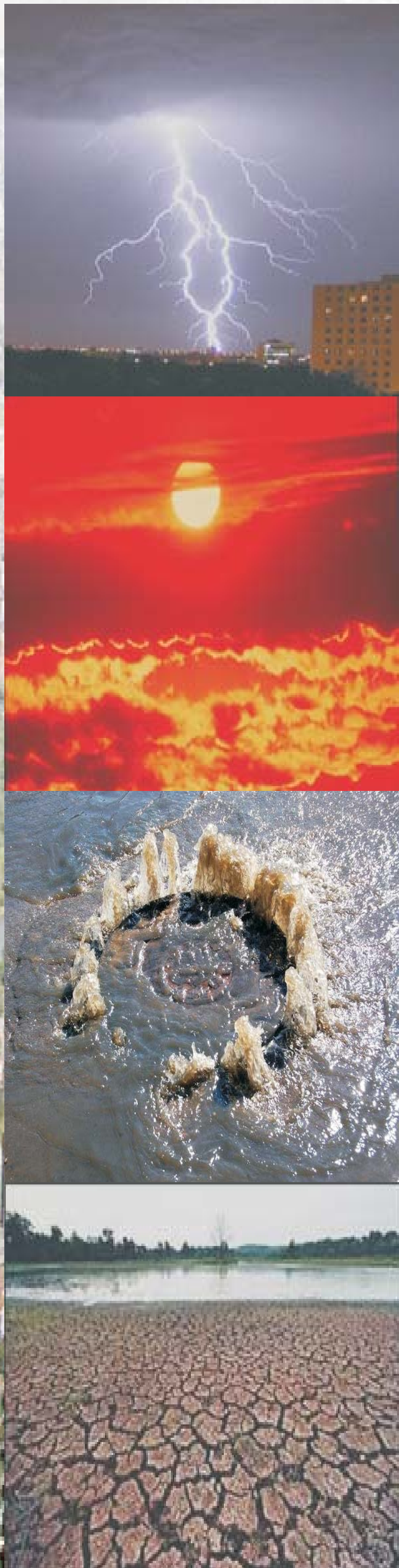
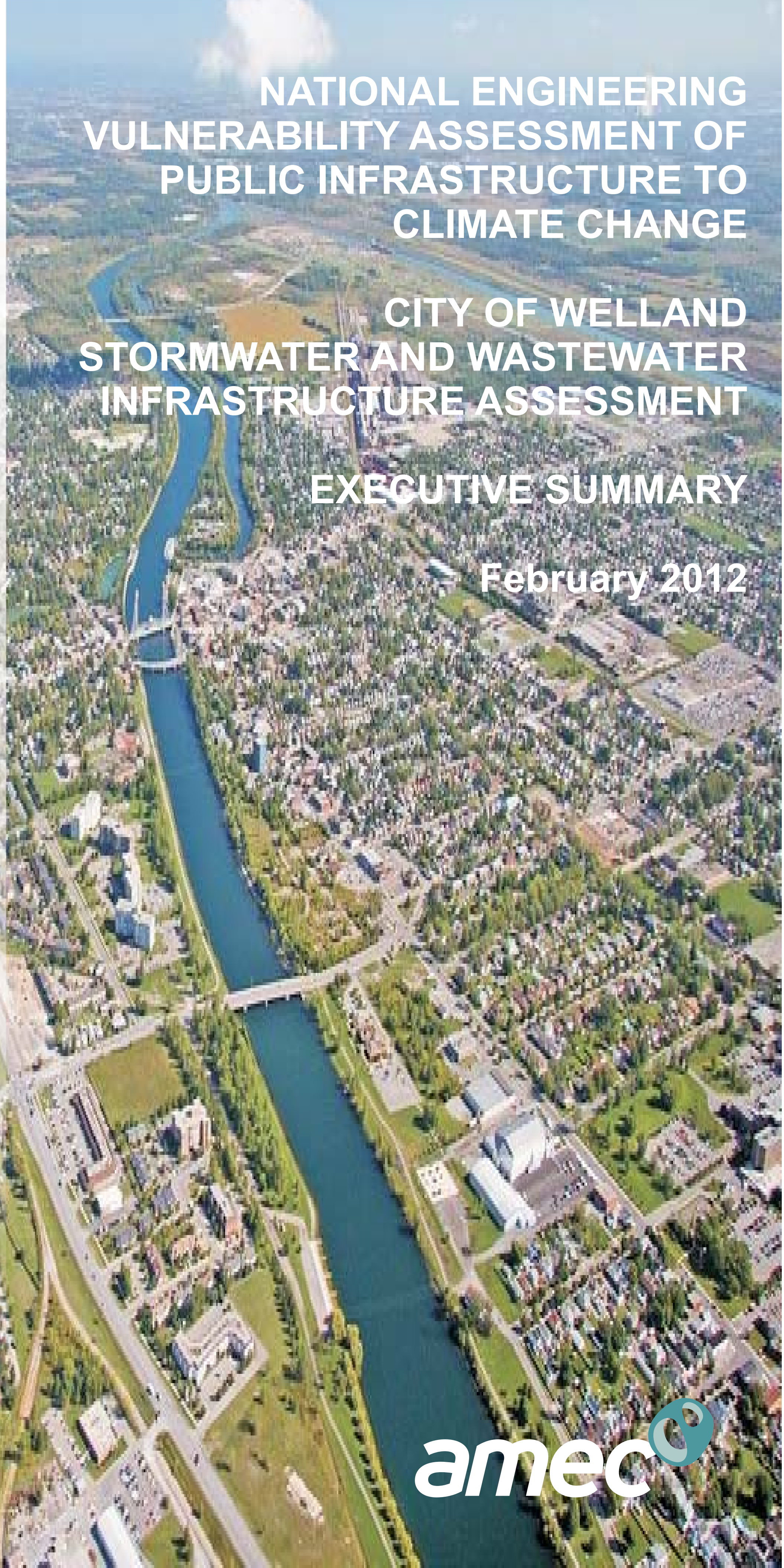
Corporation of Welland

WHERE RAILS AND WATER MEET





NATIONAL ENGINEERING VULNERABILITY ASSESSMENT OF PUBLIC INFRASTRUCTURE TO CLIMATE CHANGE

CITY OF WELLAND STORMWATER AND WASTEWATER INFRASTRUCTURE ASSESSMENT

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

Report No.: TP111002-001

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EXECUTIVE SUMMARY

Infrastructure, whether built, human or natural, is critically important to individuals and communities. The purpose of infrastructure is to protect the life, health, and social welfare of all of its inhabitants from the weather elements, to host economic activities and to sustain aesthetic and cultural values. When infrastructure fails under extreme weather conditions and can no longer provide services to communities, the result is often a disaster. As the climate changes, it is likely that risks for infrastructure failure will increase as weather patterns shift and extreme weather conditions become more variable and regionally more intense. Since infrastructure underpins so many economic activities of societies, these impacts will be significant and will require adaptation measures.

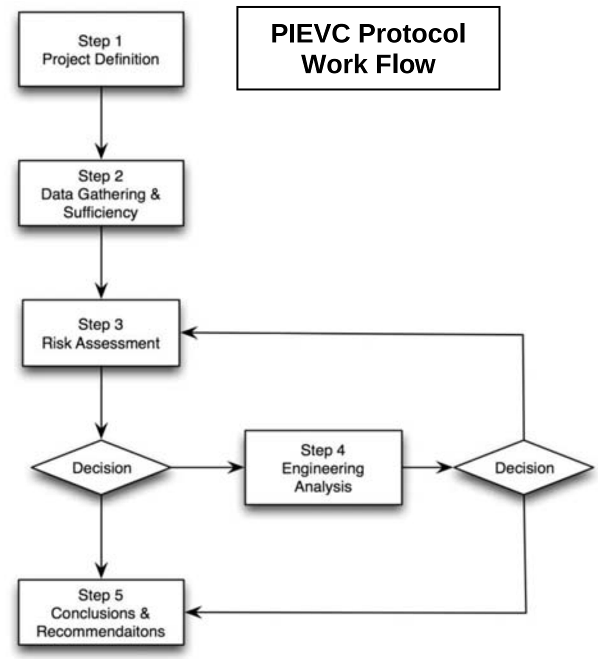
Even though municipalities share responsibilities associated with infrastructure with other levels of government, any effect of climate change is ultimately experienced locally, even if its origins are outside local jurisdictions, such as disruption of electrical power or fuel supply.

The degree to which a municipality is able to deal with the impact of climate change is often referred to as “adaptive capacity” or “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with consequences” (Intergovernmental Panel on Climate Change, 2001). The vulnerability of infrastructure systems needs to be assessed as part of municipal risk management and decision making. 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) 2906 (Mains)	17161 (Laterals) 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) 66 years (Combined)
Oldest Pipes	106 years	111 years (Sanitary) 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^oC 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 and the complete listing of recommendations is provided in Table 1.

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

Intergovernmental Panel on Climate Change, 2001 — *Climate Change 2001: Impacts, Adaptation, and Vulnerability,* Edited by James J. McCarthy Osvaldo F. Canziani, Neil A. Leary, David J. Dokken Kasey S. White, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0 521 80768 9 (hardback) / ISBN 0 521 01500 6 (paperback), 2001.

Table 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 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) 5 day total Rain (20) 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) 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) 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) 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) 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 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																
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) 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 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 (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) 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) Snow Accumulation (6) 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) 5 day total Rain (25) 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 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) 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) 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) 5 day total Rain (15) 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 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) Ice Storm (21) 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) 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) Freezing Rain (15) Heavy Snow (25) 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