplain management include upgrading infrastructure (e.g. bridges, sewer and culverts) to account for changes in frequency and magnitude of extreme rainfall events due to climate change, the application of source controls to reduce the volume of stormwater runoff and creation of policy frameworks to meet the challenges of a changing climate. Policy frameworks could include new design standards and regulations for new developments or taxation policies to reduce the costs of adaptation measures.

While in the long term the only possible solution to reduce the impacts of climate change is to reduce the levels of GHGs and their effects on the earth's atmosphere, even if all anthropogenic GHG emissions were reduced to zero today, global climate will continue to change for decades or longer due to the long life of GHGs already present in the atmosphere.

This degree of inevitable climate change underscores the importance of adaptation. Addressing adaptation is not only a requirement of the Kyoto Protocol and the UNFCCC: it is vital if we are to avoid the worst impacts of climate change and prevent putting the lives and health of communities at risk. Adaptation strategies imply learning about vulnerabilities to climate change impacts and finding the best way to address them. Vulnerability implies risk and since risk management is routinely incorporated in engineering, it has been suggested that climate change can be addressed by simply adding it as a risk factor in engineering calculations and practices.[18]

Introducing climate change as a factor in planning and development will necessarily have an impact on budgets. Institutions and governments must be aware of the financial implications when considering adaptation plans. However, while costs associated with climate change adaptation may be significant, inaction may greatly increase the costs associated with climate change impacts, both in the short term and for future generations.

In general, it seems that there is currently a greater focus on mitigation as a response to climate change impacts as opposed to adaptation measures. One reason for this may be the need for precise and specific estimates of climate change impact at regional and municipal levels in order to adapt policies and practices to account for these impacts, something which the current science and climate models are presently unable to provide. In the face of this significant uncertainty, many stakeholders have decided not to proceed with adaptation initiatives. Mitigation, on the other hand, can be approached as a best-effort initiative in each area or sector contributing greenhouse gas emissions, an approach which is not as sensitive to the accuracy of the climate change modeling at the strategy and policy development phase.

The greater focus on mitigation as opposed to adaptation is reflected, for example, in the Climate Change Action Plans that many states and cities in the US are implementing or planning to implement. While 49 mainland states will have completed climate change action plans by 2009, only 6 states will have included adaptation as part of their plans.[19] Hundreds of US cities have developed climate change action plans, but they have also focused almost exclusively on GHG emissions reduction and have not included adaptation. Exceptions to this are the plans for New York City and Seattle.[20] It is noteworthy that when adaptation measures are included in city or state plans, it is often with respect to a specific issue (such as drought or sea-level rise) and not as a comprehensive policy that involves all sectors, nor is it always referred to explicitly as adaptation to climate change. However, it can be inferred that since the issues being dealt with are similar to the issues associated with climate change, any climate change adaptation plan explicitly developed would necessarily look similar. Florida's 2007 Drought Plan, for example, does not mention climate change or adaptation.[21] Finally, in some cases when adaptation is mentioned, it is erroneously used to refer to GHG reduction and the implementation of energy efficiency measures which are primarily mitigation measures.[22]

4.0 Review of Climate Change Adaptation Practices

4.1 Scope of Investigation

The current study was initially focused on the actions Canadian municipalities are taking (or planning) specifically related to preparing stormwater management and flood control infrastructure and programs for the projected impacts of climate change in Canada. Of particular importance would be the types of practices involved, the sources of climate change projections used in evaluating impacts and the need for adaptation, the assumptions underlying those projections, and potential caveats in applying the data in a regional or municipal context.

The initial investigation was focused on determining what Canadian municipalities are doing in terms of adaptation to the local impacts of future climate change on engineered drainage and flood control infrastructure. However, findings showed that municipal climate change adaptation planning in Canada is generally in the very early stages of development, while many municipalities have not even considered the need for an adaptation plan as yet. This suggested that few Canadian examples of adaptation related specifically to stormwater and floodplain management, if any, would be found.

As a result, the scope of the investigation was expanded to include other municipalities in North America and elsewhere, as well as adaptation strategies related to other types of infrastructure relevant to the stormwater and floodplain focus. The research was also extended beyond the municipal level to include provincial/state and national government agencies and organizations responsible for providing guidance on climate change adaptation to their constituent municipalities.

Finally, the research looked at international organizations such as the United Nations and the World Bank and their involvement in funding climate change adaptation projects in the developing world. This is especially relevant to low-income countries vulnerable to the effects of weather due to heavy dependence on agriculture, limited resources, and vulnerable geographies.

4.1.1 Literature Review

A literature review was undertaken using internet search engines, online databases and online library catalogues. The websites of a number of different organizations were also consulted (municipal, provincial, state, and federal governments and agencies, as well as international organizations such as the World Bank, the Organization for Economic Cooperation and Development (OECD), and the United Nations) in search of information on adaptation plans and/or practices.

4.1.2 Questionnaire

Literature review findings suggested that climate change adaptation planning is likely being considered by municipalities in Canada but that such work has not evolved to the level where formal policies or plans have been published. To gather information on the methods and findings of municipalities at this stage of adaptation planning, a questionnaire was circulated to a number of major Canadian municipalities in divisions or departments responsible for drainage and flood control infrastructure planning or operation. A similar type of questionnaire was used by countries of the European Union in order to gather information about the state of climate change adaptation planning or practice in each member country,[23] and that questionnaire was used as a template for preparing one for this study.

The questionnaire (Appendix B) was prepared, circulated and managed using the online “Surveymonkey” service, and was sent to 21 municipalities across Canada in August 2008. There were 29 questions in total, 5 of which were open-ended questions directed only to those jurisdictions that have put into place adaptation measures.

4.1.3 Personal Communication

Where available information on adaptation planning or practices necessitated clarification or required further details, contact was made with the relevant researcher, municipal planner or staff member to ask for clarification or request further information. Various researchers were contacted directly to solicit guidance in our search for specific examples of adaptation practices.

4.2 Limitations of Study

There are some limitations inherent to the research methods used. First, research that heavily relies on online sources and search engines is inevitably biased towards documents that are a) available or referenced in other documents that are available on the web; b) available in English, although some limited research was done in Spanish. Thus some initiatives in non-English Speaking European countries, for example, may have been overlooked.

Another issue with online research is the way in which search engines work, taking into account variables that are not under control of the researcher. For example, if the number of hits that a webpage receives is considered in the algorithm that defines a search result, then documents that have been very recently uploaded to the web will not show up, no matter how significant or relevant their information.

As such, this study is not an exhaustive survey of the available information for the reasons given above. Most of the research for this study was carried out between the months of June and August, 2008. Given the continuing progress in climate change science, the increasing awareness of the issues in the public consciousness, and ongoing work to prepare our society for the changes as a result of climate change, it could be expected that additional newer information on climate change adaptation plans and initiatives may have been made available since the research for this study was concluded.

4.3 Discussion of Findings

The results of our research suggest that the need for adaptation to climate change is recognized by municipal, regional, and higher levels of government in Canada, and that all are at different stages in the lengthy process of developing and implementing policies that will lead to definite action in addressing and preparing for the projected impacts of climate change, including impacts on stormwater management and floodplain management programs and infrastructure.

Around the world, the level of development of adaptation plans appears to be highly uneven. In the United States, federal agencies like the Environmental Protection Agency (EPA) are working together with state governments to help them implement adaptation measures.[24,25] Some states, such as Alaska, have made significant progress, while others appear to have not yet recognized the need for adaptation.[26] In the European Union (EU), development efforts are similarly uneven. For instance, The Netherlands have designed adaptive flood prevention strategies and are in the process of implementing them,[27] while other countries as yet have no plans with respect to climate change adaptation.[28] In New Zealand and Australia, federal authorities have prepared climate change adaptation guidelines for local governments.[29] Transportation New Zealand prepared a strategy for infrastructure adaptation that included new design standards for transportation infrastructure that takes into account the uncertainties of climate change and the costs of replacing or retrofitting existing infrastructure.[30]

Within the lesser-developed world, international institutions (the World Bank, the Asian Development Bank and the United Nations Development Program (UNDP)) are playing a role in planning for climate change.[31] The World Bank has embarked on a four-year, ten million dollar program in the Caribbean with the objective of mainstreaming climate change adaptation. The Organization for Economic Cooperation and Development (OECD) has published several documents on adaptation to climate change, both in developed and developing countries. One of the primary objectives is mainstreaming climate change adaptation into development projects.

Community-based adaptation (CBA) is a planning and implementation framework in some lesser-developed countries, whereby external funding and technical expertise is provided to allow for a community-led response to the impacts of climate change, primarily mitigation of increasing flood risk and improving response to floods.[32,33] This process enhances the ability of local inhabitants to plan for and adapt to climate change by involving them in both the planning and implementation phases.

In 2007, the Second International Workshop on Community-Based Adaptation to Climate Change was held in Dhaka, Bangladesh, where several CBA projects were described and discussed, including projects on flood plain resource management.[34] The UNDP is carrying out ten CBA pilot projects in developing countries around the world[35], and is involved in close to 125 projects globally in such countries as Bangladesh, Bolivia, Guatemala, Jamaica, Kazakhstan, Morocco, Namibia, Niger, Samoa, and Vietnam.[36] Some NGOs, such as the Red Cross, are working on these types of projects as well.

Government development agencies in industrialized countries are also helping countries with less economic resources to implement adaptation practices. For example, the Canadian federal government, through the Canadian International Development Agency (CIDA), invested two million dollars in the World Bank's Caribbean project on mainstreaming adaptation.

4.3.1 Climate Change Adaptation Planning and Practice in Canada

4.3.1.1 Federal Initiatives

In 2006, the Office of the Auditor General carried out an investigation into Canadian Federal Government activities with respect to climate change adaptation.[37] See Appendix A (A-1). The report describes the difficulties of adapting stormwater infrastructure on the basis of existing historical weather data, such as frequency of extreme rain events. It also underscores the need for carrying out in-depth analyses of extreme weather events in the context of climate change to develop the information base for preparing adaptation plans and developing adaptation practices.

Key conclusions of the report are summarized below:

- 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.

- The government has not developed a strategy for federal adaptation efforts to indicate the expected results and timelines, and which departments would assume what responsibilities. Federal progress in working with provinces and territories has been limited.

- Furthermore, the report asserts that a “federal adaptation strategy was started in 2003 but not completed,” although “some departments have begun to work on their own strategies.” Only one (Public Safety and Emergency Preparedness Canada (PSEPC)) has been completed. Departments have made limited progress in using available information about the changing climate to assess potential implications on federal policies and programs.

- The federal government has supported the development of knowledge through impacts and adaptation research and initiatives that involve working with decision makers on adaptation solutions. There is sufficient information for adaptation planning to commence, however, the federal government has not yet organized its activities in climate science to make sure that the federal departments and others obtain needed information. (For example, a lack of up-to-date climate information such as IDF curves and limited information available to the public on possible future climate conditions would preclude a rigorous approach to adaptation planning in many areas).

The federal government – in partnership with the provincial governments – participates in several initiatives that aim to provide technical information on adaptation to all stakeholders. The Prairie Adaptation Research Collaborative (PARC)[38] is an example: in partnership with the governments of Alberta, Saskatchewan, and Manitoba, the goal of this initiative is to generate practical adaptation options. Other examples include the Ouranos Consortium[a] (where Environment Canada contributes mostly in-kind scientific staff) and a study that Environment Canada is carrying out with the municipality of Delta in British Columbia.[39] There are three federal programs focused on researching climate change impacts and adaptation:

- The Climate Change Impacts and Adaptation Program, under Natural Resources Canada, manages the Canadian Climate Impacts and Adaptation Research Network (C-CIARN), "a national network set up to assist in producing new climate change knowledge on key issues by bringing together decision makers from industry, governments, and non-governmental organizations."[40]

- Reducing Canada's Vulnerability to Climate Change,[41] also managed by Natural Resources Canada, supports research to lessen the vulnerability of Canadians and their infrastructure and communities to the impacts of climate change.

- The Adaptation and Impacts Research Division (AIRD) within Environment Canada,[42] has partnerships with and research staff located at four universities, and provides climate data, analysis, research on impacts and adaptation, tool development, and scientific advice.

[a] The Ouranos Consortium was created in 2001 by the Quebec government, Hydro-Québec and Environment Canada. It is an interdisciplinary research and development network of 250 scientists and professionals that focuses on climate sciences and climate change impacts and adaptation. It manages over 40 projects and it is the main source of North American regional climate solutions. See http://www.ouranos.ca

The OAG report acknowledges that the federal government has contributed to research to help address regional issues and it has “supported several projects to connect researchers with decision makers who need to take a changing climate into account.”[43]

Furthermore, at the federal level, climate change and its implications are considered in infrastructure projects that require approval under the Canadian Environmental Assessment Act. Such projects would include major works such as highways, bridges, river entrainment works and dams.

Infrastructure Canada considers climate change adaptation in its project review process when consideration of the impacts of climate change, and development of adaptation measures in response, is mandated in funding programs. For example, the Canadian Strategic Infrastructure Fund (CSIF) requires that applicants demonstrate how climate change adaptation is addressed in their projects. CSIF projects also require an environmental assessment under the *Canadian Environment Assessment Act*.[44]

In 2003 the Canadian Environmental Assessment Agency published “Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners”[45] to provide guidance to proponents of projects under their purview (see Appendix A (A-2)). The document focuses on: a) GHG emissions by project proponents and b) impacts of climate change on proposed projects. The explicit goal of the latter component is to “help practitioners assess, reduce and manage the adverse impacts that climate change may have on projects and ensure that these impacts will not pose a risk to the public or the environment” (Section 2.2). The document recommends develop of Impact Management Plans following assessment and quantification of the impacts of climate change on proposed projects.

4.3.1.2 Provincial Initiatives

At the provincial level, adaptation planning is at an early stage. Governments in most cases are still trying to assess what the specific impacts of climate change will be in different regions, what tools and methods are best suited for predicting changes, and what the best adaptation options will be for each sector.

The *ClimAdapt Guide to Incorporating Climate Change into the Environmental Impact Assessment Process*, developed by ClimAdapt (a network of private sector companies in Nova Scotia that provides climate change adaptation expertise) and Nova Scotia’s Climate Change Adaptation Initiative, is one attempt to establish a mechanism to incorporate climate change into the province’s Environmental Impact Assessment (EIA) processes. It is intended for developers and suggests a set of 15 guidelines that should be used throughout the EIA process[46] in order to best include climate change considerations in new development projects.[47] A summary of all guidelines can be found in Appendix A (A-3). Examples include:

- The proponent should document whether climate change is a potential consideration for the project as the initial step in the EIA (guideline #1*)*;
- Mitigation measures specific to addressing climate change impacts, possibly including any appropriate adaptation measures, should be addressed in the mitigation section of the EIA and also incorporated into the project description section of the report (guideline #13); and
- If a project is potentially sensitive to climate change within its life, the project monitoring should also include periodic review of climate change data, and/or monitoring to test

the appropriateness of the climate change working assumptions, and if necessary, allow modifications to be made to the project (guideline #14).

The province of Québec's plan for 2006-2012, *Québec and Climate Change. A Challenge for the Future. 2006-2012 Action Plan,*[48] and Ontario's *Go Green. Ontario's Action Plan on Climate Change*,[49] for example, both recognize the need to carry out vulnerability studies and to define appropriate responses according to their findings. These plans are primarily focused on GHG reduction, and specific adaptation recommendations related to issues such as stormwater and floodplain management are only conceptual in nature at this point. Quebec's plan asserts that "[i]nsofar as water management goes, using a watershed approach to planning is a highly appropriate way of preparing to adapt to the effects of climate change. In this context, the government intends to implement a hydrology modeling platform for watersheds in inhabited areas of Québec" (p. 39).

Ontario's Action Plan asserts that "[a]n Expert Panel on Adaptation will be appointed to assess the vulnerability of Ontario to the effects of climate change and to make recommendations to address these threats.

These preliminary initiatives at the Quebec and Ontario provincial level with respect to climate change and its impact on stormwater and flood control infrastructure are in contrast with other more advanced provincial initiatives in relation to climate change. Quebec's Ministry of Transportation, for example, is a partner in a research project led by the Ouranos Consortium on the sensitivity of coastlines and the vulnerability to climate change of communities on the Gulf of St. Lawrence.[50]

New Brunswick has outlined a climate change adaptation strategy for 2007-2012 that is "a combination of technological innovation; educational, incentive-based and regulatory actions; and achievable targets."[51] The plan includes a provincial risk assessment with focus on coastal areas and inland waters and "climate-proofing" development through planning policies. According to the province's website, the first year of implementation of the plan was focused on "laying the foundations for meeting the goals of the climate change action plan."[52] See Appendix A (A-4).

Alberta's action plan establishes that "[s]trategies to adapt to climate change must go hand in hand with actions… to reduce current and future greenhouse gas emissions… Research is currently underway in Alberta, along with the other Prairie provinces, to identify the risks and opportunities and the best strategies to adapt to climate change."[53] See Appendix A (A-5).

The "Government of Yukon Climate Change Strategy"[54] states that one of its goals is to "build Yukon environmental, social and economic systems able to adapt to climate change impacts" (p.7). It also sets a strategy to achieve this goal, which includes working "to incorporate climate change mitigation and adaptation measures into environmental assessment practices with the Yukon Environmental and Socio-Economic Assessment Board" (p.7).

The Newfoundland and Labrador "Climate Change Action Plan 2005"[55] recognizes the need for transportation infrastructure adaptation to climate change given their vulnerability to sea level rise and storm surges. Yet it also recognizes the need for better knowledge of how to implement adaptation measures, and it establishes that "adaptation actions will need to focus initially on data collection and analysis of impacts" (p.12). The 2007 implementation update still shows an emphasis on mitigation rather than adaptation actions.[56]

The government of Manitoba has published a document titled "Adapting to Climate Change: Preparing for the Future,"[57] where it describes some of the actions the province is putting in place: "Integrated watershed management plans are being developed to address water budgeting and water conservation; flood protection is being improved throughout the province…; Manitoba's hydrometric network is being expanded; incentives … to protect lakes and rivers are being introduced; a land planning initiative will combine traditional and western scientific knowledge to inform future decision-making" (p.47).

British Columbia has published several documents to help local governments make decisions on stormwater management. *Stormwater Planning: A Guidebook for British Columbia*,[58] was published in 2002 by the British Columbia Ministry of Water, Land, and Air Protection "to assist local governments, engineers and planners in clearly understanding the broader issues and the strategies currently available to correct stormwater-related problems."(p.1-1). The guidebook asserts that since the "stormwater management component is a requirement for approved *Liquid Waste Management Plans* (LWMPs), the Ministry will encourage any progressive steps a local government may want to take to incorporate stormwater planning into their existing LWMP."[59] . The guidebook sets performance targets for rainwater runoff volumes from individual sites. Although not designed to specifically address the consequences of climate change or to provide new standards that municipalities must comply with, this new approach to water management and the useful information included in the guidebook will have a beneficial effect towards addressing growing pressures on watersheds and communities due to population growth and climate change.[60]

The province has also prepared the "Water Sustainability Action Plan for British Columbia,"[61] a 'water-centered' strategy to development. Although not specifically thought of as a climate change adaptation strategy, climate change is recognized as a factor in increasing the amount of surface runoff. The "Water Balance Model for British Columbia,"[62] developed as a practical online tool for planners and developers to assess the impacts of land use change, can also potentially be used to address the effects of climate change and urbanization on local streams.[63] The province later shifted from the "stormwater management" approach to a more integrated "rainwater management" approach, which advocates reducing stormwater runoff and is expected to have potential beneficial effects in mitigating the impacts of climate change in British Columbia.[64] Section Five of the current provincial *Climate Change Action Plan*[65] dedicated to adaptation mentions a "10-year commitment to flood prevention," [66] but gives no further details on what specific actions will be considered.

4.3.1.3 Municipal Initiatives

Canadian municipalities have arguably gone further than other levels of government in Canada in attempts to integrate climate change adaptation into infrastructure planning and management, as described in the following examples.

<u>Halifax</u>

The Halifax Regional Municipality's (HRM) 2006 *Regional Municipal Planning Strategy* recognizes the potentially negative effects of climate change, and establishes that the Halifax Harbour Functional Plan should carry out a "mapping and modeling study to predict impacts of climate change and weather events on the shoreline of Halifax Harbour, and [make] subsequent recommendations for mitigation and risk management (see Appendix A (A-6)."[67] Furthermore, policies E-14 and E-16 of the plan proposes to restrict developments on floodplains and coastal areas respectively through the mechanism of municipal bylaws.[68]

The HRM has already implemented new design standards for certain instances of coastal infrastructure that take into account a rise in sea levels. The HRM climate change response strategy is known as the Climate SMART program (Sustainable Mitigation and Adaptation Risk Toolkit). Climate SMART "integrates and mainstreams greenhouse gas emission reduction and climate change impacts and adaptation considerations into its overall corporate decision-making process."[69] Previous to the Climate Change Risk Management Strategy, in August 2007, the Climate SMART initiative developed the "Climate Change: Developers' Risk Management Guide" (see Appendix A (A-7)).[70]

HRM developed a seven-step method to understand the potential hazards to development posed by climate change and to prioritize the adaptation practices to be implemented. These seven steps are:

1) understand the context;
2) identify climate change impacts;
3) identify the risks;
4) quantify and qualify the risks;
5) prioritize the risks;
6) identify the options to manage the risks; and
7) identify the resources, barriers and timeframes.[71]

The document enumerates climate change adaptation actions and their corresponding requirements:

Adaptation Action

- Develop vulnerability maps of communities, infrastructure and buildings at risk due to climate change impacts
- Incorporate adaptation risk assessment and risk management measures into municipal planning

Requirements

- Integrate climate change as a risk consideration
- Include climate change with life-cycle assessment: Cost/benefit analysis of climate change risks should become standard
- Update design criteria for infrastructure
- When completed, updated IDF charts related to precipitation will be made available to municipal engineers

While some Climate SMART initiatives have not yet been funded, others are already being implemented (such as the regional plan minimum coastal elevations and minimum waterbody setbacks.).[72]

The data used to predict future temperature and precipitation values in Halifax and Region were generated through statistical downscaling[73] based on global climate model results derived from the Canadian Global Coupled Model (CGCM1).[b] Results for Shearwater, NS, were used as a proxy for downtown Halifax.[74]

Vancouver

On the west coast, the City of Vancouver presents an interesting case of climate change adaptation. The City has taken several initiatives to adapt its infrastructure and development pattern to predicted increases in intense rainfall, storm surges, and annual precipitation and snowfall, yet many of the stormwater management practices that have been implemented have not been undertaken as a response to predicted future impacts of climate change. The following extract from a report from the General Manager of Engineering Services to the City Council explains:

> Well before any local projected climate change data was available to the City, Sewers Staff believed that the number and intensity of rainfall events was on the rise and therefore made appropriate changes to their design decision making. The result today is a stormwater design in separated areas that is capable of handling up to a 45% increase in rainfall intensity before flooding would occur. The projected increases in rainfall intensity for 2080 are only about half this number; however the available data is not directly comparable with traditional design information. Staff will continue to work with [the Pacific Climate Impact Consortium] PCIC and other climate scientists to obtain projected changes in 1-hour rainfall intensity and "IDF" (intensity-duration-frequency) curves… Sewers staff has implemented other stormwater initiatives that include bylaw changes that limit the impervious area for new construction… these changes result in less rainwater entering the City's system, effectively adding to the storm system's capacity.[75]

The City's approach to water management includes many of the practices that are often recommended as climate change adaptation practices (reducing impervious areas, and

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[b] The HRM report used the Canadian Climate Model (CGCM1) for future climate scenarios, assuming a GHG emission scenario of IS92a, or a business-as-usual future. This emission scenario assumes a 1% GHG increase each year for the next 100 years, i.e. doubling the concentration of GHG in that period. Temperature and precipitation projections were made using a statistical downscaling method extracting temperature and precipitation scenarios from the Canadian Climate Impacts and Scenarios (CCIS) (www.cics.uvic.ca). The resulting values of projected precipitation and temperature changes can be considered, compared with other models, close to average projections (see pages 38-40 and Appendix A of the HRM report for a more detailed explanation of the model used by HRM).

reducing runoff with a set of tools such as tree planting, the disconnection of impervious areas from the main sewers, flow control mechanisms and others).[76, 77]

Adaptation to climate change was specifically addressed in 2007, when the Climate Adaptation Working Group was established to make recommendations for the City's to act on. This group worked in cooperation with Environment Canada, the BC Government, Metro Vancouver, the Fraser Basin Council, and the Pacific Climate Impact Consortium (PCIC) and recommended a number of key steps to guide development of the City's adaptation plan, including:

- completing a city-wide vulnerability assessment,
- undertaking selected risk assessments,
- broadening the scope of adaptation planning,
- conducting selected cost/benefit analyses and
- establishing adaptation goals that are embedded in regular City infrastructure and capital planning processes.

Thus, although adaptation planning and practice are still in the very early stages in Vancouver, the City's advanced water management strategies, which were not designed in the context of climate change adaptation, will make Vancouver more resilient to the future impacts of climate change (pp.3-4).

<u>Toronto</u>

Like Vancouver, the City of Toronto has also implemented some climate change adaptation practices, some of which were in use before an official climate change adaptation plan was published in April 2008. The "Toronto Adaptation Plan"[78] —based on recommendations received from the City's divisions and agencies—enumerates some short-term actions that the city is already taking or are approved and funded for 2008/2009. Some of the short-term stormwater management actions that are in progress include: [79]

- development of extreme precipitation intensity, duration and frequency curves;
- review of urban flooding issues;
- analysis of when and where green roofs could be required to make recommendations for a green roof by-law; and
- development of draft design standards for green parking lots.

Other short-term recommendations received but not implemented as yet include undertaking a climate change vulnerability assessment of roads, bridges and culverts; expanding parkland naturalization and naturalization of lands surrounding water and wastewater facilities; increasing street tree planting; mandating citywide downspout disconnection; and elimination of new reverse slope driveways (p. 20). The City also received recommendations for development of a long-term comprehensive strategy (p.21).

4.3.2 Climate Change Adaptation Planning and Practice Outside Canada

4.3.2.1 U.S. Municipal Initiatives

Although not always as part of an official climate change adaptation plan, some cities in the United States have also implemented stormwater management practices that will improve the resilience of the communities to the potential impacts of climate change. The Pew Centre for Global Climate Change has produced a document summarizing all adaptation actions undertaken in the US. First produced in 2007, the information has been recently updated in 2008.[80] Below are some examples of adaptation actions noted in the Pew study:

Chicago, Illinois

The Chicago Department of Water has already implemented street surface level devices to restrict the rate of flow into the storm sewer systems as part of a plan for climate change adaptation.[81] Since January 1, 2008, all new developments of a certain size have to capture the first half-inch (12.5 mm) of runoff from all impervious surfaces (roofs, driveways, sidewalks, etc.), onsite, by using green roofs, permeable pavement, rain barrels and cisterns, bioswales, or rain gardens. The City is also implementing a "Green Alley" program,[82] where some of the city alleys are built with pervious asphalt, or with a rigid grid system and gravel that allows rainwater to be absorbed into the ground. The City is currently implementing green roofs and also has a subsidized rain barrel program.

In collaboration with the Metropolitan Water Reclamation District (MWRD) the City will prepare "a watershed plan that factors in projected climate changes, the first time the effects of climate change will be included in a Chicago regional infrastructure plan. The City will also collaborate with MWRD and other municipal agencies to find ways to use available space – from vacant land to parking lots – to manage stormwater."[83]

Milwaukee, Wisconsin[84]

The City of Milwaukee is implementing a downspout disconnection program, redirecting water to rain barrels, pervious areas and rain gardens to reduce the volume of stormwater runoff. The city is also implementing green roofs to intercept and abstract a part of the incident precipitation. These actions will reduce the volume of stormwater runoff that enters the drainage system, which would enhance the functioning of the drainage system under increased storm frequency and runoff volumes as a result of climate change.

Pittsburgh, Pennsylvania

The City of Pittsburgh is implementing rain barrels in neighbourhoods with sewer overflow problems and green roofs, to reduce the volume of stormwater runoff reaching the municipal drainage system. Reduction of stormwater volume is seen as one adaptation measure in response to potential increased stormwater runoff volumes as a result of climate change.

Portland, Oregon

In the City of Portland, building codes require onsite stormwater management, new municipal buildings are required to have green roofs, and homeowners receive $53 from the city for every downspout they disconnect from the sewer system. Similar to other municipalities with downspout disconnection programs, this measure will reduce the volume of stormwater entering the storm sewer systems, hence increasing the ability of the system to cope with potential higher flows due to the effects of climate change on rainfall frequency and duration.

4.3.2.2 European Union (EU) Initiatives

Directive 2007/60/EC of the European Parliament on the assessment and management of flood risks[85] establishes that, "[b]ased on available or readily derivable information, such as records and studies on long term developments, in particular impacts of climate change on the occurrence of floods," (p.30) all European Union members must undertake a preliminary flood risk assessment by 2011, complying with certain minimal requirements.

In 2007, the German Ministry of Environment designed and distributed a survey to all EU countries in order to assess the status of each country with respect to adaptation to the impacts of climate change as it relates to flood reduction and prevention. The results[86] show very a wide variation in the state of planning in the member countries, likely due to the different levels of economic development within the group. However, even among the highly industrialized countries, differences exist, as can be seen from the examples of The Netherlands and Sweden.

<u>The Netherlands</u>

The focus of climate change adaptation is on 'no regrets' strategies. The policy's guiding principles are: anticipating instead of reacting; following a three-step strategy (first retention, then storage, and as last resort, drainage). The policy is to allow more space for water; in order to prevent floods, rivers are allowed to expand into side channels and wetland areas. The basic package consists of measures such as deepening the forelands of the rivers, displacing dikes further inland, lowering of groynes in the rivers and enlarging of summer beds. Dikes would be reinforced only in cases when other measures are too expensive or inadequate.[87]

The adaptation strategy is a national strategy that aims to be prepared for discharges from the Rhine river of up to 16,000 m^3/s by 2015 and discharges up to 18,000 m^3/s after 2015 (the highest measured discharge is 12,600 m^3/s, in 1926).

- The country will invest €2.2 billion in improving safety from flooding in riverine areas.
- Provincial authorities will be responsible for ensuring that water management policy measures are incorporated in the land use planning process at the municipal level.
- A mandatory water assessment was introduced in 2000 for all larger infrastructure and spatial plans that may affect water management. Climate change adaptation has been an important argument for introducing the water assessment.

<u>Sweden</u>

In terms of adaptation, there is no national strategy as yet in Sweden.

- In reference to climate change, some municipalities have set restrictions on the location of buildings, and floor elevations and storm sewer capacities have been established in the general context of increased rainfall, stormwater flows and potential for flooding as a result of climate change impacts.

- A vulnerability study was carried out from 2005 to 2007, which included descriptions of the economic consequences for different sectors, with a focus on infrastructure, buildings, energy and water supply, forestry, agriculture, human health and biodiversity.

4.3.3 Climate Prediction and Challenges for Adaptation Planning

While the causes of climate change are global, its consequences have to be dealt with at the local level. Because the impacts of climate change will be different in each region, each jurisdiction will face very different problems (more frequent extreme weather events in one area, drought in others, or both, for example). The success of adaptation in each jurisdiction will partly depend on the ability of governments and agencies to effectively foresee these challenges, define the types of appropriate actions, and implement them in a timely manner. It is therefore of great importance to identify the specific potential local impacts of climate change, and this, in turn, requires the development of tools to predict climate change impacts at the local level. Before a municipality or a regional body decides to invest in pursuing specific changes in infrastructure due to climate change, they must first identify the problem, its magnitude, its potential consequences, appropriate solutions and ways to finance them.

The primary tools for available predicting future climate in impact assessment and adaptation studies are global climate models. While there are several global climate models in general use, each of these gives slightly to significantly different results for any given location. In fact, the degree of variation between the models can be larger than the predicted global temperature rise for some of the models, depending on the scenario adopted to describe the future evolution of GHG amounts in the atmosphere (Figure 1). One can thus sense the difficulties inherent in accepting a specific model's results as the basis for further work in development of climate change adaptation plans.

Assuming one adopts a specific model's results as the basis for further analyses, the challenge of translating these results into a form useful at the regional or municipal scale presents itself.

The global climate models employ a scheme to represent the atmosphere whereby the surface of the earth is divided into a number of grid cells, typically on the order of 250 km x 250 km. The evolving climatic conditions within each grid cell are then computed, taking into account the interactions, mass and energy flows between adjacent grid cells. While this scale of discretization is sufficient to understand global trends, the geographic boundaries of most municipalities are orders of magnitude smaller than these grid cells, and the global climate models do not fully include important processes that occur on these smaller scales, nor do they include important surface features that affect local climate, such as the North American Great Lakes which play a major role in determining the climate of the surrounding regions. Research on preparing regional scale climate models is ongoing, as well as research into various ways of scaling down the global climate model results in a rigorous manner for use at smaller spatial scales. Downscaling methods are of two general types, statistical methods and regional models. Regional models would more adequately represent the finer scale processes and features unique to a study area, with a greater degree of confidence in the model predictions as a result, but represent a large research and development effort. In the absence of fully functional regional models, more commonly used are various statistical methods that attempt to relate predictions from the global models to local predictions. Given the less deterministic nature of this downscaling, a larger degree of error is inherent in the results.

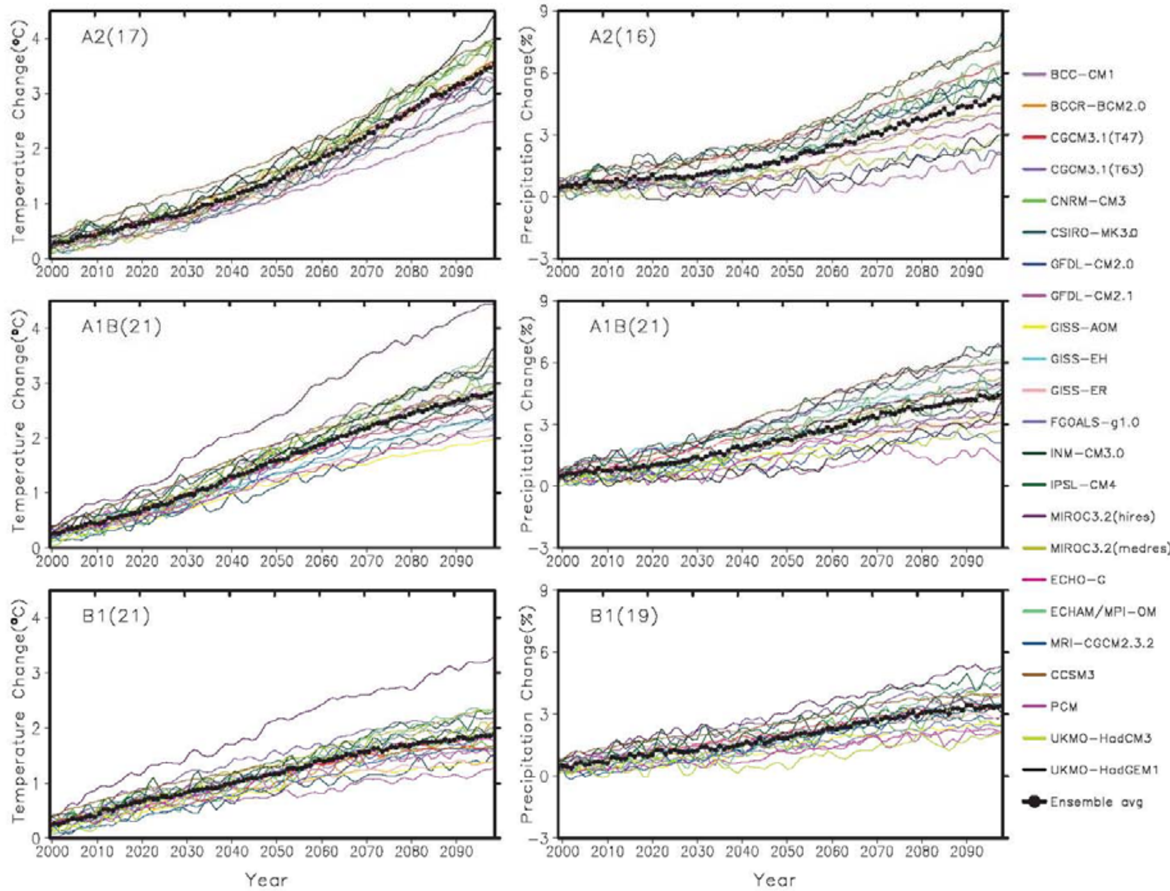

Figure 1. Time series of globally averaged (left) surface warming (surface air temperature change, °C) and (right) precipitation change (%) from the various global coupled models for the scenarios A2 (top), A1B (middle) and B1 (bottom). Numbers in parentheses following the scenario name represent the number of simulations shown. Values are annual means, relative to the 1980 to 1999 average from the corresponding 20th-century simulations, with any linear trends in the corresponding control run simulations removed. A three-point smoothing was applied. Multi-model (ensemble) mean series are marked with black dots. See Table 8.1 for model details.
Source: IPCC 4th Assessment Report, p.763

In brief, current climate science is unable to provide precise or local predictions of future climate with respect to the conditions and parameters at the local scales at which most adaptation action must take place. With respect to stormwater and floodplain management, current climate models cannot describe with sufficient detail the extreme rainfall regimes upon which policies and infrastructure in these fields are based. While predictive climate tools are improving, it can be expected that there will significant uncertainty in local climate projections for the foreseeable future that will need to be addressed in adaptation planning.

4.3.4 Climate Change Adaptation Planning in the Face of Uncertainty

Presented with the challenges described above, various entities have taken different approaches to advance their climate change adaptation planning. Transit New Zealand has taken a ‘risk management’ approach, varying the strategy depending on infrastructure vulnerability and design life. The Halifax and Region Municipality took a similar approach. Other municipalities, like Ottawa, have decided to postpone adaptation action until better data are available, given the high degree of uncertainty on climate change predictions and associated impacts. A paper discussing the rationale behind the City's position explains: "How buildings and infrastructure can adapt to impacts resulting from climate change has not been an explicit component of the Official Plan or land use planning to date. Given the uncertainty and long-term nature of these impacts, it is difficult to develop specific policies addressing climate change adaptation. Good planning principles that take into account risk management will help form the basis of an adaptation strategy."[88]

Similarly, in a specific US example related to stormwater management, the Minnesota Stormwater Steering Committee, which publishes *The Minnesota Stormwater Manual*, discussed the implications of using design storms on the basis of data that are generally considered outdated (the data come from The US Weather Bureau's 1961 Technical Publication 40, commonly known as "TP 40"). Yet the Steering Committee decided to use this reference document to define design events that should be used in Minnesota because "there is no acceptable substitute at this time."[89] Given the New Orleans experience after hurricane Katrina, it seems clear that the consequences of an extreme event occurring when a city is unprepared could have much higher costs than that of implementing preventive adaptation measures, hence a decision not to act entails accepting a degree of risk.

Michael Meyer – professor at the School of Civil and Environmental Engineering in the Georgia Institute of Technology in Atlanta, and former chair of the US Transportation Research Board – suggests that a probabilistic approach to infrastructure design is perhaps appropriate when there is a high level of uncertainty. He asserts that this "approach to infrastructure design explicitly trades off design considerations with the risks associated with structure failure, where this risk is defined broadly to include societal costs of not having the structure or infrastructure available" and that at "a minimum, the structures that will have longer useful lives should be designed with such an approach."[90] This approach notes that infrastructure that has a shorter design life will afforded opportunities to incorporate changing environmental conditions in the facility replacement schedule. In both cases, a probability of environmental change occurring over the design life is assumed – a series of designs are then prepared using several designs standards, to attempt to incorporate a future range of unknown environmental conditions. For each design, the replacement cost as well as the economic cost for disruption of the facility and the service it provides is estimated. For each design, the occurrence probability is then applied to the cost components that would be affected by changing climate conditions, resulting in a means for comparing the relative costs of including differing degrees of climate change in infrastructure design(see Appendix A (A-11).

Changing design standards and guidelines could be a necessity in the long term, but it usually is a complex and slow process that could take several years.[91] Meyer describes the possibility of a combination of short-term and long-term measures, similar to what the California earthquake engineers did when faced with a series of intense earthquakes that caused infrastructure damage: while in the long term the design standards were changed, in the short term infrastructure was retrofitted to make it more resilient to stronger events.[92]

One of the challenges with climate change adaptation is how to incorporate it into the engineering design processes, given its associated uncertainties. Infrastructure is built with design standards based on historical climatic data, yet a crucial problem posed by climate change is that historical data do not necessarily reflect what future trends might look like. Nevertheless, Auld and MacIver[93] argue that:

Until the uncertainties associated with the directions and magnitudes of changes in climate extremes are known and can be incorporated into climatic design values, the safety factors used in codes and standards may need to be increased to reflect the growing uncertainties in climatic conditions over the lifespan of the structure. Since uncertainty is well accepted as a part of construction codes and standards and the regulatory process, it should be possible to deal with the growing uncertainty of future climate design values through measures such as increasing safety factors. While regulators and the construction industry will undoubtedly be reluctant to include significant improvements and resultant increases in the costs of construction, the reality is that engineering and regulation are already based on statistical analyses of risk. Uncertainty over the future climate is one more source of variance or uncertainty that can be quantified by various methodologies (e.g. variances from different climate models).

4.3.5 Adaptation Practices in Areas other than Stormwater Infrastructure

In spite of the high level of uncertainty that climate change presents, and in spite of the potentially high costs of adaptation, some governments are taking measures to increase resilience to climate change in their jurisdictions beyond "no-regrets" measures, both for stormwater infrastructure and other infrastructure that is potentially vulnerable to the impacts of climate change.

In the Gulf of St-Lawrence, Québec, a study ordered by several provincial ministries determined that coastal erosion in the last decade has significantly increased with respect to values over the last 70 years.[94] A group of experts from the Ouranos Consortium was asked to analyze different adaptation options with regard to climate change impact on shoreline erosion. Adaptation strategies for the region are currently being analyzed based on three different scenarios; optimistic, moderate, and pessimistic. While a comprehensive understanding of the impacts of climate change on shoreline erosion in the Gulf St-Lawrence is still under development, the "regional county municipality of Sept-Rivières used erosion maps to determine "areas at risk," which were established for a 25-year future time horizon. These maps were used to implement planning controls that provide guidance for permitting or disallowing structures to be built in the protected areas."[95] These preventive measures and others will be part of a 25-year adaptation and risk management master plan that will include short-, mid- and long-term initiatives, which will vary from building protecting infrastructure to gradually withdrawing from certain areas that will be increasingly vulnerable due to the impacts of climate change.

In Boston, *Climate's Long-Term Impacts on Metropolitan Boston (CLIMB)* is a four-year, one-million-dollar research project that describes how climate change could impact the Boston Metropolitan area, the potential costs of these impacts and the adaptive measures that should be taken to minimize the effects.[96] The study concludes that municipalities will play a key role in adaptation to climate change (p. 12). Nonetheless, the City of Boston's climate action plan (see Appendix A (A-8)), like many others, focuses almost exclusively on GHG emission reduction, which places the emphasis on mitigation of impacts.[97] However, Boston provides one of the few examples where specific changes have been made to a project due to climate change. In the 1990s, the Deer Island Wastewater Treatment Plant was built 2 feet higher at an increased cost in order to accommodate the potential future sea-level rise due to the effects of climate change.[98] It is unclear upon what data this projection of sea-level rise was based.

Transit New Zealand has carried out a study to determine whether infrastructure should be retrofit or not, based on climate change projections, or what type of new infrastructure should be constructed under new design standards that take climate change into account.[99] This study concluded that there should be a distinction between infrastructure with a short design life (e.g. pavement surfaces) and long design life (e.g. bridges and some culverts): For new bridges, it was considered that it would be "uneconomic and risky" (p.17) to design them for potential larger floods, due to the uncertainty surrounding future flooding projections. Yet in the case of major bridges and culverts where provision for retrofitting would not be practical, "future climate change impacts should be considered in the design" (p.17). Finally, the evaluation of the costs of making provisions for retrofitting (enabling future lifting/lengthening if floods increase), should be made on a case-by-case basis. (See Appendix A (A-9).

Transit New Zealand has also changed its bridge design manual to include climate change impact as a design factor,[100] now requiring risk analysis for increased flood flows and consideration of bridge retrofit for changing hydrology.[101] Some new state highway projects are already considering the impacts of climate change during design and construction. For example, the new section of causeway for Auckland's Upper Harbour Corridor, State Highway 18, was built 0.3 metres higher than the existing causeway, which was raised to match it, in response to predicted sea level rise.[102]

Climate change is also considered in the stormwater drainage systems in new developments in New Zealand. In the district of Whangarei, for example, environmental engineering standards establish that design storms shall be calculated with a 20% increase in primary and secondary flows "to allow for climate change over the asset life," and that the "design of storage/attenuation and treatment systems shall also include this increase in flow." [103] See Appendix A (A-10). It appears each district decides on the specific changes to design standards, based on climate change projections from the federal government.

4.3.6 The View from Outside the Published Literature: A Discussion of Questionnaire Responses

A questionnaire was prepared consisting of three sets of questions dealing with planning for, and adapting to, the impacts of future climate change. The first set of questions refers to adaptation to climate change at the organizational level. Section 2 focuses specifically on stormwater management adaptation measures. Section 3 addresses more technical matters, such as the source and type of data used, and is directed specifically to those organizations or departments that have already undertaken adaptation measures.

The questionnaire was sent to the following 21 municipalities: Barrie, Burlington, Calgary, Edmonton, Guelph, Halifax and Region, Kingston, Kitchener, Hamilton, London, Mississauga, Montreal, Oakville, Ottawa, Quebec City, Peterborough, St. Catherine, Vancouver, Victoria, Waterloo, Windsor and Winnipeg.

At time of writing eight complete responses to the questionnaire had been received: Barrie, Calgary, Edmonton, Guelph, Halifax and Region, Oakville, Peterborough, and Windsor. All recipients of the questionnaire are encouraged to complete it, and the complete set of responses will be made available by TRCA in the future. Appendix B contains a copy of the questionnaire as well as a summary of the responses received. Where requested, respondents' names and organizations have been removed for confidentiality.

The responses indicate that at the organizational level, most planners consider the following actions to be effective or necessary:

a) formally recognize climate change adaptation as a key priority for the organizations they work for;
b) conduct research or consult with expert agencies to identify future climate changes;
c) conduct climate change impact and vulnerability assessments on existing infrastructure and programs;
d) research or evaluate possible adaptation actions and strategies;
e) develop a corporate climate change adaptation strategy for the entire organization;
f) modify program standards, design standards, maintenance programs, and emergency response plans to address the impacts of climate change;
g) consider the creation of communities resilient to climate change in land use planning.

In spite of the perceived need or importance of taking these actions, most municipalities have not yet embarked on implementing them. A number of municipalities have planned or are undertaking climate change research and vulnerability assessments, but have not yet begun to modify programs, design standards or emergency response plans accordingly. Of the respondents, Halifax, Oakville, Barrie and Calgary are planning to carry out climate change research and vulnerability assessments on existing infrastructure and programs; Edmonton, Peterborough and Guelph considered that these assessments are necessary but have as yet these have not been considered; and Windsor considered them not necessary. A similar situation is occurring with the creation of climate change resilient communities in land use planning. Although all but one considered this important, only Calgary is in the planning stage, and only Halifax has implemented changes in land use regulations to prevent flooding due to climate change. The City has done this by implementing the "Regional Plan Policies E-14 (Floodplains) and E-16 (Coastal Inundation) and region-wide local plan and zoning bylaw amendments in April 2006, which included watercourse setbacks and buffers as well as minimum elevations for development in coastal areas (except shipping harbours)."[104]

With respect to activities specifically related to stormwater and flood plain management, most municipalities have prepared inventories of existing stormwater infrastructure, assessed them and reported on their general conditions. Planners almost unanimously considered the following measures to be necessary or effective:

a) formal directives to incorporate climate change adaptation into stormwater and floodplain management programs;
b) conduct research or make consultations on future precipitation regimes;
c) conduct climate change impact and vulnerability assessments of existing stormwater management infrastructure, existing flood control infrastructure, flood protection infrastructure and flood prone communities;
d) retrofit existing conveyance and end-of-pipe stormwater infrastructure in anticipation of increased stresses due to climate change;
e) retrofit existing flood control and flood protection infrastructure;
f) change land use regulation to prevent or reduce development in flood-prone areas in anticipation of increased frequency and magnitude of flooding due to climate change;
g) modify stormwater management infrastructure design standards to increase capacity in anticipation of increased stresses due to climate change;
h) modify development standards to promote use of measures to reduce stormwater runoff volume from new urban development (e.g. green roofs, permeable paving, etc.) to counteract anticipated increases from climate change;
i) develop strategies to promote or mandate lot level management of stormwater runoff;

j) formal incorporation of climate change in emergency preparedness planning to account for potential increases in frequency of flooding and/or infrastructure failures.

Where adaptation is being planned or undertaken, estimates of climate change impacts are generally based on prediction data from Environment Canada,(based on Canadian Global Model output), which is considered by the respondents to be the best available data in most areas. In Calgary, Vancouver and Halifax, predictions from early research in Regional Climate Models by the Ouranos Consortium were used to provide more local predictions in climate change impact assessment pilot studies.

In Vancouver,[105] recommendations made by the Climate Adaptation Working Group mentioned in section 4.4.1.2 were based on data taken from the February 2008 Ouranos report *Climate Change in Canada: Climate Scenarios for the Public Infrastructure Vulnerability Assessment, Metro Vancouver Stormwater and Wastewater Infrastructure Study*.[106] A regional analysis tool was also used.[107] The Sheltair Group has also conducted studies on the impacts of climate change in Vancouver and potential adaptation options.[108]

With respect to specific changes to stormwater and floodplain management standards to address climate change, only one response was received; the City of Barrie has based an adaptation approach for stormwater infrastructure on a simple multiple of recorded precipitation, assuming a 10% increase in storm sewer pipe design inflows will be required.

5.0 Concluding Summary

Climate change will present unprecedented challenges to governments and societies. As evidenced by the rise in global average temperature, climate is changing, likely as a result of anthropogenic causes such as the rise in greenhouse gas emissions. The state of climate prediction science is constantly being improved, but at the current time it is extremely difficult to predict where, when, how and to what degree climatic events will occur at the local level. The tools that are currently available to predict climate change locally are subject to numerous limitations and alternative techniques often produce very different results. As a result, planners and decision makers are faced with high levels of uncertainty when attempting to incorporate a response to the impacts of future climate change in their planning and decision-making processes, and are hence required to define strategies to advance their climate change adaptation planning within this framework of uncertainty. While studies indicate the most costly option for governments may be to not take action,[109] the range of variability in predictions derived from global climate change models, compounded by the difficulty in downscaling those results to describe future local climate, presents a framework of uncertainty that hinders the development of climate change adaptation plans that are sufficiently prescriptive. It is not surprising, then, that the first actions of governments and agencies tend to be 'no-regrets' measures, where a benefit is realized to both the existing condition and in the event of a potential future climate change.

Perhaps due to the high degree of uncertainty involved in these issues, there is little technical guidance available (from federal/provincial governments or elsewhere) to municipalities on how to conduct climate change adaptation. Since climate change adaptation is a relatively new concept, governments and agencies have focused primarily on research as the first step towards understanding the impacts of climate change on our infrastructure and way of life, and developing response strategies to adapt to these changing conditions.

Yet even against a background of uncertainty and variability in the predictions of future climate change, there are examples where climate change is accepted as occurring, and potential effects and impacts of future climate change have been incorporated in the decision-making, planning and design processes. In Canada, the construction of the Confederation Bridge project in the early 1990s[110] provides a high-profile example of a construction project in which climate change was considered as a specific issue during the planning, review and approval process under the Canadian Environmental Assessment Act (the consideration of climate change impacts did not necessitate any further changes to the design of the bridge). In the United States, the Boston water treatment plant[111] represents perhaps the first time that climate change triggered modifications to an original design even though the design changes resulted in higher project costs. In other cases, more conservative approaches to advancing development of climate change adaptation plans, given the limitations of the current predictive tools, have been adopted, based on risk assessment and cost-benefit/life cycle approaches.[112]

Many of the impacts of climate change will be manifested as increased stresses on infrastructure assets under municipal jurisdiction, including stormwater and flood management infrastructure. It is not surprising, then, that it is municipalities and supporting regional agencies, both in Canada and elsewhere, that are taking the lead in climate change adaptation planning and practice. In spite of the variability in predictions of the scope, magnitude and type of impact on the environment as a result of future climate change, some organizations are taking the proactive approach and have already incorporated stormwater management practices that will mitigate the effects of urban drainage on the environment in general, with the associated benefit of increasing the resiliency of infrastructure. Vancouver, Chicago and Toronto are examples of this, where such practices have been put in place before formal municipal plans for climate change adaptation were prepared. These ‘no-regrets’ measures, intended to reduce runoff volume and rates to reduce the existing stresses on stormwater and flood control infrastructure as well as the natural environment, may allow infrastructure to remain viable under increased precipitation regimes well in excess of what it would be otherwise.[113] These measures include rainwater collection and re-use systems, sewer inflow-control devices, green roofs, and land use planning that seeks to increase the amount of pervious area and reduce the impact of impervious area in new developments.

Halifax represents an early and successful example of adaptation planning that involved participation and coordination of different sectors (both private and public) – one that has gone a step further than ‘no-regrets’ measures – planning or undertaking risk analyses, developing floodplain and vulnerability maps, and prescribing adaptation measures such as re-evaluating land use planning objectives, changing some infrastructure standards, and considering mechanisms to finance the costs of adaptation.[c]

Preparing for the impacts of future climate change and developing adaptation plans with respect to stormwater and floodplain management, or any other issue, will be an ongoing process that must be constantly updated to reflect advances in the predictive science. In Canada, federal and provincial governments have an important role to play in developing national and provincial adaptation strategies to guide local action. These entities would also be

[c] See documents referenced in section 4.4.1.2 under Halifax and Region initiatives, section 4.4.5 on questionnaire results for details on initiatives taken by HRM and Appendix A (A-6 and A-7).

a source for research and data necessary for development of climate change adaptation strategies, and are best positioned to coordinate the efforts of diverse groups working on climate change adaptation.

The current study suggests that in spite of all the uncertainties on future climate change, incorporation of climate change adaptation practices in stormwater management – although relatively new – is gaining momentum. Virtually all public documents related to climate change adaptation that mention stormwater or floodplain management are as recent as 2005, with some municipalities having incorporated adaptation into their climate change action plans starting in 2007.[114] Most agencies seem to be in the early stages of the adaptation planning process, and significant effort is being put into integrating adaptation in government processes and the public consciousness. However, substantial progress needs to be made before climate change adaptation becomes part of the mainstream agenda. The study suggests that there are no comprehensive, science-based approaches that currently exist to adapting stormwater and floodplain management practices for climate change that can be applied at the municipal scale. Given that this appears to be a common need and concern of municipalities both in Canada and other countries, it seems obvious that this is an issue that should be addressed by scientific agencies at provincial and federal levels of government as well as the broader research community.

There appears to be a consensus that parties at all levels must act now, as it would be economically and politically beneficial to commence assessing and preparing for the impacts of climate change, as the costs of potential societal and environmental impacts if nothing is done may ultimately be more expensive than taking action. Climate change should be mainstreamed into the general consciousness, through education and working groups with stakeholder and policy makers, and the resulting awareness leveraged into support for short and long-term measures to prepare for the impacts of climate change. These measures would include implementing "no-regrets" measures, changing land use planning principles, promoting low impact sustainable development and retro-fits of existing development, modifying infrastructure design standards to account for climate change, and undertaking continuous research on innovative stormwater management,

The contacts made with other organizations during research for this report suggest that while there are many groups looking to find ways to adapt to climate change, there has not been much work investigating what other cities, provinces, states or countries are doing. Around the world, governments and agencies, international organizations, NGOs and local communities are all participants in understanding the way communities will be impacted as a result of future climate change. The lessons from each will serve to improve the process of developing adaptation plans and implementing adaptation practices so that our communities and the environment are protected. To this end, mechanisms and tools should be created for planners and engineers to share knowledge and experience, as well as access guidance from the scientific community as the skill of the climate change predictions improve.

Appendix A – Key Texts

The following texts are extracts from key sources drawn upon in the preparation of this report. Each text is preceded by its citation

A-1

Office of the Auditor General. 2006. "Adapting to the Impacts of Climate Change." In *2006 September Report of the Commissioner of the Environment and Sustainable Development*.
http://www.oag-bvg.gc.ca/internet/English/parl_cesd_200609_02_e_14984.html

2.45 Key analysis of climate data to support infrastructure design was not conducted.

Analysis of extreme weather events is necessary to support the design of infrastructures such as storm sewers. Environment Canada has not done a comprehensive analysis of extreme rainfall events since 1991. Since then, the frequency of extreme rainfall events has increased in some areas, making it more likely that infrastructure is not adequate for current and future climate conditions (Exhibit 2.6). We found that Environment Canada has not adjusted certain factors to take into account what users of this information need to know about a changing climate. The density of the rainfall monitoring network and the level of effort required to analyze collected data and produce information about how often intense rainfall occurs have not been adjusted.

Exhibit 2.6 Building and upgrading of sewers based on outdated climate information

Many existing standards and codes depend on statistics based on historical weather data to determine specifications for infrastructure design. A good example is stormwater management. Practices used in stormwater management have evolved; however, the underlying assumptions about the climate are still usually based on historical climatic conditions, including for the frequency of intense rainfall events. Data on the frequency of intense rainfall events is derived from rainfall observation and is used to design infrastructures such as sewer systems and culverts. For example, a "25-year storm" is a rainfall event of an intensity that is expected once every 25 years, averaged over a long period, or that has a four percent chance of occurring in any given year. The upgrading of aging infrastructure to handle more intense events has significant financial implications, and climate-related data is essential to designing the upgrades. Managing aging infrastructures or building new ones on the assumption that the climate is static can have significant impacts on the eventual cost.

A-2

Canadian Environmental Assessment Agency. 2003. "Incorporating Climate Change Considerations in Environmental Assessment: General Guidance for Practitioners." http://www.ceaa.gc.ca/012/014/2_e.htm

2.2 Impacts Considerations: Where Climate Change May Affect a Project

The objective of this section is to help practitioners assess, reduce and manage the adverse impacts that climate change may have on projects and ensure that these impacts will not pose a risk to the public or the environment. The consideration of climate change impacts on a project is a component of the standard EA practice of considering possible changes to a project caused by the environment. The consideration of climate change impacts in EA should reflect regional variations in climate and environment, and jurisdictional practices.

Where the risks associated with the impacts of climate change on a project are of a private sector nature alone (for example, affecting the long-term profitability of the project), the proponent can choose to absorb this risk. However, if climate change risks extend beyond the project itself to potentially affect the public or the environment, this information must be factored into an informed decision by relevant authorities. Priority should also be given to projects that are both located in areas where there is a known sensitivity to climate change (i.e. projects located in Arctic regions or near large bodies of water), and are identified as sensitive to the effects of changing climatic parameters.

As with other considerations in EA, it should be noted that the onus remains on the practitioner to ensure sufficient and accurate information required to conclude whether or not there is a risk to the public or environment.

A-3

Bell, A., N. Collins, C. Ells, G. de Romily, A. Rossiter and R. Young. 2002. "Evaluation of the ClimAdapt Guide to Incorporating Climate Change into the Environmental Impact Assessment Process."
http://www.acee-ceaa.gc.ca/015/001/026/index_e.htm

5. Summary of Guidelines

In summary, the following guidelines should be used by proponents for including climate change considerations in EIAs. The assessment of impacts with respect to climate change will depend on the quality and specifics of the modeling data used. At present this data is, at best, regional in nature for a limited set of parameters. While the user should invoke the precautionary principle when applying these guidelines, the user should also be cautious in providing specific impacts that may not be supported by the current data set.

For Proponents:

- **Guideline #1**: As the initial step in the EIA process, the proponent should determine and document whether climate change is a potential consideration, and also declare in their submissions all information sources used.
- **Guideline #2**: Proponents of EIAs should consult with the appropriate regulatory personnel before deciding on the approach to be adopted to incorporate climate change into an EIA.
- **Guideline #3**: Proponents of EIAs, if using a risk assessment approach, should explicitly define the method used and justify the choice if the CSA standards are not followed.
- **Guideline #4**: The precautionary approach/principle should be used when incorporating climate change considerations into the EIA process, with disclosure in the EIA report of areas where it was applied.
- **Guideline #5**: Review the scoping issues relative to climate change; determine how climate change has been, or may need to be, incorporated into design criteria, ecological, socio-economic and physical factors, cumulative impacts, and the uncertainty of predictions.
- **Guideline #6**: VEC lists will not generally be modified by climate change variables given the broadness of categories used to define VECs in most environmental impact assessments. However, analysis of climate change impacts will often need to be based on specific parameters or species selected for their importance or as indicators of impacts.
- **Guideline #7**: The relevance of climate change must be analysed within spatial, temporal, ecological, administrative and technical boundaries with reference to each VEC to be assessed. The analysis must identify any effects of the project beyond its lifespan.
- **Guideline #8**: The criteria for defining significance must be applied to the effects of the project on the environment as it will exist over, and possibly beyond, the life of the project, not only at the time when the EIA is prepared.

- **Guideline #9**: Changes to VECs resulting from specific predicted climate changes must be determined with appropriate input from specialists knowledgeable in the VEC and in climate change implications. It is important that a balance be achieved in the accuracy of predictions for changes to both the climate and the VECs.
- **Guideline #10**: Once the VECs are identified and assessed, the scoping exercise should be revisited as an analytical loop within an iterative process.
- **Guideline #11**: Potential effects of the environment on the project must be examined using the same criteria for significance as used in the assessment of effects of the project on the environment. These include magnitude, geographic extent, duration and frequency, irreversibility, ecological context, and likelihood. Assessment should take into account the design criteria and uncertainty of predictions.
- **Guideline #12**: Consideration of cumulative effects should be inherently included in the EIA process when climate change is a factor, whether or not the assessment is required by the particular jurisdiction.
- **Guideline #13**: Mitigation measures specific to addressing climate change impacts, possibly including any appropriate adaptation measures, should be addressed in the mitigation section of the EIA and also incorporated into the project description section of the report.
- **Guideline #14**: If a project is potentially sensitive to climate change within its life, the project monitoring should also include periodic review of climate change data, and/or monitoring to test the appropriateness of the climate change working assumptions, and if necessary, allow modifications to be made to the project.
- **Guideline #15**: In EIA reporting, caution should be exercised to avoid over-emphasizing the need for accurate climate change predictions on a complete array of variables where significant climate change-related impacts from, or on, the project are not anticipated.

A-4

The New Brunswick Climate Change Secretariat. 2007. "New Brunswick Climate Change Adaptation Plan 2007/2012."
http://www.gnb.ca/0009/0369/0015/0001-e.asp

Incorporating climate change considerations into initiatives such as improved coastal and floodplain protection, enhanced development planning, better infrastructure standards, and the adoption of new land-management practices, will be important in growing our economy.

The Province will need to employ adaptation tools such as adopting the Government of Canada National Climate Change Adaptation Framework to raise awareness of adaptation and solutions. With such tools, the Province can facilitate and strengthen capacity for co-ordinated action on adaptation and incorporate adaptation into policy and operations. The provincial adaptation response will not only need to promote knowledge sharing networks and coordinate research on impacts and adaptation, but also have to provide methods and tools for adaptation planning in communities. This Climate Change Action Plan outlines adaptive actions in the following areas:

- Adoption of a Provincial Planning Policy;
- Strengthening measures to protect coastal areas;
- Adoption of a comprehensive water management strategy;
- Management of natural resources; and
- Risks and damages.

A-5

Province of Alberta. 2008. "Alberta's 2008 Climate Change Strategy."
http://environment.gov.ab.ca/info/library/7894.pdf

In spite of steps being taken today, scientists agree that climate change caused by human actions will continue for centuries to come. That means we need to anticipate and plan ahead to reduce our vulnerability to the impact of climate change. Strategies to adapt to climate change must go hand in hand with actions identified in this plan to reduce current and future greenhouse gas emissions. It's not a question of doing one or the other – both approaches are necessary. Research is currently underway in Alberta, along with the other Prairie provinces, to identify the risks and opportunities and the best strategies to adapt to climate change. That will involve managing short and longer term risks and taking advantage of opportunities to build a more sustainable environment. It involves looking at the impact of climate change on our province – identifying places that could see a more severe impact from climate change – along with people who could be more affected. All sectors of our economy and society need to be involved in anticipating and responding to the impact of climate change.

Actions:

- Develop a provincial Climate Change Adaptation Strategy to provide overall direction, identify measures and indicators of climate change, provide a source of information about the impacts, and identify risks and vulnerabilities. It will focus on water, biodiversity, energy, municipal infrastructure, agriculture and forestry
- Coordinate policy and research on adaptation
- Communicate and inform Albertans on the potential impacts of climate change
- Develop appropriate responses to adapt to climate change (p.21)

A-6

Halifax and Region Municipality. 2006. *Regional Municipal Planning Strategy*. http://www.halifax.ca/regionalplanning/documents/RMPS_June06.pdf

Chapter 2. Environment

2.2.4 Floodplains

Land adjacent to rivers and streams which are subject to flooding (floodplains) are unsuitable for development. Development or alteration of a floodplain can restrict the normal water drainage patterns and cause significant damage to property and infrastructure and risk to life. Limiting development on these lands reduces the need for costly flood control infrastructure such as channels, reservoirs and dykes, and protects the public from property damage and loss of life.

To minimize the effects upon natural stormwater flows, HRM will exercise control over the placement and stabilization of fill necessary for the flood proofing of structures permitted within a floodplain designation of a Secondary Planning Strategy. Through the review of subdivision applications, any roadways proposed within a floodplain designation will need to meet HRM's stormwater requirements. The following policies are intended to mitigate the consequences of flooding along major rivers and stress the environmental importance of rivers in regulating and draining water flows through watersheds.

> (Policy) E-14
> HRM shall restrict development and prohibit the placement of fill or alteration of grades in association with development that restricts the capacity of flow or increases flood levels within the 1 in 100 year and 1 in 20 year floodplains for designated watercourses, under secondary planning strategies and land use by-laws. Boardwalks and walkways, conservation uses, historic sites and monuments and wastewater, stormwater and water infrastructure shall be permitted within floodplains.
>
> (Policy) E-15
> Notwithstanding Policy E-14, within the 1 in 100 year floodplain, provisions may be made in secondary planning strategies and land use by-laws to permit development which has been adequately flood-proofed.

2.2.5 Coastal Inundation

Sea level has slowly risen along the Atlantic Coast, accelerated by global warming. Expected increases in the frequency and severity of storm events related to climate change is an additional concern. Rising sea levels and storm surges can result in increased damage to coastal communities and have significant impacts on coastal infrastructure, environmental assets, utilities, property and community economic development. The following policy mitigates the potential impact that coastal inundation and storm surge events could have on human safety. It is intended as an interim measure pending the completion of the Potential Hazards to Development Functional Plan.

(Policy) E-16

HRM shall, through the applicable land use by-law, prohibit all residential development on the coast within a 2.5 metre elevation above the ordinary high water mark, except for lands designated Halifax Harbour on the Generalized Future Land Use Map (Map 2) and industrial lands within the port of Sheet Harbour. Provisions shall be made within the by-law to permit residential accessory structures, marine dependant uses, open space uses, parking lots and temporary uses within the 2.5 metre elevation. (pp.30-31)

A-7

Halifax Regional Municipality. 2007. "Climate Change Risk Management Strategy for Halifax Regional Municipality."
http://www.halifax.ca/climate/index.html

Executive Summary: Recommended Actions and Needs for Future Actions

Recommended Actions

The IPCC suggests that the best approach to addressing climate change impacts is a mix of strategies that includes mitigation (such as HRM's GHG Reduction Plans), adaptation, technological development (to enhance both adaptation and mitigation), research (on climate science, impacts, adaptation and mitigation), and education. This approach needs to combine policies with incentive-based approaches, and actions at all levels from residents through to provincial and federal governments. A key barrier against the incorporation of climate change in decision making is that municipalities and private enterprise are unsure of or do not know how to assess the risks of climate change as rigorously as risk assessment for other risks such as commercial or security risks3. This ***risk management strategy*** provides HRM with the information necessary and the protocols to assess risks from climate change by adapting risk management guidance from other jurisdictions such as Australia and the Caribbean to HRM. In addition to implementing a risk management strategy, a number of enabling priorities were identified during the Climate SMART project that need to be in place prior to implementing specific adaptation measures. These key enablers include:

- Leverage innovative and responsive funding through external partnerships for climate change adaptation projects.
- Enhance community outreach and education on climate change to encourage participation and prepare stakeholders for possible controls; e.g. land use planning.
- Integrate up-to-date climate hazard mapping and asset inventory for each business unit with LIDAR mapping.
- Incorporate climate change one of the risk considerations into the integrated risk management program being implemented by HRM.
- As part of a life cycle assessment management system include climate change for building assets and groundwater, in particular.
- Continue to enhance inter-governmental collaboration, communication and coordination that integrates HRM's activities with federal and provincial climate change activities and clarifies lines of responsibility.
- Update of design criteria to account for climate change impacts.

Needs for Future Actions (from external parties)

The assessment highlights the need for additional data to support and improve the risk management capacities of HRM from other jurisdictions, including the federal and provincial governments, as well as universities and non-governmental organizations to facilitate decision making. These data needs include:

- more downscaling of climate change modeling specific to HRM;
- detailed digital elevation model of the vulnerable areas of HRM;
- assessment of the costs of climate change on the economy of HRM;
- development of a monitoring program and indicators to track changes in water quantity and quality;
- design criteria based on forecasting including climate change;
- improved understanding of coastal changes in response to climate change; and
- further research on the response of ecosystems to climate change.

Innovative and Responsive Funding

How to fund the variety of actions that need to be taken to adapt to climate change in HRM was a key concern to all who participated in the project as adaptation measures such as changes in design criteria are expected to increase costs to all HRM stakeholders over the business-as-usual case. Increased frequency and intensity of storm events may also result in HRM budget overruns as allowance for these events is not generally factored into the budget process. As well, the insurance industry has been assessing its risk for climate change and this may have consequences in terms of higher costs or lack of coverage for certain events for municipalities deemed to be at risk. Identifying and attracting funding is seen as an on-going process that should start within the next business planning cycle.

Recommended Action

Funding to develop risk management tools and implement adaptation measures is a primary barrier to the establishment of an effective risk management regime for identified climate change impacts in HRM. Funding for adaptation measures is primarily the responsibility of all three levels of government as each level has the jurisdictional control and responsibilities for mitigating the high risk impacts summarized in Section 6.2. Within HRM, there is a need to establish a reserve fund that will allow HRM to prepare for and respond to extreme events. This fund would not necessarily be directed to solely hard assets such as generators or snow removal equipment but could also be used for additional community outreach as well as co-funding for mapping and on-going climate modeling specific to HRM. There is a recognized need for HRM to be better able to track and allocate costs related to extreme events to support requests for post event relief funding from the provincial and federal government.

One source of funding may be provincial and federal governments, however, there is currently a lack of policy direction at both levels of government to be able to provide funding for adaptation with the exception of the recently renewed Climate Change Impacts and Adaptation Programme and FCM. Both of these sources only provide 50% of the funding required for specific projects.

Another source of funding available to HRM are municipal taxes, fees, and levies. Increases in taxes, fees, and levies would need to be accompanied by sustained community outreach and education as residents and businesses will not necessarily see immediate or concrete action attributable to the increase in the short term. Some of the financial burden should also be shared by residents and businesses in HRM through emergency preparedness and risk reduction as preparedness can reduce HRM's response costs. Guidance on measures communities and individuals can take to adapt to climate change and be prepared for extreme events is available on the HRM website at http://www.halifax.ca/climate/index.html. HRM can and has taken a lead role through its EMO and Naturally Green. As with any message, this needs to be continually reinforced beyond this project.

Addressing funding requirements is an on-going activity carried out by key HRM staff but with the addition of climate change considerations from the perspective of both mitigation and adaptation will likely require at least one full-time equivalent (FTE) in staffing.

Hazard and Risk Mapping

A key tool to enable HRM to develop appropriate plans, policy and by-laws to manage risks from climate change impacts is the development of mapping that would identify areas at risk in HRM. While some high resolution information is available on a regional scale, mapping at a scale to inform policy and decision making was not available. In the course of this project, GIS compatible mapping was developed by Environment Canada to provide HRM with the distribution of key climatic indicators across the region (see Appendix B). In addition, digital elevation modeling in sufficient detail was available for the area surrounding Halifax Harbour to enable mapping of areas susceptible to sea-level rise and storm surge events (Appendix C). The GIS mapping in this report is now available to HRM GIS users for use in planning.

Land use regulation is one of the few areas where HRM Business Units have significant degree of control over managing risks from climate change impacts. However, it was noted that in order to implement some measures (e.g., coastal setbacks), this may in result in potentially negative impacts on land values that will be challenged. As a result, HRM requires strong scientific data on which to base such planning decisions.

Recommended Action

It is well recognized within HRM that the municipality will require more detailed mapping that can be provided by the existing digital elevation models for most of the municipality. The use of LIDAR32 mapping coupled with coastal inundation modelling can improve the basis for planning decisions such as coastal set backs in vulnerable or high risks areas. Acquiring and processing LIDAR data is costly and to this point sufficient funds have not been available to map the entire municipality.

In the meantime, more precise digital elevation models should be developed for the entire region. Currently only the Halifax Harbour has a contour interval small enough (1 m or less) to accurately project areas at risk from inundation resulting from sea-level rise and storm surge associated with climate change. This information is key to providing recommendations for areas such as the Eastern Shore identified by Natural Resources Canada as having a high risk to damage from coastal inundation. Improved mapping coupled with modeling software such as Coastal DSS® developed in part by the Applied Geomatics Research Group of the Nova Scotia Community College, will lead to planning decisions that include improved predictions of climate change impacts and associated risks.

This mapping can be taken one step further by overlaying HRM's asset inventory and by doing so an estimation of potential damage and direct economic costs can be made.

HRM should continue to work with Environment Canada to identify, develop and refine mapping for key climate change parameters such as temperature, precipitation, and heat wave duration. Environment Canada continues to develop meteorological hazard mapping across Canada and this will be publicly available as the regions are completed. For example of the mapping produced see: www.hazards.ca.

In addition to mapping related to inundation and climatic indicators, risk or hazard mapping needs to include identification of evacuation routes and alternates as getting people out of peninsular Halifax which is susceptible to a number of pinch points that restrict ease of evacuation in times of emergency.

Update Design Criteria for Infrastructure

A key concern raised during the project is that design criteria for infrastructure such as storm sewers, culverts, bridges and dams need to be updated to reflect what the climate change models are projecting for HRM in terms of storm event intensity and frequency as current criteria rely on hindcasting and data sets that do not include the most recent meterological data, which shows an increase in storm intensity and frequency. This information is seen as critical to make appropriate planning decisions and to justify the increase in cost that will accompany the change in the criteria.

Recommended Action

Based on modeling developed for this project, return periods for extreme events appear to be shifting by a factor of 2 so that what was a 1 in 100 year event is being seen on a 1 in 50 year frequency. EC has developed a projection of extreme precipitation return periods out to the 2080s for use in developing new design criteria:

PERDIOD	10 YEARS	50 YEARS	100 YEARS
HISTORICAL	**102.1mm**	**135.1mm**	**149.1mm**
2020’s	148.9mm	202.6mm	225.4mm
2050’s	130.1mm	165.8mm	180.8mm
2080’s	132.8mm	175.6mm	193.7mm

In addition, precipitation Intensity-Duration-Frequency (IDF) charts related to precipitation are in the process of being updated with the latest observations for sites across Canada. As these data are finalized they will be made available to municipal engineers. In addition to work being completed by Environment Canada, the Canadian Council of Professional Engineers, through the Public Infrastructure Engineering Vulnerability Committee, is assessing the vulnerability of Canada’s infrastructure to climate change and will likely provide further guidance on incorporating climate change in engineering design.

Appendix D: Climate Change Risk Assessment Protocol for HRM Business Units

Climate SMART: Risk Management Approach to Incorporating Climate Change Into Decision Making .

Test Case: Community Development Department

Summary

Introduction

A key project outcome of the Climate SMART (Sustainable Mitigation and Risk Tool Kit) project is the development of a risk management tool or process that HRM and other municipalities can use to more fully incorporate climate change in the decision making. The process proposed was developed based on *CSA Q850-97 – Risk Management: Guidelines for Decision-Makers* and CARICOM's *Caribbean Risk Management Guidelines for Climate Change Adaptation Decision Making.* This session was designed to be an interactive walk through of the suggested method to incorporate climate change risk assessment as part of business unit planning activities and that the input received would be incorporated into the final guidance to be included in HRM's *Climate Change Risk Management Strategy*.

The risk management approach proposed consists of seven steps:

1. Document responsibilities of the business unit.
2. Identify the assets under the control of the business unit.
3. Identify potential impacts from climate change on those assets.
4. Quantify and qualify the risks.
5. Prioritize the risks.
6. Identify options to manage the risks.
7. Identify necessary resources, the barriers and the timeframes.

Results

Step 1 - Outline Responsibilities of Community Development

This step outlines the general responsibilities of a department.

- Regional and Community Planning
- Planning Applications
- Subdivisions and Development Approvals
- Permits and Inspections
- Economic development
- Culture, recreation

Step 2 - Identify 'assets' under Community Development.

This step identifies assets or issues the business unit controls. These assets will be evaluated in relation to climate change in the following steps. In the case of Community Development the following assets were identified:

- Generation of policies, by-laws, regulations
- Policies re: use of land, infrastructure
- Mitigation of uses
- Efficiencies of infrastructure and land use
- Corrective measures – short term.

Because the business unit does not manage any physical assets, the above were used as assets but it is recognized that these are areas that the business unit has control over as opposed to assets. Regardless, the process can be used with either group of factors to identify where a business unit is at risk.

Step 3 – Identification of the potential impacts from climate change on the assets.

In this step, the business unit group assembles the available information on climate change impacts, specifically information generated through the Climate SMART project. For this session, the list of potential climate change impacts developed as part of the Climate SMART were distributed prior to the meeting. This was supplemented by a presentation by Gary Lines of Environment Canada who provided an update on climate change projections and issues. In future this information will be posted on the HRM website and will be accessible to all business units. The identified climate change impacts are used as a basis for discussing the potential impacts relevant to the business unit and for developing a list of potential risks

After reviewing the Summary of Risks presented in the Agenda, the group discussed potential risks that would be come under their area of responsibility, these included:

- Potential impacts on ground thermal district heating. What are the impacts on groundwater if rainfall decreases and temperatures increase? Will using ground thermal heating compound the problem?
- Flood inundation as a result of extreme precipitation events. Will need to change development policies for flood prone areas.
- Development in the urban/rural fringe. Higher temperatures and less precipitation could lead to increased risk of forest fires.
- Evacuation of residents in the event of extreme climate events. HRM is currently at risk given the nature of the transportation network, especially getting off the peninsula.
- Proximity of transportation infrastructure to coastline.
- Risk of damage/loss of infrastructure as a result of storms/coastal flooding or inundation.
- Public and private watercourse dams in HRM – where are they? What are the risks?
- Gaining public buy-in to climate adaptation and how to get past the unwillingness of the public to discuss loss of ownership and control.
- Allocation of resources for sea-level rise planning?

- Vector borne diseases.
- Power grid overload as a result of increased temperatures – Air conditioning demands.
- Can National Building Code be modified for new construction to include a requirement to take into account designs for passive cooling of homes.

Step 4 – Quantify and qualify the risks.

In quantifying and qualifying the risks, the business unit estimates both the severity of the impacts and frequency of the event occurring.

The severity of the impact looks at identifying how significant a climate change risk is in terms of health, property damage, environmental and financial aspects. The severity is qualitatively estimated based on prior events and professional judgement. The severity is ranked as presented as Low, Medium, or High, where:

***Low** = Minor instances of impact that would be short term and reversible.*

***Medium** = Noticeable social and environmental impact that will require additional resources to adequately respond to. Opportunities for reversing impacts are limited.*

***High** = Significant social, economic and environmental impact leading to reduced quality of life. Impacts not reversible.*

The frequency relates to the relative frequency with which the risk can be expected to occur. For example, with climate change it is expected that storm surge flooding will occur more frequently. The frequency can also be presented as Low, Medium or High occurrence.

***Low** = the frequency of the impact occurring is improbable to unlikely.*

***Medium** = current knowledge indicates that the impact is likely to occur.*

***High** = the impact is highly likely or virtually certain to occur.*

Step 5 – Prioritize the risks.

This step involves summarizing the outputs of Steps 3 and 4 in order to rank impacts in terms of overall risk to provide the business unit with guidance on prioritizing actions to adapt to climate change. In this step, the frequency and consequence rankings are combined to produce and overall risk ranked as Low, Medium or High, where:

***Low** = Risks that require no or minimal actions. Minimal actions could include public education/awareness.*

***Medium** = Some actions controls will be required to reduce risks to low or negligible levels.*

***High** = These risk areas will require high-priority actions to reduce risks to low or negligible levels.*

This example only lists two impacts or risks due to time limitations but the business unit would list several risks related to climate change when the assessment is completed in full. Using the information from tables in Step 4, the risks were prioritized for each of the selected risks.

Step 6 - Identify options to manage the risks.

The business unit reviews and identifies options to manage the potential impacts identified in the preceding steps.

Step 7 - Identification of resources, barriers and timeframes.

In this step the business unit takes the adaptation options identified in Step 6 and determines resources (financial and technical) needed to implement the measures; the timeframe in which they should occur; and the possible barriers to be overcome to implement the measures.

For this test case, the group essentially combined Steps 6 and 7 and worked through a number of options for mitigating the risk as well as the potential resources required and the possible barriers. The group argued that prioritization of options was a preferred starting point as the assessment of timeframes involved a number of factors and could not be as easily assigned during the timeframe allotted for the test case. The following tables show the output of Steps 6 and 7 for risks associated with forest fire and flooding.

Appendix E. Climate Change Decision Tools

Available Data Sets for Incorporating Climate Change in HRM Decision Making

Data Sets

- **Temperature and Precipitation information for a municipality**

Values for temperature and precipitation change were generated through a statistical downscaling technique (Lines et al. 2005)34 and the results for Shearwater NS (as a proxy for downtown Halifax) are illustrated. These values are based on global climate model results derived from the Canadian Global Coupled Model (CGCM1). When utilizing such climate projections it is advisable that the range of values for a specific site from more than one model be employed to gain a sense of possible future outcomes.

The simplest and most straight-forward data set describes the plausible future values for temperature and precipitation change for a specific municipality. For this project, the climatological data for Shearwater, NS was used as a proxy (physically close to downtown Halifax).

A-8

City of Boston. 2007. "Climate: Change. The City of Boston's Climate Action Plan." http://www.cityofboston.gov/climate/pdfs/CAPJan08.pdf

> **4**. The City shall prepare an integrated plan that outlines actions to reduce the risks from the likely effects of climate change, and coordinates those actions with the City's plans for emergency response, homeland security, natural hazard mitigation, neighborhood planning and economic development.
>
> **5**. Planning for all new municipal construction and major renovation of City-owned facilities and other major municipal projects shall include an estimate of annual energy use and greenhouse gas emissions. Such planning shall also include an evaluation of the risks posed by the likely effects of climate change through 2050 to the project itself and related infrastructure and a description of potential steps to avoid, minimize or mitigate those risks. (p. 22)

A-9

Transportation New Zealand. 2005. "Adapting through policy."
http://www.transit.govt.nz/planning/climate.jsp

4.2 Transit's Position on Climate Change

To date, Transit has amended its Bridge Manual to include consideration of relevant climate change impacts as a design factor. Transit will also continue to monitor climate change data and developments regularly to review its response to climate change when appropriate.

This is a work in progress and Transit's position on climate change impacts on the state highway network is continually evolving due to the considerable uncertainties associated with this subject.

There is scope to review practices related to planning and route selection, catchment management and screening bridges for scour risk and treatment.

In the future, Transit may consider more proactive measures to reduce the vulnerability of network assets to climate change impacts. Actions that are proven to minimise risk, are cost effective, and would fit with existing processes would be preferred. Proactive maintenance works that could come up for consideration include:

- removing debris (e.g. fallen trees) in upstream parts of river catchments
- developing a scour screening procedure to identify at-risk bridges and culverts (based on Coleman and Melville (2001) and coordinated with the seismic screening procedure)
- maintaining river bed levels at bridge foundations.

A-10

Whangarei District. 2007. *Environmental Engineering Standards*. Issue 1 - June 2007.
http://www.wdc.govt.nz/resources/10151/4StormwaterDrainage.pdf

Section 4.1.1

The stormwater system for a development, including any upgrading of existing downstream systems where required, shall provide:

- Piped reticulation and/or storage or an alternative low impact system through urban areas,
- Retention and enhancement of existing natural waterways through open space areas, including parks and reserves,
- Allowance for changes in weather patterns from global warming.

Section 4.8.2

New Systems shall be designed to cope with design storms of at least the AEP in Table 4.1, with an allowance for effects of climate change. Primary and secondary flows shall be increased by 20% to allow for climate change over the asset life. (p. 59)

A-11

Meyer, M. D. (2005). "Design Standards for U.S. Transportation Infrastructure: The Implications of Climate Change." Transportation Research Board.
http://onlinepubs.trb.org/onlinepubs/sr/sr290Meyer.pdf

The life-cycle costs of infrastructure designed using this approach would depend very much on the assumed climate change actually occurring. In the short term, the costs of a 50-year bridge would be less than the costs for a 100-year bridge. And if environmental conditions have changed as expected in the design over the 50-year time frame, the costs of replacing the bridge could include the new design characteristics that reflect the changed environmental conditions. If a 100-year bridge had been built and the environmental conditions did change, the costs of retrofitting the bridge or even of replacing it would be much greater than if a 50-year bridge had been built to begin with. However, if the environmental conditions have not changed as expected, the owner of a 50-year bridge is faced with building a replacement bridge at the inflated expense of what the original bridge cost. As can be seen in this example, the level of risk and infrastructure vulnerability has associated with it a level of uncertainty, which suggests another approach toward design for potential climate change conditions.

A probabilistic approach to infrastructure design explicitly trade offs design considerations with the risks associated with structure failure, where this risk is defined broadly to include societal costs of not having the structure or infrastructure available. At a minimum, the structures that will have longer useful lives should be designed with such an approach. To a limited extent, the current design approach to some transportation infrastructure already permits uncertainty to be included in the design process. For example, the concept of design storms, and the resulting levels of precipitation and water rise, is based on a statistical assumption of the average occurrence of storms of such strength. To the extent that such allowances are incorporated into the design process, the challenge is to get the design engineer to consider such changes in the project development process, even if chosen design characteristics result in a more costly design. If the design approach does not allow for such a consideration, and some do not, then there is a need to examine current design practice for such components (such as culverts) and determine if the designs that result from current procedures are sufficient to handle additional demands due to changes in environmental conditions.

In a formal sense, probable future loss due to an extreme weather or climate-induced event (otherwise known as risk) is related to the expected level of hazard occurrence times the vulnerability of the infrastructure to damage. Given that hazard occurrence is likely to change over time (varying by type of climate-induced change; for example, higher levels of occurrence of sea level rise versus wind changes), the level of risk is also likely to change over time. Given the uncertainty associated with the varying types of climate change-induced environmental conditions, how to incorporate a risk assessment approach toward infrastructure design in general applications is unclear.

However, the characteristics of such a risk assessment approach for long-lived infrastructure in particularly sensitive areas seem more obvious. These characteristics could include:

1. Focus on infrastructure that has long lives (greater than 40 to 50 years); infrastructure designed for a shorter life has flexibility incorporated into the facility replacement schedule to account for significant changes in environmental conditions and thus do not need to be included in this approach.

2. Identify geographic areas in a jurisdiction that have particular sensitivity to changes in climate, such as coastal or low-lying areas.

3. Assign a likely occurrence probability for environmental changes occurring in these sensitive areas that reflect the likelihood that such changes will occur over the useful life of the facility.

4. Undertake different designs for the facility with varying degrees of design standards applied to account (or not) for changing environmental conditions. Estimate the cost (both replacement and economic cost due to facility disruption) of each design.

5. Apply the hazard occurrence probability to the different cost components of the design that will be affected by changing environmental conditions. Estimate the likely costs in present dollars of each design. The design with the lowest net present value cost would be the desired alternative.

These characteristics imply that the desirability of one design over another that more comprehensively includes the risk associated with climate change can be defined through relative design costs. To the extent of the author's knowledge, this approach has not been tried in practice, but it seems that there is some merit into linking alternative design costs that take into account possible changes in environmental conditions. More research and technical guidance is needed on the design implications of climate-induced environmental changes, and on risk-based approaches to designing the most cost effective and resilient facility. (pp.22-23)

Following several major earthquakes in California, civil engineers and the building construction industry worked toward changing the way structures were designed by modifying building codes and design standards. In the interim, however, most bridges in California were retrofit with "collars" around the columns that provided greater strength and resiliency in the event of an earthquake. This strategy thus depends on new building codes to provide the longer term solution as the building stock turns over, while the shorter term fix, the bridge retrofits, is designed to handle the more immediate risk. (p.26)

Appendix B – Questionnaire and Results

Planning for Climate Change – Adaptation Planning and Practices

Introduction

The current scientific literature indicates that the impacts of climate change on Canada, with or without mitigation, will likely include increased precipitation as well as changes in the distribution and intensity of snow and rain, as well as changes in temperature as this will affect freeze and thaw cycles.

The Toronto and Region Conservation Authority (TRCA) serves municipalities in the Greater Toronto Area, including the City of Toronto and the Regional Municipalities of Peel, York, and Durham. These member municipalities look to the Authority to assist in providing expertise on stormwater and floodplain management issues, along with other watershed management related issues. As climate change has only recently become an area of focus in these fields, there is little guidance available on conducting specific change impact assessment and adaptation planning.

The TRCA is conducting a survey on whether adaptation to climate change is being considered as part of the municipal planning process in Canada, with a focus on, but not limited to, stormwater infrastructure and floodplain management. We have developed a short questionnaire intended for municipalities and supporting agencies to assess the state of climate change adaptation practices in stormwater and floodplain management within their jurisdictions.

The answers to the questionnaire will allow the TRCA and its member municipalities to enhance our overall understanding of the most recent developments and strategies, provide opportunities for collaboration, and suggest directions for further work.

Thank you for your participation in the survey.

If necessary, kindly direct this link to the department or person(s) most suited to completing the survey.

1. For each of the climate change adaptation actions listed below, please mark the column(s) that most accurately reflect the current activities of your organization and/or your opinion, as appropriate. Please use the ‘comments’ area to provide additional detail regarding these activities and to reference individuals, groups or documents from whom additional information could be obtained.

Name of your department and organization						
1.) Organization-Wide Climate Change Adaptation Activities						
Adaptation Action	**Implemented**	**Planned**	**Effective/ necessary (but not planned yet)**	**Not necessary**	**Not relevant to organization**	**Comments**
1. Formal recognition of climate change adaptation as a key priority for organization	**Guelph Halifax**	**Calgary Edmonton Oakville**	**Windsor Peterborough Barrie**			
2. Conduct research or consult with expert agencies (such as Environment Canada) to identify future climate projections for organization jurisdiction	**Halifax Peterborough Oakville Barrie Edmonton**	**Calgary**	**Guelph Windsor Oakville**			
3. Conduct climate change impact and vulnerability assessments on existing infrastructure and programs	**Guelph Halifax Edmonton**	**Calgary**	**Oakville Peterborough Barrie**	**Windsor**		
4.Research/ evaluate possible adaptation actions and strategies	**Guelph Halifax Edmonton**		**Windsor Oakville Peterborough Calgary Barrie**			
5. Develop a corporate climate change adaptation strategy for entire organization	**Halifax**		**Guelph Oakville Peterborough Calgary Barrie Edmonton**	**Windsor**		
6. Modification of programs, design standards, maintenance programs, emergency response plans, etc for climate change adaptation		**Halifax Oakville Barrie Calgary**	**Guelph Oakville Peterborough Edmonton**	**Windsor**		
7. Consideration of climate change and the creation of communities resilient to climate change in land use planning	**Halifax**	**Calgary**	**Guelph Oakville Peterborough Barrie Edmonton**	**Windsor**		

2.) Activities related to stormwater and floodplain management						
Adaptation Action	**Implemented**	**Planned**	**Effective/ necessary (but not planned yet)**	**Not relevant/ necessary**	**Not relevant to organization**	**Comments**
8. Formal direction for your department to incorporate climate change adaptation into stormwater and floodplain management programs	**Halifax**	**Calgary**	**Guelph Oakville Peterborough Barrie**	**Windsor**		
9. Conduct research or consult with expert agencies for projections of future precipitation regime for organization jurisdiction	**Halifax**	**Calgary**	**Guelph Windsor Oakville Barrie**	**Peterborough**		
10. Conduct climate change impact and vulnerability assessment of existing stormwater management infrastructure	**Guelph**	**Halifax Calgary**	**Oakville Peterborough Barrie**	**Windsor**		
11. Prepare an inventory of existing stormwater infrastructure, and assess and report on their general conditions.	**Guelph Windsor Oakville Peterborough Calgary Barrie**				**Halifax**	
12. Conduct climate change impact and vulnerability assessment of existing flood control and flood protection infrastructure	**Guelph**	**Oakville Halifax Calgary Barrie**	**Peterborough Barrie**	**Windsor**		
13. Conduct climate change impact and vulnerability assessment for existing flood prone communities		**Oakville Halifax**	**Guelph Peterborough**	**Windsor Barrie**	**Calgary Barrie**	
14. Retrofit existing conveyance and end-of-pipe stormwater infrastructure in anticipation of increased stresses due to climate change		**Guelph Peterborough Barrie**	**Oakville Calgary Barrie**	**Windsor**	**Halifax**	

15. Retrofit existing flood control and flood protection infrastructure		**Guelph**	**Oakville Peterborough Calgary Barrie**	**Windsor**	**Halifax**	
16. Change land use regulations to prevent or reduce development in flood-prone areas in anticipation of increased frequency and magnitude of flooding due to climate change	**Halifax**	**Calgary Barrie**	**Guelph Oakville Peterborough**	**Windsor**		
17. Modify stormwater management infrastructure design standards to increase capacity in anticipation of increased stresses due to climate change		**Guelph Peterboroug h Calgary**	**Oakville Calgary Barrie**	**Windsor**	**Halifax**	
18. Modify development standards to promote use of measures to reduce stormwater runoff volume from new urban development (e.g. green roofs, permeable paving, etc.)to counteract anticipated increases from climate change		**Guelph Halifax Calgary**	**Oakville Halifax Peterborough Barrie**	**Windsor**		
19. Programs to retrofit existing urban areas with measures to reduce stormwater runoff volume (e.g. by promoting infiltration, restoring floodplain storage areas, disconnecting impervious areas from storm sewers) to counteract counteract increases from climate change	**Calgary**	**Guelph Windsor Oakville**	**Halifax Peterborough Barrie**			
20. Additional strategies to promote or mandate lot level management of stormwater runoff.	**Halifax**	**Halifax Calgary**	**Windsor Oakville Halifax Peterborough Barrie**	**Guelph**		

21. Formal incorporation of climate change in emergency preparedness planning to account for potential increases in frequency of flooding and/or infrastructure failures.	**Halifax**	**Halifax** **Barrie** **Calgary**	**Guelph** **Oakville** **Barrie**	**Windsor**	**Peterborough**	
Other(s) Specify:	**Halifax**		**Oakville** **Peterborough** **Barrie**			

2. If your department or organization is undertaking climate change adaptation activities related to stormwater management, please answer the following questions:

a) What are the underlying climate change projections or assumptions about the future precipitation and flooding regime on which impact assessments and adaptation planning are based? Where applicable, please describe these in terms of the expected departure from current conditions over a planning time period (e.g. 15% increase in annual precipitation and 25% increase in the maximum intensity of municipal design storms by 2050)

Guelph: Consultation with the Ministry of Environment would be needed to predict future precipitation and design standards should be updated based on that information.

Barrie: 10 percent increased in annual precipitation

Calgary: same amount of precipitation, less events, higher intensity. Higher evapotranspiration resulting in a net deficit in overall water available

b) For each assumption regarding future climate listed above, please list the sources and references used to derive the assumption. Please be specific; for example, if global or regional climate model output was used, please provide the name and version number of the model, the greenhouse gas emissions scenario(s) considered, and the source of the output data. If another type of analysis specific to your jurisdiction was conducted, please describe the methodology and list supporting references.

Barrie: considered GHG emissions

Oakville: no projections at this time. Looking for direction from work with ARC, other municipalities etc.

Calgary: NCAR, OURANOS, AWWA

c) If assumptions regarding climate change data are based on global or regional climate models, please describe how and why the models and emissions scenarios considered were selected.

Barrie: based on local rain storm collected by the City Storm Gauge

d) Please describe how the uncertainty inherent in future climate predictions is being managed in decision-making. For example, if a decision has been made to change storm sewer design standards to accommodate increased runoff quantities, please explain how the uncertainty in the prediction of future rainfall regime was considered in the determination of the size increase required for storm sewer pipes.

Barrie: reduce GHG, consider 10% increase in storm sewer pipe design

e) If assessments have been conducted to relate projections of the future precipitation to runoff or stream flow rates and volumes, please describe the methodologies used for this transformation. For example, if urban or watershed hydrological models have been used to simulate a climate change condition, please describe the model used and the method whereby the meteorological input was modified to reflect the effects of climate change.

Barrie: SWMMHYMO, PCSWMM, CANWET models are used by the City for Storm sewer design

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