ECONOMIC ASSESSMENT OF CLIMATE CHANGE SCENARIOS ON DRAINAGE INFRASTRUCTURE DESIGN

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ABSTRACT

Economic Assessment of Climate Change Scenarios on Drainage Infrastructure Design

The potential impacts of climate change on the ability of existing and planned drainage infrastructure to safely convey flood flows and prevent off-site erosion, is causing municipalities to examine the recent shifts in storm patterns (rainfall volume, intensity and frequency) and the associated implication to design approaches. This paper examines, by way of two case studies, the approaches taken by different southern Ontario centres, specifically the communities of Cambridge and Milton.

Major flooding problems were caused by severe storms in excess of a 50 year return period in 2005 and again in 2006 in the City of Cambridge. In response, a plan was prepared to alleviate the existing flood risk by way of increasing conveyance infrastructure capacity and providing designated flood storage. The uncertainty related to potential climate change impacts was examined by developing various configurations of drainage infrastructure designed to events of decreasing frequency including 100, 200, and 500 year storms, based on current intensity duration frequency relationships. Each scenario was costed and the economic implications provided to City of Cambridge administrators to review in terms of risk versus costs, in order that more informed decisions could be made when planning the City's Capital Program. The City adopted the more conservative design standards due to concerns associated with Public safety. The key project components were constructed accordingly in 2008 and 2009 (on-going).

In the Town of Milton case study, an on-going subwatershed study supporting future planned development of a Major Business Park provided the opportunity to apply meteorologic time series related to climate change scenarios, originally developed by Environment Canada and subsequently modified by Credit Valley Conservation for use in a neighbouring watershed scale assessment. A calibrated hydrologic model was used to assess the impact of modified meteorologic conditions (reflecting potential climate change scenarios) on off-site flood and erosion susceptibility, as well as the design of stormwater management infrastructure. The economic impacts, in terms of land consumption and capital costs for construction, were assessed and compared for stormwater management systems designed under current (standard) and future climate change scenarios.

1. INTRODUCTION/OVERVIEW

Climate Change is hypothesized by many to be causing changes to precipitation events including more severe, more frequent storms over a wider meteorologic period. These trends, to varying degrees, have the potential to cause significant impacts on stormwater runoff, particularly in more urbanized settings, where runoff rates are greater and response times quicker. In short, these trends would result in an increased risk of flooding, which would stress the capacity of existing conveyance infrastructure (i.e. culverts, bridges, storm sewers, stormwater management systems, etc.).

The majority of existing drainage systems have been designed over the past 50 years (+/-) and for the most part have relied on statistically-based intensity-duration-frequency relationships to generate design storms and thereby size the infrastructure. However, if the trends continue, and if the hypothesis is correct, drainage infrastructure will soon be demonstrated to be inadequate and thereby give rise for concern for public safety related to flooding.

Many Public Works officials and municipal leaders are concerned about this prospect and are beginning to examine alternative approaches for assessment and design to better manage the uncertainty regarding the potential impacts of climate change on the ability of existing and planned infrastructure, to safely convey flood flows. In the absence of clear and consistent direction at the national and provincial levels, municipalities are looking locally and using whatever tools are at their disposal to begin planning for a future affected by climate change.

Southern Ontario represents the most urbanized land mass in Canada. This area has also, in recent years, seen its share of major devastating storms, including storms in Oakville (2000), Peterborough (2004), Hamilton and North Toronto (2005), and Cambridge (2006). Two southern Ontario municipalities, the City of Cambridge, and Town of Milton have, as a result, taken alternative approaches to assessing risk and evaluating potential impacts of climate change.

The City of Cambridge suffered back-to-back storms in 2005 and 2006 with return periods over 50 years. These storms caused major flooding, particularly focussed in the Groff Mill Creek watershed, which is a highly urbanized drainage basin with predominantly commercial and industrial uses. In response to flooding problems in this watershed, a Class Environmental Assessment study was conducted leading to recommendations for infrastructure capacity improvements including creek upgrades, new culverts, and a designated flood storage basin. In order to determine a relationship between flood risk and cost, the infrastructure was assessed on the basis of alternative (more severe) return periods and the costs were provided to City Officials for assessment as part of a cost-benefit (reduced risk) assessment.

In the Town of Milton, Canada's fastest growing municipality in 2007 and 2008, Public Works officials are concerned about the adequacy of new stormwater management systems, which are currently being designed to historical rainfall records. An investigation which has adopted theoretical climate change meteorological time series was conducted in order to determine the influence on flood control stormwater management, both in terms of land consumption and capital construction costs. This paper examines the approaches taken by both of these municipalities and the resulting conclusions associated with economic impacts to stormwater infrastructure design.

Photo 1: Coronation Blvd. in the City of Cambridge in 2005

Photo 2: Overtopping of "repaired" Coronation Blvd in 2006

2. PROBLEM STATEMENT/BACKGROUND

As noted previously, climate change is hypothesized to be causing changes to the characteristics of precipitation events. As noted by many authors (such as Milly et al., 2008) such changes also belie one of the fundamental assumptions of typically accepted drainage infrastructure design:stationarity. Stationarity assumes that the statistical characteristics of a series (such as an IDF curve or flood frequency distribution) are constant over time. Thus, a 100-year return period design standard applied to drainage infrastructure remains a 100-year return period over time. Changes in precipitation patterns under climate change suggest however that this may no longer be (or never was) a valid design assumption. What was once a 100-year return period standard may, under climate change become a 50 or 25-year standard. Such changes render a great deal of previously adequately designed drainage infrastructure inadequate, and increases the risk to the public. As such, several researchers and agencies have begun trying to address this issue, through a variety of different methods.

In an unpublished work, J.P. Bruce has examined the impact of climate change upon storms in Southern Ontario, in particular Hurricane Hazel, the 1954 storm which is used as a regulatory design event throughout Southern Ontario. He suggests that the Hurricane Hazel design storm should likely be increased by the order of 16 to 20% in order to account for climate change to the year 2050.

Environment Canada, in conjunction with several Conservation Authorities and Municipalities in South Central Ontario, has examined the methodologies and processes involved with the development of IDF curves typically employed in municipal infrastructure design. The project is not only examining updates and future trends in IDF curves, but is also examining the creation of a regional rainfall database in order to address some of the shortcomings of point rainfall data. In particular, several severe storms have occurred over the last few years which have been missed by nearby point rainfall stations.

Several municipalities in the United States and Canada are also independently examining the impacts of climate change upon infrastructure through research groups. The Boston, Massachusetts area has established a project team (Climate's Long-term Impacts on Metro Boston project or CLIMB) which is examining the socio-economic and physical impact of climate change (Kirshen and Ruth, 2001). Likewise, the City of London, Ontario is working with an organization known as the Facility for Intelligent Design Support (FIDS) to examine both an update to IDF curves as well as the vulnerability of infrastructure under climate change.

The Ministry of Transportation of Ontario has funded a study of the effects of climate change on future design standards for drainage infrastructure in Ontario (Coulibaly and Shi, 2005). The study examined trends in observed precipitation data, as well as the use of global climate model/general circulation model (GCM) data to predict future daily precipitation patterns.

Environment Canada is quite active in the generation and analysis of GCM models, through agencies such as the Canadian Centre for Climate Modelling and Analysis. Mortsch et al. (2005), have examined selecting four GCM climate change scenarios for the Great Lakes – St. Lawrence basin area which essentially "box" the range of climate change uncertainty by covering the range of potential climate change impacts. Two of these recommended scenarios, the "Not as Warm and Wet" (HadCM3 B22) and the "Not as Warm and Dry" (CGCM2 B23) have been applied in the assessment discussed in Section 3.2.

Consideration has been given by several researchers to validation of these GCM results. Kunkel and Liang (2005) for instance, assessed the performance of nine different GCM simulations, and found that most models reproduced the basic precipitation patterns of the central United States. They also found that model ensemble means generally produced better agreement with observe data than any single model. However, many researchers suggest caution in applying the data from GCM simulations to smaller scale projects, which typically apply point source rainfall data. The output from GCMs is considered by many to be indicative of a grid cell average, with grid cells on the order of 10^5 to 10^6 km^2. As such, many researchers (such as Coulibaly and Shi, 2005) employ statistical downscaling techniques in order to obtain more spatially resolute climate data with good results. Another technique is the use of regional climate models (RCMs), which embed a finer grid with GCM cells, and use GCM results as boundary conditions. Guo and Senior (2006) found that modeled precipitation data from one RCM (CMM5) compared favorably with historically observed point data for the same period of record at two different locations. Such studies give further credence to the application of GCM or RCM data to local-scale projects such as those described in this paper.

3. CASE STUDIES

Considerable research is being conducted at the global, national, and provincial scales related to climate change and potential impacts on factors affecting storm runoff and drainage. Notwithstanding, there has been limited local direction offered for municipalities who are typically on the "front-line" faced with managing public risks through the design, implementation, and maintenance of storm drainage infrastructure.

This paper investigates the respective approaches taken by two southern Ontario municipalities to manage flood risk. The City of Cambridge is located in the middle portion of the Grand River watershed, a nationally acclaimed heritage river. A community of some 124,000 people, Cambridge is a highly urbanized municipality served by aging infrastructure.

The Town of Milton represents Canada's fastest growing community, more than doubling in the last eight years to a population of some 70,000. Milton is planning for growth to 150,000 people by 2031 and needs to plan for a safe stormwater management system for its future residents.

Figure 1: Location of Southern Ontario communities

3.1 Cambridge

3.1.1 Background

Numerous major storms have caused flooding impacts across Southern Ontario in recent years, including the July 16th, 2005 and September 13th, 2006 rainfall events that caused flooding in Cambridge, specifically in the Groff Mill Creek watershed. During these events, the Dumfries Conservation Area was subject to severe flooding depths and experienced trail washouts and various damages. The residence at 2235 Coronation Boulevard was surrounded by stormwater and sustained considerable basement flooding damage. Coronation Boulevard was overtopped resulting in damage to pedestrian sidewalks and the roadway embankment, as well as cutting off access to the local hospital. The Galt Country Club experienced significant damage to its channel and fairways, requiring the closure of two holes.

Figure 2: Highly urbanized Groff Mill Creek Watershed

Photo 3: Flood Damage on Galt Country Club Lands

As noted, these rainfall events were the catalyst for the City of Cambridge to conduct the Groff Mill Creek Class Environmental Assessment (Class EA) due to their magnitude and intensity, but also due to the relatively short inter-event period between them. These are all factors aligned with current trends and observations associated with climate change, which hypothesize that precipitation trends in southern Ontario (and worldwide) are changing. While meaningful local data is scarce, climate change, as related to precipitation events, is speculated to follow one or a combination of the following trends:

1. Increase in rainfall amount (mm);
2. Increase in frequency (extreme event frequency up 14% since 1970);
3. Increase in intensity (mm/hr; some climate models predict 20 to 60%);
4. Change in seasonal distribution.

These possible trends impact stormwater runoff to varying degrees including: an increase in rainfall depth directly increases runoff volume; an increase in rainfall event frequency increases the nuisance level of frequent minor flooding, and also increases the magnitude of flooding, since shorter inter-event periods leave soils saturated (the September 16, 2005 flooding event followed another significant event by only 2 days); an increase in intensity directly increases the magnitude of peak flows, which are the basis for conveyance infrastructure design; changes in seasonal patterns can reduce winter snow accumulation (which reduces spring runoff) and increase "rain-on-snow" events (which typically results in higher flows), among other impacts.

These changes in precipitation patterns and stormwater runoff response can significantly stress existing infrastructure (i.e. culverts, storm sewers, etc.), as they may not have been designed appropriately for the resulting runoff and/or frequency of occurrence in the future.

3.1.2 Intensity-Duration-Frequency Assessment

In an effort to better understand the potential influence of recent severe storms, the City of Cambridge initially elected to update its intensity-duration-frequency (IDF) parameters using the most currently available data. The existing City of Cambridge parameters are based on Atmospheric Environment Services (AES) IDF values for the period between 1971 and 1986 (inclusive) for the Waterloo Wellington 'A' gauge. As part of the Class EA, the IDF values for the period between 1971 and 2003 (inclusive) for the same gauge were obtained from Environment Canada and the City of Cambridge IDF parameters were updated accordingly.

Table 3.1.1 compares the return period rainfall depths for the 24 hour duration (as provided by the AES), for the existing and updated period of record.

TABLE 3.1.1
RAINFALL DEPTH - 24 HOUR DURATION (mm)

Data	**Return Period (Years)**					
	2	**5**	**10**	**25**	**50**	**100**
1971 - 2003	51.6	67.9	78.8	92.4	102.5	112.6
1971 - 1986	55.7	67.7	75.7	85.7	93.2	100.6

As is evident, the updated AES data for the Cambridge gauge provides higher return period rainfall depths for all frequencies above the 5 year event. The updated 100 year event rainfall depth indicates an increase of 12 %.

Subsequent analyses were completed in order to determine the relative impact of the recent major storm events of 2005 and 2006 on City of Cambridge rainfall depths. At the time of the study, the 2005 and 2006 rainfall record was not yet processed by Environment Canada. Due to their significant magnitude, it was speculated that the 2005 and 2006 rainfall records would have a significant impact on the return period depths. In order to provide a measure of the influence of the 2005 and 2006 rainfall records, frequency analyses were completed using the AES record (1971 to 2003) in combination with recorded rainfall depths for the July 15th, 2005 and September 13th, 2006 flood events. The Generalized-Extreme-Value (GEV) distribution was applied, as it provided return period depths that "best" compare with the AES values.

Frequency analysis were completed to determine the 2 though 100 year return period depths for varying periods of record to provide an indication of rainfall trends (ref. Table 3.1.2). Note that the depths for the 1971-2003 period given in Table 3.1.2 are based on the GEV fit, and thus differ slightly from those in Table 3.1.1.

TABLE 3.1.2
RAINFALL DEPTH - 24 HOUR DURATION (mm)

Period of Record	**Return Period (Years)**					
	2	**5**	**10**	**25**	**50**	**100**
1971 - 2003	52	69	79	89	101	109
1971 - 2006	55	74	86	97	111	121
1986 - 2006	53	78	91	103	118	129
1996 - 2006	51	77	95	112	134	151

The analysis indicates that expanding the period of record to 2006 (and including the subject 2005 and 2006 events) would further increase the 100 year depth from 109 mm to 121 mm (11%). By parceling the recorded rainfall into 10 year blocks, from the beginning of the period of record, there is a general trend towards increasing rainfall depths. Considering only the last 10 years (1996 to 2006) would increase the 100 year return period depth by 30 mm (25%) compared with the full period of record (1971 to 2006).

3.1.3 Risk Management Approach

Since clearly these trends cannot be validated locally (as this is a world-wide issue), a Risk Management approach (which applies cost/benefit principles) was considered for the City of Cambridge. The approach includes consideration for modifying the design standard for conveyance infrastructure capacity to less frequent design storms (i.e. from 100 year to 250 or 500 year return frequency). This approach uses a sensitivity analysis combined with an economic assessment (i.e. what return frequency relates to what size and cost of culvert?)

For the Class EA, the 250 and 500 year return period depths were calculated from existing AES data and 24 hour design storms created for application in the hydrologic/hydraulic simulations (ref. Table 3.1.3).

TABLE 3.1.3
RAINFALL DEPTH - 24 HOUR DURATION (mm)

1971 – 2003 Return Period (Years)							
2	**5**	**10**	**25**	**50**	**100**	**250**	**500**
51.6	67.9	78.8	92.4	102.5	112.6	127.6	138.3

The primary flood control recommendations associated with the Class EA included a new culvert at Coronation Blvd., an improved channel through the Galt Country Club, and a flood control system in the Dumfries Conservation Area. The design of the flood control system was maximized on the basis of available storage and off-site impacts, hence this infrastructure could not be “oversized” to account for climate change; the other infrastructure (culvert and channel) could be considered for an economic assessment versus risk. Table 3.1.4 provides a summary of the results of this investigation.

TABLE 3.1.4
COST: BENEFIT (REDUCED RISK) SUMMARY

Infrastructure	Conventional Scenario		Climate Change Scenario	
	Design Standard	**$**	**Design Standard**	**$**
Coronation Blvd. Culvert	100 year	$750,000	500 year	$900,000 (20%+)
Galt Country Club Channel	5 year	$265,000	10 year	$350,000 (32%+)

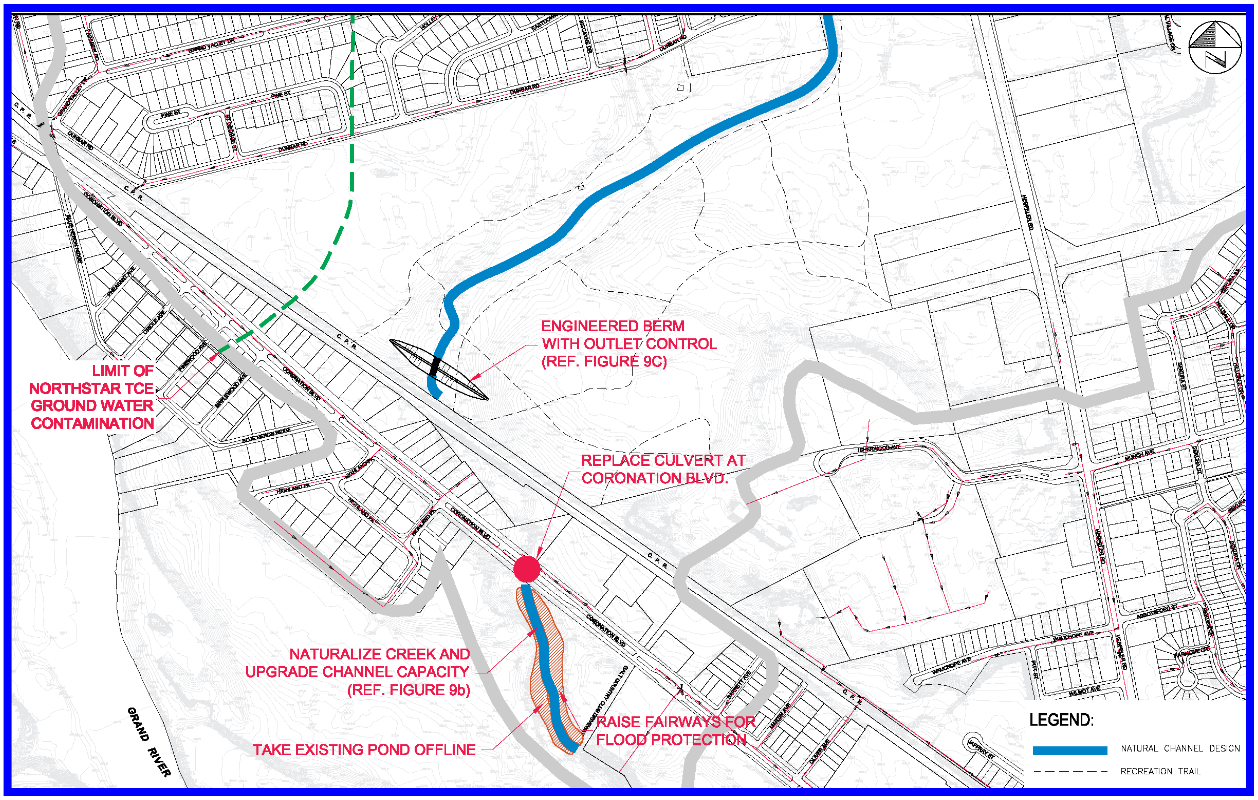

Figure 3: Proposed Drainage Improvements Groff Mill Creek Watershed.

The foregoing form of cost:benefit assessment was used to inform Senior Public Works Officials and City Council of the costs (of larger infrastructure) to reduce public risk and damages associated with flooding. After some debate and overall consideration of the benefits, City Council adopted the more conservative sizing based upon a Climate Change scenario. The decision was largely predicated on the importance of the Coronation Blvd. transportation route (main arterial, providing emergency access, including to the general hospital) and the requirement to conduct work on private property.

Photo 4: Upgraded Conveyance Channel on Galt Country Club lands.

Photo 5: Existing Deficient Coronation Blvd. Culvert.

3.2 Climate Change Assessment for Stormwater Management Infrastructure

3.2.1 Introduction

The Town of Milton, Ontario, lies west of the City of Toronto (ref. Figure 1). Over the past decade, the Town's urban boundary has been expanding in response to the growing population within the Region of Halton. The Town initiated a study for the next phase of its urban expansion, in order to analyze the existing land use hydrologic conditions within the area, and to provide clear recommendations to mitigate the risk to flooding, as well as other environmental impacts, which may result from future urban development within the area. As part of this study, the Town commissioned an assessment of the potential impacts of various Climate Change scenarios on the sizing of stormwater management infrastructure, particularly stormwater management facilities (i.e. constructed ponds and wetlands) to control flooding.

3.2.2 Study Area

The Derry Green Business Park development area, lies east of the existing urban development of the Town of Milton, within the Sixteen Mile Creek Watershed (ref. Figure 4). The Derry Green Business Park area measures 816 ha, and the current land use is primarily agricultural, with some areas of forest, small commercial (nursery) areas, and a private golf course.

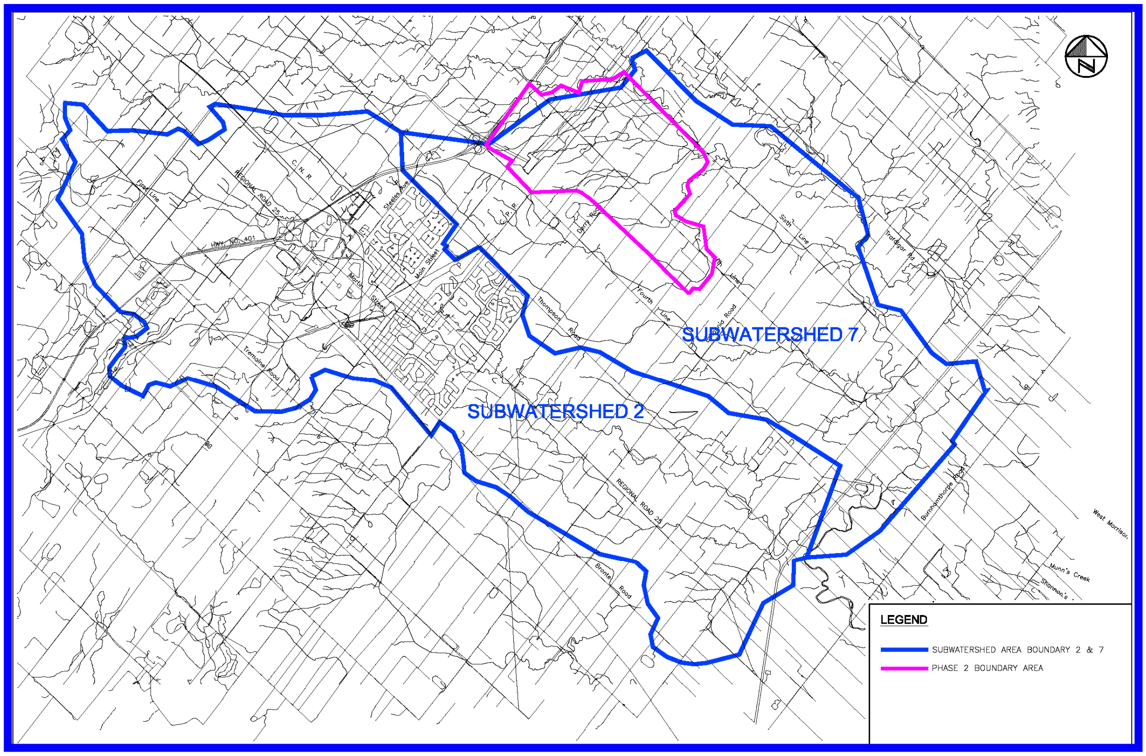

Figure 4: Derry Green Business Park Location Plan

The specific area for the Climate Change assessment lies toward the south of the Derry Green Business Park Area (ref. Figure 5). This area measures 48.7 ha, and land use conditions within this area reflect the prominently agricultural land use of the overall study area, with a forested feature to the north-west and a defined watercourse traversing the area. In addition, an existing residential area is upstream with a stormwater management facility at the drainage outlet from the residential area to the watercourse, which provides full (conventionally designed) stormwater management for the subject residential area, including quantity control (i.e. flood protection for downstream properties). Under future land use conditions, a portion of the study area would be developed, in order to provide commercial land use with supporting roads and related infrastructure (ref. Figure 6). In addition, three stormwater management facilities have been proposed in order to provide stormwater management for the site, including quantity control.

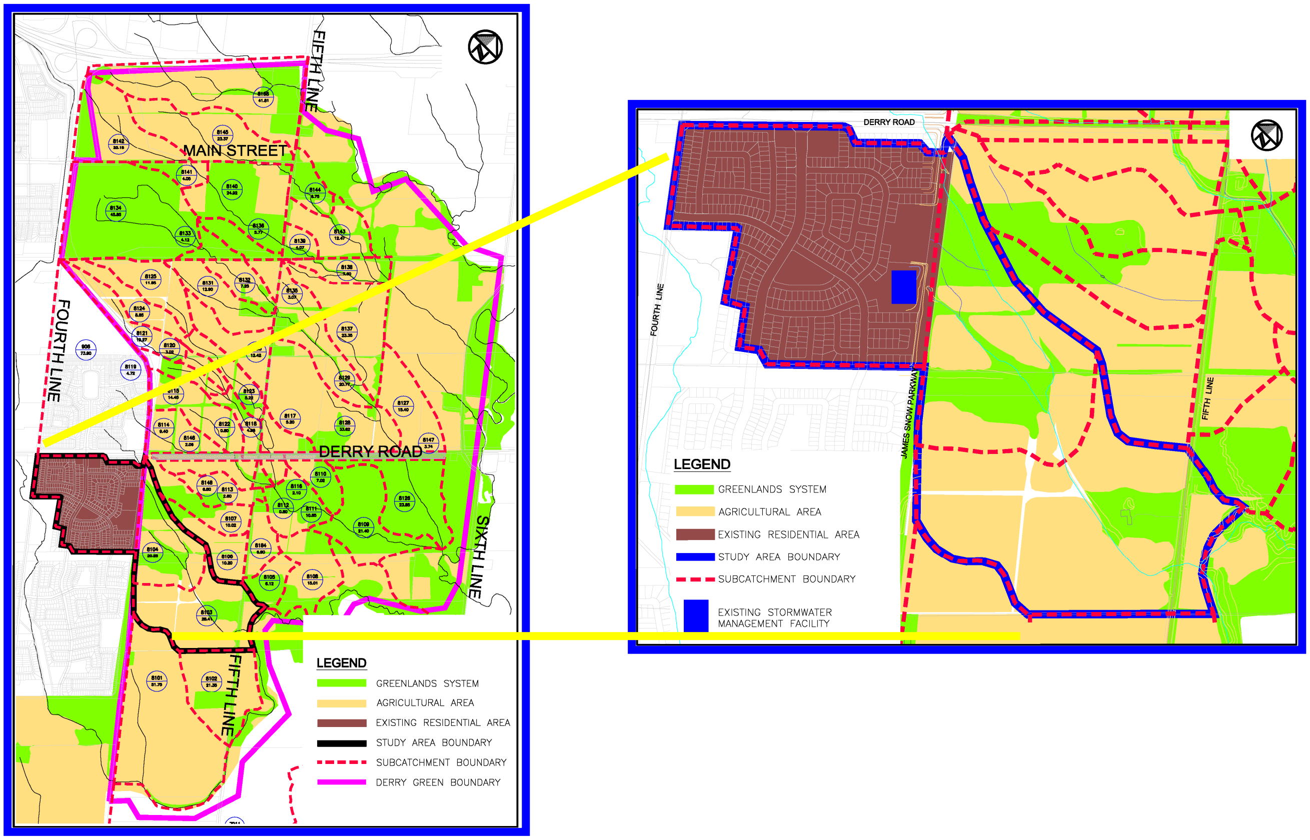

Figure 5: Climate Change Study Area Location Plan

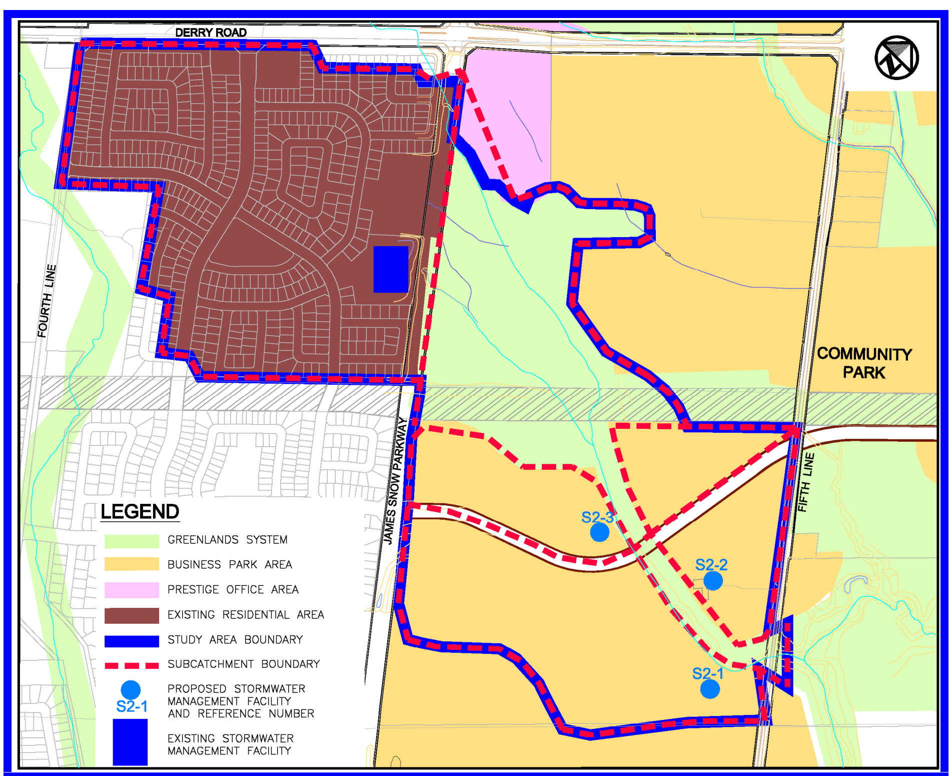

Figure 6: Future Land Use Plan

3.2.3 Hydrologic Analyses

Hydrologic analyses for the study area have been completed using the Hydrologic Simulation Program – Fortran (HSP-F) methodology. The model has been calibrated to local streamflow and rainfall data, and has been parameterized to simulate runoff from storm events, as well as snow accumulation and melt conditions. The hydrologic analyses have applied 42 years of meteorological data (1962 – 2003) for a continuous simulation, and statistical analyses have been completed for the simulated instantaneous peak flow rate at the outlet of the study area for each year of the simulation, in order to generate frequency flows to evaluate flood risk.

Analyses have been completed for the following three land use conditions:

- *Existing undeveloped land use*, whereby the model has been developed and parameterized in order to represent the current undeveloped land use conditions within the study area.
- *Future uncontrolled land use conditions*, whereby the model parameterization has been modified in order to represent the proposed future employment land use within the Derry Green Business Park area and existing land use conditions elsewhere, without any quantity controls for the Derry Green Business Park development area.
- *Future land use with "conventional" stormwater management*, whereby stormwater management facilities for the Derry Green Business Park area would maintain frequency flows at existing levels (i.e. to mitigate the increased risk of flooding from the future development) at the Derry Green Business Park outlet.

The storage-discharge relationships for the stormwater management facilities under the future land use with "conventional" stormwater management scenario have been developed such that the total volume per impervious hectare draining to the facility would be consistent (i.e. the unitary storage volume required for each facility would be the same). The total storage volume for each facility is presented in Table 3.2.1.

TABLE 3.2.1
TOTAL FLOOD CONTROL VOLUME REQUIREMENTS FOR STORMWATER MANAGEMENT FACILITIES BASED UPON HISTORIC METEOROLOGICAL CONDITIONS

Facility Reference Number	Total Flood Control Storage (m^3)
31	5060
32	1850
34	2870

The frequency flows for each of the scenarios are presented in Figure 7. The results indicate that the frequency flows and flood risk under future uncontrolled land use conditions (i.e. future developed condition without stormwater management) would increase compared to existing levels. The results also indicate that stormwater management facilities for the site would provide the requisite flood protection to maintain frequency flows at existing levels at the study area outlet.

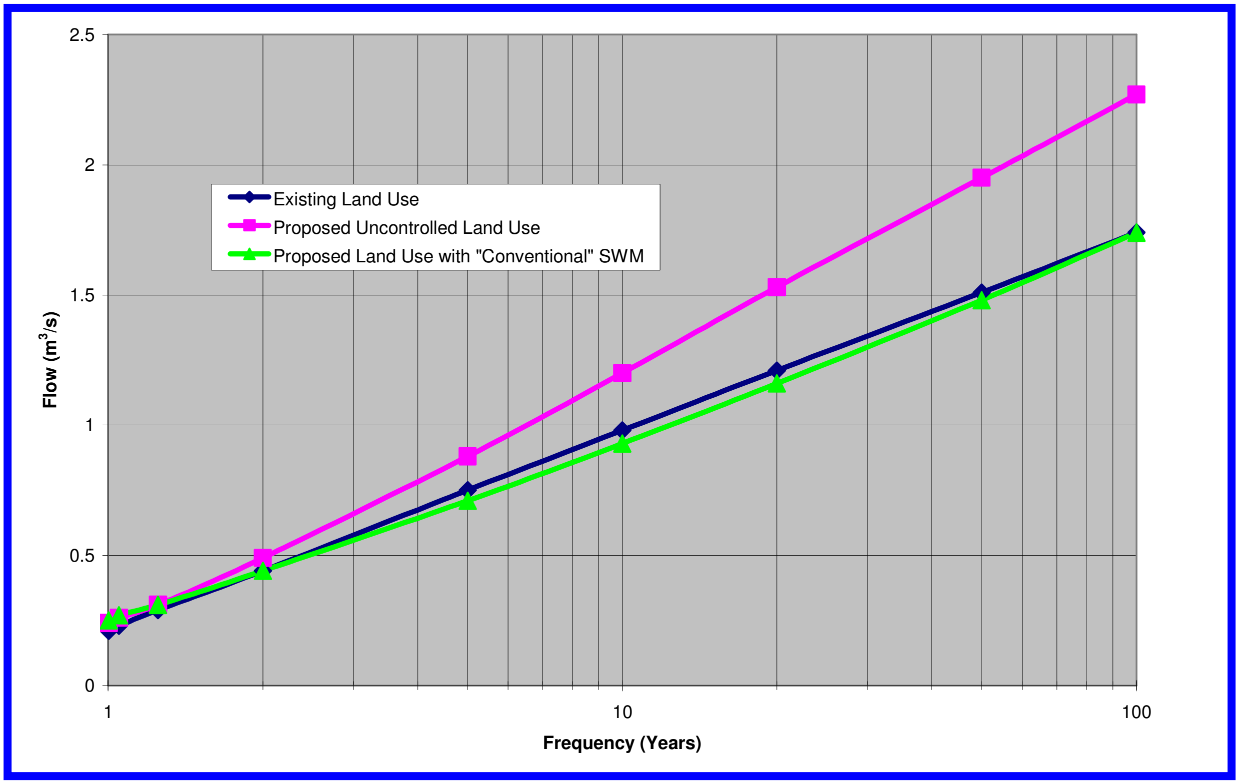

Figure 7: Frequency Analyses for Derry Green Business Park Outlet with Historic Meteorologic Data

Hydrologic analyses have been completed in order to determine: i) how the stormwater management system developed above using conventional practice would perform under Climate Change scenarios, and ii) what adjustments to stormwater management facilities would be needed in order to mitigate potential adverse flooding impacts from Climate Change (i.e. to maintain the flood risks under future land use and anticipated meteorological conditions at historic levels). Modified meteorological time series have been developed for these analyses, based upon the results of studies completed by Environment Canada, which have been initiated in order to determine the meteorological impacts associated with Climate Change. These studies have applied Global Climate Model (GCM) scenarios, which account for global variations in population growth and density, industrial practices and locations, rates and extent of deforestation. Through the application of these GCM scenarios, a series of adjustment factors for meteorological time series have been developed, which represent the outcomes of various GCM scenarios.

Two of the GCM scenarios evaluated under the Environment Canada research have been applied for this assessment: HadCM3 B22 (i.e. “hotter and wetter”), and CGCM2 B23 (i.e. “not quite as hot and drier”). The information provided by Environment Canada indicates that the meteorological conditions generated under these scenarios exhibited the greatest difference from historic conditions, and hence represent extreme conditions (i.e. greatest stressors). The adjustment factors for precipitation and temperature data have been generated, on a monthly basis, for each scenario; these factors are presented in Figures 8 and 9.

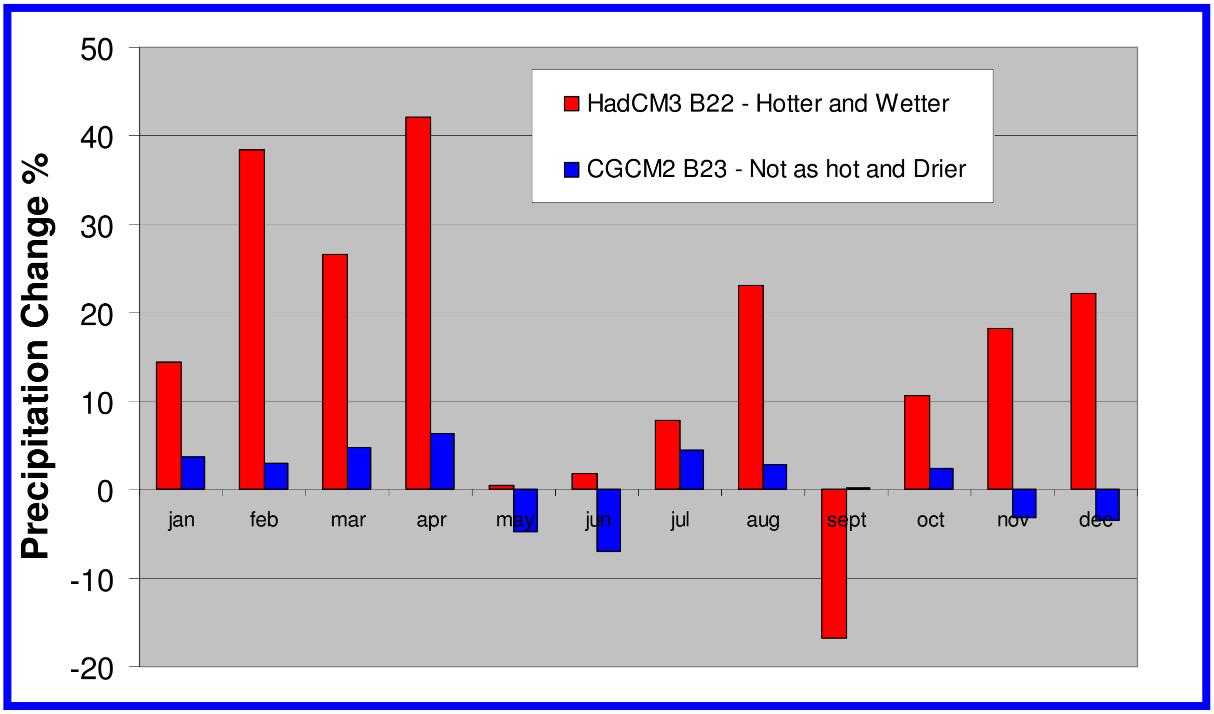

Figure 8: Monthly Adjustment Factors for Precipitation Data under Climate Change Scenarios

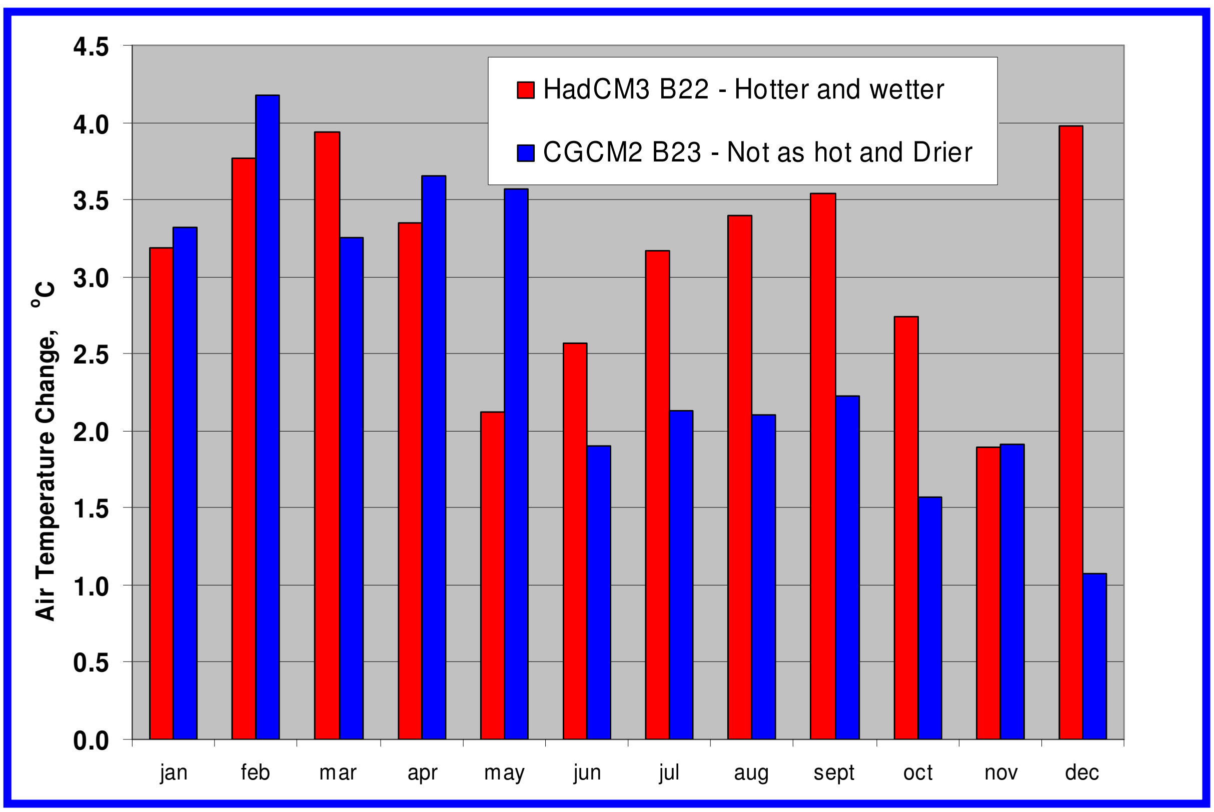

Figure 9: Monthly Adjustment Factors for Temperature Data under Climate Change Scenarios

The monthly adjustment factors have been applied to the precipitation and temperature time series for the hydrologic continuous simulation, in order to generate continuous meteorological time series for the respective Climate Change scenarios. Continuous simulations have been completed for future land use conditions with “conventional” stormwater management facilities in-place, in order to evaluate the performance of conventionally-designed stormwater management practices under the Climate Change scenarios. The results of this assessment are presented in Figure 10.

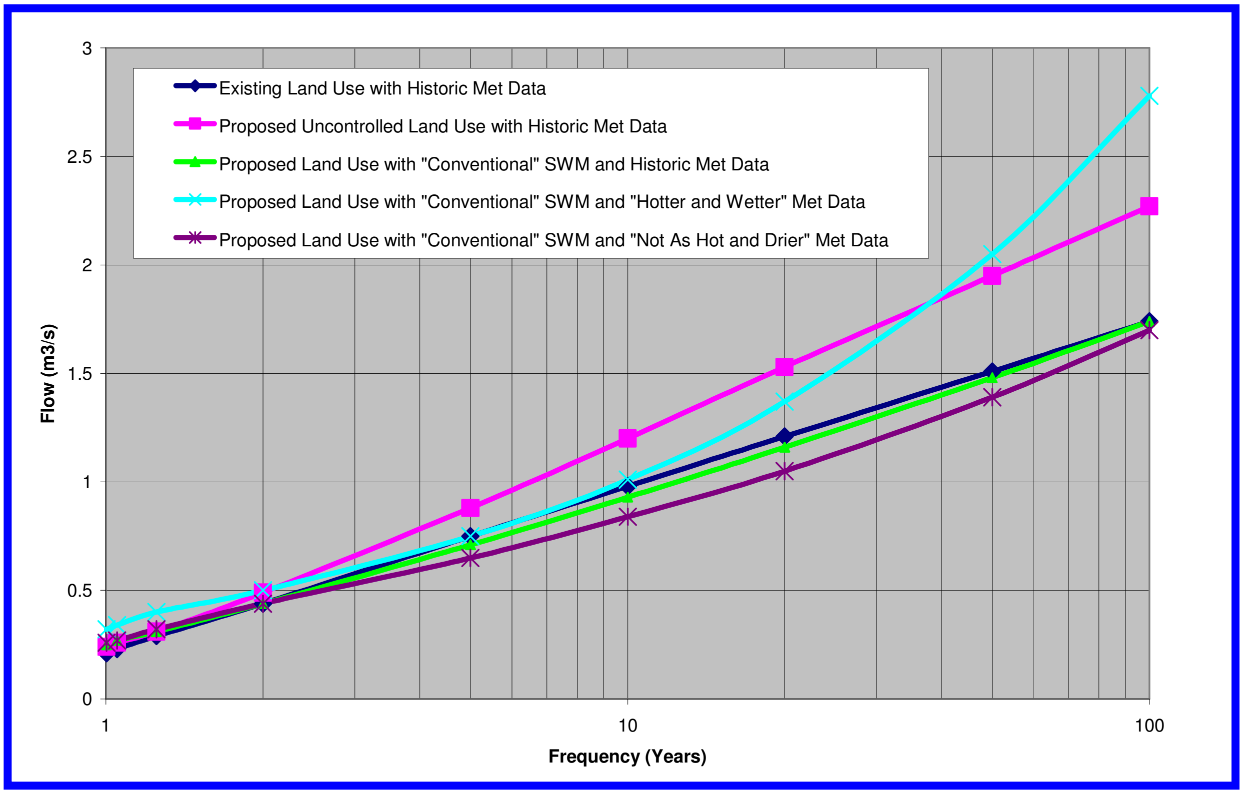

Figure 10: Frequency Analyses at Derry Green Business Park Outlet under Various Meteorologic Conditions

These results indicate that the frequency flows for future land use conditions with conventionally-designed stormwater management under the “not quite as hot and drier” Climate Change scenario would be at, or slightly below existing levels; hence, conventional stormwater management practices would be anticipated to sufficiently mitigate the increased risk of flooding associated with this particular Climate Change scenario. However, the results also indicate that the frequency flows for future land use conditions with conventionally-designed stormwater management under the “hotter and wetter” Climate Change scenario would be anticipated to exceed existing levels by as much as 60% for a 100 year storm, hence suggesting that conventional stormwater management practices would be anticipated to be insufficient to mitigate the increased risk of flooding associated with this particular Climate Change scenario.

3.2.5 Stormwater Management Requirements Under Climate Change Scenarios

In light of the foregoing, additional analyses have been completed in order to determine the modifications to stormwater management facility sizing which would be required in order to mitigate the increased risk of flooding associated with the future land use conditions under the “hotter and wetter” Climate Change scenario. For these analyses, only the sizing for the facilities within the Derry Green Business Park area have been modified; opportunities to adjust the existing stormwater management facility upstream of the Derry Green Business Park area are considered infeasible due to the existing spatial and grading constraints imposed by the surrounding development and infrastructure (thus reinforcing the need to appropriately plan for potential change).

Consistent with the approach previously applied for sizing the stormwater management facilities under the conventional stormwater management scenario, the requisite volumes for the facilities have been determined based upon a unitary volume requirement for each impervious hectare of future development.

The total detention storage volume required for each facility under each of the scenarios analyzed is summarized in Table 3.2.2.

TABLE 3.2.2
TOTAL DETENTION STORAGE VOLUME REQUIREMENTS FOR FLOOD PROTECTION FOR METEOROLOGICAL CONDITIONS ANALYZED
(m^3)

Facility Reference Number	Meteorological Dataset	
	Conventional Historic Data	"Hotter and Wetter" Climate Change
31	5060	10120
32	1850	3710
34	2870	5740

The results presented above indicate that approximately 100 % additional storage would be required in order to control post-development flows under the "hotter and wetter" Climate Change scenario to pre-development levels based upon historic data, compared to the requirements under the post-development condition with historic meteorological data. By comparison, the results indicate that, under the "not as hot and drier" Climate Change scenario, no additional storage would be required to maintain the frequency flows at historic levels. As indicated previously, the Climate Change scenarios analyzed are considered to represent the more extreme meteorological conditions which may result from Climate Change conditions. Hence, the results demonstrate a relatively high degree of variability and uncertainty associated with the meteorological and hydrologic impacts of Climate Change conditions and the requirements which may be imposed upon stormwater management infrastructure to mitigate these impacts.

3.2.6 Economic Impact Assessment for Stormwater Management Infrastructure

The results of the hydrologic analyses have been used in order to estimate the additional cost which would be required for the construction of the stormwater management facilities to mitigate the impacts of Climate Change, compared to the cost for construction of facilities sized using conventional practices. A unitary cost of \$60.00/m^3 of facility storage has been applied for this assessment; this rate has been determined through previous local assessments to reasonably reflect the cost of facility construction, including construction of inlet and outlet structures, off-site removal of excavated material, etc.

In order to determine the land cost required for the construction of each facility, a unitary rate of \$1,000,000/ha has been applied to the footprint of each facility. The facility footprint has been estimated based upon the following conditions:

- 2:1 Length to width ratio.
- 5:1 side slopes to the base of the facility.
- 2.5 m depth at maximum operating volume.
- Additional factor of 10 % applied to account for access roads, decanting zones, etc.

The estimated facility construction costs for the stormwater management facilities under the scenarios analyzed are summarized in Table 3.2.3, and the percent increase in cost for the Climate Change scenarios, compared to the requirements using historical meteorological data are summarized in Table 3.2.4.

TABLE 3.2.3
ESTIMATED CONSTRUCTION COSTS FOR STORMWATER MANAGEMENT FACILITIES FOR METEOROLOGICAL CONDITIONS ANALYZED
($)

Description	Meteorological Dataset	
	Conventional Historic Data	"Hotter and Wetter" Climate Change
Capital/Construction Cost	$586,800	$1,174,200
Land Cost	$756,900	$1,316,700
Total	**$1,343,700**	**$2,490,900**

TABLE 3.2.4
PERCENT DIFFERENCE IN STORMWATER MANAGEMENT FACILITY CONSTRUCTION COSTS FOR CLIMATE CHANGE SCENARIOS COMPARED TO REQUIREMENTS BASED UPON HISTORIC METEOROLOGICAL DATASET
(%)

Facility Reference Number	"Hotter and Wetter" Climate Change	"Not As Wet and Drier" Climate Change
Capital/Construction Cost	100.1	0
Land Cost	74.0	0
Total	**85.4**	**0**

The results in Table 3.2.4 indicate that the ultimate construction costs for future stormwater management infrastructure to mitigate the increased risk of flooding under Climate Change clearly depend upon the scenario evaluated. Based upon the economic impact assessment premised on the meteorological research completed to-date by Environment Canada, the additional cost for constructing stormwater management infrastructure to mitigate the increased risk of Climate Change could be as much as 85.4 % higher than current construction costs for stormwater management infrastructure.

4. CONCLUSIONS/RECOMMENDATIONS

Climate change is speculated by many to lead to more severe weather conditions (Coulibaly and Shi, 2005). As a result of this more severe weather, existing and planned drainage infrastructure may be deficient, leading to increased risk (safety and property) associated with flooding. Generally, research on climate change tends to be at a global or national scale. As a result, local direction tends to be sparse, yet it is primarily municipalities who need to deal with public risk through the design implementation and maintenance of storm drainage infrastructure. A simple approach, which involves assessing the economic impacts (i.e. higher costs) of larger drainage infrastructure, designed to less frequent design standards (i.e. 250 or 500 years) can provide information to assist municipal decision makers in managing this risk. Inherent in the foregoing approach is the underlying assumption that future 100 year storm events would equivocate to say a current 1 in 500 year return period event. Depending on the level of risk due to flooding, which would take into account such factors as land use, population density, damage potential, etc., Public Works Officials may elect to implement more conservative design standards premised on the foregoing approach, when linked with an economic evaluation of the incremental costs of providing infrastructure based on speculated climate change relationships.

A more complex approach has also been investigated which involves applying meteorological change variables based on global climate models. These change variables, when applied to a hydrologic modelling approach through the use of continuous time series, provide a more comprehensive response function to speculated climate change impacts. This methodology is considered particularly appropriate to assess impacts associated with the planning for stormwater management for flood control. In this regard, it is recommended that municipalities consider instituting buffers for stormwater management facilities to allow for potential future upsizing. Notwithstanding, these systems should be built to current standards, however the land area would be established to protect to future more conservative standards.

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