Adapting to Climate Change

Canada's First National Engineering Vulnerability Assessment

of

Public Infrastructure

April 2008

Appendix D
Canada-Wide Assessment Sampling Study

Canada

PIEVC CVIIP

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Canadian Council of Professional Engineers
Public Infrastructure Engineering Vulnerability Committee

National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change

PHASE III
CANADA-WIDE ASSESSMENT SAMPLING STRATEGY

A MATRIX APPROACH
FINAL REPORT

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EXECUTIVE SUMMARY

Investment in government-owned engineering infrastructure is huge, worth an estimated $154.8 billion in 2002 (Gaudreault et al, 2006). There are 900,000 to one million kilometres of roadways in Canada with over 56,000 bridges and their numbers are growing. Similar large numbers of infrastructure installations can also be identified for stormwater/wastewater, buildings and water resources themes.

As resources and time are limited to start the first Canadian National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change for all four infrastructure categories (water resources, stormwater and wastewater, buildings and roads and associated structures) it was concluded that a sound sampling strategy was required. This strategy combined with statistical techniques would enable representative sampling and analysis of the most important types of infrastructure that are prevalent in many, if not all, of Canada's regions, climatic zones and levels of government.

The overall objectives of the sampling strategy are to provide a means of:

1. Identification of areas of Canada reflective of geography, climate and infrastructure governance.

2. Identification of infrastructure characteristics that make them more or less vulnerable to the effects of climate change.

3. Identification of current and historic engineering standards, practices, policies and incentives that will need to be reviewed in depth to ensure that infrastructure is designed, operated and maintained while addressing climate change risk.

4. Identification of regional differences in climate change vulnerability.

The original NRCan/PIEVC plan to complete a number of case studies followed by a national assessment (i.e., Phase III) project has not materialized as originally envisaged because of the limited number of case studies that can be completed in the timeframe of the project. The present expectation is to take the results of the seven case studies that will be completed by March 31, 2008 and use those results, along with expert opinion to formulate conclusions and recommendations that will constitute the "first national engineering vulnerability assessment report". Further case studies and analysis will be required to prepare an updated "national" assessment to fill in the knowledge gaps with respect to infrastructure or areas of the country that have not been assessed in the first report.

In the short term (i.e., to March 31, 2008), NRCan and PIEVC have similar objectives, namely, completion of the present project, identification of vulnerabilities, identification of knowledge gaps and potentially setting the stage for the next series of national assessments. Beyond the short term, both NRCan and PIEVC will each have specific objectives with respect to the national assessment data. NRCan, as a federal department, has objectives at a national and international scale focusing on the national context of climate change induced infrastructure

vulnerabilities and increasing the statistical confidence in conclusions about Canada's climate change vulnerabilities. PIEVC, on the other hand, as a proponent for engineers in Canada, will use the results of the first and subsequent national assessment to highlight the need for climate change to be reflected in codes and guidelines for design of public infrastructure as well as in the education of engineers in Canada.

A matrix method of identifying target areas of Canada for vulnerability assessments has been developed. The three step approach promotes identification of:

- the infrastructure of interest for assessment
- what climate change influences are expected to impact this infrastructure
- where in the country these climate change influences are expected to occur

Using this matrix approach, PIEVC would be able to target areas of the country under the assumption that the "most vulnerable infrastructure will be located where the greatest climate change is anticipated".

All of the sampling strategy objectives, noted above, focus on attributes of infrastructure, all of which can be readily defined within the structure of combined matrices outlined in this report. Further, this approach supports short term Phase III (i.e., national assessment) objectives and longer-term NRCan and PIEVC objectives.

This report also provides guidance/suggestions for populating the matrices, secondary support information to assist in populating the matrices and further guidance on the sourcing of support information.

Note that the matrices presented in this report have only been populated with sufficient information to demonstrate purpose and function. Further, the values and/or attributes presented do not reflect an opinion of what attributes are considered most relevant nor an opinion with regard to scoring. The purpose of this brief is to present the matrix approach and to spur discussion and comment.

SECTION 1

INTRODUCTION

1 INTRODUCTION

1.1 BACKGROUND

Investment in government-owned engineering infrastructure is huge, worth an estimated $154.8 billion in 2002 (Gaudreault et al, 2006). There are 900,000 to one million kilometres of roadways in Canada with over 56,000 bridges and their numbers are growing. Similar large numbers of infrastructure installations can also be identified for stormwater/wastewater, buildings and water resources themes.

As resources and time are limited to start the first Canadian National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change for all four infrastructure categories (water resources, stormwater and wastewater, buildings and roads and associated structures) it was concluded that a sound sampling strategy was required. This strategy combined with statistical techniques would enable representative sampling and analysis of the most important types of infrastructure that are prevalent in many, if not all, of Canada's regions, climatic zones and levels of government.

The original NRCan/PIEVC plan to complete a number of case studies followed by a national assessment (i.e., Phase III) project has not materialized as originally envisaged because of the limited number of case studies that can be completed in the timeframe of the project. The present expectation is to take the results of the seven case studies that will be completed by March 31, 2008 and use those results, along with expert opinion to formulate conclusions and recommendations that will constitute the "first national engineering vulnerability assessment report". Further case studies and analysis will be required to prepare an updated "national" assessment to fill in the knowledge gaps with respect to infrastructure or areas of the country that have not been assessed in the first report.

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This report describes the development of a matrix method of identifying target areas of Canada for vulnerability assessments to fulfill the short and long term requirements of NRCan and PIEVC. A three step approach has been formulated that promotes identification of:

- the infrastructure of interest for assessment

- what climate change influences are expected to impact this infrastructure
- where in the country these climate change influences are expected to occur

The report also provides guidance/suggestions for populating the matrices, secondary support information to assist in populating the matrices and further guidance on the sourcing of support information. Further support and supplementary information is provided in appendices A, B, C and D relating climate change information, spatial and other boundaries, infrastructure categories and engineering standards and practices that may be useful in applying the matrix approach.

1.2 WORK SCOPE

The overall objective of the project is to develop a statistically sound sampling strategy. The foundation of this strategy will be the identification of a database of parameters that should be captured as components of vulnerability assessments. This living database will provide a mechanism for generation of data views and data mining that provide insight to PIEVC and others on the specifics and generalities of potential infrastructure vulnerability in different areas of the country or the country as a whole. More specifically, this strategy will allow:

1. Identification of areas of Canada reflective of geography, climate and infrastructure governance.
2. Identification of infrastructure characteristics that make them more or less vulnerable to the effects of climate change.
3. Identification of current and historic engineering standards, practices, policies and incentives that will need to be reviewed in depth to ensure that infrastructure is designed, operated and maintained while addressing climate change risk.
4. Identification of regional differences in climate change vulnerability.

The following elements are embodied within the overall work scope:

- Establishment of priorities for particular subcategories of infrastructure to be assessed, in concert with PIEVC;
- Review of other climate change, vulnerability and adaptation studies to determine whether these studies could provide the information necessary to populate one or more records in the vulnerability database (i.e. act as Phase II projects)
- Identification of a preferred level of certainty to provide a preliminary estimate of the sampling level required to achieve a number of pre-defined levels of statistical precision (e.g., low, medium or high)
- Discussion of sampling options that may increase the preferred level of precision and will identify other sensitivities that could increase or decrease the level of precision of the Canada-Wide Assessment for each of the four infrastructure categories.

SECTION 2

INFORMATION REVIEW

2 INFORMATION REVIEW

2.1 INTRODUCTION

The National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change is focused on four areas of infrastructure, namely;

- water resources
- stormwater and wastewater
- buildings
- roads and associated structures

The Phase I Scoping Study (Cameron et al, 2007) on climate change - infrastructure vulnerability was completed in early 2007. A review was made of how others currently conduct such vulnerability evaluations. An Engineering Protocol methodology was developed for making climate change - infrastructure vulnerability evaluations. A brief description of the Protocol is provided. As an outcome of a vulnerability evaluation, the Vulnerability Index represents the "parameter of interest" for statistical purposes.

The Phase I Scoping Study also provided a long list of potential infrastructure subcategories to the general themes. Discussions with key members of the Expert Working Groups (EWG's) and the PIEVC, including the EWG Chairs, which took place during the Phase I project were used to develop a methodology for establishing priorities for particular subcategories of infrastructure to be assessed.

Further, a number of other studies that focused on climate change, the identification of vulnerabilities and adaptation options were reviewed. These reviews focused on determination as to whether the information necessary to populate one or more records in the vulnerability database (i.e. act as Phase II projects) was available from these previous works.

2.2 PHASE I – SCOPING STUDY

The Engineering Protocol is intended to assist in effectively incorporating climate change adaptation into design, development and management decision making. The Protocol is a step by step process for defining, analysing, evaluating and prioritizing information. This procedure for incorporating climate change becomes a framework for supporting more effective decision making with greater confidence.

How infrastructure responds to climate and other related changes will influence how that is measured or quantified, and those people currently involved in infrastructure decision making are well placed to evaluate if changes in infrastructure performance would result in infrastructure vulnerabilities.

The Engineering Protocol is based on an assessment of loads and capacity. The total loads for a particular time, is the sum of the current loads (which may differ from those used for original

design purposes) plus those from climate and other changes over a specified time period. The total capacity, is the sum of the current capacity, plus maturing changes to the capacity over time (i.e. effective stormwater pipe sizes being reduced by the build up of solid materials in it), plus other additional changes to the capacity. Vulnerability is deemed to exist where the total load exceeds the total capacity. Adaptive capacity is deemed to exist where the total loads do not exceed the total capacity.

An application of the Engineering Protocol starts with a three part relationship that includes specification of the:

- infrastructure of interest
- climate and other change parameter
- performance goal, criteria, or key attribute

Further, parameter values or working assumptions are developed to reflect current load effects (LE), climate change effects (CE) and other changing effects (OE) resulting in the computation of the total load effects (TE) as the sum of LE + CE + OE.

Similarly, parameter values or working assumptions are also developed to reflect existing capacity (EC), maturing change in existing capacity (MC), and other additional changes in capacity (AC) resulting in the computation of the total capacity (TC) as the sum of EC + MC + AC.

The Vulnerability Index is computed as TE/EC. As noted previously, vulnerability is deemed to exist where the total load exceeds the total capacity or the Vulnerability Index is greater than 1.

Similarly, an Adaptive Capacity Index is computed as TE/(EC+MC). Adaptive capacity is deemed to exist where the total loads do not exceed the total capacity or the Adaptive Capacity Index is less than 1.

2.3 OTHER STUDIES

A number of studies were audited during the course of this project in order to better understand other public infrastructure climate change vulnerability assessments that have been completed. The list of studies included in this audit is not meant to be exhaustive but reflects work that was identified during the course of this project that embodied, in some measure, ideas and concepts supportive of the present study's objectives. A complete listing of references used for this study is provided in Section 5.

GENERAL

Climate Change, Permafrost, and Impacts on Civil Infrastructure*,* Special Report 01-03, U.S. Arctic Research Commission Permafrost Task Force, U.S. Arctic Research Commission, Arlington, Virginia, 2003.

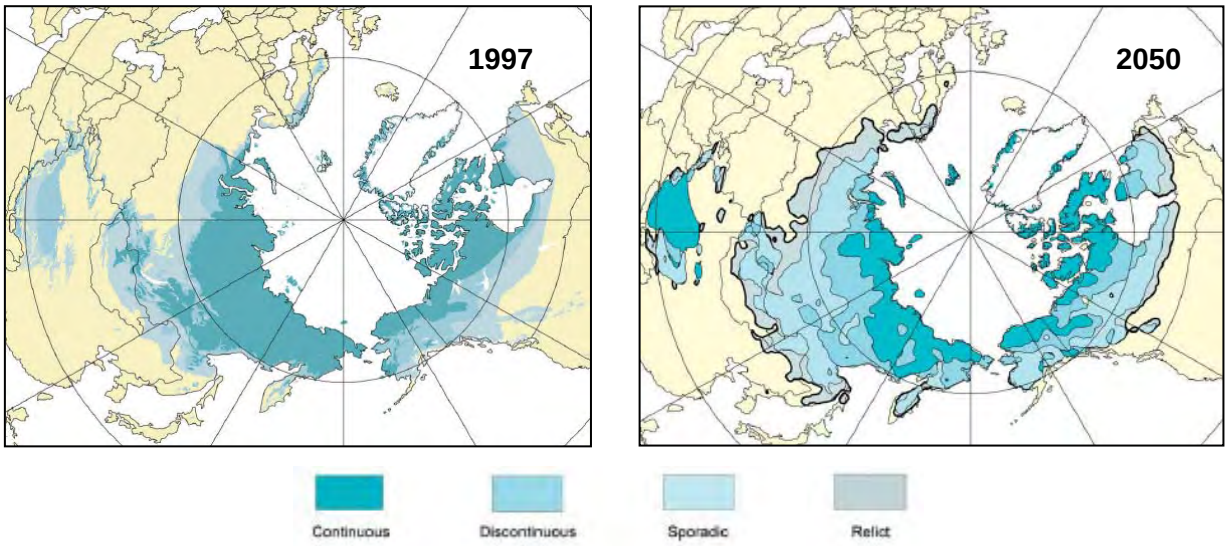

Figure 2-1
Permafrost Zonation in the Northern Hemisphere 1997 and 2050

Figure 2-1 illustrates the distribution of permafrost in the Northern Hemisphere for 1997 and the projected distribution in 2050. The primary conclusion is that a significant reduction in the area of near-surface permafrost could occur during the next century.

Permafrost, or perenially frozen ground, is a critical component of the cryosphere (portions of the Earth where water is in solid form) and the Arctic system. Permafrost regions occupy approximately 24% of the terrestrial surface of the Northern Hemisphere. The effects of climatic warming on permafrost and the seasonally thawed layer above it (the active layer) can severely disrupt ecosystems and human infrastructure such as roads, bridges, buildings, utilities, pipelines, and airstrips. The susceptibility of engineering works to thaw-induced damage is particularly relevant to communities and structures throughout northern Alaska, Russia, and Canada. It is clear from the long-term paleographic record in these areas that climatic warming can lead to increases in permafrost temperature, thickening of the active layer, and a reduction in the percentage of the terrestrial surface underlain by near-surface permafrost. Such changes can lead to extensive settlement of the ground surface, with attendant damage to infrastructure.

Figure 2-2 illustrates the potential risk to infrastructure in northern Canada, Alaska, and Russia. Canada has population centers, pipelines, and roads in areas of moderate and high hazard potential. Inuvik, a community of about 3500, is located within the moderate/high hazard potential zone. The potential for severe thaw induced disruptions to engineered works has been reported from each of these areas and problems are likely to intensify in the future.

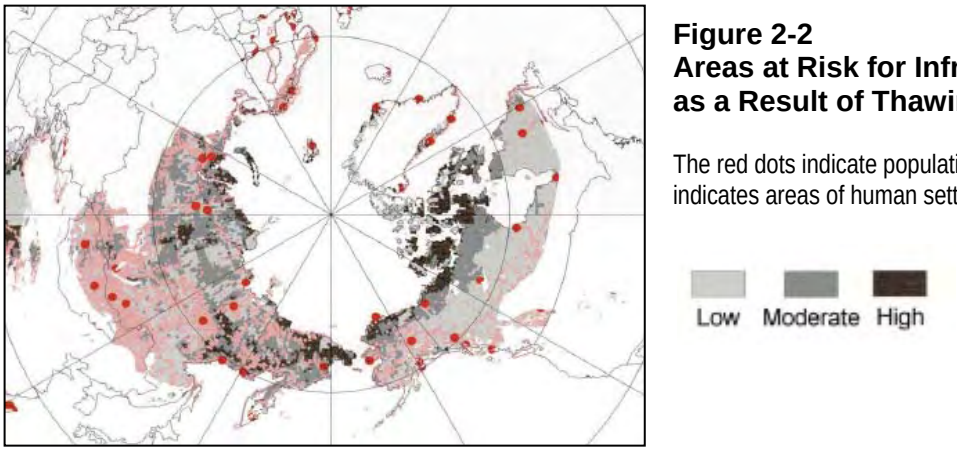

Figure 2-2
Areas at Risk for Infrastructure Damage as a Result of Thawing of Permafrost

The red dots indicate population centers; the pink shading indicates areas of human settlement.

Another reference to the study of permafrost degradation in Canada resulting from climate change is; ***Climate Change, Permafrost Degradation and Infrastructure Adaptation: Preliminary Results from a Pilot Community Case Study in the Mackenzie Valley***, R. Couture, S.D. Robinson and M.M. Burgess, Geologic Survey of Canada, Current Research 2000-B2, 2000.

The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change, M. Girard and Mortimer, M (CSA), February 2006.

The focus of the report is on the role played by codes and standards in moving climate change adaptation solutions into general practice. It describes their relationship to the design and operation of infrastructure works, and their influence upon climate change adaptation issues. It also underscores the importance of outreach strategies aimed at standards organizations and suggests practical tools for outreach implementation. Key findings from the report include;

- The existing framework related to infrastructure systems regulatory jurisdictions, laws, codes and standards is complex. The complexity and multi-jurisdictional nature of the present system can be a barrier to adaptation.
- Opportunities for enhanced adaptation and capacity building are created as standards are reviewed and updated.

- Further evaluation of the needs related to the development of new national standards could enhance adaptive capacity-building. Examples of high priority issues already identified are storm-water management, rehabilitation of existing infrastructure systems, and acute vulnerabilities in Northern infrastructure and coastal regions. National standards do not presently exist in these areas.
- Climatic load data that is referenced and/or used by codes and standards is critical to infrastructure designers and operators. Presently, the climatic loads used by designers are typically based on historical data that is no longer representative of future conditions.
- Access to high quality, reliable climatic load data is an essential element of designing resilient infrastructure.

WATER RESOURCES

Water Sector: Vulnerability and Adaptation to Climate Change - Final Report, GCSI - Global Change Strategies International Inc. and The Meteorological Service of Canada, June 2000.

Five regional water sector workshops were organized as part of the project and in all, some 330 water managers, consultants, engineers, scientists, and those affected by water issues participated in the these workshops and contributed to the content of the report.

Among the most important projected effects of the climate scenarios on Canadian water resources that were documented are:

- declines in low season river flows and lake levels and higher water temperatures in most of southern Canada, with potentially serious implications for water supplies, water allocation, hydro-power production, waste assimilation and pollution concentrations, and for freshwater ecosystems,
- ground water levels and quality are also likely to be under greater stress with levels declining in populated southern regions,
- greater frequency of high intensity rainfalls that would increase soil erosion, flash floods and storm sewer overflow,
- average annual flood peaks are expected to be lower in most regions, but occasionally very large floods are likely to occur in vulnerable river systems, (e.g. Fraser, Red, tributaries of St. Lawrence), sea level rise, combined with more severe winter storms, poses major flood and erosion risks in coastal areas, particularly in Atlantic Canada (Bay of Fundy, Northumberland Strait),
- melting of permafrost poses difficult problems for roads and infrastructure of northern regions, and
- changing flow patterns and ice conditions have direct effects on wildlife distribution and survival and, in turn, on subsistence communities of the north.

The most frequently identified adaptation strategies included;

- water conservation measures by all users
- greater emphasis on planning and preparedness for droughts and severe floods
- expanded efforts at water quality protection from agricultural, industrial and human wastes
- renewal of national (federal-provincial) monitoring efforts for water quantity, quality and climate, and
- improved procedures for fair allocation of water within basins, provinces, and between jurisdictions, taking in-stream ecosystem needs into account.

The view of most workshop participants was that Canadian water resources and the people and ecosystems dependent upon them are becoming more vulnerable to climate change impacts, rather than less. With reductions in monitoring, technical support and scientific research by senior levels of government, the knowledge database has been eroding. It was noted that these are essential to permit timely decisions on pollution, water supply and flood and drought issues.

STORMWATER AND WASTEWATER

Impacts and Adaptation of Drainage Systems, Design Methods and Policies*,* Kije Sipi Ltd *in partnership with* City of Edmonton, City of Ottawa, Mississippi Valley Conservation Authority, June 2001.

Drainage systems have always been designed based on the premise that the climate is not changing and that historical climate data can be effectively used to predict future drainage design requirements. Consequently, there is a real potential for more frequent drainage system failures and increases in the resulting flood damages and related health problems. The study examines these issues by completing a sensitivity analysis using hydrologic simulations. Hypothetical surface areas of multiple land use types were assessed along with existing urban and rural drainage basin models.

Generally, the simulation results indicated increases in peak flows and runoff volumes equal to, or greater than the given increase in precipitation and irrespective of the drainage design and analysis method used. The resulting impacts of these findings indicate future increases in drainage infrastructure costs and a reduction in the level of service of existing systems. Further, the change in frequency of storm events in combination with specific sewer network configurations may lead to either increases or decreases in flooding of municipal wastewater systems.

A review of the regulatory framework of water resources in Canada reveals a complex web of plans, regulations and policies administered by three, sometimes four levels of government.

This has resulted in inconsistent application of rules within provinces and across the country. As a result, the current legislative situation makes the implementation of adaptive measures to deal with the impacts of climate change a significant challenge.

Climate Variability and Urban Stormwater Infrastructure in Canada: Context and Case Studies**,** Watt, W.E., D. Waters and R. McLean, Toronto-Niagara Region Study Report and Working Paper Series, Report 2003-1. Meteorological Service of Canada, Waterloo, Ontario 2003.

The report provides a brief examination of the sensitivities of Canadian stormwater infrastructure to changes in climate. A short description of the history and rationale for stormwater infrastructure development precedes a general discussion of sensitivities, plausible climate change scenarios and generic impacts and responses. Climate related variables key to the design of stormwater infrastructure are identified as;

- Rainfall Intensity-Duration-Frequency (IDF) Data
- Temporal Rainfall Distribution (Design Storms)
- Critical Rain-plus-snowmelt Sequences, and
- Critical Temperature Sequences

In general it is concluded that much of this data is in need of update.

Two case studies, in which simple scenarios of future climate are incorporated into urban runoff models for catchments located in Burlington and Ottawa, Ontario, are completed. The potential impacts and options for mitigation are analysed and summarized.

The information presented in this report would seem to support application of the PIEVC Engineering Vulnerability Assessment methodology.

The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions – Social Infrastructure*,* Mohammed H.I. Dore and Ian Burton, Brock University, 2001.

The fundamental objective of this report was to collect the data necessary to be able to estimate the costs of adaptation to climate change. Questionnaires were sent out to determine climate impacts, current expenditures (both capital and operating), and other technical factors relevant to social infrastructure. This report is restricted to the costs of adaptation of the road networks and associated structures (roads, bridges, storm water management systems), and water utilities (drinking water treatment plants, and wastewater treatment plants). Significant information is presented outlining the distribution of infrastructure across Canada.

Of particular interest are the detailed case studies of water utilities in the different eco-climatic zones of Canada including; Toronto, the Region of Niagara, Montréal, Halifax, Regina, Humboldt, Swift Current, Lethbridge, Prince George, Penticton, Yellowknife and Norman Wells.

The case study for Toronto was reviewed in some detail and the available information suggests application of the PIEVC Engineering Vulnerability Assessment methodology would be supported.

BUILDINGS

Study Report No. 179 [2007], Assessment of the Need to Adapt Buildings in New Zealand to the Impacts of Climate Change**,** J. Bengtsson, R. Hargreaves and I.C. Page, Branz, 2007

The overall purpose of the study was to determine the impacts of climate change on the built environment (the focus is residential housing) and to generate a set of options for adaptation. The basis for the study was;

- topology and condition assessment of the stock of building nationally,
- regional and district councils were surveyed to obtain data on climate related damages,
- overheating and energy consumption scenarios were simulated, and
- a scenario based methodology was used to investigate social impacts.

Some facts on the inventory of buildings used in this study include the following;

- Less than 10% of buildings in the study had more than 2 storeys, with the majority being single storey dwellings.
- 70% of the dwellings are in the range of 100-200 m^2 total floor area.
- Concrete floor slab construction is used in 92% of all new detached dwellings but only represent 27% of the total inventory. Prior to 1980 most (73%) new houses were constructed on a suspended timber floor.
- For all dwellings combined the predominant cladding is clay brick for walls and sheet steel for roofs. Metal and concrete tiles are becoming more popular.
- Ceiling insulation data indicate that 45-65% of pre-1980 dwellings have 50mm or less insulation.

Climate change will, in particular, impact energy requirements for cooling with anticipated increases in indoor air temperature. Additional adaptation options included window shading, insulation (roof, floor and wall), provision for natural ventilation and double glazing or further advanced performance (e.g., low-e argon filled) windows. Apart from the suggestion for window shading, the other options would generally be considered as typical housing construction for Canada.

Other impacts to buildings noted in the report included;

- increased coastal flooding, erosion and rising water tables
- increased inland flooding
- structural considerations due to excess rainfall (primarily foundation stability as a result of excess rainfall)
- increased overheating risk
- increased forest fire risk
- increased insurance costs
- possible increased costs due to carbon / greenhouse gas charges/taxes
- increased risk due to cyclones
- increased wind loads
- increased risk pest/infestation problems

One recommendation which is applicable to the Canadian context is that development in areas with potential increased risk from flood, forest fire, temperature extremes and coastal hazards should be avoided or developed with due consideration of future climate change impacts.

Overall it is concluded that strong, early and coordinated action on climate change can limit potentially large social, cultural and economic costs.

A Checklist for Development Adapting to Climate Change, Urban Design, Spring 2007 (Issue 102), pages 36-37.

The checklist is targeted at developers, designers, architects, investors and policy makers and provides guidance in the “climate proofing” of building design. The key issues are identified below:

- Location
  - consider issues of flood risk, where appropriate
  - consider issues of coastal erosion, where appropriate
  - plan green spaces and incorporate shade to reduce the heat island effect
- Building Structure
  - incorporate potential for increased wind loading
  - incorporate potential for subsidence
  - incorporate appropriate ventilation and cooling mechanisms taking in consideration potential increases in temperature
- Building Envelope
  - design drainage system in the anticipation of increased precipitation
  - where appropriate incorporate green roofs or walls or other low albedo systems
  - design exterior systems to minimize heat gain in summer
  - design the overall envelope to minimize infiltration from increased winds and temperatures

  - cladding materials should be designed to cope with increased wind speeds

- Building Materials
  - ensure use of materials that will perform adequately in the projected climate throughout the design life of the structure/development
- Building Ventilation
  - the system should be designed to deliver temperatures (e.g., exceeding 28^{o}C for less than 1% of the time and exceeding 25^{o}C for less than 5% of the time) for the projected climate throughout the design life of the structure/development.
- Drainage
  - consider rainwater harvesting, green roof systems, and other opportunities for low impact development
- Water
  - minimize water use in buildings through consideration of rainwater collection/re-use systems
- Outdoor Spaces
  - ensure selection for vegetation take into account the projected climate
  - outdoor gardens and landscaped areas should be watering via rainwater collection systems and/or grey water recycling
  - design of waste management systems should take into consideration a hotter drier climate in the future (i.e., regarding excessive smell and pests)

The low impact development suggestions made in this article are in many ways consistent with the design criteria supported by the Leadership in Energy and Environmental Design (LEED) Green Building Rating System.

ROADS AND ASSOCIATED STRUCTURES

Impacts of Climate Change on Transportation In Canada*,* Canmore Workshop, Final Workshop Report, Transport Canada, March 2003.

A component result of the workshop was the use of a matrix approach to identify potential impacts and opportunities with climate change and associated mode and regional differences. The resultant matrix is reproduced as Table 2-1. A similar matrix is also presented documenting *Social or Economic Issues and Indirect Impacts.* The report also provides details on specific transportation modes and preferred approaches to adaptation, barriers, required research.

Table 2-1
Impacts of Climate Change on Transportation
(source: Transport Canada, 2003)

Issues	Threat	Opportunity	Region
Sea ice melting and deglaciation/opening of northwest passage	Marine	Marine	North; Coastal
Sea level rises may affect coastal infrastructure	Bridges, roads, rail, marine		Coastal
Increased frequency, severity of weather, storm surges, flooding, precipitation events affecting transportation operations and public safety (particularly in cities)	All		All
Increased frequency of freeze/thaw cycles resulting in premature degradation of infrastructure	Road, rail		All, north
Changes to lakes levels or debris flows in rivers reducing maritime freight capacity	Marine, river ferries	Rail, road	Ontario, Quebec, BC, North
Degradation of permafrost/shortening of viable northern ice road season in winter	Roads	Air	North
Droughts/extreme heat – direct (rutting), indirect impacts (increased use of automobiles for the air conditioning)	Roads; rail		Prairie, Ontario & Quebec
Landslides increased frequency; and underwater slides	Rail, road, marine, river transport		Western
Warmer winters – reduced need to de-ice/clear snow		Road, air	All
Avalanches (interruption to rail / road transport services)	Road, rail, river		Western

The road well travelled: implications of a future climate on the performance of pavement infrastructure in southern Canada, Environment Canada, March 2007.

The fundamental concern related to climate change in pavement management is the potential for premature design failure. Two sets of case studies were used to investigate the potential impacts of climate change in greater detail.

The first case study examined deterioration-relevant climate indicators that are routinely applied or referenced in management of pavement infrastructure for 17 Canadian sites, namely; Vancouver, Kelowna, Calgary, Edmonton, Regina, Winipeg, Thunder Bay, North Bay, Muskoka, Windsor, Toronto, Ottawa, Montreal, Quebec, Fredericton, Halifax and St. John's.

The second case study was used to examine the relative impact of assumptions concening pavement structure, material characteristics, traffic loads and change in climate on pavement performance for 6 sites, namely; British Columbia, Alberta, Manitoba, Ontario, Quebec and Newfoundland.

The information presented in this report would seem to support application of the PIEVC Engineering Vulnerability Assessment methodology.

SECTION 3

SAMPLING STRATEGY – A MATRIX APPROACH

3 SAMPLING STRATEGY – A MATRIX APPROACH

3.1 DEFINING INFRASTRUCTURE (STEP 1)

The PIEVC, for the purposes of the National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change, defines public infrastructure as those facilities, networks and assets operated for the collective public benefit including the health, safety, cultural or economic well-being of Canadians, whether operated by government and/or non-government agencies.

A preliminary list of infrastructure identifying categories and groupings was developed for PIEVC during Phase I of this project. The intent of the list was to provide PIEVC with a "checklist" of infrastructure to be included in the national assessment. However, a detailed, itemized list of infrastructure to be captured within the national assessment process has not, as yet, been defined beyond the four PIEVC infrastructure groupings, namely:

- water resources
- stormwater and wastewater
- buildings, and;
- roads and associated structures.

Among experts there is no consensus on the definition of infrastructure (Public Policy Forum, 2002). As such, a variety of lists categorizing infrastructure are available. Two examples of general lists are outlined below in Tables 3-1 and 3-2.

Table 3-1
Infrastructure Categorization A
(source: Public Policy Forum, 2002)

Type	Description
Physical infrastructure	roads, railways, seaports and airports
Utility infrastructure	water; waste water; electrical
Communications infrastructure	phone, cable and other telecommunication systems
Facilities supporting public activities	government buildings, hospitals, schools, cultural and recreational infrastructure (such as parks, museums, and concert halls)

Table 3-2
Infrastructure Categorization A
(source: Infrastructure Canada, 2003)

Type	Description
Border infrastructure	
Municipal infrastructure	Cultural, local transportation, tourism, telecommunications, housing, green infrastructure
Strategic infrastructure	Tourism, urban roads, public transit, water, broadband, highway

General infrastructure lists (such as those in Tables 3-1 and 3-2) do not serve the intent of a "checklist" to support the National Engineering Assessment.

Two examples of more detailed lists which are in use by Statistics Canada and Public Safety and Emergency Preparedness Canada and may serve as a basis for compilation of a PIEVC checklist of infrastructure are outlined below.

3.1.1 Statistics Canada

Statistics Canada compiles survey data on Capital and Repair Expenditures across the country. This annual survey collects data on the intentions for capital investment and the expenditures for the previous two years. Inputs are used by the Canadian System of National Accounts, particularly in the determination of the Gross Domestic Product (GDP) and Balance of Payments. The information is used by Federal and Provincial governments and agencies, trade associations, universities and international organizations for policy development and as a measure of regional activity.

The breakdown of asset type used for this survey covers about 200 descriptions of infrastructure and equipment under general categories of "Construction Expenditures" and "Machinery and Equipment Expenditures". The "Construction Expenditures" category includes sub-categories of Institutional, Industrial, Commercial, Other Non-Residential and Residential Buildings, Sewage, Mining, Oil and Gas, Waterworks, Electric Power, Transportation and Other Engineering.

Within this system, the PIEVC list of public infrastructure fit explicitly within the Institutional Buildings, Sewage Engineering, Waterworks Engineering and Transportation Engineering categories.

3.1.2 Public Safety and Emergency Preparedness Canada

Public Safety and Emergency Preparedness Canada (PSEPC) manages the National Critical Infrastructure Assurance Program. This program is an ongoing collaboration between private sector partners and federal, provincial and territorial governments. The goals of these partnerships are to provide a national framework for cooperative action and to build a resilient national critical infrastructure.

Canada's critical infrastructure consists of those physical and information technology facilities, networks, services and assets which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of Canadians or the effective functioning of governments in Canada. The PSEPC model of national critical infrastructure is made up of ten sectors as outlined in Table 3-3.

Within this system, the PIEVC categories of Water Resources and Stormwater/Wastewater would be grouped within the PSEPC Water category. The PIEVC Transportation category would fall within the PSEPC Transportation category and the PIEVC Buildings category would be spread over a number of PSEPC categories.

Table 3-3
Sectors Defining Canadian Critical Infrastructure

Sectors		Examples
1	Energy and utilities	electrical power, natural gas and oil production transmission/pipeline systems
2	Communications and information technology	telecommunications systems broadcasting systems software and hardware networks including the Internet
3	Finance	banking, securities and investment
4	Healthcare	hospitals, healthcare and blood supply facilities laboratories and pharmaceuticals
5	Food	safety, distribution, agriculture and food industry
6	Water	drinking water and wastewater management
7	Transportation	air, rail, marine and surface modes
8	Safety	chemical, biological, radiological and nuclear safety hazardous materials search and rescue emergency services dams
9	Government	services facilities information networks assets and key national sites monuments
10	Manufacturing	defence industrial base chemical industry

3.1.3 PIEVC Infrastructure Checklist

As noted previously, the intent of a PIEVC checklist of infrastructure is to assist PIEVC in quantifying the range of infrastructure to be, potentially, included in the national assessment. The checklist would also provide PIEVC with a mechanism for identifying infrastructure still to be assessed after the first national assessment is completed (i.e., identify knowledge gaps).

A matrix structure, expanding each of the PIEVC infrastructure categories, provides a simple method of describing the elements of public infrastructure as defined by PIEVC. As already noted, the overall objectives of the sampling strategy are to provide a means of identifying:

- areas of Canada that are reflective of geography, climatic regions and infrastructure governance

- attributes that make infrastructure more or less vulnerable to climate change
- current and historic engineering standards, practices, policies and incentives
- regional differences in climate change vulnerability

All of the objectives above key on attributes of infrastructure, all of which can be readily defined within the structure of combined matrices outlined in this discussion report.

Each PIEVC infrastructure category is itemized below in Tables 3-4 through 3-7. Please note that the matrices presented below have only been populated with sufficient information to demonstrate purpose and function. Further, the values and/or attributes presented do not reflect an opinion of what attributes are considered most relevant nor an opinion with regard to scoring. The purpose of this brief is to present the matrix approach and to spur discussion and comment.

The Appendices provided with this report provide information that could be useful in applying this matrix approach.

Table 3-4
Transportation Infrastructure Categories

Mode/Class	Attribute 1	Attribute 2	Attribute 3	Attribute 4 ?	Attribute 5 ?
Land	Road	Climate Zone / Geographic Location	Highways Regional Roads Municipal Streets Utility Roads	Asphalt Tar & Chip Concrete Ice Gravel/Unpaved	
	Tunnel	Climate Zone / Geographic Location		Liner System	
	Railway	Climate Zone / Geographic Location	Terminals & Stations Track		
Bridges	Road-Land Road-Water Rail-Land Rail-Water	Climate Zone / Geographic Location	Age	Beam Arch Cantilever Suspension/cable -stayed	Concrete Steel Wood Composite Masonry
Air	Not included in the first national assessment[1]				
Water					
Pipelines					
Pedestrian					

NOTES:
1. PIEVC has indicated that only transportation on land is to be included

Table 3-5
Buildings Infrastructure Categories

Mode/Class	Attribute 1 ?	Attribute 2 ?	Attribute 3 ?	Attribute 4 ?	Attribute 5 ?
School					
Library					
Government					
Hospital					
Emergency Services					
Gathering Places					
Postal Service					
Military/Defense					
Landfill					
Post Disaster Facility					
Financial					

Potential attributes include age, construction method, location (i.e., urban vs. rural, climate zone, geographic location), type of development (i.e., high-rise vs. low-rise), etc.

Table 3-6
Water Resources Infrastructure Categories

Mode/Class	Attribute 1	Attribute 2	Attribute 3 ?	Attribute 4 ?	Attribute 5 ?
Water Supply System	Population served	Surface Water Groundwater			
Dam					

PIEVC has indicated that water resources (supply) systems will be assessed in their entirety. That is, the whole system will be evaluated not just a subset of individual components.

Table 3-7
Stormwater and Wastewater Infrastructure Categories

Mode/Class	Attribute 1	Attribute 2 ?	Attribute 3 ?	Attribute 4 ?	Attribute 5 ?
Stormwater System	Population served				
Wastewater System	Population served				

PIEVC has indicated that stormwater/wastewater systems will be assessed in their entirety. That is, the whole system will be evaluated not just a subset of individual components. The exception to this might be the assessment of an individual sewershed of a larger mutli-sewershed system. However, even within the individual sewershed the entire system would be considered for evaluation.

As noted above, a primary attribute of each type of system that may be relevant to the vulnerability assessment is the population served by the system. Statistics Canada uses the following "Urban population size group" as the classification used in its standard tabulations.

1,000	–	2,499
2,500	–	4,999
5,000	–	9,999
10,000	–	24,999
25,000	–	49,999
50,000	–	99,999
100,000	–	249,999
250,000	–	499,999
500,000	–	999,999
1,000,000 and over		

The definition of what constitutes an urban area versus a rural area is somewhat more complicated (also defined by Statistics Canada). However, digital maps are available from Statistics Canada that provides boundary definitions of urban and rural areas in Canada for each census.

3.2 DEFINING CLIMATE CHANGE (STEP 2)

The next step would be to identify for each of the infrastructure elements defined in step 1, the climate change conditions/parameters to be addressed. The sample matrix below based on the transportation theme would be expanded to the full range of transportation infrastructure suggested in step 1.

This matrix would highlight climate change parameters / scenarios that affect (or do not affect) public infrastructure and assist PIEVC in identifying commonalities between types of infrastructure.

Similar matrices for Buildings, Water Resources and Stormwater and Wastewater are provided in Tables 3-9, 3-10 and 3-11.

Table 3-8
Transportation Infrastructure – Climate Change Issues

Issue	Land			Bridges			
				Road		Railway	
	Road	Tunnel	Railway	over land	over water	over land	over water
Increased severe weather	X		X	X	X	X	X
Storm surge	X	X	X	X	X	X	X
Warmer winters	X		X	X	X	X	X
Water level variability	X		X	X	X	X	X
Degradation of permafrost	X		X	X	X	X	X
Sea level rise	X		X	X	X	X	X
Sea Ice Melting							
Longer open water seasons/ changes in ice breakup				X	X	X	X
Freeze/Thaw cycles	X	X	X	X	X	X	X
Extreme heat	X		X	X	X	X	X
Freezing rain	X		X	X	X	X	X
Increased precipitation/ Higher land moisture	X		X	X	X	X	X
Increased river flooding	X		X	X	X	X	X
Landslides	X	X	X	X	X	X	X
Increased Winds	X		X	X	X	X	X
Average increase in Temperature	X		X	X	X	X	X
Other potential issues …							

Table 3-9
Buildings Infrastructure – Climate Change Issues

Issue	School	Library	Government	Hospital	Emergency Services	Gathering Places	Postal Service	Military Defense	Landfill	Post Disaster Facility	Financial
Increased severe weather											
Storm surge											
Warmer winters											
Water level variability											
Degradation of permafrost											
Sea level rise											
Sea Ice Melting											
Longer open water seasons/ changes in ice breakup											
Freeze/Thaw cycles											
Extreme heat											
Freezing rain											
Increased precipitation/ Higher land moisture											
Increased river flooding											
Landslides											
Increased Winds											
Average increase in Temperature											
Other potential issues …											

Table 3-10
Water Resources Infrastructure – Climate Change Issues

Issue	Water Supply System	Dam
Increased severe weather		
Storm surge		
Warmer winters		
Water level variability		
Degradation of permafrost		
Sea level rise		
Sea Ice Melting		
Longer open water seasons/ changes in ice breakup		
Freeze/Thaw cycles		
Extreme heat		
Freezing rain		
Increased precipitation/ Higher land moisture		
Increased river flooding		
Landslides		
Increased Winds		
Average increase in Temperature		
Other potential issues …		

Table 3-11
Stormwater & Wastewater Infrastructure – Climate Change Issues

Issue	Stormwater System	Wastewater System
Increased severe weather		
Storm surge		
Warmer winters		
Water level variability		
Degradation of permafrost		
Sea level rise		
Sea Ice Melting		
Longer open water seasons/ changes in ice breakup		
Freeze/Thaw cycles		
Extreme heat		
Freezing rain		
Increased precipitation/ Higher land moisture		
Increased river flooding		
Landslides		
Increased Winds		
Average increase in Temperature		
Other potential issues …		

3.3 DEFINING GEOGRAPHY (STEP 3)

This matrix would take the issues from step 2 and present a geographic "look" at the country to identify those locations where the "issues" will be significant.

Table 3-12
Climate Change Severity in Canada

Issue	BC	AL	SK	MB	ON	QC	NB	PE	NS	NL	YT	NT	NU
Increased severe weather													
Storm surge													
Warmer winters													
Water level variability													
Degradation of permafrost													
Sea level rise	M			L	L	H	H	H	H	H	H	H	L
Sea Ice Melting													
Longer open water seasons/ changes in ice breakup													
Freeze/thaw cycles													
Extreme heat													
Freezing rain													
Change in precipitation (winter)	L	L	L	L	L	L	L	L	L	L	H	H	H
Change in precipitation (summer)	H	H	M	M	M	M	M	M	M	M	M	H	H
Increased river flooding													
Landslides													
Increased Winds													
Average increase in Temperature (winter)	L	M	M	M	H	H	L	L	L	H	H	H	H
Average increase in Temperature (summer)	L	L	L	M	M	M	M	M	M	M	H	M	H

NOTES:
1. H – High in some areas, M – moderate in some areas, L – low in some areas

Population of this matrix could also be based on the 0 - 7 range / descriptions used in the Phase I Scoping Studies.

Each province would then be further disaggregated into regions/areas to better describe the distribution of change at a finer scale (see Table 3-13). The means by which the province is disaggregated could be by climate region, political boundary, or other spatial boundary. An example of spatial disaggregation based on climate regions defined for Quebec is presented in Figure 3-1.

Table 3-13
Climate Change Severity in Quebec

Issue	Province	Arctic	Natural Resources	St Lawrence Valley	Maritimes
Increased severe weather					
Storm surge					
Warmer winters					
Water level variability					
Degradation of permafrost					
Sea level rise	H				
Sea Ice Melting					
Longer open water seasons/ changes in ice breakup					
Freeze/thaw cycles					
Extreme heat					
Freezing rain					
Change in precipitation (winter)	L				
Change in precipitation (summer)	M				
Increased river flooding					
Landslides					
Increased Winds					
Average increase in Temperature (winter)	H				
Average increase in Temperature (summer)	M				

NOTES:
1. H – High in some areas, M – moderate in some areas, L – low in some areas
2. Areas based on Ouranos' climate regions in Quebec (see Figure 1)

These matrices would highlight areas of the country where the most change is anticipated. As such, PIEVC would be able to target areas of the country under the assumption that the "most vulnerable infrastructure will be located where the greatest climate change is anticipated".

Populating these two "geography" matrices would also highlight themes of climate change data that are not readily available.

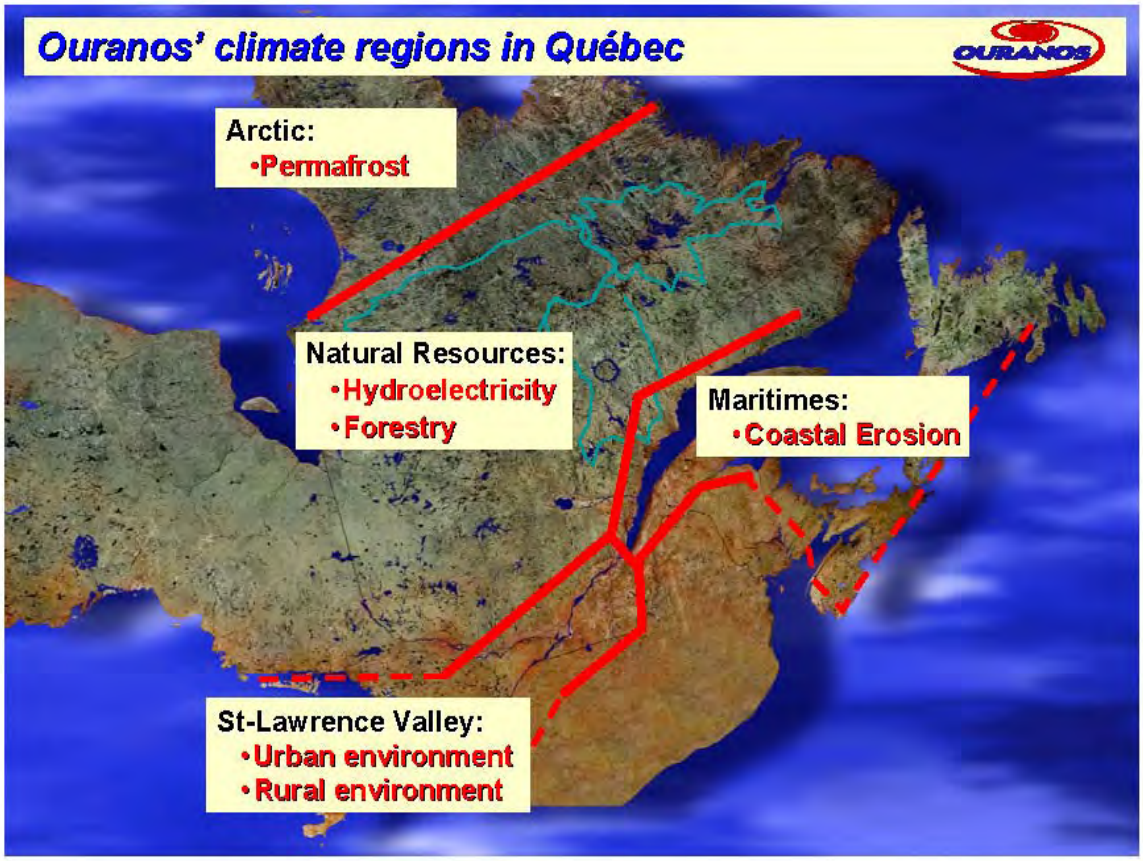

Figure 3-1
Ouranos' Climate Regions of Quebec

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

A matrix method of identifying target areas of Canada for vulnerability assessments has been developed. The three step approach promotes identification of:

- the infrastructure of interest for assessment
- what climate change influences are expected to impact this infrastructure
- where in the country these climate change influences are expected to occur

Using this matrix approach, PIEVC would be able to target areas of the country under the assumption that the “most vulnerability infrastructure will be located where the greatest climate change is anticipated”.

All of the sampling strategy objectives, noted above, focus on attributes of infrastructure, all of which can be readily defined within the structure of combined matrices outlined in this discussion paper. Further, this approach supports short term Phase III (i.e., national assessment) objectives and longer-term NRCan and PIEVC objectives.

The overall objectives of the sampling strategy are to provide a means of:

1. Identification of areas of Canada that are reflective of geography, climatic regions and infrastructure governance to conduct vulnerability assessments of the four infrastructure categories identified by the PIEVC.

2. Identification of infrastructure characteristics that make them more or less vulnerable to the effects and impacts of climate change.

3. Identification of current and historic engineering standards, practices, policies and incentives that will need to be reviewed in depth to ensure that infrastructure is designed, operated and maintained while addressing the risk due to chronic and acute climate change factors.

4. Identification of regional differences in climate change vulnerability and provide an initial assessment of the chronic and acute climate change risk to infrastructure, by region.

All of the objectives above key on attributes of infrastructure, all of which can be readily defined within the structure of combined matrices outlined in this discussion report.

4.2 RECOMMENDATIONS

It is recommended that PIEVC adopt the matrix approach detailed in this report as a basis for its sampling strategy for assessment of infrastructure vulnerability in Canada to climate change.

SECTION 5

REFERENCES

5 REFERENCES

AMEC, 2006a — *Maintenance Prioritization Database Version 1.0, Summary Report and User's Manual,* prepared for the Toronto and Region Conservation Authority*,* AMEC, 2006

AMEC, 2006b — *Coastal Zone and Climate Change on the Great Lakes, Final Report,* AMEC, July 2006

Bengtsson et al, 2007 — *Study Report No. 179 [2007], Assessment of the Need to Adapt Buildings in New Zealand to the Impacts of Climate Change*, J. Bengtsson, R. Hargreaves and I.C. Page, Branz, 2007

Cameron et al, 2007 — *Public Infrastructure Engineering Vulnerability Committee (PIEVC), Phase I Scoping Studies, Cameron Consulting Inc and AMEC Earth & Environmental, 2007.*

Dore et al, 2001 — *The Costs of Adaptation to Climate Change in Canada: A Stratified Estimate by Sectors and Regions – Social Infrastructure,* Mohammed H.I. Dore and Ian Burton, Brock University, 2001.

Environment Canada, 1998 — Environment Canada, Atmospheric Environment Service, Climate Research Branch, 1998, Climate Trends and Variations Bulletin for Canada, Ottawa.

Environment Canada, 2006 — *Municipal Water and Wastewater Survey – MWWS, Variable Description Document,* Sustainable Water Management Division, Environmental Stewardship Branch, Environment Canada, March 2006.

Environment Canada, 2006b — *Canada's Fourth National Report on Climate Change: Actions to Meet Commitments under the United Nations Framework Convention on Climate Change*, Environment Canada, 2006

Environment Canada, 2007 — *The road well travelled: implications of a future climate on the performance of pavement infrastructure in southern Canada*, Environment Canada, March 2007.

Fraser Institute, 2007 — *A Breath of Fresh Air: Market Solutions for Improving Canada's Environment*, The Fraser Institute, January 2007

Gaudreault and Lemire, 2006 — *The Age of Public Infrastructure in Canada*, Valérie Gaudreault, V. and P. Lemire. Statistics Canada, 2006, Catalogue No: 11-621-MIE2006035.

GCSI, 2000 — *Water Sector: Vulnerability and Adaptation to Climate Change - Final Report*, GCSI - Global Change Strategies International Inc. and the Meteorological Service of Canada, June 2000.

Girard et al, 2006 — *The Role of Standards in Adapting Canada's Infrastructure to the Impacts of Climate Change,* M. Girard and Mortimer, M (CSA), February 2006.

Hogg and Carr, 1985 — Hogg, W.D. and Carr, D.A. 1985. *Rainfall frequency Atlas for Canada*. Canadian Government Publishing Centre, Ottawa, Ontario.

IPCC, 1994 — *IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations*. Prepared by Working Group II [Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka (eds.)] and WMO/UNEP. CGER-IO15-'94. University College -London, UK and Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan, 59 pp.

IPCC, 2000 — *IPCC Special Report, Emissions Scenarios, Summary or Policymakers,* Intergovernmental Panel on Climate Change, 2000

IPCC-TGCIA, 1999 — *Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment*. Version 1. Prepared by Carter, T.R., M. Hulme, and M. Lal, Intergovernmental Panel on Climate Change, Task Group on Scenarios for Climate Impact Assessment.

Infrastructure Canada, 2006 — *Adapting Infrastructure To Climate Change In Canada's Cities And Communities, A Literature Review,* Research & Analysis Division, Infrastructure Canada, December 2006.

Kije Sipi, 2001 — *Impacts and Adaptation of Drainage Systems, Design Methods and Policies,* Kije Sipi Ltd *in partnership with* City of Edmonton, City of Ottawa, Mississippi Valley Conservation Authority, June 2001.

Lam et al, 2004 — *Update of the Short Duration Rainfall IDF Curves for Recent Climate in Quebec*, K. Lam, Milton, J., Nadeau, M., Vescovi, L., 57th Canadian Water Resources Association Annual Congress, June 16-18 2004, Montreal, Qc, Canada

Leggett et al, 1992 — "Emissions Scenarios for the IPCC: an Update", *Climate Change 1992: The Supplementary Report to The IPCC Scientific Assessment*, J. Leggett, W.J. Pepper, R.J. Swart, J. Edmonds, L.G. Meira Filho, I. Mintzer, M.X. Wang, and J. Watson. 1992. Cambridge University Press, UK, pp. 68-95

Mailhot et al, 2006 — *Climate change impacts on the performance of urban drainage systems for Southern Quebec*, Mailhot, A., S. Duchesne, et al., Climate Change Technology Conference, Engineering Challenges for and Solution in the 21st Century, Ottawa, 2006.

Mirza and Haider, 2003 — *The State of Infrastructure in Canada: Implications for Infrastructure Planning and Policy,* M. Saeed Mirza and Murtaza Haider, Infrastructure Canada, March 2003.

MOE, 2003 — *Stormwater Management Planning and Design Manual*, Ontario Ministry of the Environment, March 2003.

OMNR, 1988 — *Flood Plain Management in Ontario Technical Guidelines*, Ontario Ministry of Natural Resources, 1988

Stockton, 1962 — *Business Statistics,* John R. Stockton, South-Western Publishing Company, 2nd ed., 1962.

Toronto, 1998 — *City of Toronto, Scarborough District, Drainage Policy*, March 1998.

Toronto, 2006 — *Wet Weather Flow Management Policy*, City of Toronto, November 2006.

Transport Canada, 2003 — *Impacts of Climate Change on Transportation In Canada,* Canmore Workshop, Final Workshop Report, Transport Canada, March 2003.

USARC, 2003 — *Climate Change, Permafrost, and Impacts on Civil Infrastructure,* Special Report 01-03, U.S. Arctic Research Commission - Permafrost Task Force, U.S. Arctic Research Commission, Arlington, Virginia, 2003.

Wang et al, 2006 — Wang, S., A. P. Trishchenko, K. V. Khlopenkov, and A. Davidson (2006), *Comparison of International Panel on Climate Change Fourth Assessment Report climate model simulations of surface albedo with satellite products over northern latitudes*, *J. Geophys. Res.*, *111*, D21108, doi:10.1029/2005JD006728.

Watt et al, 2003 — Watt, W.E., D. Waters and R. McLean 2003. *Climate Variability and Urban Stormwater Infrastructure in Canada: Context and Case Studies*. Toronto-Niagara Region Study Report and Working Paper Series, Report 2003-1. Meteorological Service of Canada, Waterloo, Ontario.

Wilby at al, 2001 — *Using SDSM — A decision support tool for the assessment of regional climate change impacts, User Manual,* Robert L. Wilby and Dawson, C.W., 26 October 2001

Zhao, 1998 — *Trunk Sewers in Canada,* American Public Works **A**ssociation, International Public Works Congress and Exhibition, Las Vegas, Nevada, Sept. 14-17, 1998

APPENDICES

APPENDIX A - CHANGE INFORMATION
APPENDIX B - SPATIAL AND OTHER BOUNDARIES
APPENDIX C - INFRASTRUCTURE CATGORIES
APPENDIX D - STANDARDS AND PRACTICES

APPENDIX A

CHANGE INFORMATION

A CHANGE INFORMATION

A.1 INTRODUCTION

A significant task for the National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change will be to identify target regions/sites for vulnerability assessments. Different areas of the country will experience different magnitudes of change and the rate at which change occurs will also vary. This section provides descriptions of readily available information and will contribute to locating potential assessment sites or enhance site selection to optimize the population of the vulnerability database.

A.2 CLIMATE MODELS

The scientific understanding and prediction of anticipated changes in our future climate is an evolving research field with much work still to be done. However, a clear picture of the expected global climate is emerging, with an increasing degree of confidence in the prediction of climate trends at the regional level. Climate models are the primary tools used to assess future climate. (www.c-cairn.ca)

Climate models, a number of which are identified in Table A-1, are computer programs that simulate the climate system's behaviour based on the fundamental laws of physics. They are the best available representation of our planet but remain a simplified version of climate control processes. Global Climate or General Circulation Models (GCMs), simulate coarse planet climate dynamics with a horizontal spatial resolution in the order of 400 x 400 km.

Table A-1
Sources of Information and Data for General Circulation Models

Model	Source	Website
CGCM1 CGCM2	Canadian Center for Climate Modelling and Analysis (CCCma), Canada	www.cccma.ec.gc.ca
GFDLR15 GFDLR30	Geophysical Fluid Dynamics Laboratory GFDL, USA	www.gfdl.noaa.gov
ECHAM4	Max-Planck-Institute for Meteorology (MPI) and Deutsches Klimarechenzentrum (DKRZ), Germany	www.mpimet.mpg.de www.dkrz.de
CSIROMk2b	Australia's Commonwealth Scientific and Industrial Research Organisation, Australia	www.csiro.au
CCSRNIES	Center for Climate Research Studies & National Institute for Environmental Studies, Japan	www.ccsr.u-tokyo.ac.jp www.nies.go.jp
NCARPCM	National Centre for Atmospheric Research, USA	www.ncar.ucar.edu
HadCM2 HadCM3	Hadley Centre for Climate Prediction and Research HCCPR, UK	www.metoffice.gov.uk/research/hadleycentre

However, the horizontal and temporal resolution of theses GCMs is not high enough to study the regional and, more particularly, local effects of future climate change. To fill this gap, downscaling techniques have been developed in order to increase the spatial and temporal GCM output. Downscaling techniques use dynamical or statistical methods.

Dynamical methods are represented by Regional Climate Models (RCMs) with higher resolution on a certain part of the globe only. The spatial resolution of RCMs is typically about 50 x 50 km. Simulations from GCMs are used to provide nesting data or boundary conditions for the Canadian Regional Climate Model (CRCM). The main limitation of RCMs is that they are as computationally demanding as GCMs (placing constraints on the feasible domain size, number of experiments and duration of simulations). The scenarios produced by RCMs are also sensitive to the choice of boundary conditions (such as soil moisture) used to initiate experiments. Simulations from different RCMs, which may use different nesting data (GCM), different periods or different greenhouse gas (GHG) emission scenarios, may produce different results.

The Canadian Centre for Climate Modelling and Analysis (CCCma) is a division of the Climate Research Branch of the Meteorological Service of Canada itself a division of Environment Canada. The CCCma conducts research in coupled and atmospheric climate modelling, sea-ice modelling, climate variability and predictability, the carbon cycle, and a number of other areas. Climate data for the Canadian Regional Climate Model (CRCM) over the Pan-Canadian domain (see Figure A-1) with a 45km grid mesh is readily available.

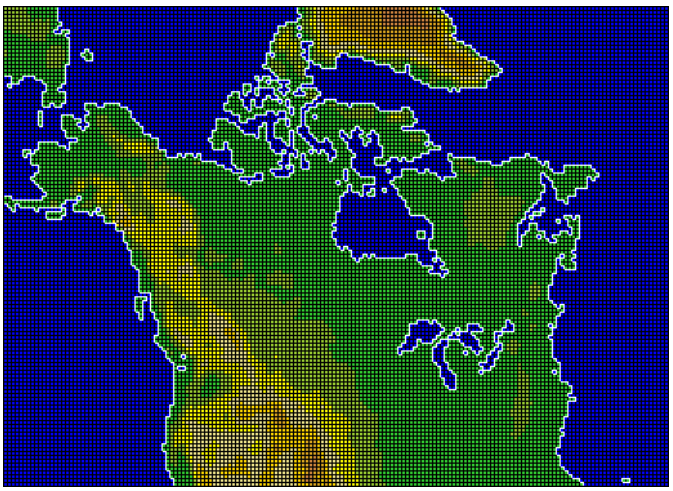

Figure A-1

Canadian Regional Climate Model over the Pan-Canadian Domain

Climate models and downscaling techniques are part of a suite of tools that can be used to determine likely climate changes for a given region. Climate models provide the virtual meteorological data that feeds into the construction of climate scenarios. Given the range of tools/software/data available, it is anticipated that vulnerability analysts will use a number of climate models and scenarios for their evaluations. As a result, it will be necessary to capture this information in the Vulnerability Database in order to prevent duplication of results (i.e., assessment of similar infrastructure types in the same climate change area).

A.3 PROJECTED CHANGES IN CLIMATE

(from www.atlas.nrcan.gc.ca unless otherwise noted)

A.3.1 Temperature Change

A simulation of projected changes in summer and winter temperatures from the period 1961 to 1990 to the period 2040 to 2060 for Canadian lands are illustrated in Figures A-2 and A-3. As indicated in the Figures, the temperature changes would not be evenly distributed geographically or seasonally and it is anticipated that the interior and northern parts of the country will experience the most warming.

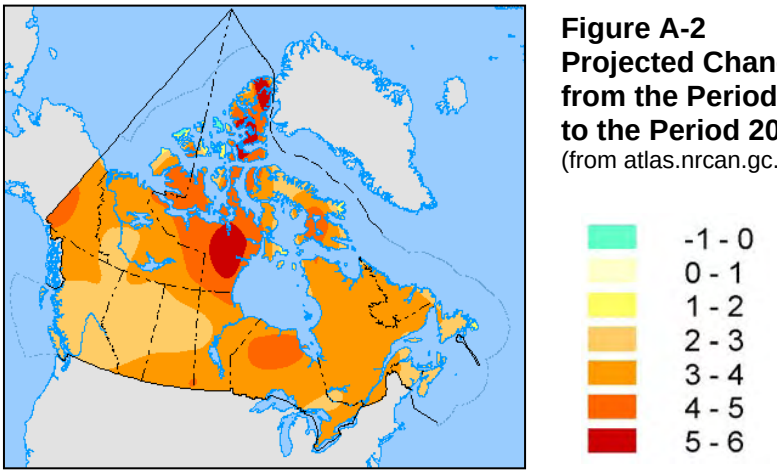

Figure A-2
Projected Changes (°C) in Summer Temperatures from the Period 1961 to 1990 to the Period 2040 to 2060
(from atlas.nrcan.gc.ca)

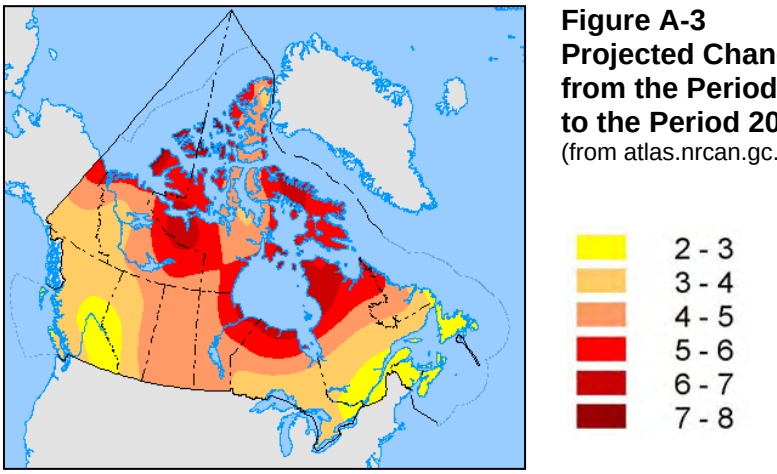

Figure A-3
Projected Changes (°C) in Winter Temperatures from the Period 1961 to 1990 to the Period 2040 to 2060
(from atlas.nrcan.gc.ca)

Vulnerability assessments addressing issues arising from changing temperature should be focused in areas of greatest anticipated change such as the north with regard to permafrost, flooding caused by ice jamming, etc. However, milder winter temperatures in the south of Canada in combination with mild winters may increase freeze/thaw cycles which could lead to increases in rates of deterioration of asphalt pavements and damage to water distribution

systems. Increases in summer temperatures may result in vulnerabilities in cooling systems and further deterioration of asphalt pavements.

A.3.2 Changes in Precipitation Patterns

Similar to projected temperature changes, projected precipitation changes would not be evenly distributed geographically or seasonally as illustrated in Figure A-4 and A-5. Summer patterns show regions with both increases and decreases in precipitation. Warmer surface temperatures would speed up the hydrological cycle at least partially, resulting in faster evaporation and more precipitation.

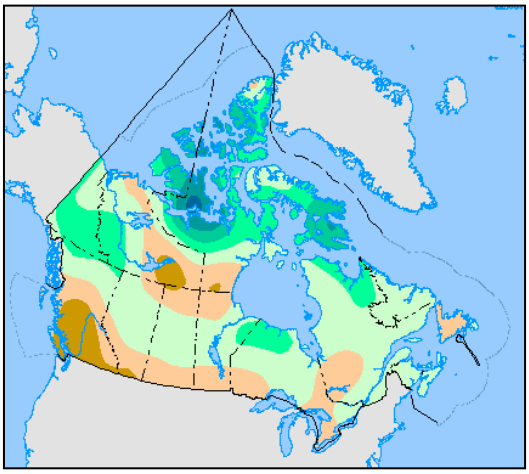

Figure A-4
Projected Changes (%) in Summer Precipitation
from the Period 1961 to 1990
to the Period 2040 to 2060
(from atlas.nrcan.gc.ca)

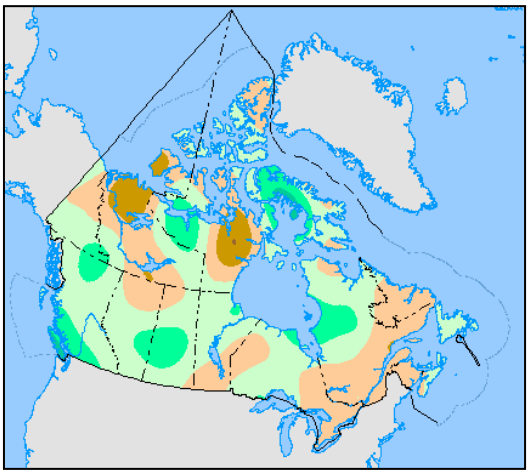

Figure A-5
Projected Changes (%) in Winter Precipitation
from the Period 1961 to 1990
to the Period 2040 to 2060
(from atlas.nrcan.gc.ca)

Vulnerability assessments addressing issues arising from changing precipitation patterns should be focused in areas of greatest anticipated change as a means of defining the potential maximum vulnerability.

On average, a warmer Earth will be a wetter Earth, although many land areas may actually become drier. Furthermore, summer precipitation over land is likely to become more intense when the warming occurs. This has the potential to cause substantial changes to flow in Canada's rivers. Some rivers will experience more frequent extreme low flows, however, all rivers could see an increase in the frequency and magnitude of floods, thus increasing the risk to humans, buildings and other structures. Figure A-6 summarizes the regional sensitivity of rivers to projected climate change in Canada.

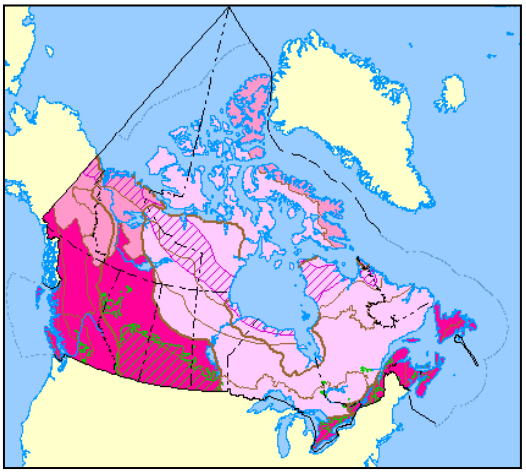

Figure A-6
Sensitivity of River Regions to Climate Change
(from atlas.nrcan.gc.ca)

A comparison of Figures A-4 and A-5 with Figure A-6 indicate that areas with “minor” anticipated changes in precipitation (i.e., less than 10%) are associated with rivers that are more sensitive and vulnerable such as southern Ontario and parts of western Canada.

A.3.3 Sea Level Rise

Climate warming is expected to cause warming of the oceans and the partial melting of glaciers and ice-caps, resulting in a global rise in sea level. By the end of this century, the global mean sea-level rise could amount to 0.09 to 0.88 metres. In Canada, where the total coastline exceeds 203,000 kilometres, sea level rise is a significant issue.

Figure A-7 shows the sensitivity of Canadian coastlines to the expected rise in sea level, due to climate warming. Sensitivity, in this context, refers to the degree to which a coastline may experience physical changes such as flooding, erosion, beach migration, and coastal dune destabilization. As noted on the map, two major regions of high sensitivity have been identified, namely: Atlantic Canada and parts of the Beaufort Sea coast.

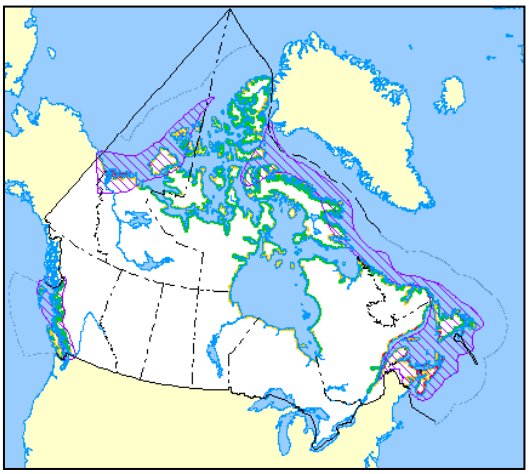

Figure A-7
Coastal Sensitivity to Sea-Level Rise
(from atlas.nrcan.gc.ca)

A.3.4 Changes in Great Lakes Water Levels

It is expected that as a result of a shorter winter with warmer temperatures, and a warmer climate overall, there will be increased evaporation resulting in a general lowering of water levels (up to 1 m) of the Great Lakes. Low water levels that were experienced in the Great Lakes during 1999 to 2001 are projected to occur more frequently in the future climate, and have significant impacts on commercial navigation and shipping. (AMEC, 2006b)

The exception to this may be Lake Ontario. In March 2006, the International Joint Commission (IJC) issued the final report detailing *Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows* (available from www.losl.org/). "The Study Board used highly sophisticated hydrologic modeling to ensure the reliability, resilience and robustness of each plan under a stochastically generated 50,000-year sequence. In addition, the Board analyzed four different climate change scenarios and used them to thoroughly test candidate plans, ensuring that none had fatal flaws that would inhibit their performance under these extreme potential conditions." (IJC, 2006)

Figure A-8 illustrates, in part, computed average Lake Ontario water levels stemming from the IJC's evaluation of a variety of operational strategies under the stochastically generated 50,000-year sequence noted above. As abstracted from this figure, the Lake Ontario average annual water level is computed as 74.7 m (IGLD 1985) for each of the four plans evaluated by the IJC. Also noted on Figure 1 are the 1% probability of exceedence (i.e., expected to exceed 1% of the time or, on average, once every 100 years) Lake Ontario water levels, which indicate a maximum water level in June of about 75.7 m for Plan B. The current 100 year Lake Ontario water level is 75.74 m.

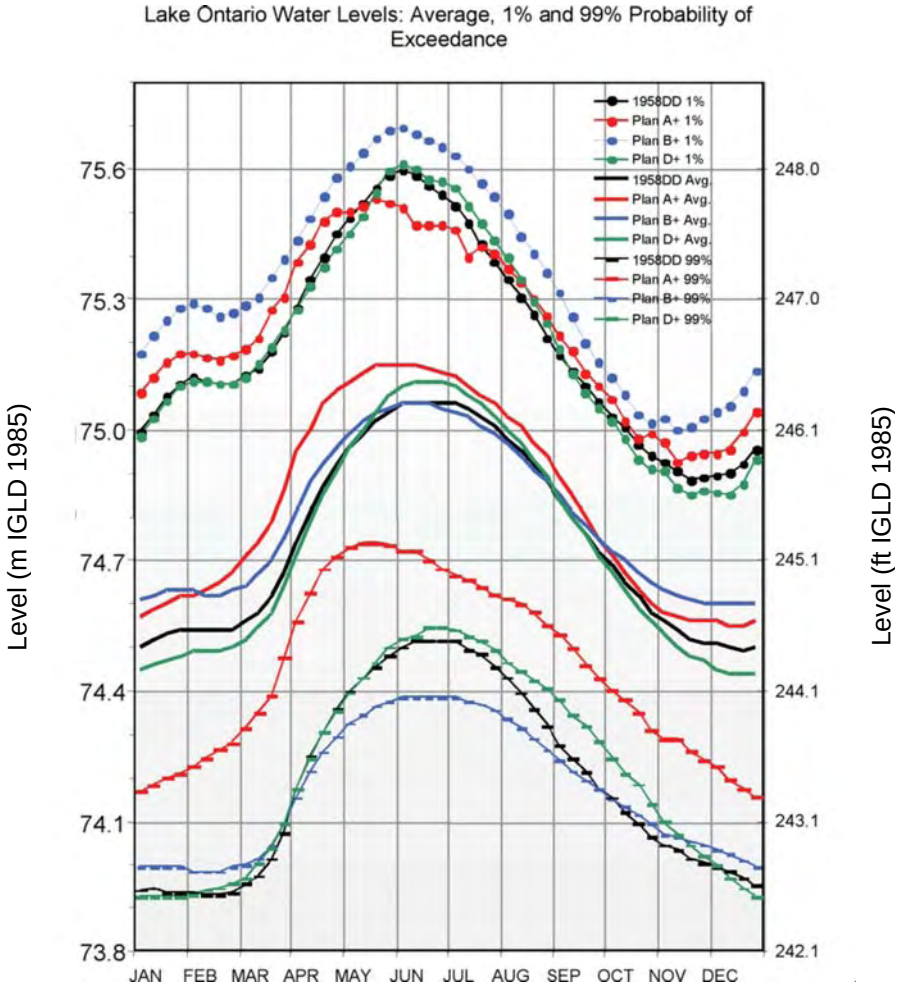

Figure A-8

Lake Ontario Water Levels
(from IJC, 2006)

A.3.5 Other Change Data

A number of other maps quantifying the impacts of climate change are available from the Atlas of Canada, including:

- Wind Erosion Risk and Climate Sensitivity Map
- Forest Fire Severity Level, 1980 to 1989 Map
- Projected Forest Fire Severity Level, 2050 to 2059 and 2090 to 2099 Maps
- Sensitivity of Peatlands to Climate Change Map

Depending on the infrastructure under consideration, one or more of these maps may offer insight into the selection of target sites for vulnerability assessment.

A.4 ATMOSPHERIC HAZARDS – CANADA
(from www.hazards.ca)

This website presents background material and map data for atmospheric hazards in Ontario. It has been created by the Meteorological Service of Canada, Environment Canada, in cooperation with Emergency Management Ontario, to assist municipalities in conducting their hazard identification and risk assessments as required by Ontario's Emergency Management and Civil Protection Act.

Two samples of information from the Atmospheric Hazards website are presented in Figures A-9 and A-10, namely Heavy Rain and Damaging Wind Occurrences in Ontario. As suggested by the rainfall map, more emphasis should be placed on infrastructure vulnerability assessments in Central to Southern Ontario and the north shore of Lake Superior. Similarly, where wind is the parameter under evaluation as a contributor to a potential vulnerability, areas including the areas noted above for rainfall plus north-eastern Ontario should be targeted.

Maps are also available from the Atmospheric Hazards website for cold, drought, flood, fog, hail, health, heat, heavy snow, hurricane, ice storm, lightning, tornado and wind conditions in Ontario. The basis for these maps is data from the Ontario Region of the Meteorological Service of Canada. As such, it is reasonable to expect that similar maps could be generated for other provinces to highlight those areas where vulnerability assessments should be targeted.

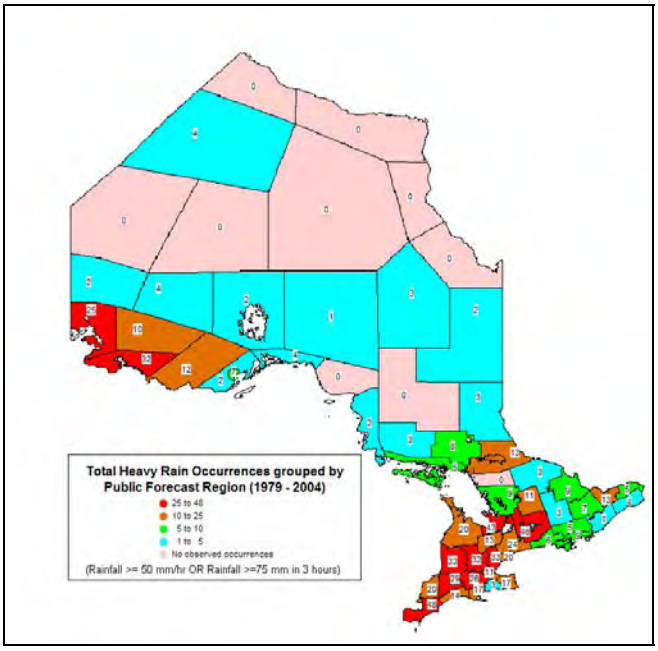

Figure A-9

Total Heavy Rain Occurrences grouped by Public Forecast Regions - Ontario (1979-2004)

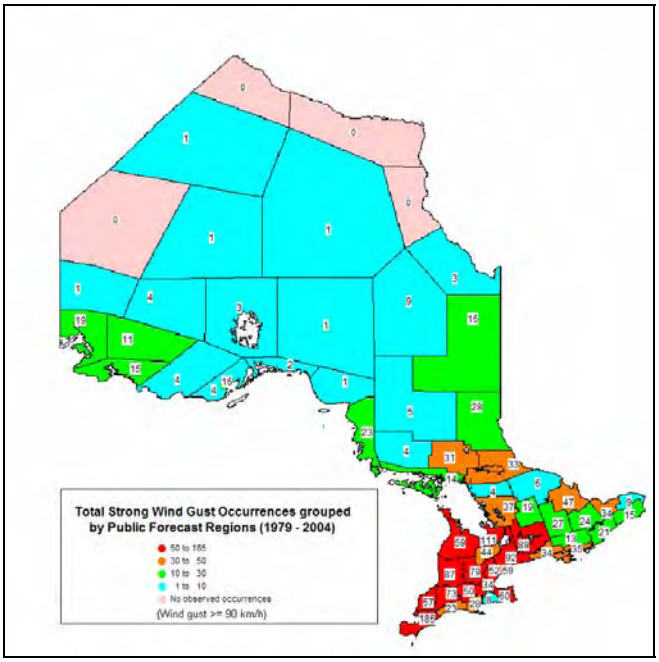

Figure A-10

Total Strong Wind Gust Occurrences grouped by Public Forecast Regions – Ontario (1979-2004)

A.5 OURANOS

The Ouranos Consortium develops and adapts the necessary tools for providing decision-makers with detailed climate change scenarios on a regional scale. The Consortium also performs evaluations of expected sectoral impacts to optimize adaptation strategies. The Climate Simulations team at Ouranos develops and uses the Canadian Regional Climate Model to provide regional climate data.

Ouranos confirmed that preparation of IDF curves under future conditions, using regional scale climate model data, for locations in Canada was possible. An area of southern Quebec (see Figure A-11) is presently the only area in the country for which a preliminary analysis has been completed. The comparison of the resultant existing and future IDF curve is presented in Figure A-12 and confirms the expectation of increased precipitation in this area. Please note that the results presented in Figure A-3 are preliminary and Ouranos should be contacted directly with regard to the specific limitations of this analysis.

This data would be very useful for determining areas of Canada where changes in design precipitation are expected, particularly with respect to stormwater/wastewater modeling and the design of water resources infrastructure.

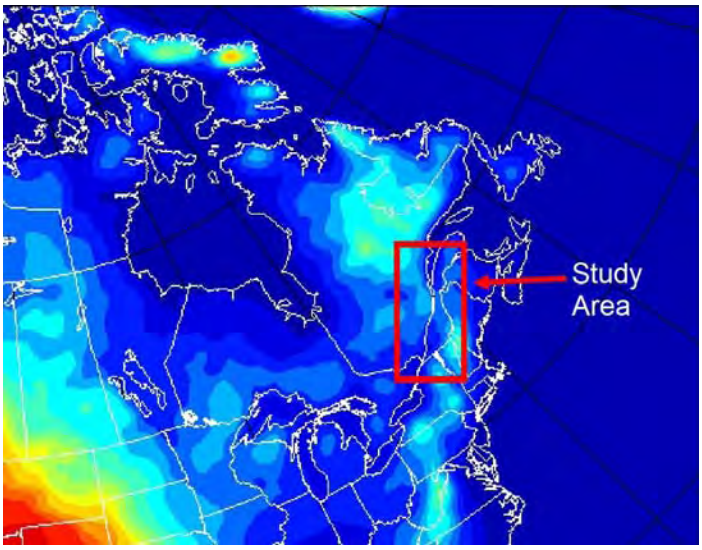

Figure A-11

Area of Southern Quebec Modeled for Preparation of Future Conditions IDF Data (from A.Mailhot et al, INRS 2006)

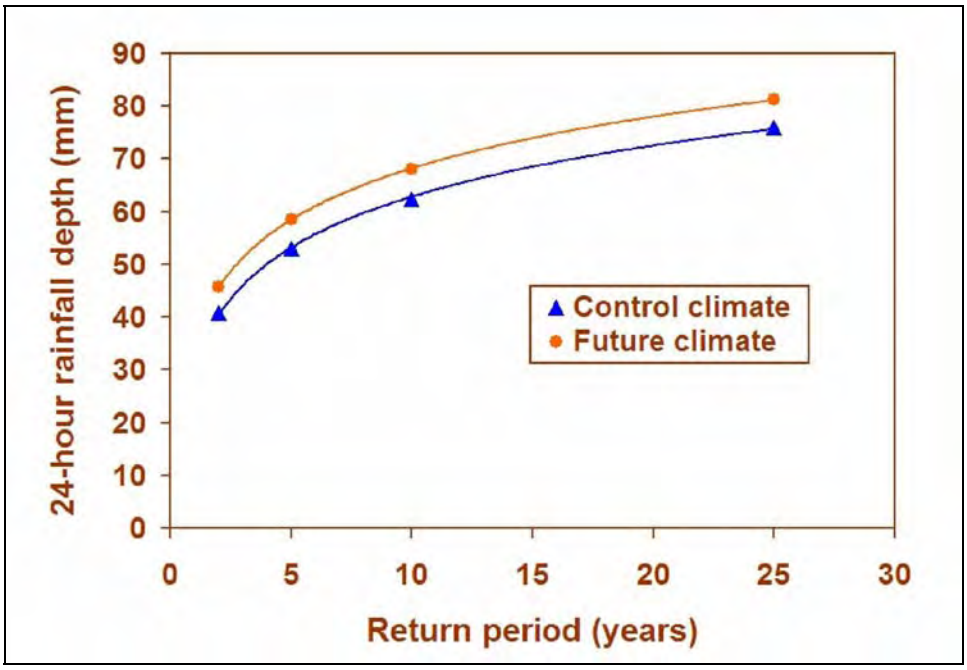

Figure A-12
Regional Average Summer Maximum 24 hour Precipitation
Comparison between Existing and Future Conditions for Southern Quebec
(from A.Mailhot et al, INRS 2006)

APPENDIX B

SPATIAL AND OTHER BOUNDARIES

B SPATIAL AND OTHER BOUNDARIES

B.1 INTRODUCTION

The Vulnerability Database will provide PIEVC and others a mechanism to comment on and assess the specifics and generalities of potential infrastructure vulnerability in different areas of the country or the country as a whole. As such, data should be gathered, as a component of a vulnerability assessment, which is reflective of geography, climatic regions and infrastructure and political governance. This data will act as potential query parameter(s) for analysts reviewing and commenting on vulnerability data.

Boundaries are discussed that may provide useful views of the vulnerability results or present an effective means of segregating vulnerability results.

B.2 GEOGRAPHIC REGIONS

There are a variety of geographic region definitions for Canada but all seem to be generally variations of one another. The general spatial extent of these regions includes the Cordillera, Interior Plains, Northern Region, Canadian Shield, Great Lakes Lowland, St. Lawrence Lowland and the Appalachian Highland.

B.2.1 Ecozones of Canada

(from http://canadianbiodiversity.mcgill.ca/english/ecozones/index.htm)

The National Ecological Framework for Canada uses ecozones for their classification. At the largest scale, there are fifteen terrestrial (see Figure B-1) and five marine ecozones (see Figure B-2). Ecozones are so large that the Maritime Provinces can all fit into one of them (Atlantic Maritime). Smaller than the ecozones are the ecoregions, and the ecodistricts are smaller yet. There are over 200 ecoregions in Canada and even more ecodistricts.

Ecozones are large and very generalized, having roughly the same land features, historical climate and organisms throughout them. Still, there are inevitably many differences across that large an area of land. Detailing those differences is done at the ecoregion and ecodistrict levels. The ecoregions for the Pacific Maritime Ecozone are illustrated in Figure B-3.

The Atlas of Canada definitions of the ecozones of Canada are available at atlas.nrcan.gc.ca/site/english/maps/environment/ecology/framework/terrestrialecozones.

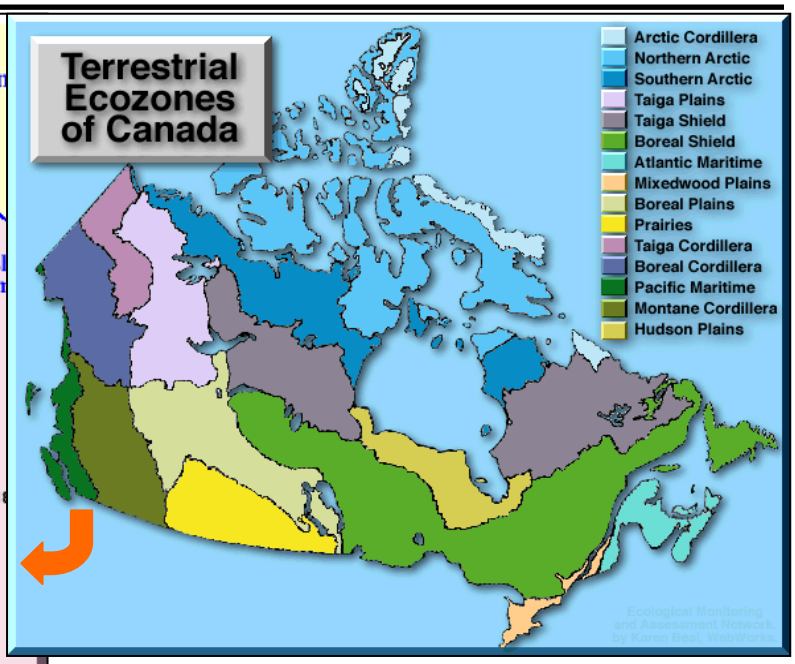

Figure B-1
Terrestrial Ecozones of Canada
(from: Environment Canada)

Figure B-3
Pacific Maritime Ecoregions
(from: Environment Canada)

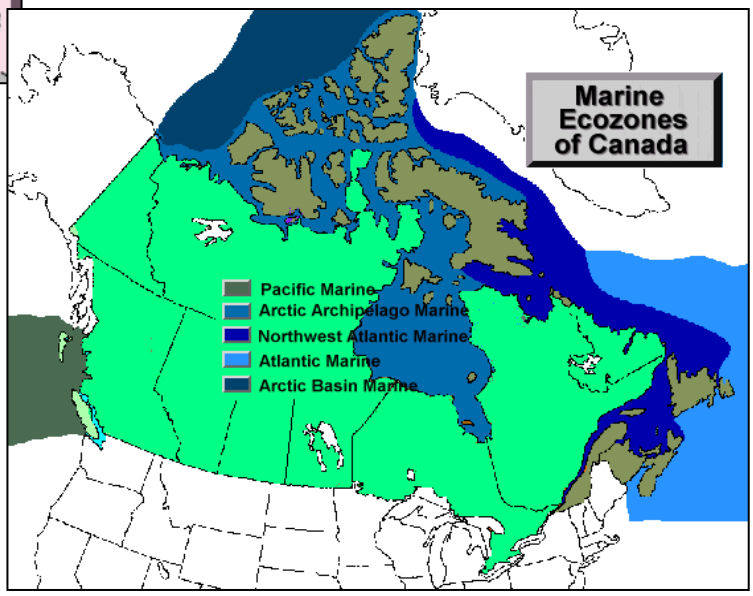

Figure B-2
Marine Ecozones of Canada
(from: www.cess.org)

B.3 CLIMATE REGIONS

A first order review of climate region definitions in Canada was completed. This review identified the Atlas of Canada as the primary source for this data. The Atlas provides three different maps on this topic, namely;

- Thornthwaite Classification – Thermal Regions (1941-70)
- Thornthwaite Classification – Moisture Regions (1941-70)
- Köppen (1920's)

AMEC contacted Joan Klaassen of Environment Canada to discuss the issue of climate regions of Canada, who forwarded AMEC's request to David Philips (also of Environment Canada). Mr. Philips suggests that use of these maps is not recommended given their age and the methodology used to develop them. They both suggest a much more up-to-date form of climate classification using applied climate maps where regions reflect a parameter such as heating degree days, snowfall amount, climate severity index, wind chill frequency, etc. Ms. Klaassen indicated that graphical information provided on the Atmospheric Hazards website (www.hazards.ca/) would allow this type of classification within Ontario and, in the future, other regions of Canada. However at this time, no climate classification maps using applied climate maps are available.

A general climate regions map for Canada was produced by Environment Canada (1998) and is illustrated in Figure B-4. Notwithstanding the discussion above, the use of this map as a means of spatially distributing target vulnerability assessment sites across the various climate regions defined in Figure B-4 may be useful.

B.4 INFRASTRUCTURE GOVERNANCE

B.4.1 Political Governance

Political governance should be reflected, in the Vulnerability Database, through the identification of the level of government as;

- federal electoral district;
- Province/Territory and Provincial/Territorial electoral district;
- regional municipality or district, and;
- local municipality

within which the infrastructure site is located.

The identification of the local conservation authority (in Ontario) or Watershed Planning and Advisory Councils (in Alberta) or similar agencies in other provinces should also be included, as relevant, for assessments of water related infrastructure.

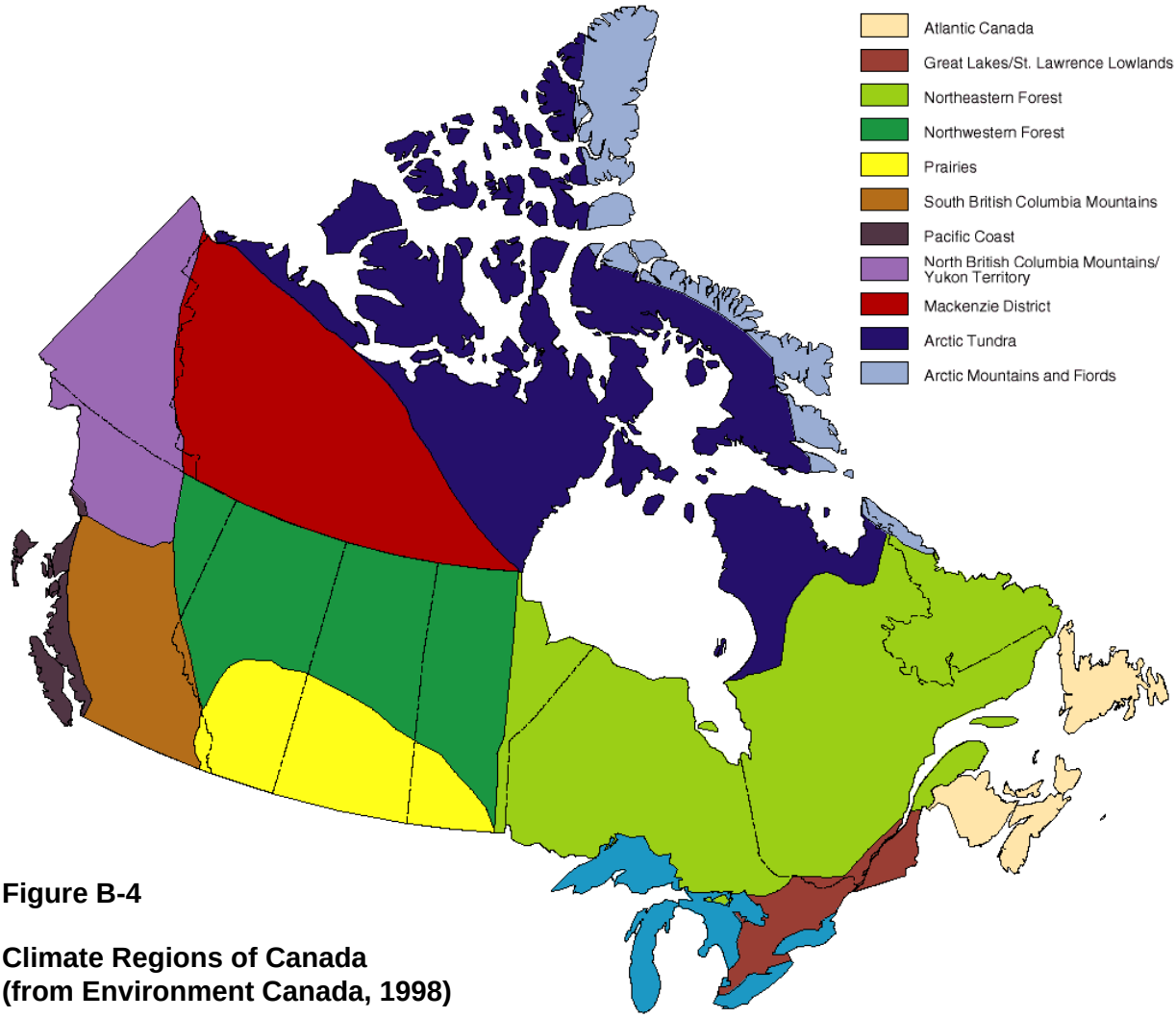

Figure B-4

Climate Regions of Canada
(from Environment Canada, 1998)

B.4.2 Design Governance

Design governance will be reflected through the identification of the relevant engineering standards, practices, policies and incentives that were applied to the design of the specific infrastructure under assessment. This subject is described in detail in Appendix D, Standards and Practices.

B.5 OTHER BOUNDARIES

B.5.1 Environment Canada Public Forecast Regions
(from http://www.on.ec.gc.ca/weather/regions/intro_e.html)

Environment Canada defines weather forecast regions for each province. Figure B-6 provides an example of the regions for southern Ontario, Each of these forecast regions is divided into smaller sub-regions which will be used to pinpoint the areas at risk when weather warnings are issued. They will also be used to split a forecast when conditions are likely to vary significantly across a region. Where possible, reference names for all of the regions were taken from the 2001 Official Road Map for Ontario to make them meaningful to both local residents and the traveling public.

This data is suggested for inclusion in the Vulnerability Database because of the link with the type of climate region data.

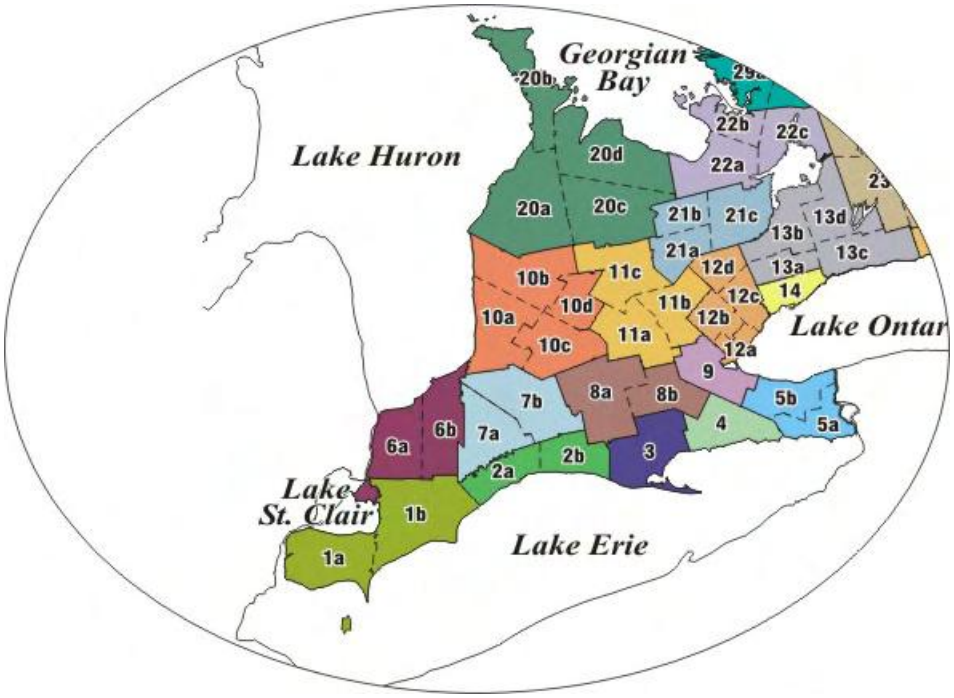

Figure B-5
Environment Canada Public Forecast Regions for Southern Ontario
(from www.on.ec.gc.ca)

B.5.2 Major Canadian Watersheds
(from the Atlas of Canada)

A drainage basin is an area that drains all precipitation received as a runoff or base flow into a particular river or set of rivers. Canada's major drainage regions are the Atlantic Ocean, Hudson Bay, Arctic Ocean, Pacific Ocean and Gulf of Mexico. These are illustrated in Figure B-6.

Additionally, the specific river basin within which the infrastructure site under assessment resides should be identified.

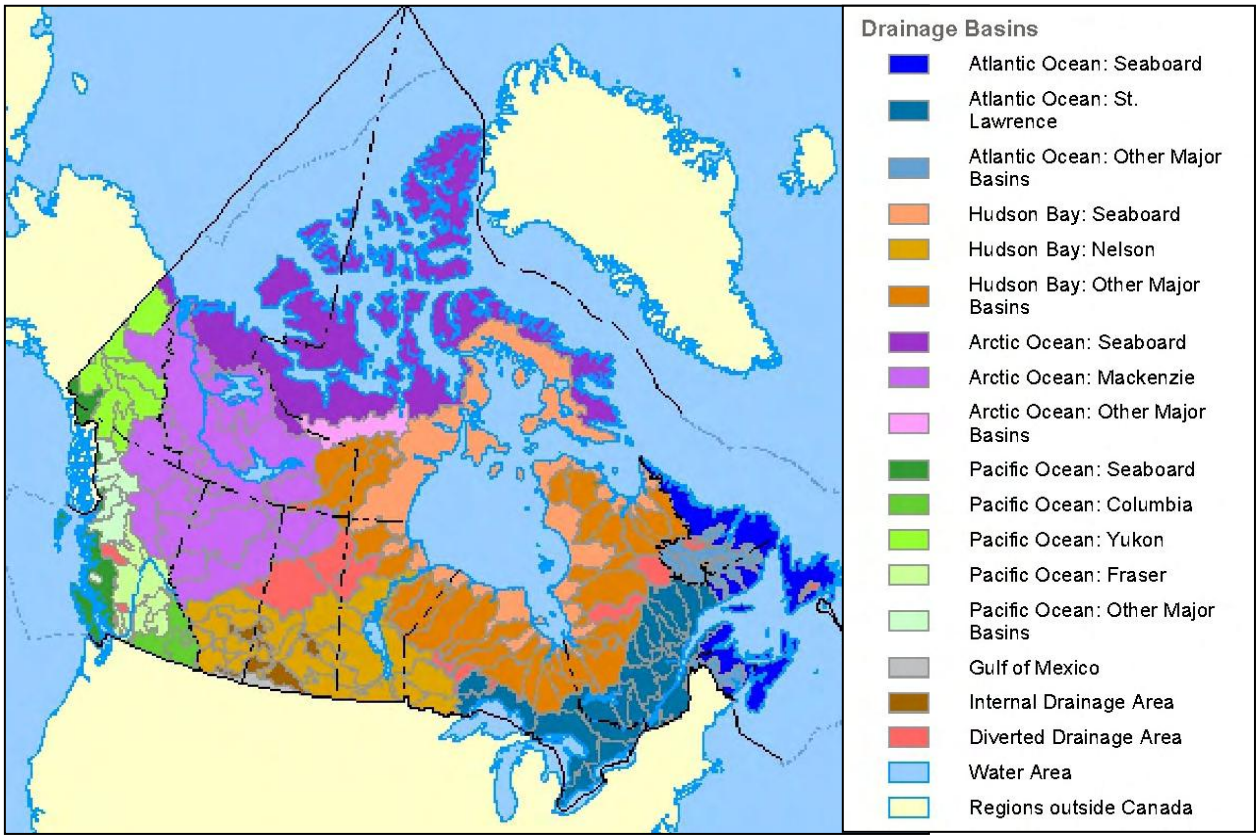

Figure B-6
Major Canadian Drainage Basins

B.5.3 Infrastructure Specific Boundaries

As noted previously, the National Engineering Assessment of the Vulnerability of Public Infrastructure to Climate Change will focus on four areas of infrastructure, namely;

- water resources

- stormwater and wastewater
- buildings
- roads and associated structures

In some cases, specific spatial definitions should be documented for these infrastructure types beyond the general classifications previously described. In the case of Water Resources, Stormwater and Wastewater and Transportation Infrastructure, the general classifications of boundary data previously described should be adequate in the context of the Vulnerability Database.

Transportation infrastructure is the exception and additional boundary information is available to better describe the spatial extent below the level of Province. In the Province of Ontario, the Ministry of Transportation manages the network of provincial roadways by Corridor Management Areas (see Figure B-7 as an example for Central Region). The Central Region Management Areas are, for the most part, based on regional and/or municipal jurisdictional boundaries. Other provincial transportation ministries use similar management areas.

Figure B-7

Ontario Ministry of Transportation
Central Region
Corridor Management Areas

APPENDIX C

INFRASTRUCTURE CATEGORIES

C INFRASTRUCTURE CATEGORIES

The information below is supplemental to Section 4 of the *Data Integrity and Availability Review* (Cameron et al, 2007) completed as a component of the Phase I Scoping Studies and represents additional sources of directly applicable infrastructure data to support population of the matrices described in the body of this report.

C.1 WATER RESOURCES INFRASTRUCTURE
(base information from www.nwri.ca)

Although there is no national inventory of all sizes of dams in Canada, the Canadian Dam Association periodically conducts an assessment and submits data to the International Commission on Large Dams. In 2000, Canada had 849 large dams (≥10 m in crest height) in operation or under construction (not including tailings-pond dams, which would add approximately 84 more dams to the total). The vast majority (70%) of large dams in Canada were constructed solely for hydroelectric production. Of the remainder, 7% were constructed primarily for water supply and 6% for irrigation, mainly in the Prairie Provinces. The rest serve a variety of purposes from flood control to navigation, recreation, or a combination of purposes.

Figure C-1 depicts the growth in the number of large dams in Canada from the start of the century to the present. Prior to the 1940s, the majority of large dam construction occurred in southern Ontario and Quebec. Since then, major dam construction has occurred in all provinces and territories.

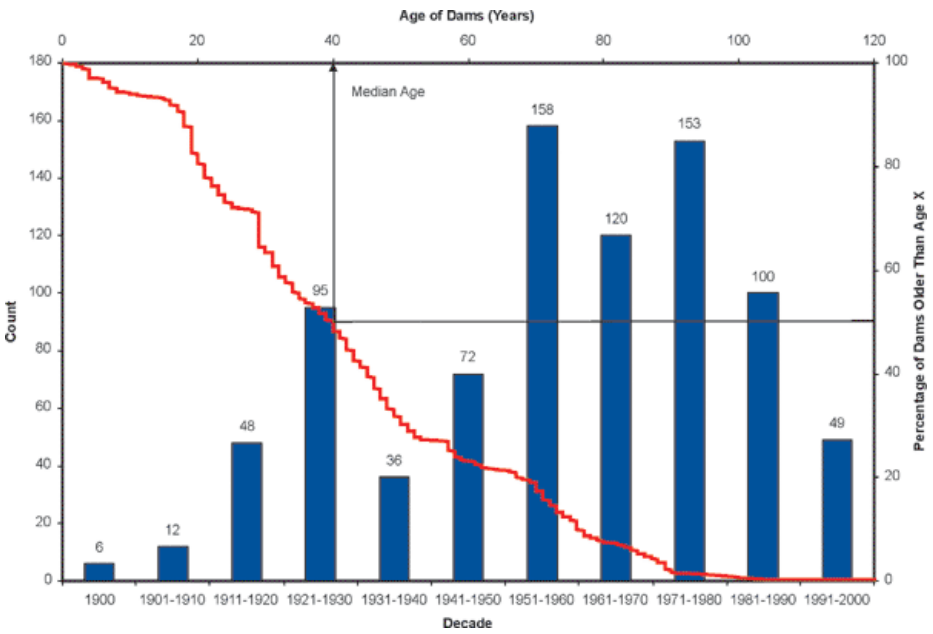

Figure C-1
Age of Dams in Canada
(source: www.nwri.ca)

Of all civil engineering works, dam failure poses some of the highest potential risk of damage to life and property. Moreover, it can lead to loss of drinking and irrigation water supplies, and of

hydroelectric generating capacity. Although there is no historical cataloguing of dam failures in Canada, fortunately there has been no major dam failure resulting in loss of life. There have been, however, numerous incidents involving smaller impounding structures, often designed to mitigate floods of short return period.

C.2 STORMWATER AND WASTEWATER INFRASTRUCTURE

Mirza and Haider (2003) reported that 68% of sanitary and combined sewers, 58% of sewage treatment systems and 53% of storm sewers in Canada did not operate at an acceptable level and needed some type of repair. A large city in Canada will have thousands of kilometres of storm sewers within their jurisdiction. As an example the City of Toronto maintains over 10,000 kilometres of sanitary, storm and combined sewers. However, it is anticipated that the approach to assessing vulnerability of conveyance networks will be completed on a drainage area (sewershed or watershed) or system basis and vulnerabilities assessed on individual sewer sections or watercourse reaches and not pre-determine length of pipe or watercourse. The number of sewersheds in the City of Toronto may be in the hundreds.

C.3 BUILDINGS INFRASTRUCTURE

This example will focus on hospitals across Canada. The website www.hospitalsoup.com was used to query total numbers of hospitals in Canada and by Province (see Table C-5). It is not suggested that this is the best source of this information, but the information provided serves the purposes of providing an example of determining sample size requirements in the context of this project.

Table C-5
Number of Hospitals in Canada

Province/Territory	Number of Hospitals[1]
British Columbia	793
Alberta	329
Saskatchewan	121
Manitoba	111
Ontario	519
Quebec	385
New Brunswick	91
Nova Scotia	86
Prince Edward Island	11
Newfoundland	54
Northwest Territories	15
Yukon	7
Nunavut	29
All Canada	2551

Source: www.hospitalsoup.com
1. The total number of hospitals listed above refers to Hospitals, Medical Facilities and Surgery Centers

C.4 ROADS AND ASSOCIATED STRUCTURES INFRASTRUCTURE

Table C-7 presents a summary of the numbers of bridges in the different provinces of Canada.

Table C-7
Number of Bridges in Canada

Province/Territory	Provincial Bridges	Regional/Municipal Bridges	Total Bridges
Alberta	3,800	8,700	12,500
British Columbia	3,000	500	3,500
Manitoba	2,400	5,800	8,200
New Brunswick	2,800	150	2,950
Newfoundland	1,900	100	2,000
Nova Scotia	3,540	280	3,820
Ontario	2,600	10,000	12,600
Prince Edward Island	1,200	50	1,250
Quebec	4,700	3,800	8,500
Saskatchewan	950	100	1,050
Northwest Territories	47	3	51
Nunavut	10	0	10
Yukon	100	1	100
Total in Canada	27,047	29,484	56,531

Source: Dore et al, 2001

1. There are an additional 33 bridges and tunnels maintained by the federal government.

Bridges are, generally, the youngest infrastructure components relative to their useful life in Canada as of 2003. They had reached only 49% of their useful life, with an average age of 22.7 years over a service life of 46 years. By 2003, federal and provincial bridges had passed the halfway mark of their useful lives; 57% in the case of federal bridges and 53% in the case of provincial. In contrast, municipal bridges were younger, and had only 41% of their useful lives behind them. Provincial bridges were primarily responsible for the aging of the total stock. Very low levels of investment by provincial governments had a direct impact on the average age of bridges, which rose from 15.4 years to 24.6 years between 1963 and 2003. (Gaudreault and Lemire, 2006)

APPENDIX D

STANDARDS AND PRACTICES

D STANDARDS AND PRACTICES

D.1 OVERVIEW

(reproduced from Infrastructure Canada, 2006)

Several published reports emphasize the importance of modifying engineering practices and codes and standards for infrastructure to incorporate climate change impacts. However, the vulnerability of different types of infrastructure and the potential impacts that new engineering requirements, codes and standards will have on climate change vulnerability are essentially unknown.

Few methodologies integrate climate change scenario information into infrastructure design. Several reports emphasize the importance of modifying engineering practices and codes and standards for infrastructure to incorporate climate change impacts. According to the Canadian Standards Association, high priorities for climate change adaptation are those without existing national standards and include stormwater management, rehabilitation of existing infrastructure, northern infrastructure, and coastal regions.

Existing infrastructure has been adapted to the variable climate conditions of the past using a set of climatic design values in building codes and other infrastructure standards. Climatic design values such as the 100 year wind storm speed or 50 year flood are estimations of the probability that a severe weather event will occur in any given year. For example, in any given year, a 20 year return period value indicates that there is on average a 1 in 20 chance that this 20 year wind storm speed could be reached or exceeded. At present, almost all infrastructure has been designed using climatic design values that have been calculated from historical climate data under the assumption that the average and extreme conditions of the past will represent conditions over the future lifespan of the structure. With climate change, these climatic design values will need to be assessed regularly, improved, updated and probably changed to reflect changing climate extremes (e.g., the event presently defining the 1 in 100 year storm may occur much more frequently, or the weight of snow or amount of rain that a structure is designed to endure may change). Structures designed using climatic design values that are based on sparse climate data or previously short dataset records are particularly vulnerable.

Existing Canadian climatic design values are in need of upgrades and regular updates. In Canada, as in other countries of the world, “current long-standing gaps and deficiencies in the determination of climatic design values prevent optimum decisions from being made on infrastructure reliability and safety.” The Auditor General of Canada noted in the 2006 Report of the Commissioner of the Environment and Sustainable Development that “there is a lack of up-to-date climate information for use in adapting the design of infrastructures such as storm sewers.” Because the process of changing structural codes and standards is a lengthy one, the use of a “Climate Change Adaptation Factor” to facilitate a continuous process of updating climatic design values over time as the climate changes has been recommended. To ensure effective “no regrets” adaptation to current and expected climate variability, it would be important that such uncertainties and deficiencies in climatic design values be addressed.

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

The engineering community in Canada is beginning to work on climate change adaptation options for infrastructure. The Engineering Institute of Canada held a Climate Change Technology Conference in May of 2006. The conference drew participants from around the globe, and papers presented included topics such as engineering adaptations for urban drainage infrastructure planning and design considerations, municipal infrastructure decisions and incorporating climate change adaptation into InfraGuide type decision making. Further, according to the CCPE: "climate change will, over the years, necessitate changes to building codes, engineering practices and standards, and will affect the way facilities are designed, ultimately altering the economic lifespan of infrastructure and thereby impacting commerce and industry."

D.2 STANDARDS AND PRACTICES BY INFRASTRUCTURE THEME

D.2.1 Water Resources Infrastructure

Water is used in two basic ways:

- In-stream uses, such as hydroelectric power generation, transportation, fisheries, wildlife, recreation, and waste disposal, take place with the water remaining in its natural setting.
- Withdrawal uses, such as thermal power generation, mineral extraction, irrigation, manufacturing, agriculture, and municipal use. This use removes water from its natural setting for a period of time and for a particular use, and eventually returns all or part of it to the source.

These uses of water represent a vast array of public infrastructure including dams/reservoirs, shipping channels, ports/docks and lock systems, water intakes and distribution systems, etc. The identification of relevant standards and guidelines for all of these types of infrastructure is

clearly beyond the scope of the present project. However, as an example, a brief outline of standards and guidelines and jurisdictional issues as applied to water management and the design of dams in Canada is presented.

D.2.1.1 Water Management

(from Environment Canada, 2006b)

Canada's provinces and territories have primary jurisdiction over water management and protection. Broad provincial water policies that address climate change issues are in place in British Columbia and Manitoba. A special focus has been put on the Okanagan Basin in British Columbia where recent research points to potentially significant water shortages in the future due to projected climate change and population growth. Drought Action Plans and Water Conservation Plans exist for many provinces and territories, including British Columbia, Saskatchewan, Ontario and Quebec.

Other recent and ongoing studies have identified needs that could represent barriers to facilitating adaptation in the water resource management sector in Canada. These include further defining jurisdictional roles and responsibilities, providing for more integrated management among jurisdictions, enhancing adaptive capacity through existing institutional frameworks (e.g., water licensing systems), improving understanding of local water systems and users, and fostering local partnerships and establishing transparent institutional arrangements at all levels. For example, considering jurisdictional roles alone, at least three federal departments or agencies, three provincial departments or agencies, watershed-based organizations and municipalities all play significant roles in water shortage management in Ontario. The recent development of a provincial drought response plan in Ontario has helped to clarify local responsibilities for drought management, which improves the capacity of communities to address water-shortage issues. In Alberta, the 2001 *Water Sharing Agreement* was found to enhance adaptive capacity by instituting an effective means of conserving water and distributing it equitably on a large scale.

D.2.1.2 Dams

There are presently no Canadian design standards or codes specifically for the design of dams (Johannsen et al., 2002). Such design standards and codes would assist in avoiding disputes and may assist in ensuring that requirements for public health and safety are satisfied.

However, a number of dam safety guidelines are presently available to dam designers as outlined in Table D-1. In the late 1980's and indeed until the 1995 CDA Guidelines, dam safety evaluation criteria was selected from various sources reflecting good engineering practice at the time.

Table 6-1
Dam Safety Regulations Across Canada
(from www.cda.ca)

Province/ Territory	Ministry/Agency	Legislation/ Regulation	Dam Safety Regulations	Guidelines *(other than CDA)*
British Columbia Water Supply Dams	Environment Water Stewardship Division	Water Act	Dam Safety Regulation	Inspection & Maintenance - Plan Submissions
Tailings Dams	Energy & Mines Mining Operations	Mines Act	Health, Safety & Reclamation Code	No
Alberta Water Supply & Tailings Dams	Water Mgmt Operations	Water Act	Water Ministerial Regulation	Dam Safety – Inspection of Small Dams
Saskatchewan Water Supply Dams	Watershed Authority	Watershed Authority Act[1]	No	No
Tailings Dams	Environment	Assessment Act	No	No
Manitoba	Water Stewardship Department	Water Res Admin & Water Rights	No (Planned within 2-5 yrs)	No
Ontario Water Supply Dams Tailings Dams (Construction)	Natural Resources	Lakes & Rivers Improvement[3] (LRIA)	Ontario Regulation 454/96 Construction[4]	LRIA Guidelines & Criteria for Approvals
Tailings Dams (Reclamation)	Northern Development & Mines[5]	Mining Act	No	No
Quebec Water Supply Dams	l'Environment (Français) Environment (English)	Sécurité des Barrages (Français) Dam Safety (English)	Règlement (Français) Dam Safety Regulation (English)	No
Tailings Dams	Ressources naturelles (Français) Natural Resources (English)	La Loi sur les mines (Français) Mining Act (English)	No	No
New Brunswick	Environment & Local Government	Clean Water Act	No[6]	No
Nova Scotia	Environment & Labour	Environment Act Regulations	No	No[7]
Newfoundland & Labrador	Environment & Conservation	Water Resources Act[8]	No (Planned within 2-5 yrs)	No
Prince Edward Island	Environment, Energy & Forestry	No	No	No
Yukon Territory	Water Board Water Res. Section[10]	Waters Act (Yukon)	No	No
Northwest Territories	MVLWB[11]	MVRMA Waters Ac	No	No
Nunavut Territory	Nunavut Water Board	Waters & Surface Rights Tribunal Act	No	No
Federal Government	Canadian Nuclear Safety Commission (Uranium Mining Related)	Nuclear Safety & Control Act Uranium Mines & Mills Reg's.[12]	No	Various
	International Joint Commission[13]	1909 Boundary Waters Treaty Act	No	No

Notes:
1. Approvals are required under the Saskatchewan Watershed Authority Act in Saskatchewan to construct and operate water storage dams.
2. The 1300 water storage dams currently identified within Saskatchewan pertains to those having a storage capacity of 40 dam3 or more. Approximately 8960 dams exist within the province having a volume of 1.0 dam3 or more.
3. See LRIA Part 1; Construction, Repair and Use of Dams.
4. Regulatory enhancements for the life-cycle management of dams are planned within 2 years.
5. Reclamation of tailings dams only, active tailings dams are regulated by MNR.
6. Under the Watercourse Alteration Regulation, a permit is required for construction of all new dams or dikes in New Brunswick.
7. CDA guidelines are the recognized industry standard in Nova Scotia. One of the requirements for obtaining an operating license is to demonstrate compliance with the CDA Guidelines.
8. Under the Water Resources Act, a permit is required for construction of all new dams or dikes in Newfoundland and Labrador.
9. Darrell Fisher is a consultant with ADI Limited in Charlottetown, PEI. He does not represent the PEI regulator but is the CDA Board member for PEI.
10. The Yukon Water Board issues licences for dams that are associated with mining, hydro projects, etc. The Water Resources Section of the Environmental Programs Branch administers the water licences that have been issued by the YWB and provides inspection services.
11. The Mackenzie Valley Resource Management Act (MVRMA) came into being in 1998 as a result of the Gwich'in and Sahtu Comprehensive Land Claims Agreements. The Act created co-management boards for both the Gwich'in and Sahtu settlement areas and it established the Mackenzie Valley Land and Water Board (MVLWB).
12. The CNSC also takes into account various other National and Provincial Regulations and Guidelines and International best practices.
13. The IJC is technically not a regulator of dam owners but is an observer on the committee.
14. Includes dams on the border, in Canada and in the US.

D.2.2 Stormwater and Wastewater Infrastructure

The banner of stormwater and wastewater infrastructure covers a wide range of elements. In an urban context, stormwater systems generally include various components such as storm sewers, manholes, catchbasins, ditches, culverts and stormwater retention ponds. Flooding issues are also related to stormwater and floodplain management. Wastewater infrastructure includes various components such as sanitary sewers, manholes, force mains, pumping stations and wastewater treatment plants.

D.2.2.1 Stormwater Infrastructure

Municipal sewer systems have been getting younger, on average, since 1997, as municipalities have been investing heavily in this type of infrastructure. In 2003, municipal systems had reached only 47% of their useful life. In contrast, provincial sewer systems had reached 71% of their useful life, and federal systems, 68%. The provincial sewer system was 24.1 years old in 2003 and the federal system 23.2 years old. However, those levels of government owned less than 20% of the total sewer system stock. Municipal sewer systems were, on average, only 15.8 years old in 2003 (see Figure D-1). (Gaudreault and Lemire, 2006)

The history of stormwater management in Canada is characterized by three eras, namely;

- Storm Sewer Era (1880-1970) – “Get rid of the water as quickly as possible”
- Stormwater Management Era (1970-1990) – “Let’s try to lower peak flows”
- Urban Stormwater Best Management Practices Era (1990-present) – “What about water quality?”

These eras are characterized by varied ‘problems’ and ‘solutions’ in terms of stormwater infrastructure. The existing stormwater infrastructure reflects this history so that some municipalities with nineteenth century neighbourhoods still have combined sewers and, at the other extreme, new developments in some municipalities have urban stormwater best management practices (BMP’s) such as extended detention ponds. The majority of urban stormwater infrastructure lies between these extremes and is dominated by storm sewers. (Watt et al, 2003)

Stormwater infrastructure, in much of Canada, falls within the jurisdiction of municipalities, resulting in a diversity of guidelines across the country. Provincial and federal governments have historically assisted with research, guidelines, data and information, and interceded with capital funding. However, the levels of provincial and federal involvement will likely decrease over the next decade and possibly beyond because of the current trend towards downloading services and associated responsibilities to lower levels of government. The primary areas where senior government agencies are involved include research; development of stormwater management guidelines; collection, analysis and provision of hydrometric data (e.g., intensity-duration-frequency curves/tables); and targeted funding programs for infrastructure renewal. In addition to governments, the urban development and the insurance industries play major roles in stormwater management, both in terms of investment costs and covering potential weather-related and other damages. (Watt et al, 2003)

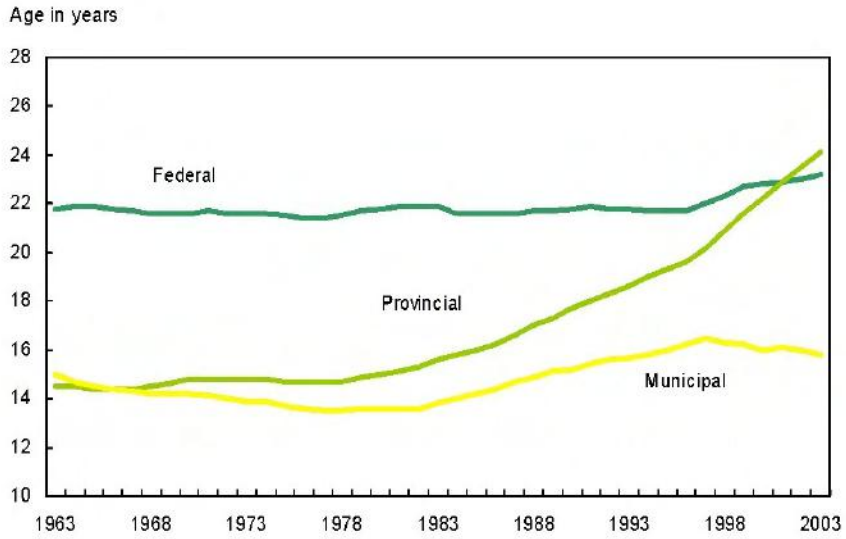

Figure D-1
Age of Sewer Systems by Level of Government
(source: Gaudreault and Lemire, 2006)

As an example, in Ontario the design of stormwater management ponds, infiltration systems and other BMP's typically adheres to the Ministry of Environment's 2003 Stormwater Management Planning and Design Manual (MOE SMPDM 2003). Within an urban setting, specific design requirements, including design storms, may also be imposed at the regional and/or municipal level. In the City of Toronto, stormwater design must adhere to *City of Toronto Wet Weather Flow Management Guidelines* (Toronto, 2006). Further requirements may also be imposed within Toronto with regard to pre-amalgamation jurisdictions such as the *City of Toronto, Scarborough District, Drainage Policy* (Toronto, 1998).

IDF data and historical rainfall normals continue to be used as the primary meteorological input for the design of stormwater infrastructure. The IDF curves for Canada were last updated in 1991 and another frequently used reference (typically where IDF curves are not available), the *Rainfall Atlas of Canada* (Hogg and Carr, 1985) is over 20 years old. Recent efforts have seen updates of some IDF curves in Quebec (Lam et al, 2004).

D.2.2.2 Flood Plain Management

(from www.ec.gc.ca unless otherwise noted)

Under the Canadian constitution, flood plain management essentially falls under the jurisdiction of the provinces, as they are primarily responsible for water resources and land use matters. The objective of the federal government is to reduce major disruptions to regional economies and to reduce disaster assistance payments. Traditionally this had been achieved by building structural measures to control flooding. In the 1950s, 1960s, 1970s, and to a lesser extent in the 1980s, the federal government allocated millions of dollars, in conjunction with the provinces, to

build dams and dykes. Extensive flood damages across Canada in the early 1970s clearly demonstrated that a new approach to reducing flood damage was needed. These flood events were the catalyst for the federal government to initiate the national Flood Damage Reduction Program (FDRP) in 1975 under the Canada Water Act. The FDRP is carried out under cost shared federal-provincial agreements.

The federal minimum criterion for defining the flood risk area is the 100 year flood, i.e., a flood that has one chance in one hundred of being equaled or exceeded in any given year. However, the federal government adopts provincial criteria if they are more stringent. For example, in British Columbia the 1 in 200 year flood is used, in Saskatchewan the 500-year flood is used, and in parts of Ontario a "regional storm" or highest observed flood is used.

FDRP agreements have been signed with all provinces and territories except, Yukon, Nunavut and Prince Edward Island.

Flood risk areas are usually divided into two zones (i.e., a two-zone approach): floodway and flood fringe. The floodway is that portion of the river's flood plain where waters are deepest, fastest and most destructive. Future development is discouraged in the floodway due to the likely danger to life and damage to property, and because the buildings themselves, by acting as obstructions, could increase flood levels upstream. Within the flood fringe, where water tends to be shallower and slower than in the floodway, new development may be permitted, provided it is adequately flood proofed. Alberta uses this two-zone approach, however, in Ontario the floodplain is defined using a one-zone principle whereby the entire floodplain is designated as the floodway.

Floodplain delineations, in Ontario, are typically completed in compliance with the Flood Plain Management in Ontario, Technical Guidelines (OMNR, 1988a) in addition to the FDRP requirements

D.2.2.3 Wastewater Infrastructure

The provinces bear primary responsibility for drinking water and sewage treatment and have generally delegated all but their regulatory responsibilities to municipalities. Although the federal government funds and oversees water utilities in aboriginal communities and in other areas under its jurisdiction, such as military bases and national parks, its role in the rest of Canada is more “strategic”. In the past, it has influenced provincial and municipal policies and practices through environmental and health regulations, subsidies to infrastructure, and the funding and coordination of research and policy development, some of which has promoted greater private-sector involvement. (Fraser Institute, 2007)

Some statistics regarding the distribution of wastewater systems across Canada (Infrastructure Canada, 2003) are presented below;

- Nearly 75% of Canadians (22.5 million people) living in some 1200 municipalities are serviced by municipal sewer systems. The remaining approximately 25% of Canadians (7.5

million people), mostly living in rural areas, rely on on-site sewage systems, primarily septic tanks and disposal fields.

- In 1999, 97% of the Canadian population on sewers was served by at least a preliminary form of wastewater treatment, compared with 93% in 1994 and 72% in 1983. The remaining 3% of Canadians serviced by sewage collection systems were not connected to wastewater treatment facilities in 1999 and discharged their untreated sewage directly into receiving water bodies.
- The degree of treatment has improved significantly since 1983 as more Canadian municipalities upgrade their wastewater treatment facilities. In 1999, secondary or advanced (tertiary) treatment was provided to 78% of the municipal population on sewers, up from 69% in 1994 and 56% in 1983.
- The degree of wastewater treatment varies greatly across Canada. In British Columbia, about 63% of the population served by sewers had secondary or tertiary treatment in 1999. In both Ontario and the Prairie provinces, over 94% of the sewered population had secondary or tertiary treatment in 1999. In Quebec, about 43% of the sewered population had primary treatment and about 54% had secondary or tertiary treatment in 1999.

Table D-2 provides an indication of the distribution of large diameter sewers in some major Canadian cities.

Table D-2
Estimated Trunk Sewers in Major Canadian Cities
(source Zhao, 1998)

Municipality	Population served	Length (km)	Diameter/size range (mm)
Calgary	767,100	5,847	200 - 3,000
Victoria Capital Regional District (CRD)	300,000	47	200 - 1,500
Edmonton	630,000	1,148	600 - 5,250
Greater Vancouver Regional District (GVRD)	1,656,000	440	150 - 3,100
Regional Municipality of Hamilton-Wentworth (RMHW)	353,300	1,988	150 - 2,600
Metro Toronto	2,200,000	358	150 - 4,100 Forced 75 - 150
Québéc City	170,000	680	N/A
Regional Municipality of Ottawa-Carleton (RMOC)	745,000	213	610 - >1,680
Regina	180,000	88	900 - 2,600
Saskatoon	203,000	152	375 - 3,050
Victoria	77,000	114	250 - >1,500

D.2.3 Buildings Infrastructure

There are many codes and practices involved in the design, development, construction, operation and management of buildings in Canada. There are, for example, numerous technical documents associated with the Canadian Standards Association (CSA) regarding the design of structures using concrete, steel and timber materials, as well as, associated practice documents

from industry groups associated with these materials. Similarly, there are many codes and practice documents regarding mechanical, electrical, communication and controls equipment used in building infrastructure. Heating, ventilation and air conditioning is typically abbreviated as HVAC.

At the design stage, locally applicable, numerical values for wind, rain, snow, degree-days, etc. typically originate from an Appendix of the most recent version of the National Building Code of Canada (NBCC). While the NBCC undergoes regular cycles of continuous improvement, it is worth noting that this is not the case with the climate data presented in the appendix. The climate data presented in the NBCC may be the "best available" information for designers and decision makers, but it is also based on older, smaller data sets for a particular location associated with older and less precise equipment than what would be used today if the values were being updated.

The locally applicable building codes vary among jurisdictions, but are typically based on the NBCC, perhaps with modifications for local conditions. Other applicable building codes exist for farm structures and for small structures. Typically the climate data (e.g., wind, rain, snow, degree-day type information) used in the decision making for these other structures, also originates with the NBCC Appendix C.

Infrastructure design parameters and thresholds documented in existing standards and codes have generally been founded upon historical weather data. The typical design approach has been to use past records of climate and assume this data can be used predict future events. Under changing climate and weather conditions, this assumption will no longer apply. The 1995 National Building Code of Canada included a section explaining the growing uncertainties that climatic design values will be subjected to under changing climate conditions. (CSA, 2006; Auld, 2002)

Regular/scheduled updates of climatic design values to reflect the additional impact of the most recent climate conditions and maintenance of quality weather/climate data networks to ensure that design standards allow critical infrastructure to remain intact under high impact weather events is needed. (CSA, 2006; Auld, 2002)

D.2.4 Roads and Associated Structures Infrastructure

(from Dore et al, 2001 unless otherwise noted)

There are currently 2,400 km of roads under federal jurisdiction in Canada. There are also 33 bridges and tunnels throughout the country that are maintained by the federal government. The national highway system includes 24 international crossings, roads and bridges under Parks Canada, roads and bridges under Public Works Canada, roads and bridges under the National Capital Commission and roads maintained by the Department of Indian and Northern Affairs. The federal government also contributes to the provincial highway system.

The provincial and territorial governments are responsible for most of the main thoroughfares in the country. The distribution of roads and bridges between the provincial and local governments

is quite variable across the country (as indicated in Table C-7 and D-2). In Ontario, regional governments assume many of the responsibilities for construction. Other provinces, such as British Columbia, also have a two-tier local government system.

Different codes and standards for road and bridge construction are in place across the country. Most municipalities and regions follow the provincial standards for road and bridge construction and no federal standard currently exists. Municipalities and regions generally follow these standards.

The 2006 Canadian Highway Bridge Design Code (CHBDC) is the 10th edition of CSA Standard CAN/CSA-S6 and the second edition under the title Canadian Highway Bridge Design Code. Used in all provincial and territorial jurisdictions, the new revisions and updates make this Code the national standard in Canada (www.csa.ca). The CHBDC replaces all existing Canadian codes including the 2000 edition CHBDC, CSA Standard CAN/CSA-S6-88, Design of Highway Bridges, its supplement, CAN/CSA-S6S1-1990, Existing Bridge Evaluation, to CSA Standard CAN/CSA-S6-88, Design of Highway Bridges and the commentary S6.1-M1990. However, these previous codes will be relevant with regard to vulnerability assessments of older bridges.

Roadways are fairly consistent in their design standards as well. Most provinces use the Transportation Association of Canada (TAC) Geometric Design Guide for Canadian Roads. The 1999 edition is the current version of this design guide. There are also guides specific to each province, which often exist to accommodate special considerations for climate within the province. Alberta and Saskatchewan have their own guides and Manitoba utilizes the US guidelines in addition to the TAC guide. Roads are currently designed to last between 15 and 25 years.

Additional information with regard to specific design criteria by Province for roads and bridges is presented below in Table D-3. Design guidelines, with regard to culvert design, vary across the Provinces but are typically related to the classification of the associated roadway.

Table D-3
Road Jurisdiction in Canada
(source: Dore et al, 2001)

Province/ Territory	Federal Roads (km)	Provincial Roads (km)	Municipal Roads (including Regional) (km)	Total Roads (km)	Road Design Criteria	Bridge Design Criteria*
Alberta	4,076 (3,973)	18,767 (18,292)	163,307 (159,172)	186,150 (181,437)	TAC plus the Alberta's "Highway Geometric Design Guide"	CAN/CSA-S6-88 AASHTO,OHBDC
British Columbia	2,626 (2,050)	54,161 (42,279)	27,413 (21,399)	84,200 (65,728)	TAC	CAN/CSA-S6-88 supplemented by OHBDC
Manitoba	2,784 (1,740)	(21,628)	(64,500)	(87,868)	TAC supplemented with AASHTO Design of Highways and Streets	CAN/CSA-S6-88 and the AASHTO Bridge Design Code
New Brunswick	400 (219)	21,300 (18,480)	3,671 (3,185)	25,371 (21,884)	TAC	CAN/CSA-S6-88
Newfoundland	500 (207)	9,000 (8,747)	4,246 (4,127)	13,746 (12,081)	TAC	CAN/CSA-S6-88 supplemented by the OHBDC
Nova Scotia	500 (291)	26,000 (23,371)	2,592 (2,330)	29,092 (25,992)	TAC	CAN/CSA-S6-88
Ontario	4,939 (2,346)	(28,458)	(137,087)	(167,891)	TAC supplemented with the Ontario's, Geometric Design Standards for Ontario Highways	OHBDC
Prince Edward Island	100 (57)	5,660 (5,128)	554 (502)	6,314 (5,687)	TAC	CAN/CSA-S6-88
Quebec	2,536 (534)	70,000 (29,344)	92,000 (90,000)	164,536 (119,878)	Quebec provincial transportation engineers use their own standards for road design	CAN/CSA-S6-88 supplemented by the Quebec publication Manual de Conception des Structures
Saskatchewan	3,939 (3,181)	32,441 (26,200)	213,620 (172,522)	250,000 (201,903)	TAC supplemented by their own design manual	CAN/CSA-S6-88 supplemented with AASHTO Bridge Design Code
Northwest Territories	800 (351)	4,400 (3895)	813 (720)	6,013 (4,966)	TAC	CAN/CSA-S6-88 supplemented by the OHBDC
Nunavut	200 (39)	(412)	(70)	(521)	There is no standard for road construction.	all bridge construction is site-specific
Yukon	600 (94)	(4,696)	(278)	(5,487)	TAC	CAN/CSA-S6-88
Total	24,000 (15,082)	(230,930)	(655,892)	(901,904)		

Figures in bold are actual numbers for 2000. Figures in brackets are numbers for 1995. All other figures are estimates.
** prior to issue of 2006 Canadian Highway Bridge Design Code*
TAC refers to the TAC Geometric Design Guide for Canadian Roads
OHBDC refers to the Ontario Highway Bridge Design Code
AASHTO refers to the American Association of State Highway and Transportation Officials