PROVINCE OF NEWFOUNDLAND AND LABRADOR
OFFICE OF CLIMATE CHANGE AND ENERGY EFFICIENCY

IMPROVING RESILIENCE TO CLIMATE CHANGE IMPACTS

CASE STUDY REPORT
STORMWATER MANAGEMENT AND STORM SEWER DESIGN, GOULDS

Report No.: TP114024-001

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EXECUTIVE SUMMARY

Infrastructure, whether built, human or natural, is critically important to individuals and communities. The purpose of infrastructure is to protect the life, health, and social welfare of all of its inhabitants from the weather elements, to host economic activities and to sustain aesthetic and cultural values. When infrastructure fails under extreme weather conditions and can no longer provide services to communities, the result is often a disaster. As the climate changes, it is likely that risks for infrastructure failure will increase as weather patterns shift and extreme weather conditions become more variable and regionally more intense. Since infrastructure underpins so many economic activities of societies, these impacts will be significant and will require adaptation measures. Even though municipalities share responsibilities associated with infrastructure with other levels of government, any effect of climate change is ultimately experienced locally, even if its origins are outside local jurisdictions, such as disruption of electrical power or fuel supply.

The degree to which a municipality is able to deal with the impact of climate change is often referred to as “adaptive capacity” or “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 consequences” (Intergovernmental Panel on Climate Change, 2001). The vulnerability of infrastructure systems needs to be assessed as part of municipal risk management and decision making. Understanding the level of vulnerability also contributes to better, more informed decision-making and policy development by providing a basis for establishing priorities.

A key aspect of the Government of Newfoundland and Labrador’s 2011 Climate Change Action Plan was to establish the Office of Climate Change and Energy Efficiency (CCEE) as a central agency located in Executive Council to lead policy and strategy development on issues relating to climate change and energy efficiency. The Office works collaboratively with other departments and agencies to ensure the subjects of climate change and energy efficiency are effectively integrated into policy development and decision making. The CCEE assists with development and better use of climate change data for the Province and consideration of how climate change will impact infrastructure. The Province has been and continues to make efforts towards maximizing the use of the available data sets, covering areas of climate variable projections, flood risk mapping, coastal vulnerability and sea level rise, to inform better planning and decision making, ultimately increasing the Province’s resilience to the potential impacts of climate change.

Engineers Canada established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC developed a protocol in 2005 to guide vulnerability assessments. The Protocol is a procedure to systematically gather and examine available data in order to develop an understanding of the relevant climate effects and associated interactions with infrastructure.

This project was developed by the CCEE, with funding support from the Province of Newfoundland and Labrador, Department of Environment and Conservation, to support the demonstration of the PIEVC Protocol towards a better understanding of potential vulnerabilities of Provincial infrastructure from climate change and to develop educational material to support two climate change workshops held in June 2014 in St. John's. These workshops were attended by about 120 government decisions makers, engineers, planners, municipal staff and other stakeholders.

The climate change vulnerability assessments which have been completed are founded on version 10 of the PIEVC Protocol and Provincial climate change datasets and targeted three (3) case study sites in Newfoundland, namely:

- Corner Brook – Main Street Bridge over Corner Brook Stream
- Goulds – Stormwater management and storm sewer design
- Placentia – Laval High School

These climate change risk assessments have been developed as demonstration projects / case studies and as such do not apply all aspects of the PIEVC Protocol. These assessments have focused only on Steps 1, 2 and 3 of the Protocol, although some recommendations (Step 5) stemming from the assessment are offered. Step 4 (Engineering Analysis) was not included in these assessments.

This report constitutes the final documentation regarding the climate change vulnerability assessment of the stormwater management infrastructure in the community of Goulds in the City of St. John's.

Recommendations stemming from the application of the PIEVC Protocol to the stormwater management infrastructure in the community of Goulds to assess risks and vulnerabilities to projected changes in climate phenomenon in the future are outlined below.

- It is recommended that this scoped climate change vulnerability assessment be completed in full for all components (referring to Steps 1 to 5) of the PIEVC protocol.[1]
- It is recommended that the Province develop full IDF relationships for relevant areas of the Province to support evaluation of future performance and design issues for stormwater collections systems.

[1] Adoption of this recommendation would encompass some of the other recommendations itemized in the list.

- It is recommended that recording of climatic events specific to the subject infrastructure be a regular procedure in the administration of the infrastructure.
- It is recommended that the climate change projections available from the Province be augmented such that the time series upon which the projections area based are made available such that more in-depth interrogation of the datasets is possible.

General recommendations regarding climate change risk assessment of infrastructure stemming from the workshops included:

- The Province should develop procedures and/or policies for incorporating risk assessment into infrastructure planning and development practices.
- The development of climate change datasets by the Province is a great step forward in breaking down perceived barriers to climate change risk assessments. However, barriers that still exist as a consequence of the lack of coordination among departments and lack of understanding of the “do nothing” scenario still need to be addressed. As such, better Government interdepartmental coordination should be advanced towards a consistent view of the requirements for incorporating risk assessment into infrastructure planning and development practices.
- The workshops clearly demonstrated value in advancing understanding of climate change issues affecting infrastructure in the Province. Further opportunities for training/education about climate change and the potential impacts to the Province should be continued for all levels of government and the private sector.
- The climate change datasets developed by the Province can generally support climate change risk assessment. However, the Province should not view these datasets as static. Examples of gaps in the datasets have already been noted (i.e., short duration IDF data). With changing science and data collection new projections are being developed around the world. The Province should develop a review cycle for its datasets. Further, the Province should also allow for new datasets to be analysed and incorporated into the larger suite of datasets.

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SECTION 1

INTRODUCTION

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1 INTRODUCTION

It has been projected that Newfoundland and Labrador (the "Province") may, in the future, experience changes in the frequency and/or severity of extreme weather as well as changes to average climate over several decades or more as a result of climate changes. These changes are expected to affect natural, social and built infrastructure, potentially having significant socio-economic consequences. The climate change assessment focus has most often been directed towards a range of mitigation options related to energy use. These have been targeted at reducing greenhouse gas emissions, encouraging public transport and increasing energy efficiency at all scales in the community. However, more recently, the focus has shifted toward adaptation measures recognizing that communities must adapt to changing climatic conditions.

The Government of Newfoundland and Labrador has recognized the potential for change in the Province and has charted a course for the Province with the 2011 Climate Change Action Plan which establishes the provincial Government's strategic approach to climate change. As a component of this strategy the Office of Climate Change and Energy Efficiency (CCEE) was initiated as a central agency located in Executive Council to lead policy and strategy development on issues relating to climate change and energy efficiency. As a key part of this mandate, the Office works collaboratively with other departments and agencies to ensure the subjects of climate change and energy efficiency are effectively integrated into policy development and decision making.[2]

A component of the CCEE's mandate is directed towards development and better use of climate change data available for the Province and consideration of how climate change will impact infrastructure. The Province has been and continues to make efforts towards maximizing the use of the data sets that have been developed, covering areas of climate change projections, flood risk mapping, coastal vulnerability and sea level rise, to inform better planning and decision making, ultimately increasing the Province's resilience to the potential impacts of climate change.

Engineers Canada, the business name of the Canadian Council of Professional Engineers, established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee a national engineering assessment of the vulnerability of Canadian public infrastructure to changing climate conditions. PIEVC developed a protocol in 2005 to guide vulnerability assessments. The Protocol is a procedure to gather and examine available data in order to develop an understanding of the relevant climate effects and their interactions with infrastructure.

This project was developed by the CCEE to support the demonstration of the PIEVC Protocol towards a better understanding of potential vulnerabilities of Provincial infrastructure from

[2] From http://www.exec.gov.nl.ca/exec/ccee/

climate change and to develop educational material to support two climate change workshops held in June 2014 in St. John's, namely:

- One (1) - ½ day workshop for Decision-Makers on Integrating Climate Risk into Infrastructure Decisions in Newfoundland and Labrador, held on June 3rd, 2014, and,
- Two (2) - one (1) day workshops for Engineers, Planners and Municipal staff on Integrating Climate Risk into Infrastructure Decisions in Newfoundland and Labrador, was held on June 4th, 2014. The second one day workshop was held on June 5th, 2014.

These climate change vulnerability assessments are founded on version 10 of the PIEVC Protocol and Provincial climate change datasets and targeted three (3) case study sites in Newfoundland, namely:

- Corner Brook – Main Street Bridge over Corner Brook Stream
- Goulds – Stormwater management and storm sewer design
- Placentia – Laval High School

As noted above, these climate change risk assessments have been developed as demonstration projects and as such do not apply all of the steps of the PIEVC Protocol.

Separate reports have been developed for each of the climate change vulnerability assessments completed for the infrastructure sites noted above. This report constitutes the final documentation regarding the climate change vulnerability assessment of the stormwater management and storm sewer infrastructure in the community of Goulds in the City of St. John's.

1.1 PROJECT OBJECTIVES

The principal objective of this study is to identify those components of the stormwater management and storm sewer infrastructure that are at risk of failure, damage and/or deterioration from extreme climatic events or significant changes to baseline climate design values. The nature and relative levels of risk are to be determined in order to establish priorities for remedial action. The assessment of vulnerability was based on the May 2012 (v10) PIEVC Protocol, premised on potentially three (3) future time frames, namely: 2020, 2050 and 2080 where data was available.

The outcomes of all of the assessments are expected to drive possible remedial action at the study-specific infrastructure locations and to support CCEE efforts to engage the engineering community and advance risk based design for infrastructure in the Province. Further, the results of this assessment will be incorporated into the national knowledge base which has been formed as a basis for analysis and development of recommendations for review of codes, standards and engineering practices.

1.2 PROJECT SCOPE

This scoped climate change vulnerability assessment will review climate change and infrastructure datasets and will apply the PIEVC Protocol specifically Steps 1 and 2, and a preliminary, independent application of Step 3 of the Protocol. This vulnerability assessment will use version 10 of the Protocol.

The intent of this assessment is to provide an overview of the PIEVC Protocol and, through an example, how its application to infrastructure can assist in understanding risks in the face of a changing climate. Further, this report provides only a preliminary risk assessment of the stormwater management and storm sewer infrastructure in the community of Goulds, in essence a starting point. As a starting point, it does not touch on all aspects of the infrastructure or all potential climatic influences. Full applications of the PIEVC Protocol have been completed for similar infrastructure elsewhere in Canada. These reports are available at the PIEVC website (www.pievc.ca) and it is encouraged that these be reviewed in advance of a more in-depth risk assessment of this infrastructure in the future.

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SECTION 2

PIEVC PROTOCOL STEP 1

PROJECT DEFINITION

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2 STEP 1 - PROJECT DEFINITION

2.1 OVERVIEW

Step 1 of the PIEVC Protocol focuses on the development of a general description for the following aspects of the project:

- location of the vulnerability assessment;
- infrastructure of concern;
- historic climate;
- existing loads on the subject infrastructure;
- age of the subject infrastructure;
- other relevant factors;
- identification of major documents and information sources.

The outcome from this step is a definition of the boundary conditions for the vulnerability assessment.

2.2 STUDY LOCATION

The community of Goulds is a rural neighbourhood within the City of St. John's located about 15 km south of the City-centre. Goulds was amalgamated with Wedgewood Park and Kilbride into the City of St. John's in 1992.[3,4] At the time of amalgamation, there were major deficiencies in the municipal water and sewer systems. Repairs and new construction have been ongoing since that time.[4]

The population of Goulds was 4,525 in 2011, representing a decrease from 2006 of about 1.5%.[5]

The Goulds area has been under development pressure (mostly for residential housing) for some time but the City has denied such development citing the area's sub-standard water and sewer infrastructure.[6] A 2010 study, commissioned by the City, concluded that a seven year improvement program totalling $51.7 million targeting the major water and sewer deficiencies was required to upgrade the infrastructure in Goulds area.[4]

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[3] Source: http://en.wikipedia.org/wiki/Goulds,_St._John's
[4] Source: St. John's Municipal Plan Review 2012, Background Report, February 15, 2012
[5] Source: Statistics Canada. 2012. Goulds, Newfoundland and Labrador (Code 1178) and Newfoundland and Labrador (Code 10) (table). Census Profile. 2011 Census. Statistics Canada Catalogue no. 98-316-XWE. Ottawa. Released October 24, 2012. http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/index.cfm?Lang=E (accessed December 8, 2014).
[6] Source: http://www.cbc.ca/news/canada/newfoundland-labrador/council-says-no-to-goulds-subdivision-1.738785

As noted in the "Flood Risk Mapping Study: Goulds, Petty Harbour and Ferryland" (BAE-Newplan Group, 1996), flooding in Goulds area has been noted to be an almost annual occurrence. Although flooding is regular, its effects appear limited to periodic roadway overtopping, some basement flooding, and regular flooding of barns and parking lot at Avalon Raceway.[7]

Eastern Newfoundland's climate is mid-boreal, marked by cool summers and winters. Communities in Newfoundland and Labrador, in general, currently are subject to a wide range of climatic events, including mid-latitude storms, hurricanes and tropical storms, snowfall and frost, plus summer drought. Recent trends suggest that such events are becoming more frequent and intense.[8,9]

[7] Flood Risk Mapping Study: Goulds, Petty Harbour and Ferryland, BAE-Newplan Group, 1996.
[8] Cameron et al., 2008
[9] AMEC, 2012b

Figure 2-1 : Study Location - Regional Context

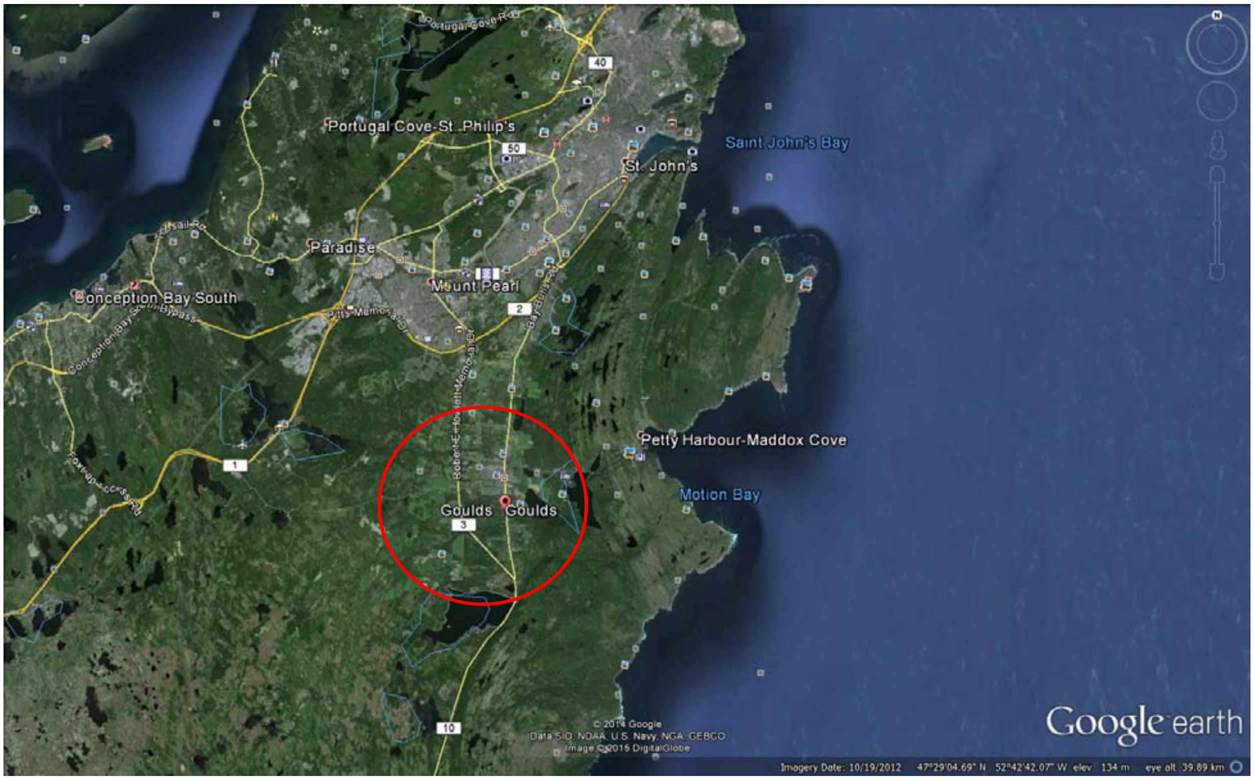

Figure 2-2 : Study Location – Local Overview

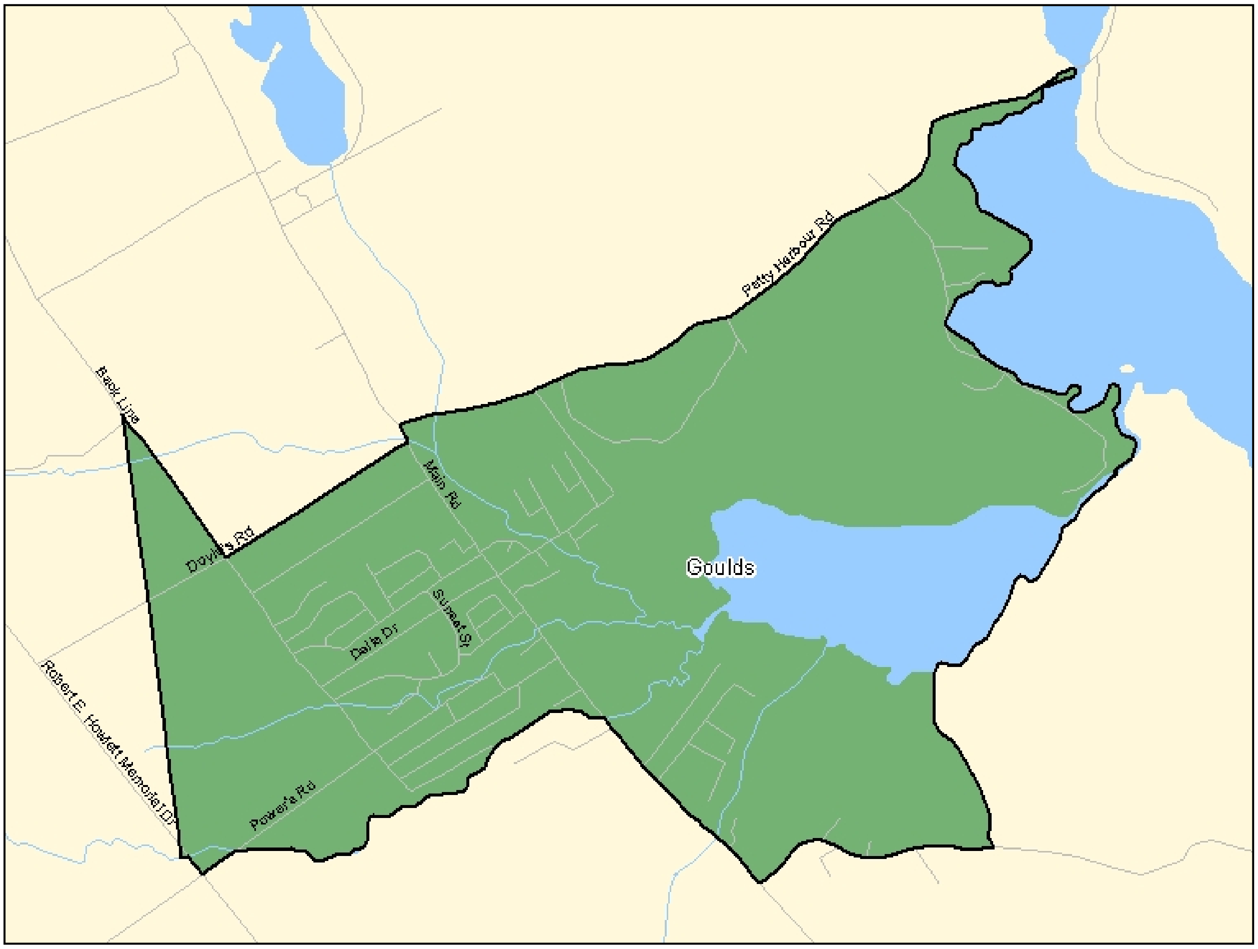

Figure 2-3 : Study Location – Local Context[10]

[10] The Goulds Population Centre as defined by Statistics Canada. Image source http://www12.statcan.gc.ca/census-recensement/2011/dp-pd/prof/details/page_Map_Carte_Detail.cfm?Lang=E&G=1&Geo1=POPC&Code1=1178&Geo2=PR&Code2=48&Data=Count&SearchText=&SearchType=Begins&SearchPR=01&B1=All&Custom=&TABID=2&geocode=1178

2.3 STUDY INFRASTRUCTURE

2.3.1 Background

Stormwater management and storm sewer design information to support this assessment was based on two fictitious residential developments for Goulds named Brookhaven Estates and Webber Estates. These developments are in fact real but have been constructed in Welland, Ontario. In formulating the three infrastructure locations for this project overall a suitable stormwater infrastructure example, with supporting data, could not be identified within Newfoundland and Labrador. As such, a surrogate scenario was developed to support the project based on the Brookhaven Estates and Webber Estates developments from Welland, Ontario.

2.3.2 Infrastructure Overview

2.3.2.1 Brookhaven Estates

The Brookhaven Estates residential development is located in Goulds (see Figure 2-4). The development consists of 23 residential lots for Phase 1 and an additional 15 lots for Phase 2 covering an area of about 2.5 ha). The stormwater management plan for the development expanded an existing stormwater management pond located on the north side of the development which also serves a portion of the residential area to the north (an area of about 8.4 ha) known as the Meadows Subdivision.

Storm sewer design sheets for the Brookhaven Estates residential development were made available from the City and formed the basis of this component of the assessment. The design sheets described six (6) storm sewer segments over a linear length of about 300 m.

2.3.2.2 Webber Estates

The Webber Estates residential development, also located in Goulds, is comprised of sixty-five (65) single family homes and thirty-seven (37) townhouses. A general site layout is illustrated in Figure 2-5. The storm sewer network design for this development comprises 40 pipes ranging in size from 200 mm to 1200 mm diameter.

This development also has a stormwater management facility but this aspect of the infrastructure was not included in this assessment due to lack of data.

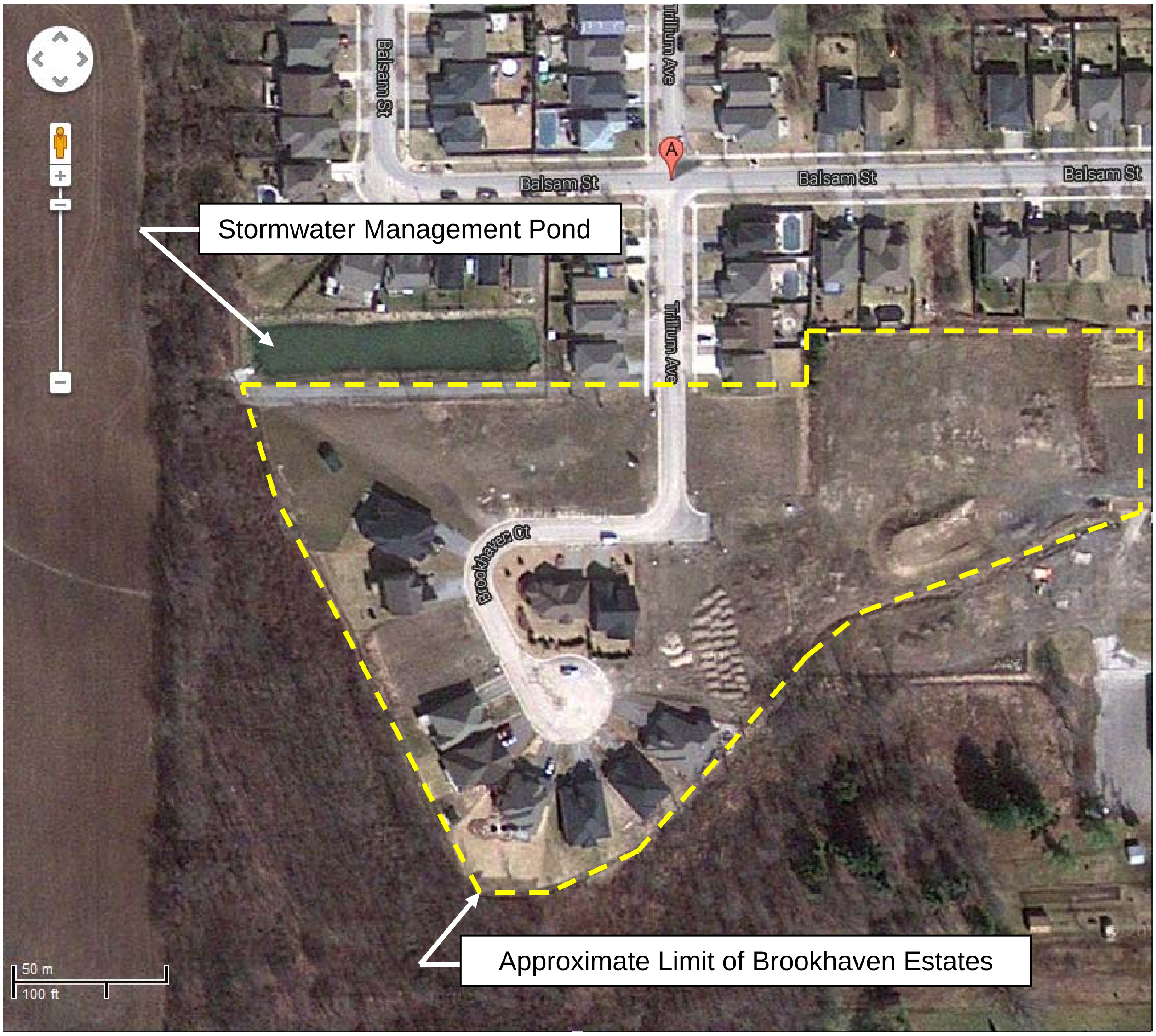

Figure 2-4 : Brookhaven Estates Overview

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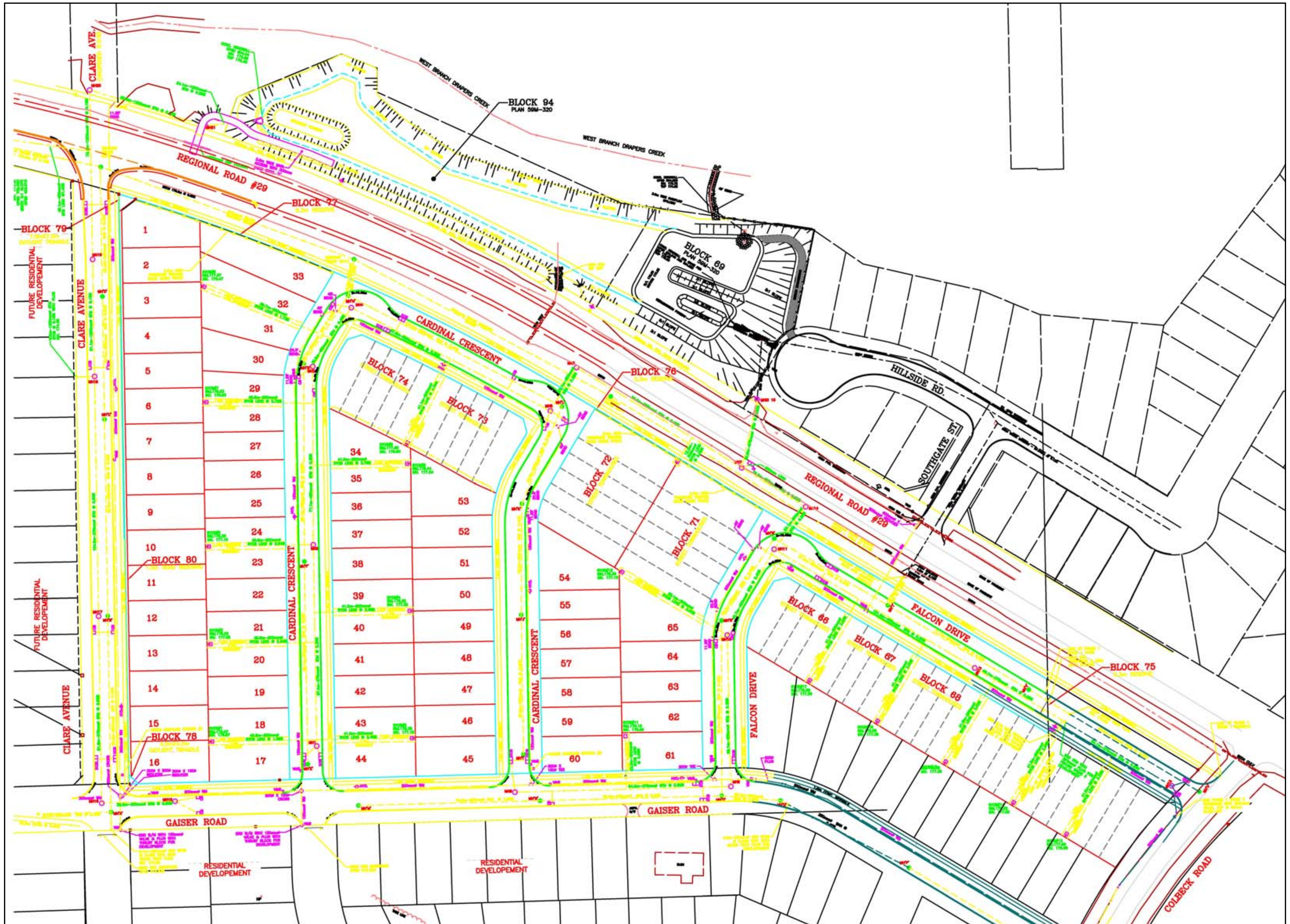

Figure 2-5 : Webber Estates Overview

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2.4 STUDY AREA CLIMATE
(from Cameron et al, 2008)

"The climate of Eastern Newfoundland is classified as mid-boreal, marked by relatively cool conditions and seasonally consistent precipitation, with humid and per-humid moisture regimes. Newfoundland lies within the Boreal Eco-climatic Province of Canada. The climate is controlled by the dominant westerly winds of the mid-latitude Northern Hemisphere, and the proximity of the relatively cold waters of the Labrador Current system of the Atlantic Ocean. Mean February sea surface temperatures are less than 0°C along the majority of the coastline. Local factors, such as topography and the prevalence of onshore and offshore breezes, create distinct meso-climatic and microclimatic regimes in many locations.

Within the Avalon Peninsula, summers are short, cool, and wet (normally, the driest and hottest month is August). Winters are moderately mild and wet. Long springs (March through June) and relatively short autumns (September through mid-October) are normal. The Avalon zone, influenced by southwesterly winds blowing landward, is considered to be the area of Newfoundland showing the most marked maritime influence. At shoreline sites, daily mean temperatures in February vary from -2.5°C to -6°C. Interior areas are 1 to 2 C° colder than adjacent coastal sites.

August daily mean temperatures vary from 14°C to 16°C, with sites exposed to maritime conditions associated with south-westerly winds being cooler than sites on the north-east coast. On local scales, summer temperature values vary with aspect. Sites in these areas that are exposed to direct south-westerly winds are somewhat more variable in temperature than are sheltered areas. Freeze-thaw cycles are generally numerous from mid-December to early April, and frost events may occur at any time from early September to June. In exposed coastal headlands, several freeze-thaw cycles may occur daily during the early and late winter.

The mean annual precipitation throughout the Avalon varies from 1500 to 1650 mm. Local variations between adjacent stations indicate that wind effects are significant in causing the amount of precipitation to be under-estimated. Individual storms (notably Gabrielle in September 2001) may bring more than 100 mm of rainfall within 24 hours. Some north-east facing slopes on the north-east Avalon received more than 200 mm of rain during Gabrielle.

Additional variations are due to aspect and differences in the proportion of precipitation types. Areas marked by larger proportions or amounts of snowfall also generally receive less total precipitation. Shoreline areas receive less snowfall and more freezing rain and drizzle than do interior locations, although rainfall events in coastal areas may be associated with freezing precipitation events inland.

In coastal sites, typically 15 to 25% of the precipitation falls as snow, although in exposed regions subject to onshore winds the proportion of snowfall may be less than 10%. Large annual variations are common.

Wind patterns vary seasonally, and local topographical effects are extremely significant in many embayments. Westerly and south-westerly winds are more prevalent throughout the year, although winds may originate from any point of the compass at any time of the year.

The south-westerly winds generally bring warm, moist air to the region from the warmer ocean surface waters south of the Burin Peninsula.

The statistical summaries in Table 2-1 provide a general overview of the study area climate. It is interesting to note steady increase in average annual precipitation over the periods noted in Table 2-1. A complete listing of the climate normals for the St. John's Airport, for each of the periods noted in Table 2-1, is available via the Environment Canada website.

2.5 OTHER RELEVANT FACTORS

In the City of St. John's, local storm sewers not requiring stormwater detention are designed based on a constant rainfall intensity of 77.2 mm/hr. This value approximates a 5 year return period, 5 minute duration design basis based on return period rainfall rates as documented for the Intensity-Duration-Frequency data for St. John's Airport published by Environment Canada (dated 2012/02/09).

If stormwater detention is required then the storm sewer system must be designed as per the stormwater detention design manual, namely:

City of St. John's, Department of Planning, Development & Engineering, Subdivision Design Manual, Division 8, Stormwater Detention, 2013.

2.6 ASSESSMENT TIME FRAMES

2.6.1 Historical

The time frame used for this assessment for representation of historical information is the period 1981-2010. This 30-year period matches the most recent climate normal period available from Environment Canada. Where independent data analyses were completed for this assessment, the 1981-2010 time frame was used unless otherwise indicated.

2.6.2 Future

It had been planned to complete the vulnerability assessment for three future periods, namely 2020, 2050 and 2080. These future periods reflect the tri-decade periods of 2005-2034, representing 2020, 2035 to 2064, representing 2050, and 2065 to 2094, representing 2080. Gaps in the available climate datasets are noted where they have been identified.

However, vulnerability assessment beyond the 2050 time frame was not completed in consideration of the design life of the subject infrastructure and availability of climate projections. That is, significant reconstruction and/or rehabilitation of the infrastructure would likely occur beyond 2050. It is also understood that the uncertainty associated with climate projections increases moving farther into the future which would limit or question the validity and/or usability of any results.

Table 2-1 : Climate Information for St. John's[11]

Climate Parameter	1961-1990	1971-2000	1981-2010
Precipitation			
Average annual precipitation	1481.7 mm	1513.7 mm	1534.2 mm
Average annual rainfall	1163.1 mm	1191.0 mm	1206.4 mm
Average annual snowfall	322.1 cm	322.3 cm	335.0 cm
Extreme daily rainfall	121.2 mm July 1946		
Extreme daily snowfall	54.9 cm February 1939	68.4 April 1999	
Extreme snow depth	n/a	n/a	180 cm February 2001
Annual occurrence of daily rainfall events (with totals >25 mm)	n/a	10.4 events throughout the year with most occurring in August, September, October and November	11.4 events per year generally between March and December
Temperature			
Daily average minimum temperature	0.8 ºC	0.6 ºC	1.0 ºC
Daily average maximum temperature	8.6 ºC	8.7 ºC	9.0 ºC
Extreme minimum temperature	-23.8 ºC March 1986 and February 1990		
Extreme maximum temperature	31.5 ºC July 1983		
Frost			
Average date of last spring frost	n/a	n/a	May 30th
Average data of first autumn frost	n/a	n/a	October 17th
Average frost free season	n/a	n/a	139 days

2.7 MAJOR DOCUMENTS AND INFORMATION SOURCES

Major documents and other information sources used to support this climate change vulnerability assessment are referenced, as appropriate, throughout this report.

[11] Source: Environment Canada Climate Normals for the St. John's Airport weather station (#8403506), Environment Canada website at http://climate.weather.gc.ca/climate_normals/index_e.html

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SECTION 3

PIEVC PROTOCOL STEP 2

DATA GATHERING AND SUFFICIENCY

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3 STEP 2 - DATA GATHERING AND SUFFICIENCY

3.1 OVERVIEW

Step 2 of the PIEVC Protocol focuses on describing aspects of the subject infrastructure that will be assessed with relevant climate change parameters. Identification of the infrastructure components to be considered for evaluation has focused on:

- what are the infrastructure components of interest to be evaluated?
- number of physical elements and location(s)
- other potential engineering / technical considerations
- operations and maintenance practices and performance goals

The second part of this task focused on identification of relevant climate information. Climatic and meteorological data (both existing/historic data, as well as, future projected climate data) has been identified and collected. The objectives of the climate analysis and projections component of this assessment are to:

- establish a set of climate parameters describing climatic and meteorological phenomena relevant to Goulds, and;
- establish a general probability of occurrence of each climate phenomena, both historically and in the future.

As noted in Section 2, for the purposes of this assessment the term “historical” is defined as comprising both the existing climate and the climate from the recent past, while the “future” climate is defined as representing three timeframes, namely 2020, 2050 and 2080, where data is available.

Given the scoping level nature of this vulnerability assessment, the AMEC Team identified features of the subject infrastructure to be considered in the assessment using the climate information gathered for this study. The development of this assessment framework is typically a collaborative effort between the consultant and infrastructure owner/operator. The infrastructure component data and the climatic data form the foundation of the risk assessment matrix which is a fundamental aspect of the Protocol.

3.2 INFRASTRUCTURE OF INTEREST

As noted previously, the infrastructure of interest for this climate change vulnerability assessment are a storm water management facility and storm sewers in the community of Goulds in the Province of Newfoundland and Labrador.

3.2.1 Subject Infrastructure

3.2.1.1 Brookhaven Estates

The stormwater management pond has been designed based on post development peak flows being maintained equal to or less than pre-development peak flows for the 2, 5, 10, 25, 50 and 100 year storm events and has the following features:

- Pond bottom elevation of 81.45 m
- 5:1 (H:V) transition from pond bottom to elevation 83.15 m
- 3:1 (H:V) transition from elevation 83.15 m to elevation 84.20 m
- An outlet configuration consisting of a 100 mm diameter orifice (invert at elevation 83.10 m) plus an overflow weir with crest at elevation 83.80 m having length 1.829 m and thickness of 200 mm.
- The 2 year and 100 year pond elevations documented as 83.75 m and 84.10 m, respectively.
- The overall pond has a length of 101.3m and a width of 24.4 m as measured to elevation 184.10 m
- The stage-storage-discharge relationship for the stormwater management pond is outlined in Table 3-1.

Storm sewer design sheets for the Brookhaven Estates residential development were made available and formed the basis of this component of the assessment. The design sheets described six (6) storm sewer segments over a linear length of about 300 m. The design for the system is described in Table 3-2.

As noted in Table 43-2 the design conveyance capacity provides an excess of capacity over what is required based on the computations. In the case of pipe #3, this excess represents about 50% of the conveyance capacity of the storm sewer which is already at the minimum available pipe size. Excess capacities for this network are greater or equal to 8%.

Table 3-1: Stage-Storage-Discharge Relationship from MIDUSS Model

Level (m)	Discharge (m^3/s)	Volume (m^3)
83.10	0	0
83.15	0.001	77.7
83.20	0.003	157.1
83.25	0.006	238.2
83.30	0.008	321.0
83.35	0.009	405.5
83.40	0.011	491.8
83.45	0.012	579.8
83.50	0.013	669.6
83.55	0.014	761.1
83.60	0.014	854.4
83.65	0.015	949.5
83.70	0.016	1046.3
83.75	0.017	1145.0
83.80	0.017	1245.5
83.85	0.049	1347.8
83.90	0.106	1451.9
83.95	0.180	1557.8
84.00	0.267	1665.6
84.05	0.366	1775.2
84.10	0.475	1886.7
84.15	0.594	2000.0
84.20	0.721	2115.3

Table 3-2 Summary of the Original Storm Sewer Design – Brookhaven Estates

Pipe #	Length (m)	Diameter (mm)	Slope (%)	Required Capacity (cms)	Provided Capacity (cms)	Excess Capacity	Velocity (m/s)
1	60.0	450	0.20	0.117	0.128	9%	0.80
2	23.4	450	0.20	0.111	0.128	15%	0.80
3	84.3	525	0.16	0.145	0.172	19%	0.80
4	41.0	300	0.35	0.037	0.057	54%	0.81
5	49.0	525	0.20	0.178	0.192	8%	0.89
6	34.6	525	0.20	0.172	0.192	12%	0.89

3.2.1.2 Webber Estates

The design information for a larger storm sewer network design comprising 40 pipes ranging in size from 200 mm to 1200 mm diameter was also provided to this assessment. This network was designed for the Webber Estates residential development (see Table 3-3).

The Webber Estates residential development is comprised of sixty-five (65) single family homes and thirty-seven (37) townhouses. A general site layout is illustrated in Figure 2-5.

Excess capacities for this network are greater or equal to 4% and vary significantly over the range of pipe diameter as indicated below:

Pipe Diameter (mm)	Excess Capacity (%)
200	67%
300-450	16%
525-675	4%
1200	10%

It is also noted that the storm sewer design for Webber Estates integrated a 1.016 Imperial units equivalency factor for computation of flow capacity for the selected sewer pipe. This factor converts the named pipe size to the actual inside pipe diameter.

3.2.2 Infrastructure Support Systems

- *Power Sources*: Power was not deemed to be a direct element of the subject infrastructure and, therefore, was not considered for this assessment.
- *Communications*: Consideration was given to modes of communication include telephone, two-way radio, e-mail, Internet, and telemetry with respect to maintenance activities associated with the subject infrastructure.
- *Transportation*: Transportation refers to the road and driving conditions that can affect operations and staff response time, as well as, adverse conditions that might disrupt normal traffic flow.
- *Personnel*: Consideration was given to staffing situations relevant to operations and maintenance of the subject infrastructure.

Table 3-3 Summary of Original Storm Sewer Design – Webber Estates

Pipe #	Length (m)	Diameter (mm)	Slope (%)	Required Capacity (cms)	Provided Capacity (cms)	Excess Capacity	Velocity (m/s)
A1	45.5	200	1.58	0.015	0.043	66%	1.33
A2	41.5	200	2.48	0.017	0.054	68%	1.66
A3	45.5	200	2.24	0.015	0.051	70%	1.58
A4	41.5	200	3.28	0.018	0.062	71%	1.91
A5	87.6	375	0.35	0.103	0.108	5%	0.95
A6	45.6	200	2.94	0.015	0.059	75%	1.81
A7	41.0	200	3.78	0.013	0.067	81%	2.05
A8	45.6	200	2.72	0.021	0.056	62%	1.74
A9	77.4	450	0.35	0.171	0.176	3%	1.07
A10	59.7	200	1.73	0.020	0.045	56%	1.39
A11	30.6	450	0.45	0.191	0.200	4%	1.22
A12	41.1	200	2.38	0.019	0.053	63%	1.63
A13	94.5	525	0.3	0.238	0.246	3%	1.10
A14	22.3	525	0.35	0.260	0.265	2%	1.19
A15	12.2	200	8	0.023	0.097	76%	2.98
A15a	88.2	525	0.4	0.276	0.284	3%	1.27
A16	23.0	200	0.95	0.020	0.033	41%	1.03
A17	94.1	375	0.5	0.107	0.129	17%	1.13
A18	55.1	200	3	0.037	0.059	37%	1.83
A19	65.9	450	0.35	0.162	0.176	8%	1.07
A20	42.6	450	0.4	0.180	0.188	4%	1.15
A21	41.5	200	3.33	0.009	0.062	86%	1.93
A22	41.5	200	2.96	0.017	0.059	72%	1.82
A23	41.5	200	3	0.012	0.059	80%	1.83
A24	100.0	375	0.25	0.080	0.092	13%	0.8
A25	41.4	200	3	0.018	0.059	70%	1.83
A26	41.2	200	3	0.018	0.059	70%	1.83
A27	100.0	450	0.25	0.143	0.149	4%	0.91
A27a	23.0	600	0.25	0.314	0.320	2%	1.10
A27b	32.5	600	0.25	0.310	0.320	3%	1.10
A28	30.5	675	0.5	0.600	0.620	3%	1.68
A29	30.5	675	0.65	0.633	0.707	10%	1.91
A30	31.9	300	0.5	0.038	0.071	47%	0.98
A31	81.4	375	0.5	0.067	0.129	48%	1.13
A32	81.4	375	0.5	0.093	0.129	28%	1.13
A33	8.0	1200	0.15	1.424	1.575	10%	1.35
A34	73.7	1200	0.15	1.502	1.575	5%	1.35
A35	73.7	1200	0.15	1.482	1.575	6%	1.35
A36	51.2	1200	0.25	1.766	2.034	13%	1.74
A37	24.1	1200	0.28	1.776	2.152	17%	1.84

3.2.3 Infrastructure Components for Assessment

The study infrastructure has been segregated into the following elemental components for the purposes of assessment:

Storm Sewer System

- Catchbasins (Inlets)
- Pipes
- Outlet

Stormwater Management Pond

- Inlet
- Quantity Control Component
- Quality Control Component
- Design Outlet
- Emergency Overflow
- Containment / Earthen Berm

Support Systems

- Communications
- Transportation
- Personnel

3.3 CURRENT DESIGN STANDARDS

The design of the stormwater infrastructure is founded upon requirements of the City of St. John's as outlined in:

City of St. John's, Department of Planning, Development & Engineering, Subdivision Design Manual, Division 8, Stormwater Detention, 2013.

3.4 JURISDICTIONAL OVERVIEW

Stormwater infrastructure located within the City of St. John's is owned and managed by the municipality.

3.5 CLIMATE ANALYSIS

3.5.1 Overview

The objectives of this component of the report are to:

- Establish a set of climate parameters describing the climatic and meteorological phenomena relevant to the case study
- Establish a general probability of occurrence of each climate parameter both historically and in the future.

As noted previously, the term “historical” relates to climate from the current time frame and recent past while “future” relates to the future time frames previously noted as 2020, 2050 and 2080. However, data for all climate variables/phenomena were not available for these periods.

It should also be noted that this climate analysis is not meant to be exhaustive. The climate information presented in the following sections is not based on new science or analyses generated through this project but a review of readily available information from other sources. It is clear that climate science is advancing rapidly and this review should not be construed as a comprehensive characterization of the historic climate or future projections of the case study.

For this study, the climate change datasets are developed by the Province were the primary source of climate data for this assessment. These datasets are described in Section 3.6.3.

As well, uncertainties in the climate projections are clearly demonstrated in the results (Finnis, 2013). The information developed and used for this project is adequate to meet the stated objectives of the case study; however, other potential users of the information should consider it in the proper context.

3.5.2 The “Long” and “Short” List of Climate Variables

A preliminary “long” list of climate parameters was developed based on climate events and change factors identified in Appendix A of the Protocol as indicated below:

- High and Low Temperature
- Heat and Cold Waves
- Extreme Diurnal Temperature Variability
- Freeze Thaw Cycles
- Heavy Rain / Daily Total Rain
- Winter Rain / Freezing Rain
- Ice cover/Thickness
- Coastal Erosion
- Sea Level and Storm Surge
- Snow Accumulation
- Blowing Snow/Blizzard
- Frost
- Hail Storm
- Hurricane/Tropical Storm
- High Winds
- Heavy Fog
- Drought/Dry Periods
- Flooding

The list was refined by AMEC[12] based on climatic and meteorological phenomena deemed relevant to the stormwater management pond and storm sewer systems in Goulds. Further

[12] The refinement exercise is typically done in collaboration with the infrastructure owner/operator

refinement was needed for rainfall oriented parameters to "dovetail" with the available climate projections.

Justification for selection of a climate parameter was based on the parameter's potential to affect vulnerability to the infrastructure and its components as a result of either an extreme or persistent occurrence.

The short list of climate variables that would be considered relevant for assessment are outlined below:

- High and Low Temperature
- Heat Waves
- Extreme Precipitation Return Periods
- Snow Accumulation

Due to the scoped nature of the present vulnerability assessment, only High and Low Temperature and Extreme Precipitation Return Periods have been assessed.

3.5.3 Climate Data Sources

3.5.3.1 Historical

The basic analysis of historical data for the study area was based on data from a variety of sources including:

- Environment Canada's Climate Normals
  (available at http://climate.weatheroffice.gc.ca/climate_normals/index_e.html)
- Environment Canada's Climate Data Online
  (available at http://climate.weatheroffice.gc.ca/climateData/canada_e.html)
- Environment Canada's Canadian Daily Climate Data (CDCD v1.02)
  (available at ftp://arcdm20.tor.ec.gc.ca/pub/dist/CDCD/)

The St. John's Airport weather station (#8403506 at 47 37'N, Longitude: 52 44'W) was used where available from the above noted data sources. Where data for this station were not available in the databases above data for a nearby station or information in the literature based on a regional context was used. Any other data sources, when used, are documented in the climate parameter specific sections that follow.

3.5.3.2 Future

To date, the Province has collected four (4) datasets with a view to establishing a basis for the Province's approach to improving resilience to climate change impacts. These data sets are:

- Climate Projections for the Province

  Projected Impacts of Climate Change for the Province of Newfoundland & Labrador
  Dr. Joel Finnis, Department of Geography Memorial University of Newfoundland
  March 22, 2013

  This study down-scaled four internationally recognized global models to develop projections for the Province. The main projections for temperature and precipitation use regional data from twelve (12) weather stations in Newfoundland and six (6) stations in Labrador, ensuring that local conditions were included in the study.

- Flood risk mapping incorporating potential climate change influences

  Flooding is a natural process and the conditions that result in floods are often predictable and usually occur in the same areas, known as flood plains. Flooding and erosion processes are quite difficult to control and avoid. As such, the best and most cost effective method of minimizing their impact is proper management and planning of known flood plains. Flood plain management usually involves the adoption of land use regulations that limit human exposure to areas prone to flooding events. The Department of Environment and Conservation has undertaken hydro-technical studies, identifying and mapping regular and climate change flood risk zones and then implementing policies to limit future flood susceptible development in those areas. Climate change flood risk maps have been developed for seven (7) communities.

  Two examples:

  - *Flood Risk Mapping Project, Corner Brook Stream and Petrie's Brook*
    Government of Newfoundland and Labrador
    Water Resources Management Division
    Department of Environment and Conservation
    Prepared by AMEC Environment & Infrastructure, February 2013

  - *Flood Risk Mapping Project, Goulds and Petty Harbour Area*
    Government of Newfoundland and Labrador
    Water Resources Management Division
    Department of Environment and Conservation
    Prepared by AMEC Environment & Infrastructure, March 2013

- Coastal Vulnerability Assessment (2011 – on-going)

  A Coastal Vulnerability Assessment program was established in 2011-12 to monitor the impact of coastal erosion in select sites. Data is now available for 104 sites around the Province, including 34 sites previously established by the Geological Survey of Canada and the Geological Survey of Newfoundland and Labrador.

This dataset is comprised of the following:

- *Coastal Monitoring in Newfoundland and Labrador: 2012 Update*
  M. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University Current Research (2013) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 13-1, pages 43-54
- *Coastal Monitoring in Newfoundland and Labrador*
  M.L. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University Current Research (2012) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 12-1, pages 191-197
- A Microsoft Excel™ spreadsheet (Coastalmonitoring_sites.xlsx[13]) identifying the monitoring sites.
- Surveyed field data and associated GIS data layers.

- Predictions of Future Sea Level Rise (2010)

  Understanding the direction and magnitude of future sea-level change is important in planning and regulating development in coastal zones. Estimates of sea level rise change leading up to 2050 and 2100 are provided for four zones covering the Province in the following reference:

  - *Past and Future Sea Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning,* Martin Batterson, Geochemistry, Geophysics and Terrain Sciences, Memorial University and David Liverman, Geological Survey of Newfoundland and Labrador, Current Research (2010) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 10-1, page 129-141

  This dataset was used to support definition of ocean water level boundary conditions for the two flood plain mapping studies previously noted.

Other readily available literature, as documented in the specific climate parameter sections that follow, was also reviewed.

3.5.4 Climate Variable Probability of Occurrence

The process of assessing the probability of a climate parameter's chance of occurrence was conducted by first identifying historical frequency. In some instances the relevant data were presented in a format that could be directly related to probability. In other instances a directly comparable format was either unintelligible or unattainable. A scoring system was used whereby a score between 0 and 7 was assigned to each parameter by subjectively relating the

[13] Provided by the Province

known or calculated frequency to one of the descriptive terms. Method A from Figure 3 of the Protocol, Probability Score Definitions, was adopted for use for this study. Figure 3, specific to Method A, is reproduced in part as Table 3-4 below.

Table 3-4 : Risk Assessment Probability Score Definitions – Method A

(source: PIEVC, 2012)

PIEVC Probability Score	Method A	Range of Occurrences (per Year)
0	Negligible or not applicable	0
1	Improbable / highly unlikely	>0 to 0.05
2	Remote	>0.05 to 0.1
3	Occasional	>0.1 to 0.25
4	Moderate / possible	>0.25 to 0.75
5	Often	>0.75 to 1.25
6	Probable	>1.25 to 2
7	Certain / highly probable	>2

In many instances, though, the characterization of a climate parameter is descriptive rather than numeric. In these cases a definable means may be required to relate the available descriptive terms to that required for numeric probabilities. This process is outlined below and follows the same process used for a recent PIEVC based vulnerability assessment of flood control dams completed by the Toronto and Region Conservation Authority (TRCA, 2010).

The process is initiated with the question “what is the likelihood that an event will occur in a given year?” For example, a climate parameter having a historical annual frequency of 0.5 would be considered to mean that the climate event would occur, on average, once every two years. In consideration of the available descriptive terms, the term “moderate/possible” best represented the likelihood of its occurrence in a given year. In other words, it is by no means certain that it will occur every year.

Following the same rationale as above, parameters with known or calculated probability scores of greater than 2 were considered very likely to occur in a given year based simply on the historical record. Therefore, any probability scores greater than 2 were considered best represented by the term “certain/highly probable”. Method A (ref. Table 3-4) relates the term “certain/highly probable” to a Probability Score of 7.

The above three rationales provide the relational benchmarks considered for this assessment. Consistency was maintained throughout the assessment process by using a suite of frequency ranges as described in Table 3-1 which related frequency ranges to PIEVC scores. Using this mechanism, where frequencies were available, the matching probability score was assigned.

3.5.4.1 High Temperature

Definition

The maximum temperature currently recorded for St. John's is 31.5°C, which occurred in July of 1983 (Environment Canada, 2011). As a reflection of the recorded high temperature, a threshold temperature of 30°C has been selected as representative of the measure of high temperatures for this report. This definition is consistent with other PIEVC protocols based climate change vulnerability assessments (e.g., TRCA, 2010; AMEC 2012).

Historical Climate

Climate normals for St. John's Airport, obtained from Environment Canada Data Online (Environment Canada, 2011) for the period from 1981 to 2010, indicate an average of 52.6 days a year with temperatures greater than 20°C, an average of 0.2 days per year had temperatures greater than 30°C and there were no days with temperaures greater than 35°C.

The findings for 'number of days with a maximum temperature >30°C' outlined in Table 3-5 were compared with the established ranges in Table 3-4, resulting in a recommended probability scale of "remote" (or "2").

Trends

In a study by Zhang et al. (2000), trends in temperature change over Canada were analyzed during the 20th century. Over southern Canada, the mean annual temperature was found to have increased between 0.5 and 1.5°C (between 1900 and 1998), with the greatest warming found in the Prairie Provinces. It was found that the change was due largely to warmer overnight temperatures, meaning that the region was becoming less cold but not hotter. Specific temperature elements included in the analysis were the minimum, maximum, and mean temperature. For southern Canada, trends were computed for the period 1900-1998 and for the rest of Canada for the period 1950-1998.

The trend in increasing overnight temperatures was statistically significant over all of southern Canada. Easterling et al. (2000) discuss a similar finding in studies on the trends of temperatures in the United States over the period 1910-1998.

Table 3-5 : Summary of High Temperature Occurence (°C)

Description	Days/Year	
	Historic[1]	2050[2]
> 20°C	52.6	increasing
> 30°C	0.2	Increasing
> 35°C	0	unchanged
Probability Score	2 remote	3 Occasional

Notes:
1. Source: Environment Canada, 2011
2. Source: Finnis, 2013

Climate Projections

Findings

As documented in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report (Finnis, 2013) daily maximum temperatures are projected to increase throughout the Province. This report indicated the largest increase, for St. John's, during the winter with temperatures increasing an average of 2.0°C with an ensemble uncertainty of 0.6. Finnis also estimated the projected increase in daily maximum temperature during the summer months (June, July, and August) to be 1.8°C, having an ensemble uncertainty of 0.4. It should be noted that Finnis' daily maximum temperatures are projected for 2038-2070. Furthermore Finnis' findings, similar to historic trends, show greater increases in overnight temperatures than daytime temperatures. The Finnis report does not provide data to compute projected daily occurrence of temperatures above 30°C.

Probability Scoring

Data for the average number of days having high temperatures in Newfoundland is not currently available in the Province's climate change datasets. As such, a quantitative estimate of the projected probability score for High Temperature can only be approximated from the available data.

Given that the findings of the Finnis report suggest an increase in daily maximum temperature it is inferred that the 'number of days with a maximum temperature >30°C' also has the potential to increase with climate change. As such, a probability score of '3' or 'occasional' has been assigned (ref. Table 3-5).

3.5.4.2 Low Temperature

Definition

The minimum temperature currently recorded for St. John's is -23.8°C, which occurred in March 1986 and February 1990 (Environment Canada, 2011). As a reflection of this recorded low temperature, a threshold of -20°C was considered a representative and the threshold for low temperature for this assessment. This definition is consistent with other PIEVC protocols based climate change vulnerability assessments (e.g., TRCA, 2010; AMEC, 2012a).

Historical Climate

Climate normals for St. John's Airport for the period from 1981 to 2010 indicate an average of 34.9 days per year with temperatures less than -10°C, 0.6 days per year with temperatures less than -20°C and 0 days per year with temperatures less than -30°C (ref. Table 3-6).

Probability Scoring

The findings for 'number of days with a minimum temperature < -20°C' were compared with the established ranges in Table 3-4, resulting in a recommended probability score of "Remote" (or "2").

Climate Projections

Findings

Daily minimum temperatures are projected to increase approximately 3 ºC to 6ºC across the Province over the period 2038-2070 (Finnis, 2013). The greatest increase would appear in Labrador (Finnis, 2010). Finnis reported that daily minimum temperatures during the winter months would increase by an average of 2.8ºC in the St. John's area, with an average ensemble uncertainty of 1.5.

Probability Scoring

The upward movement in daily minimum temperatures into the future 2038-2070 time frame suggests the probability score of "Improbable / highly unlikely" (or "1").

Table 3-6 : Summary of Low Temperature Occurence (°C)

Description	Days/Year	
	Historic[1]	2050[2]
< -10°C	0.2	decreasing
< -20°C	0.2	decreasing
< -30°C	0	n/a
Probability Score	2 Remote	1 Improbable / highly unlikely

Notes:
1. Source: Environment Canada, 2011
2. Source: Finnis, 2013

3.5.4.3 Extreme Precipitation Return Periods

Definition

An Intensity-Duration Frequency (IDF) Curve is a tool that characterizes an area's rainfall pattern. By analyzing past rainfall events, statistics about rainfall reoccurrence can be determined for various standard return periods; for example, the depth and duration of the rainfall event that statistically occurs once every 10 years.

Historical Climate

The weather station at St. John's Airport (#8403506) has a period of record from 1949 – 1996, although data for the period 1950 to 1960 is missing. The current IDF reports/data available for this stations is dated February 9, 2012.

The following comments stem from a general review of the applicability of the data from these stations to support this assessment:

- The St. John's Airport weather station, relative to Goulds, lies about 18 km to the north from the subject infrastructure.

- Figure 3-1 illustrates the Public Forecast Warning Areas used by Environment Canada. The Public Forecast Warning Area boundaries were developed by Environment Canada several decades ago based on rigorous climate studies and considerable public consultation. The City of St. John's and Goulds are located within the St. John's and Vincinity Warning Area.

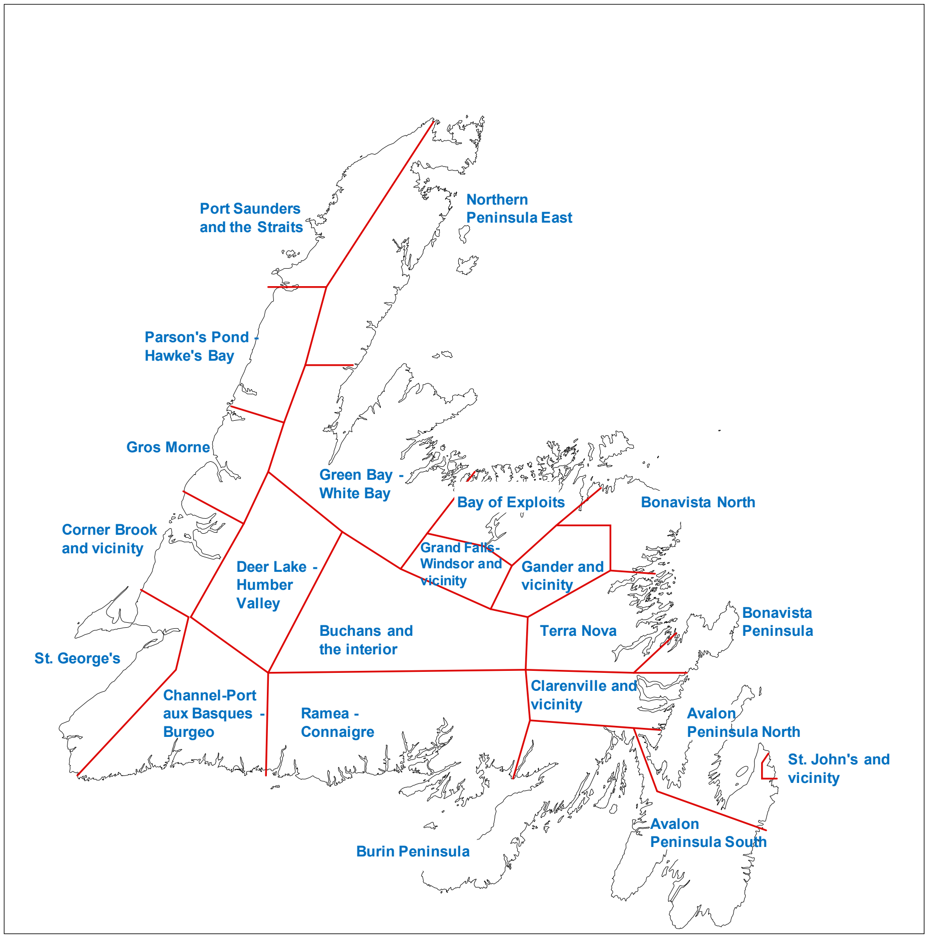

Figure 3-1 : Public Weather Warning Regions for Newfoundland
(Based on http://www.weatheroffice.gc.ca/warnings/nl_e.html)

The IDF estimates for the project area are provided in Table 3-7. The 1:20 year precipitation amounts were estimated by interpolation (using the Logarithmic trending option in Microsoft Excel[TM]) from the 1:10 year and 1:25 year amounts.

The historical extreme precipitation return periods are provided below in Table 3-8. Historical extreme precipitation return period data for St. John's was obtained from the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report. These data were accrued and analysed by Dr. Finnis from the Adjusted & Homogenized Canadian Climate Data (AHCCD) using the same methods used by Environment Canada for their IDF curves.

Table 3-7: Return Period Rainfall Amounts for St. John's Airport (mm)

Duration	Frequency				
	10 year	20 year	25 year	50 year	100 year
10 min	10.8	12.2	12.8	14.3	15.7
30 min	19.0	21.4	22.3	24.8	27.2
1 h	25.5	28.4	29.5	32.5	35.5
2 h	36.8	41.5	43.3	48.2	53.1
6 h	57.6	64.7	66.1	72.3	78.5
12 h	71.0	77.8	80.5	87.6	94.5
24 h	83.6	91.9	94.5	102.6	110.6

Table 3-8 : Summary of AHCCD-Derived Results for Extreme Precipitation Return Periods for St. John's (24 hour duration)

Description	Historic[1]	2038-2070 Period	
		Projected Mean[1]	Projected Maximum[1]
20 year	91.9	102.6	115.5
50 year	102.6	114.6	130.2
100 year	110.6	123.7	141.2
Notes: 1. Source: Finnis, 2010			

As well, as documented in the recent hydrotechnical study completed for the Gould and Petty Harbour area (AMEC, 2013), an updated version of the St. John's IDF relationships was prepared by CBCL as a component of the flood risk mapping assignment for WRMD for the Town of Logy Bay – Middle Cove – Outer Cove.

CBCL updated the City of St. John's IDF relationship using data from Environment Canada and new data from City of St. John's rain gauges. CBCL included rainfall from hurricanes Gabrielle, Igor and Chantal in its analysis which had the effect of increasing the 100 year 24 hour precipitation IDF value to 136.8 mm (compared with 110.6 mm from the current Environment Canada published IDF relationship. The CBCL IDF relationship is summarized in Table 3-9.

Table 3-9 : CBCL IDF Relationship for St. John's (2013)

Duration	Frequency	
	20 year	100 year
5 min	8.2	10.4
10 min	11.9	15.0
15 min	15.2	19.2
30 min	22.6	28.5
1 h	32.4	40.9
2 h	46.8	59.8
6 h	75.0	94.2
12 h	96.0	121.2
24 h	110.4	136.8

Probability Scoring

For this climate parameter, a probability score of '4' or 'Moderate / possible' was assigned to reflect that return period precipitation values are typical in any given year and the probability score reflects the current expectation of occurrence as a means of establishing a trend into the future (ref. Table 3-8).

Climate Projections

Findings

As reported in the *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report, precipitation levels for extreme precipitation return periods for the St. John's area are projected to increase. The greatest increase in the projected precipitation levels is noted for the 100 year event; an increase of 30.6 mm or 28% over the historic value (ref. Table 3-8).

Return rainfall projections to 2020, 2050 and 2080 were also prepared for the hydrotechnical study for Goulds and Petty Harbour (AMEC, 2013) as outlined in Table 3-10. These projections were based on the CBCL IDF relationships for St. John's. Comparing the Environment Canada published IDF data for the 24 hour duration event (110.6 mm) to the projected estimates by AMEC indicates increase of 33%, 38% and 44%, respectively for the 2020, 2050 and 2080 projections.

As noted previously the storm sewer design standard for St. John's is 77.2 mm/hr which was identified as analogous to the 5 year, 5 minute duration design rainfall event. This design event would yield a total rainfall depth of 6.4 mm. Comparing the AMEC values in Table 3-10 with the City's design standard indicates that the design standard would continue to reflect a 5 year 5 minute rainfall to 2020. However, the 5 year, 5 minute rainfall for 2050 and 2080 would slightly exceed the City's current design standard.

Table 3-10 : AMEC Projected Rainfall Estimates for St. John's[14]

		Rainfall Totals (mm) - Maximum, 2020 timeframe					
		Return period (years)					
		2	5	10	20	50	100
Storm Duration	5 min	4.8	6.4	7.4	8.3	9.6	10.6
	10 min	7.6	9.7	11.0	12.4	14.2	15.4
	15 min	9.8	12.5	14.3	15.9	18.2	19.9
	30 min	14.8	18.9	21.5	24.1	27.3	29.9
	1 hr	21.7	27.7	31.6	35.3	40.1	43.6
	2 hr	29.8	39.2	45.2	51.1	58.5	64.1
	6 hr	49.6	62.8	71.9	80.3	91.1	99.5
	12 hr	63.8	80.8	93.0	103.9	118.4	129.3
	24 hr	76.7	96.2	108.3	120.4	134.9	147.0

		Rainfall Totals (mm) - Maximum, 2050 timeframe					
		Return period (years)					
		2	5	10	20	50	100
Storm Duration	5 min	5.0	6.5	7.5	8.5	9.7	10.6
	10 min	7.9	9.9	11.3	12.6	14.4	15.6
	15 min	10.2	12.9	14.6	16.3	18.5	20.2
	30 min	15.6	19.6	22.2	24.8	28.0	30.5
	1 hr	23.1	29.1	32.9	36.6	41.4	44.9
	2 hr	31.7	41.1	47.1	53.0	60.4	66.0
	6 hr	52.4	65.7	74.7	83.2	94.0	102.5
	12 hr	67.9	85.0	97.2	108.2	122.8	133.7
	24 hr	82.0	101.7	113.8	126.0	140.4	152.5

		Rainfall Totals (mm) - Maximum, 2080 timeframe					
		Return period (years)					
		2	5	10	20	50	100
Storm Duration	5 min	5.2	6.7	7.7	8.6	9.9	10.8
	10 min	7.9	10.0	11.3	12.7	14.4	15.7
	15 min	10.2	12.9	14.7	16.3	18.6	20.2
	30 min	15.7	19.7	22.3	24.9	28.1	30.6
	1 hr	23.2	29.2	33.0	36.8	41.5	45.0
	2 hr	31.9	41.3	47.4	53.2	60.6	66.3
	6 hr	56.0	69.3	78.4	86.9	97.7	106.2
	12 hr	73.1	90.2	102.6	113.6	128.3	139.4
	24 hr	88.6	108.5	120.7	132.9	147.4	159.6

[14] Source: AMEC, 2013

The *Projected Impacts of Climate Change for the Province of Newfoundland & Labrador* report has information documenting future extreme precipitation return period data for 6 hour, 12 hour and 24 hour durations only. These durations are not sufficient to support design of storm sewer systems. As such, it is recommended that this data be expanded to include the other duration event that comprise a full IDF relationship.

Probability Scoring

A probability score of '6' or 'Probable' was assigned to reflect the significance of the increases in projected return period rainfall amounts (ref. Table 3-8).

Table 3-11 : Summary of Probability Scoring for Return Period Rainfall (mm)

Definition	Days/Year	
	Historic	2050
Return Period Rainfall – 100 Year 24 Hour Duration	110.6[1] 136.8[2]	141.2[3] 152.5[2]
Probability Score	4 Moderate / possible	6 Probable

Notes:
1. Source: Environment Canada, 2011
2. Source: AMEC, 2013
3. Source: Finnis, 2013

3.5.4.4 Climate Parameters Summary

A summary of the historical and future climate parameter probability scores is provided in Table 3-10.

Table 3-12 : Climate Parameters Summary

Climate Parameter	Anticipated Changes	
	Historic	Future 2050
Increasing		
High Temperature	3	4
Extreme Precipitation	4	6
Decreasing		
Low Temperature	2	1
Not included in this Assessment		
Heat Waves		
Snow Accumulation		

SECTION 4

PIEVC PROTOCOL STEP 3

RISK ASSESSMENT

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4 STEP 3 - RISK ASSESSMENT

4.1 OVERVIEW

An engineering vulnerability exists when the total load effects on infrastructure exceed the total capacity to withstand them, while meeting the desired performance criteria. Where the total loads or effects do not exceed the total capacity, adaptive capacity exists.

Step 3 of the PIEVC Protocol involves the identification of infrastructure components which are likely to be sensitive to changes in specific climate parameters (ref. Section 3). This step focuses on qualitative assessments as a means of prioritizing more detailed Evaluation Assessments or Engineering Analyses, if required, in Step 4 of the Protocol. In other words, professional judgment and experience are used to determine the likely effect of individual climate events on individual components of the infrastructure. To achieve this objective, the Protocol uses an assessment matrix process to assign an estimated probability and an estimated severity to each potential interaction.

As noted in Section 3.6.4, the Protocol specifies that a scaling system with values ranging from 0 to 7 be applied to rank both the potential climate events and the estimated response severity. For this project, Method A (climate probability scores) and Method E (response severity scores) have been selected as being the most appropriate based on the available data. The climate probability scores identified for use in the risk assessment are documented in Section 3.6.4 of this report.

An evaluation of this type is usually completed during a Risk Assessment Workshop which brings together representatives of the infrastructure owner/operator plus other stakeholders.

The objectives of a risk assessment workshop would include:

- learning more about interactions between infrastructure components and weather events;
- identifying anecdotal evidence of infrastructure responses to weather events;
- discussing other factors that may affect infrastructure capacity;
- identifying actions that could address climate effects,
- Identifying and documenting the local perspective relevant to the subject infrastructure.

Given the nature of this climate change vulnerability assessment (ref. Section 1.2), AMEC completed the risk assessment of the stormwater infrastructure independently.

4.2 RISK ASSESSMENT RESULTS

4.2.1 Methodology

The complete Risk Assessment Matrix for this project is included in Figure 4-1 of this report. Under each *climate effect* column heading, there are four sub-headings, as follows:

1. **Y/N (Yes/No).** This field is marked "Y" if there is an expected interaction between the infrastructure component and the climate effect, and "N" if not. This was triggered by reviewing potential *performance responses* in light of the climate variable. For example, would or could any of the following issues be affected by the anticipated changes in a climate variable:

    - Structural Design (Design)
        - Safety
            - Load carrying capacity
            - Overturning
            - Sliding
            - Fracture
            - Fatigue
            - Serviceability
        - Deflection
            - Permanent deformation
            - Cracking and deterioration
            - Vibration
        - Foundation Design Considerations
    - Infrastructure Functionality (Functionality)
        - Level of Effective Capacity (short, medium, long-term)
        - Equipment (component selection, design, process and capacity considerations)
    - Infrastructure Performance (Performance)
        - Level of Service, Serviceability, Reliability
        - Materials performance
    - Watershed, Surface Water and Groundwater (Environment)
        - Erosion along watercourses
        - Erosion scour of associated/supporting earthworks
        - Sediment transport and sedimentation
        - Channel re-alignment / meandering
        - Change in water quantity
        - Change in water quality (Water Quality)
        - Change in water resources demands
        - Change in groundwater recharge
        - Change in thermal characteristics of water resource
    - Operations and/or Maintenance
        - Structural aspects
        - Equipment aspects

    - Functionality and effective capacity
- Emergency Response (Emergencies)
    - Storm, flood, ice, water damage
- Insurance Considerations (Insurance)
- Municipal Considerations (Policies)
    - Codes
    - Public sector policy
    - Land use planning
    - Guidelines
    - Inter-government communications
- Social Effects (Social Effects)
- Economic considerations (Economic)

A general ‘Other’ category was also included to allow capture of issues not covered by the aforementioned considerations.

2. **P (Climate Probability Score Factor).** This value reflects the expectation of a change in a climate variable under the influence of climate change as outlined in Section 3.6.4.

3. **S (Response Severity Score Factor).** This value reflects the expected severity of the interaction between the climate phenomena and the infrastructure component. As such, different climate phenomena may lead to varying response severities.

4. **R (Priority of Climate Effect).** This is calculated as P multiplied by S. This priority value is used to determine how the interaction will be assessed in the next steps of the protocol. Since this is a qualitative assessment, the R should not be used to prioritize recommended actions.

At the end of this assessment, three categories of infrastructure-climate interactions emerge:

1. **R > 36.** “High” possibility of a severe effect. Interactions in this range should lead to recommendations in Step 5 of the Protocol.

2. **12 < R ≤ 36.** “Medium” possibility of a major effect. These effects are considered to be in a “grey area”, where it is uncertain whether the impact is sufficient to cause the need for recommendations. Step 4 of the protocol, which involves a quantitative analysis, can be used to determine which effects to leave aside and which to discuss further.

3. **R ≤ 12.** “Low” possibility of an effect. These infrastructure-climate interactions are typically left aside without further analysis or recommendations.

A summary of the results of the risk assessment are provided in Figure 4-1, at the end of this section. The colour coding in the Figure relates to the Priority of Climate Effect ranges (i.e., "high" (red), "medium" (yellow) and "low" (green)).

A major outcome of the risk assessment workshop was that only a few infrastructure-climate interactions were identified in the "High" category. The highest Priority of Climate Effect value was calculated as 42 with a number of infrastructure interactions with the extreme precipitation climate parameter.

4.2.2 Results

This section provides some insight to the matrix values resulting from the Risk Assessment documented in Table 4-1.

Stormwater Management Facility and Storm Sewers

The highest severity ratings are linked to performance responses that contribute to exceedence of system capacity and/or potential flooding. The climate parameter triggering these responses was Extreme Precipitation. Other views of precipitation that have been used in other similar PIEVC assessments such as, Heavy Rain, 5 Day Total Rain and Winter Rain could also be assessed but a similar outcome would be expected. Winter Rain is noted due to the significant flooding that can be generated by minor winter rain events.

Winter Rain can occur in periods when the ground is frozen leading to significant runoff episodes from minor rainfall events. An example from the Ganaraska River Watershed (located east of Toronto near Port Hope, Ontario) is cited, whereby a Winter Rain event measured as approximately a 5 year rain resulted in a 100 year flood due to frozen ground conditions across the drainage area (AMEC, 2006).

In light of the development of the projected IDF relationships, some discussion during the assessment was focused on municipal standards for design of stormwater collection systems. The City of St. John's municipal design standards presently require design of the collection system to a 5 year return period level. The projected increases in rainfall (intensity/volume) through 2050 and 2080 suggest that a current 5 year may occur more frequently in the future resulting in under performance of the system. However, the increase in frequency is expected to be marginal suggesting a change in the municipal design standard may not be necessary.

The high risk associated with the stormwater management facility earthen embankment reflects the possibility of increased rainfall resulting in overtopping of the embankment and potentially causing failure. Failure of the embankment would potentially result in damages to downstream aquatic habitat both from flooding from the released of stored stormwater runoff from the facility and from the movement of accumulated sediments from the facility.

Heat Waves were also considered to be an issue regarding stormwater management facilities and the major overland stormwater conveyance system. There is the potential during heat waves for stormwater management facilities to lose significant volumes of retained water resulting in favourable mosquito breeding conditions (Durham, 2003) and also starving receiving systems of water during minor events. A secondary effect may be that facility vegetation may die resulting in debris movement during the next wet weather event having the potential to reduce the capacity of (i.e., clog) the facility outlet or downstream conveyance system.

Roadways can be significantly impacted by high temperature and heat waves both in terms of degradation of the asphalt surface (which could lead to major flow conveyance problems) but also in terms of movement of harmful substances from the asphalt material into the environment, particularly with stormwater runoff (Sudbury, 2008).

Snow accumulation has been considered to be an issue in regard to performance of stormwater management facilities and the major stormwater conveyance system for other similar assessments. The expectation is that even though projected snow accumulation events are decreasing, having significant snow accumulated on the ground coupled with a Winter Rain event could have serious consequences.

Performance (i.e., sediment removals rates) of Oil/Grit Separators (OGS) is typically based on historic average annual rainfall conditions. Given the projected changes in annual rainfall patterns, a reduction in the performance of OGS systems is expected, resulting in poorer water quality at discharge points and/or the need for increased frequency of infrastructure maintenance.

A potential erosion issue, due to increased extreme rainfall events, is anticipated at storm outfalls, although this interaction is not considered severe.

4.3 DATA SUFFICIENCY

The Risk Assessment step of the evaluation required judgments on significance, likelihood, response and uncertainty in the context of the probability of climate effects and the severity of infrastructure responses to the effects. Some judgments could be fairly easily made based on available information, however, others required use of “indirect” information. This complicated the assessment of the response severity of climate effects on infrastructure operations, and, more specifically, introduced additional uncertainty into the assessment.

In general, the data available were sufficient for the non-numerical (qualitative), engineering judgment-based screening purposes of this risk assessment.

It is again noted that this scoped climate change vulnerability assessment reviewed climate change and infrastructure datasets as applicable to the PIEVC Protocol; specifically Steps 1 and 2, and a preliminary, independent application of Step 3 of the Protocol only.

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Infrastructure Component	Performance Response (✓ if yes)											Climate Events																			
	Structural Design	Functionality	Watershed, Surface Water and Groundwater	Operations, Maintenance, Materials Performance	Emergency Response	Insurance Considerations	Policy Considerations	Social Effects	Water Quality	Economic Considerations	*Other*	High Temperature (3 to 4)				Low Temperature (2 to 1)				Extreme Precipitation Return Periods (4 to 6)				Heat Waves (not included in this assessment)				Snow Accummulation (not included in this assessment)			
												Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R	Y/N	P	S	R
													4				1				6										
Operations and Maintenance																															
Personnel		Y		Y		Y	Y	Y				Y	4	4	16	Y	1	4	4	Y	6	3	18								
Transportation		Y		Y	Y	Y	Y			Y		Y	4	2	8	Y	1	5	5	Y	6	4	24								
Communications		Y		Y	Y	Y				Y		Y	4	2	8	Y	1	2	2	Y	6	2	12								
Stormwater Management Pond																															
Inlet	Y	Y	Y	Y								Y	4	1	4	Y	1	3	3	Y	6	2	12								
Quantity Control Component	Y	Y	Y							Y		Y	4	1	4	Y	1	4	4	Y	6	6	36								
Quality Control Component	Y	Y	Y	Y					Y	Y		Y	4	4	16	Y	1	4	4	Y	6	5	30								
Design Outlet	Y	Y	Y	Y					Y			Y	4	1	4	Y	1	2	2	Y	6	7	42								
Emergency Overflow	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	4	1	4	Y	1	2	2	Y	6	2	12								
Containment / Earthem Berm	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	4	1	4	Y	1	2	2	Y	6	7	42								
Storm Sewer System																															
Catchbasins (Inlets)	Y	Y	Y									Y	4	1	4	Y	1	2	2	Y	6	2	12								
Pipes	Y	Y	Y									Y	4	1	4	Y	1	1	1	Y	6	6	36								
Outlet	Y	Y	Y		Y			Y	Y			Y	4	1	4	Y	1	2	2	Y	6	5	30								

The highlighted values depicted in this Figure are the 'Priority of Climate Effect' or 'R' values resulting from the Risk Assessment.

Priority of Climate Effect		
R > 36	High	
12 < R ≤ 36	Medium	
R ≤ 12	Low	

Table 4-1 : Risk Assessment Results

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SECTION 5

PIEVC PROTOCOL STEP 4

ENGINEERING ANALYSIS

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5 STEP 4 - ENGINEERING ANALYSIS

Step 4 of the PIEVC Protocol focuses on the determination of adaptive capacity. Specifically, if the climate changes as described in Step 2, does the infrastructure of interest have adaptive capacity available to meet the desired performance criteria? If the adaptive capacity is determined not to exist, this evaluation determines the additional capacity required to meet the desired performance criteria, again if the climate changes as described in Step 2.

The engineering analysis step requires the assessment of the various factors that affect load and capacity of the subject infrastructure. Based on this assessment, indicators or factors are determined in order to relatively rank the potential vulnerability of the infrastructure elements to various climate effects.

As noted in the Protocol, much of the data required for Engineering Analysis may not exist, or may be very difficult to acquire, and this analysis requires the application of multi-disciplinary professional judgment. Thus, even though numerical analysis is applied, the practitioner is cautioned to avoid the perception that the analysis is definitively quantitative or based on measured parameters. The results of the analysis yield a set of parameters that can be ranked relative to each other, based on the professional judgment of the practitioner. The results can also be used to rank the relative vulnerability or resiliency of the infrastructure.

A PIEVC Protocol based engineering analysis is driven by the following steps:

1. Determine the existing load on the subject infrastructure
2. Determine the anticipated climate change load
3. Determine other change loads
4. Determine the total load
5. Determine the existing capacity
6. Calculate the projected change in existing capacity arising from aging/use of the infrastructure
7. Determine additional capacity
8. Determine the project total capacity
9. Determine the vulnerability ratio
10. Determine the capacity deficit

The mechanism by which each of these loads and capacities are computed is outlined in detail in the PIEVC Protocol.

Given the scoped approach for this climate change vulnerability assessment, this step of the Protocol was not completed for this case study.

However, an approach for engineering analysis which could be completed would be a review of the design issues associated with infrastructure based on computations using the projected extreme rainfall values. This could take two forms, namely:

1. Assessment of the performance of the infrastructure given the current design but under future rainfall, and,
2. Assessment of the changes (if any) needed in the design of the infrastructure to reflect future rainfall as the design basis.

SECTION 6

PIEVC PROTOCOL STEP 5

CONCLUSIONS AND RECOMMENDATIONS

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6 STEP 5 - CONCLUSIONS AND RECOMMENDATIONS

6.1 LIMITATIONS

The uncertainty in the assessment of the likelihood and magnitude of climate - infrastructure interactions is a limitation of this study. The judgment of likelihood and magnitude were unique to the individuals who took part in the risk assessment. The probability and risk values documented from the risk assessment are consensus views of likelihood and magnitude and the range of opinions contributes to uncertainty.

Overall, the results of this study are based on applying professional judgment to the assessment of the most current information available within the scope of the PIEVC protocol and can, therefore, be used as a guide for future action on the part of the City of St. John's and other governmental organizations.

6.2 OVERVIEW

Where vulnerability is identified, options to negate vulnerability have been assessed including reductions in load effects, changes in the performance criteria or additional capacity building. As a general rule, systems with high adaptive capacity are better able to deal with climate change impacts. Step 5 details infrastructure-specific recommendations on adaptive measures, such that the desired performance criteria are met in those circumstances where Steps 3 has indicated insufficient adaptive capacity.

As noted previously, this scoped risk assessment was limited to the application of Steps 1 and 2 of the PIEVC Protocol and a preliminary, independent application, by AMEC, of Step 3 of the Protocol.

The recommendation categories, based on the PIEVC protocol, are as follows:

- *Remedial engineering or operations action required*
- *Management action required*
- *Additional study or data required*
- *No further action required.*

The climate factors identified as potentially contributing to infrastructure vulnerability will be evidenced as gradual changes. However, often the extremes (such as extreme rainfall), even if uncommon, have a far greater impact on public perception of risk. Under climate change scenarios, some of these phenomena are anticipated to occur more frequently.

6.2.1 Stormwater Management System Infrastructure

The vulnerabilities judged to be of the highest priority for the subject infrastructure are those associated with performance responses that contribute to exceedence of system capacity and/or potential flooding. Specifically, Extreme Precipitation was identified was the primary trigger for the vulnerabilities identified. Other views of precipitation that have been used in other similar PIEVC assessments such as, Heavy Rain, 5 Day Total Rain and Winter Rain could also be assessed but a similar outcome would be expected.

6.3 RECOMMENDATIONS

As noted previously, the intent of this assessment is to provide an overview of the PIEVC Protocol and, through an example, how its application to infrastructure can assist in understanding risks in the face of a changing climate. This preliminary assessment does not touch on all aspects of the infrastructure or all potential climatic influences. As such, the first recommendation is for the assessment to be expanded/completed, such that it includes all aspects of the PIEVC Protocol and all relevant components of the subject infrastructure and climate reflecting all available information and experiences of, and input from, municipal staff. Full applications of the PIEVC Protocol have been completed for similar infrastructure elsewhere in Canada and these reports are available at the PIEVC website (www.pievc.ca). It is encouraged that these be reviewed in advance of a more in-depth risk assessment of this stormwater infrastructure in the future.

Other recommendations stemming from the application of the PIEVC Protocol to the stormwater management pond and collection system in Goulds to assess risks and vulnerabilities to projected changes in climate phenomenon in the future are outlined below.

- It is recommended that the Province develop full IDF relationships for relevant areas of the Province to support evaluation of future performance and design issues for stormwater collections systems.
- It is recommended that recording of climatic events specific to the subject infrastructure be a regular procedure in the administration of the infrastructure.
- It is recommended that the climate change projections available from the Province be augmented such that the time series upon which the projections area based are made available such that more in-depth interrogation of the datasets is possible.

General recommendations regarding climate change risk assessment of infrastructure stemming from the workshops included:

- The Province should develop procedures and/or policies for incorporating risk assessment into infrastructure planning and development practices.

- The development of climate change datasets by the Province is a great step forward in breaking down perceived barriers to climate change risk assessments. However, barriers that still exist as a consequence of the lack of coordination among departments and lack of understanding of the "do nothing" scenario still need to be addressed. As such, better Government interdepartmental coordination should be advanced towards a consistent view of the requirements for incorporating risk assessment into infrastructure planning and development practices.
- The workshops clearly demonstrated value in advancing understanding of climate change issues affecting infrastructure in the Province. Further opportunities for training/education about climate change and the potential impacts to the Province should be continued for all levels of government and the private sector.
- The climate change datasets developed by the Province can generally support climate change risk assessment. However, the Province should not view these datasets as static. Examples of gaps in the datasets have already been noted (i.e., short duration IDF data). With changing science and data collection new projections are being developed around the world. The Province should develop a review cycle for its datasets. Further, the Province should also allow for new datasets to be analysed and incorporated into the larger suite of datasets.

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SECTION 7

REFERENCES

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7 REFERENCES

AMEC, 2006	*Hydraulic Assessment and Preparation of Flood Plain Mapping of the Ganaraska River from Robertson Street to Lake Ontario*, Prepared for Cameco Corporation by AMEC Earth & Environmental, April 2006.
AMEC, 2012a	*National Engineering Vulnerability Assessment of Public Infrastructure to Climate Change, City of Welland - Stormwater and Wastewater Infrastructure Assessment*, prepared by AMEC Environment & Infrastructure for the City of Welland, February 2012.
AMEC, 2012b	*Flood Risk and Vulnerability Analysis Project*, prepared for the Water Resources Management Division, Department of Environment and Conservation, Government of Newfoundland and Labrador, by AMEC Environment & Infrastructure, June 2012.
Cameron et al., 2008	*Water Resources Public Infrastructure Vulnerability Assessment for Placentia, Newfoundland*, prepared for the Department of Environment and Conservation, Government of Newfoundland and Labrador, by Cameron Consulting Incorporated, Dr. Norm Catto, AMEC, March 2008.
Catto, 2006a	Catto, N.R. (2006a): *Impacts of climate change and variation on the natural areas of Newfoundland and Labrador*; Government of Newfoundland and Labrador, Department of Environment and Conservation, 160 p.
Catto, 2006b	Catto, N.R. (2006b): *More than 16 years, more than 16 stressors: evolution of a high energy reflective beach 1989–2005*; Géographie physique et Quaternaire, v. 60, p. 49-62.
Catto et al, 2004	Catto, N.R. and Hickman, H. (2004): *Flood hazard and vulnerability in Newfoundland communities*; Office of Critical Infrastructure and Emergency Preparedness Canada.
Catto et al, 2003	Catto, N.R., Scruton, D.A. and Ollerhead, L.M.N. (2003): *The coastline of eastern Newfoundland*; Canadian Technical Report of Fisheries and Aquatic Science 2495, catalogue no. Fs 97-6/2495E.
Batterson and Liverman, 2010	*Past and Future Sea-Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning*. Batterson, M. and D. Liverman, Current Research (2010) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 10-1, p. 129-141.
Durham, 2003	*Durham Region, Stormwater Management Pond, West Nile Virus Surveillance Study*, 2003.

Easterling et al., 2000	Easterling, D.R., G.A. Meehl, C. Parmesan, S.A. Changnon, T.R. Karl, and L.O. Mearns (2000): *Climate Extremes: Observations, Modeling, and Impacts*; Science, V. 289, pp. 2068-2074.
Environment Canada, 2011	Environment Canada's Climate Data Online http://climate.weatheroffice.gc.ca/climateData/canada_e.html (accessed February 1, 2011).
Finnis, 2012	Dr. Joel Finnis, Associate Professor, Department of Geography, Memorial University, 2012 – Stephenville rainfall projections for 2050.
Finnis, 2013	*Projected Impacts of Climate Change for the Province of Newfoundland & Labrador*, Dr. Joel Finnis, Department of Geography Memorial University of Newfoundland, March 22, 2013.
Irvine, 2012	*Coastal Monitoring in Newfoundland and Labrador M.L. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University, Current Research (2012) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 12-1, pages 191-197.*
Irvine, 2013	*Coastal Monitoring in Newfoundland and Labrador: 2012 Update* M. Irvine, Geochemistry, Geophysics and Terrain Sciences, Memorial University, Current Research (2013) Newfoundland and Labrador Department of Natural Resources, Geological Survey, Report 13-1, pages 43-54.
Sudbury, 2008	*First National Engineering Vulnerability Assessment Report, Roads and Associated Infrastructure, Final Report*, prepared for the City of Greater Sudbury, Infrastructure Services Department by Dennis Consultants, March 2008.
TRCA, 2010	*Flood Control Dam Water Resources Infrastructure Assessment, G. Lord Ross and Claireville Dam Assessment,* TRCA, 2010.
Zhang et al., 2000	*Temperature and precipitation trends in Canada during the 20th century*, Zhang, X., Vincent, L.A., Hogg, W.D. and Nitsoo A., Atmosphere-Ocean, v. 38, no. 3, p. 395 – 429, 2000.