Ontario

Ministry of Transportation

Addressing Climate Change through Engineering Practice

Climate Data Training Session for Municipal and Conservation Authority Engineers, Planners and Decision Makers

Toronto - 26 April 2017

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Ontario Ministry of Transportation

Presentation Outline

- General introduction
- Overview of Findings of MTO's climate change Investigations
- New MTO Tools Supporting Design in a Changing Climate
- MTO Design Policies Addressing Climate Change
- Next Steps

General Introduction

- The Ontario Ministry of Transportation is responsible for the administration of 1,776 km of controlled access highway and about 15,000 km of other highways.

- MTO also administers:
  - 2800 bridges of which 1310 are over water; and
  - about 2000 structural culverts (span ≥3m) and about 55,000 non-structural culverts (span< 3m)

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MTO Highway Design Documents

- MTO undertakes the design of drainage highway infrastructure based on design standards, procedures and methods published in a number of documents such as:
  - MTO Drainage Design Standards
  - MTO Drainage Management Manual
  - Guidelines (e.g. Gravity Pipe Design Guidelines)
  - Study reports (e.g. Hydrologic Design Methods, Resilience to Climate Change, Salt Impact Mitigation)
  - Provincial Engineering Memos (implementing new findings in design)

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Highway Design Documents (Cont.)

- These documents are updated on a regular basis to transfer research finding into practical application in design
- MTO depends on academic and field research to provide the fundamentals of new design methods and procedures
- Work undertaken by other jurisdictions/agencies is reviewed and the results are used to improve the design methods and procedures.

Climate Change Investigations

- MTO began the research into climate change impacts on drainage infrastructure in 2005
- Over the subsequent years research funding was secured to continue to support new innovation in design, especially, in light of climate change
- The research was undertaken in cooperation with a number of universities

Research Activities

The following studies have been undertaken to begin to understand the issue and take advantage of available data and information

1. *Identification of the Effect of Climate Change on Future Design Standards of Drainage Infrastructure in Ontario.* MTO Report HIIFP-022, 2006. Coulibaly, Paul and Shi, Xiaogang, McMaster University
2. Review of *Climate Change Data Portal using 5-member PRECIS ensemble (UK Met Office) U of Regina, 2014 - Part 1, of the Report on Investigation of Resilience, MTO 2015.*
3. *Investigation of the Resilience of Ontario Highway Drainage Infrastructure to Climate Change*. MTO Report DCSO-01, 2015
4. Development of a new empirical method for flow calculation in Ontario using the latest available rainfall and stream flow data. *Unified Ontario Flood Method (UOFM) Regional Flood Frequency Analysis of Ontario Streams Using Multiple Regression, U of Toronto, April 2016*
5. *Trend Analysis of Ontario Rainfall Record, Part 3 of the Intensity-Duration-Frequency Curves Study*, Ric Soulis, U of Waterloo, 2016

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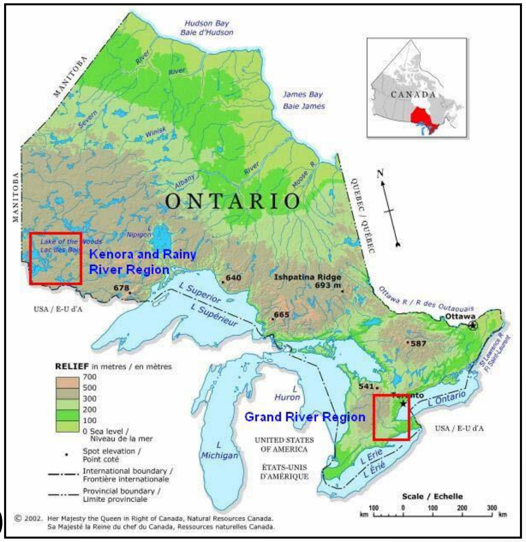
Findings of the Different Studies



1. Coulibaly, Paul and Shi, Xiaogang, McMaster University, 2006
   - This study conducted statistical downscaling model (SDSM) of CGCM2 outputs
   - This result was limited to 4 locations in southern Ontario and 4 in northern Ontario
   - Overall, the study results indicated strong and significant increase (about 24% and 35% on average) in the rainfall intensity by 2050s and 2080s respectively.

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Study Findings (Cont.)

2. Review of Climate Change Data Portal using 5-member PRECIS ensemble:
   - Findings from this review identifies the order of magnitude of climate change based on IDF values for the entire province.
   - It also provided a better understanding of how to interpret IDF predictions

Sample IDF for Northern Ontario

Based on IDF data from Climate Change Data Portal, U of Regina

2065-2095 Rainfall Prediction

Comparison to MTO 2007 IDF Curves
Bias not corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	-54%	-39%	-31%	-17%	-4%	7%	27%	38%	53%
5_yrs	-42%	-24%	-15%	0%	13%	25%	41%	51%	56%
10_yrs	-38%	-19%	-8%	8%	22%	33%	47%	55%	55%
25_yrs	-34%	-13%	-1%	16%	30%	40%	52%	58%	52%
50_yrs	-32%	-10%	2%	20%	34%	45%	56%	60%	54%
100_yrs	-30%	-8%	5%	24%	38%	47%	58%	60%	53%

Comparison to IDF curve for 1960-1990 base year
Bias corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	40%	40%	40%	40%	39%	35%	26%	22%	18%
5_yrs	37%	37%	37%	37%	37%	37%	26%	24%	21%
10_yrs	36%	36%	36%	36%	36%	38%	26%	26%	24%
25_yrs	34%	34%	34%	34%	34%	39%	26%	28%	26%
50_yrs	33%	33%	33%	33%	33%	40%	26%	29%	27%
100_yrs	33%	33%	33%	33%	33%	41%	26%	30%	29%

Comparison to IDF curve for 2007 base year
Bias corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	18%	18%	18%	18%	18%	17%	17%	14%	11%
5_yrs	16%	16%	16%	16%	16%	17%	17%	15%	13%
10_yrs	15%	15%	15%	15%	15%	17%	16%	16%	14%
25_yrs	14%	14%	14%	14%	14%	17%	16%	17%	15%
50_yrs	13%	13%	13%	13%	13%	17%	16%	18%	16%
100_yrs	12%	12%	12%	12%	12%	17%	15%	19%	16%

-50% -30% -0% +20% +40% +60%

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Sample IDF for Southern Ontario

Based on IDF data from Climate Change Data Portal, U of Regina

2065-2095 Rainfall Prediction

Comparison to MTO 2007 IDF Curves
Bias not corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	-44%	-28%	-18%	-4%	8%	19%	34%	44%	53%
5_yrs	-26%	-4%	8%	22%	30%	35%	41%	46%	48%
10_yrs	-20%	4%	18%	34%	42%	45%	44%	45%	46%
25_yrs	-14%	13%	27%	46%	53%	53%	49%	47%	45%
50_yrs	-10%	17%	32%	51%	58%	58%	52%	47%	45%
100_yrs	-7%	21%	36%	56%	63%	62%	55%	48%	45%

Comparison to IDF curve for 1960-1990 base year
Bias corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	8%	8%	8%	8%	8%	5%	4%	7%	6%
5_yrs	12%	12%	12%	12%	12%	7%	5%	7%	4%
10_yrs	14%	14%	14%	14%	14%	9%	6%	8%	3%
25_yrs	16%	16%	16%	16%	16%	11%	6%	8%	2%
50_yrs	18%	18%	18%	18%	18%	12%	7%	8%	1%
100_yrs	19%	19%	19%	19%	19%	13%	7%	9%	1%

Comparison to IDF curve for 2007 base year
Bias corrected

	5_min	10_min	15_min	30_min	1_hr	2_hr	6_hr	12_hr	24_hr
2_yrs	2%	2%	2%	2%	2%	-2%	1%	4%	3%
5_yrs	4%	4%	4%	4%	4%	0%	0%	4%	2%
10_yrs	6%	6%	6%	6%	6%	0%	-1%	4%	2%
25_yrs	7%	7%	7%	7%	7%	1%	-1%	4%	1%
50_yrs	8%	8%	8%	8%	8%	1%	-2%	4%	1%
100_yrs	9%	9%	9%	9%	9%	2%	-2%	4%	0%

-50% -30% -0% +20% +40% +60%

Lesson learned from this study

- Based on the findings from IDF comparison, the range of rainfall increase was identified as:
    - 10% - 30 % increase over the 2014 design condition
- These values were used as guidance for the assessment of the potential climate change impact on the highway drainage infrastructure analysis
- They were not considered to be the definitive climate change future predictions

Scale of rainfall variability based on historic data:
~15% increase from 25-yr to 50-yr
~15% increase from 50-yr to 100-yr

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3- Infrastructure Resilience Study

The main focus of the study was to identify if current Ontario highway drainage design standards and procedures provide resilience to possible hydrologic impacts of climate change

Canada

Finding for Storm Sewers Capacity

Network 1: (Highway 37)

Scenario	Number of Pipes Not Exceeding Design Capacity of 100% Full	Percentage of Pipes Not Exceeding Design Capacity of 100% Full	Number of Pipes Exceeding Design Capacity of 100% Full	Percentage of Pipes Exceeding Design Capacity of 100% Full
10% Increase	25	100%	0	0%
20% Increase	24	96%	1	4%
30% Increase	24	96%	1	4%

Network 2: (Highway 417)

Scenario	Number of Pipes Not Exceeding Design Capacity of 100% Full	Percentage of Pipes Not Exceeding Design Capacity of 100% Full	Number of Pipes Exceeding Design Capacity of 100% Full	Percentage of Pipes Exceeding Design Capacity of 100% Full
10% Increase	23	100%	0	0%
20% Increase	22	96%	1	4%
30% Increase	19	83%	4	17%

Test Criteria: Pipe Capacity exceeding 100% full

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Finding for Spread on Roadway

Flow Spread for the Major Flow (Hwy 37)

	Base Case m	10% Increase m	20% Increase m	30% Increase m
Average Spread	1.12	1.14	1.18	1.22
Maximum Spread	2.34	2.43	2.51	2.59
Minimum Spread	0.33	0.34	0.35	0.36

Flow Spread for the Major Flow (Hwy 417)

	Base Case m	10% Increase m	20% Increase m	30% Increase m
Average Spread	1.48	1.54	1.59	1.73
Maximum Spread	2.26	2.34	2.42	2.49
Minimum Spread	0.63	0.65	0.67	0.92

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Finding for Culverts

- 46 new or recently rehabilitated concrete and steel culverts were assessed
- Culvert sizes ranged from 450 mm diameter circular culverts up to 6100 x 2720 mm (2' x 9') box culverts

Flow	Base Flow	10% Increase in Flow	20% Increase in Flow	30% Increase in Flow
Percent Change in Number of Culverts not Meeting the Head Water Standard	0%	2%	7%	11%

Culvert Analysis Summary (Head Water to Rise/Diameter Ratio HW/D $\geq$ 1.5)

Flow	Base Flow	10% Increase in Flow	20% Increase in Flow	30% Increase in Flow
Percent Change in Number of Culverts Exceeding the Velocity Criteria as a result of climate change	0%	4%	4%	11%

Culvert Analysis Summary (Exit Flow Velocity V $\geq$ 2m/s)

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MTO Design Standard for Bridges

- Current MTO Drainage Design Standards for bridges require the design for the 25, 50 or 100 year design storm and the assessment and mitigation of the impact of the regulatory (historic extreme) storm
- These storms are generally in excess of the design storm used in determining the size of the structure opening and erosion protection measures.
- The bridge design standards require a 1.0 m (3 ft) minimum clearance for most structures. This can accommodate minor increases in headwater elevations

Conclusions from Resilience Study

- There appears to be significant resilience in highway storm sewer and culvert hydraulic capacity that can be attributed to the adequacy of the current MTO design standards and methods
- For bridges, current design practices appear to provide resilience to handle the increased flows. However, this mainly reflects the requirement for the stability of the structure not watershed flooding
- Adaptive measures can, to a great extent, address cases where infrastructure flow capacity is an issue

4- New Empirical Method for Flow Calculation for Ontario

- A new method was developed as a joint project with the University of Toronto based on the analysis 43 stations in the Boreal Shield region and 75 stations in the Mixed Wood Plains region
- The method presented in the study report titled "Flood Frequency analysis for prediction of Peak Flows to reflect current climatic conditions in Ontario" available through the MTO online library
- It is referred to as the Unified Ontario Flood Method (UOFM)
- It was implemented in MTO in March 2016 through the Provincial Engineering Memo DCSO # 2016-03

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Unified Ontario Flood Method – Equation

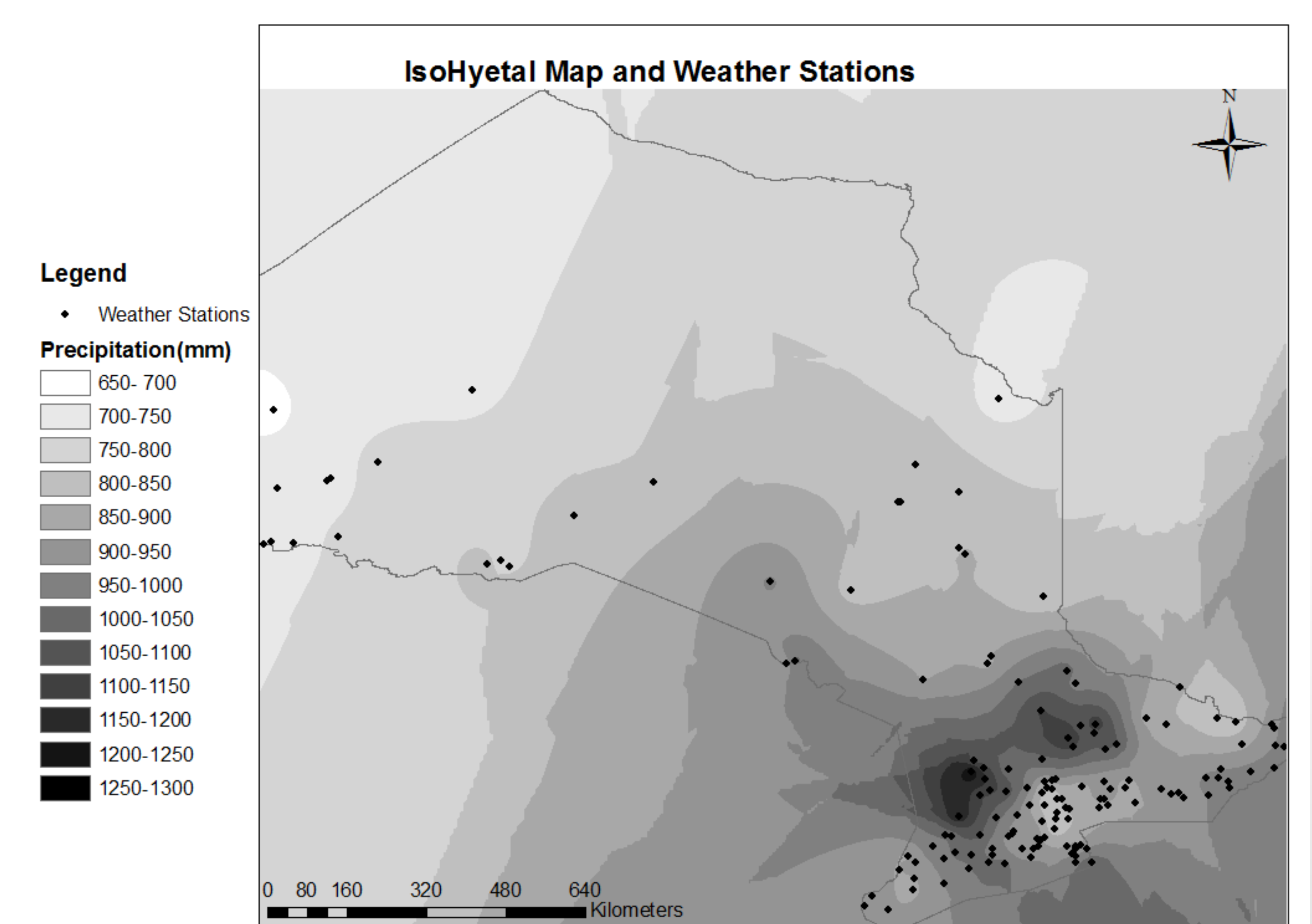
- This analysis resulted in the following regression equation for Ontario:

$$Q_{UOFM} = K_R * A^a * LI^b * P^c$$

Where

Q_{UOFM} = annual flood with a T year return period (m^3/s);
A = drainage area (km^2);
LI = lake attenuation index $=1 + \frac{WA}{A}$
WA = area of wetlands
P = mean annual precipitation (mm) (Isohyetal map or other sources);
$K_R = 10^x$ (x = from Table 3 on next slide)
a, b and c are from Table 3

Unified Ontario Flood Method – Equat



Based on Climate Normals 1981-2010

Unified Ontario Flood Method – Co

Table 3: Coefficients of the Regression Model and Output summary T

	x	a	b	c
Boreal Shield				
2	−10.870	0.839	−4.633	3.583
10	−8.583	0.795	−4.522	2.917
25	−7.834	0.779	−4.510	2.703
50	−7.371	0.769	−4.520	2.572
100	−6.967	0.759	−4.541	2.457
Mixed Wood Plains				
2	−5.483	0.756	−3.061	1.837
10	−4.139	0.734	−3.780	1.491
25	−3.680	0.728	−4.017	1.372
50	−3.397	0.724	−4.162	1.299
100	−3.151	0.721	−4.287	1.236

Unified Ontario Flood Method –

Table 5: Range of Quantile Estimates

T	Standard error (log units)	Range of Quantiles	
		Lower limit	Upper limit
Boreal Shield			
2	0.159	-31%	44%
10	0.174	-33%	49%
25	0.183	-34%	52%
50	0.189	-35%	55%
100	0.195	-36%	57%
Mixed wood Plains			
2	0.147	-29%	40%
10	0.165	-32%	46%
25	0.177	-33%	50%
50	0.186	-35%	53%
100	0.195	-36%	57%

5- Future Rainfall Prediction

- The Ministry has undertaken a study with the University of Waterloo to investigate trends in the historical rainfall records across Ontario
- A regional scale trend in extreme precipitation upwards was identified that ranges from 0.95% per decade for the 10-minute storm to 2.75% per decade for the 24-hour storm
- Implicit in this methodology is that the historical trend extends linearly into the future
- Future GHG scenarios is a subject of another study currently underway lead by the Ontario Ministry of the Environment and Climate Change and U of Waterloo

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Future Rainfall Data (Cont.)

Table 5 Summary for rate of increase $\left(\frac{mm}{h*y}\right)$ of rainfall intensity in Ontario

Duration	Rate of increase, m (mm/h/y)	Standard Error	t-stat	Lower 95% Confidence Bound	Upper 95% Confidence Bound	Linearized rate of increase, $\widehat{m}$ (mm/h/y)*	Mean rainfall, R_μ, adjusted to 1960 (mm/h)	Per cent increase per decade $10*\widehat{m}/R_\mu$
5 min	-0.0902	0.0592	-1.525	-0.2062	0.0258	0.0951	98.2	0.97
10 min	0.0375	0.0415	0.905	-0.0437	0.1188	0.0676	71.0	0.95
15 min	0.0560	0.0344	1.625	-0.0115	0.1235	0.0553	57.8	0.96
30 min	0.0568	0.0235	2.421	0.0108	0.1028	0.0393	37.8	1.04
1 h	0.0428	0.0081	5.301	0.0269	0.0586	0.0279	23.5	1.19
2 h	0.0202	0.0051	3.930	0.0101	0.0303	0.0198	14.8	1.34
6 h	0.0121	0.0023	5.285	0.0076	0.0165	0.0115	6.5	1.77
12 h	0.0081	0.0013	6.100	0.0055	0.0107	0.0082	3.8	2.16
24 h	0.0045	0.0006	6.979	0.0032	0.0057	0.0058	2.1	2.75
							Average rate of increase per decade (%):	**1.46**

*the rate of increase of the power law trend line for the given durations

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New MTO Tools for Design in a Changing Climate

One of the first steps to begin to address climate change in design was to regularly update the IDF curves as soon as data became available

- MTO updated its IDF curves in 2012, 2014 and 2016 to reflect changes in climate, based on the latest available Environment Canada data
- Further updates will continue once new rainfall data becomes available from Environment Canada
- A new update is planned for 2018
- The updates also included improvements in the statistical methods used in the assessment of the IDF values

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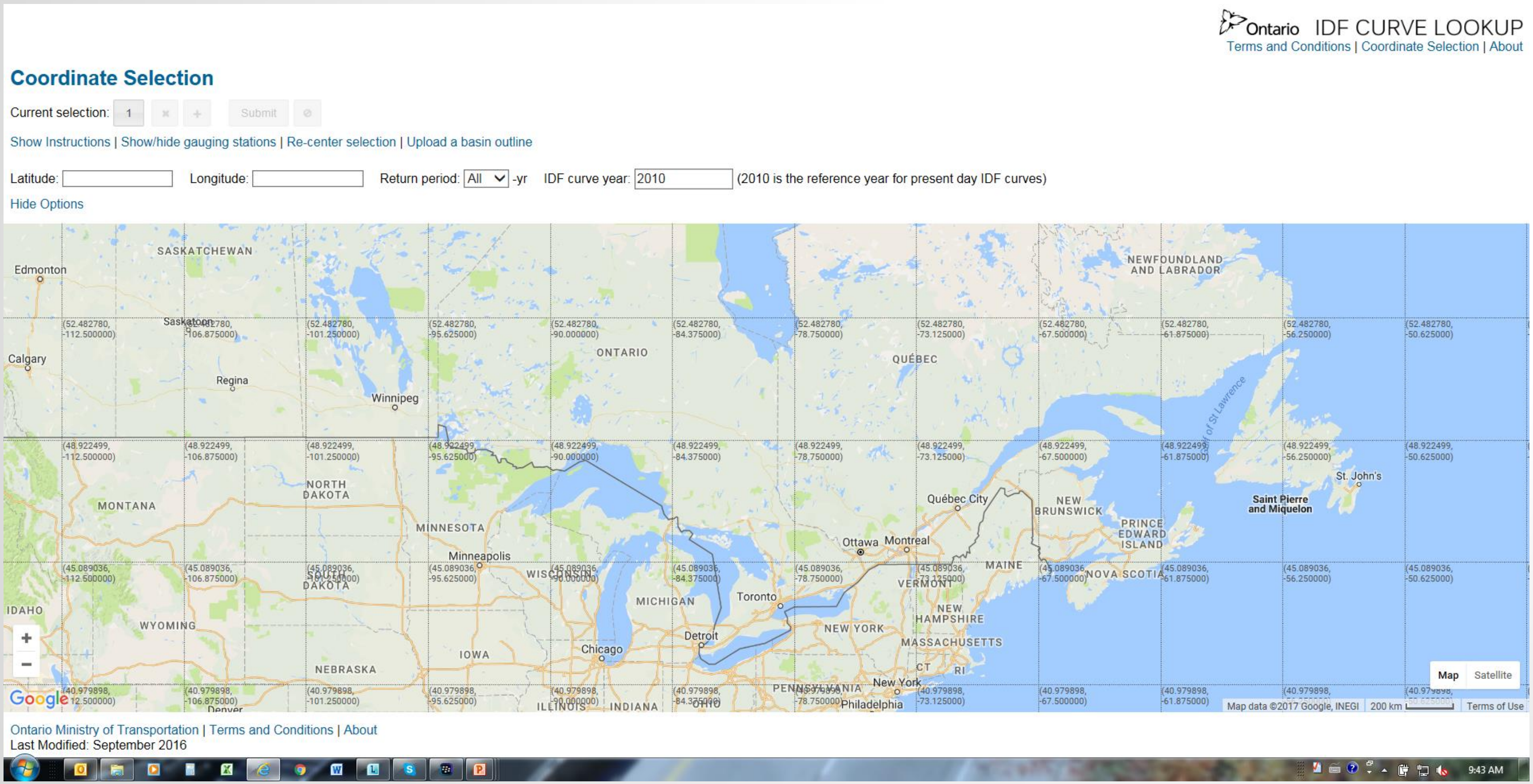
1– MTO IDF Online Application

- To facilitate the determination of IDF curves at any location in the province, MTO in cooperation with the University of Waterloo developed the IDF look-up application
- This application provides a representative IDF curve at any location in the province for:
  - A point location
  - Highway segment length (highway improvement project)
  - A water crossing catchment area (bridge or culvert design)

MTO IDF Online Application



- http://www.mto.gov.on.ca/IDF_Curves/map_acquisition.shtml

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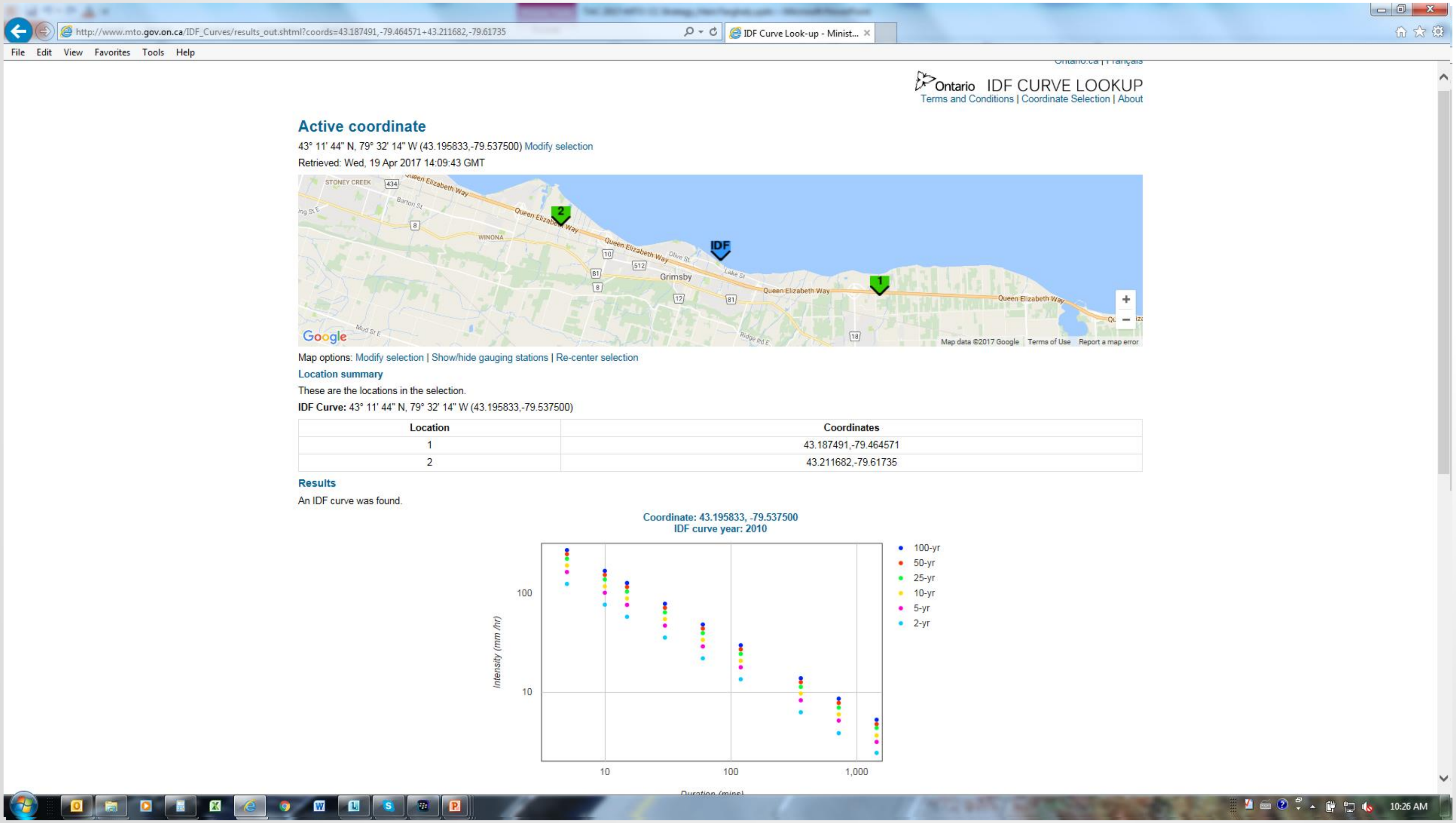
MTO IDF Online Application



2- Incorporation of Future Data into IDF Application

- The findings of the trend analysis study with the U of Waterloo were incorporated into the 2016 version of the IDF application
- It is now possible to determine the IDF curves for the base year (2010) and any future year

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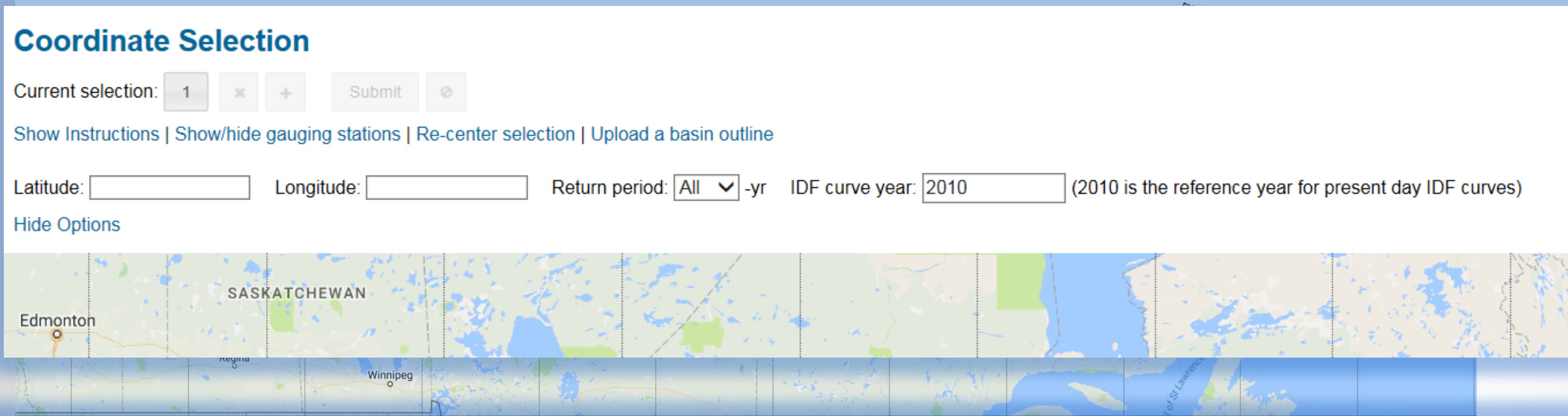
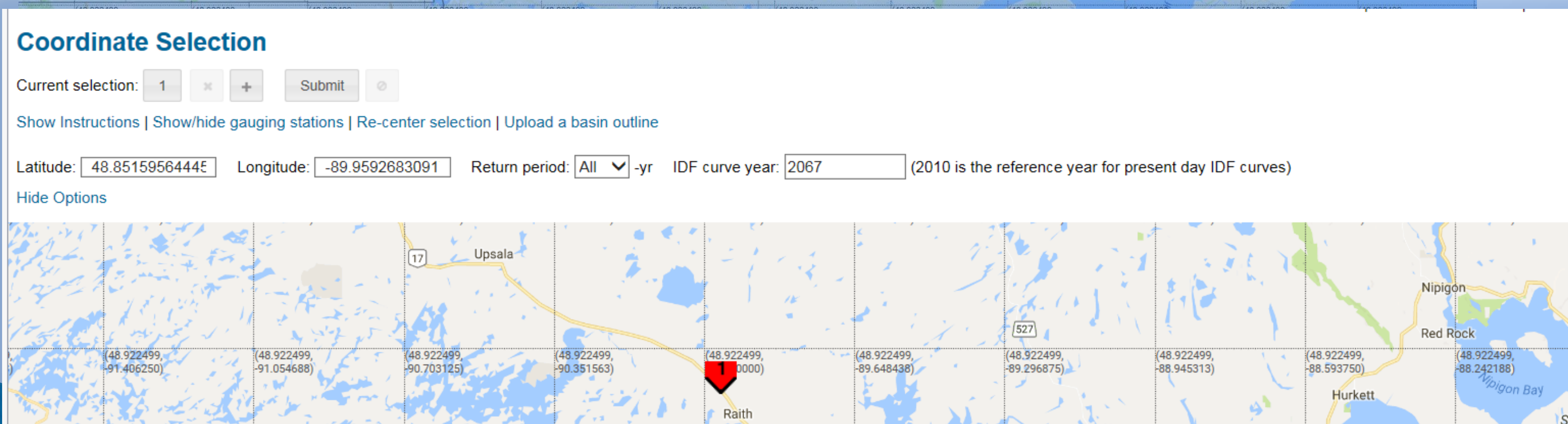
MTO IDF Online Application





Resulting Future IDF Curve

Map options: Modify selection | Show/hide gauging stations | Re-center selection

Location summary

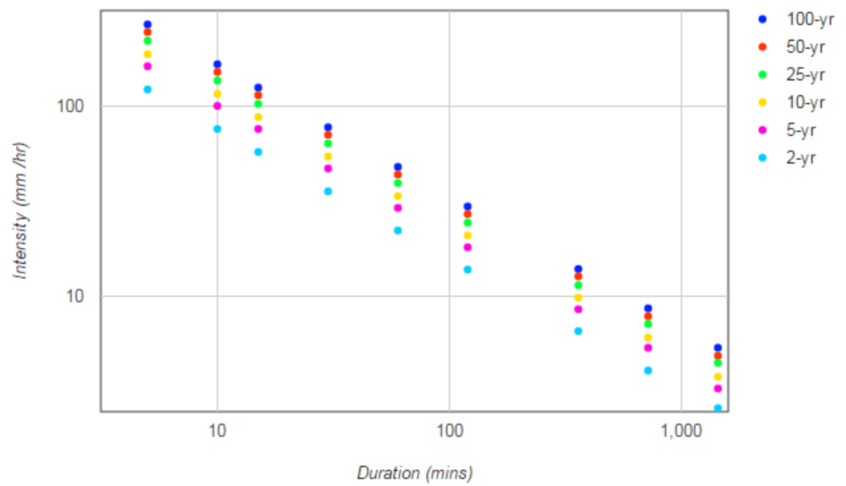
These are the locations in the selection.

IDF Curve: 46° 26' 15" N, 80° 11' 15" W (46.437500,-80.187500)

Results

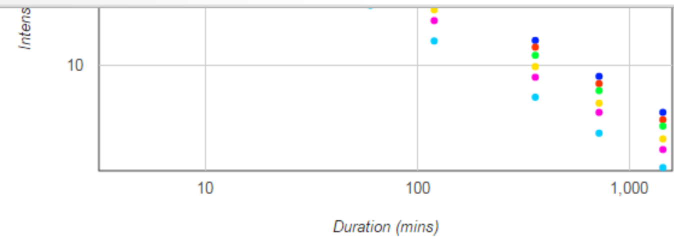
An IDF curve was found.

Coordinate: 46.437500, -80.187500
IDF curve year: 2070



Switch variable: Intensity or Depth

Resulting Future IDF Curve



Switch variable: Intensity or Depth

Coefficient summary

Data year: 2010
IDF curve year: 2070

Click a return period in the table header for more detail.

Statistics

Rainfall intensity (mm hr^{-1})

Duration	5-min	10-min	15-min	30-min	1-hr	2-hr	6-hr	12-hr	24-hr
2-yr	122.7	76.1	57.6	35.8	22.3	13.9	6.6	4.1	2.6
5-yr	162.5	100.6	76.1	47.2	29.3	18.2	8.6	5.4	3.3
10-yr	188.0	116.4	87.9	54.5	33.8	21.0	9.9	6.1	3.8
25-yr	221.0	136.7	103.2	63.9	39.6	24.5	11.5	7.2	4.5
50-yr	245.4	151.7	114.5	70.9	43.9	27.2	12.8	7.9	4.9
100-yr	269.3	166.4	125.6	77.7	48.1	29.8	14.0	8.7	5.4

Rainfall depth (mm)

Duration	5-min	10-min	15-min	30-min	1-hr	2-hr	6-hr	12-hr	24-hr
2-yr	10.2	12.7	14.4	17.9	22.3	27.8	39.6	49.2	62.4
5-yr	13.5	16.8	19.0	23.6	29.3	36.4	51.6	64.8	79.2
10-yr	15.7	19.4	22.0	27.3	33.8	42.0	59.4	73.2	91.2
25-yr	18.4	22.8	25.8	31.9	39.6	49.0	69.0	86.4	108.0
50-yr	20.4	25.3	28.6	35.5	43.9	54.4	76.8	94.8	117.6
100-yr	22.4	27.7	31.4	38.9	48.1	59.6	84.0	104.4	129.6

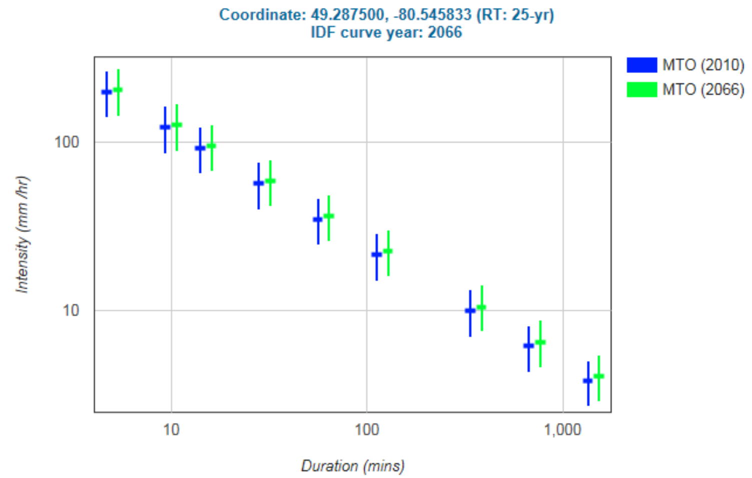
Future 25-year and Current Year Comparison

- There is an option to display both the current and future IDF values for a specific return period

Results

An IDF curve was found.

Return period: 25-yr Modify selection



Switch variable: Intensity or Depth

Coefficient summary

Data year: 2010
IDF curve year: 2066

Statistics

Rainfall intensity (mm hr^{-1})

	Data Set	5-min		10-min		15-min		30-min		1-hr		2-hr		6-hr		12-hr		24-hr	
	MTO (2010)	202.8	+63.1 -63.1	124.9	+38.9 -38.9	94.1	+29.3 -29.3	58.0	+18.0 -18.1	35.7	+11.1 -11.1	22.0	+6.8 -6.9	10.2	+3.2 -3.2	6.3	+1.9 -2.0	3.9	+1.2 -1.2
	MTO (2066)	208.1	+64.8 -64.8	128.7	+40.0 -40.1	97.2	+30.2 -30.3	60.2	+18.7 -18.8	37.3	+11.6 -11.6	23.1	+7.2 -7.2	10.8	+3.4 -3.3	6.7	+2.1 -2.1	4.2	+1.3 -1.3

25-year, 2-hour factor = 23.1/22.0 = 1.050

New Climate Change Policy

- In October 2016 MTO issued a policy requiring all highway drainage infrastructure to be designed using future rainfall predictions.
- This was implemented through a Provincial Engineering Memo (PEM) DSCO #2016-14
- The future data feature in the IDF app. V3.0, implemented in October 2016 (PEM DCSO #2016-13), is to be used as the source of future predictions

Design and Contract Standards Office #2016-14

HIGHWAY STANDARDS BRANCH

PROVINCIAL ENGINEERING MEMORANDUM

Design and Contract Standards Office #2016-14, October 28, 2016

Implementation of the Ministry's Climate Change Consideration in the Design of Highway Drainage Infrastructure

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Implementation

This memorandum is effective as of the date of issue.

Background

The Ministry has undertaken a study with the University of Waterloo to investigate trends in the historical rainfall records across Ontario to account for climate change impacts on rainfall predictions. A trend has been identified using the updated statistical analysis used in developing the latest update to the MTO Intensity Duration Frequency (IDF) curves application version 3. The IDF application is available at http://www.mto.gov.on.ca/IDF_Curves/.

Policy

Climate change shall be considered when undertaking the design of the Ministry of Transportation drainage infrastructure. Designers shall only use the MTO IDF online application V3 to determine the future rainfall predictions.

A successful design shall meet all performance standards throughout the design life of the structure. The design must satisfy both the start and end life design constraints for the range of return periods from 2 year to 100 year and the regulatory flow, in accordance with the applicable standards outlined in the MTO Drainage Design Standards. Designers shall ensure that the drainage infrastructure will accommodate future rainfall values for the year corresponding to the end of the Design Service Life of the structure in the design for conveyance, erosion, scour and stormwater management components. The design for fish passage shall meet the fish passage design drainage standard requirements at the present and future flow conditions.

When using empirical analysis methods to determine design flow rates that do not rely on IDF curves, the ratio of future rainfall values to the current values (referred to as the base year 2010 in the IDF online application V3.0) shall be determined using the IDF curves tool at the location of the drainage infrastructure. This ratio shall be applied to the design rainfall values obtained using the empirical analysis.

Designers are to exercise engineering judgment to determine whether the infrastructure will meet current and future design criteria through appropriate sizing of the infrastructure or through providing allowances for future adaptation measures. These

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Details of the New Policy

- A successful design shall meet all performance standards throughout the design life of the structure
- The design must satisfy both the start and end life design constraints
- Design continues to be in accordance with the MTO Drainage Design Standards using engineering judgement
- Designers shall apply future rainfall values for the year corresponding to the end of the Design Service Life of the structure in the design for conveyance, erosion, scour and stormwater management components
- The design for fish passage shall meet the low flow requirements at the present and future flow conditions

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Next Steps

- Continue to update the MTO IDF curve online application as new rainfall data and better climate change predictions become available
- Keep up-to-date with climate change modeling research to take advantage of advancements in the science and engineering
- Integrate new design methods in other systems such as MNRF OFAT system

Questions ?

Internet:

http://www.mto.gov.on.ca/english/publications/drainage-management.shtml

Share Point

https://intra.sse.gov.on.ca/mto/PHM/ho/HSB/DCSO/Pages/DrainageHydrology.aspx

MTO Library

http://www.mto.gov.on.ca/english/publications/mto-research-library-online-catalogue.shtml

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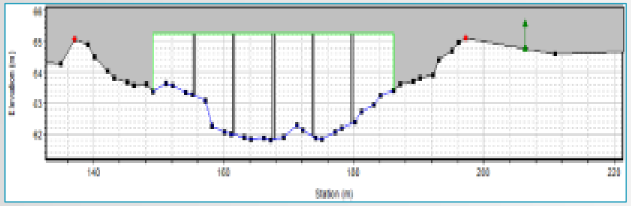
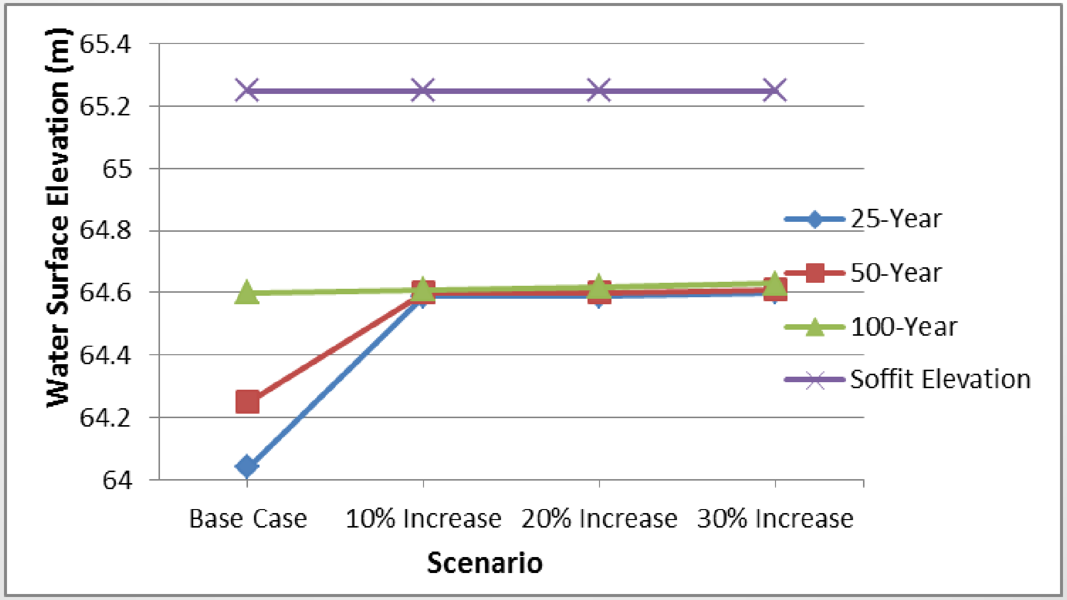
Result for Bridge Structure 1

Water Surface Elevation at the Upstream Section of the Bridge

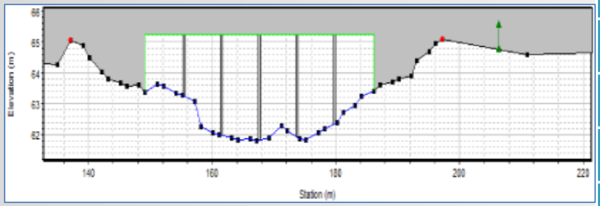


Return Period	Climate Change Scenario	H.W. Elevation m (ft))	Clearance m (ft)	Change in Clearance m (ft)
50	Base Case	64.3	1.02	0
50	10% Increase	64.6	0.67	0.35
50	20% Increase	64.6	0.67	0.35
50	30% Increase	64.6	0.66	0.36

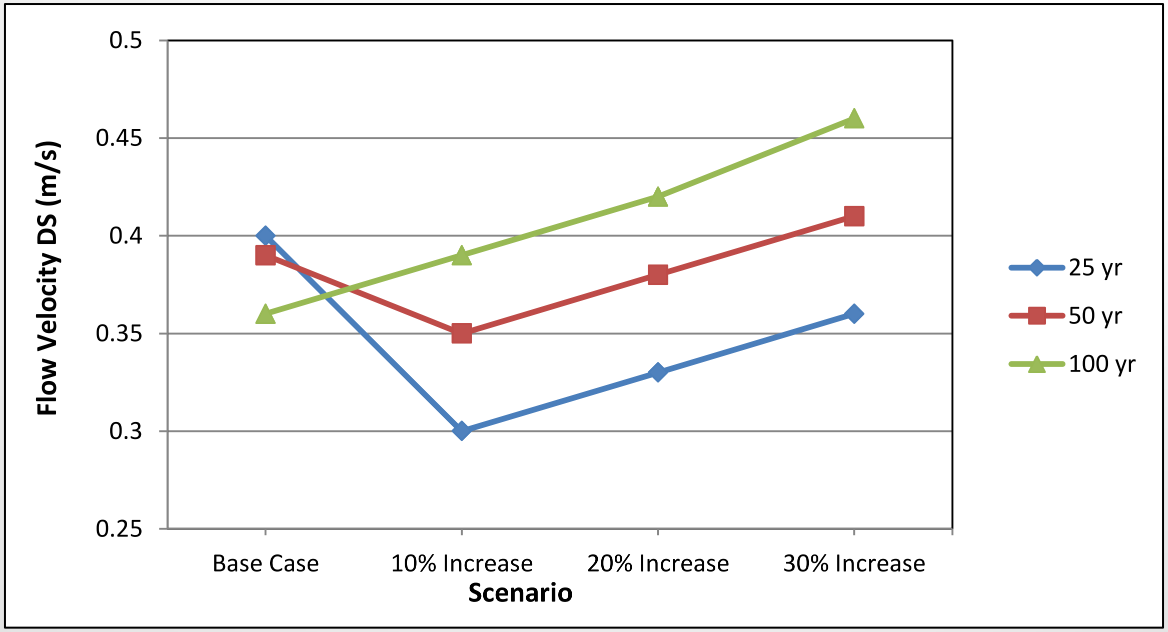


Result for Bridge Structure 1

Flow Velocity at the Downstream Section of the Bridge

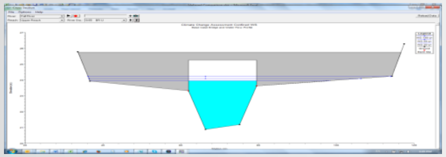


Profile	Flow Velocity	Change in Flow Velocity
	m/s	m/s
50-year Base Case	0.39	-
50-year 10% Increase	0.35	-.04
50-year 20% Increase	0.38	-.01
50 -year 30% Increase	0.41	+.02

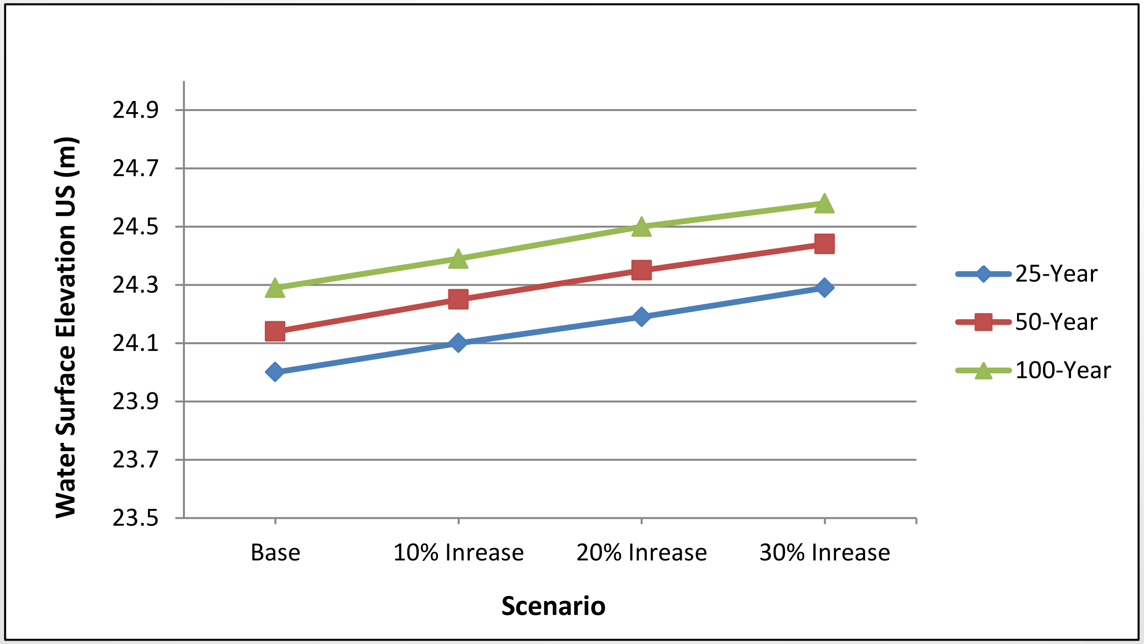


Result for Bridge Structure 2

Water Surface Elevation at the Upstream Section of the Bridge

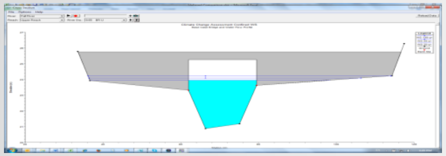


Return Period	Climate Change Scenario	H.W. Elevation m	Clearance m	Change in Clearance m
50	Base Case	24.14	1.06	–
50	10% Increase	24.25	0.95	0.11
50	20% Increase	24.35	0.85	0.21
50	30% Increase	24.44	0.76	0.3

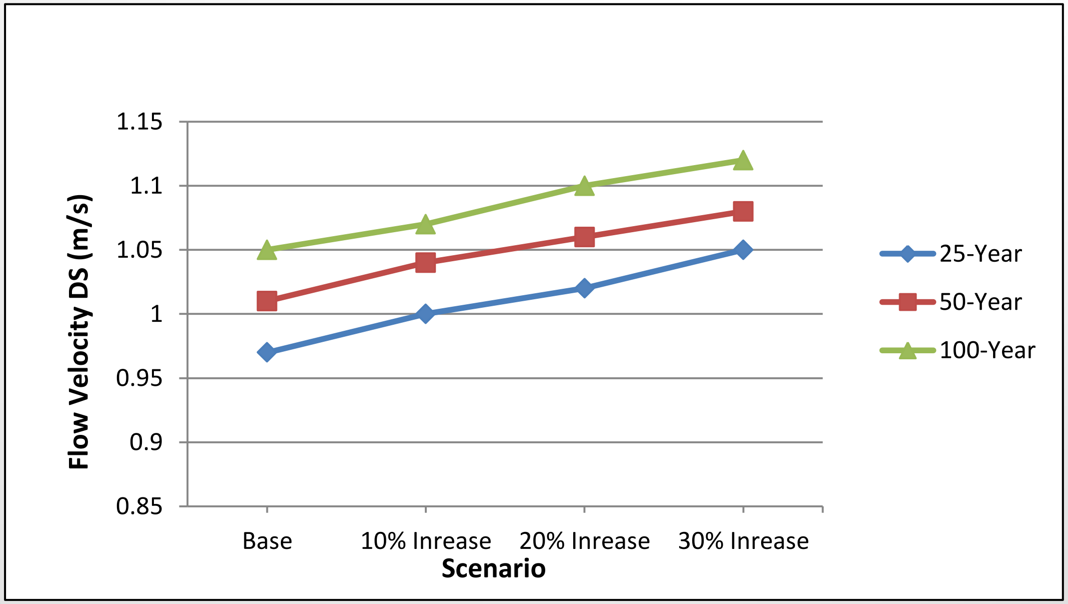


Result for Bridge Structure 2

Flow Velocity at the Downstream Section of the Bridge



Profile	Flow Velocity D/S	Change in Flow Velocity
	m/s	m/s
50-year Base Case	1.01	0
50-year 10% Increase	1.04	0.03
50-year 20% Increase	1.06	0.05
50 -year 30% Increase	1.08	0.07



Adaptation of Infrastructure to Climate Change Impacts

- The term adaptation, in the context of the current investigation, refers to measures that can allow existing infrastructure to serve their function to the end of their service life
- Adaptive measures can, to a great extent, address cases where infrastructure flow capacity is an issue

Adaptive Measures

- Two types of adaptive measures were identified:
  1. Hard measures

     These measures involve physical actions that are suitable for the different types of drainage infrastructure

  2. Soft measures

     These measures involve factors related to expanding our knowledge and modifying human behaviours and expectations

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Example of Hard Adaptive Measures for Culverts

Some of the adaptive measures that can be considered for culverts are as follows:

- Inlet improvements to reduce head loss at the entrance and reduce head water elevation (the addition of head walls, wing walls or aprons)
- Provision of additional erosion protection where flow velocities become too high
- Creation of upstream ponding area to allow excess flows to be stored and reduce the flow through culverts at high flow events
- If site conditions permit, the construction of a relief culvert may be considrered

Examples of Soft Adaptation Strategies

Some of the soft measures include:

1. Ensure ongoing and effective maintenance to maintain design level of service
2. Maintain climate data monitoring at existing locations and filling in the gaps where data is lacking
3. Develop a dialogue between hydraulic engineers, climatologists, infrastructure owners and regulators to improve on climate change modelling
4. Undertake pilot infrastructure vulnerability assessments for select infrastructure and locations to guide the process of overall risk assessment
5. Give consideration to changing levels of public expectation related to the occurrence of minor service degradation or impacts for short periods of time.

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