Adaptive Approaches in Stormwater Management

Prepared for the City of Ottawa

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Contents

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Executive Summary

This report presents information which characterises the stormwater management adaptation planning environment and provides examples of municipal stormwater management adaptation planning, programs and projects. The City of Ottawa's current Council Strategic Objectives, *Official Plan, Infrastructure Master Plan* and implementing documents such as the City's *Urban Design Guidelines and Wet Weather Infrastructure Master Plan* all contain policies and directions related to adaptation to climate change and improved stormwater management. The characterization and the examples provided in this report are intended to advise planning for and moving forward to achieve the City's policy goals.

It is widely noted in climate adaptation research and reporting — for example in a Canada wide assessment of climate adaptation state of practice completed in 2012[1] — that "*Though progress has been made, there remain significant gaps across Canada in the implementation of adaptation measures. Many sectors and regions struggle in knowing how, where and when to adapt*." While there are many factors contributing to these "gaps," research indicated examples of planning, policy, design and operations best practices which provide examples the City may be able to draw on as it considers moving forward with policy goals:

- **While there is uncertainty regarding the scope and impacts of climate change for which to plan for, municipalities are acting with confidence on available information:**
    - Climate uncertainty is similar to other uncertainties dealt with in municipal planning such as population and economic growth;
    - While the exact magnitude and timing of changes are uncertain, local, provincial and national scale reporting for impacts in the Ottawa area all predict a likelihood of more intense and more frequent rainfall events;
    - Updating stormwater management design methods based on the most up to date climate records is considered important, however uncertainty regarding climate change also suggests that use of climate change models to predict future conditions is an important tool.
- **While there is a lack of senior government policy and legislative frameworks for adaptation, municipalities are increasingly being recognized as leaders in acting on climate change:**

[1] *Mainstreaming Climate Change Adaptation in Canadian Water Resource Management – The state of practice and strategic directions for action*, Toronto and Region Conservation Authority and ESSA Technologies, November 2012. See Section 2.1.7 Adaptation Measures http://waterandclimate.ca/WP/wp-content/uploads/2012/11/MainstreamReport_FINAL_FORMATTED_Nov17.pdf

- Federal government actions have, until recently, been focussed on research, weather data compilation and reporting, as well as, support for communities undertaking adaptation planning which includes many projects related to stormwater management adaptation. The federal focus shifted in 2013 to support for resource based industries and efforts to protect industry from the effects of climate change;

- In Ontario, the provincial government has focused on adaptation planning, issuing in April 2011 a five-year "adaptation strategy and action plan" which is now being implemented. "Action" steps include developing guidance for municipalities (on-going), updating the MOE *Stormwater Management Planning and Design Manual* (on-going) and updating IDF curves (completed);

- Many cities understand that given their unique risks they cannot afford to wait for direction — or even financial assistance — from senior governments. The municipal level of government has become recognized as the leader in climate adaptation — an opportunity the City can consider as it plans to address policy goals for adaptation and stormwater management.

- **While there are a limited number of examples of successful municipal adaptation policy and planning processes, cities in Ontario including Toronto, London, Windsor and Kitchener are frequently referenced as state of practice leaders:**

  - As climate adaptation including for stormwater management may impact many municipal functions and the "costs and benefits" will vary across municipal responsibilities, it is recognized that a corporate-wide and multi-departmental planning process presents considerable challenges;

  - Research indicated that Vancouver, Toronto, Windsor and Kitchener are frequently referenced for their success in undertaking adaptation planning processes, incorporating adaptation throughout their municipal practices and innovation in stormwater management adaptation. The Toronto, Windsor and Kitchener examples are discussed in this report. Vancouver and Windsor applied what is becoming recognized as a model process for municipal adaptation planning — the ICLEI Canada *Building Adaptive and Resilient Communities* program;

  - Research indicated that examples of planning processes for stormwater adaptation in Canada, the United States, Europe, Australia and elsewhere concluded, essentially, on the same objectives, implementing measures and constraints. Regarding constraints for instance, Durban, South Africa discussed in this report, concluded on constraints which would be familiar to the City of Ottawa including: climate change factors into existing requirements for new development; justifying costs for climate change in the future when needs of the present are so great; and the politics of hard decisions on adaptation;

  - As climate related changes to precipitation may impact municipal stormwater infrastructure, it is recognized that infrastructure asset management is a fundamental component of stormwater management adaptation. Research indicated that 25 communities in Canada had used the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol to assess the climate risk and vulnerability of their infrastructure. Communities like Welland, discussed in the report, have undertaken the risk assessment process for their stormwater infrastructure and are now implementing the risk reduction recommendations.

- **While a limited number of examples of implemented stormwater management adaptation measures are in place and not yet fully proved out as cost effective through long term operational success, many of the measures being implemented are considered to be "no regret" in that even if climate change does not occur, the works which are being constructed provide sufficient value and many benefits to the community:**
    - Research identified that a number of stormwater management adaptation projects are recipients of industry awards — indicating that these types of projects represent laudable "award winning" innovation and change;
    - Research of best practice compendiums and climate adaptation reports indicated that projects in Canada, like the Richmond Hill Pioneer Park Stormwater Management Facility and the City of London's updating of IDF curves (both discussed in this report) are recognized internationally as "best practices" in stormwater management adaptation;
    - Research identified that updating IDF curves is one of the most frequently referenced stormwater management adaptation measures. Four examples are included in the report, each of which demonstrate a different approach to the update process;
    - Research identified that incorporation of stormwater adaptation measures into existing and new stormwater management ponds is one of the most frequently referenced adaptation projects. Three examples are included in this report.

- **While there are considerable concerns at the municipal level regarding the cost of adaptation, many municipalities are recognizing that the financial risks of not addressing climate change may be greater and some municipalities are recognizing that well planned adaptation will, in particular for their own stormwater management challenges, decrease municipal costs:**
    - Research identified that some municipalities are finding that stormwater management adaptation measures can be implemented cost effectively within existing programs. The City of Toronto found that their existing wet weather management program was an excellent vehicle for adaptation measures. The City of Welland found that their risks were manageable through their ongoing infrastructure rehabilitation program;

- Research identified that municipalities, like the City of Chicago through their "green streets" program discussed in this report, are finding that "green" solutions to stormwater management for road drainage, combined sewer overflow and natural channel erosion protection are less expensive than "grey" solutions, and that they provide considerable and significant community benefits.

Recommendations

Throughout this report, examples of stormwater management adaptation planning in other municipalities are highlighted. Section 13 *(pg. 62)* of this report summarizes candidate opportunities:

- Develop a common understanding of stormwater management adaptation;
- Develop a stormwater management adaptation plan, plan for adaptation as a process and develop a framework of themes;
- Promote the use of green infrastructure;
- Review the Welland infrastructure vulnerability assessment — a recent and relevant example;
- Incorporate adaptation measures as part of planned infrastructure rehabilitation;
- Ensure an interdisciplinary approach to incorporating adaptation into municipal practice;
- Review the City's standby power capacity in consideration of climate risks;
- Develop City stormwater management model tools to incorporate options for considering adaptation;
- Review the many approaches to updating Intensity-Duration-Frequency (IDF) curves;
- Review and understand the many approaches to considering the cost of climate adaptation.

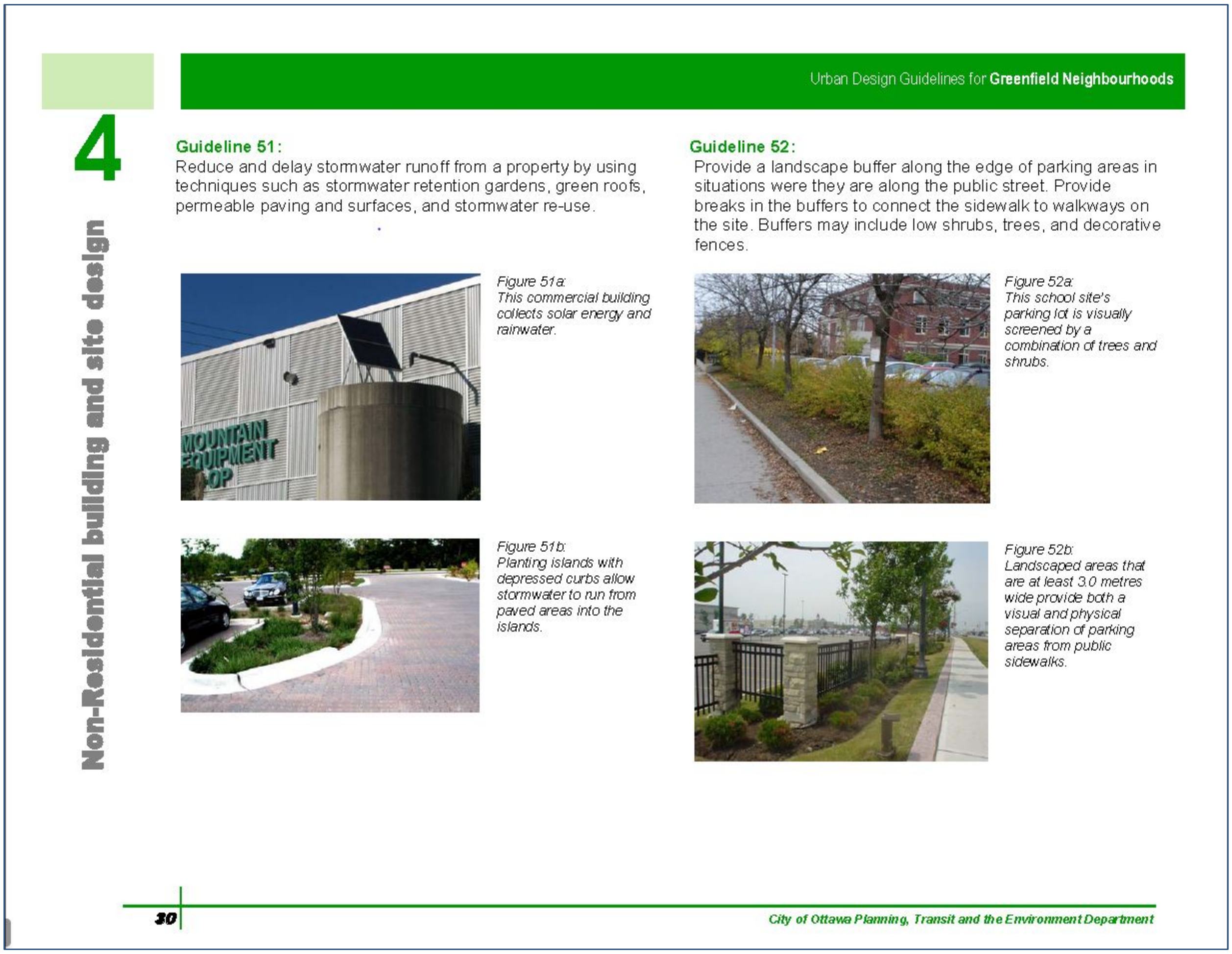
Adaptive Approaches in Stormwater Management PART A – Background

1.0 Introduction

Ottawa's current Council Strategic Objectives, *Official Plan, Infrastructure Master Plan* and implementing documents such as the *City's Urban Design Guidelines* and *Wet Weather Infrastructure Master Plan* all contain policies and directions related to adaptation to climate change and improved stormwater management.

- City Council Strategic Direction ES1 for Council term 2011-2014 promotes improved stormwater management;
- Official Plan Policy 2.4.1.3 notes "The City will take measures to adapt to the effects of climate change.";
- The *Infrastructure Master Plan* (2009) Sections 5.2 and 7.4 frame issues related to urban development and stormwater management that may be impacted by climate change including erosion, degradation of water quality and risks to property and infrastructure;
- The City's *Urban Design Guidelines for Greenfield Neighbourhoods* includes Guideline 51 that promotes reduction and delay of stormwater from development by techniques such as permeable paving and stormwater re-use – techniques that may make drainage systems more resilient to the predicted impacts of climate change;
- Recommendations in the City's *Wet Weather Infrastructure Master Plan* promote climate related updating of sewer design guidelines and vulnerability assessments;
- Informing these and all of the City's policy initiatives and subsequent actions is a goal of fiscal sustainability.

Section 6.1.6 of the *Infrastructure Master Plan* notes the City will "Research and investigate the literature available on the anticipated impacts of climate change." Stormwater management is one area where the City can consider and, where appropriate, take proactive measures to adapt to climate change. Municipal practice research is an effective way of sharing an available body of knowledge in particular in evolving policy and technical areas such as stormwater management adaptation. As a component of the 2013 update to the *Infrastructure Master Plan* the City retained Bolivar≈Phillips to complete a best practices review of municipal stormwater management adaptation efforts.



Urban Design Guidelines for **Greenfield Neighbourhoods**

4

Non-Residential building and site design

Guideline 51:
Reduce and delay stormwater runoff from a property by using techniques such as stormwater retention gardens, green roofs, permeable paving and surfaces, and stormwater re-use.

Figure 51a: This commercial building collects solar energy and rainwater.

Figure 51b: Planting islands with depressed curbs allow stormwater to run from paved areas into the islands.

Guideline 52:
Provide a landscape buffer along the edge of parking areas in situations were they are along the public street. Provide breaks in the buffers to connect the sidewalk to walkways on the site. Buffers may include low shrubs, trees, and decorative fences.

Figure 52a: This school site's parking lot is visually screened by a combination of trees and shrubs.

Figure 52b: Landscaped areas that are at least 3.0 metres wide provide both a visual and physical separation of parking areas from public sidewalks.

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Figure 1: *City of Ottawa Urban Design Guidelines*

1.1 Research Scope

A primary objective of the research is to identify and characterize best practice examples where municipalities have implemented stormwater management adaptation measures. The research includes characterization of the state of practice for municipal stormwater management adaptation and compares examples and the state of practice to the unique stormwater management history, challenges and opportunities in Ottawa. Other factors directing the research include:

- **Similar to Ottawa**: The research scope directed identification of examples of stormwater management adaptation measures undertaken by municipalities such that:
  - the examples are in Ontario and therefore have been implemented within a land use planning and stormwater management design and regulatory environment equivalent or very similar to the City of Ottawa;
  - the examples come from areas with similar climatic conditions to Ottawa and/or respond to anticipated climate change impacts that are also predicted for the Ottawa area;

- **A Spectrum of Measures:** The research scope directed identification of a spectrum of stormwater management adaptation issues and measures as a framework for considering and achieving the policy goal of improving stormwater management:
    - across municipal business practices including in policy, planning, land use, technical design, operation and maintenance;
    - across physical stormwater management infrastructure components including:
        - conveyance systems such as pipes, overland flow routes and urban streams;
        - management systems such as rooftops, ground level detention, local storage and end of pipe facilities;
        - as advised by the Ontario and Federal governments and international best practice examples;
    - compile and append a complete list of references to serve as a research tool for the City;

The benchmark established for identification of an example of municipal adaptation: "You can go take a picture of it."

- **Cost:** The research scope directed some focus on the actual or anticipated costs of stormwater management adaptation measures. In particular, the intent was to seek out information on stormwater management adaptation measures characterized as "no regret" and "low regret" measures;

- **Management of Change:** The research scope directed some focus on how identified stormwater management adaptation measures represent a change in past practices. In particular, the direction was to seek out information or examples of measures either not practiced in Ottawa, different from conventional practice in Ottawa or offering an opportunity for more efficient implementation of stormwater management adaptation efforts in Ottawa. References to existing adaptation practices in Ottawa are integrated throughout the report;

- **Candidate Opportunities:** The research scope directed that candidate opportunities be identified for the City of Ottawa to consider in further advancing its own stormwater management adaptation efforts. Opportunities are highlighted throughout this report and summarized in Section 13 *(pg. 62)*.

The scope of the research focused on urban stormwater management adaptation to climate change. Resource sections in the Appendix list references which address the broader topics of climate change, adaptation, the municipal experience with adaptation and sustainability planning and constraints to change in municipal practices.

1.2 Research Methodology

Information on the most current state of practice of stormwater management adaptation and interpretation of that information for the benefit of the City was developed using the following research steps:

- Advice from the City Project Manager at commencement and throughout the project on stormwater management and stormwater management adaptation at the City along with review of City policy, planning, reports and projects all toward characterizing the "state of practice" at the City;

- Advice from Bolivar≈Phillips' recent work history, clients and business associates regarding specific knowledge or relevant information sources;

- Use of Internet search engines with various search words to identify stormwater management adaptation information — with a focus on best practices, state of stormwater management adaptation information and comparable municipal examples;

- Placing information request posts on stormwater management adaptation blog sites to seek unpublished information regarding the most current stormwater management adaptation practices from the blog community of practice members;

- Identification of municipal, planning and engineering industry awards to stormwater management adaptation projects as a source of "best practices";

- Short listing and a focus on relevant stormwater management adaptation projects, municipalities engaged in stormwater management adaptation planning and implementation and "experts" in the area of stormwater management adaptation and local stormwater management.

In addition to direct references in the body of the report, the Appendix includes listings of the information sources that were reviewed and the subject experts who were contacted as part of the research.

1.3 Glossary of Terms[2]

Adaptation: A definition of stormwater management adaptation is important to a common understanding of purpose across the business units of the City. A selection of definitions from literature sources is provided below to illustrate the importance of a definition and terms within the definitions — for instance, different stakeholders may have different views as to what constitutes a "practical step". Also note that some definitions refer to actions while others refer to a process. Developing a common understanding of stormwater management adaptation may be an opportunity for the City to move forward with policy goals to improve stormwater management including through adaptation.

- Climate change adaptation can be defined as initiatives and measures taken to reduce the vulnerability of natural and human systems to actual or expected climate change effects. (City of Toronto);

[2] See Appendix *(pg. 72)* for a list of sources used to compile and develop these terms and definitions

- Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (used by PIEVC);
- Practical steps to protect countries and communities from the likely disruption and damage that will result from effects of climate change;
- A process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed and implemented;
- The process or outcome of a process that leads to a reduction in harm or risk, or realization of benefits associated with climate variability and climate change[3]

Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in climatic conditions.

Climate change: Any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer. Climate change may be due to natural external forces, such as changes in solar emission or slow changes in the earth's orbital elements; natural internal processes of the climate system; or anthropogenic forces, e.g. human activities generating greenhouse gases.

Coping: The use of available skills, resources and opportunities to address, manage and overcome adverse conditions with an aim to achieve basic functioning in the short term. (***NOTE:*** it is important to understand and differentiate coping from adapting when undertaking adaptation planning and therefore a definition is provided.)

Disaster Risk Management: Historically focused on disaster relief and recovery to extreme and sudden events, disaster risk management is evolving to consider a balance of measures including reduction of existing exposure and vulnerability, improving resilience and considering the short, medium and long term social impacts beyond the disaster event. Disaster risk management has many similar characteristics to, but is distinct from, stormwater management adaptation planning and measures.

Green Infrastructure: Natural and human-made elements that provide ecological and hydrological benefits. Green infrastructure can include components such as natural heritage features and systems, parklands, stormwater management systems, urban forests, permeable surfaces, and green roofs. In the area of stormwater management adaptation, green infrastructure is often discussed along with “grey infrastructure” — piped solutions to stormwater management.

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[3] *Adaptation to Climate Change: Key Terms*, Organization for Economic Co-operation and Development, 2006. The last three definitions are presented in this report, along with a discussion of the importance of definitions in promoting understanding. Definitions for many other terms are also provided. http://www.oecd.org/environment/cc/36736773.pdf

Hazard: A physical event (e.g., an intense precipitation event) that can pose a threat to a system (e.g., an urban drainage system) if the system is vulnerable to the hazard. An event does not necessarily result in risk. For instance if an extreme event occurs in an area that is not vulnerable to flooding under this event, there is no risk.

Hydrologic stationarity: The notion that the amount of water in any given place or region will be approximately the same. As water is an important driver of weather and climate, stationarity implies that seasonal weather and long term climate conditions will fluctuate predictably and within historical limits.

Mitigation: An intervention to reduce the sources or enhance the sinks for greenhouse gases that are a driver for climatic change. This strategy is used to slow the rate of climatic change.

Modelling based approaches: Use of system models, typically mathematical models, to derive quantitative predictions of change and responses in systems (compared to scenario approaches).

Low Impact Development: A comprehensive land use planning and engineering design approach with a goal of maintaining the pre-development hydrologic regime of urbanizing watersheds.

No / low regret adaptation options: Stormwater management adaptation measures which provide benefit (increased resiliency, reduced risk) regardless of climate change taking place.

Resilience: Either the extent to which a system is able to absorb adverse effects of a hazard, or the recovery time for returning after a disturbance. Resilience can be described as a buffer with links to the adaptive capacity and vulnerability of a system.

Risk: The value of a probability function of the magnitude of an individual hazard and degree of vulnerability of a system in question to that hazard to either vulnerability or hazard. A product of the frequency of the event and the vulnerability factors arising from the event; or the probability of harmful consequences arising from a hazard.

Risk based approaches: Use of scenarios to develop qualitative descriptions of change and response in systems (compared to modeling based approaches).

Triple Bottom Line: Placing a value on social and environmental cost and benefit factors in a measurable way in addition to the traditional economic measure of capital cost / selecting measures based on the lowest capital cost.

Vulnerability: Engineering vulnerability is defined as the shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure. Vulnerability is a function of:

- Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed;
- Sensitivities of infrastructure to the changes, in terms of positive or negative consequences of changes in applicable climatic conditions; and
- Built-in capacity of infrastructure to absorb any net negative consequences from the predicted changes in climatic conditions.

Win-win adaptation options: Adaptation options which provide multiple benefits. For instance, a green roof will achieve stormwater management adaptation objectives of reduced runoff from development and will also contribute to reduction of heat island effect and air quality improvement.

2.0 Framework for Considering Stormwater Management Adaptation

The City has "adapted" its approaches to managing stormwater over time and in a manner generally similar to the evolution of stormwater management practices across Ontario as well as in Canada and internationally. These steps in the historical evolution of stormwater management practices are indicative of "stormwater management adaptation" to "change" such as changing regulations, changing goals for land use planning including more compact development and changing scientific understanding of the ecological functions of surface and ground waters.

That having been said, a review of City Committee reports and Web available information on CSO strategies, a *Wet Weather Infrastructure Master Plan*, a *Water Environment Strategy*, *Public Education* and the *Ottawa River Action Plan* indicates the City has not explicitly linked current activities to stormwater management adaptation or promoted new activities as stormwater management adaptation. Absence of references suggests considerable opportunity for the City to achieve Council's goals of "improved stormwater management" by linking existing activities and forward planning activities such as the *Ottawa River Action Plan* to climate adaptation.

This suggests opportunity "next steps" arising from Ottawa's policy goal to "adapt to the effects of climate change" — perhaps a purposeful and coordinated approach to stormwater management adaptation spanning internal business practices, policy, design, operations, capital budget requirements, etc. — may be the next successful step in the evolution of stormwater management at the City.

Figure 2: *Ottawa River Action Plan Logo*

2.1 Is it Stormwater Management Adaptation?

Common understanding is essential to building common purpose when considering and implementing technically effective and cost effective stormwater management adaptation measures. The research identified a dichotomy in reporting on stormwater management adaptation. Some reports stated very specific progress in stormwater management adaptation whereas some reported that examples are very limited.[4] [5] This dichotomy is attributed to both a different understanding of common terminology and also that understanding and planning for stormwater management adaptation is evolving rapidly.

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[4] *Mainstreaming Climate Change Adaptation in Canadian Water Resource Management – The state of practice and strategic directions for action*, Toronto and Region Conservation Authority and ESSA Technologies, November 2012. See Section 2.1.7 Adaptation Measures http://waterandclimate.ca/WP/wp-content/uploads/2012/11/MainstreamReport_FINAL_FORMATTED_Nov17.pdf

[5] *The State of Climate Change Adaptation in the Great Lakes Region*, Rachel Gregg, Kirsten Feifel, Jessi Kershner, Jessica Hitt, Eco Adapt, October 2012. See comments in the Executive Summary that "concepts of adaptation have been well developed … must move from generalities to concrete actions, including implementation…" and note that the case studies presented in Section 4 Infrastructure are mostly planning and strategy projects http://ecoadapt.org/data/library-documents/EcoAdapt_GreatLakesAdaptation.pdf

2.1.1 Existing Measures

Research of information sources identified that some of the practices that have evolved in Ottawa as a response to long-standing problems, are of a type that are being represented as stormwater management adaptation opportunities in other jurisdictions. Sewer separation and combined sewer overflow control, sanitary disconnect, homeowner backflow prevention subsidies and maintenance hole and sewer remediation to reduce inflow are just some of the long-standing programs in Ottawa that are only now being considered and implemented in other jurisdictions as stormwater management adaptation measures. The Sandy Hill Park flood storage facility (winner of the 2009 Ontario Public Works Association Project of the Year), a Sewer Design Guideline requirement to "stress test" new storm sewer systems and Ottawa's *2012 Green Building Promotion Program*[6] are more recent examples in Ottawa of the types of projects and initiatives represented in other jurisdictions as stormwater management adaptation measures.

In considering "Is it adaptation?", some municipalities may characterize existing activities as adaptation. For instance in 2008 reflecting on existing activities, the City of Toronto concluded that existing efforts are "what other cities are doing as part of their climate change adaptation strategies" and concluded that "Toronto's Wet Weather Flow Master Plan is one of the world's leading climate change adaptation strategies being implemented today."[7] A similar question is well stated in a European Union report which asks "What is adaptation to climate change? And can we call a measure "adaptation" if the primary reasons for implementing are not related to climate change but climate change impacts are reduced and resilience enhanced?"[8]

While the City's existing practices provide some of the intended results of stormwater management adaptation including increased resiliency, to date these types of measures have not necessarily been identified as stormwater management adaptation or characterized in a coordinated manner in an overall stormwater or climate change adaptation plan by the City. As the City considers stormwater management adaptation planning, a listing of existing practices may not be sufficient to address the City's policy goals.

2.1.2 No Regret Measures

Similar to noting existing practices as adaptation, as described above, a common theme in reporting on and planning for stormwater management adaptation identified in information sources was promotion of measures that will provide benefit regardless of climate change — termed "no regret" measures. Many activities including bringing older stormwater management systems up to current design and legislative standards may also be characterized as "no regret."

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[6] *2012 Green Building Promotion Program*, City of Ottawa. The report does not make any reference to climate change or adaptation however in Sec 2.1 a stated purpose is to reduce and improve stormwater runoff. The Program document draws examples from some of the City of Toronto's programs described in this report including in Sec 10.2. http://ottawa.ca/sites/ottawa.ca/files/migrated/files/cap178204.pdf

[7] *The Plan in Action 5 Year Summary Report*, City of Toronto, 2008. See in particular p 17. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/wwfmp_5yr_implementation_report.pdf

[8] *Adaptation Inspiration Book: 22 Implemented Cases of Local Climate Change Adaptation to Inspire European Citizens*, Circle 2: Climate Impact Research & Response Coordination for a Larger Europe (EU FP7 ERA-NET) **2013**. Developed between 2010 and 2013, "For the first time a large survey has been done to collect measures that have been taken to adapt to climate change in Europe." Of the 22 case studies, 8 deal with flooding although not urban flooding. Cost estimates are provided. See p 13 for quote. http://www.circle-era.eu/np4/%7B$clientServletPath%7D/?newsId=432&fileName=BOOK_150_dpi.pdf

While promotion of no regret measures as adaptation has considerable value including contributing to the discussion of the "cost" of climate change, "no regret" measures are not a substitute for a risk and vulnerability approach to considering stormwater management adaptation including careful analysis of possible trade-offs in technical benefits of measures, overall long-term spending to reduce risks and vulnerabilities, on-going monitoring of the success of measures and the best available science regarding predictions of climate change impacts.[9]

2.1.3 Green Infrastructure

Green infrastructure and low impact development (LID)[10] have many common elements with the objectives of stormwater management adaptation; however, like existing measures and no regret actions, techniques and the promotion of green infrastructure/LID was well developed in some jurisdictions when climate change, mitigation and more recently adaptation began to be considered at the municipal level.

The City's *Infrastructure Master Plan* promotes green infrastructure however the scope of promotion is limited to giving "greater consideration" to green infrastructure in the context of capacity management of urban systems. This level of commitment is very different from other cities including a number of cities in the northeastern United States with similar climate, anticipated climate change impacts and infrastructure profiles as Ottawa. Some cities have adopted and are moving forward aggressively with green infrastructure plans as a cost effective (and some assert cost saving) plan to address infrastructure deficits, combined sewer overflows, water resource improvements and climate risks[11]. The success of these green infrastructure plans is worth noting as a possible avenue for stormwater management adaptation (and many other no regret benefits) in Ottawa and is discussed further in Section 9 *(pg. 44)*.

2.2 Proposed Scope of "Stormwater Management Adaptation"

The very nature of climate change and the City's policy objective to "take measures to adapt" suggests new measures and new approaches. As such, continuing current practices or modifying current practices to address previously established needs and priorities — the same and more of the same — may not constitute adaptation or be a sufficient response to the City's policy goals. Also, characterizing existing activities as stormwater management adaptation may result in delays to the development of a fully formed adaptation strategy or plan.

Drawing on information provided in literature sources including those best practice examples discussed in this report it, is proposed that "stormwater management adaptation" be considered as a planning process. A frequent planning process referenced in literature sources is the international ICLEI municipal adaptation planning methodology.

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[9] *No Regrets Adaptation Actions: Stop Saying That*, Shaun Martin, June 2012, Climate Prep Blog Roll, http://www.climateprep.org/2012/06/12/no-regrets-adaptation-actions-stop-saying-that/

[10] *Low Impact Development Stormwater Management Planning and Design Guide*, 2010, Credit Valley Conservation and Toronto Region Conservation Authority http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/LID%20SWM%20Guide%20-%20v1.0_2010_1_no%20appendices.pdf

[11] *Rooftops to Rivers II – Green Strategies for Controlling Stormwater and Combined Sewer Overflows*, National Resources Defense Council, 2011. This report includes case study examples from US cities and from Toronto with good summaries of the capital cost and anticipated cost savings of municipal strategies which rely on green infrastructure to achieve CSO reduction, infrastructure life cycle optimization and community quality of life improvement.http://www.nrdc.org/water/pollution/rooftopsii/files/rooftopstoriversII.pdf

Since 2010 in Canada, 17 communities have joined the ICLEI Canada “BARC” program and both Vancouver and Windsor have completed adaptation strategies under the program. (The Building Adaptive and Resilience Communities — BARC — program is a fee for service program. For cities over 200,000 population the fee is $20,000 annually[12]). For ICLEI and other organizations promoting adaptation, adaptation is a trans-disciplinary challenge affecting every aspect of municipal organization. The process definition which follows is modelled on ICLEI definitions and provides an example which may be appropriate for the City:

> *Stormwater management adaptation consists of co-ordinated structural and non-structural changes in practices and approaches to stormwater management developed within an integrated social, environmental and fiscal sustainability focused municipal planning process for climate change.*

Municipalities are acting on a wide variety of fronts undertaking activities that are all valuable individual elements in the overall approach to stormwater management adaptation. The research presented in this report indicates a wide variety of approaches and measures and includes experiences in overcoming constraints to change which may advise “next steps” in addressing the City’s policy goals to adapt to climate change and improve stormwater management.

2.2.1 Framework Themes

Research objectives include identification of a number of themes under which to examine climate adaptation best practice examples and assist in considering next steps to meet the policy goals. Research of literature, examples of municipal adaptation planning and consideration of the City’s existing activities suggests that the following themes may constitute a “framework”:

- Updating Design Tools – the IDF Curve
- Risk and Vulnerability Assessments
- Integrating Stormwater Management Adaptation into Modeling Tools
- Protecting Infrastructure in Design Exceedence Events
- Urban Streets
- Green Infrastructure and LID
- Stormwater Management Facilities
- Operational Stormwater Management Adaptation Measures

Examples of best practices in stormwater management adaptation including under the above themes are provided in Part B *(pg. 27)*.

2.3 Anticipated Local Weather Changes

An essential element of a framework for considering measures to adapt to the effects of climate change is understanding how large scale average changes in climate will manifest themselves in terms of daily and local weather events. It is those weather events which provide the underlying basis for municipal scale actions.

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[12] ICLEI Canada Building Adaptive and Resilient Communities Web site http://icleicanada.org/programs/adaptation/barc

Anticipated changes in the local climate have previously been summarized in the City's report entitled Climate Change Adaptation Process.[13]

- Ouranos, an international consortium focused on climate sciences, impacts and adaptation, has run numerous climate models for different regions of Canada. The Province of Ontario has also run models to project climate change for Ontario. These models project the following conditions for the Ottawa region:
    - From Ouranos' climate modeling, summers in Ottawa are projected to be 4.5-5 °C warmer and precipitation 10 per cent higher between 2080-2100 should no mitigation of greenhouse gases occurs. In winter, the average temperature could be 6-7°C warmer and precipitation 24-35 per cent higher. Should some mitigation actions be taken, summers could be 2-3°C warmer with up to a five-per cent increase in precipitation and winters could be 3-4°C warmer on average with a 10-20 per cent increase in precipitation.
    - Projections for 2014-2070 from the Provincial government estimate (in the absence of any mitigation) summer temperatures could increase by 2-3°C in Eastern Ontario, with increases of up to 4°C in winter, and increases in precipitation for both seasons of up to 10 per cent. Later forecasts for 2071-2100 are similar to Ouranos' projections but predict lower precipitation increases. (See [14] and [15] for other analyses which make similar predictions).

Is it weather or climate? Weather is the mix of events that happen each day and at a local level. Climate is the average weather pattern in a place over many years.

The anticipated changes summarized above, reflect information provided in other local, regional and global predictions of changes to precipitation patterns including in the following documents:

- In 2008 the Mississippi Valley Conservation Authority held a two day workshop titled *Weathering the Change: Adapting to Climate Change in the Mississippi Valley*[16] to discuss climate change in the watershed including stormwater management adaptation. The workshop identified and discussed anticipated changes and measures to adapt to those changes including measures related to possible increased flooding (including during the winter), lowered groundwater levels resulting in increased temperatures in surface waters (due to less base flow) and impacts on wells and water

Same as 2 above http://ottawa.ca/calendar/ottawa/citycouncil/occ/2008/08-28/pec/ACS2008-PTE-ECO-0013.htm[14] *Ontario Centre for Climate Impacts and Adaptation Resources Climate Trends, Historical Climate Trends for Ottawa CDA*, Ontario, 2011. Graphs showing data trends for temperature and precipitation from 1890 – 2010. http://www.climateontario.ca/doc/publications/HistoricalClimateTrendsForOttawaCDA.pdf

[14] *Ontario Centre for Climate Impacts and Adaptation Resources Climate Trends, Historical Climate Trends for Ottawa CDA*, Ontario, 2011. Graphs showing data trends for temperature and precipitation from 1890 – 2010. http://www.climateontario.ca/doc/publications/HistoricalClimateTrendsForOttawaCDA.pdf

[15] Climate Change Scenario over Ontario Based on the Canadian Regional Climate Model (CRCM4.2), Line Bourdages, David Huard, Ouranos, May 2010. A standardized climate model "downscaled" based on the weather data from the Ottawa International Airport. http://www.ouranos.ca/Ontario/Results_html/Rapport.pdf

[16] *Weathering the Change: Adapting to Climate Change in the Mississippi Valley*, Mississippi Valley Conservation and the Mississippi Valley Field Naturalists workshop, 2008. All presentations at the workshop are available at http://www.mvc.on.ca/conservation-education/climate-change/81-public-workshops-

quality. The lead participants in the workshop subsequently published a summary report[17];

- Ontario's *Climate Ready* report[18] describes increasing precipitation and changing precipitation patterns along with increasing temperatures and resulting increased occurrences of major events as some of the risks which need to be addressed through stormwater management adaptation.[19] (See also the interactive Ministry of Natural Resources Climate Change Mapping tool.[20]);

- Natural Resources Canada reports on the results of the Intergovernmental Panel on Climate Change in *Climate Change Impacts and Stormwater Adaptation A Canadian Perspective*[21] noting that while uncertainty exists and local conditions will vary, more frequent and intense weather events related to stormwater management (both precipitation and drought) and the resulting stress on infrastructure are to be expected;

- The University of Waterloo and the Intact Foundation's *Climate Change Adaptation: A Priorities Plan for Canada* describes Canada-wide climate trends related to heat stress and precipitation similar to the above noted changes. The report includes detailed perspectives on urban infrastructure including that "it is critical that stormwater adaptation … be applied using a 'no-regrets' framework" (see pg. 27 of the referenced report). The report characterizes no-regrets as "actions that improve infrastructure resiliency and generate community benefits, whether anticipated climate change materializes or not."[22]

2.4 Stormwater Infrastructure Components and Stress

An essential element of the framework for considering measures to adapt to the effects of climate change is an understanding and inventory of the City's physical stormwater infrastructure as well as the municipal management tools which can be used to achieve stormwater management adaptation. These are two of the main elements of the well regarded PIEVC process for assessing infrastructure risk and vulnerability to climate change.[23]

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[17] *From Impacts Toward Adaptation – Mississippi Watershed in a Changing Climate*, Paul Egginton, Beth Lavender, 2008 A report summarizing the workshop noted above. http://mvfn.ca/wordpress/wp-content/uploads/2008/11/from-impacts-towards-adaptation-mississippi-watershed-in-a-changing-climate.pdf

[18] *Climate Ready – Ontario's Adaptation Strategy and Action Plan 2011 – 2014*, Government of Ontario, 2011. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_085423.pdf

[19] *Climate Change Projections for Ontario: Practical information for policy makers and planners*, Ministry of Natural Resources, 2007. http://www.mnr.gov.on.ca/en/Business/OFRI/Publication/MNR_E005587P.html

[20] Web based climate change mapping tool for Ontario, Ministry of Natural Resources. http://www.mnr.gov.on.ca/en/Business/ClimateChange/1ColumnSubPage/STDPROD_093198.html

[21] *Climate Change Impacts and Adaptation A Canadian Perspective,* Natural Resources Canada, 2004. See Section titled "Water Resources". http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.earth-sciences/files/pdf/perspective/pdf/report_e.pdf

[22] *Climate Change Adaptation: A Priorities Plan for Canada – Report of the Climate Change Adaptation Project (Canada),* Dr. Blair Feltmate, Chair, Dr. Jason Thistlethwaite, Director, Intact Foundation and University of Waterloo, 2011 https://uwaterloo.ca/environment/sites/ca.environment/files/uploads/files/CCAP-Report-30May-Final.pdf

[23] Public Infrastructure Engineering Vulnerability Committee Web site http://www.pievc.ca/e/index_.cfm

Figure 3: *NE Siskiyou Green Street Retrofit Project, Portland, Oregon, U.S.A.*

2.4.1 Stormwater Infrastructure

Ottawa has a large and complex physical infrastructure dedicated to stormwater management. The City's *Wet Weather Infrastructure Master Plan* promotes updating of the *Sewer Design Guidelines* to ensure that designs are resilient to climate change. Each component may be impacted by climate change and offers opportunities for stormwater management adaptation measures.

Conveyance systems are:

- A combined sewer system in the central area;
- Regional trunk sanitary sewers that respond to wet weather events;
- Partially separated sewer systems of varying design capacities;
- Fully separated sewer systems of varying design capacities;
- Engineered major overland flow paths;
- Stormwater pumping facilities;
- Urban and suburban roadside ditches;
- Natural watercourses and drains;
- Curbs and gutters, catchbasins and maintenance holes of varying designs.

Facilities:

- Stormwater outfalls to streams and rivers of all sizes including submerged and seasonally submerged outfalls;
- Stormwater management ponds of varying types and designs;
- Engineered stormwater surface detention facilities (e.g., sawtooth patterns in road design);
- Engineered infiltration systems;
- Underground storage tanks;
- Temporary seasonal flood protection measures.

Identification, inventory and performance/condition assessment of Ottawa's existing infrastructure is achieved through the Infrastructure Services Department's inventory, condition assessment and priorities planning process including condition rating, mapping and priority planning database tools.

Inventory along with "risk assessments" and "vulnerability assessments", noted in Recommendation #6-1-5 of the City's *Wet Weather Infrastructure Master Plan*, were a key stormwater management adaptation framework element identified in the information sources reviewed for this project. For example:

- In 2001, the City participated in a research project on climate change and greenfield urban stormwater infrastructure contributing inventory data from the newly developing Central Park subdivision[24]. The report anticipated a climate change scenario, used current design practices and sewer modelling and predicted resulting stresses related to capacity for conveyance. Also, the report determined that a stormwater management adaptation measure to increase pipe size in order to protect level of service under the selected climate change scenario would result in a 2% increase in pipe related costs. (This finding has relevance to the "costs of stormwater management adaptation" discussed throughout this report. While this example is derived from a greenfield development, existing stormwater management deficiencies along with aging infrastructure already present significant fiscal and liability challenges. Life cycle rehabilitation of existing infrastructure, while having construction factors additional to greenfield development, may provide opportunities for adaptation measures like capacity improvements and may provide a "no regret" stormwater management adaptation measure at costs similar to those determined in this example.)

- Recently, "risk and vulnerability" assessments including application of the Engineers Canada PIEVC methodology have become a well recognized first step in stormwater management adaptation planning for communities. (A number of assessments have been completed through the Federally funded Regional Stormwater Adaptation Collaborative.) A recent example, Welland's Stormwater and Wastewater Infrastructure Assessment completed in February 2012[25] (see a more detailed summary of this project in Section 4.1 *pg. 33*), offers an example to the City on the scope of such an assessment, along with the types of conclusions and benefits that are generated by this type of assessment. Welland's assessment notes individual system components, a number of climate variables and the impact of the variable on a number of performance criteria including cost. The table below includes sample information from Table 6.1 of Welland's infrastructure assessment report.

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

[25] *City of Welland Stormwater and Wastewater Infrastructure Assessment Technical Report*, City of Welland and AMEC Environment and Infrastructure, February 2012. See, in particular, Table 6.1. http://www.pievc.ca/e/casedocs/welland/Final%20Report_Town_of_Welland.pdf

__Table 1:__ Sample information from Welland's Infrastructure Report

Infrastructure Component	Climate Variable	Design	Functionality	Performance	Insurance	Cost Range to Address Risk	Implementation time frame
Catch basins and pipes	Heavy rain and a 5 day rainfall event	x	x	x	x	$$	Short
SWM Facilities	Heat wave	x	x	x	x	$	Medium
	Heavy rain	x	x	x	x	$$	Short
	Snow accumulation	x	x	x	x	$	Medium
Oil grit separators	Heavy rain	x	x	x		$	Medium

2.4.2 Stormwater Management Adaptation Administration Tools

In addition to physical infrastructure, the City has a range of programs and management tools which may provide avenues to implement new stormwater management adaptation measures and initiatives:

- *Official Plan* policies for stormwater management and stormwater management adaptation;
- Subwatershed planning and community design plans directed to consider and advise on stormwater management adaptation issues and opportunities;
- Zoning bylaws which consider built form and lot coverage issues;
- Urban design guidelines which promote or require consideration of stormwater management adaptation measures;
- Sewer design guidelines which provide specific direction or advise consideration of stormwater adaptation measures;
- Infrastructure inventory programs including data collection and work planning which considers climate impacts and stormwater management adaptation opportunities;
- Operation and maintenance practices in consideration of stormwater adaptation measures;
- Programming to address historic stormwater management issues including the *Ottawa River Action Plan*;
- Tax and rate incentive tools as motivators for property owners and developers to align and help achieve stormwater management adaptation objectives;
- Municipal public education initiatives to inform residents and businesses regarding private property opportunities for stormwater management adaptation.

2.5 Senior Government Direction

An important element of a framework for considering measures to adapt to the effects of climate change is direction from senior governments. Municipalities often rely on senior governments for policies and legislation and in some cases financial resources to address municipal challenges. While the Provincial and Federal governments undertake and fund climate adaptation initiatives, some of the information sources reviewed as part of this project commented that more direction and financial assistance is needed from senior governments.[26]

2.5.1 Province of Ontario

2.5.1.1 Provincial Policy Statement 2005

The *Provincial Policy Statement 2005* (PPS) provides direction to Ontario's municipalities. While using a variety of words to provide that direction including "promote," "recognize" and "consider", municipalities are required to "be consistent with" the PPS in all decision making.

Whereas the current PPS contains only one reference to climate change,[27] draft changes released by the Province in November 2012 make over 10 references to climate, changing climate, stormwater management adaptation and resilience[28] including:

- Policy 1.6.1 requires that provision of public infrastructure considers the impacts of climate change;
- Policy 1.6.2 encourages the use of green infrastructure to augment traditional infrastructure;
- Policy 1.7.1 notes that long term economic prosperity is to be ensured through minimizing the negative impacts of climate change;
- Policy 1.8.1 directs municipalities to support climate change stormwater management adaptation through decisions on land use and development patterns;
- Policy 3.1.3 directs municipalities to consider increase in risk associated with hazard lands resulting from climate change.

The draft changes to the PPS also include a new policy providing direction on planning for stormwater management and detailing objectives which, while not specifically tied to stormwater management adaptation in the draft policy, include objectives typically related to stormwater management adaptation planning, specifically policies d) and e) below:

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[26] *Preparing for the Impacts of Climate Change on Stormwater and Floodplain Management: A Review of Adaptation Plans and Practices*, Toronto and Region Conservation Authority and Region of Peel, February **2009**. The report asserts that in 2009 there were no Federal or Provincial initiatives that provide guidance or insights on adaptation in stormwater (page 1). Also at that time "No examples were found in Canada … assessment and adaptation planning … specific to stormwater … (on pg. 2) http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/95903b5b-93a9-4cc0-8a13-7580fdd2b7c8.pdf

[27] *Provincial Policy Statement 2005*. See Policy 1.1.3.2.a.3 where the reference is related to land use patterns and air quality http://www.mah.gov.on.ca/Page1485.aspx

[28] Draft changes to the *Provincial Policy Statement 2005*. http://www.mah.gov.on.ca/Page9990.aspx#1.6

Draft PPS Policy 1.6.5.7 Planning for stormwater management shall:

a) minimize, or, where possible, prevent increases in contaminant loads;
b) minimize change in water balance and erosion;
c) not increase risks to human health and safety and property damage;
d) maintain or increase the extent and function of vegetative and pervious surfaces; and
e) promote stormwater management best practices, including stormwater attenuation and reuse.

2.5.1.2 The Provincial Government's Stormwater Management Adaptation Planning

The Province of Ontario has undertaken a number of initiatives related to policy and planning for climate change, mitigation and stormwater management adaptation generally focussing on the Provincial role in energy production and management, the Provincial role in stewardship of land and water resources and the Provincial role in transportation networks and efficiency. The Province has also placed a priority on working collaboratively with municipalities in order to assist their efforts to adapt to climate change.

Climate Ready: Ontario's Adaptation Strategy and Action Plan 2011 - 2014[29] released April 2011 is the Province's current statement on stormwater management adaptation plans and actions. The report includes five "Goals" and thirty-seven "Actions" including actions which provide advice and direction to municipalities implementing stormwater management adaptation including:

Action 10: Develop Guidance for Stormwater Management

The Province appointed an expert panel on climate change whose November 2009 Report[30] has advised the Action Plan. Information presented in the report includes:

- Section 2.2.3 Infrastructure notes flood events in Toronto and Peterborough to illustrate risk and identifies that most of Ontario's stormwater infrastructure was built before modern design considerations for stormwater and the impacts of climate change were evident. The report goes on to recognize that infrastructure renewal including Federal Infrastructure Stimulus initiatives provide opportunity to incorporate stormwater management adaptation measures into stormwater infrastructure;

- The Ministry of the Environment completed a policy review of municipal stormwater management in light of climate change[31] in March 2010 which has advised the Action Plan. Conclusions of the review include:

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[29] *Climate Ready: Ontario's Adaptation Strategy and Action Plan 2011 – 2014*, Province of Ontario, 2011. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_085423.pdf

[30] *Adapting to Climate Change in Ontario, Toward the Design and Implementation of a Strategy and Action Plan, The Expert Panel on Climate Change Adaptation Report to the Minister of the Environment*, November 2009. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079212.pdf

[31] *Policy Review Of Municipal Stormwater Management In Light Of Climate Change*, Ministry of the Environment, 2010. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_082453.pdf

- A MOE policy framework is needed to support municipal actions to adapt to climate change;

- The 2003 *Stormwater Management Planning and Design Manual* requires updating;

- Noting a number of Provincial ministries have responsibilities related to stormwater management, the policy review recommends ministries work with municipalities and conservation authorities to seek solutions for resilient municipal stormwater management systems that are adaptive to climate change.

Action 26: Update Intensity Duration Frequency Curves

In collaboration with the University of Waterloo, the Ministry of Transportation has developed a Web based tool for obtaining IDF curves that has incorporated recent data and a statistical evaluation methodology developed in consideration of design needs and objectives, climate change and peak design events. The tool can be accessed at: http://www.mto.gov.on.ca/IDF_Curves/ (See also [32].)

Action 35: Establish and Lead Ontario's Regional Adaptation Collaborative

This commitment to partner to establish Ontario's Regional Adaptation Collaborative (RAC) under the Natural Resources Canada program has led to the completion of a number of stormwater management adaptation demonstration projects through the term of Ontario's initiative[33] January 2011 to March 2012 including[34]:

- Climate Change and Toronto Culverts: An analysis of three road culverts using the PIEVC assessment tool;

- Risks to Welland's Water Infrastructure from Climate Change: An analysis of stormwater infrastructure using the PIEVC assessment tool;

- Pioneer Park Stormwater Management Rehabilitation: A Case Study of the project recounting stormwater management adaptation measures incorporated into rehabilitation of an existing facility.

Ready for Change? An Assessment of Ontario's Adaptation Strategy[35] is the Ontario Environment Commissioner's analysis of the Province's action plan. Overall, the analysis concludes that "Climate Ready represents a significant contribution towards a growing national and international policy movement designed to better prepare us for the anticipated impacts of climate change." Note that the Commissioner's conclusion regarding a "growing policy

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[32] *Let it Rain – New Design Support Tool to Identify Rainfall Intensity Duration Frequency Across Ontario*, MTO RoadTalk Article 3, Fall 2010. http://www.mto.gov.on.ca/english/transtek/roadtalk/rt16-4/RT16-4.pdf

[33] Personal Communication: Industry experts contacted during this project noted that they understood funding has been provided to complete two additional case studies in each of the RAC regions on Canada.

[34] NRCan Web site providing links to all of the Ontario RAC projects. http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/case-study/11981

[35] *Ready for Change? An Assessment of Ontario's Adaptation Strategy*, Environment Commissioner of Ontario's Special Report to the Legislative Assembly of Ontario, March 2012 http://www.eco.on.ca/uploads/Reports-special/2012-Adaptation/Ready-for-Change-bookmarked.pdf

movement" is indicative of the state of practice including that there are not today numerous examples of fully implemented stormwater management adaptation measures or programs in municipalities in Ontario.

2.5.2 Federal Government

The Federal Government has in recent years focused its efforts related to climate change, including stormwater management adaptation, on projects and funding aimed at providing credible, scientifically sound information to support stormwater management adaptation planning and decision-making. Efforts have also focused on helping prepare for climate-related impacts, for example, the work of Environment Canada's Canadian Climate Change Scenarios Network[36] provision of raw data and maintenance of spatial downscaling tools.

For direct relevance to stormwater adaptation, the unique Natural Resources Canada (NRCan) three-year (2010-2013) Regional Adaptation Collaborative (RAC) resulted in a number of case studies aimed at helping communities consider stormwater management adaptation (see all Ontario RAC projects[37]). Some of the case studies are discussed elsewhere in this report including Welland's PIEVC assessment of stormwater infrastructure. Other RAC projects in Ontario include:

- Climate Change and Toronto Culverts (2011): Three road culverts were evaluated using the PIEVC infrastructure risk assessment protocol in a first step toward applying adaptive management for all culverts;
- Vulnerability of Sanitary Sewer System – Town of Prescott (2012): Areas and operations of the Town's sanitary sewage system that may be at increased risk of failure and/or damage due to potential change in climate were identified with the PIEVC infrastructure risk assessment protocol.

In 2012, the focus of NRCan activities transitioned to enhancing competitiveness by equipping decision-makers in regions and natural resource industries with tools and information needed to understand and adapt to the effects of a changing climate. In April 2013 the Climate Change Impacts and Adaptation Division of NRCan issued a Request for Proposals for cost-shared projects that address the Governments priorities in six areas: Coastal Management, Economics, Energy, Mining, Measuring Progress and the North.[38] The project descriptions suggest the new program will not have the same focus on communities or relevance to stormwater management adaptation as the RAC program.

2.6 Stormwater Adaptation Advocacy in Ontario

There are a number of resources available to the City that offer advice and insight regarding the implementation of stormwater management adaptation measures.

[36] Canadian Climate Change Scenarios Network Web site http://www.cccsn.ec.gc.ca/index.php?page=main

[37] Natural Resources Canada Ontario RAC Studies http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/case-study/11981

[38] *Natural Resources Canada, Enhancing Competitiveness in a Changing Climate, Call for Proposals* issued 15 April 2013. http://www.nrcan.gc.ca/earth-sciences/sites/www.nrcan.gc.ca.earth-sciences/files/pdf/change/pdf/call_apr_2013-eng.pdf

2.6.1 Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)

http://www.climateontario.ca

OCCIAR is a university-based resource hub for researchers and stakeholders searching for information on climate change impacts and adaptation. In addition to a comprehensive resource library and case study library, the Centre manages a number of projects including the Climate Change Community of Practice — an interactive online community that brings people together to discuss the latest research and thinking around climate change stormwater management adaptation in Canada and internationally. Sign in required at http://www.ccstormwater.ca/?signin and examples of Web content include:

- An events listing including the World Conference on Disaster Management held in Toronto June 23, 2013;
- A listing of Webinars including the recent (April 16, 2013) Webinar titled *Storm Warning: The Loss of Hydrologic Stationarity & Its Consequences* by Bob Sanford, the EPCOR Chair of the Canadian Partnership Initiative in support of United Nations "Water for Life" Decade;
- A comprehensive Links page including international resources.

2.6.2 Clean Air Partnership (Climate adaptation initiatives)

http://www.cleanairpartnership.org

Clean Air Partnership (CAP) undertakes a number of activities related to climate adaptation and provides resources including case studies reporting on stormwater management adaptation. The July 2012 report *Accelerating Stormwater Adaptation in Canadian Communities*[39] notes that since commencing work on climate change adaptation CAP has identified that there have been few publicized examples of on-going municipal stormwater management adaptation practices. The report includes a number of case studies demonstrating stormwater management adaptation as well as recordings of Webinars for those projects.

2.6.3 Toronto and Region Conservation Authority (TRCA)

The TRCA along with its municipal and regional partners have been strong proponents of stormwater management adaptation. Their 2009 report *Preparing for the Impacts of Climate Change on Stormwater and Floodplain Management: A Review of Stormwater Adaptation Plans and Practices*[40] found that a number of municipalities and agencies had commenced planning for stormwater adaptation and a few communities had commenced some actions, but overall there was a lack of direction and tools advising municipalities and little communication between communities on successes.

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[39] Clean Air Partnership *Accelerating Climate Change Adaptation in Canadian Municipalities* Web site including the 2012 report, case studies and Webinars. http://www.cleanairpartnership.org/accelerating_climate_change_adaptation

[40] *Preparing for the Impacts of Climate Change on Stormwater and Flooplain Management: A Review of Adaptation Plans and Practices*, Toronto and Region Conservations Authority and Region of Peel, February 2009. See Conclusions section. http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/95903b5b-93a9-4cc0-8a13-7580fdd2b7c8.pdf

TRCA updated the study in March 2012 with their *Mainstream: The National Water Adaptation to Climate Change Forum*[41] and the associated development of the *National Compendium of Water Adaptation Knowledge*.[42] The Forum along with the compendium drew conclusions similar to the 2009 report noting that many communities had invested in plans and increasingly in vulnerability assessments but practical implementation of stormwater management adaptation remains constrained by a number of factors including uncertainty regarding climate change, existing regulations, lack of financial resources and the constraints of single-purpose funding streams and a lack of awareness of or expectations for adaptive measures.

[41] Mainstream: The National Water Adaptation to Climate Change Forum, organized by the Toronto and Region Conservation Authority, March 2012. http://www.trca.on.ca/dotAsset/133847.pdf

[42] National Compendium of Water Adaptation Knowledge Web site. Requires sign in to access resources. http://waterandclimate.ca/wp/

Adaptive Approaches in Stormwater Management
PART B – Examples of Municipal Action

As noted earlier, an objective of this review is to establish candidate framework elements for the City to consider in moving forward to achieve the policy goals of adapting to the effects of climate change and improving stormwater management. Consideration of information provided in studies, examples of municipal action and understanding of existing initiatives at the City has suggested the following themes:

- Updating Design Tools – the IDF Curve *(Section 3, pg. 28)*;
- Risk and Vulnerability Assessments *(Section 4, pg. 32)*;
- Integrating Stormwater Management Adaptation into Modeling Tools *(Section 5, pg. 35)*;
- Protecting Infrastructure in Design Exceedence Events *(Section 6, pg. 37)*;
- Urban Streets *(Section 7, pg. 39)*;
- Green Infrastructure and LID *(Section 8, pg. 41)*;
- Stormwater Management Facilities *(Section 9, pg. 44)*;
- Operational Stormwater Management Adaptation Measures *(Section 10, pg. 48)*.

An additional and important theme — the anticipated cost of stormwater management adaptation — is discussed in Section 12 *(pg. 57)*.

In the sections below, one or more examples have been selected under each framework theme based on a number of criteria including:

- to provide a spectrum of measures,
- to compile "best practice" examples, in some cases based on awards; and
- to illustrate adaptation measures which may be considered by the City.

Some of the examples are similar to measures undertaken in Ottawa and those examples are provided if they have been characterized as adaptation by the municipality or as measures within a municipal adaptation plan. In each case, references to source materials are provided so that further information about these examples can be researched independently. (***NOTE:*** some of the content in Case Studies *(pg. 70)* has been copied from research sources. Footer references to the research sources have been provided as content source attribution.)

3.0 Updating Design Tools – the IDF Curve

The Intensity-Duration-Frequency (IDF) curve is a key element in stormwater management planning and design and, based on the municipal practices review conducted in this study, a principle stormwater management adaptation tool for municipalities. The City's "stress test" practice of increasing the rainfall intensity in the City's design curves by 20% is an example of using the IDF curves as a stormwater management adaptation tool.

Literature indicates municipalities are updating the IDF curve in a number of ways and primarily ensuring that all available data is used and that the most recent data is included in curve development. Updating IDF curves using the best set of historical data — an approach which presumes hydrologic stationarity even while acknowledging change — may not be an appropriate approach to stormwater management adaptation. Some municipalities are using climate models and future scenarios to anticipate both weather changes and risks to infrastructure.

The Standards Council of Canada's *Technical Guide Development, interpretation, and use of rainfall intensity-duration-frequency (IDF) information: Guideline for Canadian water resources practitioners*[43] is a resource that "provides some of the first formal evidence and advice for the incorporation of forward-looking information into IDF values and related design activities, such that the effects of climate change can be better considered."

3.1 City of Guelph IDF Update (2007)

When updating their IDF curves in 2007, Guelph considered the possible impacts of "global warming."[44]

The rationale for the IDF curves update included that the existing curves were based on a limited data set (16 years) and as ponding of stormwater and some flooding had been observed, a curve update was appropriate in advance of a major capital upgrade program in Ward 1 in Guelph.

Guelph used the Consolidated Frequency Analysis tool developed by Environment Canada, the 3LN statistical transformation method to extrapolate data beyond observed values, the least squares regression analysis Miduss Curvefit and a 43 year data set to develop new IDF curves. The results of the analysis indicated that in general the new rainfall volumes and depths were lower than the existing curves for frequent events (10% - 15%) and somewhat higher for longer durations (5% - 7% for the 50 and 100 year storm for 12 and 24 hour durations).

Guelph considered climate change and design impacts in the update process, concluding that literature available at the time suggested a 15% increase in rainfall depth resulting from climate change. In comparison to the results of the IDF update process which identified that new curves would be lower than existing curves for the short duration events used to design the minor

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[43] *Technical Guide Development, interpretation, and use of rainfall intensity-duration-frequency (IDF) information: Guideline for Canadian water resources practitioners, Document PLUS 4013-12,* Standards Council of Canada, 2012. http://www.scc.ca/en/standardsdb/standards/26336

[44] *Frequency Analysis of Maximum Rainfall and IDF Design Curve Update*, Earthtech Canada Inc. for the City of Guelph, 2007, http://guelph.ca/wp-content/uploads/SMMP-Appendix_E_Combined_IDF_Report.pdf

drainage system, Guelph concluded to continue to use the existing curves and consider the "overdesign" as a climate adaptation measure (and also a benefit of consistency with past practices). Guelph also noted some resilience resulting from the use of standard pipe sizes which are generally sized up from design requirements. Regarding design of stormwater management facilities, Guelph noted use of Table 3.1 in the MOE stormwater manual will continue and therefore facilities would still be designed on the same basis. A possible increase in bypass of facilities is noted and it is suggested by Guelph that MOE may need to revise Table 3.1 to address climate change.

3.2 City of London and University of Western Ontario IDF Update

London's Thames River has a history of serious floods. In 2007 London partnered with the University of Western Ontario (UWO) to complete a study on the river's vulnerability to flooding and concluded that the intensity and frequency of serious floods would increase as a result of climate change. In response to the UWO findings, London commissioned the University to analyze the intensity and duration of annual rainfall as a starting point from which to inform the design of stormwater infrastructure and the protection of buildings. The analysis focussed on short duration events and included development of an original procedure to analyse data — a "non-parametric K-Nearest Neighbour weather generator algorithm" along with a "sophisticated shuffling mechanism" (from the Executive Summary).[45] The update process compared London's existing IDF curves and modified curves based on a more current data set with curves based on a modified data set generated through a Global Circulation Model for climate change.

The simulation results indicated that rainfall magnitude would increase for all durations and return periods from between 10.7% and 34.9% with an average value of 21%. City Council, in considering the recommendations of the report, approved an increase of London's IDF curves by 21%. Since the change, London has commenced a review of the performance risks for existing stormwater management facilities. All subwatershed studies and existing stormwater facility designs are under review towards recommendations for action.[46]

3.3 Ontario Ministry of Transportation IDF Update and Web Tool

The Ontario Ministry of Transportation in collaboration with the University of Waterloo has developed a Web tool which generates IDF curves for any project location or area in Ontario incorporating the most recent information available regarding rainfall frequencies and intensities.[47] The Ministry project had two objectives — to promote use of current data and to address needs for projects in remote locations where station precipitation data may not be available close by. This last factor mandated an alternative approach to interpolation and analysis of data from multiple stations.

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[45] *Updated rainfall intensity duration frequency curves for the City of London under the changing climate*, Slobodan P. Simonovic and Angela Peck, University of Western Ontario, 2010 http://www.london.ca/Sewer_and_Wastewater/pdfs/IDFReportFinal.pdf

[46] Personal communication with the City's consultant completing the analysis.

[47] *Let it Rain!,* Road Talk Article 3, Fall 2010, Ministry of Transportation http://www.mto.gov.on.ca/english/transtek/roadtalk/rt16-4/RT16-4.pdf

Preliminary tests using an Inverse-Weighted-Distance analysis indicated that physiographic factors had an impact on IDF curve statistics. As a result, the tool includes physiographic characteristics as independent variables in regression analysis of station statistics. The tool also weighs station data based on length of record and all results report a statistical error value.

Regarding the frequency and intensity of extreme storms, the project technical report[48] comments on the analysis of all station data in Ontario that there is an equivalent trend of stations recording lower than average values and states “the impression that the occurrence of extreme storms is increasing is more likely to be the consequence of more observations.” (pg. 9 of the above report) (Access the tool at: http://www.mto.gov.on.ca/IDF_Curves/front.php.)

3.4 Development of Future IDF Curves for Welland (2012)

In association with a PIEVC risk assessment of stormwater infrastructure, Welland undertook a review of IDF curves.[49] The motivation for the review was unique — a preventative investigation of infrastructure performance based on expected precipitation characteristics in two future scenarios — 2020 and 2050. The 2050 time line was selected as a time over which all of Welland’s infrastructure would be replaced through ongoing life cycle investments. The methodology used in Welland was to apply Global Climate Models to the historical series of temperature and precipitation data to arrive at new data series. 112 alternatives — combinations of 3 greenhouse gas emission scenarios, 16 Global Climate Models and a set of well researched downscale projections — were applied to the historical data and each resulting data set was analysed using a conventional statistical process to arrive at IDF curves. The 112 IDF curves were then aggregated to a mean, a maximum and a 90th percentile non-exceedence value for each duration and intensity. The methodology employed an approach to extreme value statistics which, at the time, was unpublished.

As was determined in the Guelph analysis, comparison of the curves originally established in 1963 to a current data set showed that the 1963 curves are conservative. In fact, comparison to the two future modelled scenarios showed that the 1963 curves are conservative for many duration/return intervals. In conclusion, the report notes that continued use of the 1963 curves is important, but that interpretation and use of statistical analyses should be advised by more basic questions:

> *An analysis may indicate a statistical rationale for change, but have the existing curves served to provide sufficient property protection? Is there evidence that current practice is substantially under or over protective?*

- There is significant uncertainty in statistical analysis and scientific understanding of climate change — a delay in action may actually provide benefit if new methods or information become available;

[48] *Renewal of MTO IDF Curves*, 2010, Authors Drs. Ric Soulis, Frank Seglenieks, Don Burn and Jenn Hale, Daniel Princz, Sophie Xiong, University of Waterloo Available as a .pdf from MTO Library Services – Google title

[49] *Development of Projected Intensity-Duration-Frequency Curves for Welland, Ontario, Canada*, AMEC Environment & Infrastructure, 2012 http://www.welland.ca/Eng/pdfs/AppC-WellandReportFinal.pdf

- Anecdotal information from recent storm events may be of considerable value;
- Severe events can be very isolated and that characteristic may increase with change — aggregate analysis of station data may still underestimate the types of events which may result in significant damages.

3.5 Key Insights

- Review and update of IDF curves is being undertaken by a number of municipalities using a variety of methodologies;
- Existing curves may be conservative — an update process does not necessarily result in an increase in the curves;
- Historical analysis assumes climate variation is “stationary,” in other words, climate data falls within a consistent range of parameters without significant change in long-term trends. However, with the effects of climate change, it is anticipated that historic precipitation trends will no longer be a reliable indicator of future precipitation trends.
- While there is some uncertainty in translating the many global climate models to local conditions, use of climate models to generate future patterns of rainfall and the resulting IDF curves is a means to consider adaptation measures.

4.0 Risk and Vulnerability Assessments

Risk and vulnerability assessments are increasingly being recognized as an appropriate first step in stormwater and climate change adaptation planning and in particular for assessments of infrastructure related risks. Recommendations in the City's *Wet Weather Infrastructure Master Plan* point to vulnerability assessments. Such assessments are particularly important to planning in a constrained financial environment including for the significant investments which are made in physical infrastructure.

The City is familiar with risk and vulnerability analysis. The *Choosing our Futures* initiatives in 2011 and 2012 prepared three final reports including *Ottawa's Long Term Risk Prevention and Mitigation Plan*[50]. The Plan includes climate change as just one of the risks facing the City (others include population dynamics and a shifting global economy) and provides a discussion of what constitutes risk, vulnerability and resilience. The Plan promotes adaptation as a means to reduce risk and stormwater management best practices as a "lever" (Table 1, pg. 26 of the *Mitigation Plan*) to address risks. Another initiative in Ottawa related to risk is the Conservation Authorities' initiative in 2013 to update delineation and designation of flood prone areas.[51]

While there are a number of methodologies for risk and vulnerability assessment, the PIEVC Protocol developed by Engineers Canada in 2005 and updated in 2009 and 2011 (Version 10[52]) has been specifically developed to consider climate risks to public infrastructure.[53] Stormwater was one of the first categories of infrastructure which the Committee focused on. As of November 2012, thirty two communities had used the Protocol to undertake assessments, seven of which focus on stormwater management (see Case Studies under the Documents tab on the PIEVC Web site).

The PIEVC methodology for infrastructure analysis is based on a concept of total load effects, vulnerability and risk. Each infrastructure component is assessed based on existing load, future load due to conventional factors such as population growth and increased/changed loads predicted to result from climate change. When total load exceeds the capacity of the infrastructure component to withstand that load, the infrastructure component is considered vulnerable. Once the infrastructure component is determined to be vulnerable, the likelihood of the various load effects is considered to establish risk. Various combinations result, as an example, from highly vulnerable but very low risk to low vulnerability but very high risk.

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[50] *Ottawa's Long Term Risk Prevention and Mitigation Plan*, City of Ottawa, 2012. Note the other plans prepared as part of Choosing our Future are the *Sustainability and Resilience Plan* and the *Energy and Emissions Plan*. http://ottawa.ca/calendar/ottawa/citycouncil/ec/2012/02-21/03-Document%205%20-%20Ottawa_Risk%20Plan_FINAL%5B1%5D.pdf

[51] *Floodplain mapping studies underway within the City of Ottawa*, Conservation Authority News Release January 2013 http://www.mvc.on.ca/news-releases/216-floodplain-mapping-studies-underway-within-the-city-of-ottawa-local-input-welcome-

[52] *Climate Change and Infrastructure Vulnerability Assessment*, Joel Nodelman and Joan Nodelman, FCM Workshop Powerpoint, February 2012. The powerpoint provides a good overview of the methodology. http://www.fcm.ca/Documents/presentations/2012/workshops/PIEVC_Joel_Nodelman_Protocol_Overview_EN.pdf

[53] PIEVC Web site http://www.pievc.ca/e/index_.cfm

In 2008 and following initial efforts to apply the Protocol, Engineers Canada issued the *Adapting to Climate Change – Canada's First National Engineering Vulnerability Assessment of Public Infrastructure report*.[54] Regarding stormwater (and wastewater) infrastructure in Canada the report commented:

- Stormwater and wastewater systems are vulnerable to electric power interruption. Presence of standby power is important to mitigating vulnerabilities;
- Flood plain mapping, which is based on past experience, should be based upon flooding impacts anticipated in the future as a result of climate change;
- Effective asset management can mitigate vulnerability;
- Guidelines are needed to match local circumstances to acceptable risk levels.

4.0.1 Adding Social Vulnerability to Infrastructure Vulnerability

The methodologies used to undertake risk and vulnerability assessments of engineered infrastructure are evolving beyond risk of failure and replacement/repair or system upgrade costs to include the social risks and related costs connected to the period following infrastructure failures. Toronto is currently developing a new tool for risk and vulnerability assessment which extends physical analysis of risk and vulnerability to social analysis of the demographics of the population that may be impacted by infrastructure failures. As an example, the methodology has inventoried where electrical substations may fail in flood prone areas and the tool considers the demography of the population in the affected area and their ability to manage without electricity.[55, 56]

4.1 Welland Stormwater Infrastructure Assessment (February 2012)

One of the most recent projects completed using the PIEVC Version 9 tool is Welland's stormwater and wastewater infrastructure assessment.[57] Motivation for Welland was to ensure rehabilitation and new infrastructure would meet climate change challenges, to consider risks to aging infrastructure and sewer overflows and to update design standards from the existing 1960 IDF curve and a two-year design level of service.

One of the first steps in Welland's process was a "risk workshop":

- Included engineers, operators, climate specialist and resource managers;

[54] *Adapting to Climate Change – Canada's First National Engineering Vulnerability Assessment of Public Infrastructure,* Engineers Canada, April **2008**. http://www.pievc.ca/e/Adapting_to_climate_Change_Report_Final.pdf

[55] Direct communication with City of Toronto staff planning and implementing the new tool.

[56] http://www.eenews.net/stories/1059973881

[57] *Case #22 Assessment of Town of Welland's Stormwater and Wastewater Collection and Treatment System* PIEVC Web documents including executive summary and full technical reports http://www.pievc.ca/e/doc_project_single.cfm?dsid=3&projid=22

- The workshop first focused on a qualitative assessment in which professional judgment and experience was used to consider individual climate events and effect on infrastructure;
- Infrastructure systems considered in the assessment, in addition to piped infrastructure, included power systems, communication systems, transportation systems and personnel;
- Established a future date of 2050 and made climate predictions upon which infrastructure capacity was determined (based on published information and existing climate model projections — climate analysis was not the focus of the project). 2050 was chosen in relation to the design life of Welland's infrastructure — it was anticipated that over that time all infrastructure would be upgraded to new standards.

The next steps in the process considered the interactions between climate and infrastructure to identify areas to focus on based on local community priorities. For instance, varying water levels in the Welland River were known to contribute to sewer backup, so that was included as an analysis factor in the risk assessment.

The "action plan summary" for the study identified that:

- The majority of recommendations were for additional study (21/44);
- The majority of recommendations could be addressed individually at a cost of <$100,000 (33/44);
- A balance of recommendations were considered "ASAP" (12), "Short term" (13) and "Medium term" (19).

4.2 Key Insights

- There is a growing body of examples of assessments and the methodologies have been updated based on experience;
- Risk assessments are typically "high level" and the findings may point to the need for data gathering to support more detailed assessments;

5.0 Integrating Stormwater Management Adaptation into Modelling Tools

Modeling is an important tool in stormwater management. In the late 1970’s, academic research in Ottawa led to the development of a number of computer modelling tools and City staff and the local consulting community are well versed in the use of these tools.

5.1 Seaton Community Master Servicing Plan (2013)

The *Central Pickering Development Plan*,[58] approved in 2006, included a policy to “Explore the use of sustainable technologies in the capture, conveyance and treatment of stormwater runoff” (pg. 62 in the referenced report). The Terms of Reference for the *Master Servicing Plan* (2007) [59] included direction to model “control of runoff volumes through techniques such as infiltration” and “incorporate the principals of low impact development” (pg. 5 of the referenced report).

The Master Servicing Plan used a range of hydraulic, hydrologic and groundwater models and developed a methodology to assess the effectiveness of low impact development measures:[60]

- Roof downspout disconnect was simulated by routing impervious rooftops to pervious areas;
- Capture of the first 5 mm of rainfall was modeled by increasing depression storage;
- The PRMS model61 results were analyzed to determine the effectiveness of LID measures on mitigating impacts on groundwater levels;
- The percentage reduction in surface runoff volume from application of LID from the PRMS model was incorporated into the QUALHYMO model as equivalent percentage reduction in impervious area and was analyzed to determine the effectiveness of LID measures on mitigating erosion impacts and the potential to eliminate SWM facilities based on implementation of LID measures only was assessed;
- Surface features and groundwater features were linked by using recharge determined from the PRMS model including scenarios with LID measures as input to the MODFLOW (groundwater) model.

Based on model results of implementation of LID measures it was determined that the average annual recharge to groundwater will increase by 44 mm per year in the post development condition and the average annual post-development runoff volume will be reduced by 43% compared to alternatives without LID measures.

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[58] *Central Pickering Development Plan*, City of Pickering, May 2006. http://www.mah.gov.on.ca/Asset1849.aspx

[59] *Terms of Reference, Master Environmental Servicing Plan, Seaton Community, City of Pickering*, http://www.pickering.ca/en/cityhall/resources/mesp_termsofreference.pdf

[60] *Master Environmental Servicing Plan Amendment, Chapter B Water Resources, Seaton Community, City of Pickering* , February 2013 See in particular Section 4.7.5 Model Results Discussion starting on page B-73 http://www.pickering.ca/en/cityhall/resources/MESPAR_Feb2013_B.pdf

[61] The Precipitation-Runoff Modeling System model simulates the hydrologic cycle at a watershed scale. PRMS can evaluate the response of various combinations of climate and land use on streamflow and general watershed hydrology. PRMS is one of an extensive suite of watershed modeling tools developed and maintained by the US Geological Survey “MOWS” initiative: http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/PRMS.html; http://wwwbrr.cr.usgs.gov/projects/SW_MoWS/Software.html

5.2 Key Insights

- The effects of climate change are across the full range of hydrologic and hydraulic factors considered in stormwater models;
- New ways of undertaking modeling and linking model outputs to model inputs must be considered to represent climate changes.

6.0 Protecting Infrastructure in Design Exceedence Events

Stormwater management design accepts that there will be risks when design parameters are exceeded. Infrastructure design which considers failure modes can prove to be more resilient and, if less damage to an infrastructure element occurs in failure, can promote a faster recovery from failure conditions.

6.1 West Don Land's Flood Protection Landform (under construction)

- 2011 Canadian Architect Award of Excellence for the stormwater treatment facility
- 2012 Canadian Urban Institute Brownie Award for contribution to the public realm

The West Don Land's Flood Protection Landform has an objective of removing 210 ha of regulatory flood plain from an area in downtown Toronto.[62] A comprehensive redevelopment plan has been developed for the area including use of 32 ha of the area as a host site for the 2015 Pan Am Games and a 7.5 ha community park on top of the landform.

Figure 4: *West Don Lands Concept Plan*

The design of the landform included a number of measures to mitigate any impacts which may result from flooding and a changing climate:

- Some tolerance for climate change has been included in the establishment of the height of the landform;

- Land use on top of the landform will be a public space to allow for cost effective adaptation if required in the future;

[62] http://www.trca.on.ca/dotAsset/25786.pdf

- Fill slopes on the wet side of the landform will be 3-10% to minimize erosion during flood events;
- Fill slopes on the dry side of the landform will be flatter still — 1.5% - 2.5% — to reduce potential damages to the structure should the landform overtop;
- Foundations will not encroach closer than 120 from the footprint of the landform;
- All site services were designed in consideration of the landform — no services will be installed in the landform;
- The top and core of the landform will be constructed with low permeability materials to prevent instability and piping during prolonged rain events and prolonged high flow events on the wet side of the landform.

6.2 Finch Avenue Culvert Failure

A severe storm event in Toronto on August 19, 2005 and the failure of the Finch Avenue Culvert became national news and generated considerable reporting of climate change, water resource management and municipal infrastructure liabilities. Replacement of the culvert cost $4M and there were significant municipal costs associated with managing the failure. The storm event also caused significant private property damages resulting in estimated private insurance costs exceeding $600M.

Analysis of the Finch Avenue Culvert failure resulted in identification of minor design and operational changes which would contribute to greater resilience for the new culvert and as lessons for all future culvert construction:

- A review of the existing design indicated that stormwater drainage from Finch Avenue was directed to internal locations in the culvert. The new design routes drainage on Finch Avenue on the surface to a spillway which directs flow downstream of the culvert;
- The headwalls of the new culvert were “hardened” to ensure the long term durability of the culvert entrance;
- Debris collecting at the culvert entrance may have contributed to the failure. Toronto recognized that due to Emerald Ash Borer tree loss, many trees may become weak and may result in increased and sizable debris in area waterways. As an operational measure, Toronto is investigating creek corridors and the need for landscape maintenance as an adaptation measure.

6.3 Key Insights

- Design features which consider infrastructure performance in severe conditions will contribute to long term performance and cost savings;
- Operation and maintenance are key to maintaining the performance of infrastructure under design stress loads.

7.0 Green Streets

Research indicated that green streets are a focus of stormwater management planning including adaptation opportunity and other "no regret" benefits in many communities:

- streets and sidewalks make up a considerable proportion of the impervious area in cities;
- maintaining design standard performance for the drainage and major flow conveyance elements of streets is important to public transportation efficiency and safety;
- drainage from streets is a source of pollutants and sediments carried by stormwater to natural systems;
- streets are publicly owned and regularly rehabilitated;
- current urban planning is placing a focus on the role of urban streets in promoting quality of life in cities.

Ottawa has a well established and funded program for street reconstruction. As reconstruction only happens every 30 – 50 years it is important to consider opportunities in each reconstruction project at a time when change can be implemented in the most cost effective manner. As noted in City policy and in research sources, green streets provide stormwater management improvement and climate resilience, can reduce overall infrastructure costs and will provide significant community benefits. New design techniques which recognize the need to provide adequate soil for street trees (while at the same time providing storage for stormwater) and other landscape quality and maintenance factors will help overcome concerns regarding tree survivability. This is a common concern stated in research sources arising from past experience with street trees.

It costs \$10,000 to provide the recommended 15 m^3 of soil for a street tree using "Silva cells" compared to a few hundred dollars using typical measures.

The City's *Road Corridor Design Guidelines*[63] provide a strong policy basis for the City to move forward through its own rehabilitation program to consider "green street" opportunities and perhaps even a program which would result in the "greenest street in Canada" (see next section).

7.1 Cermak Road – the Greenest Street in America

Completed in 2010 and 2011, the 1.5 km, \$16M rehabilitation of Cermak Road and Blue Island Avenue in Chicago is promoted as the "the greenest street in America"[64, 65]. Part of Chicago's

[63] A video discussing the project overall project: http://www.youtube.com/watch?feature=player_embedded&v=55527rWYdyE

[64] Cermak Road Blue Island Avenue Sustainable Streetscape, City of Chicago project summary sheet http://www.cityofchicago.org/dam/city/depts/cdot/CBISS_flier_2010.pdf

[65] Chicago Rebuilds Streets Greener and Leaner, T.R. Witcher, November 2012, American Society of Civil Engineering E Magazine article http://www.asce.org/CEMagazine/Article.aspx?id=23622321988

Climate Action Plan's focus on adaptation[66], the project included a number of sustainability elements which actually resulted in a project cost 20% less than similar scale projects.[67]

An example of integrating stormwater management adaptation in the project is the stormwater rain garden installed in a right-of-way which was being closed on a property adjacent to the project. In the vicinity of the rain gardens, sidewalks were widened to create a system in which water moves from roofs, streets, plaza and sidewalk into a series of design elements consisting of sunken garden beds and a shallow drainage ditch filled with drought-tolerant vegetation. Water is then channelled across a "zero-depth" water feature (an area where water is directed and flows across, but with no permanent planned water depth). The stormwater finally trickles into a ball field. The feature will divert 80 percent of the typical annual rainfall away from the storm sewer.

7.2 Street Tree Survival Strategy Case Study in Toronto

The Clean Air Partnership, noting that street trees are an important part of many adaptation plans including for stormwater management adaptation, prepared a comprehensive review of issues which must be addressed to ensure the success of street tree planting.[68] By focusing on Toronto, the case study was able to address specific issues such as the appropriateness of native trees, the street side environment for trees in Toronto's existing and changing climate, new tree planting technologies and Toronto's urban design tools as a management tool for implementing street tree planting and improved street tree survival/vigorous growth.

The Case Study notes a number of pilot projects in Toronto including a project which provides direct connection from catch basins to "Silva cells" — large, lightweight frames into which soil is placed. These frames prevent soil compaction and provide a location for healthy root growth. The soil also has a 20% voids ratio and with a direct connection to catch basins, retains stormwater which both reduces and slows runoff and provides for tree health.[69] The size of the pilot installation was designed to capture runoff from a 5 cm rain event over a 24 hour period. (See also the US EPA *Green Streets Handbook* which also provides advice on technical and management issues associated with successful green streets.[70])

7.3 Key Insights

- Green streets are a stormwater management adaptation measure which can be implemented by municipalities as part of scheduled road rehabilitation;
- The features of green streets provide many community benefits.

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[66] Web content for the adaptation measures in Chicago's Climate Action Plan http://www.chicagoclimateaction.org/pages/adaptation/11.php

[67] Interview with Janet Attarian, Project Manager http://www.chicagotalks.org/2012/11/11/pilsen-home-to-greenest-street-in-america/

[68] *A Street Tree Survival Strategy in Toronto*, Clean Air Partnership, January 2012 http://www.cleanairpartnership.org/files/StreetTrees%20Final.pdf

[69] *Toronto Pioneers Underground Bioretention*, Case Study Summary, Deeproot. Deeproot is a supplier of tree care and stormwater management products for urban environment. http://www.deeproot.com/silvapdfs/caseStudies/Queens%20Way%20Case%20Study_New.pdf

[70] *Managing Wet Weather with Green Infrastructure – Green Streets*, US Environmental Protection Agency, 2008. http://water.epa.gov/infrastructure/greeninfrastructure/upload/gi_munichandbook_green_streets.pdf

8.0 Green Infrastructure and Low–Impact Development (LID)

The City has already recognized green infrastructure and green infrastructure techniques in Council's Term of Council priorities, the *Infrastructure Master Plan* and guideline documents and for goals such as improved quality of life, improved air quality, improved stormwater quality and reduced burdens on stormwater infrastructure. The features of green infrastructure including reducing stormwater runoff volumes and providing some quality improvements to stormwater will function under the anticipated effects of climate change including more intense and more frequent precipitation events — a "no regret" measure. Research indicated that, while there are constraints to implementing green infrastructure at the municipal level including lack of familiarity, uncertainties surrounding performance and apprehension regarding maintenance issues,[71] green infrastructure and LID are featured prominently in many municipal stormwater management programs including for stormwater management adaptation purposes.

8.1 2013 International Low Impact Development Symposium

Symposiums and conferences provide insight into the state of practice. The 2013 International Low Impact Development Symposium held on August 18, 2013 in St. Paul Minnesota, included a significant participation level from Great Lakes states.[72]

Topics listed in the draft Program included:

- Green Infrastructure for CSO Communities;
- Green Infrastructure Standards, Construction and Inspection;
- Municipal Green Infrastructure Programs (with presentations from New York City and Portland);
- Urban Trees and Stormwater Management;
- Implementation Strategies for LID Retrofits;
- LID Optimization Modelling;
- The Art of LID: Unique LID Designs;
- LID Planning for Climate Change Adaptation;
- Sustainable Cities and Social Technical Models.

In addition to conference program topics, the conference had a parallel short course program:

- Green Roof Design for Stormwater Engineers;
- Rainwater Harvesting for Stormwater Benefits;
- Community Stormwater Response: Identifying Barriers and Opportunities for Adaptation;
- Green Highways and Green Streets;
- Incorporating LID into Municipal Programs.

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[71] *Greening Stormwater Management in Ontario, An Analysis of Challenges and Opportunities*, Matt Binstock, Canadian Institute for Environmental Law and Policy, June 2011 http://greeninfrastructureontario.org/sites/greeninfrastructureontario.org/files/GreeningStormManOntario.pdf

[72] Symposium Web site http://www.cce.umn.edu/2013-International-Low-Impact-Development-Symposium/index.html

8.2 Rooftops to Rivers II (2011) Green Strategies for Controlling Stormwater and Combined Sewer Overflows.

The National Resources Defence Council's *Rooftops to Rivers II* reports on the NRDC's "Emerald Cities" initiative.[73] Version II is a follow-up to a similar report in 2006. The 2011 report notes specific progress in a few cities, but overall that municipalities are not making progress in understanding and adopting green infrastructure strategies as cost effective solutions to stormwater management challenges resulting from regulatory pressures, growth pressures and climate pressures.

The NRDC Emerald Cities initiative aims to overcome the "grey vs. green" method of considering green infrastructure to promote a "grey and green" method and a process to consider and adopt green solutions. The Emerald Cities initiative sets out a six step process:

- Develop a long term green infrastructure plan to prioritize infrastructure investment;
- Develop strong retention standards to minimize the volume of stormwater runoff from development;
- Require the use of green infrastructure to reduce runoff;
- Provide incentives for property owners;
- Undertake demonstration projects, provide workshops and affirmative assistance;
- Ensure dedicated funding to support green infrastructure investments.

Toronto is used as a case study in the report, noting that Toronto has addressed four of the six elements of the Emerald City. Only Philadelphia is listed as achieving all six elements including an assertion by Philadelphia that their plan "will save billions."[74] [75] (In 2006, Chicago was the top listed city with five of six elements.) Philadelphia's *Green City Clean Waters* plan[76] has a goal of establishing the most comprehensive urban network of green infrastructure in the United States. Elements of the plan include:

- A state approved requirement which will result in at least one-third of the impervious surface in the combined sewer area requiring retrofit;
- The plan relies on green infrastructure to achieve the majority of legislated CSO reductions;
- Plans for a greater investment in green infrastructure than grey infrastructure;
- Funding the plan from an impervious area stormwater fee;
- Incentives offered for reduced stormwater fees, free design assistance, low interest loans, a green roof tax credit, rain barrel giveaways and expedited permit review.

[73] Rooftops to Rivers II: Green Strategies for Controlling Stormwater and Combined Sewer Overflows, Noah Garrison, Karen Hobbs, Natural Resources Defense Council, 2011 http://www.nrdc.org/water/pollution/rooftopsii/files/rooftopstoriversII.pdf

[74] *Cost Savings Week Begins With A Project That Will Save Billions!,* City of Philadelphia Official Blog Site, February 2013 http://www.phillywatersheds.org/cost-savings-week-begins-project-will-save-billions

[75] *Choosing Green over Gray: Philadelphia's Innovative Stormwater Management Infrastructure Plan*, Sarah Madden, Massachusetts Institute of Technology, June **2010**. This Master's thesis presents a comprehensive discussion of the process whereby the City developed and gained approval for its plan including how the political process interacted with sustainability planning and the timing of specific climate events. http://stuff.mit.edu/afs/athena/dept/cron/project/urban-sustainability/Stormwater_Sarah%20Madden/sarahmadden_thesis_MIT.pdf

[76] City of Philadelphia Web site for the Green Cities Clean Water plan http://www.phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan

Other examples provided in the report include:

- Milwaukee, Wisconsin: Milwaukee's 2009 *Fresh Coast Green Solutions: Weaving Milwaukee's Green and Grey Infrastructure into a Sustainable Future*[77] and other initiatives led to a 4 out of 5 star rating in the Emerald City criteria. The plan notes Milwaukee's commitment to "large scale" green infrastructure — preservation and restoration of natural landscape features such as forests, flood plains and wetlands and the important role of "small scale" measures such as rain gardens, green roofs and reuse;

- Syracuse, New York: In 2009, Syracuse became the first city in the United States with a legal requirement to reduce sewer overflows using green infrastructure with a plan to reduce 2/3 of overflows using green infrastructure. Also, surrounding Onondaga County was the winner of the 2013 US Water Alliance Water Prize for its Save the Water program to embrace green infrastructure solutions to wet weather problems.[78]

8.3 LID Initiatives in Ontario

The Province of Ontario has recognized the need to move forward with greater implementation of LID approaches and is currently funding a number of LID efforts via the "Showcasing Water Innovation" program including pilot installations on residential, industrial and commercial lands, and public lands and rights-of-way. These efforts include the preparation of design and construction guidelines intended to assist municipalities in moving forward with LID projects. Additional detailed information about these on-going initiatives funded by the Province is provided here:

http://www.creditvalleyca.ca/low-impact-development/showcasing-water-innovation-2/

These initial efforts are essential given that LID represents a considerable shift in municipal engineering practice. There are also a number of barriers to moving forward including lack of local knowledge about LID technologies, their applicability to the local climate, and the long-term effectiveness of lot level measures implemented on private property. Notwithstanding what the City can learn from the experience of other municipalities and jurisdictions, local efforts are required if LID approaches are to be effectively integrated into existing SWM design guidelines and standards.

[77] *Fresh Coast Green Solutions: Weaving Milwaukee's Green and Grey Infrastructure into a Sustainable Future* City of Milwaukee, 2009 The plan sets a goal of zero sewer overflows and zero flooded basements. The plan includes a deep tunnel for combines sewage storage and significant dedication to green infrastructure and notes Milwaukee is implementing many measures similar to Toronto. http://v3.mmsd.com/assetsclient/documents/sustainability/SustainBookletWeb1209.pdf

[78] Save the Rain Web site http://savetherain.us/

9.0 Stormwater Management Facilities

Municipalities are finding stormwater management adaptation opportunities as they address life cycle requirements for existing stormwater management facilities including ponds. Also, new facilities offer opportunities to bring new practices to stormwater management adaptation. Regarding life cycle management, Section 5.2.2 Stormwater Management Polices in the *Infrastructure Master Plan* includes policies directing retrofit activities and an overall need for a City wide stormwater management retrofit plan.

A strategic approach to retrofit planning and for implementation of new facilities offers an opportunity to incorporate stormwater management adaptation considerations. Coordination of stormwater management adaptation with existing programming may provide a cost effective opportunity to implement stormwater management adaptation measures in Ottawa.

Coordination of stormwater management adaptation measures with road and sewer rehabilitation programming may provide a cost effective opportunity to implement stormwater adaptation.

9.1 Pioneer Park Stormwater Management Facility (2009)

- Richmond Hill, Ontario, 2009
- Ontario Public Works Association Technical Innovation Award 2010
- Federation of Canadian Municipalities and Insurance Bureau of Canada Watershed Award 2010

Figure 5: *Pioneer Park Stormwater Management Facility*

The Pioneer Park project is characterized in the research sources as the “first major stormwater facility rehabilitation in Canada”. Pioneer Park was the first of 10 planned major pond rehabilitation projects in Richmond Hill whose priorities and scope of rehabilitation were developed keeping in mind stormwater management adaptation opportunities. In particular for Pioneer Park:

- The existing facility was an on-line structure originally constructed to provide flood protection to a 26 ha area. The facility had a history of outlet blockages and backwater conditions;
- Located adjacent to York Central Hospital and Major Mackenzie Drive, a comprehensive risk assessment indicated that facility rehabilitation to minimize risks to the road infrastructure / an important emergency preparedness route was an important benefit;
- A watershed level planning review indicated the facility could be expanded to provide cost effective flood protection to a 740 ha built tributary area including areas with no previous stormwater management;
- Candidate design features of the facility were recognized as innovative however they were also viewed as opportunities that could be used by the Town to advise the design and operation of the planned future projects;
- As a specific stormwater management adaptation measure, the spillway was designed to accommodate 2x the Hurricane Hazel regional storm outflow rate. Culverts installed under Major Mackenzie Drive with similar capacity were installed to ensure protection of critical infrastructure;
- Oil-grit separators were installed at inlets to improve operational efficiency and maintain performance of the flood control elements of the facility;
- Facility cost: $6.3M:
    - at a serviced area of 740 ha, $8,500 / serviced ha;
    - with a permanent pool volume of 8,200m^3, $770/ m^3;
    - with an on-line flood protection volume of 30,000 m^3 , $210/ m^3.
- Lesson learned: A multi-disciplinary approach involving engineering, environmental and public infrastructure needs allows innovative solutions to climate related challenges to be developed. The project demonstrated that landscape plays an integral role in stormwater management adaptation.

Resources:

- [Clean Air Partnership Case Study (2012)]
- [Climate Consortium Case Study (2012)]
- [Insurance Bureau of Canada Feature Video]
- [Town of Richmond Hill Presentation]

9.2 Earl Bales Stormwater Management Facility (2011)

- North York, City of Toronto, 2011
- 2012 Toronto Region Conservation Authority Living City Award
- 2012 Short List Canadian Consulting Engineering Awards

At 3.2 ha, the facility is characterized in research resources as the largest facility in Ontario constructed to serve an existing developed area and therefore an example of how stormwater can be a resource in the built urban environment. As a component of the City of Toronto's *Wet Weather Flow Management Master Plan*, the motivation for construction of the facility was primarily environmental remediation however the design process and the final facility features model an adaptive approach to considering stormwater management solutions.

The principle adaptation features of the facility which contributed to best practice awards included: planned for "rainwater harvesting" — pond water will be used for golf course irrigation during the summer and for snow-making in winter; comprehensive sampling facilities were installed so that, over and above compliance requirements, data on facility operation and performance will be studied and monitored; design elements beyond minimum requirements to provide a "safety factor". In addition to erosion protection, the facility provides upstream flood protection to an existing 500 ha developed area. Phase 2, yet to be initiated, will add 100 ha of drainage area. The location of the facility used and rehabilitated a piece of public property — the long abandoned site of a wastewater treatment plant.

Resources:

- TRCA Feature Story on Earl Bales Facility
- MMM Submission to the Canadian Consulting Engineers Awards
- Daily Commercial News Feature Story on Earl Bales Park

9.3 Lendrum Place "Dual Use" Soccer Field Retrofit (2010)

- City of Edmonton, 2010
- Insurance Bureau of Canada and the Federation of Canadian Municipalities Watershed Award 2011

On July 11, 2004 an extreme rainfall event flooded over 4,000 basements throughout Edmonton. According to the IBC, there were 12,000 claims totalling $180 million dollars. In response to the flooding, Edmonton completed flood investigation studies and conceptual designs for 43 of the neighbourhoods most heavily affected by the flooding.

The neighbourhood of Lendrum Place had about 98 basements flooded during the July 2004 event. Investigations determined that the neighbourhood's sewer systems were overloaded and that the excess water ponded on the surface, causing flood damage. Originally elevated above the adjacent areas when constructed, Edmonton redeveloped the Lendrum Place school field at an elevation below the adjacent roadways as a flood control measure in a manner similar to Ottawa's Sandy Hill project.

The elevation of the field area allows surcharged storm sewers to "back up" into the soccer field area before backing up into basements or surcharging to the road surface. Once levels in the sewer system recede, the water in the field area drains back into the sewer through the same pipes which flooded the area. Recognizing the importance of the recreation function of the soccer fields, the fields were underlain with a sand and geocomposite drainage layer and an underdrain system which ensures the fields returns to functionality soon after a flood event.

Resources:

- City of Edmonton Presentation to Area Residents on Lendrum Place Facility
- Edmonton Journal Feature Story

9.4 Key Insights

- Infrastructure rehabilitation programs are well suited to a long term adaptation program;
- Stormwater and stormwater management areas can be a community resource;
- “Dual-use” facilities may present compromises to both users, but careful design can provide for cost effective public infrastructure.

10.0 Operational Stormwater Management Adaptation Measures

Operators play important roles in the management of stormwater infrastructure including ongoing programs for inspections and maintenance to extend life cycle and ensure proper performance (in particular during severe events) and undertaking immediate and then ongoing emergency responses when severe events cause damages which may include complete infrastructure failure.

Municipal operations and operators are at significant risk from the effects of climate change, in particular regarding the responsibilities for operational responses to very local severe precipitation events. Operations staff and operational planning must address a wide variety of factors when considering stormwater management adaptation, including issues such as staffing levels and personnel safety when responding to sudden events causing damages through to understanding and planning for the challenges of mobilizing equipment and operational responses possibly concurrent with a severe weather event.

10.1 Seattle Rainwatch

The City has used post event radar analysis in its stormwater management planning. In Seattle a live Web based tool has been developed to optimize operational responses to severe precipitation events. Using radar and 17 rain gauges, the live analysis tool assesses rainfall every 6 minutes. Seattle operations staff have knowledge of locations which may be at risk in severe events and use the tool to anticipate operational needs and dispatch operation crews to known vulnerable locations. The tool is available to the public and will send messages to a resident's smart phone warning of a severe event, providing accumulated precipitation and predicting total accumulation allowing homeowners to act and mitigate their own risks.

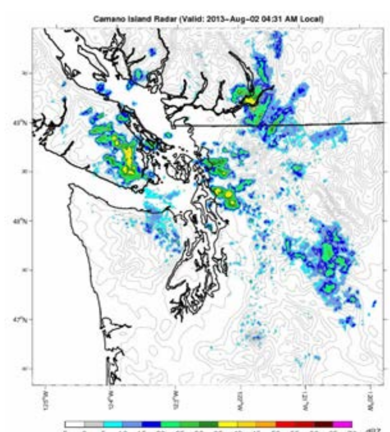

Figure 6: *Seattle Rainwatch Screen Capture*

Seattle Rainwatch is a live tool which can be accessed at http://www.atmos.washington.edu/SPU/ and at http://m.seattle.gov/rainwatch.htm.

10.2 Key Insights

- Tools which provide very current information on system performance will allow more effective operational responses to climate impact.

Adaptive Approaches in Stormwater Management
PART C – From Plan to Action

11.0 Action Plan Examples

11.1 City of London – Stormwater Management the Focus (2007)

London in south-western Ontario has a core urban area surrounded by both suburban areas and a large rural area. The Thames River and major tributaries flow through the core of London and, due to a history of flooding, the river is controlled through a large network of dams and dykes.

Between 2003 and 2007, Western University, located in London, completed a study of *Assessment of Risk and Vulnerability to Changing Climatic Conditions*.[79] The University used London as a place based test for the research (see for instance details regarding Project XI provided on the Web site). Research concluded that the core of London — long subject to flooding and flood protection measures — is at increased risk as a result of climate change. The study author presented the results to London City Council.

While the Western research focused on riverine flooding, the research project resulted in an increased awareness of climate change risk and vulnerability at London City Council including in the design and function of the City's water resource management infrastructure. As a result, London undertook a review of IDF curves which was conducted by the same research team. While the review indicated increased risks, London recognized that more work needed to be done in order to determine the risk and consequences associated with the various infrastructure elements (floodways, culverts, dikes, bridges, street and sewer design, etc.) that will be impacted and to determine appropriate go forward management strategies — a project London estimated would take 2-3 years.

In December 2007 London adopted a 2 phase climate change adaptation strategy focused on stormwater management. Phase 1 of the strategy focussed on immediate tasks (completed in one year) to update London's IDF curves, undertake a stormwater practices review and consider general risks related to stormwater management. Recognizing the importance of the IDF curves to many aspects of stormwater management, Phase 2 of the strategy (to be completed within 3 years) included implementation of new IDF curves and a review of existing subwatershed studies in light of the new curves. London also planned for development of a "green infrastructure strategy" in Phase 2 with a goal to minimize stormwater conveyance and detention requirements and to formalize a broader long term climate change strategy for the protection of the public, property and municipal infrastructure.[80]

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[79] Western University Project Web site http://www.eng.uwo.ca/research/iclr/fids/cfcas-climate.html. See, for instance, Project XI

University of Western Ontario Floods: Mapping Vulnerability in the Upper Thames Watershed Under Climate Change, Andrea Hebb and Linda Morts, August 2007 http://www.eng.uwo.ca/research/iclr/fids/publications/cfcas-climate/reports/Vulnerability_Mapping_Report.pdf

[80] *Review of Rainfall Intensity Duration Frequency Curves for City of London Under Climate Change*, Report to Environment and Transportation Committee, City of London, December 10, 2007

Coincidentally with the strategy underway, major flooding events occurred twice in 2008.

Short-term components of the strategy have included an analysis of how much combined sewer overflow will pass through municipal infrastructure and how it will affect the size of a management system and vulnerability assessments of municipal beaches, roads and essential buildings. The strategy's long-term components provide for a more detailed assessment of vulnerability, a strategy to protect infrastructure and private property, and the development of green infrastructure for stormwater management.

London has invested $1.3 million in these activities to date. One result of the strategy is that London has taken over responsibility from property developers for constructing all major stormwater management infrastructure. (Text adapted from[81]. See also [82] and [83].)

11.2 City of Toronto – They Already Had An "Adaptive Plan"

Toronto has for some time been pursuing action to address existing stormwater management deficiencies. The City will be familiar with Toronto initiatives as they are similar to efforts the City has undertaken including addressing combined sewer overflows, "search and destroy" cross connection efforts, a homeowner basement flood protection subsidy program and undertaking major capital projects aimed at addressing localized basement flooding.[84]

The evolution of Toronto's current approach to stormwater management adaptation can be traced to the *Wet Weather Flow Master Plan* (WWFMP) adopted in 2003.[85, 86] Recognizing "state of practice" for the time, the WWFMP promoted wet weather flow management on a watershed basis and a hierarchy of solutions and was in some respects similar to the City's current *Ottawa River Action Plan*[87] (winner of the 2012 Ontario Public Works Association Project of the Year in the Environment[88]). Considering costs, the WWFMP outlined a 25 year implementation schedule. At the time the key objectives of the plan included cleanup of

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http://council.london.ca/meetings/Archives/Agendas/Environment%20and%20Transportation%20Committee%20Agendas/ETC%20Agendas%202008/2007-12-10%20Agenda/item%206.pdf

[81] 2010 Sustainable Communities Conference and Trade Show - Climate Adaptation - Planning Resilient Communities Session, Transcript of comments by Berta Krichker City of London http://www.fcm.ca/home/events/past-conferences/2010-sustainable-communities-conference-and-trade-show-post-conference-resources/full-summary-climate-adaptation-planning-resilient-communities.htm

[82] *City of London: Vulnerability of Infrastructure to Climate Change Final Report*, Angela Peck, Elisabeth Bowering, S.P. Simonovic, University of Waterloo Report No: 074, April 2011 http://www.eng.uwo.ca/research/iclr/fids/publications/products/74.pdf and http://www.london.ca/Sewer_and_Wastewater/pdfs/FinalReportVICC.pdf

[83] *Methodology for Assessment of Climate Change Caused Flood Risk to Municipal Infrastructure (City of London Case Study)*, Dragan Sredojevic, M.E.Sc, Upper Thames Conservation Authority, March 2011. Presentation to the CA Climate Adaptation Workshop Series http://www.climateontario.ca/doc/workshop/2011FebMarch/Dragam%20Sredojevic%20-%20London.pdf

[84] Similarities in technical issues and time lines include that the former City of Ottawa developed a combined sewer area control plan in 1993 and the new City of Ottawa undertook a City wide assessment of flood prone areas in 200? - RB

[85] City of Toronto Wet Weather Flow Master Plan Web site http://www.toronto.ca/water/protecting_quality/wwfmp/

[86] Between 2003 and 2008 the City of Toronto undertook considerable effort related to stormwater management including adaptation measures. Text in this section describes a number of technical reports, Committee reports and dates. To assist with clarity, a summary listing of these is provided in the Appendix.

[87] Web content overview of the Ottawa River Action Plan http://ottawa.ca/en/residents/water-and-environment/air-land-and-water/projects-descriptions and stating the plan is "to protect the health of the Ottawa River"

[88] Ottawa River Action Plan Receives Public Works Project of the Year, City of Ottawa media advisory http://ottawa.ca/cgi-bin/pressco.pl?&Elist=18214&lang=en

Toronto's waterfront and restoration of urban streams — a plan and a financial commitment to address existing problems. "Climate change" and "adaptation" were not discussed in the 2003 WWFMP.

In 2006 the WWFMP priorities were refocused on basement and surface flooding prevention including significant initiatives to identify and plan for remediation of flood prone areas. Similar to a program undertaken by the City,[89] program priority investigations identified 31 flood prone areas most in pre-1970's "soup bowl" development. In 2006, noting the severe damages which resulted from the May 12, 2000 and August 9, 2005 storms, the WWFMP update report does not point to climate change or possible increased risks arising from climate change.[90] Other sections of the update report provide progress on all of the WWFMP program elements including operational practices, conveyance controls, source control measures and public outreach. While indicative of an adaptive approach, the suite of measures under the WWFMP was not characterized as such in 2006.

Coincident with the change in focus of the WWFMP, in 2007 and 2008 Toronto developed its climate change strategy[91] including Recommendation 13 to prepare a plan to adapt to climate change. Arising from the recommendation, Toronto adopted what is considered to be the first municipal climate adaptation strategy in Canada.[92] While early versions of the strategy focused on the process to develop a plan and activities, input from stakeholders encouraged the strategy process to include the characterization and alignment of existing activities as adaptation as well as identification of new short term adaptation measures which could be implemented in advance of a longer term finalization of an overall adaptation strategy (see Recommendation 5 in the above referenced report).

As a result and in addressing a desire to identify short term measures, Toronto prepared the *Ahead of the Storm – Development of a Climate Change Adaptation Strategy* report (approved in April 2008).[93] In recognizing that the WWFMP was Toronto's "single most relevant policy" for climate change adaptation, the report concluded that Toronto's existing efforts are "what other cities are doing as part of their climate change adaptation strategies."[94] *Ahead of the Storm* included a significant focus on stormwater management.

Ahead of the Storm summarized opportunities to build on existing efforts and within existing budget envelopes (see Table 1, pg. 17 of the aforementioned report, including a vulnerability

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[89] *Basement Flooding Review Summary of Investigations and Action Plan*, Report to Planning and Environment Committee, October 25, 2005. http://ottawa.ca/calendar/ottawa/citycouncil/pec/2005/11-08/ACS2005-PWS-INF-0006.htm

[90] *Wet Weather Flow Master Plan Implementation Report 2006*, City of Toronto, October 2007. See in particular p 15. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/implementation-report-2006.pdf

[91] *Change is in the Air – Climate Change, Clean Air and Sustainable Energy Action Plan*, City of Toronto, June 2007 http://www.toronto.ca/changeisintheair/pdf/clean_air_action_plan.pdf

[92] *Climate Change Adaptation Strategy Staff Report*, City of Toronto, May 13, 2008 http://www.toronto.ca/legdocs/mmis/2008/pe/bgrd/backgroundfile-12950.pdf

[93] *Ahead of the Storm - Development of a Climate Change Adaptation Strategy*, City of Toronto, April 2008. http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf

[94] *The Plan in Action 5 Year Summary Report, City of Toronto*, 2008. See in particular p 16. http://www.toronto.ca/water/protecting_quality/wwfmmp/pdf/wwfmp_5yr_implementation_report.pdf

and risk assessment of city operations and development of extreme event IDF curves) and listed candidate measures brought forward by City staff that, while unfunded, were considered to present opportunity (see Table 2, pg. 19 of the referenced report, including vulnerability assessments of culverts, introducing new standards to promote tree health in rights-of-way, enact a City wide mandatory downspout disconnect and prohibit new reverse slope driveways).

With a focus on "action" while at the same time working to develop a comprehensive long term climate adaptation plan, Toronto reported on progress in 2011[95] including:

- A new Toronto Green Standard with mandatory performance targets, the objectives of which include reduction of stormwater runoff;
- A new Green Roof Bylaw which requires a green roof on all new developments with a gross floor area greater than 2000 square meters;
- A City wide mandatory downspout disconnect program in place[96];
- A bylaw reducing construction of new reverse slope driveways in place;
- Climate change engineering vulnerability risk assessments of several culverts;
- Characterization of Toronto's goal to increase tree canopy from 17% to between 30% and 50% as an adaptive measure for stormwater management;
- Progress reports on Toronto's Basement Flood Protection Program and Wet Weather Flow Master Plans taking climate adaptation into consideration;
- Pilot projects for greening parking lots.

Toronto identified and coordinated many short term stormwater management adaptation actions both within existing programs and as cost effective new initiatives in advance of preparation of a long term climate adaptation strategy.

Continuing to assess climate risks and vulnerability, Toronto undertook the *Toronto's Future Weather & Climate Driver Study* in 2012. Formulating drivers and predictions of future weather, the Outcomes Report[97] notes that past assessments of climate change have focussed on averages but that for infrastructure design and development of adaptation measures, analysis of extreme events is more relevant. The study conclusions compare projections of average

[95] *Toronto's Adaptation Actions Updated* April 2011, Staff summary http://www.toronto.ca/teo/adaptation/pdf/toronto_cc_adapt_actions.pdf

[96] A voluntary program had been in place since 1998. Under the new Bylaw, homeowners have 3 – 8 years to comply. It is expected that 350,000 homes will be disconnected by 2016

[97] http://www.toronto.ca/teo/pdf/tfwcds-summary.pdf

changes to predictions of changes in extremes and found that while the average number of storms in the winter is predicted to decrease and the number of storms in the summer is predicted to remain the same, the maximum amount of rainfall expected in a single day and in any single hour more than doubles. The study concludes by noting benefits of future weather predictions to inform present and future infrastructure decisions.

11.2.1 Clean Air Partnership Climate Action Plan Process Review

A published analysis from the Clean Air Partnerships (CAP) team comments on the process of incorporating adaptation into Toronto's climate change action plan strategy and provides process perspectives useful for municipalities considering adaptation planning:[98]

- While considered a "first" and a "best practice" when finalized in July 2007, Toronto's *Climate Change, Clean Air and Sustainable Energy Action Plan* focused on green house gas emission control and only included adaptation in Recommendation 13: to identify the scope of an adaptation plan, engage stakeholders and prepare a plan;

- There were initial problems getting commitments from all departments to participate in development of the adaptation component of the plan *(see pg. 5 of the CAP report)*;

- Staff who had already been thinking about climate impacts were better able to identify activities that protect against future climate impacts *(pg. 8 of the CAP report)*;

- In early stages, staff assigned to the project had difficulty understanding the differences between mitigation and adaptation *(pg. 8 of the CAP report)*;

- The original outline of a climate adaptation strategy identified a long term process. Senior team members expressed concerns regarding a long time frame for a research-based process. The project team was asked to identify measures which could be implemented immediately *(p 10 of the CAP report)*.

11.3 City of Windsor Climate Change Adaptation Plan (2012)

Windsor's Plan is a very recent example of how Ontario municipalities are evolving in planning for climate change adaptation.[99] The Windsor Plan was developed through participation in the ICLEI Climate Change Adaptation Initiative which provided a straightforward and timely methodology to prepare a plan. The ICLEI methodology was adopted by Windsor Council in November 2010 and the final Council approved plan is dated November 2012 suggesting a very fast time line for an innovative municipal planning process. (Vancouver adopted their adaptation strategy in July 2012 and was the first Canadian municipality to adopt a strategy developed using the ICLEI methodology[100]).

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[98] *Climate Change Actions in the City of Toronto – Lessons Learned for Great Lakes Cities*, 2008, Jennifer Penney, Clean Air Partnership. See in particular Chapter 3 regarding stormwater. http://www.cleanairpartnership.org/files/Climate%20Change%20Adaptation%20in%20the%20City%20of%20Toronto%20-%20Lessons%20for%20Great%20Lakes%20Communities%20(Penney,%20J.%202008).pdf

[99] *City of Windsor Climate Change Action Plan*, September 2012 http://www.citywindsor.ca/residents/environment/Environmental-Master-Plan/Documents/Windsor%20Climate%20Change%20Adaptation%20Plan.pdf

[100] *Climate Change Adaptation Strategy*, City of Vancouver, July 2012 http://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf

While sewer flooding and a spike in heat related illnesses were noted to be drivers of the preparation of the plan, Windsor's plan asserts that it is a proactive plan to consider municipal practices and risks from an adaptation lens. Different from infrastructure vulnerability studies, Windsor focused on identification of overall risks to the City and its residents. The listing of substantial risks is unique in its focus on impacts to operations and the very unique finding in item 1 *(pg. 16 in the Windsor Plan)*:

1. Development policies created in the absence of Climate Change considerations may create additional vulnerability to the impacts of climate change;
2. Increase in operating / maintenance demands to deal with climate extremes;
3. Increased chance of flooding of basements, roads and other infrastructure;
4. Increase in demand to all areas of Operations when responding to an increase in severe storms (during and after);
5. Increase in public health risks due to extreme heat.

Another unique feature of the Plan (and recounting the evolution of Toronto's plan) is a focus on short term measures — what can be done right now. Measures identified include mandatory downspout disconnect and backflow preventer valve installation, increased sewer camera program efforts, increased use of catch basin flow restrictors and sealed maintenance hole covers, update of IDF curves and creation of an extreme weather reserve fund.

In addition to short term measures, Windsor identified medium and long term measures in keeping with a planning approach to adaptation including incorporating climate change into Windsor's city policies and plans, making a commitment to monitoring climate change, ensuring on-going evaluation of the effectiveness of measures and recognition of the importance of public engagement.

11.4 Climate Ready Utilities

Municipal utilities will be at the front line of responding to climate induced changes to stormwater management and proactive stormwater management adaptation measures. The US EPA report *Climate Ready Water Utilities*[101] contains recommendations that will assist utilities to increase resilience to climate change. The report notes that as of January 2011 (date of report) efforts have focused on achieving a common understanding of the problems facing utilities and that the EPA report takes a next step by outlining practical steps to advance efforts to adapt to climate change. Key recommendations in the report include:

- Improve and better integrate watershed planning and management in response to climate uncertainty and impacts;
- Increase interdependent sector knowledge of mutual challenges and needs;

[101] *Climate Ready Water Utilities,* US EPA, December **2010,** http://water.epa.gov/drink/ndwac/climatechange/upload/CRWU-NDWAC-Final-Report-12-09-10-2.pdf

- Improve understanding and access to locally relevant climate information;
- Assist utilities in development of adaptive capacity to respond to climate change alteration of underlying ecological conditions and systems;
- Promote continuing education on climate change among utility staff.

The report also outlines resources needed to ensure a “climate ready utility”:

- **Internal Understanding and Education:** To assess and implement change, a comprehensive awareness of environmental and water utility operating conditions, trends and options is needed;
- **Partnership Building:** There is shared risk and responsibility among all water related sectors. Water utilities need to identify all interrelated entities to participate in developing solutions;
- **Climate Impact Assessment:** An assessment of climate change impacts at the local level is needed in order for utilities to plan measures to adapt;
- **Climate Adaptation Decision Support:** A structured methodology for considering climate scenarios, utility operating conditions, costs and benefits is needed to support short and long term decision making;
- **Stakeholder Communication:** A utility must understand its stakeholder groups and their needs and perspectives. Stakeholder support though effective communication will ensure customers, elected officials and the broader community support the utilities initiatives.

11.5 Durban, South Africa

While each community must undertake stormwater management adaptation within its local context, a review of climate adaptation literature including for stormwater management demonstrates that processes which have been implemented to date for planning and implementing stormwater management adaptation — primarily responding to intense precipitation events and associated urban flooding — are generally similar in all locations.

In 2009, Durban, South Africa, approved the *Climate Change – Municipal Adaptation Plan Health and Water*. A summary of the action steps to consider and address urban flooding demonstrates some of the principal components of moving stormwater management adaptation from plan to action:[102]

- Analysis of the latest rainfall / runoff projections;
- Revise rainfall data in line with latest projections. Review every five years;
- Develop a Master Drainage Plan;
- Retain biological buffers to flooding;

[102] *Catchment and Stormwater Adaptation Actions and Strategies*, Geoff Tooley, Catchment Management, Ethekwini Municipality, 2010. Presentation to the 2010 Resilient Cities conference in Bonn Germany. http://resilient-cities.iclei.org/fileadmin/sites/resilient-cities/files/docs/F5-Bonn2010-Tooley.pdf

- Ensure asset management plans consider revised rainfall / runoff assessments in assessing condition of infrastructure;
- Amend development standards to incorporate fixed parameters for runoff from new development;
- Undertake public awareness of retrofitting and stormwater runoff reduction from existing developments;
- Identify and protect key infrastructure assets.

Experience implementing the municipal plan has identified some broad challenges and solutions (which may sound familiar) and may advise stormwater management adaptation planning at the City:

Challenges:

- Bringing climate change factors into today's municipal actions;
- Including climate change factors into existing requirements for new development;
- Justifying costs for climate change in the future when needs of the present are so great;
- Finding funding sources to fund the necessary studies on climate change;
- Shortage of technical staff with the capacity to implement climate change work;
- The politics of hard decisions on adaptation.

Opportunities:

- Supportive political and technical leadership;
- Include climate change in existing requirements (without calling it climate change);
- Cross sector dialogue to ensure efforts in one sector do not have negative effects on another.

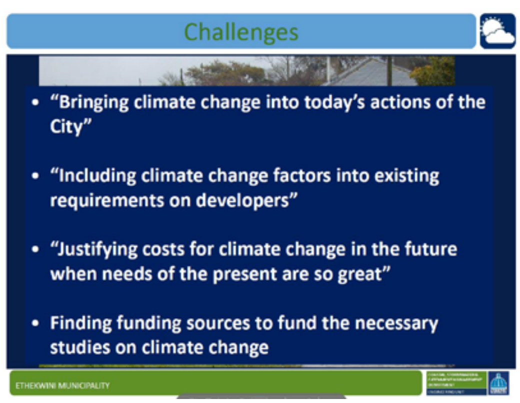

Figure 7: *Durban Challenges to Implement Adaptation*

11.6 Key Insights

- Stormwater management adaptation is a key element of municipal adaptation planning;
- Existing measures can constitute a plan;
- A broad planning and stakeholder involvement process will ensure maximum value and effectiveness.

12.0 Cost of Action

Research identified many reports which describe how climate change will have a significant economic cost to society and that assigning value to action (and inaction) related to climate change helps determine the benefits of mitigation and adaptation measures and to compare options. However, all reports caution on the uncertainty of cost predictions noting complexities, variability and uncertainty regarding the pace, magnitude and local manifestations of climate change:

- *Paying the Price: the Economic Impacts of Climate Change for Canada*,[103] prepared by the National Roundtable on the Environment and the Economy in 2011, determined that overall costs arising from climate change will reach from $21B to $91B annually depending on climate scenarios and population growth predictions. Some of the cost issues reported include impacts to Canada's forestry industry (climate induced slowed growth and die off), risks to coastal communities (sea level rise) and climate generated changes to northern communities (melting of permafrost);

- *National Water Program 2012 Strategy: Response to Climate Change* prepared by the US EPA emphasizes working collaboratively, developing tools, managing risk and incorporating adaptation into core programs. The report also notes that many existing funded activities and programs will become even more important in light of climate change referencing emergency preparedness, protecting watersheds and managing stormwater. Yet the report only dedicates two pages to the economics of climate change actions noting a need to monitor developments regarding how to characterize costs and benefits to support decision-making. That this 2012 report points to previously prepared reports from 2006, 2001 and 2000 is indicative of the lack of information regarding costs.[104]

The cost of climate change impacts is not the same as the cost of adaptation including for stormwater management. Similar to reporting on the cost of climate change, research did not identify a comprehensive body of literature based on good evidence of incurred costs of adaptation. As an example, in 2009 the US National Association of Clean Water Agencies and Association of Metropolitan Water Agencies published a report titled *Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs* (author's emphasis). The report pointed out significant costs attributed to adaptation for water and wastewater utilities — between $448B and $944B through 2050.[105]

Complicating research into the cost of stormwater management adaptation is that, like the many definitions for adaptation, there are different ways to state and account for costs attributed to climate change adaptation including for stormwater management:

[103] *Paying the Price: the Economic Impacts of Climate Change for Canada*, National Roundtable on the Environment and the Economy, September 2011 http://collectionscanada.gc.ca/Webarchives2/20130322181153/http://nrtee-trnee.ca/wp-content/uploads/2011/09/paying-the-price-executive-summary.pdf

[104] *National Water Program 2012 Strategy: Response to Climate Change,* US EPA, 2012. See p. 20 regarding the economics of climate change. http://water.epa.gov/scitech/climatechange/upload/epa_2012_climate_water_strategy_full_report_final.pdf

[105] *Confronting Climate Change: An Early Analysis of Water and Wastewater Adaptation Costs* National Association of Clean Water Agencies and Association of Metropolitan Water Agencies, 2009 http://www.amwa.net/galleries/climate-change/ConfrontingClimateChangeOct09.pdf

- Some sources estimated the costs of “failing to adapt to climate change” noting recent insurance payments associated with significant urban flooding events and state costs will rise the longer action to adapt is delayed (e.g. the *Climate Ready Ontario’s Adaptation Strategy and Action Plan 2011-2014*[106]). A similar case is made when “savings” are asserted when adaptation measures result in a predicted reduction in future damages;

- There has been significant reporting in Canada regarding the “infrastructure deficit.” Some sources suggested that adaptation will add to these already high costs either through climate induced premature wear or replacement in order to provide a level of service appropriate to a changing climate;[107]

- Some sources (including the Welland report discussed above and the City of Saanich that undertook a similar assessment of infrastructure[108]) considered their ability to adapt to climate change impacts in infrastructure including stormwater infrastructure was “High-Medium” noting that asset management programs would result in ongoing replacement and provide an opportunity to implement adaptation including increased capacity at a low cost. As noted in Section 11.2 *(pg. 50)*, Toronto has characterized their existing and fully funded *Wet Weather Flow Master Plan* as an adaptation plan — suggesting a significant portion of the costs of adaptation may already be included in established plans and approved budgets;

- Some sources advocated that investments in adaptation and in particular green infrastructure will result in costs less than for grey infrastructure solutions and with added benefits to air quality, heat island effect and community quality of life. The cities profiled in the *Rooftop to Rivers II* report noted in Section 8.2 *(pg. 42)* all concluded that adaptation through green infrastructure was the most cost effective way to address existing deficiencies and adapt to climate change. These cities drew on the many additional benefits which will result from green infrastructure programs as a factor in considering overall costs and benefits;

- Some sources pointed to changes which will result in economic benefit such as climate change effects on agricultural production or reduction in home heating oil costs to note that decision making must lean heavily on broad based assessments of costs and benefits.

A number of research sources did note that “Adapting to climate change is both possible and cost-effective.” (e.g. pg. 7 in *Paying the Price: the Economic Impacts of Climate Change for Canada* reference[109]) and go on to address a number of “adaptation myths”:

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[106] *Climate Ready Ontario’s Adaptation Strategy and Action Plan 2011-2014* , Province of Ontario, 2010. See comments on p. 27 regarding cost estimates of climate change. http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_085423.pdf

[107] *Paying the Price: the Economic Impacts of Climate Change for Canada*, National Roundtable on the Environment and the Economy, September 2011 http://collectionscanada.gc.ca/Webarchives2/20130322181153/http://nrtee-trnee.ca/wp-content/uploads/2011/09/paying-the-price-executive-summary.pdf

[108] *Adapting to Climate Change in Saanich: A Discussion Paper*, City of Saanich, 2010. The section on Infrastructure notes the City has High-Med capacity to adapt to risks. http://www.saanich.ca/living/climate/pdf/SaanichAdaptationDiscussionPaper2010-FINAL.pdf

- Adaptation is too costly: The cost of adaptation is likely less costly than doing nothing as doing nothing will result in increasing exposure to climate risks;

- Adaptation will require costly new measures, legislation, regulation, etc., none of which is in place: Adaptation does not require new and untested measures. For stormwater management, many existing measures which have been promoted to address stormwater generated environmental degradation are the same measures which may contribute climate resilience to stormwater systems;

- There is too much uncertainty in climate change to act — spending may be wasted: All engineering including in particular for stormwater management's use of design storms and return periods has a risk based approach including the use of safety factors. Considering a range of scenarios is an adaptive approach which can reasonably conclude on a cost appropriate action;

- We will have to change what we are doing and at considerable organizational cost: Adaptation may best be implemented by integrating adaptation into existing processes such as policy and planning, environmental assessments, design guidelines, building codes which state weather related design factors, etc. One adaptation measure — promotion of integrating municipal business practices over an adaptation theme — may, as is often asserted for other municipal business practice integration processes ("breaking down silos"), actually save money.

In considering the costs of stormwater management adaptation including information from published reports, understanding the basis of cost reporting and the variability in cost reporting will ensure that cost information informs debate about City actions.

12.1 Cost Examples

Research provided numerous cost statements (some examples noted in the body of the report are recounted here) most typically the capital cost of an infrastructure project undertaken with adaptation measures incorporated though the cost differential or premium for adaptation measures is typically not detailed. Also, research provided some information on the cost of studies to plan for adaptation activities and the evolution of municipal approaches to financing stormwater management adaptation.

The costs summarized here and as reported in referenced documents may not be indicative of the "cost of stormwater management adaptation" nor directly comparable to costs for the City. All planning, design, construction and operation initiatives and associated management contexts are unique and may impact costs.

Perhaps the most relevant factor to note in considering the costs of stormwater adaptation is that in the initiatives listed below and as found in other referenced reports, municipalities in Ontario and elsewhere have moved forward and in some cases very aggressively with stormwater management adaptation planning and stormwater adaptation measures.

12.1.1 City of Welland Cost of Adaptation Planning

Welland undertook a risk and vulnerability assessment of stormwater infrastructure using the PIEVC methodology.[109] The final report details recommendations the majority of which are for further study to establish and confirm adaptation measures. Study needs were identified in 3 categories of cost: < $100,000 (33 recommendations); $100,000 to $500,000 (19 recommendations); +$500,000 (0 recommendations) including (from Table 6.1 of the PIEVC methodology):

Table 2: *Recommendations and Costs of Adaptation Measures*

Recommendation	Cost
Determine the effect of climate change on achievable flow reduction through separation and I/I programs	$100-$500k
Applicability of updated IDF curves for sewer design	<$100k
Applicability of green infrastructure as an adaptation measure	<$100k
Assess impact of excess heat on SWM facility functions	<$100k
Assess impact of reduced efficiency of oil grit separators on receiving streams (more frequent storms will reduce efficiency)	<$100k

12.1.2 Green Infrastructure

City of Toronto Tower Renewal Program – Toronto considers the number and spatial distribution of tall apartment buildings to be unique in North America and an opportunity for social, environmental and economic sustainability including stormwater management adaptation.[110] The tower renewal program commenced with a comprehensive benefits analysis to prove out the value of building retrofit to building owners, the community and the City of Toronto (in savings which will be generated by reduced needs for City services including stormwater management infrastructure.) In establishing the benefits including financial benefits to Toronto and recognizing that financing of building upgrades presents challenges to property owners, the program includes a financial program to encourage owners to undertake retrofit projects.

Stormwater management retrofit at campus type apartment sites (where significant green space areas are often located over parking facilities) were identified as a priority opportunity to meet program goals including adapting to climate change *(pg. 21 of the Tower Renewal Program)*. Toronto investigated and costed a suite of opportunities at 5 sample sites.[111] The study found that runoff peak flow rates and volumes from the sample sites are predicted to be reduced by an average of 10% in a 5 year storm event (the peak reduction was 18%) and that the average retrofit costs for the 5 sample sites was $100,000. As a way of comparison, the study notes *(pg. 42 of the Stormwater Management Feasibility Study)* that a review of recent sewer improvement

[109] http://www.pievc.ca/e/doc_project_single.cfm?dsid=3&projid=22

[110] *Tower Renewal Implementation Book*, City of Toronto, September 2011 http://www.toronto.ca/city_manager/pdf/tr_implementation_book.pdf

[111] *Stormwater Management Feasibility Study*, City of Toronto Tower Renewal Program, March 2011 http://www.toronto.ca/tower_renewal/pdf/stormwater.pdf

projects yielded a sewer replacement cost of approx. $10,000 per meter and concluded “the comparison emphasizes the value of considering … improvements as a possible means to avoiding costly sewer upgrade works.”[112]

Authored in 2011 and with a focus on apartment campus retrofit, the study provides the following unit cost estimates for a variety of site retrofit measures noting, importantly, that cost sources were primarily from projects actually completed and in the Toronto area *(pg. 41 of the above referenced report)*:

- Cistern / Rainwater harvesting tank: $530 / m^3 (e.g. 22 m3 unit specified at Parkway site);
- Bioretention area and rain garden: $630 / 100 m^2 (e.g. 0.10 ha area specified at Markham site);
- Wetland or SWM detention facility: $6,000 / 100 m^2 (e.g. 0.12 ha area specified at Kipling site);
- Permeable pavement: $150 / m^2 (e.g. 301 m^2 area specified at Wellesley site);
- Reforestation area: $690 / 100 m^2 (e.g. 0.10 ha area specified at Markham site);
- Urban forest: $430 / 100 m^2 (e.g. 0.25 ha area specified at Wellesley site);
- Naturalized area: $580 / 100 m^2 (e.g. 0.32 ha area specified at Kipling site).

US EPA *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* – The benchmark 2007 US EPA report compared “traditional” stormwater management solutions to LID solutions from implemented projects and based on estimates of costs. In the examples provided in the report, the LID projects showed consistent evidence of significant capital cost savings. The report cautions regarding the cost of land and lost development potential from area intensive LID methods.[113] (*The recent Low Impact Development Stormwater Management and Planning Guideline* prepared by Toronto Region and Credit Valley Conservation Authorities quotes the study, suggesting that more up to date information is not available for Ontario.[114])

Milwaukee’s *Fresh Coast Green Solutions* – Milwaukee’s 2009 report is subtitled *Weaving Milwaukee's Green & Grey Infrastructure for a Sustainable Future*.[115] The report provides cost estimates for “green” solutions to stormwater management:

- rain gardens $3 - $12/sqft ($3.75 per gallon of controlled stormwater);
- naturalized area $3,400-$6,000 / acre ($0.07 per gallon);
- porous pavement $87,000 - $217,000 / acre ($0.35 per gallon);
- constructed wetland $40,000 - $82,000 / acre ($0.06 per gallon);
- operational in 1994 and with a storage capacity of 405M gallons, the adjusted cost per gallon of stormwater controlled in the City’s 19 mile long system is $2.42 per gallon.

[112] While not noted in the report, it is assumed the high value of replacement costs is for full rehabilitation of the right-of-way.

[113] *Reducing Stormwater Costs Through Low Impact Development Strategies and Practices*, US EPA, 2007
http://water.epa.gov/polwaste/green/upload/2008_01_02_NPS_lid_costs07uments_reducingstormwatercosts-2.pdf

[114] http://www.sustainabletechnologies.ca/Portals/_Rainbow/Documents/LID%20SWM%20Guide%20-%20v1.0_2010_1_no%20appendices.pdf

[115] *Fresh Coast Green Solutions: Weaving Milwaukee’s Green and Grey Infrastructure into a Sustainable Future* City of Milwaukee, 2009 The plan sets a goal of zero sewer overflows and zero flooded basements. The plan includes a deep tunnel for combines sewage storage and significant dedication to green infrastructure and notes Milwaukee is implementing many measures similar to Toronto. See chart on p. 16 of the report for a cost summary.
http://v3.mmsd.com/assetsclient/documents/sustainability/SustainBookletWeb1209.pdf

12.1.3 Kitchener's Stormwater Utility and Rate Structure

Kitchener transferred stormwater management funding from property taxes to a user-fee program, effective Jan. 1, 2011. A principal feature of a dedicated funding source was to allow flexibility to respond to climate change and to create increased awareness of the costs and importance of managing stormwater. The new stormwater user fee appeared on monthly utility bills beginning in February 2011. The average single dwelling homeowner will be charged approximately $9.73/per month for stormwater management. This funding model allows Kitchener to dedicate dollars specifically to stormwater management — a service that Kitchener considered had been consistently under funded or considered a low priority for historical funding from the tax base.

Commencing in 2004, Kitchener undertook a planning process which resulted in both the creation of a dedicated utility and in 2011 a dedicated income source. Kitchener valued its stormwater assets at $265M in 2011 including 700 km of sewers and 100 stormwater management ponds. A need for a dedicated income source was promoted as a solution to a sustainable funding gap — a need to increase historical spending by approximately 50%. An important finding of the review of service level was that, like other City services, the amount of service a resident receives is not proportional to the property assessment. The difference for stormwater services was that there is a relatively simple means to determine level of service based on the physical features of an individual property. That same characteristic could be used to incentivize private property actions to reduce stormwater runoff through an up to 45% reduction in the residential stormwater rate which can be achieved through private property measures.[116]

13.0 Opportunities to Promote Adaptation

Research identified a broad range of municipal stormwater management adaptation drivers, planning processes and implemented measures. Throughout the report where example measures were considered to offer opportunity for Ottawa, they were highlighted.

The following provides additional comments and perspectives regarding the opportunities identified in the report.

13.1 Common Understanding of Stormwater Management Adaptation

Research identified a range of definitions for "stormwater management adaptation" including reports which provided examples of projects and studies which outlined process. Research also identified that stormwater management decision making typically occurs across a number of municipal business units and that lack of a common level of understanding of climate change adaptation may hinder progress. Developing a common understanding of "stormwater management adaptation" at the City will facilitate decision making on both existing and new initiatives undertaken toward policy goals to improve stormwater management including through adaptation.

[116] Residential Credit Application Form http://www.kitchener.ca/en/livinginkitchener/Stormwater_Credit_Application_Residential.asp

13.2 Stormwater Management Adaptation Plan

Research identified few examples of long implemented stormwater management adaptation measures – the state of practice for adaptation is in its infancy. Many reports outlined a process through which a stormwater management adaptation plan could be developed independently or as a component of a broader corporate plan — notably the ICLEI methodology. The City may research planning methodologies and compare to existing initiatives and corporate strategic planning methods. The goal of the research would be to identify a process which will work within the City's existing business practices and align best with policy goals to improve stormwater management including through adaptation.

13.2.1 Consider Adaptation as a Process

Research identified that some information sources identify stormwater management adaptation as an inventory of measures while other information sources identify stormwater management adaptation as a process. A candidate definition for a process is proposed in Section 2.2 *(pg. 14)*:

> *Co-ordinated structural and non-structural changes in practices and approaches to stormwater management developed within an integrated social, environmental and fiscal sustainability focussed municipal planning process for climate change.*

13.2.2 Candidate Themes

Research identified that the topic of stormwater management adaptation is discussed in information sources under Chapter and Section headings (or Web tabs) selected to provide a logical presentation of the issues being addressed in the information source. Selecting specific topics as subsets of the overall topic of stormwater management adaptation within a coordinated framework may help start to define tasks of a magnitude and scope which can be initiated within existing staff and budget resources as well as help define business unit responsibilities.

The following themes may provide a starting point for discussion:

- Updating Design Tools – the IDF Curve;
- Risk and Vulnerability Assessments;
- Integrating Stormwater Management Adaptation into Modeling Tools;
- Protecting Infrastructure in Design Exceedence Events;
- Urban Streets;
- Green Infrastructure and LID;
- Stormwater Management Facilities;
- Operational Stormwater Management Adaptation Measures.

13.3 Green Infrastructure

Research identified that the City's policies and guidelines are supportive of green infrastructure as an adaptation measure however a review of City Committee reports and plans like the *Ottawa River Actio Plan* family of measures shows these do not highlight the opportunity to the extent that other municipalities facing the same climate and infrastructure challenges as Ottawa have. A more detailed review of the municipal plans of cities such as Philadelphia including direct contact with municipal representatives to obtain the most recent information of successes and challenges may help the City determine if the benefits other municipalities have identified could be achieved in Ottawa.

13.4 Welland – A Recent Example of a Risk Study

A mandate of the research was to identify current information sources. Completed in February 2012, Welland's wastewater and stormwater infrastructure using the PIEVC assessment tool provides a very current example of the scope, level of effort and possible conclusions that could arise if the City undertook a similar study as recommended in the *Wet Weather Infrastructure Master Plan*. A detailed review of the report including an assessment of the comparability of business unit processes between Welland and Ottawa as well as contact with Welland municipal staff could advise the City on the costs and benefits of this type of assessment.

13.5 Rehabilitation Opportunities

Research identified that some of the communities that had undertaken a stormwater management infrastructure assessment concluded that existing infrastructure capacities, if performing as designed, did not present a high risk. Welland and Saanich both concluded that their ongoing rehabilitation program is an appropriate tool to address stormwater management adaptation. Welland and London identified that in updating their IDF curves, old curves proved to be conservative and updated curves were actually lower bringing new perspectives to the capability of their infrastructure and reducing to some degree the anxiety associated with considering climate change.

13.6 Interdisciplinary Project Scope and Management

Research identified that a multi-disciplinary approach involving engineering, environment and the role and opportunity in public infrastructure (e.g. parks, public buildings, etc.) allows innovative solutions to climate change-related challenges to be developed. The City's project development and management processes include communication among business units. Adding climate issues including for stormwater management adaptation into process flow charts and measures will help ensure common understanding and promote new skills to participate in a discussion of adaptation.

13.7 Standby Power Capacity Review

Research indicated that the presence of standby power is one of the most important factors in mitigation during an emergency event as resulting from intense rainfall and flooding. Also, that power supply is important in the the post event recovery period. A review of the City's standby power risks and capabilities may be a stand alone adaptation step which could contribute to the City's resilience to severe weather events. Discussions with Ottawa Hydro and Ontario Power Generation may also promote, in the longer term, resilience in Ottawa's power systems.

13.8 Modelling Stormwater Management Adaptation

Modelling is an important tool in stormwater management and the City has well established modeling methodologies and staff expertise. A review of modeling methodologies in consideration of stormwater management adaptation including how to account for the City's goals for improved stormwater management and intensification may be a stand alone adaptation step which can be used to improve the resilience of existing and new systems designed or re-designed using these modeling tools.

13.9 Adaptation Approach to Updating IDF Curves

Research indicated that updating IDF curves is being undertaken in a number of municipalities and also that there are a variety of updating methodologies being used. A more comprehensive technical review of the information sources provided in this report and other detailed descriptions of update processes may be a first step in an adaptation focused IDF update process at the City. As discussed in the projects detailed in this report, the results of an IDF update process may instigate a wide variety of policy discussions which may form a subsequent step in stormwater management adaptation planning.

13.10 Green Infrastructure for CSO Control

Research indicated that a number of municipalities in the northeast United States that have infrastructure profiles and core area construction challenges similar to Ottawa including combined sewers have embraced a role for green infrastructure in their combined sewer overflow management projects. Given the scope of the predicted cost savings (and considering the many other benefits these cities have identified), a detailed technical review of the projects outlined in this report and contact with municipal representatives in cities such as Milwaukee and Philadelphia to obtain the most recent information of successes and challenges may help the City determine if the benefits other municipalities have identified could be achieved in Ottawa.

13.11 Green Streets Pilot Projects

Green streets are an application of the green infrastructure methods supported by City policy and noted above. Many research sources noted the role of pilot projects as a first step in testing methods well practiced in other areas. A pilot program for green streets including sufficient projects to demonstrate alternative designs as reference for future projects would help achieve Ottawa's green streets policy goals[117] and stormwater improvement policy goals.

13.12 Cost of Stormwater Management Adaptation

Research indicated that cost factors are used to both incite concern and action on anticipated climate change impacts and assure readers that there are net financial benefits from addressing climate change including the implementation of stormwater management adaptation measures. In the context of the reports in which this information was provided, the information was accurate. However, cost information has strong influence in municipal decision making in particular given today's fiscal constraints. Any use of cost information related to stormwater management adaptation must clearly detail sources, the relevance of the source, the cost analysis methodology as it relates to the current reporting requirement, a statement of confidence in the cost information and a statement in "costs" which are not quantified but must form part of decision making. A more detailed analysis of the cost information and sources provided in this report and of other sources toward development of a confident statement of stormwater adaptation costs relevant to Ottawa could help ensure that the best available cost information informs debate about City actions.

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[117] City of Ottawa *Design and Planning Guidelines Section 8.1 Green Street Designs* http://ottawa.ca/en/city-hall/planning-and-development/community-plans-and-design-guidelines/design-and-planning-0/80/81

Appendix 1: List of Additional Resources

City of Ottawa Climate Actions

2012 Green Building Promotion Program
http://ottawa.ca/sites/ottawa.ca/files/migrated/files/cap178204.pdf

Term of Council Priorities, Report to Finance and Economic Development Committee, June 7, 2011
http://www.ottawa.ca/calendar/ottawa/citycouncil/occ/2011/07-13/fedco/01%20-%20ACS2011-CMR-FED-0004%20-%20Council%20Priorities.htm

Air Quality and Climate Change Management Plan, 2004
http://ottawa.ca/sites/ottawa.ca/files/migrated/files/cap078824.pdf

Climate Change Adaptation Plan Process, Report to Planning Transit and Environment Committee, 25 June 2008
http://ottawa.ca/calendar/ottawa/citycouncil/occ/2008/08-28/pec/ACS2008-PTE-ECO-0013.htm

Adapting to Climate Change in Ottawa, Ontario Centre for Climate Impacts and Adaptation Resources Workshop, 2009
http://www.climateontario.ca/doc/workshop/2009WorkshopReport/Ottawa%20Workshop%20Final%20Report.pdf

Choosing Our Future Risk Prevention and Mitigation Plan, 2012
http://ottawa.ca/calendar/ottawa/citycouncil/occ/2012/02-22/ec/03-Document%205%20-%20Ottawa_Risk%20Plan_FINAL%5B1%5D.pdf

Case Study – Ottawa's Climate Change Adaptation Planning Process, Presentation to the Canadian Network of Asset Managers, 2010
http://www.cnam.ca/uploads/Documents/Workshop/2010/presentations/CNAM10_Session_3-_A_Changing_Climate_for_Infrastrucutre_Assets_Isernhagen.pdf

Other Municipal Climate Actions

City of Toronto
http://www.toronto.ca/teo/adaptation/resilience.htm
http://www.toronto.ca/teo/adaptation/index.htm
http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf
http://www.toronto.ca/teo/adaptation/pdf/toronto_cc_adapt_actions.pdf
City of Hamilton
http://www.cleanairpartnership.org/files/Hamilton%20Final.pdf

Town of Ajax
http://www.cleanairpartnership.org/files/Ajax%20Final.pdf

Provincial Government Resources

Ministry of Municipal Affairs and Housing Planning for Climate Change: The Ministry provides advice on how climate change can be incorporated into planning tools like Official Plans or Plans of Subdivision. http://www.mah.gov.on.ca/Page6857.aspx

Ministry of Municipal Affairs and Housing Draft Provincial Policy Statement: The Province has issued draft changes to the PPS. The PPS 2005 included the word "climate" once and had only one policy which referenced stormwater. Under the draft changes, the word "climate" appears 12 times and there are new policies directly speaking to stormwater — draft Policy 1.6.5.7 in Section 1.6 Infrastructure and Public Services http://www.mah.gov.on.ca/Page9990.aspx#Preamble

Ministry of Natural Resources: The Ministry focuses on approaches to ecosystem-focused adaptive management related to issues such as such as impacts of warmer temperatures on vegetation along waterways, coldwater fish habitat, wetland water levels, tourism activities (e.g. skiing, snowmobiling, and ice fishing), and the composition of tree species in the forest.
http://www.mnr.gov.on.ca/en/Business/ClimateChange/2ColumnSubPage/STDPROD_090113.html

Ministry of the Environment Stormwater Adaptation: This Ministry Web site includes a link to the Province's "Expert Panel on Climate Adaptation" report (November 2009) and the resulting policy review of municipal stormwater management in light of climate change (March 2010)
http://www.ene.gov.on.ca/environment/en/subject/stormwater_management/STDPROD_076046.html

Ouranos – Consortium on Regional Climatology and Adaptation to Climate Change
Based in Quebec, Ouranos is a consortium that brings together 400 scientists and professionals from different disciplines. It focuses on two main themes: Climate Sciences and Impacts & Adaptation. http://www.ouranos.ca/en/default.php

Provincial Government Reports

Adapting to Climate Change in Ontario November 2009
http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079212.pdf

Climate Ready: Ontario's Adaptation Strategy and Action Plan 2011 – 2015 April 2011
http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_085423.pdf

Ready for Change? An assessment of Ontario's climate change adaptation strategy, Environment Commissioner, March 2012
http://www.eco.on.ca/uploads/Reports-special/2012-Adaptation/Ready-for-Change-bookmarked.pdf

Conservation Ontario's Response to "Climate Ready", June 2011
http://www.conservation-ontario.on.ca/resources/reports/documents/COResponsetoClimateReadyreportfinaljune10.pdf

Federal

Canada’s Action on Climate Change
http://www.climatechange.gc.ca/default.asp?lang=En&n=72F16A84-1

Climate Change Impacts and Adaptation Division, Natural Resources Canada
The Division has managed the development and programming of six Regional Adaptation Collaboratives including the Ontario RAC to undertake projects which demonstrate adaptation. A number of RAC funded projects deal with stormwater management adaptation.
http://www.nrcan.gc.ca/earth-sciences/about/organization/organization-structure/climate-change-impacts-adaptation-division/283

Case Studies: http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/case-study/155

Canadian Climate Change Scenarios Network, Environment Canada
The CCCSN is a partner interface for distributing climate change scenarios and adaptation research. http://www.cccsn.ec.gc.ca/?page=main&lang=en

Partners for Climate Protection
The Partners for Climate Protection (PCP) program is a network of Canadian municipal governments that have committed to reducing greenhouse gases and acting on climate change.
http://www.fcm.ca/home/programs/partners-for-climate-protection.htm

FCM Climate Change Adaptation Program
Local governments play a key role in preparing their communities to build resilience and establish the right conditions for adaptation. Governments must take climate change into account when managing their assets and programs, services and economic development. Increased investment in a community's ability to overcome natural disasters will safeguard existing economic progress, and increase the economy's climate-related resilience.
http://www.fcm.ca/home/issues/environment/climate-change-adaptation/taking-action.htm
Case Studies: http://www.fcm.ca/home/issues/environment/climate-change-adaptation/adaptation-resources/case-studies.htm

Non-governmental and Academic Resources

Climate Change Adaptation Community of Practice
The Climate Change Adaptation Community of Practice (CoP) is facilitated and maintained by the Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR). The CoP grew out of a 2008 summit on climate change adaptation that was attended by provincial, territorial and federal government representatives, as well as members of the Canadian scientific, academic, and engineering communities. The Library provides an extensive resource of reports on climate adaptation (member sign-up required to access Library resources).
http://www.ccadaptation.ca/about

Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR)
OCCIAR is a university-based resource hub for researchers and stakeholders searching for information on climate change impacts and adaptation. The centre communicates the latest research on climate change impacts and adaptation; liaises with partners across Canada to encourage adaptation to climate change and aids in the development of tools to assist with municipal adaptation. http://www.climateontario.ca/

The Ontario Regional Climate Change Consortium
Since February of 2010, CC-RAI has been working with universities, as well as private and private sector organizations across the province to develop a pan-Ontario climate science, research and services initiative.
http://www.climateconsortium.ca/wp-content/uploads/2011/07/Final-DRAFT-orccc-jULY-4-1PM-.pdf

Stormwater – The Journal for Surface Water Quality Professionals
The Journal has many current news articles about adaptation and related issues.
http://www.stormh2o.com/SW/SWhome.aspx

Ontario Climate Consortium
The Ontario Climate Consortium (OCC or Consortium) represents a distributed collective of scientists, researchers and practitioners from across Ontario with a focus on addressing climate change issues pertinent to Ontario and beyond. The OCC is hosting its 1st Annual Climate Change Research Symposium in May 2013.
http://climateontario.org/wp/

Great Lakes Integrated Sciences and Assessment Center
The Great Lakes Integrated Sciences and Assessments Center (GLISA) is a collaboration of the University of Michigan and Michigan State University, with the participation of Ohio State University and Michigan Sea Grant. GLISA is part of a national network of regional centers focused on adaptation to climate change and variability
http://www.glisa.msu.edu/about/index.php

The Great Lakes and St. Lawrence Cities Initiative
Through an integrated approach to environmental, social and economic agendas within communities, U.S. and Canadian mayors of the Cities Initiative are leading a movement that will sustain our freshwater resources including stormwater management.
http://www.glslcities.org/
http://www.glslcities.org/initiatives/greencities/stormwater.cfm

Municipal Resources for Adapting to Climate Change, Federation of Canadian Municipalities, 2009. This short report from the Partners for Climate Protection (PCP) program — a partnership between FCM and ICLEI Local Governments for Sustainability — provides links to resources and organizations and a brief section detailing the activities of a number of Canadian and international cities who are well advanced in climate adaptation.
http://www.fcm.ca/Documents/reports/PCP/Municipal_Resources_for_Adapting_to_Climate_Change_EN.pdf

Building Adaptive and Resilient Communities (BARC) Web resource, ICLEI Local Governments for Sustainability Canada. The ICLEI program is an internationally recognized resource for municipal adaptation planning.
http://www.icleicanada.org/programs/adaptation/barc-resources

Urban Flooding in Canada: Loss side risk reduction through voluntary retrofit programs, code interpretation and bylaws, Dan Sandink, February 2013. See also the Institute for Catastrophic Loss Reduction Web resource.
http://www.iclr.org/images/Urban_Flooding_in_Canada_-_ICLR_-_2013.pdf
http://www.iclr.org/home.html

Case Studies

Cermak/Blue Island Sustainable Streetscape, Chicago Dept. of Transport, 2012. Billed as the most sustainable street in the United States, this project involves transformation of a 2 mile stretch of urban street to address a complete set of sustainability goals. Phase 1 of the $14M project, completed in 2012, will divert 80% of stormwater from Chicago's combined sewer system. Information about the project and Chicago's Green Streets program can be found at the following links:
http://environment.transportation.org/environmental_issues/sustainability/case_studies.aspx
http://www.cityofchicago.org/content/dam/city/depts/cdot/CDOTProjects/PilsenSustainableStreetGuide.pdf
http://www.cityofchicago.org/city/en/depts/cdot/supp_info/streetscapes_andsustainabledesign.html
http://www.glslcities.org/greencities/Powerpoints/02_Attarian_Presentation.pdf

Case Study Compendiums

Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure, United States Environmental Protection Agency, August 2010 (EPA-841-F-10-004)
http://www.epa.gov/owow/NPS/lid/gi_case_studies_2010.pdf

National Resources Canada Regional Adaptation Collaborative. This $30M federal program's goal was to translate climate science into actions through funding projects demonstrating adaptation. While the program has officially ended, it is understood that NRCan is currently seeking two more projects in each of six RAC regions to develop additional case studies. A number of the completed RAC projects address stormwater management adaptation.
http://www.nrcan.gc.ca/earth-sciences/climate-change/community-adaptation/case-study/155

Environmental Protection Agency Stormwater Case Studies
EPA has developed a series of stormwater case studies to help Phase II municipal separate storm sewer systems (MS4s) get started on or improve their stormwater management programs. http://cfpub.epa.gov/npdes/stormwater/casestudies.cfm

Cities Preparing for Climate Change: A study of six urban regions
This report incorporates the lessons learned from six “early adopters” — London, New York, Boston region, Halifax, Greater Vancouver, and Seattle and King County — and addresses these experiences by phase of the adaptation planning process.
http://www.cleanairpartnership.org/pdf/cities_climate_change.pdf

Stormwater Management Best Practice Information

Greening Stormwater Management in Ontario, An Analysis of Challenges and Opportunities, Matt Binstock, Canadian Institiue for Environmental Law and Policy, June 2011
http://greeninfrastructureontario.org/sites/greeninfrastructureontario.org/files/GreeningStormManOntario.pdf

Innovative Stormwater Management Practices Web site. An online database and showcase of LID practices in Ontario developed by the Toronto Region Conservation Authority
http://www.iswm.ca/

Peeling Back the Pavement – A Blueprint for Reinventing Rainwater Management in Canada’s Communities, Susanne Porter-Bopp et al, 2011, Co-published by Environmental Law Centre, University of Victoria http://poliswaterproject.org/sites/default/files/Peeling_Back_lowres_nov17.pdf

Green Infrastructure Ontario Coalition Web site
The coalition advocates:

- decision-makers in both the public and private sector to quantify the economic, social, environmental and health benefits of green infrastructure
- policy improvements at both the municipal and provincial level to facilitate green infrastructure opportunities
- a shift in both public and private investment, that leads to greater protection and enhancement of green infrastructure

http://greeninfrastructureontario.org/

US EPA Green Infrastructure Case Studies
Green infrastructure first emerged as an alternative approach to stormwater management in the early 1990s. Since then, stormwater professionals have accumulated an extensive body of knowledge on the design of green infrastructure practices that improve the triple bottom line, and on the development of policies that support this approach.
http://water.epa.gov/infrastructure/greeninfrastructure/index.cfm#tabs-4

WERF Sustainable Stormwater Best Management Practices (BMPs) Case Studies
To learn how stormwater best management practices can be successfully implemented, key players from a small, but representative, sample of places actively promoting and developing stormwater BMPs were interviewed.
http://www.werf.org/liveablecommunities/studies_main.htm

TRCA ISWM Innovative LID Showcase and Sustainable Technologies Evaluation Program
Featured studies can be found at:
http://www.iswm.ca/lid_map.php
http://www.sustainabletechnologies.ca/

Rooftops to Rivers II – Green Strategies for Controlling Stormwater and Combined Sewer Overflows, National Resources Defense Council, 2011. This report includes case study examples from US cities and from Toronto with good summaries of the capital cost and anticipated cost savings of municipal strategies.
http://www.nrdc.org/water/pollution/rooftopsii/files/rooftopstoriversII.pdf

Choosing Green over Gray: Philadelphia's Innovative Stormwater Management Infrastructure Plan, Sarah Madden, Masachusetts Institute of Technology, June 2010. This Master's thesis presents a comprehensive discussion of the process whereby the City developed and gained approval for its plan. http://stuff.mit.edu/afs/athena/dept/cron/project/urban-sustainability/Stormwater_Sarah%20Madden/sarahmadden_thesis_MIT.pdf

Fresh Coast Green Solutions: Weaving Milwaukee's Green and Grey Infrastructure into a Sustainable Future City of Milwaukee, 2009 The plan sets a goal of zero sewer overflows and zero flooded basements. The plan includes a deep tunnel for combines sewage storage and significant dedication to green infrastructure and notes Milwaukee is implementing many measures similar to Toronto.
http://v3.mmsd.com/assetsclient/documents/sustainability/SustainBookletWeb1209.pdf

Cost Analysis of Stormwater Adaptation

Unpave a Parking Lot and Put up a Paradise: Using Green Infrastructure and Ecosystem Services to Achieve Cost Effective Compliance, Robert McKinstry Jr., David Prior, Jennifer E. Durst, Anna C. Montalban, Kimberly D. Magini, September 2012, Enviromental Law Institute. This article summarizes that Philadelphia's "Green Cities, Clean Waters" program, which will invest $2.5 billion in green infrastructure, has an anticipated savings of $8 billion compared to a "traditional grey infrastructure".
http://www.eli.org/pdf/42.10824.pdf

Adaptation to Climate Change – Green Stormwater Management for Communities Across New York State, New York State Department of Transportation, 2013. This recent report (and the referenced summary presentation) includes cost analysis for a range of green infrastructure solutions along with case study information from locations including upper New York State.
http://www.earth.columbia.edu/sitefiles/file/education/documents/2013/NYSDOT_AdaptationtoCC.pdf
http://www.dec.ny.gov/docs/administration_pdf/giWebstearn.pdf

Adaptation Strategies Guide for Water Utilities, US EPA, January 2012. This document is a Web enabled workbook which details climate risks and adaptation measures based on 7 subregions in the United States including the Northeast. Each measure is listed against a qualitative cost factor and no regret measures are highlighted.
http://water.epa.gov/infrastructure/watersecurity/climate/upload/epa817k11003.pdf

Climate Adaptation "State of Practice" and other Recent Reports

Barriers and guidelines for public policies on climate change adaptation: A missed opportunity of scientific knowledge-brokerage, February 2013, Natural Resources Forum Vol. 37, Issue 1, pp 1-18: The article concludes that the many adaptation guidelines developed to assist in promotion of adaptation are neither comprehensive nor systematic, focusing on subjective experiences rather than on empirical research findings.
http://www.ccadaptation.ca/documents/generalpolicyinstitutionalarrangements/barriersandguidelinesforpublicpoliciesonclimatechangeadaptationamiss

Mainstreaming Climate Change Adaptation in Canadian Water Resource Management November 2012, Toronto and Region Conservation Authority and ESSA Technologies. The report provides a snapshot of the current state-of-practice with respect of climate change adaptation in water resource management across Canada including promoting understanding of the "loss of stationarity". Section 3.2.6 discusses strengthening of infrastructure to a greater range of extremes and Section 3.2.7 promotes showcasing of adaptation measures.
http://waterandclimate.ca/WP/wp-content/uploads/2012/11/MainstreamReport_FINAL_FORMATTED_Nov17.pdf

Adapting to Climate Change: An Introduction for Canadian Municipalities, G.R.A Richardson, Natural Resources Canada, 2010: The report includes eleven case studies including reporting on Metro Vancouver's Stormwater Management Strategy and London's Climate Change Adaptation Strategy.
http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca.earth-sciences/files/pdf/mun/pdf/mun_e.pdf

Community Based Adaptation Planning, Clean Air Partnership Web resource including case studies.
http://www.cleanairpartnership.org/cai_case_studies

Engineering Literature Review: Water resources – infrastructure impacts, vulnerabilities and design considerations for future climate change
This review includes information on water infrastructure and climate change resource documents, impacts of climate change on water resources, and a summary, discussion and recommendations. http://www.pievc.ca/e/Appendix_C_Literature_Reviews.pdf

Federation of Canadian Municipalities Climate Adaptation Resources
Provides details, guidance, and tools to help municipalities begin an adaptation process.
http://www.fcm.ca/home/issues/environment/climate-change-adaptation.htm

International Cities

Leveraging Public Spending for Greener Cities, Powerpoint presentation by Steve Moddemeyer, City of Seattle. This Powerpoint presents a good overview of Seattle's progress on its comprehensive sustainability plan including an interesting graphic showing redevelopment of green in urban environments *(Slide 25)*.
https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/16459/moddemeyer.pdf?sequence=2

Sustainable Infrastructure in Seattle – Leveraging Capital for Sustainable Outcomes, International Water Association Presentation Singapore 2012, Steve Moddemeyer, City of Seattle. This paper presents a wide ranging view of the municipal challenges of climate change, urban growth and infrastructure costs and how Seattle is addressing those challenges.
http://www.atlantaregional.com/File%20Library/Local%20Gov%20Services/mgt%20and%20ops/Community%20Practices/Moddemeyer-SingaporeIWA-544-1-.pdf

International Reports and Web Resources

Adaptation Inspiration Book: 22 Implemented Cases of Local Climate Change Adaptation to Inspire European Citizens, Circle 2: Climate Impact Research & Response Coordination for a Larger Europe (EU FP7 ERA-NET) 2013. Of the 22 case studies, 8 deal with flooding. Cost estimates are provided.
http://www.circle-era.eu/np4/%7B$clientServletPath%7D/?newsId=432&fileName=BOOK_150_dpi.pdf

The State of Adaptation in the United States, April 2013: Prepared by EcoAdapt, a Washington State based advocacy group, the report includes Chapter 4 – Preparing Human Communities and the Built Environment for Climate Change.
http://ecoadapt.org/data/documents/TheStateofAdaptationintheUnitedStates2013.pdf

The State of Adaptation in the Great Lakes Region, October 2012: Prepared by EcoAdapt, a Washington State based advocacy group, the report includes a chapter describing adaptation projects and programs in the Great Lakes Region and a 159 page Appendix of Adaptation Case Studies including many Ontario stormwater adaptation projects.
http://ecoadapt.org/data/library-documents/EcoAdapt_GreatLakesAdaptation.pdf

National Fish, Wildlife and Plants Climate Adaptation Strategy, April 2013: In partnership with State and Tribal agencies, the Obama Administration released the first nationwide strategy to help public and private decision makers address the impacts that climate change is having on natural resources and the people and economies that depend on them.
http://www.wildlifeadaptationstrategy.gov/

A comprehensive review of climate adaptation in the United States: more than before, but less than needed, October 2012. Published on open source site Springerlink.com. R. Bierbaum, School of Natural Resources and Environment, University of Michigan lead author

Implementing Climate Change Adaptation – Lessons Learned from Ten Examples prepared by Headwaters Economics, a nonprofit research group, in February 2012. The ten examples are US cities.
http://headwaterseconomics.org/wphw/wp-content/uploads/Climate_Adaptation_Lessons_Learned.pdf

Confronting Climate Change: Science, Impacts, and Solutions
This Webpage provides access to a series of in-depth reports on the potential consequences of climate change in several regions and states: the Midwest (IN, MN, MO, OH), Northeast (CT, MA, ME, NH, NJ, NY, PA, RI, VT), Great Lakes region, and the Gulf Coast. To find the relevant publication, search the page for the name of the state or region.
http://www.ucsusa.org/publications
http://www.climatehotmap.org/global-warming-effects/lakes-and-rivers.html

Prepared – Enabling Change: http://www.prepared-fp7.eu/
Over a period of five years commencing in February 2010, the European Commission is funding “Prepared – Enabling Change” to work with a number of urban utilities to advance strategies to meet anticipated challenges brought about by climate change. The Web site contains short summaries of the sponsored projects, including a number of projects focused on achieving management of combined sewer overflows. A report titled Review Climate Change Impacts on Urban Stormwater and Adaptation includes an overview of issues as well as summary reports of the Barcelona and Oslo projects: http://www.prepared-fp7.eu/viewer/file.aspx?fileinfoID=283

A Survey of Climate Change Adaptation Planning, Heinz Center for Science, Economics, and the Environment, 2007. This report includes US, Canadian and International examples. Canadian examples are Quebec, Toronto and Vancouver.
http://public.wsu.edu/~forda/285/Survey%20of%20Climate%20Change%20Adaptation%20Planning.pdf

Managing the Risks of Extreme Events andDisasters to Advance Climate Change Adaptation, Intergovernmental Panel on Climate Change 2011. See in particular Chapter 4 – New Dimensions in Disaster Risk, Exposure, Vulnerability and Resilience which discusses the relationships between disaster management and adaptation.
http://ipcc-wg2.gov/SREX/images/uploads/SREX-Chap1_FINAL.pdf

Corporate Risk Case Study: City of Chicago Climate Change Task Force
This document reports the results of a Corporate Risk case study modeled for the City of Chicago’s municipally controlled assets. Although it does not provide information on the proprietary methodology used, it does show output that can be obtained by such an analysis, which may be useful to others considering whether to undertake such an analysis.
http://www.chicagoclimateaction.org/filebin/pdf/report/CorporateRisk2008August5.pdf

Terms and Definitions

Some of the terms and definitions provided in Section 1.3 *(pg. 8)* were sourced from the following Web sites:

http://www.peopleandplace.net/media_library/text/2009/5/19/glossary_of_climate_adaptation_and_decision-making

http://www.idrc.ca/EN/Resources/Tools_and_Training/Manuals/Integrated%20Climate%20Risk%20Assessment%20-%20Training%20Manual.pdf

http://www.pievc.ca/e/doc_glossary.cfm

http://www.climate-adaptation.info/?page_id=51

http://ipcc-wg2.gov/SREX/images/uploads/SREX-Chap1_FINAL.pdf

http://greeninfrastructureontario.org/

http://lowimpactdevelopment.org/index.htm

http://www.ec.gc.ca/Publications/1F12B5E2-B32F-4802-B8D2-7D6419CD0F9D%5CCompendiumEnglish.pdf

Appendix 2: Expert Contacts

The following stormwater and climate change adaptation practitioners and experts were interviewed as a component of the research project. Interviewees were asked for their perspectives on the state of practice for stormwater management adaptation as well as references to any projects they considered examples of best practice. The input and perspectives from interviewees guided the development of the report.

The authors wish to extend our appreciation to the interviewees for their input and time.

City of Toronto:

- David T. MacLeod, Senior Environmental Specialist, Environment & Energy Office
- Ted Bowering, Manager, Storm Water Management, Water Infrastructure Management, Toronto Water
- Nazareno Capano, Manager, Operational Planning and Policy, Transportation Services
- Devin Causley, MCIP RPP, Manager, Climate Change Programs, Federation of Canadian Municipalities
- Harris Switzman, Project Manager, Climate Change Adaptation, Toronto and Region Conservation
- Jean-François Sabourin, M.Eng, ing., Director of Water Resources Projects, J.F. Sabourin and Associates Inc.
- Jackie Oblak, Climate Specialist, Mississippi Valley Conservation
- Kevin Behan, Director of Research, Clean Air Partnership
- Mike Sullivan, Chair Canadian Institute of Planners Climate Committee
- Hiran Sandanayake, Chair Canadian Water and Wastewater Association Climate Committee
- Nicholas Ruder, Policy Advisor, Association of Municipalities of Ontario
- Nicola Crawhall, Deputy Director Great Lakes & St. Lawrence Cities Initiative