Assessing Climate Change Risk to Stormwater & Wastewater Infrastructure

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Abstract

Welland, Ontario, commissioned a study to assess the resiliency of its stormwater/combined sewer systems and the wastewater treatment plant to potential climate change impacts using the Public Infrastructure Engineering Vulnerability Committee vulnerability assessment protocol in 2012/2013. The assessment outcomes are supporting municipal decision making as related to improved infrastructure risk management, thereby increasing confidence related to infrastructure planning in light of future uncertainty.

The City is using outcomes from the assessment to review options for changes to its storm sewer design criteria related to potential impacts to design performance levels for existing infrastructure and potential impacts to future expenditures for infrastructure which could influence its sewer separation program.

Keywords: climate change, risk, vulnerability, resiliency, sewer, PIEVC, adaptation

Résumé

Welland, en Ontario, a évalué la résilience de ses / réseaux unitaires d'eaux pluviales et l'usine de traitement des eaux usées, en 2013, aux impacts potentiels du changement climatique en utilisant l'ingénierie des infrastructures publiques protocole Comité sur la vulnérabilité de l'évaluation de la vulnérabilité. Les résultats de l'évaluation soutiennent personnel de la Ville pour une meilleure gestion des risques de l'infrastructure, ce qui augmente la confiance liée à la planification de l'infrastructure à la lumière de l'incertitude du futur.

La Ville utilise également les résultats de l'évaluation pour examiner les options pour des modifications à leurs critères de conception des égouts pluviaux, les impacts potentiels pour concevoir des niveaux de performance pour les infrastructures et les impacts potentiels existant pour les dépenses futures pour l'infrastructure qui pourrait influer sur leur programme de séparation des égouts.

Mots clés: Changement climatique, risque, vulnérabilité, résilience, canalisation d'égout, PIEVC, adaptation

1. Introduction

A comprehensive climate change risk assessment and adaptation planning study was completed for the City of Welland in February 2012 [2]. The assessment encompassed the municipality's stormwater and wastewater collection infrastructure including the wastewater treatment plant. The risk assessment followed the climate change vulnerability assessment protocol developed by the Public Infrastructure Engineering Vulnerability Committee (PIEVC) of Engineers Canada. A component of the risk assessment study included updating of the City of

Welland's 1960's vintage Intensity-Duration-Frequency (IDF) rainfall data and development of projected IDF curves. The objective was to develop IDF curves reflective of the predicted changes in the characteristics of precipitation that might be caused by projected changes in climate. IDF relationships were obtained for the present (namely the 2000 Environment Canada IDF relationship) and developed for two future time frames, namely 2020 and 2050.

It was anticipated that the assessment of past, present and future IDF data would establish appropriate direction for re-definition of rainfall design standards for the City of Welland. However, this assessment suggested that adoption of the 2000 IDF data over the 1963 would in fact cause a relaxation of planning standards for many types of infrastructure. Further, uncertainties embodied within the projected IDF relationships did not establish a clear path forward in this regard.

As such, recommendations were made as an outcome of the 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, as follows:

- Firstly, it was 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 the risk assessment, be evaluated to determine long-term applicability for the storm sewer collection system design, operation and maintenance.
- Secondly, it was recommended that the implications of a change from the current design standard, namely a 2 year design rainfall event, 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.

This paper documents the analyses completed towards addressing the issues identified in the above recommendations through:

- Update of the projected IDF relationships for Port Colborne.
- Assessment of the influence of the various IDF rainfall relationships on the design of stormwater management end-of-pipe systems, largely related to stormwater management quantity control.
- Assessment of a shift in the current municipal design criteria for sizing of storm sewers, 2 year return period, to a 5 year return period and beyond.

2. IDF relationships update

An objective of the 2012 climate change risk assessment study was the update the current City of Welland's design IDF rainfall data (ref. Table 1) developed in 1963. This objective was extended to also include development of future IDF data for the project time periods of 2020 and 2050. The update and projection effort was based on rainfall data published by Environment Canada in 2010 (based on a 1964 to 2000 dataset) for the weather station at Port Colborne (gauge #6136606) for the 2012 effort [2] and 2012 Environment Canada data (based on a 1964 to 2007 dataset) for the current analyses. A comparison of the 2010 and 2012 Environment Canada IDF curves, presented in Table 2, indicates notable increases in precipitation intensities for longer duration, less frequent events, in the 4% to 7% range, approximately.

Table 1. Current City of Welland design rainfall intensity data [1]

Duration	Rainfall Intensity (mm/hr) by Return Period (yrs)					
	2	5	10	25	50	100
5 min	99.8	118.1	133.4	159.5	175.0	193.8
10 min	77.2	90.6	101.3	118.5	130.2	143.0
15 min	63.6	74.4	82.8	95.9	105.5	115.4
30 min	42.8	49.9	55.3	63.4	70.0	76.3
1 hr	27.0	31.5	35.0	40.1	44.4	48.4
2 hr	16.4	19.2	21.4	24.7	27.5	30.0
4 hr	9.8	11.5	12.9	14.9	16.8	18.3
6 hr	7.1	8.4	9.5	11.1	12.5	13.7
12 hr	4.2	5.0	5.6	6.7	7.5	8.3
24 hr	2.4	2.9	3.3	4.0	4.5	5.0

Table 2. Comparison of historical IDF data for Port Colborne (#6136606)

Duration	Return Interval, Years					
	2	5	10	25	50	100
Comparison of precipitation intensities over the specified duration - 2012 to 2010						
5 min	0.6%	0.0%	*-0.2%*	*-0.5%*	*-0.7%*	*-0.8%*
10 min	0.8%	0.5%	0.4%	0.2%	0.1%	0.1%
15 min	0.8%	*-0.1%*	*-0.4%*	*-0.6%*	*-0.9%*	*-1.0%*
30 min	1.4%	0.4%	0.0%	*-0.6%*	*-0.9%*	*-1.1%*
1 hr	1.7%	0.6%	0.0%	*-0.4%*	*-0.8%*	*-0.9%*
2 hr	1.4%	0.0%	0.0%	*-0.4%*	*-0.3%*	*-0.6%*
4 hr	2.6%	2.8%	1.5%	2.5%	1.7%	2.1%
6 hr	1.7%	2.5%	5.3%	5.3%	5.5%	5.6%
12 hr	2.9%	4.1%	5.1%	5.6%	6.3%	6.8%
24 hr	5.0%	3.6%	3.0%	5.1%	4.5%	4.2%
Notes:		indicates 2012 IDF data < 2010 IDF data				

Similarly, Table 3 summarizes the comparison of the 2012 Environment Canada IDF data for Port Colborne with the current IDF design data for Welland (1963 vintage). The data reviewed for the 2012 vulnerability assessment supported the same conclusion, illustrated in Table 4, whereby aspects of the current Welland IDF data critical for storm sewer design (i.e. 2 year design basis for the City of Welland) were still conservative when compared with 2012 IDF data. However, aspects of the Welland IDF data, critical for design of stormwater management quantity controls, were not.

To develop the projected IDF curves, the precipitation intensities in the historical IDF curve were adjusted to reflect projected changes in climate using a statistical modelling technique described briefly herein and detailed in [2].

The approach selected for this work uses a statistical model that derives the sensitivity of extreme precipitation to climate conditions from the historical climate information for the site. In this case the historical climate was characterized by observations of monthly average temperature and monthly total precipitation at the Port Colborne weather station. The statistical model was fit to the local climate data and the historical monthly precipitation maxima, using a form of regression. Information about future monthly average temperature and monthly total precipitation was obtained from the output of 112 runs of General Circulation Models (GCMs) sourced through the World Climate Research Programme's Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset [4].

Table 3. Comparison of 2012 to 1963 IDF Data for Port Colborne (#6136606)

Duration	Return Interval, Years					
	2	5	10	25	50	100
5 min	*-6%*	*-2%*	*-1%*	*-6%*	*-6%*	*-8%*
10 min	*-16%*	*-7%*	*-5%*	*-5%*	*-5%*	*-5%*
15 min	*-17%*	*-7%*	*-3%*	*-2%*	*-1%*	*-1%*
30 min	*-15%*	*-2%*	4%	8%	9%	10%
1 hr	*-14%*	1%	7%	11%	12%	14%
2 hr	*-15%*	*-3%*	1%	4%	4%	5%
4 hr	*-19%*	*-3%*	5%	8%	5%	5%
6 hr	*-17%*	*-1%*	5%	8%	8%	9%
12 hr	*-14%*	2%	11%	12%	12%	13%
24 hr	*-13%*	0%	3%	2%	2%	0%
	(shaded)	indicates 2012 IDF data < 1963 IDF data				

The archive contains projections of monthly precipitation and temperature, with each projection consisting of an overlap period from 1950 through 1999 and a projection period from 2000 through 2099. Each projection is the output from a run of one of 16 GCMs using one of the B1, A1B or A2 emissions scenarios. Each GCM run was compared internally to establish a projected future 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 approach, which is referred to as the delta approach, is used to reduce some of the inevitable bias inherent in projections of future climate.

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 and six return intervals. 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. For reporting purposes, these results were aggregated into the mean, maximum and 90th percentile non-exceedance value of precipitation intensity for each duration and return interval. The maximum results for 2020 and 2050 are summarized in Table 4.

Also presented in Table 4, is the comparison between the 2020 and 2050 maximum IDF data with the current Welland design IDF data. This comparison confirms that all projected rainfall intensities for these scenarios exceed the current Welland design intensities. However, comparison of the mean and 90th percentile non-exceedance value precipitation intensity estimates did not yield a similar conclusions in that IDF values reflected in the current Welland design data were still conservative for both 2020 and 2050.

Table 4. Projected 2020 and 2050 Maximum IDF Data

Duration	Precipitation intensities (mm/hr) by Return Interval (years) with percentage change from current Welland IDF					
	2	5	10	25	50	100
2020						
5 min	134.8 / 35%	150.6 / 28%	162.9 / 22%	179.5 / 13%	192.3 / 10%	205.1 / 6%
10 min	90.6 / 17%	103.7 / 14%	113.7 / 12%	126.9 / 7%	137.0 / 5%	147.3 / 3%
15 min	72.1 / 13%	83.6 / 12%	92.3 / 11%	103.8 / 8%	113.1 / 7%	123.1 / 7%
30 min	49.7 / 16%	61.5 / 23%	69.5 / 26%	79.9 / 26%	87.5 / 25%	95.3 / 25%
1 hr	32.5 / 20%	40.2 / 28%	45.5 / 30%	52.3 / 30%	57.5 / 30%	62.6 / 29%
2 hr	19.5 / 19%	23.5 / 22%	26.4 / 23%	30.1 / 22%	32.9 / 20%	35.8 / 19%
4 hr	11.4 / 16%	14.4 / 25%	16.4 / 27%	18.9 / 27%	20.7 / 23%	22.6 / 23%
6 hr	8.5 / 20%	10.9 / 30%	12.6 / 33%	14.5 / 31%	16.0 / 28%	17.5 / 28%
12 hr	4.8 / 14%	6.5 / 30%	7.7 / 38%	9.1 / 36%	9.9 / 32%	10.9 / 31%
24 hr	2.9 / 21%	3.8 / 31%	4.3 / 30%	5.0 / 25%	5.5 / 22%	5.9 / 18%
2050						
5 min	143.7 / 44%	158.2 / 34%	170.0 / 27%	186.2 / 17%	198.6 / 13%	211.3 / 9%
10 min	96.4 / 25%	108.7 / 20%	118.4 / 17%	131.3 / 11%	141.4 / 9%	151.5 / 6%
15 min	76.5 / 20%	87.3 / 17%	95.8 / 16%	107.2 / 12%	115.8 / 10%	124.5 / 8%
30 min	51.1 / 19%	62.7 / 26%	70.8 / 28%	81.1 / 28%	88.7 / 27%	96.5 / 26%
1 hr	33.4 / 24%	41.0 / 30%	46.3 / 32%	53.2 / 33%	58.3 / 31%	63.4 / 31%
2 hr	20.1 / 23%	24.0 / 25%	26.9 / 26%	30.6 / 24%	33.4 / 21%	36.2 / 21%
4 hr	11.8 / 20%	14.6 / 27%	16.7 / 29%	19.2 / 29%	21.0 / 25%	22.9 / 25%
6 hr	8.8 / 24%	11.1 / 32%	12.8 / 35%	14.8 / 33%	16.3 / 30%	17.8 / 30%
12 hr	4.9 / 17%	6.6 / 32%	7.9 / 41%	9.2 / 37%	10.1 / 35%	11.1 / 34%
24 hr	3.0 / 25%	3.9 / 34%	4.4 / 33%	5.1 / 28%	5.6 / 24%	6.0 / 20%

3. IDF shift and influences on stormwater management

This component of the analysis focused on the influence of changing design rainfall on the design of stormwater management end-of-pipe systems, largely related to the objective of stormwater management quantity control (flooding and erosion management). For this assessment, a pilot study area and hydrologic model was provided by the City of Welland as a base, which could then be evaluated using the current design storm approach (based upon the existing IDF information) and then compared against the proposed 2020 and 2050 IDF data. The 2 year through 100 year design storms were evaluated and the requisite flood storage for post- to pre-development land use, in compliance with Province of Ontario [5] and local municipal guidelines [1], developed accordingly. This required the computation of Existing, Future without stormwater management, and Future with stormwater management Land Use Conditions, from which the required stormwater management volumes would be derived accordingly. The differences in the required stormwater management volumes were then used to establish additional construction costs and additional land requirements, which were then converted into a cost premium as a percentage over the existing base design.

3.1 SWM facility performance and design, based on current IDF design rainfall

The hydrologic model provided by the City for this evaluation represents the Brookhaven Estates residential development [6] located in the north-west area of the City near the intersection of South Pelham Road and Woodlawn Road (ref. Figure 1). The development consists of 23 residential lots for Phase 1 and an additional 15 lots for Phase 2 covering an area of about 2.5 hectares (ha). The stormwater management (SWM) plan for the development expanded an existing SWM facility located on the north side of the development which also serves a portion of the residential area to the north (an area of about 8.4 ha).

The SWM facility was designed based on post-development peak flows being maintained equal to, or less than, pre-development peak flows for the 2, 5, 10, 25, 50 and 100 year storm events and has the following features [6]:

- Pond bottom elevation of 181.45 m
- 5:1 (H:V) transition from pond bottom to elevation 183.15 m and 3:1 (H:V) transition from elevation 183.15 m to elevation 184.20 m
- An outlet configuration consisting of a 100 mm diameter orifice (invert at elevation 183.1 m) plus an overflow weir with crest at elevation 183.80 m having length 1.83 m and thickness of 200 mm.
- 2 year and 100 year pond elevations documented as 183.75 m and 184.10 m, respectively.

The design of the Brookhaven Estates SWM facility based on the current Welland IDF design rainfall is summarized in Table 5.

Table 5. SWM facility design based on the current IDF design standard

Return Period (yrs)	Peak Flows (m^3/s)			SWM Facility Metrics	
	Pre	Post no controls	Post with controls	Level (m)	Volume (m^3)
2	0.089	0.589	0.051	183.85	1350.51
5	0.143	0.766	0.098	183.89	1437.00
10	0.195	0.920	0.145	183.93	1507.70
25	0.287	1.171	0.229	183.98	1618.05
50	0.388	1.369	0.326	184.03	1730.70
100	0.474	1.583	0.421	184.08	1831.61

3.2 SWM facility performance and design based on other IDF data

Table 6 summarizes the investigation of scenarios whereby the current current IDF design standard is used to design the volumetric requirements of the Brookhaven Estates SWM facility and then at some point in the future, the pond must perform under alternate rainfall conditions, as represented by the various IDF relationships previously discussed.

The results of this analysis suggest that, although SWM facility performance is degraded, the pond will be able to safely pass stormwater runoff resulting from all of the evaluated rainfall events with the exception of two (2); namely the 100 year storm (maximum variation) for 2020 and 2050. It would be expected that under these two rainfall conditions overtopping of the SWM facility embankment would occur, resulting in possible failure of the containment embankment. It should also be noted that under numerous other rainfall conditions freeboard under maximum computed water levels would be essentially zero (0).

Table 7 summarizes the assessment of the SWM facility design based on the alternate design rainfall IDF relationships. For this evaluation an estimate of the additional land area required to support additional storage volume requirements was also included. In this case, the pond width was maintained as constant and the length varied to develop the additional storage required.

Based on the known location and dimensions for the approved SWM facility it is clear that this assumption would not have been an option as the current SWM facility essentially occupies all of the available land up to the creek allowance. Expansion of the pond area to develop additional storage would have most likely required a re-configuration of the lots within the development.

Table 6. SWM facility performance for various IDF scenarios

Return Period (yrs)	Event Duration (hrs)	Peak Flows (m^3/s)			SWM Facility Metrics		*Change from Design*	
		Pre	Post no controls	Post with controls	Level (m)	Volume (m^3)	*Maximum Water Level (m)*	*Volume (m^3)*
2012								
2	4	0.051	0.458	0.017	183.74	1120	*-0.11*	*-230*
5	4	0.142	0.725	0.097	183.89	1435	*0.00*	*-2*
10	4	0.227	0.918	0.175	183.95	1551	*0.02*	*44*
25	4	0.360	1.181	0.307	184.02	1709	*0.04*	*91*
50	4	0.487	1.391	0.431	184.08	1842	*0.05*	*112*
100	4	0.613	1.598	0.560	184.14	1968	*0.06*	*137*
2020 Maximum								
2	4	0.145	0.785	0.099	183.89	1439	*0.04*	*89*
5	4	0.275	1.036	0.218	183.97	1605	*0.08*	*168*
10	4	0.386	1.211	0.332	184.03	1737	*0.11*	*230*
25	4	0.540	1.473	0.499	184.11	1910	*0.13*	*292*
50	4	0.674	1.673	0.607	184.16	2012	*0.13*	*282*
100	4	0.846	1.884	Overtopped			*N/A*	*N/A*
2050 Maximum								
2	4	0.158	0.846	0.108	183.90	1455	*0.05*	*105*
5	4	0.285	1.097	0.229	183.99	1619	*0.09*	*182*
10	4	0.409	1.275	0.354	184.04	1762	*0.12*	*254*
25	4	0.546	1.528	0.514	184.12	1924	*0.14*	*306*
50	4	0.708	1.736	0.634	184.17	2037	*0.14*	*306*
100	4	0.880	1.932	Overtopped			*N/A*	*N/A*

Table 7. SWM facility design based on alternate IDF scenarios

IDF Scenario	SWM Facility Metrics				Approximate Additional Cost		
	Total Volume Required (m^3)	Additional Volume Required (m^3)	Additional Land Required (m^2)	(%)	Land[1] $$$	Construction[2] $$$	Total $$$
Current City of Welland	1831.6	----	--	--	---	--	---
2012	2299.7	468.1	614.5	24%	$92,170	$30,426	$122,595
2020 - Maximum	3280.4	1448.8	1879.1	74%	$281,865	$94,171	$376,036
2020 – 90th Percentile	2652.1	820.5	1060.8	42%	$159,121	$53,332	$212,453
2020 - Mean	2428.3	596.7	763.2	30%	$114,487	$38,785	$153,271
2050 - Maximum	3455.3	1623.7	2102.3	83%	$315,340	$105,540	$420,880
2050 – 90th Percentile	2881.4	1049.8	1358.4	54%	$203,755	$68,236	$271,991
2050 - Mean	2532.2	700.6	912.0	36%	$136,804	$45,538	$182,342

The SWM facility, as constructed, controls the 100 year design event runoff to a water level of 184.08 m while utilizing a storage volume of about 1800 m^3. As a result of the second evaluation, it was determined that the 2012 IDF relationship results in higher runoff (volume and peak flow) which, in turn, results in the need for a SWM facility having a larger volume. It was further determined that a SWM facility having a maximum operational volume of about 3500 m^3 would be required to adequately control the 100 year event (for the 2050 Maximum IDF) while maintaining a maximum water level of 184.08 m. This required storage volume is about 90% more than the approved design.

Notwithstanding the limitations of the valuation assumption used in this regard, an estimate of the value of the land was based on information provided by the City of Welland Integrated Services - Planning Division. The City indicated that a sale value of approximately $1,400 to $1,500 per linear foot of frontage as a reasonable estimate. This valuation was associated with a standard lot within the development which has dimensions 14.39 m (frontage) by 33.49 m (depth). This results in an approximate valuation of about $71,000 for a lot or about $150 per square metre. This unit value of land was used to estimate the additional cost associated with the alternate SWM facility designs.

As a result of the additional required storage volumes for the alternate rainfall conditions, the extra costs for construction ranged from about $95,000 to about $420,000. The latter cost associated with building the extra storage required to control the 100 year 2050 Maximum design storm.

When making decisions that will be affected by climate, it is important to consider that the industry's understanding of climate and climate change will increase with time, so a decision that can be delayed may benefit from new and better information. Given the uncertainty associated with rainfall projections into the future, but recognizing the possible need to expand SWM control facilities in the future, a prudent adaptation planning approach would be to set aside lands near the existing facility, or planned/proposed facility, such that expansion in the future, if necessary, can be accommodated.

4. Change in municipal design standard

Welland currently uses a 2 year design criteria, in conjunction with the IDF relationship outlined in Tables 1 and 2, for storm sewer design. This component of the evaluation quantified:

(1) impacts resulting from a shift in sizing of storm sewers to one of the other IDF relationships, and;

(2) an alternate return period design basis.

Based upon the change in required sewer pipe size, a cost premium was developed as a percentage over the network based on incremental pipe cost. This assessment provides a level of financial impact, which can then be weighed against the increased benefit associated with reduced minor system flood risk.

The general expectation of extreme rainfall in southern Ontario, as influenced by climate change, suggests less days with rain but larger (higher volume and intensity) rainfall events when they do occur. Some research even suggests the return period associated with specific rainfall events will be halved; that is, the current 100 year rain will become the future 50 year rain; the current 10 year rain will become the future 5 year rain; and so on. In light of this, a change to a less frequent return period design rainfall may be considered good engineering judgment and a means of ensuring adequate performance of newly designed stormwater infrastructure.

4.1 Storm sewer design based on current IDF design rainfall

Storm sewer design sheets for the Brookhaven Estates residential development were made available from the City of Welland and formed the basis of this component of the assessment. The design sheets described six (6) storm sewer segments (pipe sizes 300 mm to 525 mm diameter) over a linear length of about 300 m with excess capacities greater or equal to 8%. It was recognized that this is a relatively simple network and the extra capacity available in the design may in fact mask issues associated with storm sewer design when considering alternate IDF relationships as reflected in this assessment.

The issue noted in regard to the Brookhaven Estates storm sewer network suggested that an assessment using a larger, more complex storm network with larger pipe elements may reflect a different outcome. As a result of this concern, the City of Welland provided a larger storm sewer network design comprising 40 pipes ranging in size from 200 mm to 1200 mm diameter. This network was designed for the Webber Estates residential development [7] which is comprised of sixty-five (65) single family homes and thirty-seven (37) townhouses. The storm sewer design sheets for the Webber Estates development were made available from the City of Welland and formed the basis of this component of the assessment. Excess capacities for this network are greater or equal to 4% and vary significantly (4% to 67%) over the range of pipe diameters in the network.

4.2 Storm sewer design based on other IDF data

Table 8 summarizes the results of the alternate storm sewer designs based on the other IDF relationships for the Brookhaven Estates development. The evaluation was completed for all alternate IDF data for the 2 year, 5 year, 10 year and 25 year design return periods.

The assessment indicates that applying some of the alternate IDF data would not change the storm sewer network design (e.g. 2 year – 2020, 90th percentile and Mean IDF and 2005 Mean IDF). The upper range incremental cost (59%) represents the design associated with the 2050 Maximum IDF relationship. The evaluation also indicates that of the 32 alternate IDF relationships used as the basis for the storm sewer network design, only 7 alternate network designs result. Further, within a matrix of 32 possible design alternatives 18 (or 56%) yield the same design. This is particular interesting for the 10 year design basis where all alternate IDF data yield the same network design. As well, this same network design is represented across all of the return period design basis. For example, the network designed for a 2020 2 year Maximum IDF will maintain a 2 year performance level for the 2050 2 year Maximum IDF, as well accommodate without surcharge the 2050 5 year Maximum IDF, 2050 10 year Maximum IDF and a 25 year event under current conditions (as represented by the Environment Canada 2012 IDF relationship).

Similarly, Table 9 summarizes the results of the alternate IDF design basis assessment for the Webber Estates storm sewer network. A similar colour shading association is reflected where the storm sewer design for the development is common across alternate IDF relationships.

Similar relationships and comparison between the designs associated with the alternate IDF relationships can be made for the Webber Estates storm sewer network. Although, it is clear from this assessment that different storm sewer networks will be impacted differently under various design precipitation scenarios.

Table 8. Storm sewer design summary for Brookhaven Estates with alternate IDF data

Feature	Current Design IDF	EC IDF	Maximum IDF	90th Percentile IDF	Mean IDF	Maximum IDF	90th Percentile IDF	Mean IDF
	1963	2012	2020			2050		
	Pipe Sizes (mm) and Costs based on a 2 Year Design Rainfall							
Total Pipe Cost	$28,352	$28,352	$35,102	$28,352	$28,352	$35,102	$31,360	$28,352
% of Original Cost	100%	100%	124%	100%	100%	124%	111%	100%
	Pipe Sizes (mm) and Costs based on a 5 Year Design Rainfall							
Total Pipe Cost	$32,069	$32,069	$35,102	$35,102	$32,069	$35,102	$35,102	$35,102
% of Original Cost	113%	113%	124%	124%	113%	124%	124%	124%
	Pipe Sizes (mm) and Costs based on a 10 Year Design Rainfall							
Total Pipe Cost	$35,102	$35,102	$35,102	$35,102	$35,102	$35,102	$35,102	$35,102
% of Original Cost	124%	124%	124%	124%	124%	124%	124%	124%
	Pipe Sizes (mm) and Costs based on a 25 Year Design Rainfall							
Total Pipe Cost	$35,102	$35,102	$45,144	$41,310	$35,102	$45,144	$42,142	$41,310
% of Original Cost	124%	124%	159%	146%	124%	159%	149%	146%
Notes:			*City of Welland Approved Design and similar alternate designs*					
	Colour coded cells		*Cells colour coded where the storm sewer design is the same*					

Table 9. Storm sewer design summary for Webber Estates with alternate IDF data

Feature	Current Design IDF	EC IDF	Maximum IDF	90th Percentile IDF	Mean IDF	Maximum IDF	90th Percentile IDF	Mean IDF
	1963	2012	2020			2050		
	Costs based on a 2 Year Design Rainfall							
Total Pipe Cost	$310,580	$310,580	$333,125	$312,289	$310,580	$333,125	$323,656	$310,580
% of Original Cost	100%	100%	107%	101%	100%	107%	104%	100%
	Costs based on a 5 Year Design Rainfall							
Total Pipe Cost	$333,125	$325,733	$333,125	$332,865	$333,125	$337,132	$333,125	$333,125
% of Original Cost	107%	105%	107%	107%	107%	109%	107%	107%
	Costs based on a 10 Year Design Rainfall							
Total Pipe Cost	$333,125	$333,125	$360,730	$333,125	$333,125	$368,218	$337,132	$333,125
% of Original Cost	107%	107%	116%	107%	107%	119%	109%	107%
	Costs based on a 25 Year Design Rainfall							
Total Pipe Cost	$352,083	$352,083	$369,752	$369,752	$360,730	$370,496	$369,752	$363,517
% of Original Cost	113%	113%	119%	119%	116%	119%	119%	117%
Notes:			*City of Welland Approved Design and similar alternate designs*					
	Colour coded cells		*Cells colour coded where the storm sewer design is the same*					

Of importance, though, in comparison between the results for the Brookhaven Estates and the Webber Estates scenarios, is where common storm sewer designs result. For the Brookhaven Estates scenario a common design results in 18 (24% premium over the original cost estimate) of the 32 alternate design IDF relationships. Similarly, for Webber Estates a common design results in 13 (7% premium over the original cost estimate) of the 32 alternate design IDF relationships.

In contrast to the adaptation plan suggested for expansion of the SWM facility, decisions regarding adaptation planning and implementation for subsurface infrastructure should be made at the time of major reconstruction when excavations are open. At this time, for storm sewer networks, the incremental cost of adaptation can be directly related to the cost of installing the next larger commercial pipe size.

5. Conclusions

Stationarity is founded upon the idea that natural systems are variable only within a defined boundary. It implies that any variable, including precipitation, has a probability density function that does not change with time, and whose characteristics can be estimated from a time series of data collected in the field [3]. With projected changes in climate variability, precipitation included, it is suggested that changes will also occur with the characteristics of the associated probability density function. This would suggest that reliance on historical data as a means of estimating future occurrence, may not be the best approach.

The development of projected IDF relationships provides the basis upon which assessment of the implications of changing rainfall patterns on infrastructure design and performance, can be based. For this assessment, when considering how to interpret the projected values the first decision 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 apply the 2050 estimates.

It was noted in the vulnerability assessment [2], that the Maximum IDF representation is typically excluded as the basis for planning decisions as it represents a single estimate, from the ensemble of estimates, and is therefore quite sensitive to error or artefacts. Quantile values, such as the 90th Percentile value and the Mean, are estimated in the context of all ensemble values and are therefore not as volatile. As the Mean IDF representation embodies the broadest base of future precipitation estimates, a Mean IDF representation should be used for future assessment and design of infrastructure.

This result suggests that adopting a 10 year design standard may be possible with no or limited additional financial impact to design and construction of the storm sewer networks when compared with a 5 year design standard for the 2050 Mean IDF relationship. This holds true across both storm sewer network examples. This would require additional investment in infrastructure as demonstrated by this analysis in the range 7% to 24% however, the benefits would be tangible though, in less frequent major system flooding and development of adequate minor system capacity to accommodate expected changes in future rainfall patterns for more frequent and intense rainfall events.

6. References

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7. Biographies

Peter Nimmrichter has over 25 years of experience in surface water resources engineering for the public and private sector. Peter has been involved in climate change related projects for the past 10 years with a focus on climate change vulnerability assessment and adaptation planning for municipal infrastructure and flood risk management. Peter is currently the Vice Chair of the Climate Change Committee for the Ontario Water Works Association.

Ron Scheckenberger has worked in the water resources engineering field since 1981. His expertise extends to all areas of water resources including watershed planning, stormwater policy preparation, stormwater quality and quantity management, hydraulics, hydrology, flood/erosion control, conceptual, preliminary/final design, economic evaluations, Development Charges, implementation programming, compliance monitoring, permitting/approvals, peer review, and expert testimony. Ron has authored or co-authored over 30 technical papers and presented many of these at conferences in Canada and the United States.

Marvin Ingebrigtsen is a Professional Engineer specializing in Water Resource Engineering. Marvin has been employed by the City of Welland since 2005. Marvin is currently the Technical Analyst - Infrastructure Programs, responsible for the city infrastructure asset management. Prior to joining the City of Welland, Marvin spent approximately eleven years in the Consulting Engineering field involved primarily with the design and construction of municipal drainage, capital and private development projects.