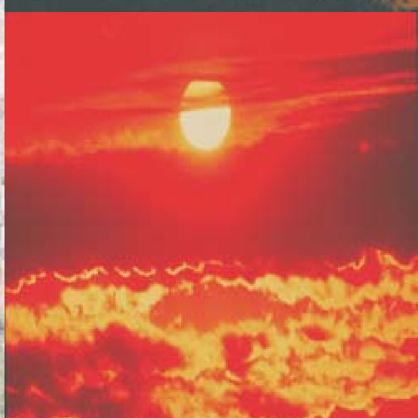
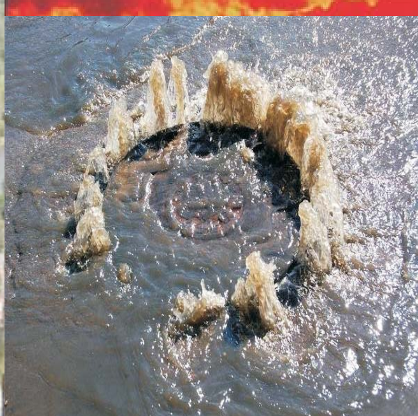
# NATIONAL ENGINEERING VULNERABILITY ASSESSMENT OF PUBLIC INFRASTRUCTURE TO CLIMATE CHANGE

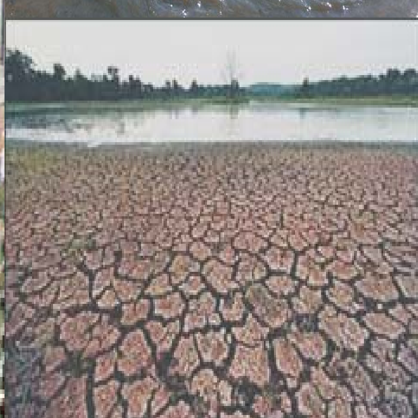
## CITY OF WELLAND STORMWATER AND WASTEWATER INFRASTRUCTURE ASSESSMENT

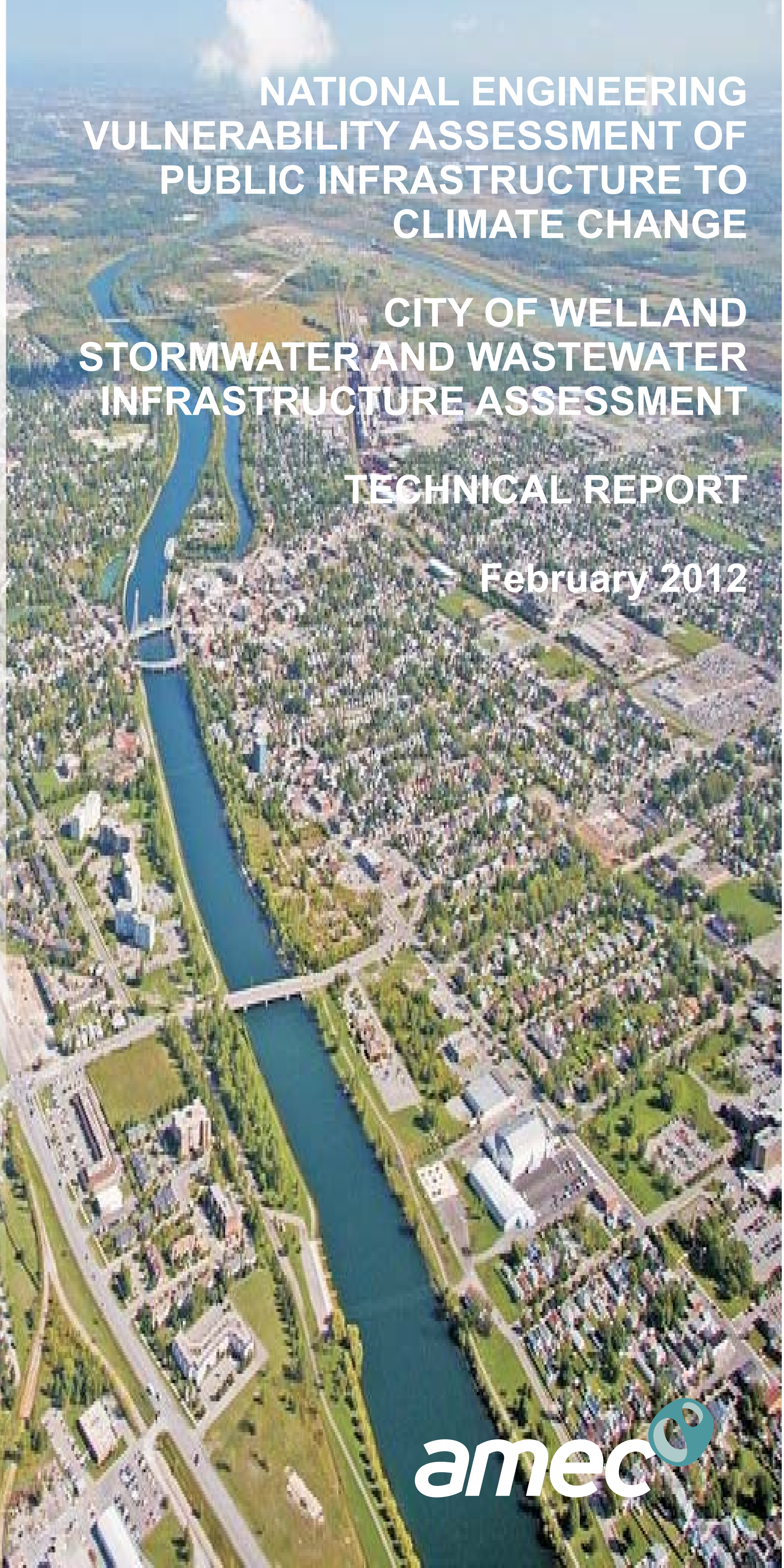
## TECHNICAL REPORT

**February 2012**









**NATIONAL ENGINEERING VULNERABILITY ASSESSMENT OF PUBLIC INFRASTRUCTURE TO CLIMATE CHANGE**

**CITY OF WELLAND**
**STORMWATER AND WASTEWATER INFRASTRUCTURE ASSESSMENT**

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February 2012

# TABLE OF CONTENTS

Page

List of Tables iv
List of Figures v
Approvals vi
Distribution Record vii
Executive Summary viii

1 INTRODUCTION 1-1
1.1 PROJECT OBJECTIVES 1-2
1.2 PROJECT SCOPE 1-3

2 PROJECT DEFINITION 2-1
2.1 OVERVIEW 2-1
2.2 STUDY LOCATION 2-1
2.3 STUDY INFRASTRUCTURE 2-4
2.3.1 Collection System 2-4
2.3.2 Welland Wastewater Treatment Plant (WWTP) 2-5
2.3.3 Existing Loads 2-6
2.3.4 Jurisdictional Issues 2-11
2.4 STUDY AREA CLIMATE 2-12
2.5 ASSESSMENT TIME FRAMES 2-12
2.5.1 Historical 2-12
2.5.2 Future 2-13

3 DATA GATHERING AND SUFFICIENCY 3-1
3.1 OVERVIEW 3-1
3.2 INFRASTRUCTURE OF INTEREST 3-1
3.2.1 Stormwater, Sanitary and Combined Collection Systems 3-2
3.3 CLIMATE ANALYSIS 3-13
3.3.1 Overview 3-13
3.3.2 The “Long” List of Climate Variables 3-13
3.3.3 Climate Data Sources 3-14
3.3.4 Climate Variable Probability of Occurrence 3-17

4 RISK ASSESSMENT 4-1
4.1 OVERVIEW 4-1
4.2 RISK ASSESSMENT RESULTS 4-3
4.2.1 Methodology 4-3
4.2.2 Results 4-5
4.3 DATA SUFFICIENCY 4-11

5 ENGINEERING ANALYSIS ........ 5-1
5.1 OVERVIEW ........ 5-1
5.2 ANALYSIS RESULTS ........ 5-2
5.2.1 Sanitary System ........ 5-2
5.2.2 Stormwater System ........ 5-10
5.3 ANALYSIS SUMMARY ........ 5-16
5.4 DATA SUFFICIENCY ........ 5-16

6 CONCLUSIONS AND RECOMMENDATIONS ........ 6-1
6.1 LIMITATIONS ........ 6-1
6.2 OVERVIEW ........ 6-1
6.2.1 Wastewater/Combined Collection System ........ 6-2
6.2.2 Stormwater Collection System ........ 6-3
6.2.3 Welland Wastewater Treatment Plant ........ 6-3
6.3 RECOMMENDATIONS ........ 6-4
6.3.1 Recommendations Associated with Development of IDF Relationships ........ 6-6

7 REFERENCES ........ 7-1

## APPENDICES

APPENDIX A - Project Documentation

APPENDIX B - Welland Wastewater Treatment Plant, Certificate of Approval #5273-7TYN6T, dated July 30, 2009

APPENDIX C - Development of Projected Intensity-Duration-Frequency Curves for Welland, Ontario, Canada

APPENDIX D - Environment Canada Climate Normals 1971-2000 for Welland

APPENDIX E - Municipal Standards – Storm and Sanitary Sewers

APPENDIX F - PIEVC Protocol – Risk Assessment Matrices

Please note that this document has been formatted for double sided printing.

# LIST OF TABLES

Table 2-1 : Regulator Design Interception Capacity ....................2-8

Table 3-1 : Stormwater Collection System Component Infrastructure ....................3-2
Table 3-2 : Wastewater Collection System Component Infrastructure ....................3-4
Table 3-3 : Downscaled CMIP3 Projections ....................3-16
Table 3-4 : Risk Assessment Probability Scale Factors – Method A ....................3-17
Table 3-5 : Summary of High Temperature Days ....................3-19
Table 3-6 : Summary of Low Temperature Days ....................3-22
Table 3-7 : Summary of Heat Waves ....................3-25
Table 3-8 : Summary of Cold Waves ....................3-27
Table 3-9 : Summary of Freeze/Thaw Days ....................3-31
Table 3-10: Number of Days with Heavy Rainfall ....................3-33
Table 3-11 : Summary of Total Precipitation for Welland ....................3-35
Table 3-13 : 24-hour Total Precipitation from IDF Data for Port Colborne ....................3-36
Table 3-14 : Summary of Heavy Snowfall Days ....................3-43
Table 3-15 : Summary of Snow DepthTrends in Ontario ....................3-45
Table 3-16: Tornado Occurrences in the Welland Area for the Period 1918 – 2003 ....................3-52
Table 3-17 : Summary of Drought / Dry Periods ....................3-54
Table 3-18 : Climate Parameters Summary ....................3-59

Table 4-1 : Risk Workshop Participants ....................4-2

Table 5-1 : Overflow Analysis (RVA, 2003) ....................5-3
Table 5-2 : Overflow Analysis (AMEC, 2011) ....................5-4
Table 5-3 : Volumetric Control Analysis ....................5-4
Table 5-4 : Projected Future Rainfall ....................5-5
Table 5-5 : Review of 2 Year Design Rainfall Maximum Intensity ....................5-12
Table 5-6 : Summary of the Engineering Analysis ....................5-17

Table 6-1 : Recommendations ....................6-9
Table 6-2 : Municipal Storm Sewer Design Standards for Select Cities in Ontario....................6-15

## LIST OF FIGURES


Figure 2-1 : Study Location - Regional Context ....2-2
Figure 2-2 : Study Location – Local Context ....2-3
Figure 2-3 : Types of Sewers in the City of Welland ....2-4
Figure 2-4 : CSO Locations ....2-9
Figure 2-5 : How a Flow Control Regulatory Works in a Combined Sewer ....2-10

Figure 3-1 : Spatial Distribution of Subject Infrastructure ....3-5
Figure 3-2 : Infrastructure by Age ....3-6
Figure 3-3 : Infrastructure by Material ....3-6
Figure 3-4 : Infrastructure by Size ....3-7
Figure 3-5 : Infrastructure by Condition ....3-8
Figure 3-6 : WWTP Process Schematic ....3-10
Figure 3-7 : Seasonal Maximum Temperatures, Niagara Region, 1970-2009 ....3-20
Figure 3-8 : Winter National Temperature Departures and Long-Term Trend, 1948 – 2011 ...3-24
Figure 3-9 : Extreme Hot Days, Niagara Region, 1970 to 2009 ....3-25
Figure 3-10 : Extreme Cold Days, Niagara Region, 1970 to 2009 ....3-27
Figure 3-11 : Recorded Diurnal Temperature Variation for Welland ....3-29
Figure 3-12 : Summary of Recorded Freeze/Thaw Days for Welland ....3-32
Figure 3-13 : Precipitation Frequency by Season, Niagara Region, 1970 to 2009 ....3-35
Figure 3-14 : Trends in Spring Snow to Total Precipitation Ratio (1950-1999) ....3-39
Figure 3-15 : Past and Future Winter Precipitation for the Niagara Region ....3-40
Figure 3-16 : Underlying Soils in Welland and Area ....3-57
Figure 3-17: Regulatory Flood Plain near the Welland WWTP ....3-58

Figure 4-1 : Risk Assessment Results ....4-12
Figure 4-2 : Sensitivity Analysis of Risk Assessment Results ....4-13

## APPROVALS

February 14, 2012

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Date

February 14, 2012

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Date

| Rev. | Description | Prepared By | Checked | Date |
|---|---|---|---|---|
| 001 | Draft Report | PN, BH | RS | September 2011 |
| 002 | Final Report | PN, BH | RS | February 2012 |
| | | | | |
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# DISTRIBUTION RECORD

| Copy No. | Name | Title/Location | Revision | | | |
|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 |
| 1, 2 | L. Widdifield | Client:<br>City of Welland | X | X | | |
| 3 - 7 | D. Lapp | Engineers Canada | X | X | | |
| 8, 9 | H. Jun | Ministry of Environment | X | X | | |
| 10 | R. Scheckenberger | Project Manager:<br>AMEC Environment & Infrastructure | X | X | | |
| 11 | P. Nimmrichter | Project Engineer:<br>AMEC Environment & Infrastructure | X | X | | |
| 12 | File | Document Control:<br>AMEC Environment & Infrastructure | X | X | | |

Please note that Rev 001 of the report was prepared in PDF format only.

## 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.

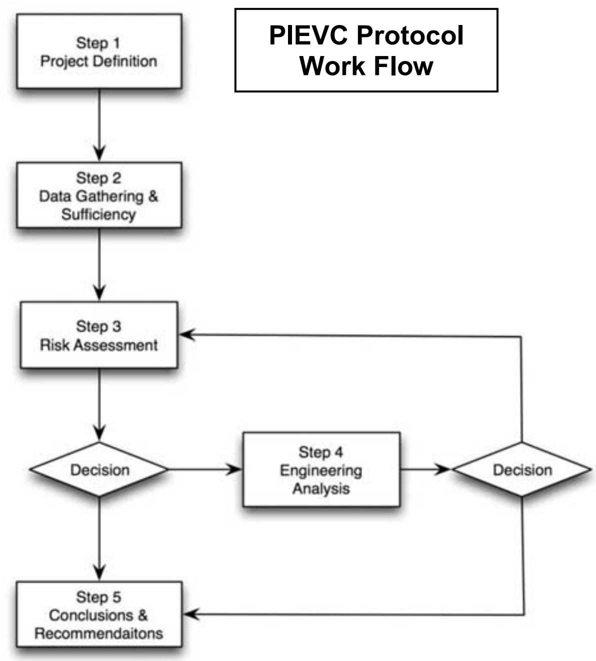
Even though municipalities share responsibilities associated with infrastructure with other levels of government, any effect of climate change is ultimately experienced locally, even if its origins are outside local jurisdictions, such as disruption of electrical power or fuel supply.

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. This also helps determine the level of adaptation required as a means of mitigating climate change vulnerability. Understanding the level of vulnerability also contributes to better, more informed decision-making and policy development by providing a basis for establishing priorities.

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.

The present study, which includes both an application of the PIEVC climate change vulnerability assessment protocol and an update of the City of Welland’s vintage Intensity-Duration-Frequency (IDF) rainfall data, is a co-operative initiative between the City of Welland, Region of Niagara, PIEVC and the Ontario Ministry of Environment. Members of the PIEVC Climate Change Vulnerability Risk Assessment for Municipal Stormwater and Wastewater Infrastructure Steering Committee include the organizations named above plus WaterSmart Niagara, Engineers Canada, Great Lakes and St. Lawrence Cities Initiative, and Environment Canada. The results from this and other studies have been, and will be, used by PIEVC to establish a Canada-wide vulnerability assessment for buildings, roads, stormwater and wastewater, and water resources.

The principal objective of this study is to identify those components of the City of Welland's wastewater and surface drainage collection systems 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 April 2009 PIEVC Protocol, premised on two future time frames, namely: 2020 and 2050. A visual outline of the PIEVC Protocol's five (5) step process is outlined below.




Step 1 – Project Definition identified the focus infrastructure for this study, namely; the stormwater and wastewater collection systems in the City of Welland and the Regional Municipality of Niagara's trunk level wastewater collection system and wastewater treatment plant (WWTP) that serves Welland.

Step 2 – Data Gathering and Sufficiency focused 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

Summary information regarding the storm and sanitary systems is below:

| Descriptor | Storm | Sanitary/Combined |
|---|---|---|
| # of Pipes | 1717 (Laterals)<br>2906 (Mains) | 17161 (Laterals)<br>3789 (Mains) |
| Total Length | 186 km | 268 km |
| Maximum Size | 3000 mm | 2700 mm |
| Minimum Size | 150 mm | 125 mm |
| Average Age of Pipes | 30 years | 42 years (Sanitary)<br>66 years (Combined) |
| Oldest Pipes | 106 years | 111 years (Sanitary)<br>110 years (Combined) |

The existing wastewater treatment plant services Welland and the communities of Pelham, Port Robinson, and South Thorold, in addition to a number of non-residential sources. The Welland WWTP consists of a conventional activated sludge plant with effluent filtration, a parallel physical chemical treatment plant to provide treatment of storm flows, effluent disinfection by chlorination followed by de-chlorination, and biosolids stabilization in a two stage mesophilic anaerobic digestion process. Stabilized biosolids are stored on site prior to being hauled to the Region's centralized biosolids processing and storage facility at Garner Road. Treated effluent is discharged to the Welland River, a sensitive receiver tributary to the Niagara River.

In addition to the physical infrastructure, the following operational aspects of the subject infrastructure were also considered:

- Administration/Personnel
- Power
- Transportation (primarily related to supplies delivery)
- Communications

The second part of Step 2 focused on identification of relevant climate information both existing/historic data and future projected climate. The objectives of the climate analysis and projections component of this assessment were to:

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

This effort focused on the following climate phenomenon:

- High/Low Temperature
- Heat & Cold Waves
- Extreme Diurnal Temperature Variability
- Freeze Thaw Cycles
- Heavy Rain
- Daily Total Rainfall
- Winter Rain
- Freezing Rain
- Ice Storm
- Snow Accumulation
- Blowing Snow/Blizzard
- Lightning
- Hail Storm
- Hurricane/Tropical Storm
- High Winds
- Tornado
- Drought/Dry Period
- Heavy Fog

Additional issues reviewed for this assessment included Lake Erie water levels, local groundwater levels and flooding of the Welland River.

Some general outcomes from this assessment included:

- The number of days per year with temperatures exceeding 35$^{o}$C is expected, on average, to remain unchanged from historic norms through the 2020 period. However, further into the future, through 2050, significant increases of about 4 time's present occurrence are projected.

- The number of days per year with temperatures below -20°C will, on average, be in steady decline through 2050.
- The occurrence of heat waves (three or more consecutive days when the maximum temperature is 32°C or higher) is projected to remain static through 2020 but marginally increase through 2050.
- Days per year experiencing a freeze/thaw cycle (a maximum daily temperature above 0°C and a minimum temperature below 0°C) are in decline.
- Rainfall is expected to increase. This includes postulated increases in the occurrence of winter rain events and increases in the severity of individual rain events.
- An almost doubling of the occurrence of drought/dry periods (defined as 10 or more consecutive days without measurable precipitation) is projected through 2020.

The second objective of this study was the update the City of Welland's 1960's vintage Intensity Duration Frequency (IDF) rainfall curves. This objective was extended to also include development of future IDF data for the project time periods (2020 and 2050). The review of a compendium of past, present and future IDF data would establish appropriate direction for re-definition of rainfall design standards for the City of Welland.

The approach selected for the development of projected IDF data used a statistical model that derives the sensitivity of extreme precipitation to climate conditions from the historical climate information for the City. In this case, the historical climate was characterized by observations of temperature and precipitation at the Port Colborne weather station; the nearest to Welland with available data. The statistical model was fitted to the local climate data and the historical monthly precipitation maxima using a form of regression. Information about future temperature and precipitation was obtained from Global Climate Model (GCM) output. Each of 112 GCM runs established projected future time series of *change* in temperature and precipitation. These changes were used to adjust the historical record of temperature and precipitation to reflect future conditions. This produced 112 future climate scenarios that were based on the historical record but which reflected the projected future change in climate. This methodology is referred to as the *delta* approach.

The statistical model of extreme precipitation was then run against each of these adjusted records to obtain estimates of climate-impacted extreme precipitation intensities for each of the nine durations (5, 10, 15, and 30 minutes and 1, 2, 6, 12, and 24 hours) and six return periods (2, 5, 10, 25, 50, and 100 year). These estimates reflect the bias in the statistical model, so one more run of the statistical model was made against the average historical climate conditions to provide a baseline set of extreme precipitation intensities and this set of baseline intensities was compared against each of the 112 estimates of climate-impacted intensities to determine the *change* in intensity attributable to the change in climate. These changes were then applied to the values in the historical IDF curve to obtain the final projected values of precipitation intensity.

The 112 projections used to characterize future climate conditions produced an equal number of estimates of projected precipitation intensities. These results were then used to develop mean, maximum and 90th percentile non-exceedance values of precipitation intensity for each duration and return interval making up a standard IDF curve.

A comparison between the 1963 City of Welland and 2000 Environment Canada IDF data for Port Colborne weather station and the projected future IDF data (for 2020 and 2050) for the 2 year design rainfall event (the current municipal standard for stormwater system design) is presented in the following tables. As noted in the tables, the 1963 IDF values for shorter duration events are conservative even through future periods when compared with average results. Future period maximum IDF values are consistently greater than the corresponding 1963 values with some increases greater than 20%. The comparison of future IDF values with the 2000 Environment Canada IDF data for Port Colborne weather station shows consistent increases for all durations across all scenarios with maximum increases (as much as 54%) associated with shorter duration events.

| Duration | Comparison of Current and Projected Rainfall Intensities to 1963 Values | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1963 | 2000 | 2020 | | | 2050 | | |
| | | | average | 90th percentile | maximum | average | 90th percentile | maximum |
| 10 minute | 100% | 82% | 91% | 98% | 115% | 94% | 104% | 122% |
| 15 minute | 100% | 82% | 91% | 97% | 113% | 94% | 103% | 119% |
| 30 minute | 100% | 88% | 96% | 105% | 121% | 100% | 111% | 124% |
| 1 hour | 100% | 97% | 110% | 108% | 117% | 82% | 112% | 112% |
| 4 hour | 100% | 99% | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |
| 6 hour | 100% | 109% | 110% | 111% | 118% | 80% | 112% | 116% |
| 10 hour | 100% | 143% | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* | *n/a* |

| Duration | Comparison of Projected Rainfall Intensities to 2000 Values | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2000 | 2020 | | | 2050 | | |
| | | average | 90th percentile | maximum | average | 90th percentile | maximum |
| 5 minute | 100% | 112% | 122% | 144% | 117% | 130% | 154% |
| 10 minute | 100% | 110% | 119% | 139% | 114% | 126% | 148% |
| 15 minute | 100% | 111% | 118% | 137% | 114% | 125% | 146% |
| 30 minute | 100% | 110% | 119% | 137% | 113% | 126% | 141% |
| 1 hour | 100% | 110% | 119% | 139% | 114% | 128% | 143% |
| 2 hour | 100% | 110% | 120% | 139% | 114% | 128% | 143% |
| 6 hour | 100% | 110% | 123% | 145% | 116% | 129% | 150% |
| 12 hour | 100% | 103% | 113% | 134% | 106% | 120% | 136% |
| 24 hour | 100% | 110% | 118% | 138% | 110% | 124% | 142% |

Step 3 of the PIEVC Protocol involved the identification of infrastructure components which are likely to be sensitive to changes in specific climate phenomenon focusing on qualitative assessments as a means of prioritizing more detailed Evaluation Assessments. In other words, professional judgment and experience are used to determine the likely effect of individual climate events on individual components of 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. This evaluation was completed during the Risk Assessment Workshop which was held at the offices of the City of Welland on May 18, 2011. This gathering brought together representatives from the City of Welland, Regional Municipality of Niagara, Ministry of Environment, Engineers Canada, Credit Valley Conservation, INRS (Institut national de la recherche scientifique) University and the AMEC Project Team.

The objectives of the workshop included:

- 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.

The PIEVC Protocol defines a risk ranking scheme of High, Medium and Low. As an outcome of the Risk Assessment Workshop no infrastructure/climate relationships were identified in the High risk category. Infrastructure/climate relationships in the Medium category were identified primarily with a focus to define impacts from projected increases in rainfall events. Other issues related to personnel and increasing average temperature and supply delivery during extreme weather were also identified.

Step 4 focused on the determination of adaptive capacity. Specifically, if the climate changes as described in Step 2, does the subject infrastructure have adaptive capacity available to meet the desired performance criterion? If the adaptive capacity is determined not to exist, this evaluation determined the additional capacity required to meet the desired performance criteria, again if the climate changes as described in Step 2. This analysis was conducted as a “desktop” exercise focused on the:

- Wastewater/combined collection system using Ministry of Environment Procedure F-5-5 as the performance criteria; and,
- stormwater collection system using the current 2 year Municipal Standard design rainfall event as the performance criteria.

Both systems were identified to have capacity deficits based on this assessment, although the deficit associated with the stormwater system is less than that associated with the wastewater system.

Step 5 details infrastructure-specific recommendations on adaptive measures, such that the desired performance criteria are met in those circumstances where Steps 3 and 4 have indicated insufficient adaptive capacity. 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.

Additional parameters associated with the recommendations included a suggested time frame for implementation, an anticipated cost range associated with implementation of the recommendation, and a suggestion as to involvement of level(s) of government (i.e., the City of Welland and/or the Region of Niagara) most appropriate to implement the particular recommendation.

A total of forty-four (44) recommendations were made. The following summaries provide an overview of these recommendations:

| Action Classifications | # of recommendations |
|---|---|
| Additional Study as a prerequisite for Management Action | 1 |
| Additional Study as a prerequisite for Management and/or Operational Action | 6 |
| Additional Study as a prerequisite for Remedial Action | 2 |
| Additional Study as a prerequisite for Remedial Action and/or Management Action | 21 |
| Management Action | 12 |
| Management and/or Operational Action | 2 |

| Recommendation Cost Range | # of recommendations |
|---|---|
| < $100,000 | 33 |
| $100,000 to $500,00 | 11 |
| $500,000+ | 0 |

| Implementation Time Frame | # of recommendations |
|---|---|
| ASAP | 12 |
| Short | 13 |
| Medium | 19 |

| Recommended Action by | # of recommendations |
|---|---|
| City | 12 |
| Region | 8 |
| City & Region | 24 |

The following recommendations are made as an outcome of the PIEVC risk assessment of City of Welland infrastructure coupled with the development of current and projected IDF relationships for the Environment Canada weather stations at Port Colborne (ref. Appendix C of the Technical Report):

- The City of Welland municipal standards outline the design of storm sewers based on IDF curves (Rainfall Intensity Duration Frequency curves). The City of Welland has used a 1963 based IDF relationship for storm sewer design until the present. It is recommended that the implications (as related to performance and life cycle costing) of the application of the current Environment Canada (i.e., 2000) or the projected (i.e., 2020 and 2050) IDF relationships, developed for this risk assessment, be evaluated to determine long-term applicability for the storm sewer collection system design, operation and maintenance. In the context of the PIEVC recommendations categories, this would be considered 'Additional Study as a prerequisite for Remedial Action and/or Management Action'.
- The City of Welland infrastructure design standards presently direct the use of the 2 year return period rainfall design event for design of storm sewers in the municipality. It is recommended that the implications of a change in this design standard to a 5 year or a 10 year design rainfall event should be evaluated in the context of current sewer infrastructure capital plans, performance metrics and long-term sewer objectives. In the context of the PIEVC recommendations categories, this would be considered 'Additional Study as a pre-requisite for Remedial Action and/or Management Action'.

The outcomes of this assessment are expected to drive future remedial action at the study-specific infrastructure locations in the City of Welland. Further, the results of this assessment will be incorporated into the PIEVC national knowledge base which has been formed as a basis for analysis and development of recommendations for review of codes, standards and engineering practices across Canada.

## REFERENCES

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# SECTION 1

# INTRODUCTION

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# 1 INTRODUCTION

It has been projected that Ontario 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 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.

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.

The original catalyst for the City of Welland climate change vulnerability assessment of public infrastructure stemmed from the availability of funding through the partnership of the Niagara Water Strategy (Region of Niagara) and Ministry of Environment (MOE) the potential to update the City of Welland's 1960's vintage Intensity Duration Frequency (IDF) rainfall curves.

There are several other drivers for this assessment as well including:

- the need to address CSO's in the community
    - The recent implementation of high-rate treatment in Niagara Falls means that Welland now has one of the highest rates of combined sewer overflows (CSO) in the Region. The Municipality is currently engaged in separation of the existing combined sewer system with the objective of avoiding storage tanks which involves an overall re-design of the system. Sewer separation has been determined to be the preferred approach due to significant basement flooding particularly in the upper portion of the system.
- setting design standards for new development
    - Greenfield development potential remains in Welland. This new development will result in additional loads to the existing stormwater and wastewater systems.
    - The design standard for a considerable amount of the existing stormwater infrastructure in Welland is a 2 year design rainfall from the early 1960's.

- historical flooding
  - The CSO's currently flow to an interceptor however the hydraulic grade line is too high at the cross connection points, resulting in repeated flooding events. High water levels in the Welland River also cause an issue and, as such, the Municipality is pursuing flap valves as a mitigation measure.
  - City staff have identified loading issues with existing infrastructure systems and they envision these existing issues (surcharging and flooding) being exacerbated under the influence of climate change.

The present study, which includes both an application of the PIEVC climate change vulnerability assessment protocol and update of the City's vintage IDF rainfall data, is a co-operative initiative between the City of Welland, Region of Niagara, PIEVC and the Ontario Ministry of Environment. Members of the PIEVC Climate Change Vulnerability Risk Assessment for Municipal Stormwater and Wastewater Infrastructure Steering Committee include the organizations named above plus WaterSmart Niagara, Engineers Canada, Great Lakes and St. Lawrence Cities Initiative, and Environment Canada. The results from this and other studies have been and will be used by PIEVC to establish a Canada-wide vulnerability assessment for buildings, roads, stormwater and wastewater, and water resources.

This report constitutes the final documentation regarding the climate change vulnerability assessment of stormwater and wastewater infrastructure in the City of Welland, Ontario.

## 1.1 PROJECT OBJECTIVES

The principal objective of this study is to identify those components of the City of Welland's wastewater and surface drainage collection systems 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 April 2009 PIEVC Protocol, premised on two future time frames, namely: 2020 and 2050.

The second objective of this study is the update the City of Welland's 1960's vintage Intensity Duration Frequency (IDF) rainfall curves. This objective was extended to also include development of future IDF data for the project time periods (2020 and 2050). A more detailed description of the time frames is provided in Section 2.5 of this report. The review of the compendium of past, present and future IDF data would establish appropriate direction for re-definition of rainfall design standards for the City of Welland.

The outcomes of this assessment are expected to drive possible remedial action at the study-specific infrastructure locations. 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

The comprehensive scope of work for this project is outlined in the document – "Schedule A - National Engineering Vulnerability Assessment of Public Infrastructure to Climate Change, City of Welland Infrastructure Assessment, Work Statement, October 2010" (provided in Appendix A of this report). This document specifies the following basic elements as comprising this project:

- The location of the wastewater collection system and surface water drainage system to be studied are owned and operated by the City of Welland. The wastewater treatment plant (WWTP) is owned and operated by the Region of Niagara.

- The study is to address potential impacts of future climate change for the decades of 2020 and 2050 through the following tasks:

  1. Define the infrastructure components for the wastewater collection system and surface water drainage system for the City of Welland that encompass its design, construction, management, operation and maintenance.

  2. Identify and document the applicable design codes, standards, criteria as well as applicable policies, best practices and procedures for each of the infrastructure components as available through design and operational specifications, as-built drawings etc. at the time when the infrastructure was designed and constructed, where such information exists and is available.

  3. Using professional judgment and experience review available climatic data relative to the project location and assessment time horizon. Based on this review establish for each climate parameter and infrastructure indicator, the probability of a climate change event affecting the infrastructure or infrastructure component in a manner that adversely affects the functionality of the infrastructure.

  4. Using professional judgment and experience, determine the likely effects of individual; climate events on individual components of the infrastructure, using the assessment matrix and process described in Step 3 of the PIEVC Engineering Protocol, Version 9.

  5. Undertake consultations with the City of Welland management, planning, engineering, operations and maintenance staff. This consultation must include the convening of a workshop with participants from Welland, the Consultant's Project team, the PIEVC Project Advisory Group and climate experts as appropriate.

  6. In accordance with Step 5 of the PIEVC Engineering Protocol, provide recommendations to address the engineering vulnerabilities based on the critical infrastructure-climate interactions identified in previous steps.

7. Prepare a report that includes an Executive Summary, description of the baseline and projected climatic parameters, identification and description of the infrastructure components and the assessment of the engineering vulnerabilities and recommended remedial actions.

A detailed work scope was provided to the City of Welland in December 2010 as the first deliverable of this project.

A distinct element of item 3, above, is the update the City of Welland's 1960's vintage IDF rainfall curves to the present time frame (i.e., 2010) and development of future IDF data for the project time periods (2020 and 2080). A detailed outline of the methodology used for projected IDF data development is provided as Appendix C to this report.

# SECTION 2

# PIEVC PROTOCOL STEP 1

# PROJECT DEFINITION

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# 2 PROJECT DEFINITION

## 2.1 OVERVIEW

Step 1 of the PIEVC Protocol focuses on 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 City of Welland ("Welland") lies in the south-eastern corner of the Province of Ontario between the Great Lakes of Erie and Ontario in the Niagara Peninsula fruit belt (ref. Figure 2-1 and Figure 2-2). Welland is a lower tier member community within the Regional Municipality of Niagara (upper tier).

The community covers a geographic area of about 85 $km^2$ and lies at an elevation of about 175m above sea level. General land slopes across the community average about 2%. Soils in the area are generally classified as heavy clay.

The population of Welland was 50,331 in 2006, representing an increase from 2001 of about 4%. The population increase for the community is expected to continue with projected populations of 53,700, 59,500 and 66,500 for the years 2011, 2021 and 2031, respectively. Extrapolating this data to the future suggests the population of Welland for 2050 to reach about 77,700 people.


**Figure 2-1 : Study Location - Regional Context**

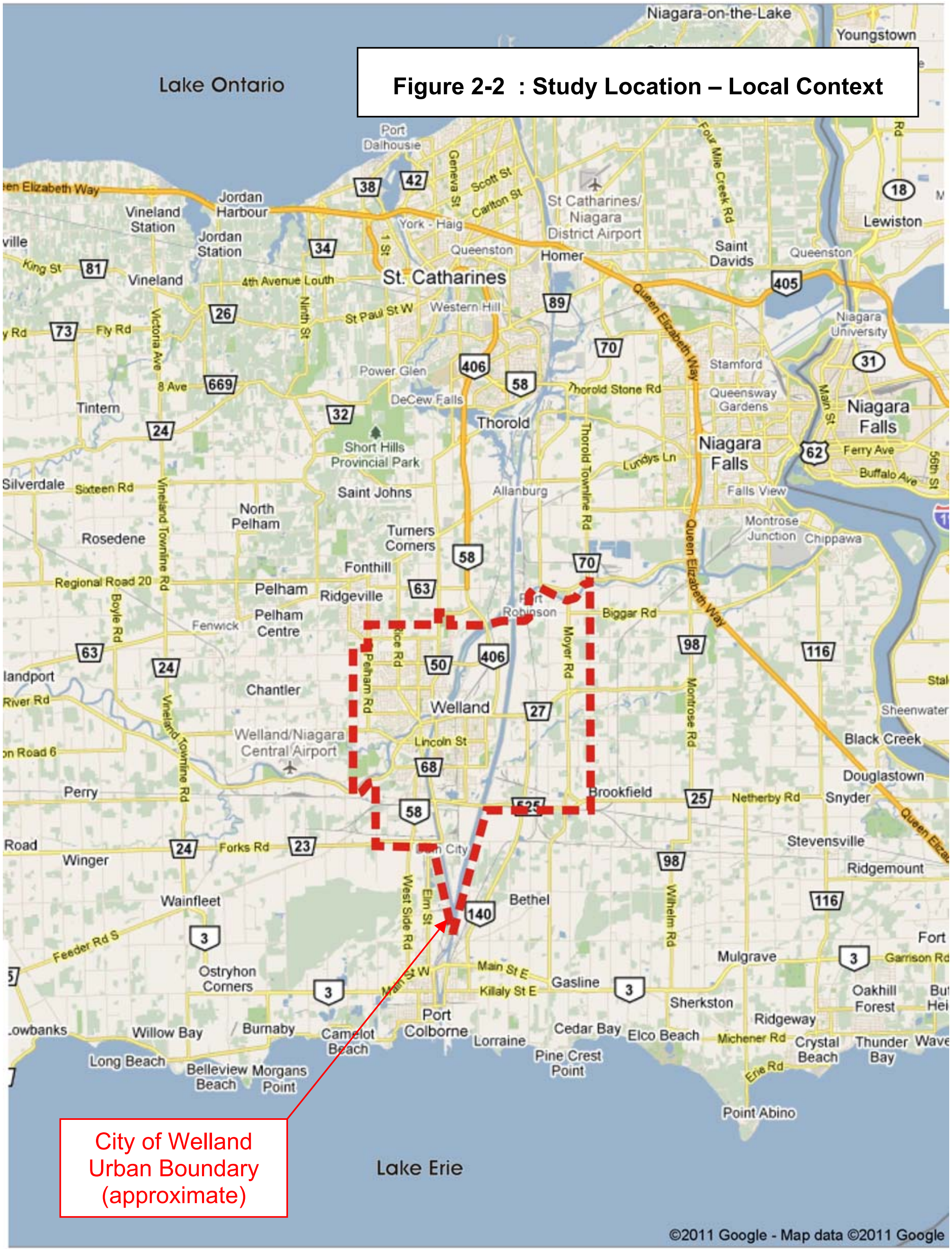



**Figure 2-2 : Study Location – Local Context**

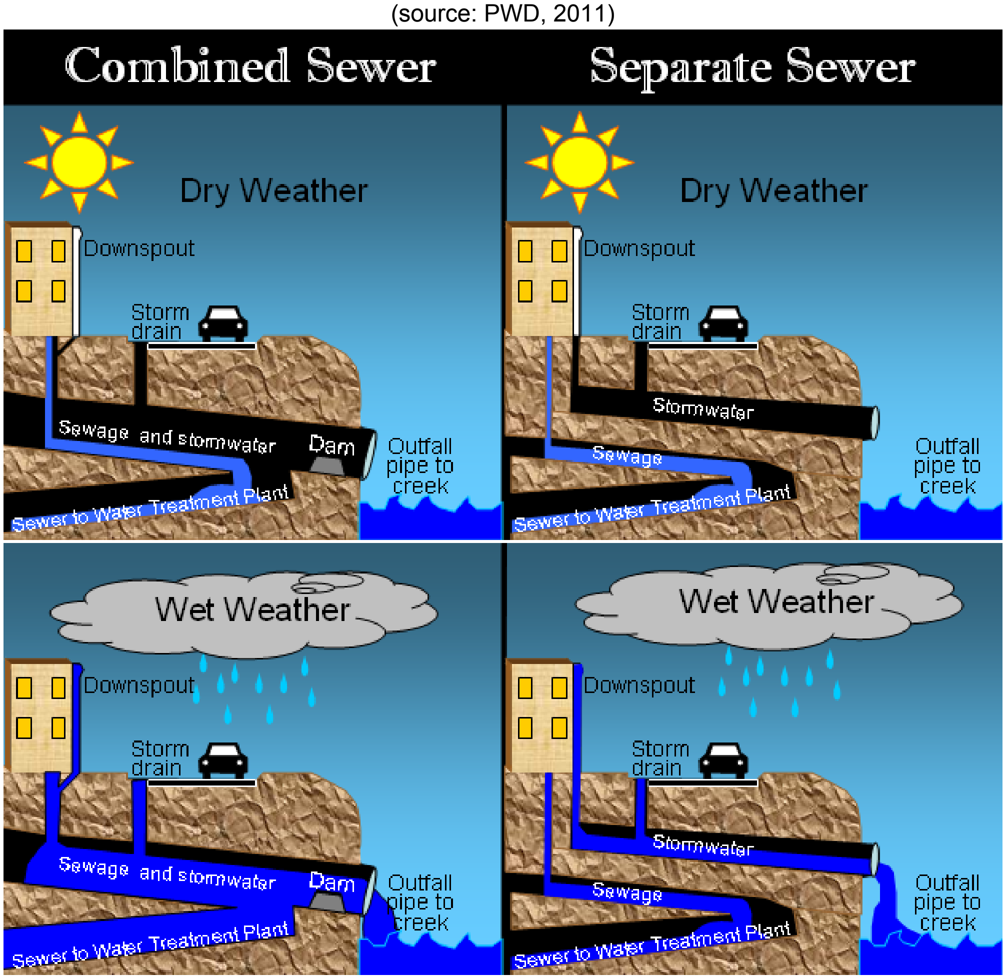
## 2.3 STUDY INFRASTRUCTURE

The study infrastructure can generally be described as the stormwater and wastewater systems for the City of Welland. The upstream boundary of the systems is represented by the inlets to the systems. The downstream boundary is represented by the wastewater treatment plant and the Welland River and Canal systems. This assessment will include that (sanitary, storm, combined) infrastructure relevant to the City of Welland's stormwater and wastewater systems between these two boundaries.

### 2.3.1 Collection System

The City's collection system is comprised of sanitary, storm and combined sewers. The conveyance concepts associated with each of these systems is illustrated below.

**Figure 2-3 : Types of Sewers in the City of Welland**
(source: PWD, 2011)



The municipal collection system dates to the early part of the 1900's. The early sewerage system was largely comprised of combined sewers (storm and sanitary). Some sewers, built as early as 1902, are still in use today. The service life of the City's sewerage infrastructure has been defined as 80 years but the service life of this type of infrastructure is commonly estimated at between 50 to 100 years depending on component type, construction material and environment. About 50% of the City's existing sanitary pipe system was constructed before 1970.

The City's storm sewer system also dates to the earlier part of the 1900's, specifically 1910. The bulk (about 70%) of the City's existing storm pipe system is less than 40 years old.

Niagara Region currently provides trunk level wastewater collection and treatment services for Welland. The Region's current Water and Wastewater Master Servicing Plan was updated in 2003, however, since that time significant Provincial policies and regulations have been implemented, requiring the Region to update its planning and servicing vision. In response, the Region has initiated the Water and Wastewater Master Servicing Plan Study to identify a long-term water and wastewater servicing strategy to support growth in the Region through 2031.

The earliest of the Region's sanitary pipes, in the study area, is dated 1966, however about 90% of the sanitary system is less than 40 years old. Similarly, the earliest of the Region's storm pipes is dated 1946 and about 85% of the storm system is less than 40 years old.

The overall collection system also includes some privately-held infrastructure however these elements are not included in this assessment specifically. It should be noted, however, that recommendations relevant to infrastructure owned/operated by the City or Region may also be relevant to this private infrastructure insofar that climate change impacts may affect these privately held infrastructure in a similar manner to that under City or Region control.

A detailed description of the storm, sanitary and combined collection systems is presented in Section 3.2.2 and an illustrated overview of the subject infrastructure is provided in Figure 3-1.

### 2.3.2 Welland Wastewater Treatment Plant (WWTP)

Wastewater treatment facilities are complex facilities that include many structural, mechanical, electrical, instrumentation/control, and civil works systems (e.g. on-site roads, buried pipes). For planning purposes, structural components (e.g. process tankage, buildings) are typically assumed to have a service life in the order of 50 years. Mechanical and electrical systems are generally expected to be replaced within a 25 year time frame.

Changes in technology and regulatory requirements, combined with the need to expand treatment capacity to accommodate growth of the service population, can impact the originally envisioned design life of any given system or component.

Welland Wastewater Treatment Plant
(image source: XCG, 2011)

The present WWTP serves both the City of Welland and the Town of Pelham and is owned and operated by the Regional Municipality of Niagara. It has a current rated capacity of 54,550 $m^3$/day and a peak flow rate of 118,000 $m^3$/day (as defined from the present Certificate of Approval #5273-7TYN6T, dated July 30, 2009, provided in Appendix B). A detailed description of the plant and operations is presented in Section 3.2.2.

As noted previously, the Region is presently completing a Water and Wastewater Master Servicing Plan Study which includes expansion of the WWTP capacity.

### 2.3.3 Existing Loads

The 'Combined Sewer Overflow – Environmental Study Report' (RVA, 2003) provides an overview of the existing loads on the subject infrastructure. Table 2-1 provides an overview of the capacities of the existing interceptors.

The following information has also been obtained from the RVA (2003) report:

- The flow regulators can intercept a total flow that is 5 times greater than the capacity of the Wastewater Treatment Plant. The concept of a combined sewer regulator or flow control structure is illustrated in Figure 2-5.
- Overall regulator design interception capacities ranged from 3 times dry weather flow at Lock Street to 156 times dry weather flow at Shotwell. The average design interception rate is 15 times dry weather flow.
- Regulator capacities, when normalized to their drainage areas, range from 0.3 L/sec/ha at Lock Street to 14.0 L/sec/ha at Shotwell. The average capacity is 19 L/sec/ha.
- There was evidence of periodic blockages occurring in siphons in the system.

An overflow analysis was completed as a component of the RVA (2003) study. The objective of the analysis was to determine the volume of CSO's discharged into the Welland River during the primary contact season of April 15 through November 15. The Ministry of Environment

Procedure F-5-5 requires that for an average year all dry weather flow plus 90% of wet weather flow must be captured within the system and receive equivalent to primary treatment during the contact season. The RVA (2003) analysis indicated that volumetric control varied across the system from 0% to 100 %, with a system wide average of 64%.

The City of Welland has also indicated that once compliance with MOE Procedure F-5-5 expectations for combined sewer systems is achieved, compliance with the Ministry of Environment Procedure F-5-1, which outlines an expectation of 100% capture and treatment, is expected.

In 2009, the City of Welland retained the consulting services of AMEC to develop a simplified model that would be capable of quantifying the combined sewer overflow (CSO) events into the Welland River for reporting to the Ontario Ministry of the Environment. The model will be used to quantify spill rate, volume, duration, frequency and mass loading of CBOD (Carbonaceous biochemical oxygen demand) and TSS (Total Suspended Solids) for CSO events. The model was developed using MS Excel, rather than XP-SWMM software that was used by RVA (2003). Both models utilized different input parameters and modeling techniques.

In 2010, AMEC conducted modelling for the 18 CSO locations, which determined the CSO events at each location on a monthly basis, from April to November. The model represents overflows based on surcharging in the Interceptor using flow depths measured along the Interceptor. Based on the RVA (2003) study, the City has estimated that this surcharging will contribute to 90% of the overflows, whereas the other 10% will be attributed to direct bypass from the incoming trunk sewers. The model yielded a system wide average of 97.8% of the wet weather flows captured and treated for 2010.

There may be several factors contributing to the substantial difference between RVA (2003) results and AMEC (2011) results. A major contributing factor may be the rainfall volumes experienced in 1980 (“typical” year) and 2010. 2010 was a relatively dry year when compared to the “typical” year, which would likely increase the volumetric control at the WWTP. Another contributing factor is that since the RVA (2003) study, the City of Welland has completed several sewer separation studies to improve the frequency, duration and volume of CSO events that occur.

Other comments offered by Welland staff regarding the existing capacity of the collection system include:

- Areas susceptible to basement flooding, either due to a surcharged trunk sewer or high sewer to low ground elevation, include the following areas Broadway, Clare Avenue, Northwest area (includes Balsam area, South Pelham, Heritage Lane area), East Wartime area and the Fitch Pumping Station area.

- Potential system choke points include the Ontario Road Pumping Station and Lyons Creek Reservoir, Feeder Road Pumping Station, Lancaster Road Pumping Station (owned and operated by Niagara Region), Dain City Pumping Station (owned by the City and operated by the Region), Fitch Pumping Station (owned and operated by the City), Wastewater Treatment Plant (capacity issues), South Bank Interceptor (inadequate capacity exacerbates flooding in the Broadway area), Woodlawn trunk Sewer and Siphons.

**Table 2-1 : Regulator Design Interception Capacity**
(source: RVA, 2003)

| Regulator Location | Design Interception Capacity (L/sec) |
|---|---|
| Oxford-Atlas-Wellington (OAW) | 1819 |
| Downs Drive | 74 |
| McAlpine | 147 |
| McMaster | 290 |
| Burgar | 260 |
| Dorothy / Hellems | 163 |
| King | 710 |
| Locke Street (Aqueduct) | 413 |
| Niagara Street North | 75 |
| Shotwell | 140 |
| Niagara Street South | 150 |
| Denistoun St. | 80 |
| Prince Charles South | 340 |
| First Avenue #1 | 920 |
| First Avenue #2 | n/a |
| Prince Charles North | 130 |
| Ridgewood | 620 |
| Riverside / Maple Avenue | 170 |

**Figure 2-4 : CSO Locations**
(source: XCG, 2011)

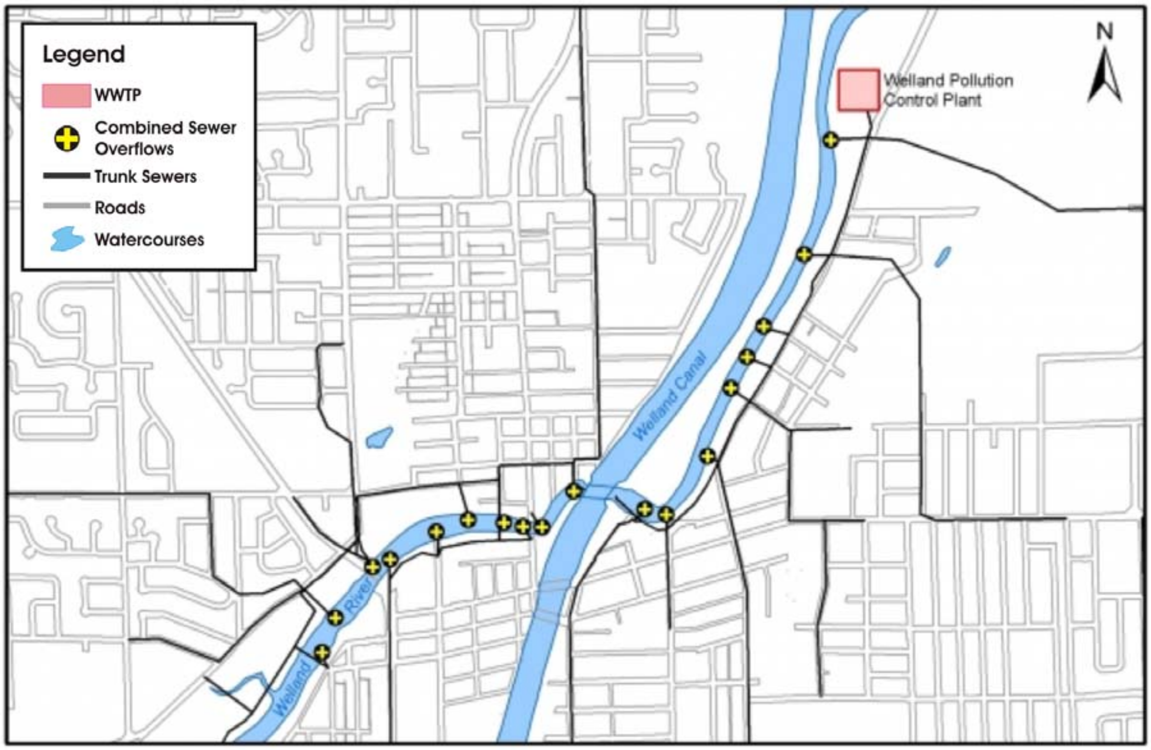
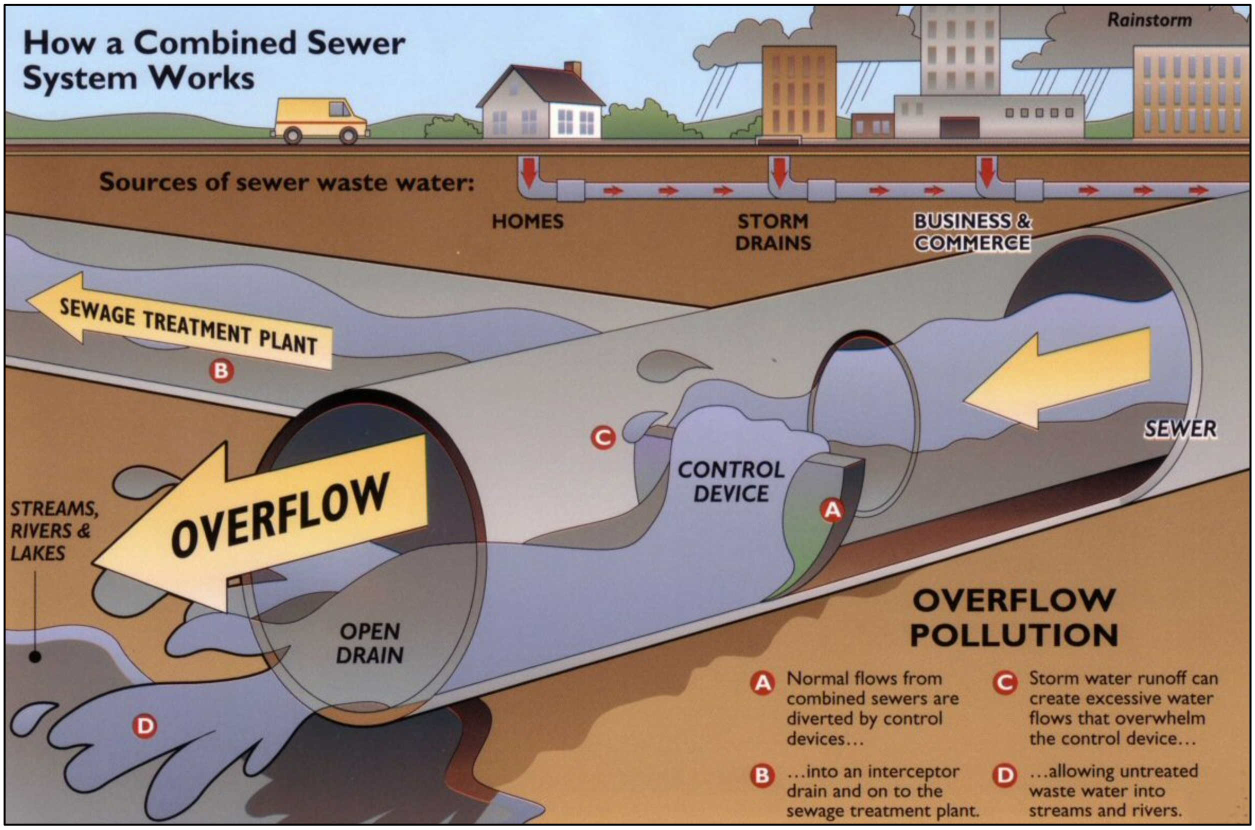


**Figure 2-5 : How a Flow Control Regulatory Works in a Combined Sewer**
(source: Moundsville, 2011)



### 2.3.4 Jurisdictional Issues

In southern Ontario there are three different types of municipal government structures: regions, counties and single-tier municipalities. Within a region, such as the Region of Niagara, a town or a city, such as the City of Welland, is referred to as a "lower tier" municipality.

In a two tier system of local government, some services are delivered by the upper tier municipality. Upper tier municipalities often co-ordinate service delivery between municipalities in their area or provide area-wide services.

The services typically provided from regional government, or "upper tier" municipality, include: arterial roads; transit; policing; sewer and water systems; waste disposal, sewage/wastewater treatment; region-wide land use planning and development; as well as health and social services.

The "lower tier" municipalities within regions are generally responsible for local roads, fire protection, garbage collection, recreation and local land use planning needs.

In many cases, services are assigned by legislation to upper or lower tiers either exclusively or non-exclusively. Waste management is a good example. Frequently lower tier municipalities are exclusively responsible for collecting garbage, while the upper tier municipality is exclusively responsible for disposal and for broader waste management matters. In other cases, responsibility can be shared by both levels of local government.

An example of shared responsibility is the sewer network in the City of Welland. The City owns, operates and maintains the bulk of the municipal sewer network including storm, sanitary and combined, while the Region owns, operates and maintains trunk and interceptor sewers which provide conveyance of sanitary flows in particular to the WWTP.

The Region is also responsible for the CSO's throughout the region. The CSO's allow flow in excess of sewer pipe capacity to flow directly, untreated, into ditches and other waterways. There are 283 CSO locations in the Region of Niagara, of which 19[1] are located within the municipal boundary of the City of Welland. There are 18 overflows located along the Regional Interceptor system, which were modelled by AMEC in 2010.

The City of Welland and the Regional Municipality of Niagara work co-operatively to operate the infrastructure which is the focus of this climate change vulnerability assessment. Welland staff has not indicated any specific operational issues in working with Niagara Region.

[1] Source: www.regional.niagara.on.ca/living/water/pdf/locations-of-sewer-overflows-in-Niagara-Region.pdf

## 2.4 STUDY AREA CLIMATE

The climate in the City of Welland is moderated by the Great Lakes typically; mild without extremes in temperature or precipitation throughout the year. The statistical summaries below provide a general overview of the study area climate.

- Precipitation[2]
  - Average precipitation: 991.3mm (152.9mm snowfall / 838.4 mm rainfall)
  - Extreme daily rainfall: 141 mm (July 1892)
  - Extreme daily snowfall: 81.3 cm (March 1900)
  - Extreme snow depth: 28 cm (January 1996)
  - Rainfall events (with totals >25 mm in one day) generally occur between June and October and average about 5 events per year
- Temperature[2]
  - Daily average minimum temperature: 3.7$^{o}$C
  - Daily average maximum temperature: 13.2$^{o}$C
  - Extreme minimum temperature: -32.8$^{o}$C (January 1884)
  - Extreme maximum temperature: 37.8$^{o}$C (July 1911)
- Frost[3]
  - earliest last spring frost: April 8$^{th}$
  - earliest first autumn frost: September 10$^{th}$
  - Average frost free season: 161 days (May 4 to October 13)

A complete listing of the climate normals for Welland is provided in Appendix D.

## 2.5 ASSESSMENT TIME FRAMES

### 2.5.1 Historical

The time frame used for this assessment for representation of historical information is the period 1971-2000. This 30-year period matches the most recent climate normal period available from Environment Canada. Further, this period is also used for data representation from the Atmospheric Hazards website (ref. ontario.hazards.ca). This time frame is also consistent with baseline climate data periods used for most projections (the other is 1961-1990). Where

[2] Source: Environment Canada Climate Normals 1971-2000 for the Welland weather station (#6139445), Environment Canada, 2011e
[3] Source: Welland, 2010

independent data analyses were completed for this assessment, the 1971-2000 time frame was used unless otherwise indicated.

### 2.5.2 Future

Two future periods have been identified for this assessment, namely 2020 and 2050, consistent with the development of projected IDF data (ref. Appendix C). The general time frame used for future IDF data projections are the periods 2005-2034, representing 2020, and 2035 to 2064, representing 2050. In some cases the periods 2011-2040 and 2041-2070 have also been used to represent the 2020 and 2050 period properties, respectively, depending on data availability.

Vulnerability assessment beyond the 2050 time frame was not completed in consideration of the design life of the subject infrastructure. 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.

# SECTION 3

# PIEVC PROTOCOL STEP 2

# DATA GATHERING AND SUFFICIENCY

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# 3 DATA GATHERING AND SUFFICIENCY

## 3.1 OVERVIEW

Step 2 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 has focuses on identification of relevant climate information. Climatic and meteorological data (both existing/historic data, as well as, future projected climate data) is 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 the City of Welland, 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 two timeframes, namely 2020 and 2050.

This task of the assessment has also included an update and future projection of the City’s IDF relationships (ref. Appendix C). Although not a “standard” task within the PIEVC protocol, it does reflect a quantitative approach to defining potential changes to extreme rainfall. The IDF analysis has also provided a secondary benefit of offering a foundation of projected temperature data which could be used to define other future climate variables.

The AMEC Team, in consultation with City staff, identified features of the subject infrastructure to be considered in the assessment using the climate information gathered for this study. Together, the infrastructure component data and the climatic data form the foundation of the risk assessment matrix (ref. Appendix F) which is a fundamental aspect of the Protocol.

## 3.2 INFRASTRUCTURE OF INTEREST

The City of Welland is the outgrowth of a settlement which commenced about the year 1788, when a scattering of farms between what are now named Quaker Road and South Pelham Street, along the Welland River came to be. In 1829, when a wooden aqueduct was built to carry the Welland Canal over the Welland River, a true urban presence of settlement came to be around that location. The settlement was called Aqueduct or The Aqueduct. On November 14, 1844, following the replacement of the wooden Aqueduct by one of stone, the name was changed to Merrittsville. The settlement was incorporated as the Village of Welland on July 24, 1858. Incorporation as a Town took place on January 1, 1878, and as a City on July 1, 1917 (Welland, 2011c). This early development of the municipality is evident in the age of some stormwater and wastewater infrastructure exceeding 100 years.

### 3.2.1 Stormwater, Sanitary and Combined Collection Systems

A GIS database of the subject infrastructure related to the storm, sanitary and combined collection systems was provided by the City. This database has formed the basis for describing the infrastructure components relating to the stormwater and wastewater collection systems. Additional information has been abstracted from the City database specific to each collection system. It should be noted that components of the collection system under Region of Niagara control are also defined in the City of Welland database.

#### 3.2.1.1 Stormwater Collection System

The infrastructure components of the stormwater collection system, and associated information, are outlined in Table 3-1.

**Table 3-1 : Stormwater Collection System Component Infrastructure**

| Infrastructure Component | Number | Description/Details |
|---|---|---|
| Catchbasins | 6538 | |
| Manholes | 2749 | |
| Pipes | 1717 - Laterals<br>2906 - Mains<br>186km - Total Length<br>3000 mm - Max Size<br>150 mm - Min Size | Database includes culverts[1], forcemains[2], inverted siphons[2], outfall pipe, overflow pipe, pipe stub, sewer, tunnel[3] |
| Outfalls | 19 | All outfalls from the stormwater system discharge to the Welland River or Recreational Canal. |
| Stormwater Management Ponds | 7 | Six (6) wet ponds and one (1) constructed wetland |
| Oil Grit Separators | 2 | |
| Major Systems[1] (Old and New) | n/a | |

Notes:
1. For the purposes of this assessment the major system was generally inclusive of above ground conveyance systems including culverts.
2. The stormwater collection system infrastructure database designates many combined sewers as storm sewers. As such forcemains and inverted siphons were included as components of the wastewater collection system.
3. Tunnels and pipes, in the context of this collection system, serve the same purpose but are designated differently in the database based on construction method.

Flow monitors are not included in the list of stormwater (or wastewater) collection system infrastructure to be assessed as no permanent flow monitors are installed in the City's system. The City does periodically complete flow monitoring within the collection systems (storm and wastewater) but these efforts are completed with temporarily installed data collection devices.

The spatial distribution of the City's stormwater collection system is illustrated in Figure 3-1.

#### 3.2.1.2 Wastewater (Sanitary/Combined) Collection System

The infrastructure components of the wastewater collection system, and associated information, are outlined in Table 3-2. The spatial distribution of the City's wastewater (only) and combined (stormwater and wastewater in one pipe) collection systems is illustrated in Figure 3-1.

Figure 3-2 provides an overview of the age of the subject infrastructure and indicates the average age of Welland's overall sewer system is about 37 years in 2011, with the storm network being the youngest and the combined being the oldest. In 2000, the average age of Welland's sewer system was about 44 years which is comparatively old to Canada's average municipal sewer system age of about 15 years (Gaudreault and Lemire, 2006). The data also indicate that a significant inventory of sewers (about 1123), covering a length of about 7 km, were constructed in Welland between 2001 and the 2011, as defined from the City's sewer database.

As illustrated in Figures 3-3 and 3-4, the network is constructed with piping of various materials and sizes, as follows:

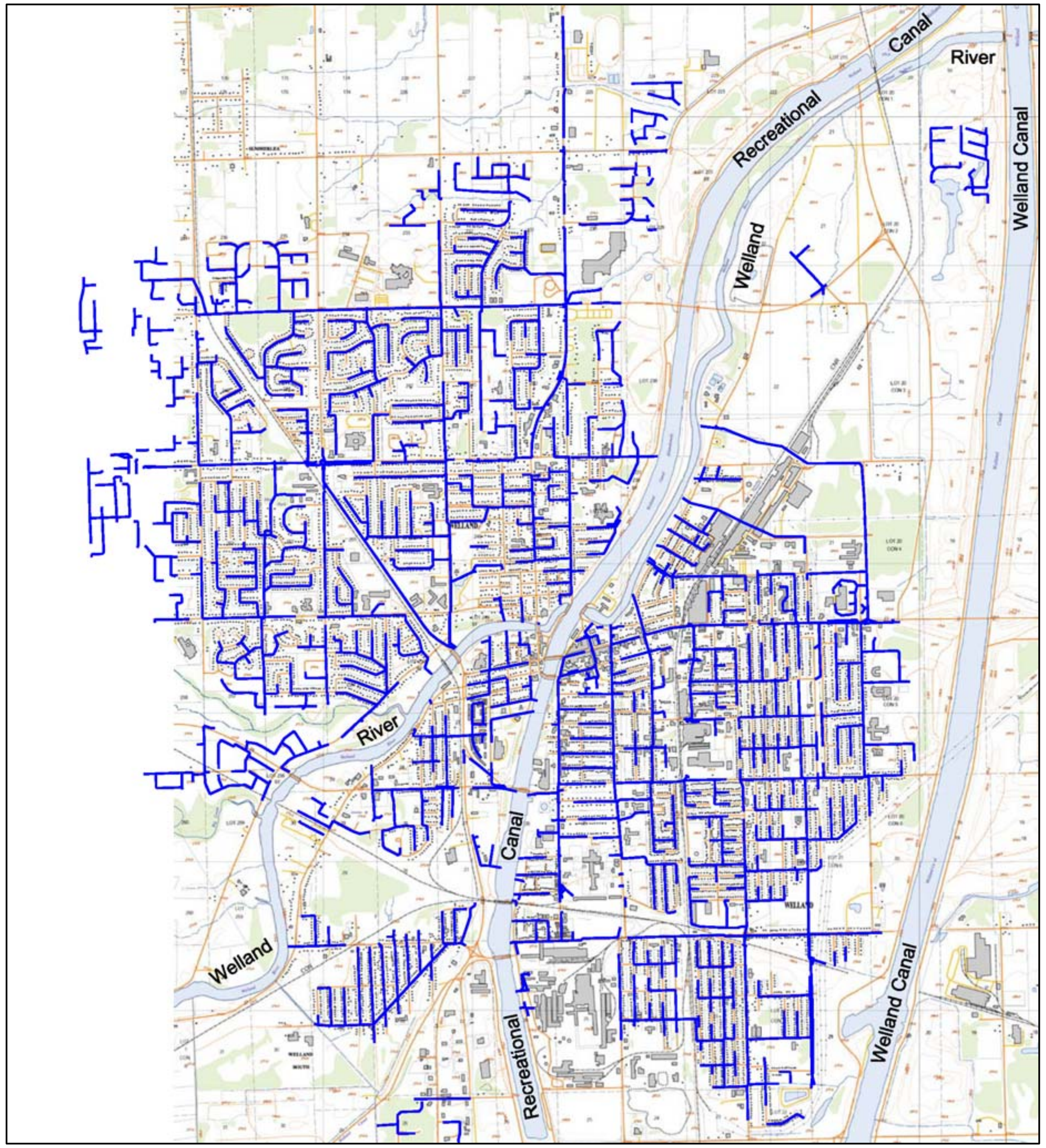
- Materials - Vitrified Clay, Concrete Pipe, Asbestos Concrete, Polyvinyl Chloride, Reinforced Concrete, High Density Polyethylene
- Pipe diameters from 300mm to 3000mm

Figure 3-4 indicates about 80% of the storm collection system is still in good serviceable condition with greater than 45% of useful life remaining (i.e., condition rating A or B). Conversely, the bulk of the combined system is showing its age with moderate deterioration or functioning with deterioration (i.e., condition rating C or D). The condition of the sanitary system is almost evenly distributed across the A, B and C ratings. The large component of the sanitary system defined as "unknown" is an indication that many of the newest sanitary sewers have not yet been assessed.

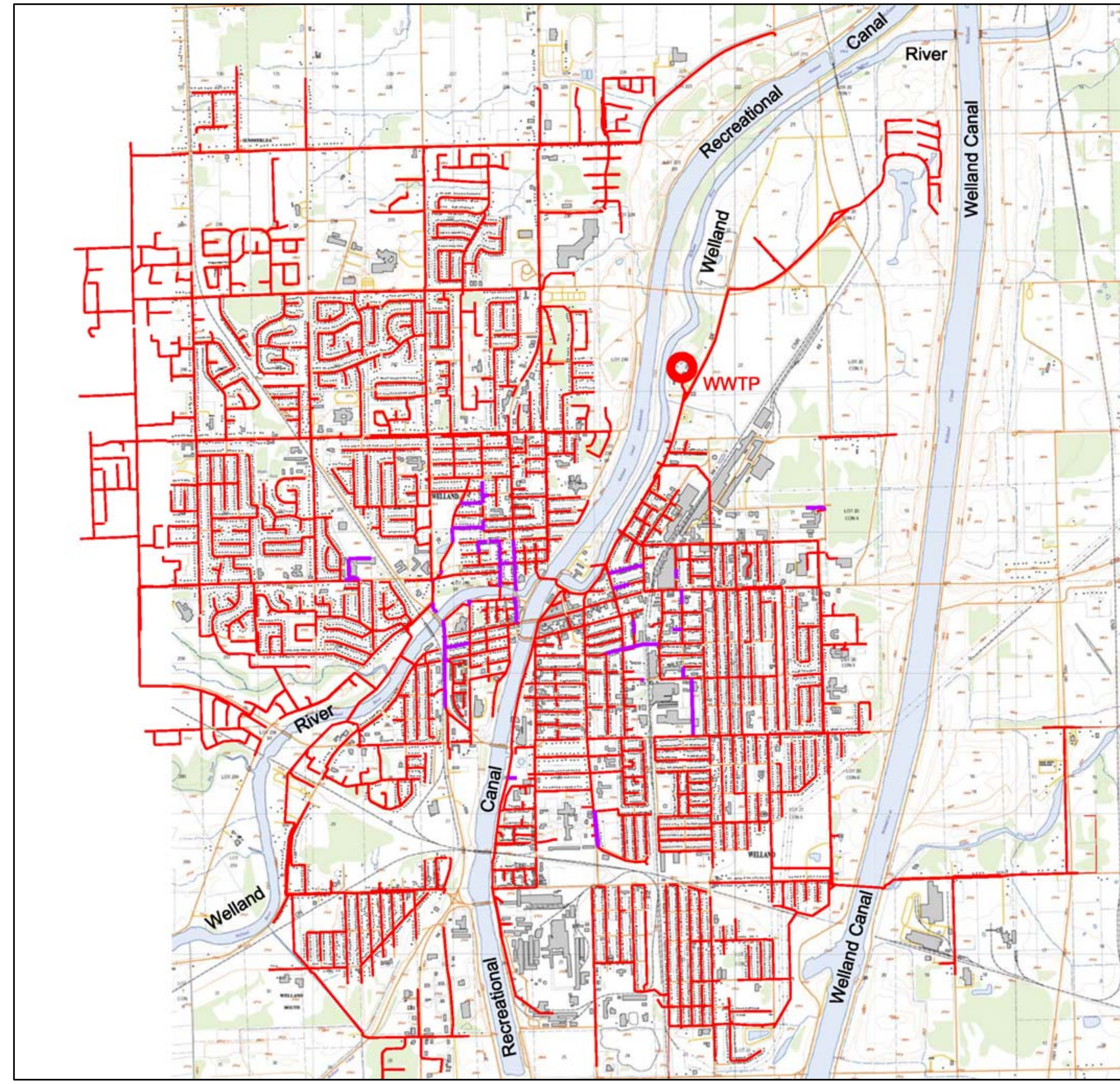
In each of Figures 3-2, 3-3, 3-4 and 3-5 the defined asset classes are Sanitary, Combined and Storm (sewers). The figures represent a visualization of what portion of the overall asset class has a particular attribute such as age, material, size or condition. As an example from Figure 3-2, 100% of the storm sewers are 70 years old or younger. Similarly, from Figure 3-3, more than 90% of the storm sewers are made of concrete pipe ("CP").

**Table 3-2 : Wastewater Collection System Component Infrastructure**

| Infrastructure Component | Number | Description/Details |
|---|---|---|
| Manholes | Sanitary - 3597<br>Combined - 99 | |
| Pipes | 17161 - Laterals<br>3789 - Mains<br>268km - Total Length<br>2700 mm - Max Size<br>125 mm - Min Size | Database includes information for:<br>• Main_pipe (including stubs and overflows)<br>• Box_culvert<br>• Forcemain<br>• Culvert<br>• Inverted_siphon<br>• Tunnel<br>• Service_pipe (including road drains, trade pipes, park drains, roadside drains, ICI, lot drains, forcemains)<br>• Outfall_pipe |
| Forcemains | 11 | A forcemain is a pressurized pipe conveying stormwater runoff and/or sewage |
| Inverted Siphons | 3 | Inverted siphons are sewer pipes that must dip below an obstruction to form a "U" shaped flow path. Liquid flowing in one end simply forces liquid up and out the other end, but solids like sand or other debris may accumulate. For the City's infrastructure inverted siphons convey flow under the Welland Rivers and Recreational Canal. |
| Reservoirs | 5 | Reservoirs act as temporary holding facilities for combined sewage upstream of pumping stations. The reservoirs store flow in excess of the capacity of the pumping station. If the capacity of the reservoir is exceeded a CSO occurs or an un-controlled overflow. |
| Pump Stations | 5 | The need for pumping sewage arises, generally, when the existing topography and required minimum sewer grades create deep sewers that have high construction costs. Pumping moves the flow to higher elevation from where it can then conveyed by gravity. |
| Flow Control Structures | 3 | These structures are generally located inside of manholes and consist of a weir that directs dry weather flow to the sewage treatment plant, while wet weather flow will overtop the weir and be conveyed along separate path, typically to a CSO. |
| Combined Sewer Overflows / Regulators (CSO's) | 19 | A combined sewer overflow, or CSO, is the discharge of wastewater and stormwater from a combined sewer system directly to a receiving water. 18 CSO's are located along the Regional Interceptor system, and were modelled by AMEC (2011). |




**Stormwater Collection System**




**Wastewater / Combined Collection and Treatment System**

**Figure 3-1 : Spatial Distribution of Subject Infrastructure**

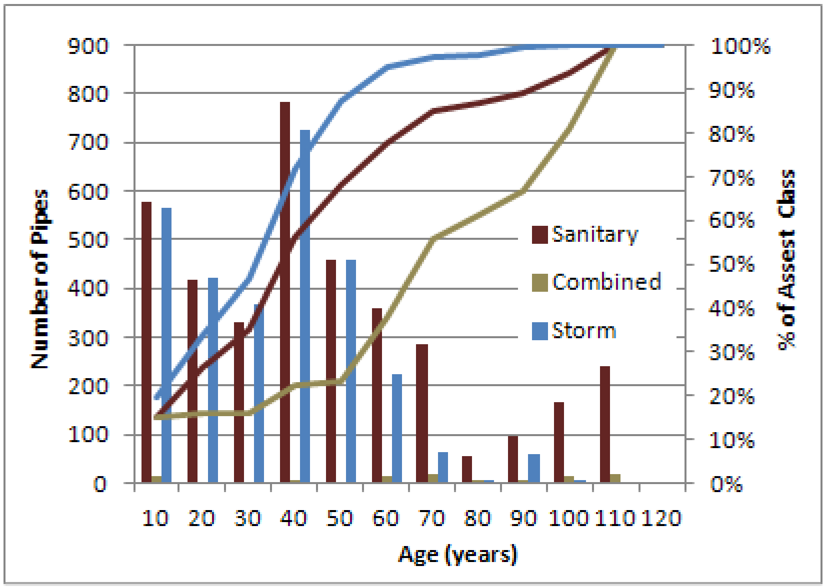



**Figure 3-2 : Infrastructure by Age**

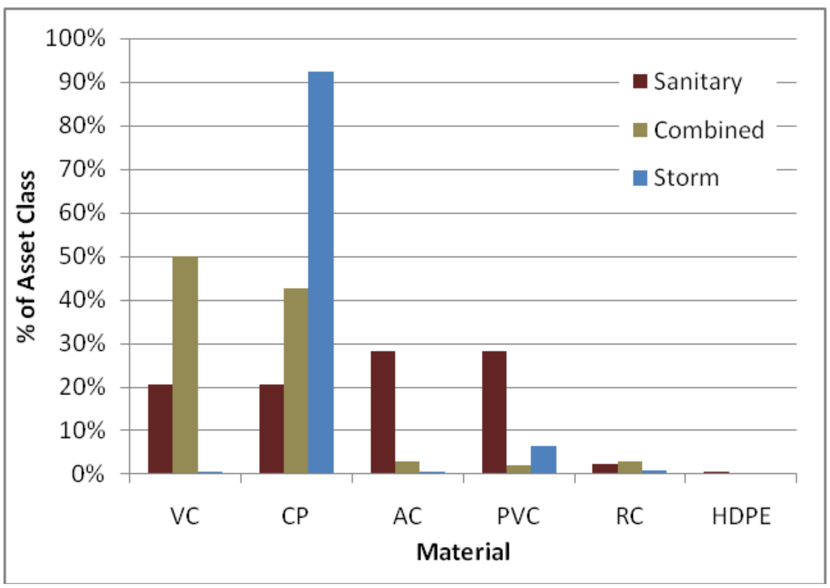



**Figure 3-3 : Infrastructure by Material**

| | |
|---|---|
| VC | Vitrified Clay |
| CP | Concrete Pipe |
| AC | Asbestos Concrete |
| PVC | Polyvinyl Chloride |
| RC | Reinforced Concrete |
| HDPE | High Density Polyethylene |

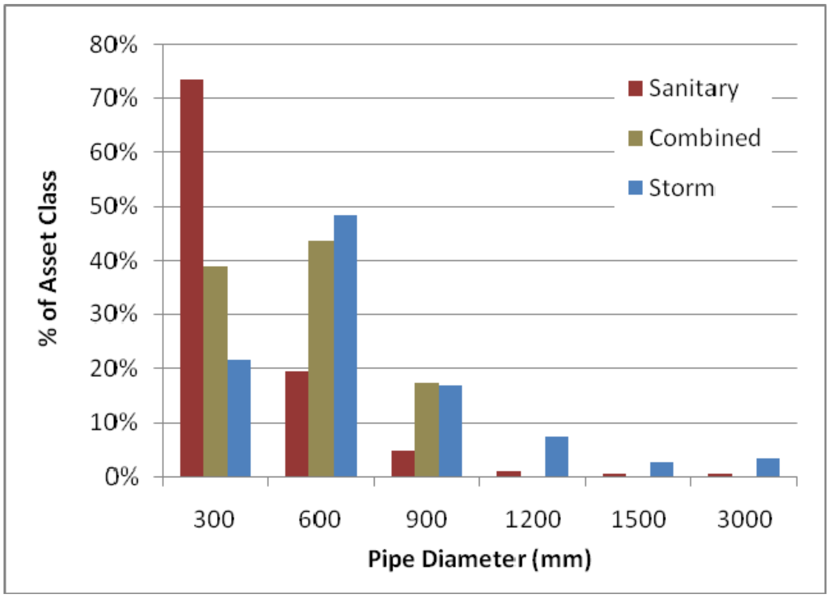



**Figure 3-4 : Infrastructure by Size**

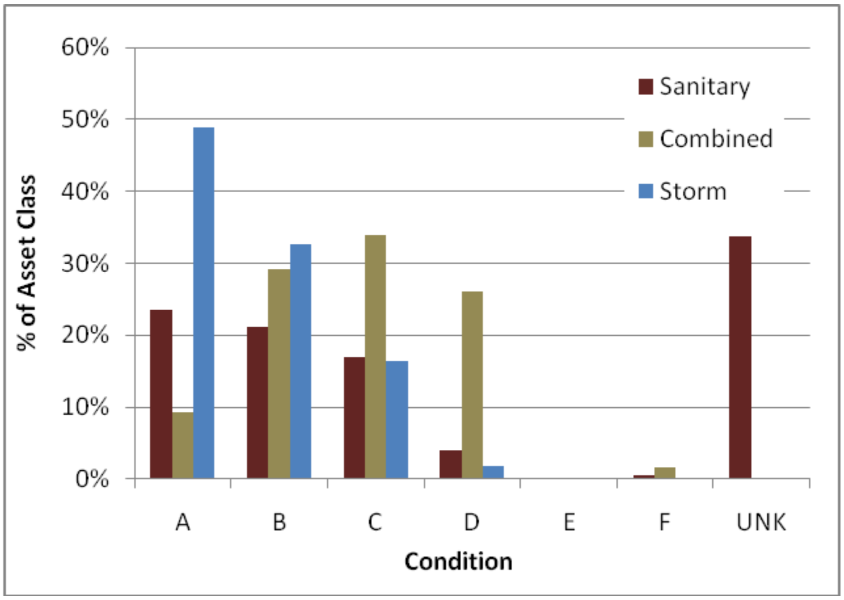



**Figure 3-5 : Infrastructure by Condition**

| Rating | Description | Useful Life Remaining |
|---|---|---|
| A | Newly installed or like new | >64% |
| B | First signs of aging | ≥ 45% and ≤ 64% |
| C | Moderate aging/ deterioration | ≥ 29% and ≤ 44% |
| D | Asset functioning with deterioration | ≥ 18% and ≤ 28% |
| F | Loss of function imminent | < 18% |
| UNK | Unknown | |

Notes:
Rating 'F' has the following descriptors:

- Severe distress with extensive loss of pipe structural integrity
- Asset substantially derelict with no residual life expectancy
- Asset unserviceable

### 3.2.1.3 Wastewater Treatment Plant (WWTP)

The existing WWTP services Welland and the communities of Pelham, Port Robinson, and South Thorold. In addition, the plant services wastewater from the following non-residential sources:

- Commercial and industrial wastewater;
- Humberstone Landfill leachate;
- Atlas Landfill leachate;
- Station Road Landfill leachate;
- Septage; and
- Garner Road Biosolids Storage Facility supernatant and centrate.

The leachate from the Humberstone Landfill and Atlas Landfill are pumped directly into the collection system. Station Road Landfill leachate, septage, and supernatant/centrate flows from the Garner Road Biosolids Storage Facility are currently hauled to the Welland WWTP and discharged directly into the head works of the plant. In the future, the supernatant/centrate from the Garner Road Biosolids Facility is to be pumped into the Welland WWTP collection system in Port Robinson.

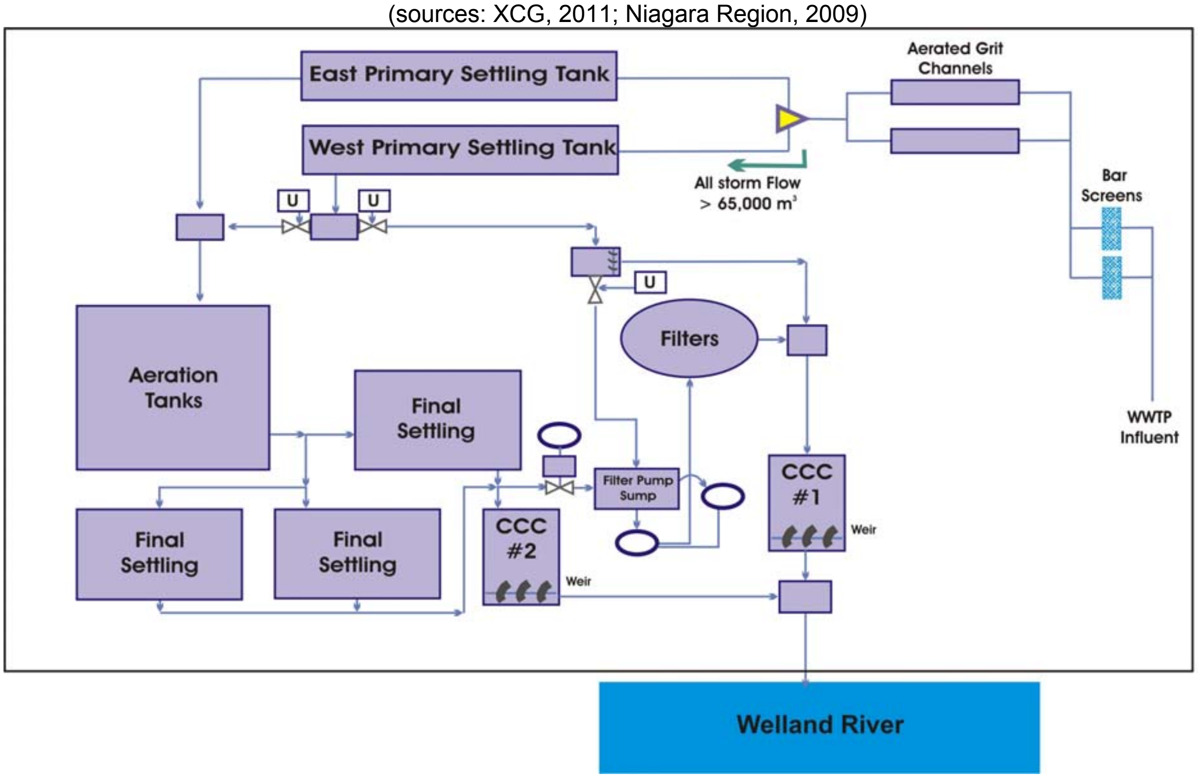
The Welland WWTP consists of a conventional activated sludge plant with effluent filtration, a parallel physical chemical treatment plant to provide treatment of storm flows, effluent disinfection by chlorination followed by de-chlorination, and biosolids stabilization in a two stage mesophilic anaerobic digestion process. Stabilized biosolids are stored on site prior to being hauled to the Region's centralized biosolids processing and storage facility at Garner Road. Treated effluent is discharged to the Welland River, a sensitive receiver tributary to the Niagara River. For a general description of wastewater treatment processes (primary, secondary, etc.) additional information can be sourced via the Safe Drinking Water Foundation website at http://www.safewater.org.

The existing facility is capable of providing physical/chemical treatment during wet weather and can be operated in storm mode whereby physical/chemical treatment and disinfection is provided for an additional wet weather capacity. A basic outline of WWTP components and processes is provided below (as detailed in the current Certificate of Approval). A process schematic of the WWTP is illustrated in Figure 3-6.

- Rated capacity of 54,550 $m^3$/day average daily flow and a 118,000 $m^3$/day Peak Flow Rate
- Main sewage pumping station – three (3) pumps with capacity 55,690 $m^3$/day each (134,000 $m^3$/day available at high wet well levels)
- Screening facilities
- Grit Removal facility (with air supply system)

- Flow Splitter – directs flow (up to 9,900 $m^3$/day) always to the physical/chemical plant and excess (to 65,000 $m^3$/day) to conventional treatment plant, flow in excess of 65,000 $m^3$/day directed to the physical/chemical plant.

**Figure 3-6 : WWTP Process Schematic**
(sources: XCG, 2011; Niagara Region, 2009)




- Physical Chemical Treatment Plant
  - o Two flocculation tanks with mixers for dispersion of coagulants
  - o Two primary settling tanks each with longitudinal chain and flight type sludge collection
- Conventional Treatment Plant
  - o Activated sludge treatment with tertiary filtration
  - o Three primary settling tanks each with longitudinal chain and flight type sludge collection
  - o Four aeration tanks used for biological treatment equipped with a surface type mechanical aerator
  - o Final settling tank
- Effluent Filtration System
  - o One filter pumping station (four pumps)
  - o Three dual media deep bed filters
  - o Backwash water holding tank

- Disinfection System
- Phosphorus Removal System
- Anaerobic Digestion System
- Biosolids Management
- Outfall to Welland River
- Flow Meters and Monitoring Instrumentation
- Standby Power comprised of one (1) 1000 kW diesel generator with a 9,213 L (about 2450 US gallons) fuel tank with containment. This amount of fuel has the potential to power the facility for about 1.5 days (full load) to about 5 days (1/4 load).

In current operation, minimum flows of 9,900 $m^3$/day, and all flows in excess of 65,000 $m^3$/day are diverted by a flow splitter to the physical/chemical plant (the West or Storm Primary Clarifiers). Flow up to 65,000 $m^3$/day is treated in the East Primary Clarifiers and in the conventional activated sludge plant.

The effluent filters are intended to treat flows up to a peak flow rate of 68,130 $m^3$/day, or in excess of the capacity of the conventional activated sludge plant. Up to 17,048 $m^3$/day of effluent from the physical chemical treatment is blended with the conventional activated sludge plant effluent for tertiary filtration.

The plant has no bypass mechanism so flow into the plant is restricted to the capacity of the plant at the inlet to the plant wet well. As such, if the inflow is in excess of plant capacity an overflow upstream of the plant will occur.

As reported in WWTP Upgrade and Expansion Conceptual Design Report (Niagara Region, 2011), the projected flows will exceed the existing plant capacity of 54,550 m3/d, between the years 2014 to 2022.

As noted previously, the Region of Niagara has initiated the Water and Wastewater Master Servicing Plan Study to identify a long-term water and wastewater servicing strategy to support growth in the Region through 2031. The objective of the Water and Wastewater Master Servicing Plan is to develop a long-term servicing strategy for Niagara Region's water and wastewater systems. This includes wastewater sewers, watermains, water and wastewater treatment plants and facilities. The study area covers the entirety of Niagara Region's water and wastewater systems. The Master Servicing Plan study is to be integrated with growth projections from the Region's Planning department, specifically the Growth Management Strategy.

#### 3.2.1.4 Infrastructure Support Systems

- Power Sources

  Power is required at the pump stations and SCADA locations. Primary power is provided from the grid. Back-up power generation is only available at the WTTP as described above.

- Communications

  Modes of communication include telephone, two-way radio, e-mail, Internet, and telemetry at the WWTP.

- Transportation

  Transportation refers to the road and driving conditions that can affect operations and staff response time.

- Personnel

  Consideration was given to staffing situations relevant to operations and maintenance of the subject infrastructure. This was segregated into City and Region staff with focus to their respective infrastructure.

## 3.3 CLIMATE ANALYSIS

### 3.3.1 Overview

The objectives of this study component were to:

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

As noted previously, noted the term 'historical' relates to climate from the current time frame and recent past while "future" relates to the two future time frames identified for this study, namely 2020 and 2050.

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, with the exception of the effort to prepare updated and projected IDF relationships, 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 for the Welland study area.

As well, uncertainty in climate projections is clearly demonstrated in the varied results from the present array of Global Climate Models (GCM's). The information developed and used for this project is adequate to meet the stated objectives of the study, however, other potential users of the information should consider it in the proper context.

### 3.3.2 The "Long" 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/Low Temperature
- Heat & Cold Waves
- Extreme Diurnal Temperature Variability
- Freeze Thaw Cycles
- Heavy Rain
- Daily Total Rainfall
- Winter Rain
- Freezing Rain
- Ice Storm
- Snow Accumulation
- Blowing Snow/Blizzard
- Lightning
- Hail Storm
- Hurricane/Tropical Storm
- High Winds
- Tornado
- Drought/Dry Period
- Heavy Fog

The list was refined based on climatic and meteorological phenomena deemed relevant to the City of Welland in consultation with the Project Team. 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.

### 3.3.3 Climate Data Sources

#### 3.3.3.1 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 (ref. Appendix D)

  (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/)
- Canadian Atmospheric Hazards Network – Ontario node

  (available at http://ontario.hazards.ca/intro-e.html)

The Welland weather station (#6139445 at 42°59'33.096" N by 79°15'40.098" W) was used where available from the above noted data sources. Where data for the Welland station was not available in the databases above, as was the case for certain climate parameters (i.e., ice storms, lightning, hurricanes, and tornado), 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.

#### 3.3.3.2 Future

Future climate projections were analyzed using climate model output from:

- Environment Canada's Canadian Climate Change Scenario Network (CCCSN)

  (available at http://cccsn.ca/?page=main)
- Intergovernmental Panel on Climate Change (IPCC) 4$^{th}$ Assessment Report (IPCC, 2007)
- World Climate Research Programme's (WCRP) Coupled Model Inter-comparison Project Phase 3 (CMIP3) multi-model dataset (WCRP CMIP3, 2009)
- Other readily available literature as documented in the specific climate parameter sections that follow.

Climate projections for a number of climate parameters were obtained from the bias-corrected and spatially downscaled WCRP CMIP3 Climate Projections archive (WCRP CMIP3, 2009) described by Maurer (2007). The WCRP archive was developed jointly by the U.S. Bureau of Reclamation, Santa Clara College and the Lawrence Livermore National Laboratory. The WCRP-CMIP3 archive has been developed using peer reviewed methods (Wood et al. 2002, Wood et al. 2004, and Maurer, 2007) and is currently being used by the U.S. Bureau of Reclamation and many other entities, such as the IPCC's Working Group 1, for climate change impact analyses.

The 112 projections in the WCRP-CMIP3 archive originate from runs of 16 GCMs using the B1, A1B and A2 scenarios of future greenhouse gas emissions, as shown in Table 3-3. For each of the 112 scenarios and for each month of the year, a precipitation ratio and a temperature offset were calculated between the overlap period and each of the future projection periods. These adjustment factors were then used to adjust the daily historical maximum temperature, minimum temperature and precipitation values for Port Colborne (the nearest long term full meteorological station) from 1964 – 2011 by applying the appropriate month’s adjustment ratio or offset for each day of the month. Both maximum and minimum temperatures were adjusted by the same offset.

The projected climate data consist of monthly values of average precipitation and average temperature at a spatial resolution of 1/8$^{th}$ degree. Each projection has an overlap period from 1950 through 1999 and a projection period from 2000 through 2099.

The precipitation and temperature values for grid cells were weighted according to their distance from Port Colborne, Ontario (42.889046N, -79.2513W). Typically, four grid cells would be weighted to characterize a point, however the WRCP archive does not include projections over Lake Ontario, so only the two grid cells that encompass the study area and the Port Colborne station were used to characterize future conditions at Port Colborne. The grid cells at 42.9375N, -79.3125W (0.471146 weight) and 42.9375N, -79.1825W (0.528854 weight) were used to calculate both the monthly total precipitation and the average daily temperature for each month of the year for the overlap period and two future periods, 2020 (2005-2034) and 2050 (2035-2064).

**Table 3-3 : Downscaled CMIP3 Projections**
(source: LLNL, 2011)

| | SRES Scenario | | | |
|---|---|---|---|---|
| | a1b | a2 | b1 | Total |
| GCM | Number of Runs | | | |
| bccr_bcm2_0 | 1 | 1 | 1 | 3 |
| cccma_cgcm3_1 | 5 | 5 | 5 | 15 |
| cnrm_cm3 | 1 | 1 | 1 | 3 |
| csiro_mk3_0 | 1 | 1 | 1 | 3 |
| gfdl_cm2_0 | 1 | 1 | 1 | 3 |
| gfdl_cm2_1 | 1 | 1 | 1 | 3 |
| giss_model_e_r | 2 | 1 | 1 | 4 |
| inmcm3_0 | 1 | 1 | 1 | 3 |
| ipsl_cm4 | 1 | 1 | 1 | 3 |
| miroc3_2_medres | 3 | 3 | 3 | 9 |
| miub_echo_g | 3 | 3 | 3 | 9 |
| mpi_echam5 | 3 | 3 | 3 | 9 |
| mri_cgcm2_3_2a | 5 | 5 | 5 | 15 |
| ncar_ccsm3_0 | 6 | 4 | 7 | 17 |
| ncar_pcm1 | 4 | 4 | 2 | 10 |
| ukmo_hadcm3 | 1 | 1 | 1 | 3 |
| Total | 39 | 36 | 37 | 112 |

Notes:
1. SRES - Special Report on Emissions Scenarios (SRES, 2000)
2. Ref. Table 3, Appendix C for definition GCM's in the archive

The results of the adjusted daily data were then processed to find:

- The number of days when the maximum temperature (Tmax) exceeded 30°C;
- The number of days when Tmax exceeded 35°C;
- The number of days when the minimum temperature (Tmin) was less than -20°C;
- The number of days when Tmin was less than -25°C;
- Heat waves (3 or more consecutive days with a Tmax greater than or equal to 32°C)[4],
- Cold waves (3 or more consecutive days with Tmax less than -10°C)[5];
- Freeze Thaw cycles (# of days when Tmin was less than 0°C and Tmax was greater than 0°C); and,

[4] As defined by Environment Canada … see http://ontario.hazards.ca/maps/trends/wsdi-e.html
[5] Environment Canada defines a "Cold Wave" in south central and southwestern Ontario, when minimum temperatures are expected to fall to -20°C or less with maximum temperatures not expected to rise above -10°C over a 3 day period. This has been interpreted as 3 or more consecutive days with Tmax less than -10°C to simplify the analysis using the available data.

- and Drought Periods (10 or more consecutive days with less than 0.2 mm of precipitation)[6].

For the Heat Waves and Cold Waves, 3-5 days in a row were considered 1 period while 6 days in a row would count as 2 periods (of 3 days each) and 6-8 days in a row would also count as 2 periods changing into 3 periods in a row on the 9th consecutive day of heat or cold and increasing in the same manner.

The historical period (with no adjustment) was also processed to give a baseline to compare the future projection periods against.

### 3.3.4 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. A scoring system was used whereby a score between 0 and 7 was assigned to each parameter by subjectively relating the known or calculated frequency to one of the descriptive terms. Method A from Figure 8 of the Protocol, Probability Scale Factors, was adopted for use for this study. Figure 8, specific to Method A, is reproduced in part as Table 3-4 below.

**Table 3-4 : Risk Assessment Probability Scale Factors – Method A**
(source: PIEVC, 2009)

| 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 was 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).

[6] The term drought has always been difficult to define. Its meanings often differ between individuals, depending on how the water shortages impact on their lives. For the purposes of this study the definition of 10 consecutive days with rain < 0.2mm has been adopted consistent with the drought analysis data presented at the Ontario Hazards website at http://ontario.hazards.ca/maps/background/Drought-e.html

The process is initiated with the question “what is the likelihood that an event will occur in a given year?” If one considers a climate parameter to have a historical annual frequency of 0.5 then this can be considered to mean that the climate event would occur about once every two years on average. 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.

Method A (ref. Table 3-4) relates the term “negligible or not applicable” to a Probability Score of zero (0). It was considered that regardless of how low the frequency, this term did not apply to any parameter being evaluated for his assessment. As such, no scores of “0” were assigned.

The above three rationales provided relational benchmarks to consider for this assessment. Consistency was maintained throughout the assessment process by using a suite of frequency ranges as described in Table 3-4 which related frequency ranges to PIEVC scores. Using this mechanism, where frequencies were available, the matching probability score was assigned.

#### 3.3.4.1 High Temperature

**Definition**

The maximum temperature currently recorded for Welland is 37.8°C, which occurred in July of 1911 and again in August of 1948 (TWN, 2011). As a reflection of the recorded high temperature, a threshold temperature of 35°C has been selected as representative of the measure of high temperature for this study. This definition is consistent with other PIEVC Protocol based climate change vulnerability assessments (e.g., TRCA, 2010).

**Historical Climate**

Climate Normals for Welland, obtained from Environment Canada Data Online (Environment Canada, 2011b) for the periods from 1971 to 2000, indicate an average of seven days a year with temperatures greater than 30°C and an average of 0.06 days per year had temperatures greater than 35°C (ref. Table 3-5).

The findings for ‘number of days with a maximum temperature > 35°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 over Canada were analyzed during the 20th century. 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.

**Table 3-5 : Summary of High Temperature Days**

| Description | Days/Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| > 30°C | 7 | 9 | 17 |
| > 35°C | 0.06 | 0.08 | 0.33 |
| Probability Scale | 2<br>remote | 2<br>remote | 4<br>Moderate / possible |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

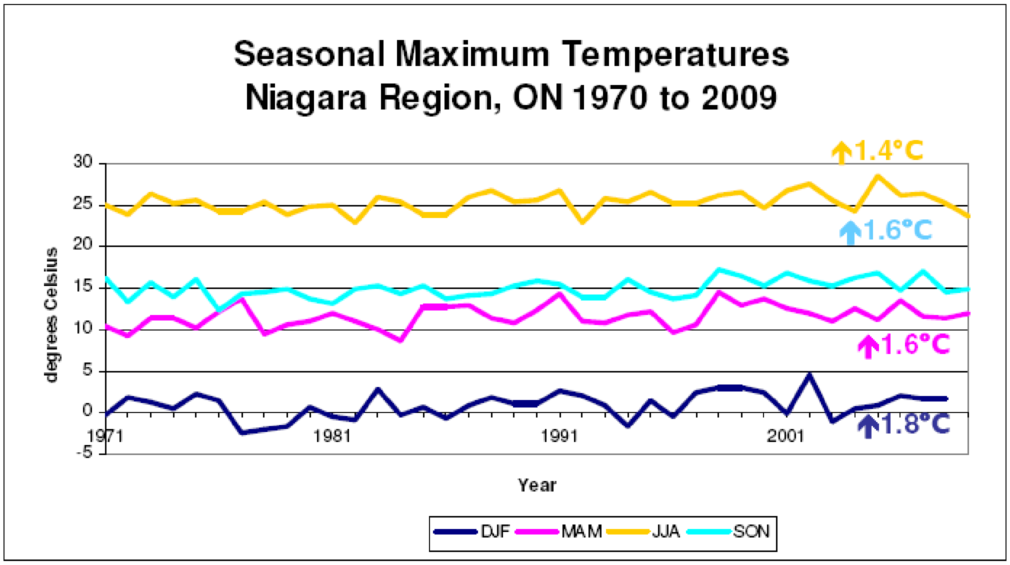
Over southern Canada, the mean annual temperature was found to have increased between 0.5 and 1.5°C (between 1900 and 1998), with the greatest warming found in the Prairie Provinces. It was found that the change was due largely to warmer overnight temperatures, meaning that the region was becoming less cold but not hotter. The trend in increasing overnight temperatures was statistically significant over all of southern Canada. Even though a positive trend in daytime maximum temperatures was found for southern Ontario, it was not statistically significant. Easterling et al. (2000) discuss a similar finding in studies on the trends of temperatures in the Unites States over the period 1910-1998.

Hamilton and Whitelaw (1999) examined long-term climate trends from stations along or near the Niagara Escarpment. Stations within the Niagara Peninsula included Niagara Falls (1902-1995), St. Catharines (1902-1996) and Welland (1895-1998). These stations (at the time of the analyses) had records of 93, 94 and 103 years, respectively. Observations with regard to temperature identified long-term increases in mean annual temperature of 0.6°C at St. Catharines and 0.7°C at Welland. Generally these increases were highest in winter and spring and lower in summer and fall. Most of the increase in mean temperature was due to rising minimum values and as a result daily temperature ranges declined about 1.0°C.

Fenech and Shaw (2010) completed a review of climate data for the Niagara Region based on the Vineland and other weather stations in the Region. Figure 3-7 illustrates seasonal variations and trends in temperature for the Region indicating upward trends in temperature for all seasons.

Tan and Reynolds (2003) describe the climate of south-western Ontario as generally drier in the last decade but also conclude that temperature is on the rise.

**Figure 3-7 : Seasonal Maximum Temperatures, Niagara Region, 1970-2009**
(source: Fenech and Shaw, 2010)




## Climate Projections

## Findings

Zwiers and Kharin (1998) performed $CO_2$ doubling experiments with a GCM in equilibrium mode. A GCM in equilibrium mode simply means that the atmosphere-ocean interface is in equilibrium and is not truly coupled as more recent models are. This study looked at 20-year return values of selected parameters and found that the 20-year return value for maximum temperature increased by approximately 6°C over southern Ontario.

Environment Canada has its own coupled GCM known as the CGCM2 (Canadian Coupled Global Climate Model). The horizontal resolution of the model is approximately 300 km by 400 km. The model has been run for a variety of scenarios over Canada to simulate past and present conditions under increased $CO_2$ concentrations. Winter temperatures in the vicinity of Welland are predicted to rise 2°C by 2040 and by as much as 5°C by 2100 over the base period of 1971-2000. Similar temperature changes are expected to occur during the summer months.

A specific analysis of occurrence of High Temperature days was completed, for this study, using the WCRP CMIP3 database for 2020 and 2050. The results of this analysis are summarized in Table 3-5. It is clear that the trend in High Temperature is upward with numbers of days above 30°C and 35°C, on average, increasing into the future with a marginal increase from historic conditions to the 2020 time frame, but a significant, comparable, increase between the 2020 and 2050 time frames.

**Probability Scoring**

In consideration of this increase in High Temperature into the future 2020 time frame, the probability score remains unchanged from the historic time frame as "remote" (or "2"). However, the future 2050 time frame results increase the probability scoring for this climate parameter to "Moderate / possible" (or "4").

### 3.3.4.2 Low Temperature

**Definition**

The minimum temperature currently recorded for Welland is -32.8°C, which occurred in January of 1882 (TWN, 2011). As a reflection of this recorded low temperature, a threshold of -30°C was considered a representative and the measure of low temperature for this study has been identified as the number of days where the minimum daily temperature was less than -30°C. This definition is consistent with other PIEVC Protocol based climate change vulnerability assessments (e.g., TRCA, 2010).

**Historical Climate**

Climate normals for Welland, obtained from Environment Canada Data Online Environment Canada 2011b) for the periods from 1971 to 2000 indicate an average of three days a year with temperatures less than -20°C and an average of 0 days per year had temperatures less than -30°C (ref. Table 3-6).

**Probability Scoring**

The findings for 'number of days with a maximum temperature < -30°C' outlined in Table 3-6 were compared with the established ranges in Table 3-4, resulting in a recommended probability score of "Improbable / highly unlikely" (or "1").

**Table 3-6 : Summary of Low Temperature Days**

| Description | Days/Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| < -20°C | 3.1 | 0.6 | 0.4 |
| < -30°C | 0+ | 0+ | 0+ |
| Probability Scale | 1<br>Improbable / highly unlikely | 1<br>Improbable / highly unlikely | 1<br>Improbable / highly unlikely |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

**Trends**

Osborne (2011) analysed temperature trends in Canada during the last sixty years concluding that changes are not consistent across Canada. Only during autumn in the extreme south of Ontario and Quebec has there not been any rise or drop in the average temperature since 1948. For most seasons and regions however, the trend since 1948 has been to a warmer climate with increases in average temperatures from 1948 to 2007 of 0.9°C, 1.0°C, 0.5°C and 0.2°C for winter, spring, summer and autumn, respectively, for the Great Lakes and St. Lawrence lowlands of southern Ontario and Quebec.

Figure 3-8 depicts the upward trend for winter temperature illustrating that winter temperatures have been at or above normal since 1996/1997. The red dashed linear trend line indicates winter temperatures have warmed over the last 64 years by about 2.8°C. The *Winter Summary 2010/2011 Climate Trends and Variations Bulletin,* (Environment Canada, 2011c) also indicates that of the ten warmest winters recorded, 4 have occurred within the last decade, and 11 of the last 20 years are listed among the 20 warmest.

The trend analysis completed by Fenech and Shaw (2010) (ref. Figure 3-7) also confirms upwards trends in winter temperatures.

As noted previously, Hamilton and Whitelaw (1999) examined long-term climate trends from stations along or near the Niagara Escarpment and noted long-term increases in mean annual temperature in the region. These increases were generally noted to be highest in winter and spring (i.e., when maximum low temperatures would be expected) and most of the increase in mean temperature was due to rising minimum values.

**Climate Projections**

**Findings**

Minimum temperatures averaged increases of about 2.7 ºC across Ontario for projections over the period 2071-2100. Higher minimum temperatures would appear mainly in southern Ontario, while the highest would appear along the shores of the Great Lakes. (OMOE, 2010)

A specific analysis of Low Temperature was completed, for this study, using the WCRP CMIP3 database. The results of this analysis are summarized in Table 3-6. It is clear that the trend in Low Temperature is upward with numbers of days below -20°C, on average, decreasing significantly into the future. Further, Welland does not generally experience extreme low temperatures (i.e., below -30°C) presently and with increasing coldest temperatures projected into the future there is an even further decreased expectation of extreme low temperatures.

**Probability Scoring**

The upward movement in minimum temperatures into the future 2020 time frame suggests average annual minimum temperatures will also increase. As such, the recommended probability score of "Improbable / highly unlikely" (or "1") associated with the Historic time frame remains unchanged.

### 3.3.4.3 Heat Waves

**Definition**

A heat wave, as defined by Environment Canada, is considered to have occurred when there are three or more consecutive days when the maximum temperature is 32°C or higher. This Environment Canada definition was also used for this study.

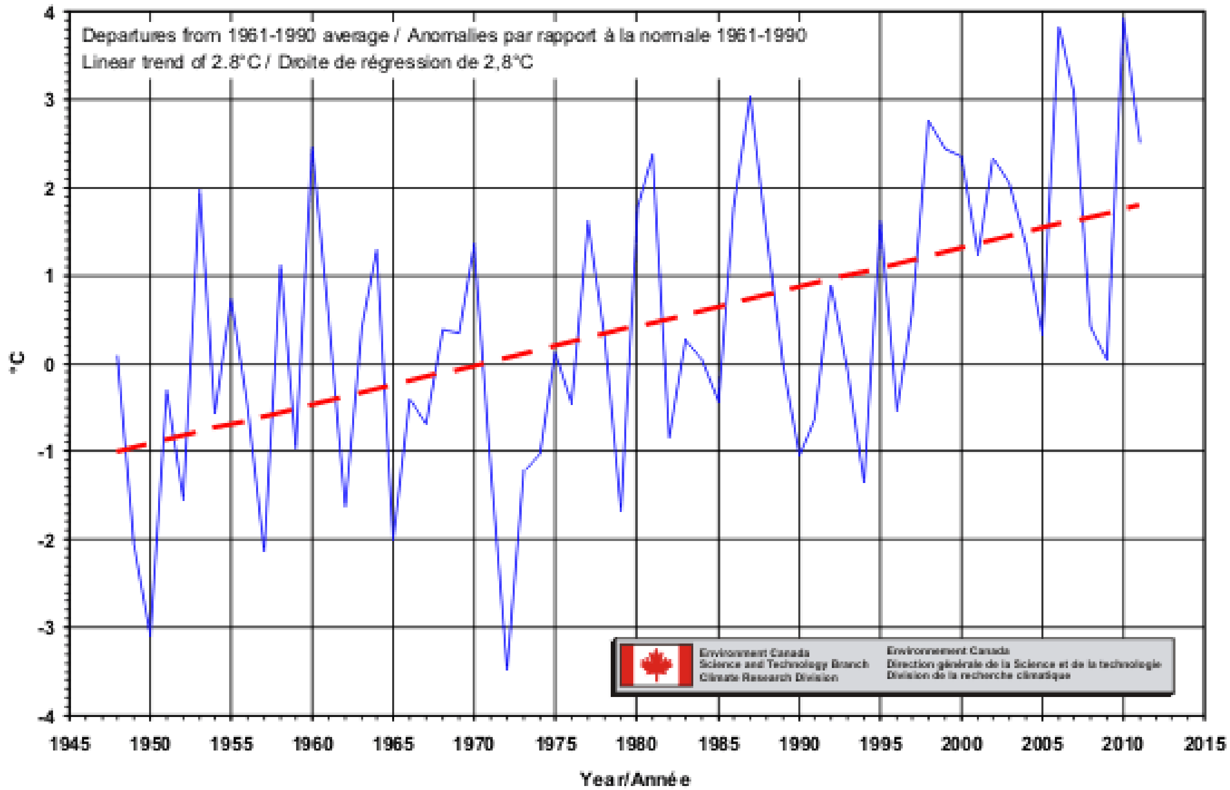
**Historical Climate**

Daily temperature for Welland, obtained from Environment Canada's Climate Data Online (Environment Canada, 2011b), was analysed for the occurrence of heat waves from 1971 to 2000. It was determined that in the 30-year period, four heat waves had been recorded in Welland, an average of 0.2 heat waves per year (5/30). A single three-day heat wave was recorded in 1975. The other three heat waves were recorded in 1988, two of which lasted the defining three days and the other heat wave lasting for six days[7].

A further review of daily temperature data for Welland for the period 2001 through 2011 was completed. During this period an additional 5 heat waves were recorded, one of which occurred in July 2011.

[7] Consistent with the methodology used to quantify future projections of heat wave, the historic heat wave lasting 6 days was considered for this assessment to represent two (2) occurrences.

**Figure 3-8 : Winter National Temperature Departures and Long-Term Trend, 1948 – 2011**
(source: Environment Canada, 2011c)




## Probability Scoring

The finding for 'number of heat waves' outlined in Table 3-7 was compared with the established ranges in Table 3-4, resulting in a recommended probability score of "Occasional" (or "3").

## Trends

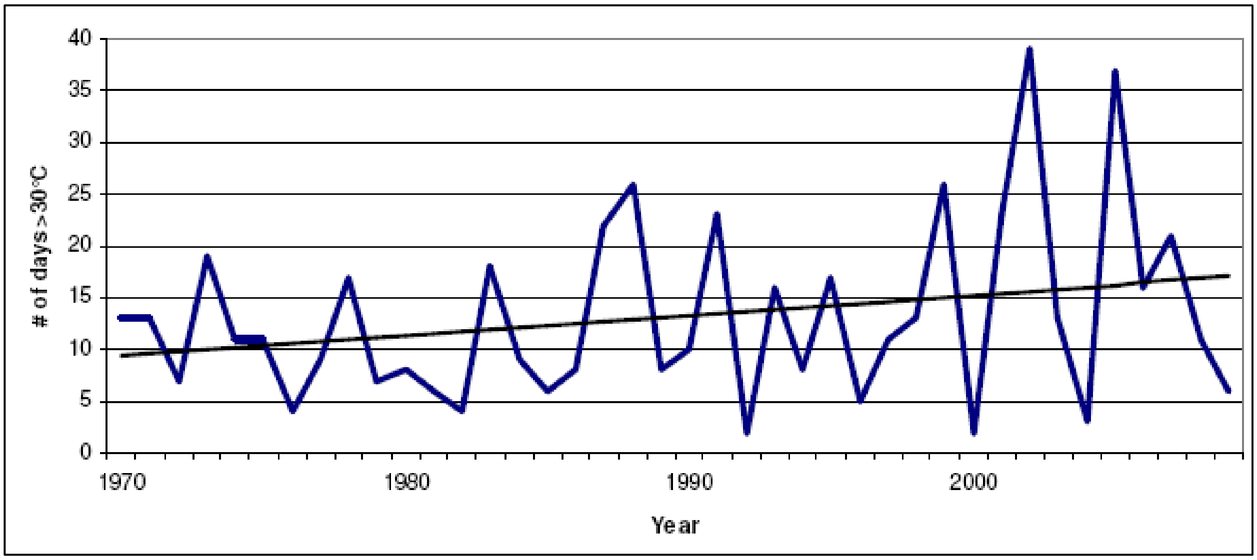
Although there was no specific assessment of heat waves (in the context of the definition used for the Welland study), Fenech and Shaw (2010) analysed numbers of extreme hot days per year for Niagara Region. The definition used for an extreme hot day was a day with a maximum temperature greater than 30°C and there is a clear upward trend in the annual number of extreme hot days as illustrated in Figure 3-9. The data for Port Colborne showed only 25 days and 33 days, respectively, for the years 2002 and 2005 which is marginally different from the Fenech and Shaw (2010) data for 2002 and 2005 showing maximum extreme heat days of > 35 days in each year. Nonetheless, the data suggests that as the number of extreme hot days increases the potential for increasing heat waves (as defined for the Welland study) will also increase.

**Table 3-7 : Summary of Heat Waves**

| Description | Days/Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| Occurrences of three or more consecutive days when the maximum temperature > 32°C | 0.2 | 0.2 | 0.4 |
| Probability Scale | 3<br>Occasional | 3<br>Occasional | 4<br>Moderate / possible |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

**Figure 3-9 : Extreme Hot Days, Niagara Region, 1970 to 2009**
(source: Fenech and Shaw, 2010)




## Climate Projections

## Findings

Recent projections of heat waves for Ontario for the period 2071-2100 show dramatic increases in their frequency for both the A2 and B2 scenarios compared with the baseline experience. (OMOE, 2010)

A specific analysis of Heat Waves was completed using the WCRP CMIP3 database. The results of this analysis are summarized in Table 3-7.

The trend for heat waves in the near term (i.e., 2020) remains essentially unchanged from the present experience. However, the expectation of heat waves for the 2050 period trends upward.

**Probability Scoring**

The upward movement in minimum temperatures into the future 2020 time frame suggests the number of heat waves would increase. However, the assessment suggests the number of heat waves through the 2020 time frame remains essentially unchanged from historic frequency (namely, “Occasional” or “3”). However, the future 2050 time frame results increase the probability scoring for this climate parameter to “Moderate / possible” (or “4”).

#### 3.3.4.4 Cold Waves

**Definition**

For this study, and to better relate with the definition of a heat wave, a cold wave was considered to be three or more consecutive days with a minimum temperature of -20°C, or colder, and a maximum temperature of -10°C.

**Historical Climate**

Daily temperature data for Welland, obtained from Environment Canada’s Climate Data Online (Environment Canada, 2011b), was analysed for the occurrence of cold waves. Two cold waves were recorded in the 30-year period from 1971 to 2000 resulting in an average occurrence of 0.07 (2/30) cold waves a year (ref. Table 3-8). Each of the cold waves, recorded in 1971 and 1999, lasted the defining three days.

**Probability Scoring**

The findings for ‘number of cold waves’ outlined in Table 3-8 were compared with the established ranges in Table 3-4, resulting in a recommended probability score of “Remote” (or “2”).

**Trends**

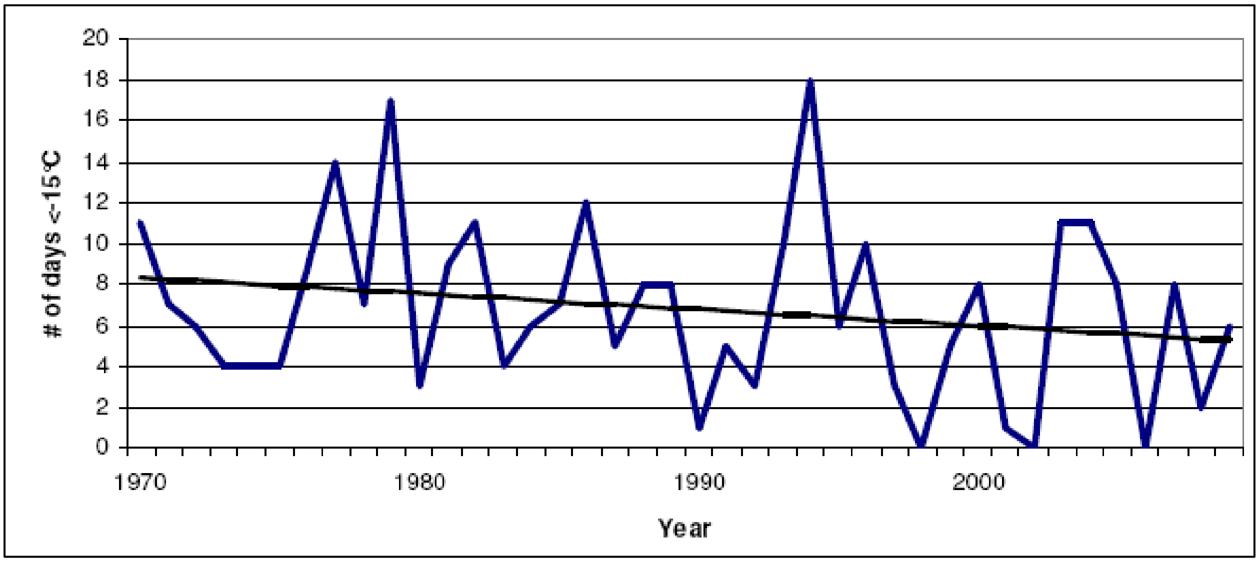
In a manner similar to their assessment of extreme hot days, Fenech and Shaw (2010) analysed numbers of extreme cold days per year for Niagara Region. The definition used for an extreme cold day was a day with a maximum temperature less than -15$^{o}$C and there is a clear downward trend in the annual number of extreme cold days as illustrated in Figure 3-10. This suggests that a trend to fewer extreme cold days per years also decreases the potential for cold waves (as defined for the Welland study) on an annual basis.

**Table 3-8 : Summary of Cold Waves**

| Description | Days/Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| Occurrences of three or more consecutive days with a maximum temperature of -10°C | 0.07 | 3.4 | 2.4 |
| Probability Scale | 2<br>Remote | 2<br>Remote | 2<br>Remote |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

**Figure 3-10 : Extreme Cold Days, Niagara Region, 1970 to 2009**
(source: Fenech and Shaw, 2010)



**Climate Projections**

**Findings**

A specific analysis of Cold Waves was completed using the WCRP CMIP3 database. The results of this analysis are summarized in Table 3-8. The analysis indicated a range of cold wave occurrences per year from 0 to a maximum of 9, averaging 3.4 in 2020 and 2.4 in 2050.

**Probability Scoring**

The analysis results are inconsistent with the historic time frame results. However, the downward trend in cold waves through the future time frames is consistent with anticipated rising temperatures. As such, the trend was used as a basis for maintaining the probability as "Remote" or "2".

### 3.3.4.5 Extreme Diurnal Temperature Variability

**Definition**

The difference between the maximum and minimum temperature in a day is the diurnal temperature variability. There is no accepted definition for an extreme diurnal temperature. The Toronto and Region Conservation Authority climate change vulnerability study of a number of flood control dams (TRCA, 2010) used a 25$^{o}$C range for extreme diurnal temperature. A review of the data climate data for Welland from 1971 through 2009 indicates an average diurnal temperature of 22.1$^{o}$C with a maximum diurnal temperature of 29.5$^{o}$C. As such, for this study a diurnal temperature variability of 25°C was considered to represent an extreme temperature variation.

**Historical Climate**

Occurrences of extreme diurnal temperature variability from 1971 to 2000 were analysed from daily temperature data obtained from Environment Canada's Data Online (Environment Canada 2011b). Two occurrences of diurnal temperatures exceeding 25°C were recorded over the period 1971 to 2000 resulting in an average occurrence of 0.07 (2/30) extreme diurnal temperature variations a year. The two occurrences were in 1971 and 1997.

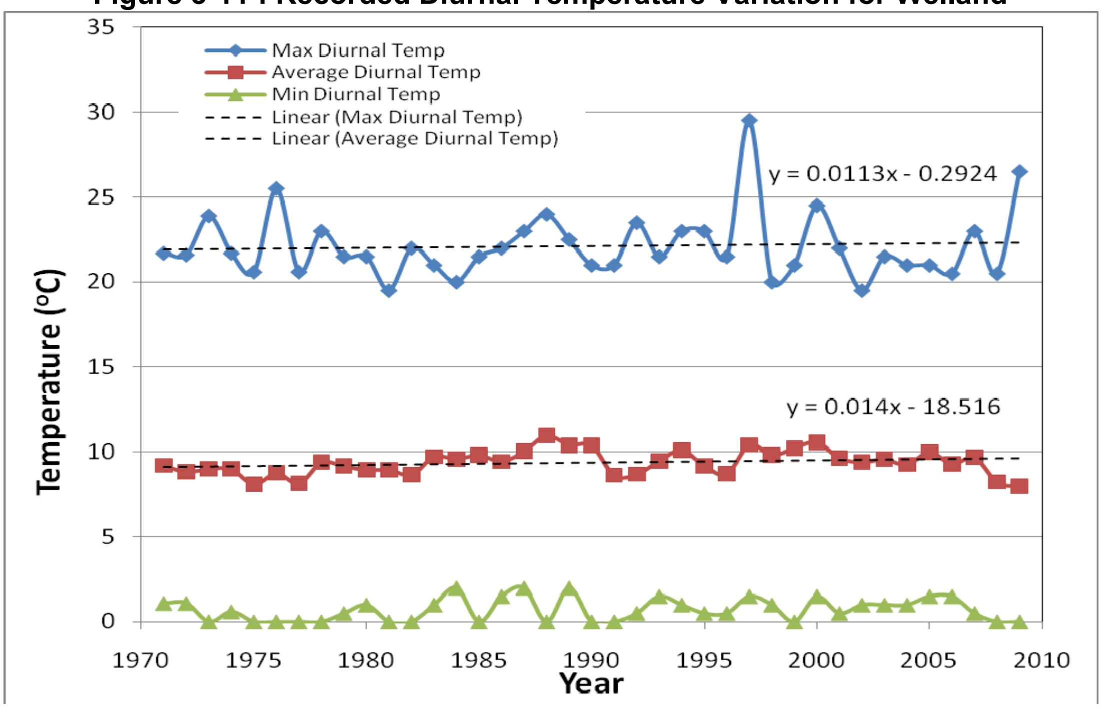
**Probability Scoring**

In consideration of the available information a probability score of "Remote" or "2" was assigned to this parameter.

## Trends

An analysis of the daily diurnal temperature data obtained from Environment Canada's Data Online (Environment Canada 2011b) is illustrated in Figure 3-11. Daily diurnal temperatures were averaged over the year to provide maximum, average and minimum daily diurnal temperatures for each year in the available data (1971 through 2009). A simple linear trend line suggests a very slight upward trend, however, this is interpreted as representing essentially no change in diurnal temperatures over the period of record.

**Figure 3-11 : Recorded Diurnal Temperature Variation for Welland**




## Climate Projections

## Findings

The IPCC global climate projections indicate a decrease in the diurnal temperature variation in most regions. In addition, IPCC recognized climate model outputs available on the CCCSN for the grid cell encompassing the study area project a mean maximum air temperature increase of 2.6°C and an annual mean minimum air temperature increase of about 2.7°C (CCCSN, 2009). It may be postulated from this that minimum air temperatures are likely to increase more than maximum air temperatures thus reducing diurnal variability. Further, information from the CCCSN indicates differences between average annual minimum and maximum temperatures are decreasing into the future.

It was also noted that the Welland area generally experiences relatively low diurnal temperature variability because of the moderating effects on temperature of the surrounding Great Lakes. It is suggested as well that global warming may not significantly affect the diurnal temperatures since diurnal temperature is driven by diurnal cycle of incoming solar radiation. (OMOE, 2010)

**Probability Scoring**

In consideration of the available information the future probability score was maintained as the historic time frame score of “Remote” or “2”.

#### 3.3.4.6 Freeze Thaw (freeze thaw cycles, changes in frost season)

**Definition**

The average number of days with a maximum daily temperature above 0°C and a minimum temperature below 0°C define a day of freeze thaw conditions.[8]

**Historical Climate**

Daily temperature data for Welland was obtained from Environment Canada’s Climate Data Online (Environment Canada, 2011b). Data was analysed from 1971 to 2000 for the occurrence of freeze thaw days based on the above definition. A total of 2266 days in this 30 year period had freeze thaw temperatures. The average number of days per year with freeze thaw conditions was 75 (2266/30) (ref. Table 3-9).

**Probability Scoring**

Given that freeze/thaw temperatures are expected annually, the frequency of occurrence in the context of this parameter was represented as “the expected average annual number of occurrences”. Hence, an average of 75 freeze/thaw cycles are anticipated annually and this number was therefore used as a gauge for assigning probability. A probability score of “Moderate / possible” or “4” was assigned.

**Trends**

Historically observed freeze-thaw cycle frequencies for Welland for the period 1970- 2006, based on observed temperatures, are illustrated in Figure 3-12. Analysis of the historical data indicates an upward trend in winter freeze-thaw cycles for Welland – a trend that is likely to continue with expected initial winter warming. The number of freeze-thaw cycles has averaged 76 days for the historical period, increasing to 77 days when averaged over the period from 1980-2007 and 80 days over period from 1990-2007. This is considered a short term phenomena as long term annual frequency of freeze thaw cycles is expected to decline with

[8] Source: http://cccsn.ca/?page=bioc-help

rising temperature. As illustrated in Figure 3-7 and Figure 3-8 there is a historic upward trend in winter temperatures. The relatively small increases experienced in recent history (ref. Figure 3-7) have propagated increases in the frequency of freeze thaw days with relatively mild Welland winter temperatures moving previously below zero temperatures to the freeze thaw range.

**Table 3-9 : Summary of Freeze/Thaw Days**

| Description | Days/Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| Number of days with a maximum daily temperature above 0°C and a minimum temperature below 0°C | 75 | 63 | 56 |
| Probability Scale | 4<br>Moderate / possible | 3<br>Occasional | 2<br>Remote |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

## Climate Projections

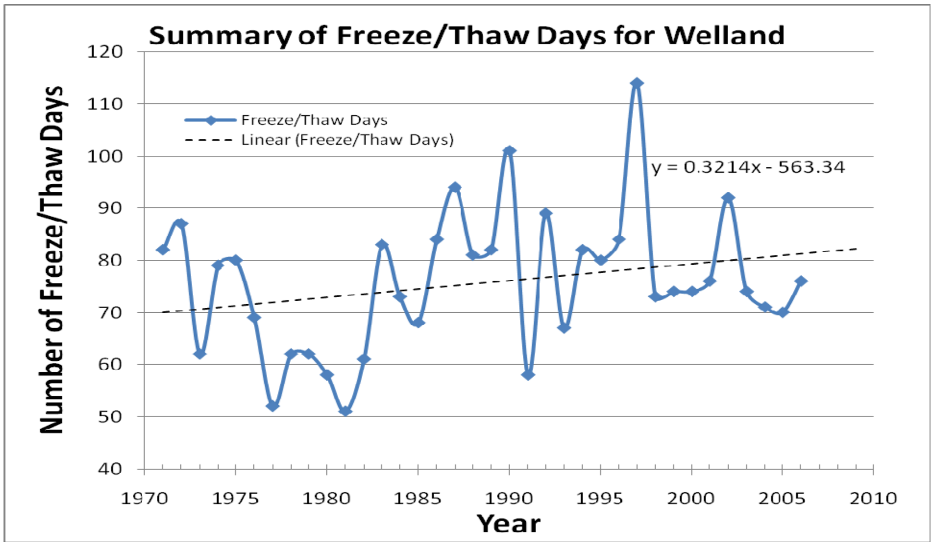
### Findings

A specific analysis of Freeze Thaw Days was completed using the WCRP CMIP3 database. The results of this analysis are summarized in Table 3-9. The analysis indicated a decreasing trend in number of freeze thaw days per year averaging 63 in 2020 and 56 in 2050.

### Probability Scoring

The probability score for the future was adjusted downward from the historic value of “4” to “3” and then “2” for the 2020 and 2050 time frames, respectively, in consideration of the decreasing average number of day as expected with freeze thaw conditions.

**Figure 3-12 : Summary of Recorded Freeze/Thaw Days for Welland**




### 3.3.4.7 Heavy Rain

**Definition**

Heavy rain warnings are issued by Environment Canada when more than 50 mm of rain is expected in a 12-hour period. However, for the purpose of this study, heavy rain conditions were considered when 50 mm of rain (or more) was recorded in one day, as this data was more accessible and is still considered to represent an extreme rainfall event. It should be noted that for the purposes of this assessment rain occurring in one day is consider analogous to 24 hour rainfall.

This definition of heavy rain represents (approximately) a 24 hour 2 year design rainfall event as defined from the Environment Canada 2000 IDF data for Port Colborne (gauge # 6136606). Similarly, 50mm of rain in a 12 hour period would represent approximately a design rainfall greater than 2 years and less than 5 years. The current IDF data used by Welland for design purposes (RVA, 1970) does not provide rainfall estimates for a 24 hour duration event.

**Historical Climate**

Daily precipitation data for Welland was obtained from Environment Canada Data Online (Environment Canada, 2011b) and analysed for the occurrence of heavy rain from 1971 to 2000. A total of 10 heavy rainfall events, as defined above, occurred in the 30-year period resulting in a frequency of occurrence of 0.33 (10/30) (ref. Table 3-10). A secondary assessment was also completed using the Environment Canada CDCD Extract program database and analysed for the occurrence of heavy rain over the period 1873 to 2005. A total of 49 heavy rainfall events were recorded for the 133-year period resulting in a frequency of occurrence of 0.37 (49/133), which approximates a 3-year return period event but which is not significantly different from the 1971 to 2000 period.

The maximum daily rainfall recorded for Welland was 141 mm on July 3rd, 1892 (TWN, 2011).

**Table 3-10: Number of Days with Heavy Rainfall**

| Description | Days per Year | | |
|---|---|---|---|
| | Historic[1] | 2020 | 2050 |
| Number of days with rainfall >= 50 mm | 0.33 | see Projected IDF | see Projected IDF |
| Probability Scale | 4 Moderate / possible | 5 Often | 5 Often |

Notes:
1. Source: Environment Canada, 2011b

**Probability Scoring**

Based on the findings above, 0.33 (days per year with rainfall greater than or equal to 50 mm over a 24 hour period) was compared to the established ranges in Table 3-4 resulting in a probability score of "Moderate / possible" or "4".

**Trends**

Zhang and Burn (2009) completed a trend analysis on extreme precipitation data for stations near London, Ontario for the periods of 1974 to 2003, 1969 to 2003 and 1964 to 2003. It was concluded that the 40 year period had no significant trends, the 35 year period had a few positive trends and the 30 year period showed a number of negative trends.

Hamilton and Whitelaw (1999) concluded the trend in precipitation along the Niagara Escarpment Biosphere Reserve show recent increases in total precipitation.

The Atmospheric Hazards – Ontario Region website offers the following trend information for Welland:

- The trend in the 'Number of Days with ≥ 95th Percentile Rainfall[9]' showed a non-significant decrease (Vincent and Mekis, 2006)
- The trend in the 'Single Day Intensity Index for Rain (ratio of annual total rainfall to number of days with rain)' showed a non-significant decrease (Vincent and Mekis, 2006)
- The trend in the 'Highest 1 Day Rainfall' showed a non-significant increase (Vincent and Mekis, 2001 and 2006)
- The trend in the 'Number of Days with Precipitation ≥ 20 mm' showed a non-significant increase (Vincent and Mekis, 2006)

[9] 95th Percentile Rainfall represents about 24mm (Atmospheric Hazards – Ontario Region website)

Fenech and Shaw reviewed annual average rainfall over the period 1970 to 2009 and concluded a 2% average increase over the period. However, when the data were viewed on a seasonal basis (ref. Figure 3-13) increases of 3%, 1% and 6% were identified for the periods DJF[10], MAM, JJA, respectively, and a decrease of 3% for the period SON. It is clear that annual average rainfall and heavy rainfall (as defined for this analysis) are not the same, however, the results of the Fenech and Shaw analyses suggest a possible trend towards larger rainfall events.

## Climate Projections

### Findings

The 'Localizer' reporting tool available at the Atmospheric Hazards – Ontario Region website is a quick way of determining the multi-model mean projected change of temperature and precipitation on a monthly, seasonal and annual timescales for locations across Canada. The Localizer uses the climatology of an observation station for the period of 1971-2000 as the baseline climate in all cases. The model projected changes for the period 1971-2000 and the future time periods (2020s, 2050s and 2080s) are then added to the observed baseline. This results in a projected future scenario which is 'bias-corrected' to the location.

Table 3-11 provides a summary of total precipitation based on a Localizer report for Welland which illustrates a general increase in total precipitation for each projected time period and across the reported SRES (Special Report on Emissions Scenarios) scenarios on an annual basis. A similar conclusion, with minor exceptions, applies to the seasonal precipitation totals as well.

IPCC recognized climate model outputs available on the CCCSN for the grid cell encompassing the study area, project increases in annual precipitation for the Welland area (CCCSN, 2009b) as summarized in Table 3-12. Increases in seasonal precipitation are also expected for the winter and spring, with significant increases further into the future. Projected increases for the 2050 time frame are very sensitive to the base ensemble but point to potential significant increases in total precipitation over the winter and spring and significant decreases in total precipitation over the summer months.

Again, it should be noted that annual average rainfall and heavy rainfall (as defined for this analysis) are not the same, nonetheless, the expectation of increased seasonal rainfall in the future suggests the potential for more extreme rainfall events.

[10] DJF – December/January/February;
MAM – March/April/May;
JJA – June/July/August;
SON – September/October/November

**Figure 3-13 : Precipitation Frequency by Season, Niagara Region, 1970 to 2009**
(source: Fenech and Shaw, 2010)

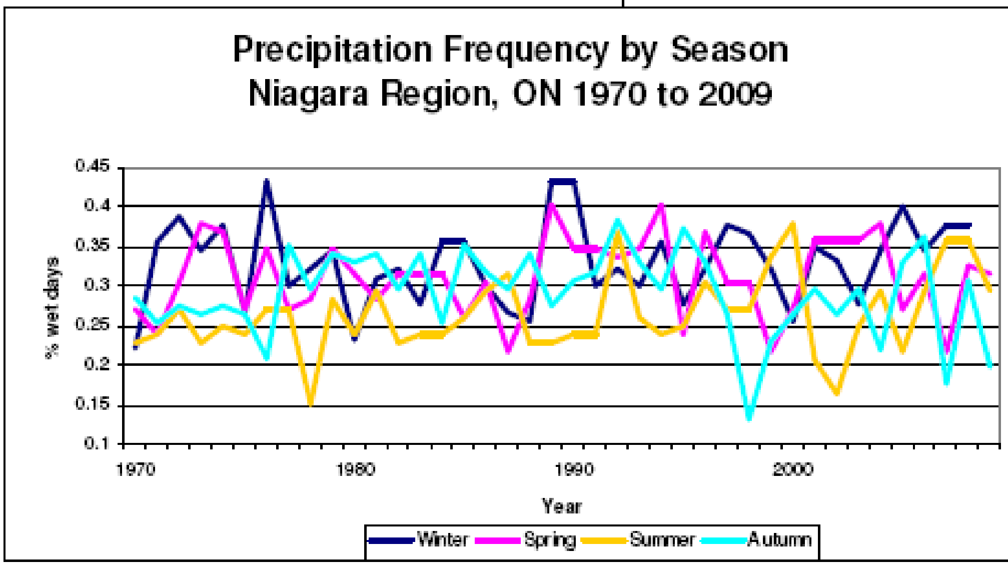



**Table 3-11 : Summary of Total Precipitation for Welland**
(source: Atmospheric Hazards – Ontario Region Website)

| Time Period/ SRES Scenario | Total Precipitation (mm) | | | | |
|---|---|---|---|---|---|
| | Annual | Winter | Spring | Summer | Autumn |
| 1971-2000 | 988.7 | 238.1 | 232.0 | 244.6 | 274.1 |
| SR-B1 (Low) | | | | | |
| 2020's | 1008.8 ± 32.0 | 252.0 ± 10.4 | 237.3 ± 12.0 | 246.4 ± 15.8 | 273.4 ± 17.1 |
| 2050's | 1028.7 ± 37.7 | 254.4 ± 12.3 | 247.4 ± 11.4 | 250.3 ± 19.5 | 275.9 ± 19.8 |
| 2080's | 1046.3 ± 39.9 | 262.8 ± 12.5 | 255.8 ± 16.8 | 246.0 ± 19.7 | 279.6 ± 18.9 |
| SR-A1B (Medium) | | | | | |
| 2020s | 1018.8 ± 31.6 | 254.5 ± 8.6 | 242.5 ± 11.1 | 243.7 ± 16.7 | 278.5 ± 17.6 |
| 2050s | 1035.3 ± 44.2 | 261.0 ± 12.1 | 249.9 ± 18.6 | 243.8 ± 23.0 | 281.6 ± 19.7 |
| 2080s | 1068.7 ± 56.6 | 271.7 ± 14.0 | 263.5 ± 22.3 | 246.0 ± 27.4 | 287.7 ± 26.1 |
| SR-A2 (High) | | | | | |
| 2020s | 1007.0 ± 32.1 | 247.8 ± 10.9 | 236.9 ± 13.1 | 247.0 ± 14.3 | 275.5 ± 17.5 |
| 2050s | 1039.4 ± 49.3 | 261.8 ± 14.7 | 249.1 ± 16.4 | 242.8 ± 24.3 | 287.8 ± 18.5 |
| 2080s | 1069.6 ± 87.3 | 278.2 ± 21.4 | 267.2 ± 30.7 | 238.3 ± 38.5 | 287.0 ± 29.6 |

A component deliverable of this project was the development of IDF data for the two future time frames, namely 2020 and 2050. The analysis towards quantification of the future IDF data is presented in Appendix C.  Table 3-13 presents summary IDF information for the range of data available for this project. By comparison to the current (i.e., 2000) IDF data for Port Colborne projected rainfall is expected to increase. This is a consistent conclusion across of the return periods and durations.

**Table 3-12 : Projected Changes in Precipitation**
(source: Atmospheric Hazards – Ontario Region Website)

| Time Period | Change in Total Precipitation (%) | | | | |
|---|---|---|---|---|---|
| | **Annual** | **Winter** | **Spring** | **Summer** | **Autumn** |
| National AR4-A1B Ensemble Seasonal and Annual Precipitation Change (1971-2000 base line) | | | | | |
| 2020's | 3.1 | 6.9 | 4.3 | -0.3 | 1.7 |
| 2050's | 4.7 | 9.7 | 7.5 | -0.3 | 2.8 |
| 2080's | 8.1 | 14.4 | 13.5 | 0.7 | 4.8 |
| 2050s Ensemble Seasonal and Annual Precipitation Change (1961-1990 base line) | | | | | |
| Low | 0 to 5 | 5 to 10 | 5 to 10 | 0 to 5 | 0 to 5 |
| Medium | 0 to 5 | 5 to 10 | 5 to 10 | 0 to 5 | 0 to 5 |
| High | 0 to 5 | 10 to 15 | 5 to 10 | -5 to 0 | 0 to 5 |
| CRCM High | 5 to 10 | 20 to 30 | 20 to 25 | -25 to -20 | -5 to 0 |
| Notes:<br>1. CRCM – Canadian Regional Climate Model | | | | | |

As noted previously, heavy rain as defined for the purposes of this assessment represents (approximately) a 24 hour 2 year design rainfall event using the current IDF data for Port Colborne. A comparison with the 2020 and 2050 IDF data suggests a minor increase in the expected frequency of this type of event (i.e., 50mm of rain in 24 hours). This increase is more substantive when the heavy rain definition is compared with the 90$^{th}$ percentile and Maximum projected IDF relationships.

The information regarding future rainfall suggests a general increase in total rainfall the potential for individual rain events to yield larger total volumes of rain. Further, the IDF data indicates a general increase in extreme rainfall events.

**Table 3-13 : 24-hour Total Precipitation from IDF Data for Port Colborne**

| Vintage | 24 Hour Total Rainfall (mm) by Return Period (yrs) | | | | | |
|---|---|---|---|---|---|---|
| | **2** | **5** | **10** | **25** | **50** | **100** |
| 1963 | n/a | n/a | n/a | n/a | n/a | n/a |
| 2000 | 48.1 | 66.3 | 78.3 | 93.5 | 104.8 | 116.0 |
| Projected Mean | | | | | | |
| 2020 | 51.7 | 71.7 | 84.1 | 98.5 | 110.6 | 120.1 |
| 2050 | 53.4 | 73.5 | 85.9 | 100.4 | 112.5 | 122.0 |
| Projected 90$^{th}$ Percentile | | | | | | |
| 2020 | 56.6 | 77.0 | 89.3 | 103.5 | 115.7 | 125.2 |
| 2050 | 59.7 | 80.4 | 93.1 | 107.6 | 119.9 | 129.4 |
| Projected Maximum | | | | | | |
| 2020 | 66.2 | 87.4 | 100.3 | 115.0 | 127.4 | 136.9 |
| 2050 | 68.1 | 89.6 | 102.5 | 117.2 | 129.6 | 139.1 |
| Notes:<br>1. The current (i.e., 1963 vintage) IDF data for Welland has durations to 10 hours only. | | | | | | |

**Probability Scoring**

Given the available information, the probability score for the future heavy rainfall was adjusted upward to a value of “5” or “Often”.

### 3.3.4.8 Heavy 5-Day Total Rainfall

**Definition**

Heavy 5-day rainfall was defined as a total rainfall exceeding 100 mm in a five day period. The period of rainfall was chosen to be consistent with other rainfall research (as referenced below) and to be reflective of a prolonged rain period. The volume of rainfall was chosen subjectively to represent a substantial amount of rainfall in a relatively short period of time.

**Historical Climate**

Daily rainfall data was obtained for Welland from Environment Canada’s Data Online (Environment Canada, 2011b). The data was analysed for 5-day periods with greater than 100 mm total rainfall. The number of heavy 5-day rainfall occurrences was considered in the 30-year period extending from 1971 to 2000. A total of 14 heavy 5-day rainfall events based on the above definition occurred in this 30-year period, or an average of 0.47 occurrences per year.

**Probability Scoring**

Based on the findings above a probability score of “Moderate / possible” or “4” was assigned.

**Trends**

An analysis of Ontario rainfall data for the period 1950-2003 was completed focusing on identifying trends for highest 5-day rainfall (Klaassen and Comer, 2005). It was concluded that the highest 5-day rainfall does not show any consistent pattern of changes over the period 1950-2003. Further, the majority of stations (~95%) do not show significant trends for the 54 year period either.

**Climate Projections**

**Findings**

Vincent and Mekis (2004) showed a significant decrease in the intensity of rain (ratio between annual total rainfall and the number of days with rain) in southern Canada from 1950 to 2001, however concluded that there were no consistent changes in the highest 5 day maximum rainfall. A subsequent study by Vincent and Mekis (2006) supported this finding and showed that the number of days with rain increased from 1950 to 2003 throughout southern Canada. They also found a decrease in the intensity of rain.

Information regarding rainfall which has been presented thus far suggests more rain over the year and more days with rain annually. From this information an upward trend for 5-day rainfall into the future can be postulated.

**Probability Scoring**

Based on the findings above a probability score of “Often” or “5” was assigned.

#### 3.3.4.9 Winter Rain

**Definition**

Winter rainfall is defined as the number of days with total rainfall greater than 25 mm during the months of January, February and March in a given year. Environment Canada issues a winter rainfall warning when 25 mm or more of rainfall is anticipated within a 24-hour period when the ground is frozen or snow covered. It was assumed for the purposes of this study that frozen or snow covered ground would most likely occur in January, February or March. Rainfall on frozen ground has the potential to result in significantly greater runoff conditions than during other seasons and has therefore been considered separately for this assessment.

**Historical Climate**

Daily precipitation data from 1971 to 2000 was obtained from Environment Canada’s Data Online (Environment Canada, 2011b) was analysed for the occurrence of winter rain. It was determined that a total of 9 winter rain events, as defined above, occurred in this 30-year period, or an average of 0.30 per year.

**Probability Scoring**

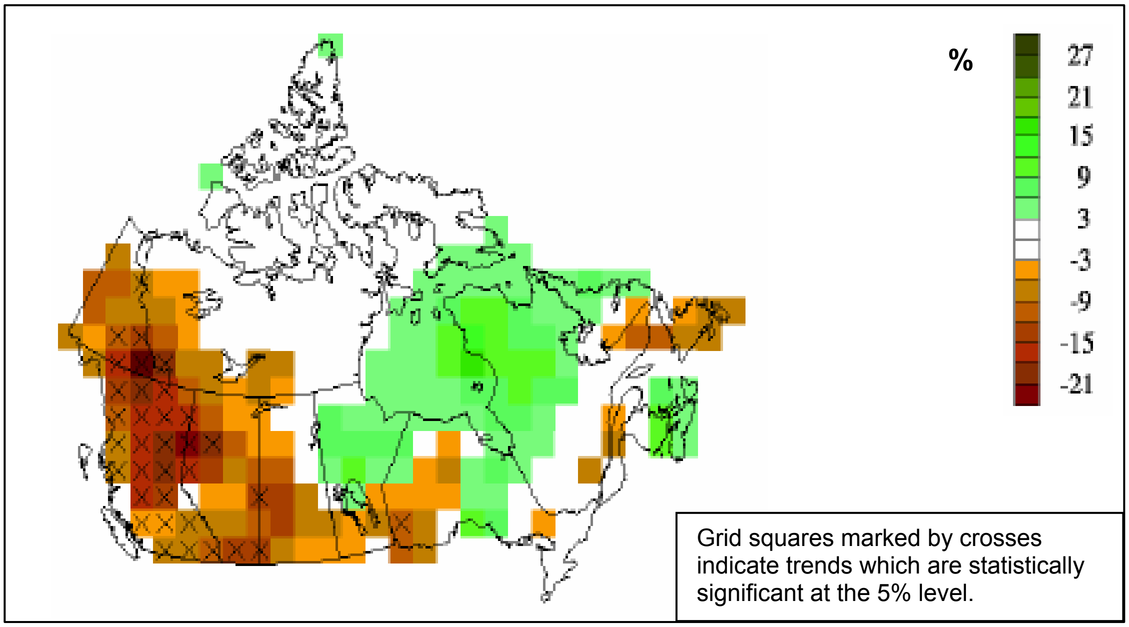
Based on the findings above a probability score of “Moderate / possible” or “4” was assigned.

**Trends**

The climate has been becoming gradually wetter and warmer in southern Canada throughout the entire past century, and in all of Canada during the latter half of the century (Zhang et al., 2000).

Annual total precipitation has increased by an average of 12% in southern Canada over the past century generally associated with more rain during the spring, summer and autumn. However, the ratio of snowfall to total precipitation has been decreasing in the winter and spring in distinct areas of the country (ref. Figure 3-14). As illustrated in Figure 3-14 there was no discernable trend identified in the change from spring snow to rain for the Welland area for the period 1950-1999. (Barrow et al., 2004)

**Figure 3-14 : Trends in Spring Snow to Total Precipitation Ratio (1950-1999)**
(source: Barrow et al., 2004; Figure 2.6)




Hamilton and Whitelaw (1999) identified long-term precipitation trends along the Niagara Escarpment based on a review data from stations at Owen Sound, Toronto and Welland. They found the highest increases in the fall season for all stations (12 to 31%), Owen Sound MOE showed marked increases in winter and spring, while Welland had an increasing trend in summer. For annual rainfall, Owen Sound MOE and Welland had significant increases of 27% and 23% while Toronto showed an insignificant increase of 9%. At Welland, increases in fall, winter, and summer rainfall were 30%, 24%, and 20%, respectively. Snowfall trends for Welland were downward showing a decline of 20% over the study period.

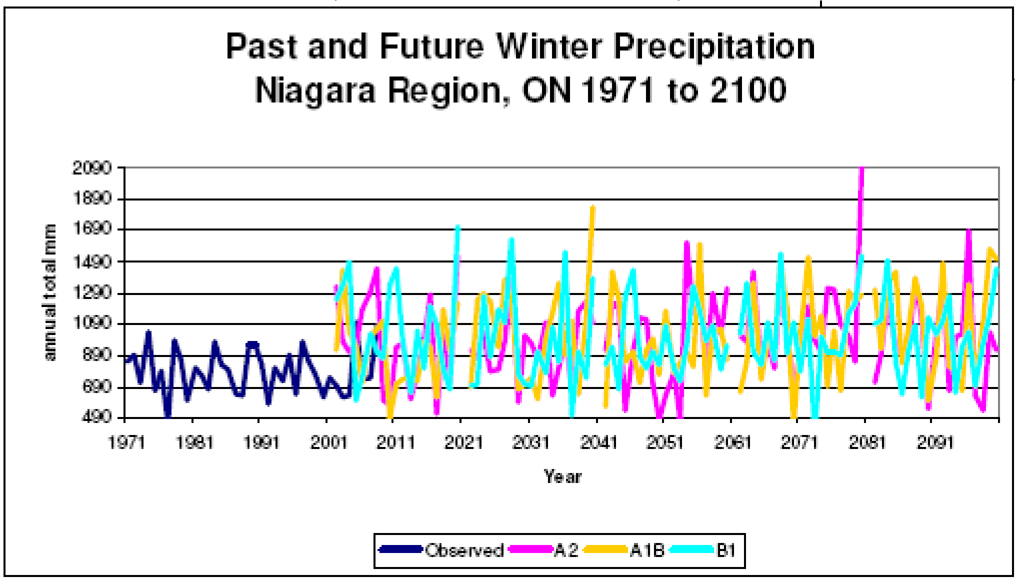
## Climate Projections

### Findings

Fenech and Shaw (2010) in a review of climate change issues in the Niagara Region documented increases projected Winter Precipitation through to 2100. As illustrated in Figure 3-15, the A2, A1B and B1 SRES scenarios all project an upward trend in winter precipitation. Similar increases are documented in Table 3-12. Although it is understood that winter precipitation and winter rainfall are not completely the same, increased winter precipitation under a warming climate suggests the potential for increased winter rain.

Increased winter precipitation coupled with the projected upward trend in temperature suggests a change from winter/spring snow to winter/spring rain which would be consistent with the recent trend established by Hamilton and Whitelaw (1999).

**Figure 3-15 : Past and Future Winter Precipitation for the Niagara Region**
(source Fenech and Shaw, 2010)




## Probability Scoring

Based on the findings above a probability score of "Often" or "5" was assigned.

### 3.3.4.10 Freezing Rain

## Definition

Freezing rain is rain that falls as liquid but then freezes on contact with the ground and other exposed objects to form a coating of ice on these surfaces (Environment Canada, 2011a). Freezing rain days for this study have been identified as a day with freezing precipitation if there is an occurrence of 0.2 mm or more of rain or drizzle which turns to ice on contact with the underlying surface which is consistent with the definition used by Environment Canada.

## Historical Climate

Data for the 'days with freezing precipitation (freezing rain and freezing drizzle)' was obtained from Environment Canada's National Climate Data Archive for the period 1971-2000. Environment Canada's Ontario Hazards website provides freezing precipitation data for major recording centers with 24 hour recording capability (Icestorm-Dayswithfrzprecip-e.xls). Hourly data is not recorded for Welland, therefore freezing precipitation data was downloaded for the closest recorded locations, namely; Toronto Lester B. Pearson International Airport and London International Airport located approximately 100 km north and 200 km west km of Welland. The database reports 8.8 days per year with freezing precipitation at Toronto Lester B. Pearson International Airport and 11.8 days per year at London International Airport. The average number of hours during the winter season with freezing rain was 17.1 at Toronto Lester B. Pearson International Airport and 23.7 hours at the London International Airport.

**Probability Scoring**

Based on the findings above a probability score of “Moderate / possible” or “4” was assigned.

**Trends**

In 2003, the Meteorological Service of Canada, Atmospheric Sciences Division-Ontario Region, completed a severe ice storm risks study for south-central Canada (Klaassen et al., 2003). One of the objectives of the research was to determine whether or not there was an increase or decrease in the total number of seasonal freezing rain hours and days observed at a number of sites in Ontario and Quebec station over the period November to April 1953/54-2000/01. The closest stations to Welland used in the study were Toronto Lester B. Pearson International Airport and London International Airport. The results of the trend analysis suggests that the risks of freezing rain occurrence have remained relatively the same or have been slightly decreasing in north-western Ontario, southern Ontario and central Ontario during the period 1953-2001.

**Climate Projections**

**Findings**

Cheng et al. (2007, 2011) analysed the possible impacts of climate change on freezing rain in south-central Canada using downscaled future climate scenarios. It was concluded that in the coldest months, eastern Canada could potentially receive more freezing rain events in the future than was experienced during the period 1958–2007. The increase in the number of daily freezing rain events could be progressively greater from south to north or from southwest to northeast across eastern Canada. The southern Ontario region (Region 3), in which Welland is located, showed the potential increase for severe freezing rain events (≥6 h per day) to be about 46% and 49% over the historic period for 2050 and 2080, respectively.

**Probability Scoring**

Based on the findings above a probability score of “Often” or “5” was assigned.

### 3.3.4.11 Ice Storm

**Definition**

An ice storm for this study is defined as a storm with freezing rain that leaves everything glazed in a coating of ice. For this study, an ice storm occurrence is defined when the daily freezing rain amounts to 25 mm or more. This definition is consistent with that used for the ‘Estimation of

Severe Ice Storm Risks for South-Central Canada' (Klaassen et al, 2003). Their rationale was based on the current CSA standard for transmission lines (but not necessarily local distribution lines) which recommends that structures be designed for 25–30 mm of radial ice accumulation or build-up on power lines in southern Ontario.

**Historical Climate**

Based on the definition above, Tables 7 and 8 from the Klaassen et al. (2003) study were used to understand the occurrences of major freezing rain events affecting Welland and area. Nine (9) regional storms were identified as possibly affecting the Welland area for the period 1844 to 2002 (159 years) or a frequency of 0.06 storms per year.

**Probability Scoring**

Based on the findings above a probability score of "Remote" or "2" was assigned.

**Trends**

Klaassen et al. (2003) suggested that the Great Lakes may influence a decreasing trend in frequency of freezing rain on the western and southern shores of Lake Ontario and northern shore of Lake Erie during the fall, early winter and early spring. It was also suggested that freezing rain storms may decelerate as they cross the Great Lakes, which could prolong the duration of freezing rain in the central and eastern Great Lakes region. Overall, the results suggested that the risks of average freezing rain occurrence are generally unchanged or have been decreasing in north-western Ontario, southern Ontario or central Ontario over the period 1953-2001.

Although, the information above does not speak specifically trends using the definition of ice storm used for this study it is surmised that the conclusion of unchanging historic freezing rain occurrence in the study area can be extended to occurrence of ice storms.

**Climate Projections**

**Findings**

As documented in Section 3.3.4.10 Freezing Rain, Cheng et al (2007) concluded generally that the increase in the number of daily freezing rain events could be progressively greater from south to north or from southwest to northeast across eastern Canada and specifically, that Region 3, in which Welland is located, showed the potential increase for severe freezing rain events (≥6 hr per day) to be about 46% and 49% over the period 1958–2007 for 2050 and 2080, respectively. It was further concluded, the magnitude of percentage increases in future freezing rain events for the three colder months is generally greater for longer duration events than for shorter duration events suggesting the potential of greater ice accumulation during events.

**Probability Scoring**

Based on the findings above a probability score of "Occasional" or "3" was assigned.

### 3.3.4.12 Heavy Snow

**Definition**

Environment Canada issues snowfall warnings in Ontario when 15 cm or more of snow falls within 12 hours or less[11]. However, historic climate data, snowfall included, is only readily available in daily time steps. As such and for the purposes of this study, heavy snowfall has been defined as any day with a total amount of snowfall greater than or equal to 25 cm.

**Historical Climate**

Daily snowfall data for the period 1971 to 2000 was obtained from Environment Canada's Data Online (Environment Canada, 2011b) and analysed for snowfall events in excess of 10 cm and 25 cm per day. During this 30-year period, there were 128 days with snowfall accumulations of 10 cm or greater above or an average of 4.3 days per year (ref. Table 3-14). Similarly, there were 31 total days or 1.0 day per year with heavy snowfall, as defined above. The highest recorded daily snowfall in Welland was 81.3 cm which occurred on March 1, 1900 (TWN, 2011).

**Probability Scoring**

Based on the findings above a probability score of "Certain / Highly Probable" or "7" was assigned.

**Table 3-14 : Summary of Heavy Snowfall Days**

| Description | Days per Year | | |
|---|---|---|---|
| | Historic[1] | 2020 | 2050 |
| Number of days with snowfall >= 10 cm | 4.3 | n/a | n/a |
| Number of days with snowfall >= 25 cm | 1.0 | n/a | n/a |
| Probability Scale | 7<br>Certain / Highly Probable | 6<br>Probable | 5<br>Often |

Notes:
1. Source: Environment Canada, 2011b

[11] http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=D9553AB5-1#snowfall

**Trends**

Snowfall trends are generally downward for the past 50 years with higher spring temperatures leading to a change from precipitation as snow to rain in some parts of southern Canada (CCME, 2003).

Further, as documented in Section 3.3.4.9 Winter Rain, snowfall trends for Welland were downward showing a decline of 20% (Hamilton and Whitelaw, 1999).

**Climate Projections**

**Findings**

As discussed in Section 3.3.4.2 Low Temperature, the upward trend in minimum temperatures suggests that conditions may be too warm for precipitation to fall as snow (CCME, 2003). Further, the summer "shoulder" seasons are expected to expand into the traditional colder months of the year with a resulting shorter snow season (AMEC, 2006).

**Probability Scoring**

Based on the findings above a probability score of "Probable" or "6" was assigned for the 2020's time frame and "Often" or "5" for the 2050's time frame.

#### 3.3.4.13 Snow Accumulation

**Definition**

Snow accumulation was defined subjectively, for the purposes of this study, as the number days per year when a snow depth of 25 cm or more is on the ground. The value of 25 cm was chosen subjectively.

**Historical Climate**

An assessment of historic snow accumulation for Welland was completed using data from the Environment Canada CDCD Extract program database for the period 1983 to 2006 (the available data record). An examination of the data indicated an occurrence of 16 days (or 0.67 days per year) with snow greater than or equal to 20 cm and 4 days (or 0.17 days per year) with 25 cm of more of snow on the ground. No days with snow depth of 30cm or more were recorded for the available data period.

**Probability Scoring**

Based on the findings above a probability score of "Occasional" or "3" was assigned.

**Trends**

A study of Canadian regional snow cover trends for various regions of Canada was completed by the Canadian Cryospheric Information Network for the period 1955/56 to 2002/03 (CCIN, 2011). The regional snow cover series for the study were generated from in situ daily snow depth observations at stations with at least 38 years data in the period since 1955. Table 3-15 provides a summary of snow depth data for Southern Ontario and Quebec documenting a shorter snow season and a decreasing trend in snow depth.

**Climate Projections**

**Findings**

Projections of warmer temperatures are consistent with observed historic trends in the Toronto region, where the frost-free period has lengthened and total annual snowfall has decreased. Snow cover, depth and duration have also been reduced (TRCA, 2011). Projected increasing cold season temperatures may suggest the historic decreasing snow depth trend will continue.

**Table 3-15 : Summary of Snow DepthTrends in Ontario**

(source: CCIN, 2011)

| # of Stations | Start Date of Continuous Snow[1] | End Date of Continuous Snow[2] | Snow Cover Days[3] | |
|---|---|---|---|---|
| | | | Aug-Jan | Feb-Jul |
| 17 | 0.18 day/yr | -0.06 day/yr | -0.13 day/yr | -0.18 day/yr |

| Total SCD[4] | Max Snow Depth[5] | Date of Max Snow Depth[6] | Mean Snow Depth[7] |
|---|---|---|---|
| -0.31 day/yr | -0.12 cm/yr | -0.23 day/yr | -1.26 cm/yr |

**Notes:**

(1) Date when there were 14 consecutive days with daily snow depth greater-than-or-equal to 4 cm
(2) Date when there were 14 consecutive days with daily snow depth less than 4 cm
(3) Number of days with a daily snow depth greater-than-or-equal to 2 cm
(4) Number of days in the snow cover year with daily snow depth greater-than-or-equal to 2 cm
(5) Maximum daily snow depth during period of continuous snow cover
(6) Date corresponding to maximum reported daily snow depth for snow season
(7) Mean daily snow depth during period of continuous snow cover

**Probability Scoring**

Based on the findings above a probability score of “Remote” or “2” was assigned.

### 3.3.4.14 Blowing Snow/Blizzard

**Definition**

Blowing snow is defined as particles of snow raised by the wind to sufficient heights above the ground to reduce the horizontal visibility at eye level to less than approximately 10 km.

A blizzard is defined by a minimum of four hours of reduced to 1 km or less, winds of 50 km/h or more and wind chill values of -25°C or less (Websters, 2011).

**Historical Climate**

Data downloaded from the Atmospheric Hazards Website – Ontario website reported for St. Catharines, the closest recorded point to Welland, reported 3.8 days per year (average) with blowing snow for the period 1971-2000. For consistency with other stations with 24-hour reporting capabilities, Toronto Lester B. Pearson International Airport reported an average of 7.8 days per year with blowing snow and the City of London an average of 14.9 days per year with blowing snow.

**Probability Scoring**

Based on the findings above a probability score of “Moderate / Probable” or “4” was assigned.

**Trends**

No literature sources specific to trends regarding blowing snow or blizzards were identified for review. However, previous discussions in this report support a downward trend in snowfall, shortening of the snow season and increasing winter temperatures. These combined effects suggest the potential for a decreasing occurrence of blowing snow and blizzards.

**Climate Projections**

**Findings**

No studies specifically focused on projection of future occurrence of blowing snow or blizzards were identified. Discussions regarding other aspects of future snow conditions are presented elsewhere in this report but these provide no context to suggest changes in future blowing snow or blizzards conditions.

**Probability Scoring**

Based on the lack of information regarding climate projections for blowing snow and/or blizzards an unchanged probability score of “Moderate / Probable” or “4” was assigned.

#### 3.3.4.15 Lightning

**Definition**

Lightning is a flash of light that accompanies an abrupt electric discharge from cloud to cloud or from cloud to earth accompanied by the emission of light (Environment Canada, 2011c).

For this study, two measures of lightning occurrence in southern Ontario and adjacent geographic areas, as detected by the integrated North American Lightning Detection Network (NALDN) (Environment Canada, 2011d), have been reported, namely:

- average number of days per year with occurrence of cloud-to-ground lightning
- average number of cloud-to-ground lightning flashes per square kilometre per year

**Historical Climate**

Data retrieved from the Atmospheric Hazards Website – Ontario indicates that for Welland there are about 28 days per year with lightning at an average of 1.5 flashes per square kilometre. The website also provides information which indicates, on average, about 30 days per year with thunderstorms (based on data from 1971-2000).

**Probability Scoring**

Based on the findings above a probability score of “Moderate / Probable” or “4” was assigned.

**Trends**

No trend information regarding lightning was found.

**Climate Projections**

**Findings**

A survey of community water system managers conducted in South Carolina and the Susquehanna River Basin in 2000 revealed that over 50 percent had experienced lightning events over the past 5 years (Mills et al, 2009). This same study found that over 40% of system managers in South Carolina and over 20% of those in the Susquehanna River Basin expected to be impacted with considerable or catastrophic problems related to lightning during the next 10 years.

Observational evidence shows a connection between lightning activity around the world and variations in global surface temperature (Pereira et al., 2010; Price, 2008). Some experiments have computed a 6% increase in lightning activity for every 1°C rise in the earth’s average temperature (Francis and Hengeveld, 1998).

Increasing temperatures for the Welland area have already been discussed and linked with the information may suggest a potential for lightning occurrence to increase as well.

**Probability Scoring**

Notwithstanding, the information above is not sufficiently substantive to suggest a change of the probability score from the historic period of “Moderate / Probable” or “4”.

### 3.3.4.16 Hail Storm

**Definition**

Hail is a form of solid precipitation which consists of balls or irregular lumps of ice with a diameter greater than 5 mm.[12] Hail is generally observed during thunderstorms. For the purposes of this study, this parameter was evaluated as the average number of days per year when hail can be expected.

**Historical Climate**

Data obtained from Environment Canada's Ontario Hazards website (Environment Canada, Hail Dayswithhail.xls) reported average annual number of days with hail for the period 1971-2000 for principal weather observation stations having at least 20 years of record (airport locations) were analysed. Principal weather observation stations nearest to Welland are Toronto Lester B. Pearson International Airport and London International Airport which reported average number of days with hail per year as 1.1 days and 1.5 days, respectively, for the period of record for the months of May through September.

**Probability Scoring**

Based on the information above a probability score of "Moderate / Probable" or "4" was assigned.

**Trends**

No trend information was found for hail storms.

**Climate Projections**

**Findings**

A statistical analysis of hail storms in France defined a close correlation between average summer nighttime temperatures and hail activity (Francis and Hengeveld, 1998). This report also details a link between night time temperatures and hailstorms focused on minimum night time temperature and the following day afternoon dewpoint temperature whereby night time temperatures are influenced by the amount of water vapour in the air, and for that reason they are a good predictor of the following afternoon's dewpoint temperature. The dewpoint is the temperature at which the air is saturated with water vapour and the afternoon dewpoint is a useful predictor of unsettled weather, since it indicates how much water vapour is available to fuel a developing storm. It stands to reason, therefore, that a rise in summer minimum temperatures may therefore be an indicator that the atmosphere is more prone to thunderstorm, and hence hail, activity.

[12] http://ontario.hazards.ca/maps/background/Hail-e.html

**Probability Scoring**

A probability score of "Moderate / Probable" or "4" was maintained given the lack of information to define or suggest a trend for hail into the future specific to the Welland area.

### 3.3.4.17 Hurricane/Tropical Storm

**Definition**

Hurricanes are cyclones of tropical origin with wind speeds of at least 119 kilometres per hour or 74 miles per hour[13]. Hurricanes historically are downgraded to tropical storms by the time they reach Ontario, as the storms rapidly weaken as they move inland due to frictional drag. However, heavy rains may continue to fall over inland regions.

**Historical Climate**

Historically, southern Ontario has experienced heavy rains and thunderstorms associated with the remnants of a hurricane or tropical cyclone. Within a 48 hour period, in October 1954, more than 285 mm of rain fell in the Toronto area as a result of the remnants of Hurricane Hazel (Environment Canada, 2010).. This event caused the worst flooding documented in 200 years. The occurrence of a Hurricane Hazel magnitude event was calculated to have a 1 in 200 year or 0.005 recurrence interval.

In September of 2004, the remnants of Hurricane Frances passed through the extreme south-eastern Lake Ontario region. The storm centre did not enter Ontario; however, regions in the area experienced heavy rain, with the heaviest rain reported in Kingston (Environment Canada, 2011a). The Environment Canada weather station at Welland recorded 101 mm of rain over September 8th and 9th.

More recently, on August 30th 2005 heavy rain and tropical storm force wind gusts were reported in southern Ontario as Hurricane Katrina passed over the region. The Environment Canada weather stations at Port Colborne and Welland recorded 102 mm and 93.4 mm of rain, respectively, on this day.

**Probability Scoring**

Based on the information above a probability score of "Improbable / highly unlikely" or "1" was assigned.

**Trends**

Hurricane records for the tropical Atlantic have been reasonably good since 1970, however, and these data show a declining trend in annual hurricane frequency, although both 1995 and 1996

[13] http://www.aoml.noaa.gov/general/lib/defining.html

saw a larger than average number of storms (Francis and Hengeveld, 1998). Conversely, USGCRP (2008) indicates that there is observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures, however, there is no clear trend in the annual numbers of tropical cyclones.

It is noted that no studies were identified that provide information regarding trends in storm tracks across Welland and area.

**Climate Projections**

**Findings**

CCSP (2008) concludes that it is likely that hurricane wind speeds and core rainfall rates will increase in response to human-caused warming. Analyses of model simulations suggest that for each 1°C increase in tropical sea surface temperatures, hurricane surface wind speeds will increase by 1 to 8% and core rainfall rates by 6 to 18%. The report further states that frequency changes are currently too uncertain for confident projections and that the spatial distribution of hurricanes will likely change.

No specific information was identified detailing projected hurricane influences for Welland and area.

**Probability Scoring**

Based on the information above a probability score of “Remote” or “2” was assigned.

#### 3.3.4.18 High Wind

**Definition**

Wind warnings are issued in Ontario by Environment Canada when sustained winds of 70 km/h or more and/or gusts to 90 km/h or more are anticipated.[14] However, wind data readily available from the Ontario Hazards Website (http://ontario.hazards.ca) summarizes days with sustained winds greater than 63 km/h. As such, high wind, for the purposes of this study, has been defined as average days per year with sustained winds greater than 63 km/hour.

**Historical Climate**

Daily data downloaded from Environment Canada’s Data Online (Environment Canada, 2011b) website did not consistently report daily wind speeds for Welland. In the absence of available wind speed data for Welland and for consistency with other parameters, the average number of

[14] http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=D9553AB5-1#wind

days per year with wind speeds greater than 63 km/h is provided for Toronto Lester B. Pearson International Airport and the London International Airport. The average number of days per year with mean wind speeds greater than 63 km/hour for the period 1971 – 2000 was downloaded ('WINDSTORM-daysgreater63kmh.xls') from the Environment Canada website and analysed for occurrence of high wind based on the definition above. The database recorded the average number of days with high wind speeds at Toronto Lester B. Pearson International Airport as 7.2 days per year and, similarly, 2.8 days for the London International Airport.

**Probability Scoring**

Based on the information above a probability score of “Moderate/possible” or “4” was assigned.

**Trends**

No trend information for high wind was identified.

**Climate Projections**

**Findings**

No projection information for high wind was identified.

**Probability Scoring**

Based on the lack of information regarding projected conditions for high wind a probability score of “Moderate/possible” or “4” was maintained.

#### 3.3.4.19 Tornado

**Definition**

A tornado is defined as a small but extremely violent storm, characterized by the distinctive funnel clouds that descend to the ground from the base of a thundercloud.[15] Historically, reported tornadoes in southern Ontario that have caused the most damage have occurred in a section referred to as “Tornado Alley” which extends from the Michigan border through southern Ontario to Lake Simcoe.[16]

**Historical Climate**

A database of confirmed and probable tornadoes for the period 1918 to 2003 for the Province of Ontario was downloaded from the Environment Canada website (Tornado-locationandstrength2003-e.xl). The data were analysed for recorded incidents within 10 km of

[15] http://www.nssl.noaa.gov/edu/safety/tornadoguide.html
[16] http://ontario.hazards.ca/maps/background/Tornado-e.html

the city limits and within the city limits. Two tornadoes have occurred within the city limits during the period from 1918 to 2003, and four have occurred within 10 km of the city limits. This translates to 0.09 (6 tornadoes per 86 years) tornadoes per year. A list of tornadoes passing through this area, their strength and date of occurrence are listed in Table 3-16.

The Fujita scale is used to rate the severity of tornadoes as a measure of the damage they cause. For the tornadoes recorded in this study area, the reported Fujita scale levels were:

- F0 indicating light winds (64 to 116 km/hr) and some damage;
- F1 indicating moderate winds (117 to 180 km/hr), capable of overturning automobiles; and,
- F2 representing considerable winds (181 to 252 km/hr)

**Table 3-16: Tornado Occurrences in the Welland Area for the Period 1918 – 2003**

| Latitude | Longitude | Fujita-Scale | Date |
|---|---|---|---|
| Within the city limits of Welland | | | |
| 42.97 | -79.24 | 0 | 5-Oct-78 |
| 42.97 | -79.25 | 0 | 3-Sep-78 |
| Within 10 km of the city limits of Welland | | | |
| 42.88 | -79.15 | 0 | 2-May-36 |
| 42.94 | -79.05 | 2 | 19-May-40 |
| 42.89 | -79.14 | 1 | 1-Jun-61 |
| 42.94 | -79.05 | 0 | 26-Jul-78 |

The Fujita scale levels continue as follows:

- F3 representing winds (253 to 330 km/hr)
- F4 representing winds (331 to 417 km/hr)
- F5 representing winds (418 to 509 km/hr)

No tornadoes above an F2 level have been recorded in the Welland area.

**Probability Scoring**

Based on the information above a probability score of “Remote” or “2” was assigned.

**Trends**

CCME (2003) indicates that the number of reported tornadoes has increased over the past century. However, it is also noted that it is unclear whether this increase represents a real increase in the number of tornadoes or just an increase in the number of reported tornadoes.

A cursory review of internet literature focused on trends in tornado activity in the United States suggests a similar debate over there being more tornadoes or technology has advanced (e.g., Doppler radar) so that more tornadoes can be identified and confirmed.

**Climate Projections**

**Findings**

CCME (2003) suggests that a longer warm season may result in preferable conditions for increased risk of severe hot weather phenomena such as thunderstorm, hail and tornado activity. However, Balling and Cerveny (2003) state "*any link of tornado activity with climatic change of any kind should be treated with the greatest skepticism. The ingredients that go into the creation of a tornado are so varied and complex that they could never be an accurate indicator of climate change*".

**Probability Scoring**

A probability score of "Remote" or "2" was maintained given that no information regarding projected tornado activity and climate change was available.

#### 3.3.4.20 Drought/Dry Period

**Definition**

A meteorological drought is defined in terms of a "significant precipitation departure from normal over a prolonged period" (Atmospheric Hazards – Ontario Region, 2011). To be considered measurable rainfall, 0.2 mm or more must occur before a "day with" is counted. For this study, a drought/dry period was defined as 10 or more consecutive days without measurable precipitation. The 10 day period was defined subjectively.

**Historical Climate**

Daily precipitation data for the period 1971 to 2000 was obtained from Environment Canada's Data Online (Environment Canada, 2011b). Occurrences of drought/dry conditions in the warm months (i.e. May through September) were analysed for 10 consecutive days or more without measurable amounts of rain, as defined above. During the 30 year period, 42 occurrences of non-measurable amounts of rain were recorded or an average of 1.4 drought/dry occurrences per year.

**Probability Scoring**

Based on the information above a probability score of "Probable" or "6" was assigned.

## Trends

Vincent and Mekis (2004, 2005) reported a significant negative trend for the maximum number of consecutive dry days over the period 1900-2001. Their statistical analyses showed 51 stations with a significant downward trend for consecutive dry days over the period 1900-2001 (23 with no significant trend and 0 with an upward trend). Over the period 1950-2001, 35 stations showed a non-significant downward trend, 198 showed no trend and 4 a non-significant upward trend. No information for specific stations was provided in their reporting.

**Table 3-17 : Summary of Drought / Dry Periods**

| Description | Days per Year | | |
|---|---|---|---|
| | Historic[1] | 2020[2] | 2050[2] |
| 10 or more consecutive days without measurable precipitation | 1.4 | 2.5 | 2.5 |
| Probability Scale | 6 | 7 | 7 |
| | Probable | Certain / Highly Probable | Certain / Highly Probable |

Notes:
1. Source: Environment Canada, 2011b
2. Source: WCRP CMIP3, 2009

## Climate Projections

## Findings

A specific analysis of dry periods was completed using the WCRP CMIP3 database. The results of this analysis are summarized in Table 3-17. It is clear that the trend in inter-rain event dry periods is upward with numbers of dry days, on average, increasing into the future.

By extension, and in combination with climate projections for increased rainfall, as discussed in Sections 3.3.4.7 and 3.3.4.8, average total rainfall associated with individual events may also be increasing.

## Probability Scoring

Based on the information above a probability score of “Certain / Highly Probable” or “7” was assigned.

#### 3.3.4.21 Heavy Fog

**Definition**

Environment Canada defines a day as having had 'some fog' when there is at least one hour during that day when the horizontal visibility is reduced to less than 1 km by fog.[17] The fog is defined as 'heavy' when the horizontal visibility is reduced or obscured to less than 0.4 km.[18] Fog for this purpose is defined as a suspension of very small water droplets reducing the horizontal visibility. Average number of hours per year with occurrence of fog reducing visibility to 0 km was downloaded from the Environment Canada website.

**Historical Climate**

The database of Average Number of Days with some fog for Welland (obtained from the Atmospheric Hazards – Ontario Region website) indicated an average 30 days per year for the period 1971 – 1999.

Data for the 'hours with zero km visibility in fog, ice fog or freezing fog' graphic was extracted from Environment Canada's National Climate Data Archive for the period 1971-2000. Only principal weather observing stations (typically airport locations) taking hourly observations 24 hours per day and having at least 20 years of record were used in the analyses. No data was available specifically for Welland or the nearby area. As such, data for the nearest weather stations namely, Toronto's Lester B. Pearson International Airport and London International Airport was assessed. The available database of fog information indicated an average of 15 hours per year of heavy fog for Toronto's Lester B. Pearson International Airport and an average 24 hours per year at London International Airport for the years 1971 – 2000.

**Probability Scoring**

Based on the information above a probability score of "Moderate / Possible" or "4" was assigned.

**Trends**

Muraca et al (2001) reviewed fog data for Canada for the period 1971-1999 and documented a downward trend in the number of fog days (with visibility less than 1km). This decreasing trend was identified at stations across Canada with decreases ranging from 20% to 40%.

[17] http://ontario.hazards.ca/maps/background/Fog-e.html

## Climate Projections

## Findings

No climate projection information was found specific to fog.

## Probability Scoring

In the absence of specific climate projection information for fog, the probability scoring was left unchanged as “Moderate / Possible” or “4”.

### 3.3.4.22 Lake Erie Water Levels

An assessment of the potential influences of changing Lake Erie water levels on the subject infrastructure was also completed. The decline in annual Lake Erie levels could be as much as between 0.6m-1.4m from the IGLD 1985 of 174.18m (GRCA, 2010). Although, Lake Erie water levels are expected to drop in the future, the Locks at top of Welland Canal and recreational water canal will have the effect of negating any impacts from dropping water levels in the Welland Recreational Canal. As such, and in conversation with City of Welland staff, Lake Erie water levels levels were not considered further in this assessment.

### 3.3.4.23 Groundwater Levels

City of Welland staff indicated that groundwater levels are generally very deep across the study area and have not historically been a problem for the study infrastructure in the Welland area. Figure 3-16 illustrates the distribution of underlying soils in the study area. Of note is the large area of clay plain (which acts as a barrier to groundwater) which has much to do with groundwater not being a significant influence for the study infrastructure. As such, and in conversation with City of Welland staff, groundwater levels were not considered further in this assessment.

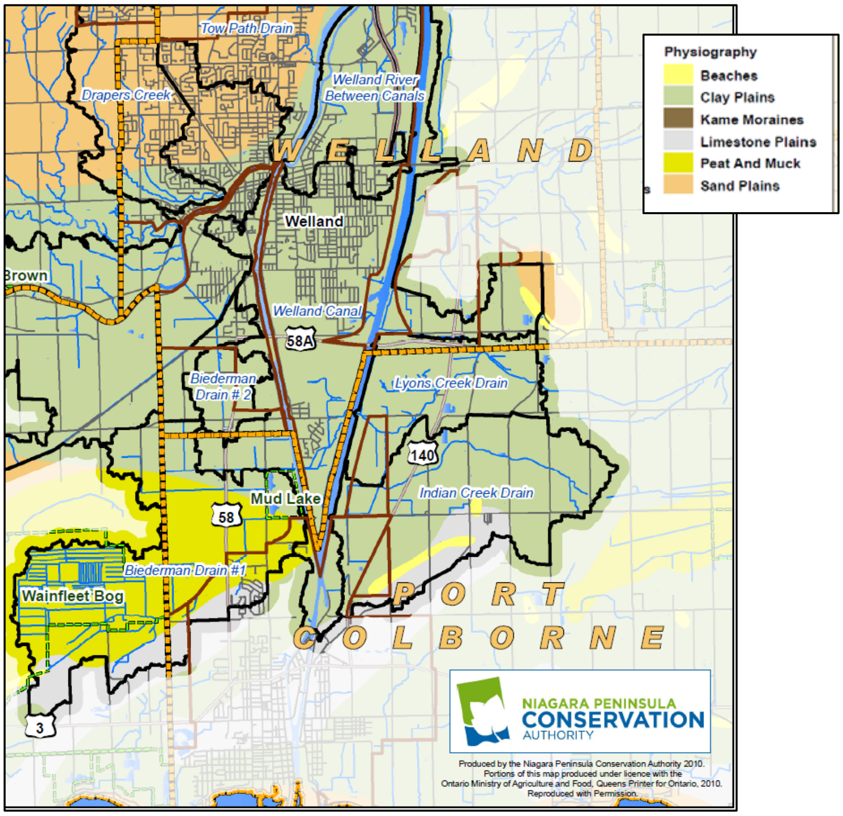



**Figure 3-16 : Underlying Soils in Welland and Area**
(source: NPCA, 2010)

### 3.3.4.24 Welland River Water Fluctuations - Flooding

The floodplain of the Welland River is relatively constrained to near the top of bank through the study area. The WWTP is considered though to be at some risk of flooding being situated on the right bank of the Welland River. Figure 3-17 illustrates the Regulatory Flood Plain in the vicinity of the WWTP (from NPCA). Hydraulic section 3497 lies through the WWTP and across the river as indicated from the Niagara Navigator Map Interface website (http://navigator.yourniagara.ca/navigator/#). This section is noted as having a Regulatory Flood elevation of 174.48m. Topographic information made available from the City of Welland provides a spot elevation of 176.5m along the red line (circled in red) in the image below. The Regulatory Flood Plain depicted in Figure 3-17 is based on a delineation of the 100 year flood. As such, a probability of “1” of “Remote” was assigned to flooding for the historical time frame.

Originally, the Welland River drained directly into the Niagara River at Niagara Falls. However, its flow is now diverted entirely into the Queenston-Chippawa Power Canal. Since 1953, the lower portion of the Welland River flows in reverse, drawing Niagara River water to the Power Canal. This regulated diversion of water in the lower Welland River creates a pattern of regular diurnal fluctuations in water levels that extend approximately 60 km upstream of the diversion (PPE, 2003).

As previously discussed, increases in extreme rainfall events are anticipated in the future. This may translate into an increased risk of flooding at higher flood levels than previously expected and/or experienced. As such, the WWTP may be at increased flood risk in future years. The evaluation of flood plains is complex and increases in rainfall do not always result in equal (percentage based) increases in computed water levels. As such, and given the lack of other substantive information, the probability of "1" or "Remote" was maintained for flooding.

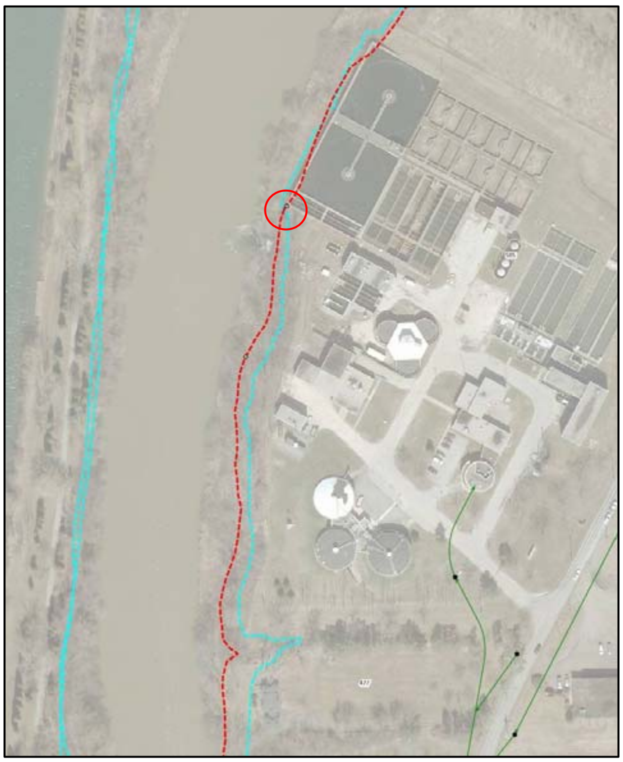


**Figure 3-17: Regulatory Flood Plain near the Welland WWTP**
*(source: Niagara Peninsula Conservation Authority website, background image courtesy of the City of Welland [2011b])*

*Note: The **blue line** depicts the Regulatory Flood Plain limit*

### 3.3.4.25 Climate Parameters Summary

A summary of the historical and future climate parameter probability scores is provided in Table 3-18. As noted below, the selected probabilities associated with a substantial number of parameters remain unchanged from the historic period into the future. Three winter related parameters have been identified with decreased probability moving into the future, primarily related to the anticipation of rising temperature. Eight parameters have been identified with increasing probability moving into the future. Of particular interest are increases in the rain related parameters which could have a direct impact on performance of the subject infrastructure.

**Table 3-18 : Climate Parameters Summary**

| Climate Parameter | Anticipated Changes | | |
|---|---|---|---|
| | Historic | Future[1] | |
| | | 2020 | 2050 |
| **Increasing** | | | |
| Drought/Dry Period | 6 | 7 | 7 |
| Heavy Rain | 4 | 5 | 5 |
| 5-day Total Rain | 4 | 5 | 5 |
| Freezing Rain | 4 | 5 | 5 |
| Winter Rain | 4 | 4 | 5 |
| Heat Wave | 3 | 3 | 4 |
| High Temperature | 2 | 2 | 4 |
| Ice Storm | 2 | 3 | 3 |
| Hurricane/Tropical Storm | 1 | 2 | 2 |
| **Decreasing** | | | |
| Heavy Snow | 7 | 6 | 5 |
| Freeze Thaw Cycles | 4 | 3 | 2 |
| Snow Accumulation | 3 | 2 | 2 |
| **Unchanged** | | | |
| Blowing Snow / Blizzard | 4 | 4 | 4 |
| Lightning | 4 | 4 | 4 |
| Hailstorm | 4 | 4 | 4 |
| High Winds | 4 | 4 | 4 |
| Heavy Fog | 4 | 4 | 4 |
| Tornado | 2 | 2 | 2 |
| Cold Wave | 2 | 2 | 2 |
| Extreme Diurnal Temperature | 2 | 2 | 2 |
| Low Temperature | 1 | 1 | 1 |
| Flooding | 1 | 1 | 1 |

NOTES:

1. The general time frame used for future IDF data projections are the periods 2005-2034, representing 2020, and 2035 to 2064, representing 2050. In some cases the periods 2011-2040 and 2041-2070 have also been used to represent the 2020 and 2050 period properties, respectively, depending on data availability.

# SECTION 4

# PIEVC PROTOCOL STEP 3

# RISK ASSESSMENT

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# 4 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 involved 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 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. Appendix B contains the full Protocol and explanation of vulnerability assessment methodology.

As noted in Section 3.3.4, 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 scale factors) and Method E (response severity scale factors) has been selected as being the most appropriate based on the available data. The climate probability scale factors identified for use in the risk assessment are documented in Section 3.3.4 of this report.

This evaluation was completed during the Risk Assessment Workshop which was held at the offices of the City of Welland on May 18, 2011. This gathering brought together representatives from the City of Welland, Regional Municipality of Niagara, Ministry of Environment, Engineers Canada, Credit Valley Conservation with INRS (Institut national de la recherche scientifique) University and the AMEC Project Team. A list of participants is provided in Table 4-1.

The objectives of the workshop included:

- 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.

Information obtained during the Risk Assessment Workshop has been incorporated into this report.

**Table 4-1 : Risk Workshop Participants**

| Name | Affiliation | |
|---|---|---|
| Ron Scheckenberger | AMEC Project Team | Project Manager, Stormwater Infrastructure Specialist |
| Peter Nimmrichter | AMEC Project Team | Project Engineer, Stormwater Infrastructure Specialist |
| Mike Lywood[1] | AMEC Project Team | Wastewater Infrastructure Specialist |
| Cameron Ells | AMEC Project Team | PIEVC Protocol Specialist, Workshop Facilitator |
| Lisa Vespi[2] | AMEC Project Team | Knowledgeable of the combined sewer and CSO network in the City of Welland |
| Lara Widdifield | City of Welland | Infrastructure Planning Technologist Engineering, Public Works and Transportation Services |
| Vincent Beaudoin | City of Welland | General Foreman Water/Sewer |
| Marvin Ingebrigtsen | City of Welland | Technical Analyst Infrastructure Programs Engineering, Public Works and Transportation Services |
| Ilze Andzans | Region of Niagara | Project Manager WaterSmart Niagara |
| Peter Baker | Region of Niagara | Associate Director Water & Wastewater Engineering |
| David Lapp | Engineers Canada | Manager, Professional Practice |
| Bob Dunn | Engineers Canada | Chair of the Environment & Sustainability Committee |
| Henry Jun | Ontario Ministry of Environment | Senior Policy Analyst Land and Water Policy Branch |
| Alain Mailhot | INRS – Eau, Terre, et Environnement | Professor, Urban Hydrology Specialist, Specialist in the statistical analysis of IDF relationships |
| Amanjot Singh | Credit Valley Conservation | Water Quality Engineer |

NOTES:
1. Mr. Lywood is also former Environmental Engineer and Water and Sewer Division Engineer at the Region of Niagara. As Environmental Engineer responsible for the design and construction of water and wastewater infrastructure. As Water and Sewer Division Engineer responsible for the operation of Niagara's water and wastewater treatment, collection, distribution and storage facilities, Niagara's industrial waste program, and the operation of its laboratory.
2. Ms. Vespi is Project Engineer currently involved in the CSO modelling assessment study for the City of Welland.

## 4.2 RISK ASSESSMENT RESULTS

### 4.2.1 Methodology

The complete Risk Assessment Matrix for this project is included in Appendix C 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 Scale Factor).** This value reflects the expectation of a change in a climate variable under the influence of climate change.

3. **S (Response Severity Scale 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 completed at the workshop 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 no infrastructure-climate interactions were identified in the “High” category. The highest Priority of Climate Effect value was calculated as 25, still within the ‘Medium” range, with a number of infrastructure interactions with ‘Heavy Rain’ and ‘5 Day Total Rain’.

As noted, the qualitative nature of the risk assessment process is based on engineering and professional judgment. The documented results represent a consensus amongst the workshop participants for a particular interaction. However, the initial discussion on a specific climate variable – infrastructure component interaction would usually begin with some participants reflecting opinions of a lower severity and others a higher severity. As a consideration of this discussion, a sensitivity analysis was performed using the Response Severity Scale Factor and the Climate Probability Scale Factor, to determine if alternate estimates (consensus values) would have significantly affected overall Priorities of Climate Effect.

The results of this sensitivity analysis are summarized in Figure 4-2, at the end of this section. The sensitivity analysis results indicate that only with increases in both the Response Severity Scale Factor and the Climate Probability Scale Factor of at least 1 factor would the resultant Priorities of Climate Effect be in the “High” category. In some cases, one of the variables would have to increase by 2 factors, in addition to the other increasing by at least 1 factor, to result in a High category. This suggests some buffer in the infrastructure to accommodate worse conditions (whether worse weather as a result of climate or more severe impacts as a result of changing climate conditions, or both) than expected.

However, the sensitivity analysis also clearly demonstrates that the critical relationships are between the capacity/functionality of the storm and sanitary collection systems and rainfall (in its many forms). Therefore, in the absence of any interactions in the ‘High’ category, the focus moving forward will target this general relationship.

### 4.2.2 Results

This section provides some insight to the matrix values resulting from the Risk Assessment Workshop documented in Table 4-1 (and Appendix C).

#### a) Wastewater/Combined Collection Systems

The highest severity ratings are linked to performance responses that contribute to environmental contamination or risks to public health and safety (namely, CSO’s) and failure of the system in the context of Ministry of Environment Procedure F-5-5. The climate parameters triggering these responses were Heavy Rain and 5 Day Total Rain.

Projected increases in Winter Rain frequency was also seen as potentially adding to the frequency of CSO events, given that 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) was 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, 2006b).

The combined sewer system is connected to the surface drainage network through street catchbasins, roof leaders and drain tiles. City of Welland staff has commented that current funding constraints will extend the completion timeframe of the sewer separation program beyond originally planned, perhaps to 2015 or longer. This is certainly within the time frame of projected 2020 rainfall increases. Such increases, whether intensities and/or volumes, will result in increased flows in the combined sewer system. The end result will be a potential increase in the CSO frequency and volume.

Infrastructure funding to maintain the existing collection system and replacing aging components of the system is also constrained and identified as sub-ordinate to the sewer separation program.

The roof leader and drain tile disconnection program offered by the City of Welland is an on-going mitigation strategy to reduce extraneous flows entering the combined sewer system. However, City of Welland staff has commented that community participation has been surprisingly low and hence staff does not expect any significant increase in participation in the future.

The City of Welland wastewater collection system is also subject to inflow and infiltration (I&I). Inflow is the direct ingress of water from sources such as storm sewer cross-connections and overland flow through manhole lids. Infiltration occurs when water first seeps into the ground then enters the pipes or manholes through defects. The municipal design standards make no accommodation in capacity for I&I. The result is reduced capacity in the system. Given the dense soils in the area, City staff has commented that the granular backfill associated with sewer installation provides an excellent conduit for infiltration into the system. Increased rainfall is expected to exacerbate this problem.

Increased flows at the pump stations may exceed pump station capacity, which could result in overflows locally or upstream. The health and environmental impact could be considerable, but based on current operation the probability is considered low.

The potential loss of electricity supply to the pumping stations was also identified as a potential impact of severe weather.

Reservoirs in the system will provide some flexibility to accommodate higher flows. However, City staff has already identified capacity issues (representing a balance between pump capacity and reservoir storage capacity) have already been raised at locations in the system.

The wastewater collection system discharges to the Welland River at a number of outfalls. Increased rainfall is expected to increase the flows at these outfalls (given that the frequency CSO's is expected to increase). If the outfalls are undersized, higher discharge velocities will lead to erosion at the mouth of the outfall pipe. However, the severity associated with this potential interaction is not considered severe.

It was also noted that extreme weather events could increase construction costs directly through delays, wear and tear on materials and equipment, and increased insurance costs for contractors.

Some consideration was given to a potential change in the Ministry of Environment Procedure F-5-5. , the aspects of change discussed were: the policy becomes a directive (i.e., mandatory), the guideline for treatment of wet weather flow is increased (e.g., from 90% to 100%), or both. For a system already under stress either change would be significant. Notwithstanding, once the City of Welland achieves compliance with Ministry of Environment Procedure F-5-5, compliance with MOE Procedure F-5-1, which outlines an expectation of 100% capture and treatment, is expected.

### b) Stormwater Collection Systems

The highest severity ratings are linked to performance responses that contribute to exceedence of system capacity and/or flooding. The climate parameters triggering these responses included Heavy Rain, 5 Day Total Rain and Winter Rain. Winter Rain was noted again due to the significant flooding that can be generated by minor winter rain events, as noted previously.

In light of the development of the projected IDF relationships (ref. Appendix C), some discussion during the workshop was focused on municipal standards for design of the collection system. The City of Welland municipal design standards (ref. Appendix E) presently require design of the collection system to a 2 year return period level. The projected increases in rainfall (intensity/volume) through 2020 and 2050 suggest that a current 2 year may occur more frequently in the future resulting in under performance of the system. This suggests a change in the municipal design standard may be a consideration.

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 downstream conveyance system.

The City of Welland Municipal Standards defines that "the major system shall convey the City of Welland 100 year design storm overland within the right-of-way leading to the watershed's major outlet. Relief shall be provided in low points to prevent the depth of ponding from exceeding 0.60 metres".[18] 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 was considered to be an issue in conjunction with Winter Rain in regard to performance of, again, stormwater management facilities and the major stormwater conveyance system. The expectation was 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 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.

Similar to the wastewater collection system, the stormwater collection system discharges to the Welland River at a number of outfalls. A potential erosion issue, due to increased extreme rainfall events is anticipated at storm outfalls, although this interaction is not considered severe.

#### c) Welland Wastewater Treatment Plant (WWTP)

The primary performance responses considered in the WWTP risk assessment were related to functionality, operations and maintenance, and integrity of both the infrastructure components and the site itself. Within these broad categories capacity was certainly the principal focus. The climate parameters triggering these responses included Heavy Rain and 5 Day Total Rain.

Heat Waves were considered to be of concern for the main pumping station because of mechanical and maintenance issues associated with deterioration of equipment under extreme heat conditions.

Tornados were considered to be of significance but only if one were to touch down at, or very near to, the plant. Disruption of other services related to personnel getting to/from the plant for operation and maintenance activities was also considered.

The City of Welland relies on land application of its biosolids from the WWTP for beneficial reuse. The biosolids are injected into the ground on agricultural lands as a means of recycling nutrients in the environment. During the time of the year when land application is not permitted (by MOE) or feasible (farmer constraints), the biosolids are transported to sludge storage lagoons for temporary storage. The Nutrient Management Act, 2002 and O. Reg 267/03 as

[18] City of Welland Municipal Design Standards (February 2011), Section 7.2.1, page 7-1

amended regulate biosolids application in Ontario. The season available for land application is controlled by the MOE and by the farmer. There is only a small window in the crop production cycle when biosolids can be applied and this window differs depending on crop type. A number of climate parameter issues could result, namely;

- During heavy rains, the soil may become saturated and hence unsuitable for vehicle access.
- Inability to access agricultural lands for land application of biosolids may present a capacity issue for biosolids storage facilities (i.e., insufficient capacity for storage of biosolids)
- During heavy rains, the likelihood of biosolids runoff also increases.
- The probability of a vehicular accident while transporting biosolids (to the land application site and returning from the site and/or the lagoon storage site) also potentially increases due to poor driving conditions, potentially flooded roads/ditches and decreased visibility.

These issues are also applicable to 5 Day Total Rain, Freezing Rain, Ice Storms, and Hurricanes.

An example of the disruption resulting from a biosolids spill occurred in Welland in 2008. A biosolids spill from one dump truck resulted in nearby homes being evacuated for two days and a $100,000 fine to the hauler (ref. Toronto Star, 2008). The spill resulted when the driver braked suddenly and the biosolids spilled from the vehicle.

An issue was identified regarding the 100 year floodplain of the Welland River. The frequency associated with the 100 year floodplain of 0.01 resulted in the low severity however limited information suggests additional study to quantify the 100 year flood water level in the vicinity of the WWTP under the influence of climate change (i.e., increased extreme rainfall) is warranted. The treatment plant lies immediately beside the Welland River and if it is determined that the 100 year floodplain would inundate a portion of the WWTP, the severity of performance response would increase significantly.

Increases in extreme high temperatures could also impact heating / ventilation / air conditioning systems (HVAC), which could affect staff working conditions and process equipment. Although no specific design information was reviewed in this context, Region of Niagara operations staff did not indicate any particular concerns along these lines under current operations.

Increased average temperatures could impact the WWTP infrastructure from a corrosion perspective. Specifically, increased wastewater temperatures would enhance wastewater fermentation in the collection system, in turn producing more hydrogen sulphide. Additional hydrogen sulphide released into the atmosphere at the WWTP would increase the potential for corrosion at the facility. This risk associated with this interaction was considered to be low.

Also of interest in regard to the WWTP, but not specifically a performance indicator, is the jurisdictional relationship between the City of Welland and the Regional Municipality of Niagara.

Efforts toward enhanced jurisdictional co-ordination between the City and Region in regard to both the collection systems and WWTP is seen as an opportunity for both levels of government to optimize efforts.

**d) Administration**

The primary performance responses considered in regard to Personnel were related to their ability to complete normal (and emergency) operations and maintenance activities specific to the collection systems and WWWTP. Climate parameters seen to impact these activities included Heavy Rain, 5 Day Total Rain, Freezing Rain, Ice Storm, Hurricane/Tropical Storm, Heavy Snow, Snow Accumulation, Winter Rain, Lightning, Hail Storm, and High Winds. In general, the noted climate conditions all could contribute to impaired movement of crews and associated resources and equipment.

High Temperature and Heat Waves were noted due to potential impacts on crews to maintain a normal operations and maintenance schedule. Current Occupational Health and Safety requirements in Ontario have protocols for working outdoors in hot weather. This includes availability of fluids, rest/cooling stations, duration of exposure, etc. Increases in occurrence of high temperature days and heat waves may change the nature of working in hot weather perhaps resulting in shorter work days, longer rest/cooling periods, etc. Ultimately, additional staff may be required for a “normal” crew to affect the same operations/maintenance efforts.

One aspect of the risk assessment that was not included in the City of Welland workshop was ‘Record Keeping’. This was a significant aspect of the assessment completed for Metro Vancouver, BC (Metro Vancouver, 2008) where permanent flow monitoring was an infrastructure component. As noted in their assessment report, “planning for the effects of extreme events can be aided by recording not only the weather event data, but also by logging system responses. In the case of the conveyance system, essential data to collect includes daily CSO volumes at each outfall, sewer flows at key points, such as control points, and maintenance and operations records related to extreme events.”

**e) Electrical Power**

Potential impacts to the base electrical transmission system were identified. The climate parameters associated with system responses were generally related to those that could affect damages to the transmission system such as Ice Storms, Lightning, High Winds and Tornados.

However, the backup electrical system available at the WWTP has performed effectively even during the significant blackout of 2003 (personal communication with Peter Baker, Region of Niagara) and would generally only be disrupted through flooding of the generator system.

### f) Transportation

The assessment of transportation systems specifically related to impacts to the ability of supplies to be delivered to the City and WWTP. Again, climate parameters that could potentially impact or disrupt ground transport were identified, such as Freezing Rain, Ice Storms and Tornados. Of particular importance was the delivery of fuel for the backup generator at the WWTP. The climate events precipitating impacts to transportation systems are also associated with disruption to electrical transmission systems suggesting the backup power system at the WWTP may also be in operation as a result of these events.

### g) Communications

Communication systems necessary to maintain operation of the collection systems and WWTP were not considered to be serious risk from any of the climate phenomena evaluated for this risk assessment.

## 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 – for example, vulnerability of the WWTP to flooding due to increases in flood levels in the Welland River. However, many of the judgments had to be made using “indirect” information. For example, while estimated increases in total annual precipitation were available, how this climate effect could translate into wet-weather wastewater flows was unknown – such a complex analysis was outside the scope of the current assessment. This complicated the assessment of the response severity of climate effects on infrastructure operations, and, more specifically, introduced additional uncertainty into the assessment.

As noted, the Region of Niagara is presently engaged in the Water and Wastewater Master Servicing Plan Study to identify a long-term water and wastewater servicing strategy to support growth in the Region, including the City of Welland. The purpose of this Study is to address the Region's water and wastewater servicing needs to the year 2031. This large infrastructure upgrade program will offer the Region a well-timed opportunity to rectify any climate-related vulnerabilities of the existing WWTP infrastructure in Welland. However, the Risk Assessment was conducted “independent” of this program; that is, any vulnerability of the existing WWTP infrastructure, regardless of this impending program, was identified. The same approach was used in the context of the City of Welland’s sewer separation policy, which will impact the collection system and WWTP over time.

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

**Figure 4-1 : Risk Assessment Results**

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

| Priority of Climate Effect | | |
|---|---|---|
| R ≥ 36 | High | (red) |
| 12 < R < 36 | Medium | (yellow) |
| R ≤ 12 | Low | (green) |

| | Performance Response | | | | | | | | | | | Climate Parameters | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Infrastructure Component | 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 | Heat Wave | Heavy Rain | 5 day Total Rain | Freezing Rain | Ice Storm | Hurricane / Tropical Storm | Drought / Dry Period | Heavy Snow | Snow Accumulation | Freeze Thaw Cycles | Winter Rain | Blowing Snow / Blizzard | Lightning | Hailstorm | High Winds | Tornado | Heavy Fog | Low Temperature | Cold Wave | Extreme Diurnal Temperature | Flooding (100 year) (aka Regulatory) |
| ***Administration*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Personnel | | Y | | Y | Y | Y | Y | Y | | | | 16 | 16 | 20 | 10 | 15 | 12 | 8 | | 25 | 6 | 6 | 10 | | 20 | 12 | 12 | | | | | | |
| ***Storm Collection System*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Catchbasins | Y | Y | Y | Y | | Y | | Y | Y | | | | | 20 | 15 | 10 | 6 | 10 | | | | | 10 | | | | | 2 | | | | | 1 |
| Manholes | Y | Y | Y | Y | | Y | | Y | | | | | | 10 | 10 | 10 | 6 | 4 | | | | | 5 | | | | | 2 | | | | | 1 |
| Pipes | Y | Y | Y | Y | | | Y | | | | | | | 15 | 15 | | | 6 | | | | | 15 | | | | | | | 3 | | | |
| Outfalls | Y | Y | Y | Y | | | Y | Y | | | | | | 25 | 25 | | | 10 | | | | | 25 | | | | | | | 3 | | | |
| SWM Ponds | Y | Y | Y | Y | Y | Y | Y | Y | | | | 16 | 20 | 25 | | | | | | | 6 | | | | | | | 12 | | | | | |
| Oil Grit Separator | Y | Y | Y | Y | | | Y | | | | | | | 15 | 20 | | | | | | | | | | | | | | | | | | |
| Major System - Old | Y | Y | | Y | Y | Y | Y | Y | | | | 12 | 16 | 20 | 10 | 10 | 9 | 10 | | 10 | 6 | | 25 | | | | | 10 | | | | | |
| Major System - New | Y | Y | | Y | Y | Y | Y | Y | | | | 12 | 16 | 20 | | 5 | 6 | 8 | | 10 | 6 | | 25 | | | | | 10 | | | | | |
| ***Sanitary Collection System*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Manholes | Y | Y | | Y | Y | Y | | Y | | | | | | 20 | 15 | 10 | | | | 10 | 4 | 4 | 20 | | | | | 6 | | | | | |
| Pipes | Y | Y | | Y | Y | Y | Y | Y | | | | | | 20 | 20 | | | 8 | | | | | 20 | | | | | | | | | | |
| Forcemains | Y | Y | | | | | Y | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Inverted Syphons | Y | Y | | Y | | | | | Y | | | | | 25 | 25 | | | 10 | | | | | | | | | | | | | | | |
| Reservoirs | | Y | | | Y | | Y | Y | | | | | | 10 | 15 | | | 6 | | | | | | | | | | | | | | | |
| Pump Stations | | Y | | | Y | | | Y | | | | | | 25 | 20 | | | 10 | | | | | | | 28 | | | | | | | | |
| Flow Control Structures | Y | Y | Y | Y | Y | | Y | Y | Y | | | | | 25 | 25 | | | 10 | | | | | 10 | | | | 4 | | | | | | 3 |
| CSO's | Y | Y | Y | Y | Y | | Y | Y | Y | | | | | 25 | 25 | | | 10 | | | | | 5 | | | | 4 | | | | | | 3 |
| ***WWTP*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Main Pumping Station | Y | Y | | Y | Y | Y | Y | Y | | | | 16 | 16 | 15 | 10 | | 9 | 10 | | | | | | 8 | 12 | | | 14 | 8 | 2 | | | |
| Screening, Grit Removal, Flow Splitter | Y | Y | | Y | Y | | | Y | | Y | | | 12 | 20 | 20 | | 6 | 8 | | | | | 15 | | | | | 14 | | 2 | 4 | | |
| Plant Systems | Y | Y | Y | Y | | | | | Y | | | | | | | | | 6 | | | | | | | | | | 10 | | | | | 7 |
| Outfall to Welland River | | Y | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 |
| BioSolids Management | | Y | | Y | | | Y | Y | | | | | | 15 | 15 | 10 | 6 | 14 | | 10 | 4 | | 15 | 8 | | | | 10 | 8 | | | | |
| ***Electric Power*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Transmission Lines | Y | Y | | Y | Y | | | | | | | 8 | 8 | 10 | | 5 | 15 | 12 | | | | | | | 12 | | 12 | 12 | | | | | |
| Standby Generators | | Y | | Y | Y | Y | | | Y | | | | | | | | | | | | | | | | | | | | | | | | 5 |
| ***Transportation*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Supplies Delivery | | Y | | Y | Y | Y | | | Y | | | | | 10 | 10 | 15 | 21 | 12 | | 10 | 4 | | | | | | | 14 | 8 | | | | |
| ***Communications*** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Telephone, Telemetry | Y | Y | | Y | Y | | | | | | | | | | | 5 | 9 | 12 | | | | | | | 8 | | | 8 | | | | | |

Climate Events

**Heat Wave**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 16 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | | | | | | | | | |
| Manholes | | | | | | | | | |
| Pipes | | | | | | | | | |
| Outfalls | | | | | | | | | |
| SWM Ponds | 20 | 25 | 24 | 30 | 28 | 30 | 36 | 35 | 42 |
| Oil Grit Separator | | | | | | | | | |
| Major System - Old | 16 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| Major System - New | 16 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | | | | | | | | | |
| Pipes | | | | | | | | | |
| Forcemains | | | | | | | | | |
| Inverted Syphons | | | | | | | | | |
| Reservoirs | | | | | | | | | |
| Pump Stations | | | | | | | | | |
| Flow Control Structures | | | | | | | | | |
| CSO's | | | | | | | | | |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | 16 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| Screening, Grit Removal, Flow Splitter | 12 | 15 | 16 | 18 | 20 | 20 | 24 | 25 | 30 |
| Plant Systems | | | | | | | | | |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | | | | | | | | | |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | 8 | 10 | 12 | 12 | 16 | 15 | 18 | 20 | 24 |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | | | | | | | | | |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | | | | | | | | | |

**Heavy Rain**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Manholes | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Pipes | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Outfalls | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| SWM Ponds | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| Oil Grit Separator | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Major System - Old | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Major System - New | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Pipes | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Forcemains | | | | | | | | | |
| Inverted Syphons | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| Reservoirs | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Pump Stations | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| Flow Control Structures | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| CSO's | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | 15 | 18 | 24 | 21 | 25 | 24 | 28 | 30 | 35 |
| Screening, Grit Removal, Flow Splitter | 20 | 24 | 30 | 28 | 30 | 30 | 35 | 36 | 42 |
| Plant Systems | | | | | | | | | |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 15 | 18 | 24 | 21 | 25 | 24 | 28 | 30 | 35 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | | | | | | | | | |

**5 day Total Rain**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Manholes | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Pipes | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Outfalls | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| SWM Ponds | | | | | | | | | |
| Oil Grit Separator | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Major System - Old | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Major System - New | | | | | | | | | |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Pipes | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Forcemains | | | | | | | | | |
| Inverted Syphons | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| Reservoirs | 15 | 18 | 20 | 21 | 25 | 24 | 28 | 30 | 35 |
| Pump Stations | 20 | 24 | 25 | 28 | 30 | 30 | 35 | 36 | 42 |
| Flow Control Structures | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| CSO's | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | 10 | 12 | 18 | 14 | 20 | 18 | 21 | 24 | 28 |
| Screening, Grit Removal, Flow Splitter | 20 | 24 | 30 | 28 | 30 | 30 | 35 | 36 | 42 |
| Plant Systems | | | | | | | | | |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 15 | 18 | 24 | 21 | 25 | 24 | 28 | 30 | 35 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | | | | | | | | | |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | | | | | | | | | |

**Hurricane / Tropical Storm**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 8 | 12 | 10 | 16 | 12 | 15 | 20 | 18 | 24 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| Manholes | 4 | 6 | 6 | 8 | 8 | 9 | 12 | 12 | 16 |
| Pipes | 6 | 9 | 8 | 12 | 10 | 12 | 16 | 15 | 20 |
| Outfalls | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| SWM Ponds | | | | | | | | | |
| Oil Grit Separator | | | | | | | | | |
| Major System - Old | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| Major System - New | 8 | 12 | 10 | 16 | 12 | 15 | 20 | 18 | 24 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | | | | | | | | | |
| Pipes | 8 | 12 | 10 | 16 | 12 | 15 | 20 | 18 | 24 |
| Forcemains | | | | | | | | | |
| Inverted Syphons | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| Reservoirs | 6 | 9 | 8 | 12 | 10 | 12 | 16 | 15 | 20 |
| Pump Stations | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| Flow Control Structures | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| CSO's | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | 10 | 15 | 18 | 20 | 14 | 18 | 24 | 21 | 28 |
| Screening, Grit Removal, Flow Splitter | 8 | 12 | 15 | 16 | 12 | 15 | 20 | 18 | 24 |
| Plant Systems | 6 | 9 | 12 | 12 | 10 | 12 | 16 | 15 | 20 |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 14 | 21 | 24 | 28 | 18 | 24 | 32 | 27 | 36 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | 12 | 18 | 14 | 24 | 14 | 21 | 28 | 21 | 28 |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | 12 | 18 | 14 | 24 | 14 | 21 | 28 | 21 | 28 |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | 12 | 18 | 14 | 24 | 14 | 21 | 28 | 21 | 28 |

**Heavy Snow**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 25 | 30 | 30 | 35 | 35 | 36 | 42 | 42 | 49 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | | | | | | | | | |
| Manholes | | | | | | | | | |
| Pipes | | | | | | | | | |
| Outfalls | | | | | | | | | |
| SWM Ponds | | | | | | | | | |
| Oil Grit Separator | | | | | | | | | |
| Major System - Old | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Major System - New | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| Pipes | | | | | | | | | |
| Forcemains | | | | | | | | | |
| Inverted Syphons | | | | | | | | | |
| Reservoirs | | | | | | | | | |
| Pump Stations | | | | | | | | | |
| Flow Control Structures | | | | | | | | | |
| CSO's | | | | | | | | | |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | | | | | | | | | |
| Screening, Grit Removal, Flow Splitter | | | | | | | | | |
| Plant Systems | | | | | | | | | |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 10 | 12 | 18 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | | | | | | | | | |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | 10 | 12 | 15 | 14 | 20 | 18 | 21 | 24 | 28 |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | | | | | | | | | |

**Winter Rain**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | 10 | 10 | 12 | 12 | 16 | 15 | 18 | 20 | 24 |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | 10 | 10 | 12 | 12 | 16 | 15 | 18 | 20 | 24 |
| Manholes | 5 | 5 | 8 | 6 | 12 | 10 | 12 | 15 | 18 |
| Pipes | 15 | 15 | 16 | 18 | 20 | 20 | 24 | 25 | 30 |
| Outfalls | 25 | 25 | 24 | 30 | 28 | 30 | 36 | 35 | 42 |
| SWM Ponds | | | | | | | | | |
| Oil Grit Separator | | | | | | | | | |
| Major System - Old | 25 | 25 | 24 | 30 | 28 | 30 | 36 | 35 | 42 |
| Major System - New | 25 | 25 | 24 | 30 | 28 | 30 | 36 | 35 | 42 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | 20 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| Pipes | 20 | 20 | 20 | 24 | 24 | 25 | 30 | 30 | 36 |
| Forcemains | | | | | | | | | |
| Inverted Syphons | | | | | | | | | |
| Reservoirs | | | | | | | | | |
| Pump Stations | | | | | | | | | |
| Flow Control Structures | 10 | 10 | 12 | 12 | 16 | 15 | 18 | 20 | 24 |
| CSO's | 5 | 5 | 8 | 6 | 12 | 10 | 12 | 15 | 18 |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | | | | | | | | | |
| Screening, Grit Removal, Flow Splitter | 15 | 15 | 20 | 18 | 20 | 20 | 24 | 25 | 30 |
| Plant Systems | | | | | | | | | |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 15 | 15 | 20 | 18 | 20 | 20 | 24 | 25 | 30 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | | | | | | | | | |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | | | | | | | | | |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | | | | | | | | | |

**Tornado**

| Infrastructure Component | Base | P1/S0 | P0/S1 | P2/S0 | P0/S2 | P1/S1 | P2/S1 | P1/S2 | P2/S2 |
|---|---|---|---|---|---|---|---|---|---|
| *Administration* | | | | | | | | | |
| Personnel | | | | | | | | | |
| *Storm Collection System* | | | | | | | | | |
| Catchbasins | 2 | 3 | 4 | 4 | 6 | 6 | 8 | 9 | 12 |
| Manholes | 2 | 3 | 4 | 4 | 6 | 6 | 8 | 9 | 12 |
| Pipes | | | | | | | | | |
| Outfalls | | | | | | | | | |
| SWM Ponds | 12 | 18 | 14 | 24 | 14 | 21 | 28 | 21 | 28 |
| Oil Grit Separator | | | | | | | | | |
| Major System - Old | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| Major System - New | 10 | 15 | 12 | 20 | 14 | 18 | 24 | 21 | 28 |
| *Sanitary Collection System* | | | | | | | | | |
| Manholes | 6 | 9 | 8 | 12 | 10 | 12 | 16 | 15 | 20 |
| Pipes | | | | | | | | | |
| Forcemains | | | | | | | | | |
| Inverted Syphons | | | | | | | | | |
| Reservoirs | | | | | | | | | |
| Pump Stations | | | | | | | | | |
| Flow Control Structures | | | | | | | | | |
| CSO's | | | | | | | | | |
| *WWTP* | | | | | | | | | |
| Main Pumping Station | 14 | 21 | 24 | 28 | 18 | 24 | 32 | 27 | 36 |
| Screening, Grit Removal, Flow Splitter | 14 | 21 | 24 | 28 | 18 | 24 | 32 | 27 | 36 |
| Plant Systems | 10 | 15 | 18 | 20 | 14 | 18 | 24 | 21 | 28 |
| Outfall to Welland River | | | | | | | | | |
| BioSolids Management | 10 | 15 | 18 | 20 | 14 | 18 | 24 | 21 | 28 |
| *Electric Power* | | | | | | | | | |
| Transmission Lines | 12 | 18 | 14 | 24 | 14 | 21 | 28 | 21 | 28 |
| Standby Generators | | | | | | | | | |
| *Transportation* | | | | | | | | | |
| Supplies Delivery | 14 | 21 | 14 | 28 | 14 | 21 | 28 | 21 | 28 |
| *Communications* | | | | | | | | | |
| Telephone, Telemetry | 8 | 12 | 10 | 16 | 12 | 15 | 20 | 18 | 24 |

**Figure 4-2 : Sensitivity Analysis of Risk Assessment Results**

The highlighted values depicted in this Figure are the ‘Priority of Climate Effect’ or ‘R’ values resulting from a sensitivity analysis of the results of the Risk Assessment Workshop. The “Base” value is that determined in the workshop, while the variations (e.g., P1/S0, P1/S1, etc.) represent deviations from the base values. The examples above represent denote an increase in probability score or factor by 1 (P1) and no change in severity score or factor (S0).

| Priority of Climate Effect | | |
|---|---|---|
| R ≥ 36 | High | (red) |
| 12 < R < 36 | Medium | (yellow) |
| R ≤ 12 | Low | (green) |

# SECTION 5

# PIEVC PROTOCOL STEP 4

# ENGINEERING ANALYSIS

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# 5 ENGINEERING ANALYSIS

## 5.1 OVERVIEW

Step 4 focused 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 criterion? If the adaptive capacity is determined not to exist, this evaluation determined the additional capacity required to meet the desired performance criteria, again if the climate changes as described in Step 2. This analysis was conducted as a “desktop” exercise using the equations and spreadsheets provided with the Protocol.

The engineering analysis step requires the assessment of the various factors that affect load and capacity of the 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

## 5.2 ANALYSIS RESULTS

### 5.2.1 Sanitary System

#### 5.2.1.1 Existing Loads ($L_E$)

The nature of the storm and sanitary collection system for the City of Welland suggests two alternate approaches for the engineering analysis, namely, one base on a detailed investigation of individual infrastructure components or an aggregated approach which views the system as a whole.

As a means of determining the most appropriate approach for this study, a definition of the function or capacity of the system was required. Again, this definition of function/capacity can be on many levels, again detailed/local issues or aggregated/municipal issues. For the purposes of this engineering analysis an aggregated/municipal issues-based definition of function was considered most appropriate to the scope of the study.

For this engineering assessment, the function of the subject infrastructure has been defined as supporting the objectives of Ministry of the Environment CSO Procedure F-5-5. This policy outlines an expectation that 90% of wet weather flow receive equivalent to primary treatment during the primary contact season (generally the seven months from April to October).

A detailed assessment of the subject infrastructure, in the context of MOE Procedure F-5-5, was completed in 2003 (RVA, 2003) and 2010 (AMEC, 2011). The results of the RVA assessment are summarized in Table 5-1 and indicate a system-wide performance level of 64% volumetric control which indicates non-compliance with Procedure F-5-5. At the individual infrastructure component level, however, the results indicate a number of the regulators/outfalls (7 out of 16) are in compliance with the Procedure. The results of the AMEC assessment are summarized in Table 5-2 and Table 5-3 and indicate a system-wide performance level of 97.8% volumetric control for 2010. Table 5-2 illustrates the active overflows within the system for 2010 from greatest impact to least impact, including the frequencies, durations, and volumes for the entire monitoring period. Table 5-3 illustrates the total volumes and percent volumes of wet weather flows captured and treated, as well as for overflows caused by Interceptor surcharging and direct by-pass from the incoming trunk sewers. The volumetric control has been represented based on a system-wide analysis rather than on a per overflow location basis as in the RVA (2003) study.

There may be several factors contributing to the substantial difference between RVA (2003) results and AMEC (2011) results. A major contributing factor may be the rainfall volumes experienced in 1980 ("typical" year) and 2010. The rainfall volumes of each year are 555.9mm and 469mm, respectively (average rainfall is 574.8mm April to October). As 2010, was a dry year when compared to the "typical" year, this would likely reduce the amount of CSO events, thus, increasing the volumetric control. Another contributing factor may be that since the RVA

(2003) study, the City of Welland has completed several sewer separation studies to decrease the frequency, duration and volume of CSO events that occur.

For the purposes of this engineering analysis the existing load on the system will be represented as "90" or the compliance limit for MOE Procedure F-5-5.

**Table 5-1 : Overflow Analysis (RVA, 2003)**

| Regulator ID/Outfall Location | Design Capacity | Total Wet Weather Volume | Overflow Volume | % of Overflow Attributed to Surcharged Interceptor | Intercepted Wet Weather Flow | % Volumetric Control | # of Events |
|---|---|---|---|---|---|---|---|
| | (L/sec) | ($m^3$) | ($m^3$) | | ($m^3$) | (% Cr) | |
| Oxford-Atlas-Wellington (OAW) | 1,819 | 678,570 | 27,371 | 82 | 651,199 | 96 | 7 |
| Downs Drive | 74 | 5,602 | 0 | 0 | 5,602 | 100 | 0 |
| McAlpine | 147 | 110,516 | 7,077 | 0 | 103,439 | 94 | 3 |
| McMaster | 290 | 87,926 | 36,143 | 10 | 51,783 | 59 | 8 |
| Burgar | 250 | 69,792 | 23,288 | 98 | 46,504 | 67 | 8 |
| Dorothy/Hellems | 163 | 103,357 | 117,815 | 93 | 0 | 0 | 17 |
| King | 710 | 158,870 | 9,595 | 59 | 149,275 | 94 | 3 |
| Locke St. (Aqueduct) | 413 | 253,992 | 44,300 | 76 | 209,692 | 83 | 7 |
| Niagara St. N. | 75 | 10,507 | 10 | 0 | 10,497 | 100 | 1 |
| Shotwell | 140 | 17,614 | 0 | 0 | 17,614 | 100 | 0 |
| Niagara St. S. | 150 | 5,718 | 69,119 | 99 | 0 | 0 | 16 |
| Denistoun St. | 80 | 3,110 | 78,644 | 99 | 0 | 0 | 17 |
| Prince Charles S. | 340 | 10,787 | 16,463 | 96 | 0 | 0 | 16 |
| First Avenue #1 | 920 | 23,994 | 76,290 | 98 | 0 | 0 | 16 |
| First Avenue #2 | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| Prince Charles N. | 130 | 34,753 | 10,362 | 8 | 24,391 | 70 | 8 |
| Ridgewood (Fitch/McNab) | 620 | 122,949 | 101,747 | 98 | 21,202 | 17 | 13 |
| Riverside/ Maple Ave. | 170 | 15,446 | 1,245 | 64 | 14,201 | 92 | 5 |
| System Wide | 6,491 | 1,735,437 | 620,099 | 92 | 1,113,311 | 64 | |

**Table 5-2 : Overflow Analysis (AMEC, 2011)**

| Location | Occurrence Frequency | Vol. ($m^3$) | Duration (hrs) | Duration (% of total period) |
|---|---|---|---|---|
| Prince Charles Dr. S | 9 | 28,301.7 | 78.8 | 1.69% |
| Niagara St. S. | 9 | 28,124.9 | 108.0 | 2.32% |
| Denistoun St. | 9 | 20,113.3 | 89.5 | 1.92% |
| Fitch St. / McNab St. | 6 | 9,969.4 | 32.0 | 0.69% |
| First Avenue #1 | 6 | 7,128.9 | 34.3 | 0.74% |
| Prince Charles Dr. N | 1 | 225.4 | 3.25 | 0.07% |

**Table 5-3 : Volumetric Control Analysis**
(source: AMEC, 2011)

| Total CSO – Interceptor Surcharging[1] (1000 $m^3$) | Total CSO – Direct Bypass from Trunk (1000 $m^3$) | Total Treated / Captured WWF[2] (1000 $m^3$) | Total Flows – Combined Sewer System[3] (1000$m^3$) | CSO Volumetric Percentage (%) | Treated / Captured Volumetric Percentage (%) |
|---|---|---|---|---|---|
| 93.86 | 9.39 | 4,647.46 | 4,750.71 | 2.17% | 97.83% |

NOTES:

1. Total CSO Volumes are based on flows calculated by the CSO Model
2. Total Treated / Captured Wet Weather Flows (WWF) are based on metered total flows entering the WPCP. A base, dry weather flow has been estimated from the total flows and subtracted to obtain wet weather flows.
3. Total flows are the sum of all Columns 1, 2 and 3

#### 5.2.1.2 Climate Change and Other Loads ($L_C$ and $L_O$)

**Climate Change Load ($L_C$)**

The RVA (2003) analysis was completed using rainfall for 1980, which was considered, at the time, to be a typical year for rainfall (based on the available records) for the City of Welland. Rainfall data for the Environment Canada weather station at Port Colborne was used. The total rainfall in 1980 was 773.6mm, with 555.9mm falling during the period April to October.

As noted in throughout this report, the climate in two future time frames has been evaluated, namely 2020 and 2050. As noted in Section 2.5.2, these timeframes are generally represented by the periods 2005-2034, representing 2020, and 2035 to 2064, representing 2050. The projected total annual rainfall, averaged over these time periods for the 112 modelled scenarios, is 1002.1mm and 1024.6mm for 2020 and 2050, respectively. Similarly, the total April to

October rainfall, averaged over these time periods is 586mm and 594mm for 2020 and 2050, respectively (ref. Table 5-4).

Computed increases in total rainfall, for 2020 and 2050, for the April to October period over the 1980 rainfall data used by RVA (2003) are about 30mm and 38mm, respectively or about an increase of 5% and 7%.

**Table 5-4 : Projected Future Rainfall**

| Time Period | | Total Precipitation (mm) | | |
|---|---|---|---|---|
| Historical | | | | |
| 1980 | April-October | 555.9 | | |
| 1980 | Annual | 899.0 | | |
| 1999 | April-October | 652.9 | | |
| 1999 | Annual | 1126.0 | | |
| 2010[2] | April-October | 483.0 / 458.2 | | |
| 2010[2] | Annual | 649.1 / 829.1 | | |
| Projected[1] | | Average | Max | Min |
| 2020 | April-October | 585.7 | 691.5 | 527.6 |
| 2020 | Annual | 1002.1 | 1123.3 | 921.5 |
| 2050 | April-October | 594.4 | 694.8 | 504.6 |
| 2050 | Annual | 1024.6 | 1151.7 | 929.1 |

**NOTES:**
1. Based on averages of monthly and annual rainfall totals from the 112 scenarios modeled using the WCRP multi-model database (WCRP CMIP3, 2009)
2. The results are provided for Environment Canada weather stations at Welland and Port Colborne (e.g., Welland / Port Colborne). The Port Colborne data is also provided as significant data gaps exist in the record for the Welland station.

As a separate approach, City staff has indicated that CSO's will generally occur when rainfall amounts of about 25 mm are experienced from convective events (shorter duration, more intense rainfall events). The present (i.e. RVA, 1963) IDF relationships for the City indicate a 2-year, 1-hour design rainfall event as having a total volume of 23.6 mm. A 2-year design storm is also presently the design requirement for storm sewers in the City of Welland (Welland, 2011a). The same design storm in 2020 is calculated to have a total volume of 27.2 mm, and similarly in 2050 a total volume of 29.2mm (in both cases for the 90$^{th}$ percentile IDF relationship). These changes represent increases in total volume of 15% and 24%, respectively.
A detailed hydrologic assessment would be able to compute the resultant total load in these future periods under projected rainfall conditions. However, this type of computation is beyond the scope of this assessment. As such, the change information related to the total rainfall over

the April to October period and change information related to the 2-year rainfall event (also typical of causing CSO's) were reviewed in the context of quantifying the Climate Change Load variable. It was concluded that the CSO causal effect, being analogous with a 2-year rainfall event, best represents future impacts to the system from projected future rainfall. As such, the Climate Change Load variable has been computed as the average of the aforementioned percentage change (15% and 24%, see page 5-5) between existing and future rainfall conditions, or 20%, for the two future time frames. The climate change load will therefore be estimated as "20" in the context of this assessment.

**Other Loads ($L_O$)**

The City of Welland Official Plan (Welland, 2010b) provides a 20 year vision of land use for the City to the year 2030 within the current urban boundary. The Plan is reviewed and updated on a five year basis to ensure provincial and regional conformity and to monitor progress and make modifications as required. Within the context of an Official Plan review, a review of the urban boundary can also be included. This was done for the present Official Plan update and focused on two parcels one 104 hectares in size and the other about 265 hectares. It was recommended that the second parcel (about 265 ha) be included in the urban boundary. This parcel has Industrial, Commercial, Agricultural, Residential, and Open Space land use designations. Of particular interest in the context of the present assessment is that this parcel already has all necessary municipal services. As such, loads on the subject infrastructure from this parcel are already represented in the system.

No other loads are anticipated that are not already represented in the system and, as such, other loads are quantified for the purposes of this engineering analysis as "0".

#### 5.2.1.3 Total Load ($L_T$)

The total projected load on the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$L_T = L_E + L_C + L_O$$

Where:

$L_T$ = Total projected load on the infrastructure based on typical rainfall year
$L_E$ = Existing load on the infrastructure
$L_C$ = Projected load on the infrastructure resulting from climate change
$L_O$ = Projected load on the infrastructure resulting from other changes

As such, the Total Load on the system is:

$$L_T = 100 + 20 + 0 = 120$$

#### 5.2.1.4 Existing Capacity ($C_E$)

As noted in Section 5.2.1, the detailed assessment completed by RVA (2003) identified the existing capacity of the subject infrastructure as 64% in the context of Ministry of the Environment Procedure F-5-5.

As such, existing capacity is quantified for the purposes of this engineering analysis as “64”.

The results of the AMEC (2011) study have not been utilized for the existing capacity parameter as 2010 was found to be a dry year, thus, likely resulting in greater volumetric control at the WWTP than the typical year. Continued modeling and rainfall analysis will allow for a better representation of how the current CSO system is operating.

#### 5.2.1.5 Impact of Infrastructure Aging/Use ($C_M$)

Replacement of aging infrastructure (leaking pipes contributing to Infiltration/Inflow) is an on-going initiative of the City of Welland. As illustrated in Figure 3-2, the City’s infrastructure has elements which are considered comparatively old. Further, as illustrated in Figure 3-5, a measurable portion of the infrastructure is considered in categories described as ‘Moderate aging and/or deterioration’, ‘Asset functioning with deterioration’ and ‘Loss of function imminent’.

However, the focus of the present sewer budget is on CSO reduction and sewer separation with replacement of aging and critical sewer infrastructure a secondary component. However, the City recognizes this deficiency and is moving to raise budgets focused on rehabilitation works to a sustainable level for maintaining the infrastructure. Nonetheless, limited budgets and forecasts of further funding reductions are making efforts to reduce CSO’s and maintain the existing infrastructure difficult.

As such, the impact of aging infrastructure and the difficulties the City is having finding budget to dedicate to the maintenance/replacement of this infrastructure is quantified for the purposes of this engineering analysis as “15”.

#### 5.2.1.6 Additional Capacity ($C_A$)

Two significant initiatives have (and will) affect the capacity of the subject infrastructure, namely;

- City of Welland policies

  The City is actively engaged in a number of strategies to limit/reduce stormwater flow in the sanitary system. These are outlined below.

  Firstly, the City of Welland has embarked on an extensive sewer separation program to reduce CSO volumes into the Welland River. Although implementation of the sewer separation program has reduced CSO discharges to the Welland River, the City recognized that more is needed to be done to meet Provincial Policy guidelines. A cost-effective and practical long term CSO plan was developed which will meet the expectations of the Ministry of the Environment Procedure F-5-5 in the interim and ultimately meet the expectations of Procedure F-5-1 for all new development areas. Related initiatives include:

- o Extensive Sewer Separation in the Oxford-Atlas-Wellington (OAW) Area, the largest contributor of combined sewage flow in the City, was initiated in 2004. This was a joint effort with the Region of Niagara and the new OAW sewer is now complete with preparations to complete final connections underway. The estimated combined sewage reduction is 5-10%, increasing the estimated total wet weather flow capture rate to approximately 73% (based on the typical year of 1980 and RVA modeling results). Bypass of the WWTP will also be reduced through reduction in wet weather flows.
- o Update of Pollution Protection Control Program (PPCP) to address MOE regulated discharge of sewage to receiving waters, to commence in 2015
- o Work with the Region of Niagara to ensure proposed High Rate Treatment Facility (HRT) is appropriately sized
- o Replacement of aging infrastructure (leaking pipes contributing to Infiltration/Inflow) as noted above.

Secondly, the Welland Conservation Program includes a number of initiatives focused on limiting wet weather inflow to the sanitary sewer system. These initiatives include:

- o a downspout disconnection initiative which began in the summer of 2006. The program's objective was to eliminate direct and indirect connections to the sanitary sewer, in accordance to By-Law #3913, by informing the public of the importance of disconnection as a flood-proofing preventative measure.
- o replacement incentives for residents who install low-flow toilets. Toilets represent the largest single use of household water at approximately 30%. Since 1998, the building code has mandated low-flow toilets be installed in new homes. However, most homes in Welland were built before this time and therefore do not realize the benefits (both financial and environmental) of low-flush toilets.
- o replacement incentives for residents who install energy-efficient washing machines. Washing machines represent the second largest use of water in the home at approximately 20%. Efficient washers use only about 65% of the water and 50% of the energy that conventional washers use.
- o a rain barrel purchase program for residents subsidized by the City of Welland and Region of Niagara.

- Region of Niagara Water and Wastewater Master Servicing Plan

  The objective of the Plan is to develop a long-term servicing strategy for Niagara Region's water and wastewater systems. The plan will accommodate projected growth in Welland’s population and employment through 2031. When the planned changes, which include upgrades to pumping stations, increasing pipe capacity and expansion of the WWTP, are completed this should have a positive impact (i.e., increase) on capacity.

The combined effect of the City of Welland policies and the implementation of the Region’s Wastewater Master Servicing Plan will be to attain compliance with the Ministry of the Environment Procedure F-5-5 which outlines an expectation that 90% of wet weather flow receive equivalent to primary treatment during the primary contact season. As noted previously, the capacity of the system, based on the typical year and RVA modeling results, in the context of Procedure F-5-5 (and this engineering analysis) is “64”. As such, the anticipated additional capacity embodied within these initiatives is quantified as “26” (or 90-64) at a minimum. Capacity increases in excess of “26” may ultimately be attained, but for the purposes of this engineering analysis a conservative approach has been adopted with an expectation of meeting the minimum requirement of Procedure F-5-5 with the initiatives noted above.

### 5.2.1.7 Project Total Capacity ($C_T$)

The total projected capacity of the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$C_T = C_E - C_M + C_A$$

Where:

$C_T$ = Total projected capacity of the infrastructure based on the typical rainfall year
$C_E$ = Existing capacity of the infrastructure
$C_M$ = Projected change in capacity of the infrastructure resulting from aging/use
$C_A$ = Projected additional capacity of the infrastructure

As such, the Total Capacity of the system is:

$$C_T = 64 - 15 + 26 = 75$$

### 5.2.1.8 Vulnerability Ratio ($V_R$)

The vulnerability ratio of the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$V_R = L_T / C_T$$

Where:

$V_R$ = Vulnerability Ratio
$L_T$ = Projected total load on the infrastructure
$C_T$ = Projected total capacity of the infrastructure based on the typical rainfall year

*When VR > 1, the infrastructure component is vulnerable*
*When VR < 1, the infrastructure component has adaptive capacity*

As such, the Vulnerability Ratio of the infrastructure is:

$$\mathbf{V_R = 120 / 75 = 1.6}$$

The computed ratio of 1.6 indicates the infrastructure is vulnerable.

#### 5.2.1.9 Capacity Deficit ($C_D$)

Where vulnerability has been identified for the infrastructure components that have been selected for engineering analysis, the projected capacity deficit is calculated using the following equation:

$$\mathbf{C_D = L_T - C_T}$$

Where:

$C_D$ = Projected capacity deficit of the infrastructure component
$L_T$ = Projected total load on the infrastructure
$C_T$ = Projected total capacity of the infrastructure based on the typical rainfall year

As such, the capacity deficit of the infrastructure is:

$$\mathbf{C_D = 120 - 75 = 45}$$

### 5.2.2 Stormwater System

#### 5.2.2.1 Existing Loads ($L_E$)

The municipal issues-based definition of functionality, similar to that used for the combined/sanitary system, has been adopted for the engineering analysis of the stormwater system.

For this engineering assessment, the function of the subject infrastructure has been defined as the capability of safely conveying storm runoff from the 2 year design rainfall event without surcharge. The 2 year design rainfall event is defined from the current (i.e., 1963) IDF relationship for the City of Welland.

A detailed assessment of the separated stormwater system, in manner similar to that completed for the combined/sanitary system, has not been completed as a part of the current scope. Rather, for the purposes of this engineering analysis the existing load on the system has been represented as "100" or the capacity of the system as a percentage of design rainfall.

### 5.2.2.2 Climate Change and Other Loads ($L_C$ and $L_O$)

**Climate Change Load ($L_C$)**

As noted in throughout this report, climate phenomena in two future time frames have been evaluated, namely 2020 and 2050. The projected total annual rainfall, averaged over these time periods for the 112 modelled scenarios, is 1002.1mm and 1024.6mm for 2020 and 2050, respectively (ref. Table 5-4) representing only approximately 1% and 3% increases. As discussed in Section 3.3.4.7 (Heavy Rain), the information regarding future rainfall suggests a general increase in total rainfall and the IDF data suggests increases in individual large rainfall events. Table 5-5 summarizes historic and projected 2 year design rainfall for various durations.

As outlined in Table 5-5, a comparison of IDF values for 2000 and 1963 indicates a general trend with the 2000 value being in alignment with the 1963 values for the shorter durations. The trend deviates for the longer duration events which begin to exceed the 1963 values for the 6 hour duration. Given that the Port Colborne IDF relationship reasonably reflects rainfall conditions for Welland, it can be concluded that the 1963 IDF values form a reasonable design basis for existing conditions over a range of event durations.

Table 5-5 also provides a comparison of IDF values for 2000, 2020 and 2050. The future period rainfall intensities are provided as the mean, maximum and 90$^{th}$ percentile values. The trend over both future time periods is increasing with average increases between 10% and about 45% (including average, maximum and 90$^{th}$ percentile values). Focusing on the 90$^{th}$ percentile values only, average increases are 19% and 26% over all event durations for the two modelled time periods. The overall 90$^{th}$ percentile average increase is about 23%.

The climate change load has therefore been estimated as "23" in the context of this assessment.

### Table 5-5 : Review of 2 Year Design Rainfall Maximum Intensity (mm/hr)

| Duration | Time Period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1963 | 2000 | 2020[1] | | | 2050[1] | | |
| | | | average | max | 90th | average | max | 90th |
| 5 minute | n/a | 92.8 | 104.2 | 133.9 | 113.4 | 108.9 | 142.8 | 121.0 |
| 10 minute | 78.2 | 64.5 | 70.8 | 89.9 | 76.6 | 73.6 | 95.7 | 81.5 |
| 15 minute | n/a | 52.1 | 57.6 | 71.6 | 61.7 | 59.6 | 75.9 | 65.3 |
| 30 minute | n/a | 35.7 | 39.1 | 49.0 | 42.6 | 40.5 | 50.4 | 45.1 |
| 1 hour | 23.6 | 22.9 | 25.1 | 31.9 | 27.2 | 26.1 | 32.8 | 29.2 |
| 2 hour | n/a | 13.8 | 15.2 | 19.2 | 16.6 | 15.8 | 19.8 | 17.6 |
| 4 hour | 8.1 | 8.0 | n/a | n/a | n/a | n/a | n/a | n/a |
| 6 hour | 5.6 | 5.8 | 6.4 | 8.4 | 7.1 | 6.7 | 8.7 | 7.5 |
| 10 hour | 2.8 | 4.0 | n/a | n/a | n/a | n/a | n/a | n/a |
| 12 hour | n/a | 3.5 | 3.6 | 4.7 | 3.9 | 3.7 | 4.8 | 4.2 |
| 24 hour | n/a | 2.0 | 2.2 | 2.8 | 2.4 | 2.2 | 2.8 | 2.5 |

| Deviation of 2000 IDF values from 1963 | | |
|---|---|---|
| **Duration** | **1963** | **2000** |
| 5 minute | n/a | n/a |
| 10 minute | 100 | 82.5 |
| 1 hour | 100 | 97.0 |
| 4 hour | 100 | 98.8 |
| 6 hour | 100 | 103.6 |
| 10 hour | 100 | 142.9 |

| Deviation of 2020 and 2050 IDF values from 2000 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | **2020** | | | **2050** | | |
| ` | **2000** | **average** | **max** | **90th** | **average** | **max** | **90th** |
| 5 minute | 100 | 112.3 | 144.3 | 122.2 | 117.3 | 153.9 | 130.4 |
| 10 minute | 100 | 109.8 | 139.4 | 118.8 | 114.1 | 148.3 | 126.4 |
| 15 minute | 100 | 110.6 | 137.4 | 118.4 | 114.4 | 145.6 | 125.4 |
| 30 minute | 100 | 109.5 | 137.4 | 119.2 | 113.4 | 141.3 | 126.2 |
| 1 hour | 100 | 109.6 | 139.3 | 118.8 | 114.0 | 143.4 | 127.5 |
| 2 hour | 100 | 110.1 | 139.3 | 120.2 | 114.5 | 143.4 | 127.5 |
| 6 hour | 100 | 110.3 | 144.9 | 123.0 | 115.5 | 149.5 | 129.4 |
| 12 hour | 100 | 102.9 | 134.1 | 112.7 | 105.7 | 135.8 | 119.5 |
| 24 hour | 100 | 110.0 | 137.9 | 117.9 | 110.0 | 142.0 | 124.3 |
| *Average* | | 109.5 | 139.3 | 119.0 | 113.2 | 144.8 | 126.3 |
| *Average over 2020 & 2050* | | 111.3 | 142.1 | 122.7 | | | |

**NOTES:**
1. Based on averages of monthly and annual rainfall totals from the 112 scenarios modeled using the WCRP multi-model database (WCRP CMIP3, 2009)
2. The results are provided for Environment Canada weather stations at Welland and Port Colborne (e.g., Welland / Port Colborne). The Port Colborne data is also provided as significant data gaps exist in the record for the Welland station.
3. Maximum Intensity as mm/hr

**Other Loads ($L_O$)**

No other loads are anticipated that are not already represented in the system and, as such, other loads have been quantified for the purposes of this engineering analysis as “0”.

#### 5.2.2.3 Total Load ($L_T$)

The total projected load on the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$L_T = L_E + L_C + L_O$$

Where:

$L_T$ = Total projected load on the infrastructure based on typical rainfall year
$L_E$ = Existing load on the infrastructure
$L_C$ = Projected load on the infrastructure resulting from climate change
$L_O$ = Projected load on the infrastructure resulting from other changes

As such, the Total Load on the system is:

$$L_T = 100 + 23 + 0 = 123$$

#### 5.2.2.4 Existing Capacity ($C_E$)

The two year design rainfall event as defined from the existing Welland IDF relationship (from 1963) is the current standard for storm sewer design in the municipality. Given that the comparison to the 2000 Environment Canada IDF relationship for Port Colborne does not indicate significant increase for most of the available durations, the existing capacity is quantified for the purposes of this engineering analysis as “100”.

#### 5.2.2.5 Impact of Infrastructure Aging/Use ($C_M$)

About 90% of the municipal stormwater infrastructure is 50 years old or younger and 80%, 40 years old or younger (see Figure 3-2). The bulk of the stormwater infrastructure has a condition rating of “C” or better (see Figure 3-5) meaning substantial serviceable life remains.

It has already been identified that the City has limited budgets and forecasts of further funding reductions is making maintenance of the existing combined/sanitary network difficult. It is anticipated that as the storm sewer system age’s similar maintenance funding issues will arise.

As such, the impact of aging infrastructure and the difficulties the City is having finding budget to dedicate to the maintenance/replacement of this infrastructure is quantified for the purposes of this engineering analysis as “5”.

#### 5.2.2.6 Additional Capacity ($C_A$)

Two initiatives have (and will) affect the capacity of the subject infrastructure, namely;

- City of Welland policies

  The Welland Conservation Program includes a number of initiatives (previously noted in Section 5.2.1.6) focused on limiting wet weather inflow to the sanitary sewer system, however these same initiatives will have a positive influence on (by reducing) storm sewer flows as well. These initiatives include:

  - A rain barrel purchase program for residents subsidized by the City of Welland and Region of Niagara. The Rain Barrel Purchase program sold over 550 subsidized rain barrels to Welland residents in 2006 representing about 32,000 litres of water per year (York Region, 2008) diverted from the stormwater sewer systems.

    The Statistics Canada community profile for The City of Welland defines 20,715 private households of which about 15,743 are houses (Statistics Canada, 2007). Assuming the rain barrel sales noted above were purchased by individual home owners (1 per household) penetration was limited to only about 3.5%. If this rain barrel program were to continue at a similar rate 100% penetration would require about 30 years.

- Low Impact Development (LID) Opportunities

  LID is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. LID employs principles such as preserving and recreating natural landscape features, minimizing effective imperviousness to create functional and appealing site drainage that treat stormwater as a resource rather than a waste product. There are many practices that have been used to adhere to these principles such as bio-retention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. By implementing LID principles and practices, water can be managed in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed. Applied on a broad scale, LID can maintain or restore a watershed's hydrologic and ecological functions.

As such, the anticipated additional capacity embodied within these initiatives is quantified as “10”, although this value is considered arbitrary given that no practical methodology is available to determine the actual influence of these efforts on stormwater flows in this study’s scope.

### 5.2.2.7 Project Total Capacity ($C_T$)

The total projected capacity of the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$C_T = C_E - C_M + C_A$$

Where:

$C_T$ = Total projected capacity of the infrastructure based on the typical rainfall year
$C_E$ = Existing capacity of the infrastructure
$C_M$ = Projected change in capacity of the infrastructure resulting from aging/use
$C_A$ = Projected additional capacity of the infrastructure

As such, the Total Capacity of the system is:

$$C_T = 100 - 5 + 10 = 105$$

### 5.2.2.8 Vulnerability Ratio ($V_R$)

The vulnerability ratio of the infrastructure components that were selected for engineering analysis is calculated using the equation:

$$V_R = L_T / C_T$$

Where:

$V_R$ = Vulnerability Ratio
$L_T$ = Projected total load on the infrastructure
$C_T$ = Projected total capacity of the infrastructure

*When VR > 1, the infrastructure component is vulnerable*
*When VR < 1, the infrastructure component has adaptive capacity*

As such, the Vulnerability Ratio of the infrastructure is:

$$V_R = 123 / 105 = 1.2$$

The computed ratio of 1.2 indicates the infrastructure is vulnerable.

### 5.2.2.9 Capacity Deficit ($C_D$)

Where vulnerability has been identified for the infrastructure components that have been selected for engineering analysis, the projected capacity deficit is calculated using the following equation:

$$C_D = L_T - C_T$$

Where:

$C_D$ = Projected capacity deficit of the infrastructure component
$L_T$ = Projected total load on the infrastructure
$C_T$ = Projected total capacity of the infrastructure

As such, the capacity deficit of the infrastructure is:

$$C_D = 123 - 105 = 18$$

## 5.3 ANALYSIS SUMMARY

Table 5-6 provides a summary of the engineering analysis computations. The results of the engineering analysis confirm that:

- the infrastructure system, as a whole, is vulnerable to projected future climate, and;
- a capacity deficit presently exists and is expected to continue into the future.

## 5.4 DATA SUFFICIENCY

As noted in Section 5.2.1, the engineering analysis was conducted as a “desktop” exercise using the equations and spreadsheets provided with the Protocol. Further, this analysis was based on an aggregated/municipal issues based definition of infrastructure function as the data necessary to complete the analysis on individual infrastructure components, (as outlined in Section 4), was not available without detailed hydrologic and hydraulic modeling that is beyond the scope of this assessment. Nonetheless, the data used to support the level of engineering analysis completed for this assessment, relevant to the aggregated/municipal issues based definition of infrastructure function, were considered appropriate and sufficient.

As required by the Ministry of the Environment, the City of Welland will continue to monitor the CSO’s at all overflow locations along the Interceptor system. While the capacity and vulnerability of the infrastructure is represented using RVA (2003) study results based on 1980 rainfall, the typical rainfall year, the values may vary depending on the amount of annual rainfall, specifically, volumetric control, as well as the continued efforts made by the City to separate storm and sanitary sewers in their system.

**Table 5-6 : Summary of the Engineering Analysis**

| Parameter | Notation | Value |
|---|---|---|
| **Wastewater/Combined System** | | |
| existing load | $L_E$ | 100 |
| anticipated climate change load | $L_C$ | 20 |
| other change loads | $L_O$ | 0 |
| total load | $L_T$ | 120 |
| existing capacity | $C_E$ | 64 |
| projected change in existing capacity from aging/use | $C_M$ | 15 |
| additional capacity | $C_A$ | 26 |
| project total capacity | $C_T$ | 75 |
| vulnerability ratio | $V_R$ | 1.6 |
| capacity deficit | $C_D$ | 45 |
| **Stormwater System** | | |
| existing load | $L_E$ | 100 |
| anticipated climate change load | $L_C$ | 23 |
| other change loads | $L_O$ | 0 |
| total load | $L_T$ | 123 |
| existing capacity | $C_E$ | 100 |
| projected change in existing capacity from aging/use | $C_M$ | 5 |
| additional capacity | $C_A$ | 10 |
| project total capacity | $C_T$ | 105 |
| vulnerability ratio | $V_R$ | 1.2 |
| capacity deficit | $C_D$ | 18 |

# SECTION 6

# PIEVC PROTOCOL STEP 5

# CONCLUSIONS AND RECOMMENDATIONS

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# 6 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. As outlined in Step 3, judgment of likelihood and magnitude were unique to the individuals who took part in the risk assessment workshop. The probability and risk values documented from the workshop are consensus views of likelihood and magnitude and the range of opinions contributes to uncertainty.

Step 4 involved an engineering analysis of the entire system as a whole as opposed to individual infrastructure components. This approach was adopted, as conducting the analysis on an individual infrastructure component basis was not possible, given the complexities and interactions within the system. Detailed modeling would be required to quantify the impact of projected rainfall increases and changes in other climate variables into the future and to understand the cascade effects of changes to individual infrastructure components on overall system performance. Hence, there is uncertainty in both how the system will respond to changing climate and how localized changes to the system impact performance.

Further, the primary performance objective for the system is based on Ministry of Environment Procedure F-5-5, keeping in mind that once compliance with F-5-5 is achieved compliance with MOE Procedure F-5-1 is expected to be mandated. Changing public perception of the environment may, in the future, lead to more stringent performance targets.

Overall though, 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 Welland.

## 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 (ref. Table 6-1) on adaptive measures, such that the desired performance criteria are met in those circumstances where Steps 3 and 4 have indicated insufficient adaptive capacity.

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.

In fact, the greatest pressure to initiate adaptive action comes not from climate change but from timing of planned infrastructure improvements such as the WWTP upgrades and combined sewer separation program. So while perceived changes in the future climate effects may have revealed infrastructure vulnerabilities, the City of Welland is in an ideal position to proactively mitigate and adapt to these challenges through existing programs with its area partners.

### 6.2.1 Wastewater/Combined Collection System

The vulnerabilities judged to be of the highest priority for the wastewater collection system are those associated with performance responses that contribute to environmental contamination or risks to public health and safety (namely, CSO's) and failure of the system in the context of Ministry of Environment Procedure F-5-5. Specifically, increased rainfall and the associated increase in sewer flow were identified as triggers for these vulnerabilities.

A number of lower-ranked interactions and considerations associated with the wastewater collection system were also identified, as outlined below:

- potential for system capacity decreases resulting from increased inflow and infiltration linked with increased rainfall
- projected increases in Winter Rain frequency potentially adding to the frequency of CSO events
- funding issues related to both sewer separation and on-going maintenance of the system
- lack of community participation in City programs aimed at mitigation/reduction of stormwater runoff into the combined system
- potential for loss of power to pumping stations as a result of projected increases frequency of severe weather
- increased potential for erosion at outfall locations resulting from projected changes in rainfall patterns

Some consideration was also given to a potential change in the Ministry of Environment Procedure F-5-5. The aspects of change discussed were: the procedure/expectation becomes a directive (i.e., mandatory), the guideline for treatment of wet weather flow is increased (e.g., from 90% to 100%), or both. For a system already under stress either change would be significant. Notwithstanding, once the City of Welland achieves compliance with Ministry of Environment Procedure F-5-5, compliance with MOE Procedure F-5-1, which outlines an expectation of 100% capture and treatment, is expected.

### 6.2.2 Stormwater Collection System

The vulnerabilities judged to be of the highest priority for the stormwater collection system are those associated with performance responses that contribute to exceedence of system capacity and/or flooding. Specifically, increased rainfall and the associated increase in sewer flow were identified as triggers for these vulnerabilities.

A number of lower-ranked interactions and considerations associated with the stormwater collection system were also identified, as outlined below:

- The potential impacts of heat waves on functionality of stormwater management systems and major overland flow paths
- Potential decreasing removal rates associated with oil/grit separators given the projected changes in annual rainfall patterns
- Increased potential for erosion at outfall locations resulting from projected changes in rainfall patterns

### 6.2.3 Welland Wastewater Treatment Plant

The vulnerabilities judged to be of the highest priority at the treatment plant are those associated with the screening, grit removal and flow splitters. Operation of these systems under projected increasing rainfall conditions would reduce their operational life leading to increased maintenance and replacement costs. Further, limited capacity under increased flow conditions in the future could lead to increased frequency of CSO's.

There are a few lower-ranked interactions between:

- the main pumping station and heat waves and increasing rainfall
- biosolids management and increasing rainfall
- the plant in general (as represented by the main pumping station and screening, grit removal and flow splitters) and possible increased potential for tornadoes

These vulnerabilities are related not only to functionality of the systems under projected future climate conditions, but are also related to fixed plant capacity leading to potential increases in CSO's in the future.

At this point there is considerable uncertainty in the significance of these vulnerabilities, particularly given the relative magnitude of the estimated climate effects and the potential ability of the City of Welland's sewer separation policy to mitigate these vulnerabilities. Additional study to develop the relationship between these climate variables and the resultant impact on wet-weather wastewater flows may provide enhanced information to assess potential impacts on the treatment system. However, given initiatives by the Regional Municipality of Niagara with regard to future planning of the WWTP capabilities, a more practical approach to deal with these vulnerabilities may be to incorporate them into design of upgrade facilities. In this case, the Region would consider and account for potential increases in plant capacity, and in the context of other uncertainties (e.g. sewer separation, future population growth, water consumption reduction).

There is also considerable uncertainty in the potential for increased threat from tornadoes. Nonetheless, the occurrence of such an event, now or in the future, in the proximity of the WWTP could seriously impact the ability of the plant to operate. Again, incorporation of design considerations into the upgrade of the facilities could be a practical approach to deal with this vulnerability.

Also a lower ranked interaction was related to the WWTP site itself due to a potential flooding susceptibility directly from the Welland River. Additional study to understand potential increases in flooding along the reach of the Welland River near the WWTP would provide a basis for better understanding the risk posed by direct flooding under future climate conditions.

## 6.3 RECOMMENDATIONS

As noted previously, Table 6-1 details the recommendations stemming from the application of the PIEVC Protocol to the stormwater and wastewater (including combined) collection systems and the Welland Wastewater Treatment Plant to assess risks and vulnerabilities to projected changes in climate phenomenon in the future. The results of the development of updated and projected IDF relationships for the City of Welland have also been integrated into the recommendations where relevant.

Table 6-1 details the following elements:

- Infrastructure components and climate variable interactions taken directly from the risk assessment workshop matrices where a significant interaction was identified. An additional “General” grouping of recommendations has been added where no specific climate variable interaction was available.
- Recommendation categories consistent with the PIEVC classification detailed in Section 6.2.
- Comments on Recommendations provide additional details with regard to the recommendation and its basis.
- Performance Responses are, again, taken directly from the Risk Assessment Workshop matrices for the defined infrastructure/climate variable interaction. For those recommendations in the ”General” grouping, performance responses have been identified based on engineering judgement and experience with similar infrastructure. The Performance Responses also provide a means by which recommendations can be grouped

or sorted. As an example, group all of the recommendations which are relevant to "Water Quality" issues.

- Cost Range provides a suggested range of costs that can reasonably be associated with implementation of the recommendation as outlined below.

| | |
|---|---|
| $ | < $100,000 |
| $$ | $100,000 to $500,00 |
| $$$ | $500,000+ |

This information provides a gauge with which the recommendations can be grouped for planning and budgeting purposes.

- Time Frame provides a similar suggested implementation target for recommendations as "ASAP" –as soon as possible meaning these initiatives are immediately relevant, particularly in the context of present programs and initiatives on-going by the City and Region. A "Short" time frame suggests initiation of a recommendation with 5 years. A "Medium" time frame suggests initiation of a recommendation with 10 years and is particularly relevant to climate phenomena that are expected to impact the subject infrastructure in the short term.
- As noted throughout the assessment, the subject infrastructure is linked between the City of Welland and the Region of Niagara. It is clear that some recommendations will have implications for both the City and the Region. Implementation of these recommendations should be a co-operative effort between the two levels of government.

A total of forty-four (44) recommendations are detailed in Table 6-1. The following summaries provide an overview of these recommendations:

| Action Classifications | # of recommendations |
|---|---|
| Additional Study as a prerequisite for Management Action | 1 |
| Additional Study as a prerequisite for Management and/or Operational Action | 6 |
| Additional Study as a prerequisite for Remedial Action | 2 |
| Additional Study as a prerequisite for Remedial Action and/or Management Action | 21 |
| Management Action | 12 |
| Management and/or Operational Action | 2 |

| Recommendation Cost Range | # of recommendations |
|---|---|
| < $100,000 | 33 |
| $100,000 to $500,00 | 11 |
| $500,000+ | 0 |

| Implementation Time Frame | # of recommendations |
|---|---|
| ASAP | 12 |
| Short | 13 |
| Medium | 19 |

| Recommended Action by | # of recommendations |
|---|---|
| City | 12 |
| Region | 8 |
| City & Region | 24 |

### 6.3.1 Recommendations Associated with Development of IDF Relationships

An added component of this project was focused on the development of projected intensity-duration-frequency curves (IDF curves) for the City of Welland. The objective of the work was to develop IDF curves reflective of the changes in the characteristics of precipitation that might be caused by projected changes in climate. IDF relationships were obtained/developed for the present (namely the 2000 Environment Canada IDF relationship) and two future time frames, namely 2020 and 2050. A summary of the IDF analysis is provided in Appendix C of this report. The following general conclusions stem from the analysis:

- the 1963 IDF curves is conservative relative to the estimates made in the 2000 IDF curves. Thus, adoption of the 2000 curves would effect a relaxation of planning standards for many types of infrastructure.
- the 1963 curves were conservative relative to the current (2000) estimates and even relative to the projected (2020 and 2050) values for many duration/return interval combinations. In those instances, it is reasonable to retain the 1963 intensities. However, doing so does not insure that those intensities will be appropriate, it simply maintains current practice.
- the projected IDF curves display significant differences across the mean, the 90$^{th}$ percentile value and the maximum value. Conventionally, the maximum value is excluded as the basis for planning decisions because it represents a single estimate and is therefore quite sensitive to error or artifacts. Quantile values, such as the 90$^{th}$ percentile value and the mean, are estimated in the context of all values and are therefore not as volatile.

When considering how to interpret the projected values the first thing to consider is whether to use the 2020 or 2050 estimates. For most duration/return-interval combinations there is not a large difference in estimated intensity between 2020 and 2050.Therefore, it is reasonable to use estimates from either time frame, but a mildly conservative choice would be to use the 2050 estimates.

When making decisions that will be affected by climate, it is important to consider that our understanding of climate and climate change will increase with time, so a decision that can be delayed may benefit from new and better information. For decisions that must be made now, it is important to consider the lifetime of the decision. Decisions with shorter lifetimes, less than about 20 years, for example, will have less exposure to the impacts of climate change. Decisions with longer lifetimes, around fifty years or more, for example, are much more likely to exist in a substantially different climate. The degree of rigor of analysis in decision-making should take into account the decision lifetime.

It will also be important to evaluate and document the uncertainties to be addressed through the recommended actions. As noted above, society's understanding of climate and climate change will increase with time and conversely uncertainty of future climate projections will, hopefully, diminish with time. However, uncertainty at some level will be expected to continue as related to predictions of future climate. In many cases professional and/or experiential judgement may provide an effective means of bridging the gaps.

It is also appropriate to consider the nature of the consequences of the failure of infrastructure. If the consequence of failure is destruction of infrastructure or property, then a more conservative approach is warranted than would be the case where a failure results in temporary inconvenience.

Finally, it is crucially important to ask if these projected intensities make sense given the broad experience with infrastructure in Welland. Welland has used the existing IDF curves for almost 50 years—how well has it protected people and property in that considerable period? Is there evidence that the current practice is substantially under- or over-protective? Are there particular durations of storms that are particularly damaging? Consideration should be given to expected costs versus expected reductions in losses. Anecdotal information regarding recent storm events should also be considered. There is considerable spatial variability in precipitation, but measurements of precipitation are made at point locations. Flood and drainage infrastructure and natural watersheds, on the other hand, integrate the effect of precipitation over larger areas and reflect the shape and motion of storms, so if historical storms have overwhelmed infrastructure designed based on the current IDF curve, that event provides evidence that the precipitation intensities in the current IDF curve may underestimate the impact of actual precipitation events and suggests a more conservative interpretation of the available information. Given all these considerations, it is entirely appropriate to develop an official IDF curves that are a hybrid of the existing curves, projected values, and values set based on judgment, considering all of the available information.

As the development of the IDF relationships is not strictly a standard component of the PIEVC assessment protocol, recommendations associated specifically with this aspect of the project have not been included in Table 6-1 but are detailed below for separate consideration by the City.

The municipal storm sewer design standards for a number of municipalities in southern Ontario are outlined in Table 6-2. As indicated in Table 6-2, municipalities in southern Ontario have adopted a range of design criteria for storm sewer design. In the review of these municipal design standards, none was noted to have a requirement for integration of climate change into the storm sewer design process. Perhaps this idea is affected through other municipal policies such as Official Plans, as is the case in Welland. There are many reasons why climate change adaptation options are not yet regularly incorporated into infrastructure design and why climatic design information does not include climate change projections. These include uncertainties in climate change projections, uncertainties and gaps in existing climatic design values, and a shortage of sufficient climate station records. Nonetheless, projections for a changing climate in the Welland area, as documented in Section 3 of this report, suggests recognition of climate change in the design process for storm sewers specifically, and perhaps other infrastructure, in the City of Welland.

As such, the following recommendations are made as an outcome of the PIEVC risk assessment of City of Welland infrastructure coupled with the development of current and projected IDF relationships for the Environment Canada weather stations at Port Colborne (ref. Appendix C):

- Firstly, the City of Welland municipal standards outline the design of storm sewers based on IDF curves (Rainfall Intensity Duration Frequency curves). The City of Welland has used a 1963 based IDF relationship for storm sewer design until the present. It is recommended that the implications (as related to performance and life cycle costing) of the application of the current Environment Canada (i.e., 2000) or the projected (i.e., 2020 and 2050) IDF relationships, developed for this risk assessment, be evaluated to determine long-term applicability for the storm sewer collection system design, operation and maintenance. In the context of the PIEVC recommendations categories, this would be considered ‘Additional Study as a prerequisite for Remedial Action and/or Management Action’.

- Secondly, the City of Welland infrastructure design standards presently direct the use of the 2 year return period rainfall design event for design of storm sewers in the municipality. It is recommended that the implications of a change in this design standard to a 5 year or a 10 year design rainfall event should be evaluated in the context of current sewer infrastructure capital plans, performance metrics and long-term sewer objectives. In the context of the PIEVC recommendations categories, this would be considered ‘Additional Study as a pre-requisite for Remedial Action and/or Management Action’.

**Table 6-1 : Recommendations**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses: Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wastewater / Combined Collection System** | | | | | | | | | | | | | | | | |
| General | General | Management Action | It is recommended that the City of Welland continue to work with the Regional Municipality of Niagara to determine the effect of climate change on achievable flow reduction through sewer separation and inflow and infiltration reduction programs. | Y | Y | | | | | Y | Y | Y | | $$ | Short | City & Region |
| | | Management Action | Many of the recommendations in this study would be most effective if completed in conjunction with ongoing and new Municipal and Regional initiatives, continued co-ordination and dialogue required. | | | | | | | Y | | | | $ | ASAP | City & Region |
| | | Management Action | Infrastructure funding to complete the sewer separation program is constrained resulting in implementation delays. Welland should work with all levels of government to establish a consistent funding program for the sewer separation program. | Y | Y | | | | | Y | | Y | | $ | ASAP | City & Region |
| | | Management Action | Infrastructure funding to maintain the existing collection system and replacing aging components of the system is required. Welland should work with all levels of government to establish a consistent funding program for the sewer maintenance program. | Y | Y | | Y | | | Y | Y | Y | | $ | ASAP | City & Region |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | An assessment of the impact of a change in the Ministry of Environment Procedure F-5-5 and/or the impact of compliance with Ministry of Environment Procedure F-5-1 should be completed. | Y | Y | | Y | | | Y | | Y | | $ | Short | City & Region |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | Infrastructure vulnerability exists to increased rain as a trigger for increased frequency of CSO's. Mitigation is possible through on-going and currently planned sewer separation. Beyond this, the extent of the impact is partially dependent on the design standard of the separated sewer systems and the allowance for inflow and infiltration. Further study is required to identify the relationship between increased rainfall and inflow and infiltration rates in the collection systems. | Y | Y | | | | | | | Y | | $$ | Short | City |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | City of Welland programs aimed at reducing wet weather flow in the collection systems are on-going. These should be continued and actively promoted to residents perhaps through increased educational opportunities. An assessment of the applicability of green infrastructure, as an additional tool to increase resiliency in adapting to climate change, should be completed. | Y | Y | | | | | Y | Y | | | $ | Short | City |

| **$$$ Range of Anticipated Cost for Implementation of Recommendation** | | |
|---|---|---|
| | $ | < $100,000 |
| | $$ | to $500,000 |
| | $$$ | $500,000+ |

| **Time Frame** | | |
|---|---|---|
| | **ASAP** | as soon as possible |
| | **Short** | implementation should be initiated within 5 years |
| | **Medium** | implementation should be initiated within 10 years |

**Priority of Climate Effect** This value represents the Response Severity Scale Factor (P) multiplied by the Climate Probability Scale Factor (S) and is used to determine how the interaction will be assessed in the context of the PIEVC Protocol. The Climate Probability Scale Factor reflects the expectation of a change in a climate variable under the influence of climate change. The Response Severity Scale Factor 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.

**Table 6-1 : Recommendations (cont'd)**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses: Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wastewater / Combined Collection System (cont'd)** | | | | | | | | | | | | | | | | |
| Manholes and Pipes | Heavy Rain (20)<br>5 day total Rain (20)<br>Winter Rain (20) | Additional Study as a prerequisite for Remedial Action and/or Management Action | An assessment of collection system capacity requirements under projected rainfall conditions should be completed. | Y | Y | | Y | Y | Y | Y | Y | | | $ | Short | City & Region |
| Inverted Siphons | Heavy Rain (25)<br>5 day total Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Projected increases in rainfall could increase the flow, velocities, and head loss in siphons, which has the potential to cause backups in the collection system, resulting in additional volumes of CSO's. An assessment of siphon capacity requirements under projected rainfall conditions should be completed. | Y | Y | | Y | | | | | Y | | $ | Short | City & Region |
| Reservoirs | 5 day total Rain (15) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Reservoirs in the system provide some flexibility to accommodate higher flows which will result from projected increases in rainfall. Capacity issues have already been identified at locations in the system. An assessment of reservoir capacity requirements under projected rainfall conditions should be completed. | | Y | | | Y | | Y | Y | | | $ | Medium | City & Region |
| Pumping Stations | Heavy Rain (25)<br>5 day total Rain (20) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Increased flows, as a result of projected changes in rainfall, at the pump stations may exceed pump station capacity, which could result in additional volumes (and frequency) of CSO's. An assessment of pump capacity requirements under projected rainfall conditions should be completed. | | Y | | | Y | | | Y | | | $$ | Medium | Region |
| | General | Management Action | The loss of electricity supply to the pumping stations was identified as a potential impact of severe weather. Ensure adequate backup power and / or emergency plans for the pumping stations. | | Y | | | Y | | | Y | | | $$ | Medium | City & Region |
| Flow Control Structures | Heavy Rain (25)<br>5 day total Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Assessment of the current capacity and future loads at each structure subsequent to sewer separation should be completed. Will need to build on current work (AMEC 2011) and subsequent/future needs. | Y | Y | Y | Y | Y | | Y | Y | Y | | $ | Medium | City & Region |
| CSO's | Heavy Rain (25)<br>5 day total Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Increased rainfall is expected to increase the flows at these the outfalls (given that the frequency and magnitude of CSO's is expected to increase). If the outfalls are undersized, higher discharge velocities may lead to erosion at the mouth of the outfall pipe. Additional study is required to ensure that outfall capacity and configuration is appropriate to accommodate projected future increases in rainfall. | Y | Y | Y | Y | Y | | Y | Y | Y | | $ | Medium | City & Region |

**Table 6-1 : Recommendations (cont'd)**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses: Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stormwater Collection System** | | | | | | | | | | | | | | | | |
| General | General | Management Action | It is recommended that the City of Welland continue to work with the Regional Municipality of Niagara to determine the effect of climate change on achievable flow reduction through sewer separation and inflow and infiltration programs. | Y | Y | | | | | Y | Y | Y | | $$ | Short | City & Region |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | The City of Welland municipal standards outline the design of storm sewers based on IDF curves (Rainfall Intensity Duration Frequency curves). The City of Welland has used a 1963 based IDF relationship for sewer design until the present. The Application implications of the updated (i.e., 2011) and the projected (i.e., 2020 and 2050) IDF relationships, developed for this risk assessment, should be evaluated to determine long-term applicability for sewer design. | Y | Y | | Y | | | Y | | | | $ | ASAP | City |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | The City of Welland municipal standards direct the use of the 2 year return period rainfall design event for design of storm sewers. The implications of a change in this design standard to a 5 year or a 10 year design rainfall event should be evaluated in the context of current sewer infrastructure capital plans and long-term sewer objectives. | Y | Y | | Y | | | Y | | | | $ | ASAP | City |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | City of Welland programs aimed at reducing wet weather flow in the collection systems are on-going. These should be continued and actively promoted to residents. An assessment of the applicability of green infrastructure, as an additional tool to increase resiliency in adapting to climate change, should be completed. | Y | Y | | | | | Y | Y | | | $ | Short | City |
| | | Management Action | Infrastructure funding to maintain the existing collection system and replacing aging components of the system is required. Welland should work with all levels of government to establish a consistent funding program for the sewer maintenance program. | Y | Y | | Y | | | Y | Y | Y | | $ | ASAP | City & Region |
| | | Management Action | Many of the recommendations in this study would be most effective if completed in conjunction with ongoing and new Municipal and Regional initiatives; continued co-ordination and dialogue required. | | | | | | | Y | | | | $ | ASAP | City & Region |
| | | Additional Study as a prerequisite for Remedial Action and/or Management Action | Projected increases in Winter Rain frequency was identified as potentially adding to the frequency of CSO events given that Winter Rain can occur in periods when the ground is frozen leading to significant run off episodes from minor rainfall events. The impact of Winter Rain on the stormwater collection system and flooding should be assessed. | Y | Y | | | Y | | Y | | Y | | $ | Medium | City |
| Catchbasins and Pipes | Heavy Rain (20)<br>5 day total Rain (15) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Additional study is required to ensure that sufficient capacity is available in the system to accommodate projected increase in rainfall. | Y | Y | Y | Y | | Y | Y | Y | Y | | $$ | Short | City & Region |

**Table 6-1 : Recommendations (cont'd)**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses | | | | | | | | | | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | | | |
| **Stormwater Collection System (cont'd)** | | | | | | | | | | | | | | | | |
| SWM Facilities | Heat Wave (20) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Heat Waves are considered to be a potential issue regarding stormwater management facilities and the major overland stormwater conveyance systems. There is the potential during heat waves for stormwater management facilities to lose significant volumes of retained water resulting in favourable mosquito breeding conditions. A secondary effect may be that pond 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 downstream conveyance system. | Y | Y | Y | Y | Y | Y | Y | Y | | | $ | Medium | City |
| | Heavy Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Additional study is required to ensure that sufficient capacity is available in the stormwater management system to accommodate projected increase in rainfall (related to flooding and erosion). | Y | Y | Y | Y | Y | Y | Y | Y | | | $$ | Short | City & Region |
| | Snow Accumulation (6) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Snow accumulation can be an issue in conjunction with Winter Rain in regard to performance of, stormwater management facilities and the major overland stormwater conveyance system. 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 results. The potential impact of Winter Rain coupled with Snow Accumulation in SWM Facilities should be assessed. | Y | Y | Y | Y | Y | Y | Y | Y | | | $ | Medium | City |
| Oil Grit Separators | Heavy Rain (15)<br>5 Day Total Rain (20) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Performance (i.e., sediment removals rates) of Oil/Grit Separators is typically based on historic average annual rainfall conditions. Given the projected changes in annual rainfall patterns, OGS performance is expected to be reduced. The impact of this potential change on receiving system water quality and maintenance frequency and costs should be assessed. | Y | Y | Y | Y | | | Y | | | | $ | Medium | City |
| Major Overland System (New and Old) | Heat Wave (16) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Roadways, which often act as the major system conveyance, can be significantly impacted by high temperature and heat waves both in terms of degradation of the asphalt surface and in terms of movement of harmful substances from the asphalt material into the environment, particularly with stormwater runoff. An assessment of road conditions in the context of capacity and impact for major flow and quality should be completed. | Y | Y | | Y | Y | Y | Y | Y | | | $ | Medium | City |
| | Heavy Rain (20)<br>Snow Accumulation (6)<br>Winter Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | Given the projected changes in annual rainfall patterns, the major overland runoff systems are expected to be in use more frequently, potentially leading to increased frequency of flooding. Assessment of the capacity of the major systems should be completed. | Y | Y | | Y | Y | Y | Y | Y | | | $$ | Short | City |
| Outfalls | Heavy Rain (25)<br>5 day total Rain (25)<br>Winter Rain (25) | Additional Study as a prerequisite for Remedial Action and/or Management Action | The stormwater collection system discharges to the Welland River at a number of outfalls. A potential erosion issue, due to increased extreme rainfall events, is anticipated at storm outfalls. Additional study is required to ensure that outfall capacity and configuration is appropriate to accommodate projected future increases in rainfall. | Y | Y | Y | Y | | | Y | Y | | | $ | Medium | City |

**Table 6-1 : Recommendations (cont'd)**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses | | | | | | | | | | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | | | |
| **WWTP** | | | | | | | | | | | | | | | | |
| General | Floods (7) | Additional Study as a prerequisite for Remedial Action | The impact of climate change on the Welland River 100 year flood is not known and should be quantified to determine if a vulnerability to future flood conditions exists. | Y | Y | Y | Y | Y | Y | | | Y | | $ | Short | Region |
| | High Temperature (16)<br>Heat Wave (16) | Management Action | Increases in extreme high temperatures could also impact heating / ventilation / air conditioning systems (HVAC), which could affect staff working conditions and process equipment. Ensure the HVAC systems are capable of operating effectively under projected changes in high temperature. | Y | Y | Y | Y | Y | Y | | | Y | | $$ | Medium | Region |
| | General | Management Action | Efforts toward enhanced jurisdictional co-ordination between the City and Region in regard to both the collection systems and WWTP is seen as an opportunity for both levels of government to optimize efforts. | | | | | | | Y | | | | $ | ASAP | City & Region |
| Main Pumping Station | Heat Wave (16) | Additional Study as a prerequisite for Management and/or Operational Action | Increased average temperatures could also impact the WWTP infrastructure from a corrosion perspective. Specifically, increased wastewater temperatures would enhance wastewater fermentation in the collection system, in turn producing more hydrogen sulphide. Additional hydrogen sulphide released into the atmosphere at the WWTP would increase the potential for corrosion at the facility. This risk associated with this interaction was considered to be low but should be a consideration in future design efforts. | Y | Y | | Y | Y | Y | Y | Y | | | $$ | Medium | Region |
| | Heavy Rain (15) | Management Action | Any planning efforts determining requirements for the WWTP should take climate change issues in account. | Y | Y | | Y | Y | Y | Y | Y | | | $ | ASAP | Region |
| | Tornado (14) | Additional Study as a prerequisite for Management and/or Operational Action | Tornados were considered to be of significance but only if one were to touch down at or very near to the plant. Disruption of other services related to personnel getting to/from the plant for operation and maintenance activities should be a consideration in future facility planning efforts. | Y | Y | | Y | Y | Y | Y | Y | | | $ | Medium | Region |
| Screening, Grit Removal and Flow Splitter | Heavy Rain (20)<br>5 day total Rain (20) | Management Action | Any planning efforts determining requirements for the WWTP should take climate change issues in account. | Y | Y | | Y | Y | | | Y | | Y | $ | ASAP | Region |
| | Tornado (14) | Additional Study as a prerequisite for Management and/or Operational Action | Tornados were considered to be of significance but only if one were to touch down at or very near to the plant. Disruption of other services related to personnel getting to/from the plant for operation and maintenance activities was also considered. | Y | Y | | Y | Y | | | Y | | Y | $ | Medium | Region |
| BioSolids Management | Heavy Rain (15)<br>5 day total Rain (15)<br>Hurricane/ Tropical Storm (14) | Additional Study as a prerequisite for Management and/or Operational Action | The potential impact of climate change on biosolids management (storage, land application timing, transport, environmental contamination, etc.) should be assessed. | Y | Y | | Y | | Y | Y | Y | | | $$ | Short | City & Region |

**Table 6-1 : Recommendations (cont'd)**

| Infrastructure Component | Climate Variable / (Priority of Climate Effect) | Recommendation Category | Comments on Recommendations | Performance Responses | | | | | | | | | | Cost Range | Implementation Time Frame | Recommended Action By |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Design | Functionality | Environment | Performance | Emergencies | Insurance | Policies | Social Effects | Water Quality | Economic | | | |
| **Electrical Power** | | | | | | | | | | | | | | | | |
| Transmission Lines | Ice Storm (15) | Additional Study as a prerequisite for Remedial Action | The loss of electricity from the grid is generally mitigated through maintenance of backup generation capability at the WWTP. Ensure adequate backup power and / or emergency plans for the WWTP and other pumping stations. | Y | Y | | Y | Y | | | | | | $ | Medium | City & Region |
| **Transportation** | | | | | | | | | | | | | | | | |
| Supplies Delivery | Freezing Rain (15)<br>Ice Storm (21)<br>Tornado (14) | Additional Study as a prerequisite for Management and/or Operational Action | An assessment of transportation systems specifically related to impacts to the ability of supplies to be delivered to the City and WWTP should be completed. The climate events precipitating impacts to transportation systems are also associated with disruption to electrical transmission systems suggesting the backup power system at the WWTP may also be in operation as a result of these events, requiring fuel delivery. | | Y | | Y | Y | Y | | | Y | | $ | Medium | City & Region |
| **Personnel** | High Temperature (16)<br>Heat Wave (16) | Additional Study as a prerequisite for Management Action | Current Occupational Health and Safety requirements related to outdoor activities (maintenance and operations) in Ontario in hot weather should be reviewed in the context of projected increased frequency of high temperatures and heat waves. Managerial action as required to accommodate safe working conditions in the expectation of increasing hot weather episodes should be assessed. | | | | Y | Y | Y | Y | | | Y | $ | Medium | City & Region |
| | Heavy Rain (20)<br>Freezing Rain (15)<br>Heavy Snow (25)<br>Snow Accumulation (6) | Additional Study as a prerequisite for Management and/or Operational Action | Projected changes in climate conditions may contribute to impaired movement of crews and associated resources and equipment to affect maintenance and/or emergency repairs to the collections systems and/or the WWTP. Managerial and/or operational action as required to ensure availability of maintenance staff and equipment during extreme weather should be assessed. | | | | Y | Y | Y | Y | | | Y | $ | Medium | City & Region |
| **Records** | General | Management and/or Operational Action | Log events and situations (such as infrastructure failure, maintenance issues and operations responses) related to extreme weather in an easily accessible database. | | | | | | | | | | | $ | ASAP | City & Region |
| | | Management and/or Operational Action | Record locations of street/basement flooding, approximate degree of flooding, and impacts on operations, emergency response, and the public. | Y | Y | | Y | Y | Y | Y | | Y | | $ | ASAP | City & Region |

**Table 6-2 : Municipal Storm Sewer Design Standards for Select Cities in Ontario**

| Municipality | Storm Sewer Design Standard | Year of Standard |
|---|---|---|
| London | 2 year | 2010 |
| Toronto | 2 year | 2009 |
| Welland | 2 year | 2011 |
| Barrie | 5 year | 2009 |
| Burlington | 5 year | 1977 |
| Fort Erie | 5 year | 2004 |
| Hamilton | 5 year | 2007 |
| Niagara Falls | 5 year | 1992 |
| Ottawa | 5 year | 1986 |
| St Catharines | 5 year | 1992 |
| Brampton | 10 year | 2008 |
| Mississauga | 10 year | 2009 |
| Oakville | 2 year for low / medium residential<br>10 year for high value commercial / downtown area | 2011 |
| Windsor | 25 year | 2009 |

# SECTION 7

# REFERENCES

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# 7 REFERENCES


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# APPENDICES

**APPENDIX A - Project Documentation**

**APPENDIX B - Welland Wastewater Treatment Plant, Certificate of Approval #5273-7TYN6T, dated July 30, 2009**

**APPENDIX C - Development of Projected Intensity-Duration-Frequency Curves for Welland, Ontario, Canada**

**APPENDIX D - Environment Canada Climate Normals 1971-2000 for Welland**

**APPENDIX E - Municipal Standards – Storm and Sanitary Sewers**

**APPENDIX F - PIEVC Protocol – Risk Assessment Matrices**

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# APPENDIX A

# Project Documentation

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# APPENDIX B

## Welland Wastewater Treatment Plant, Certificate of Approval

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# APPENDIX C

## Development of Projected Intensity-Duration-Frequency Curves

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# APPENDIX D

## Environment Canada Climate Normals 1971-2000 for Welland

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# APPENDIX E

## Municipal Standards – Storm and Sanitary Sewers

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# APPENDIX F

# PIEVC Protocol – Risk Assessment Matrices

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