IDF Trends Study With MSC Weather Data Using Regression Analysis in Ontario

by

Chon In Wong

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Applied Science
in
Civil Engineering

Waterloo, Ontario, Canada, 2014

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The Ministry of Transportation (MTO) uses Intensity Duration Frequency (IDF) information that was developed with Environment Canada weather information up to 1989 for various infrastructure designs. The IDF curves needed an update to ensure the drainage design for infrastructures are up to current standards given the current extreme precipitation. The goals of this research were 1) to update the old IDF information to current standards and to develop a web interface as a more accessible method to find IDF curves in Ontario, (MTO currently uses hardcopy of design manuals for IDF information) and 2) to study past weather trends to develop IDF curves for 2090. Regression analysis was used to update the IDF curves and the analysis was performed with independent variables: calendar year of the weather station (set to 2012), station longitude and latitude, station elevation, barrier height, slope Y, slope X and distance of the each weather station from the closest body of water. The result of the regression analysis was validated with Environment Canada and National Oceanic and Atmospheric Administration data, which showed little statistical differences. The "IDF Lookup Website" was developed as a more assessable method to obtain IDF information. The IDF Lookup Website interpolates weather information between weather stations, allowing the users to easily acquire IDF curves for Ontario by selecting the location of interest on a map. Finally, IDF information for 2090 was obtained using the regression analysis and the corresponding IDF curves for 1-hour storm duration in Ontario were produced. The results were then validated with McMaster's downscaling study. The regression analysis and the downscaling study predicted similar weather trends and showed little statistical difference.

Acknowledgements

I am indebted to all the kind people around me. It would not have been possible for me to finish my thesis without them.

Foremost, I am deeply grateful to my supervisor Dr. Ric Soulis for the help and support throughout my research. He was patient with me even though I can be a slow learner at times.

I want to thank my parents; they were always there for me through the good times and bad. I also want to thank my friends whom I have met throughout the years from school or elsewhere for their support and encouragement.

To Father and Mother

Table of Contents

AUTHOR'S DECLARATION ii

Abstract iii

Acknowledgements iv

List of Figures viii

List of Tables xi

List of Equations xii

Preface xiii

Chapter 1: MTO IDF Curves Renewal 1
1.1 An Introduction to IDF Curves 1
1.2 Outdated IDF Information 4
1.3 Phase I IDF Lookup Website 5
1.4 Station Data Regression Analysis 6
1.5 Ontario Data Regression Analysis 8

Chapter 2: MTO IDF Curves Update 15
2.1 Further Research 15
2.2 Defining Uncertainty 15
2.3 Updated Station Data and Validation 17
  2.3.1 Weight Factor Version 1 17
2.4 Confidence Limits 18

Chapter 3: Time Trend Estimation 23
3.1 Preparations for IDF Prediction Regression Analysis 23
  3.1.1 Weight Factor Version 2 and Standard Error 24
  3.1.2 Regression Result Validation 25
3.2 Regression Analysis for Year 2012 26
3.3 Regression Validation Calendar Year 2012 28
  3.3.1 National Oceanic and Atmospheric Administration Comparison 28
3.3 Regression Analysis for 2090 Design Values 34
3.4 Regression Validation Calendar Year 2090 36
  3.4.1 McMaster Comparison 36
  3.4.2 Environment Canada Climate Change Comparison 42
3.5 New IDF Lookup Website 44
3.6 Weather Data: Behind The Scene 49

Conclusion 55

Appendix A: Rainfall Intensity-Duration Frequency Values for Canadian Locations (pg 1-16) 58

Appendix B: "A" Coefficient Comparison Post Phase II Average Record Year ..74

Appendix C: Detailed Regression Results for 2012..77

Appendix D: Post Phase II 1-hour Storm Intensity Comparison for 2012..........80

Appendix E: Detailed Regression Results for 2090 83

Appendix F: Post Phase II 1-hour Storm Intensity Comparison for 2090 86

Bibliography..91

List of Figures

Figure 1) Ontario, Canada 2
Figure 2) MSC Weather Stations in Northern Ontario 3
Figure 3) MSC Weather Stations in Southern Ontario 4
Figure 4) Latitude Parameter Visualization for Ontario 10
Figure 5) Longitude Parameter Visualization for Ontario 10
Figure 6) Barrier Height (m) Parameter Visualization for Ontario 11
Figure 7) East/West Slope Parameter Visualization for Ontario 11
Figure 8) North/South Slope Parameter Visualization for Ontario 12
Figure 9) Elevation (m) Parameter Visualization for Ontario 12
Figure 10) Distance to Water (km) Parameter Visualization for Ontario 13
Figure 11) Maximum Rainfall Depth in Ontario Observed vs. Regression Prediction (1-hour Duration, 5 Year Return Period) 14
Figure 12) IDF Curve Example by Environment Canada 16
Figure 13) Phase II 1-hour Storm Estimated vs. Environment Canada Station Values 18
Figure 14) Ottawa RC "A" Coefficient Return Periods 2-100 Years 20
Figure 15) Ottawa Airport "A" Coefficient Return Periods 2-100 Years 20
Figure 16) Armstrong Airport "A" Coefficient Return Periods 2-100 Years 21
Figure 17) Kenora Airport "A" Coefficient Return Periods 2-100 Years 21
Figure 18) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year 26
Figure 19) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year for 2012 28
Figure 20) PFDS, An IDF Search Engine for the United States, on the NOAA Website 30
Figure 21) IDF Location Selection on PFDS 30
Figure 22) IDF Curve for an 1-hour Storm for Detroit on PFDS 31
Figure 23) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Curves for 2-year Return Period Storms Comparison. Intensity (mm/hr) vs. Storm Duration (hrs) 32
Figure 24) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Comparison for 25-year Return Period 33
Figure 25) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Comparison for 25-year Return Period (with Confidence Interval) 33
Figure 26) 1-hour Storm 2090 Regression Prediction for Ontario 35
Figure 27) Brantford Weather Station 1-hour Storm Rainfall Intensities McMaster Records and Downscaling Prediction from 1970-2080 37
Figure 28) Brantford Weather Station 1-Hour Storm Rainfall Intensities Atlas of Canada Records and Regression Analysis Prediction from 1970-2090 37

Figure 29) Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Brantford 2050 39
Figure 30) Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Brantford 2080 39
Figure 31)Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Rawson Lake 2050 41
Figure 32)Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Rawson Lake 2080 41
Figure 33) Environment Canada Rainfall Depth Prediction for 24-hour Rainfall Duration Event Based on the IPCC A2 Model 43
Figure 34) University of Waterloo IDF Regression 1-hour Storm Prediction for Brantford 43
Figure 35) Front Page of the IDF Curve Lookup Website 44
Figure 36) Location of Interest Selection on the IDF Lookup Website 45
Figure 37) Sample Output for Rainfall Intensity vs. Rainfall Duration And Table for "A" And "B" Coefficients for All Return Periods 46
Figure 38) Sample Output for Rainfall Intensity for Each Return Period and Duration Combination 46
Figure 39) Sample Output Figure for Rainfall Intensity vs. Duration from the IDF Lookup Website 47
Figure 40) Sample Output Figure for Rainfall Depth vs. Duration from the IDF Lookup Website 47
Figure 41) Sample Output for “A” and “B” Parameters, Rainfall Intensity and Rainfall Depth from the IDF Lookup Website 48
Figure 42) Two Location Selected for A Sample Study on the IDF Lookup Website 48
Figure 43) Phase II 1-hour Storm Estimated vs. Environment Canada Station Values 55
Figure 44) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year 56
Figure 45) “A” Coefficient Regression Results for a 2-year Return Period 74
Figure 46) “A” Coefficient Regression Results for a 5-year Return Period 75
Figure 47) “A” Coefficient Regression Results for a 10-year Return Period 75
Figure 48) “A” Coefficient Regression Results for a 50-year Return Period 76
Figure 49) “A” Coefficient Regression Results for a 100-year Return Period 76
Figure 50) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 2-year Return Period for year 2012 80
Figure 51)1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 5-year Return Period for year 2012 81

Figure 52) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 10-year Return Period for year 2012........................ 81
Figure 53) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 50-year Return Period for year 2012........................ 82
Figure 54) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 100-year Return Period for year 2012...................... 82
Figure 55) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 2-year Return Period for year 2090.......................... 86
Figure 56) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 5-year Return Period for year 2090.......................... 87
Figure 57) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 10-year Return Period for year 2090........................ 88
Figure 58) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 50-year Return Period for year 2090........................ 89
Figure 59) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 100-year Return Period for year 2090...................... 90

List of Tables

Table 1) Regression Coefficients, Standard Error and Confidence Limits (ON) 13
Table 2) Sample Regression Results 2-year Return Period for Year 2012 27
Table 3) Geological Information for Sample Weather Stations 49
Table 4) Recording Information for Sample Weather Stations 50
Table 5) “A” Coefficients Used in Equation $R=AT^B$ for Sample Weather Stations 51
Table 6) "B" Coefficients Used in Equation $R=AT^B$ for Sample Weather Stations 51
Table 7) Sample Geological Information 53
Table 8) Sample Geological Information After Normalization 53
Table 9) Sample log Values of "A" Parameters 54
Table 10) 5-Year Return Period Regression Result for 2012 77
Table 11) 10-Year Return Period Regression Result for 2012 78
Table 12) 50-Year Return Period Regression Result for 2012 78
Table 13) 100-Year Return Period Regression Result for 2012 79
Table 14) 2-Year Return Period Regression Result for 2090 83
Table 15) 5-Year Return Period Regression Result for 2090 84
Table 16) 10-Year Return Period Regression Result for 2090 84
Table 17) 50-Year Return Period Regression Result for 2090 85
Table 18) 100-Year Return Period Regression Result for 2090 85

List of Equations

Equation 1) Basic Rainfall Intensity Equation 6
Equation 2) Basic Rainfall Intensity Equation Transformed 7
Equation 3) Regression Formula 7
Equation 4) Cartesian Standard Error 16
Equation 5) Phase II Weight Factor 18
Equation 6) Upper and Lower Bound 95% Confidence Limit 19
Equation 7) Average Record Year of Weather Stations 23
Equation 8) Weight Factor Equation 24
Equation 9) Standard Error of Regression 24
Equation 10) Sum of the Squared Residuals 25

Preface

Accurate information on extreme precipitation events of various duration and frequency are critical for standards and management for infrastructure design. (UIC, 2011) MTO had been using the design manual "MTO Drainage Management Manual", which was written in 1989 for highway drainage design. Intensity-Duration-Frequency (IDF) information in Ontario was updated with regression analysis with geological parameters as independent variables. The regression analysis could also be used to study the trend of weather information to predict the behavior of precipitation in the future. Phase I of the IDF renewal project updated the current IDF curves to reasonable design values. Phase II of the IDF renewal project focused on lowering the standard error, but at the same time adding a time trend to the regression. Validation of the results was done for the year 2012 with weather information obtained from National Oceanic and Atmospheric Administration (NOAA). A website was also developed as a user-friendly tool for the public to assess the current IDF information and provide updates in the future. Research continued after Phase II. Post Phase II of the project aimed to provide IDF curves for 2090 for 1-hour storm duration in Ontario, including return periods 2, 5, 10, 50 and 100 years.

Chapter 1: MTO IDF Curves Renewal

1.1 An Introduction to IDF Curves

The rainfall Intensity-Duration-Frequency (IDF) curve is commonly used to estimate rainfall intensity. IDF curves show the extreme precipitation events for different combination of storm durations and frequency of occurrences. Rainfall intensity is relevant for many engineering designs, such as hydrologic analysis for drainage design. (WRR, 2011) According to the guideline "Development, interpretation, and use of rainfall intensity-duration-frequency (IDF) information: Guideline for Canadian water resources practitioners" published by Canadian Standard Association, IDF information have increased demand. The main reasons are urban development leading to less permeable watersheds for runoff, and the likelihood of climate change leading to an increase of intensity and frequency of extreme precipitation events. (WRR, 2011)

The Waterloo Multiple Physiographic Parameter Regression (WATMAPPR) Post-Processing application delivered the output files in 54 comma-separated files. Each files contained over 7 million grid points which were bounded by 58°45'00" N, 98°45'00" W to 40°00'00" N, 71°40'00" W, covering Ontario. (RMI, 2010)

The IDF renewal project studied rainfall data by the National Climate Data Information Archive of Environment Canada. The projected started in 2008 and the approached was to use regression analysis to find possible relationships between IDF information and geological parameters. The data included rainfall intensities and A and B parameters for calculating the rainfall intensities across 125 stations in Ontario for a range of return periods and chance of reoccurrence. WATMAPPR was used as the interpolation method to compensate for the fact that weather stations are sparse in the Northern region of Ontario. (Figure 1) (Figure 2)

Figure 1) Ontario, Canada

Highways span across every region in Ontario; however, only Southern Ontario's weather station densities approach international standards (Figure 3). The WATMAPPR interpolation method uses a large domain digital elevation model (DEM) to generate a square grid system and derive a comprehensive set of secondary physiographic characteristics for integration. A single set of equations was produced. The set of equations was used to produce IDF curve parameters throughout the province.

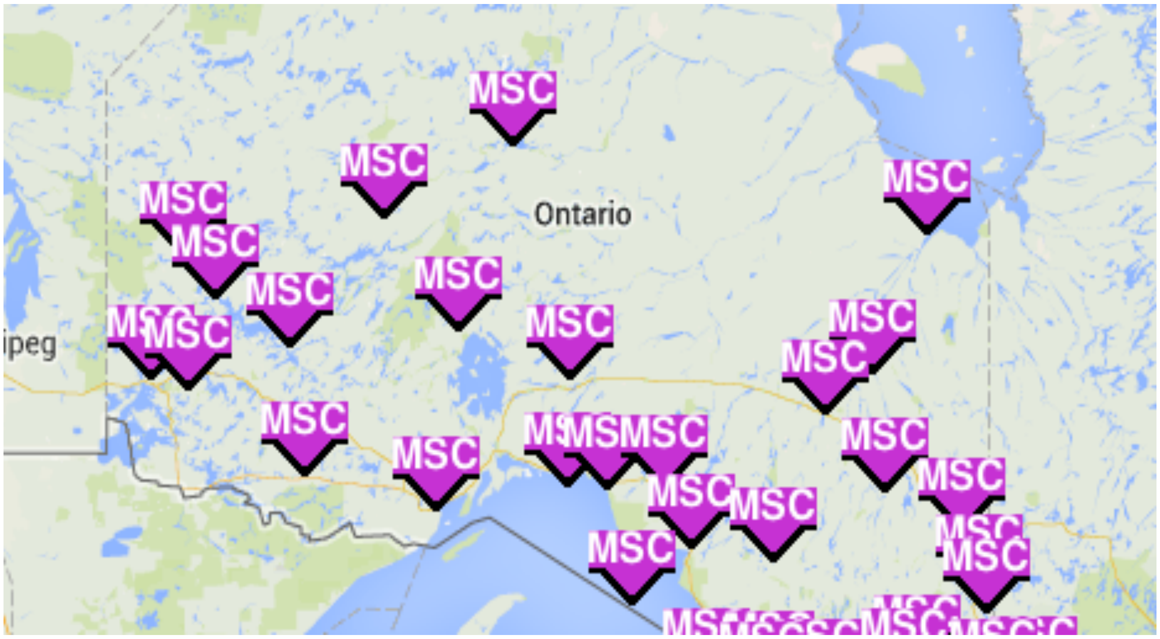


Figure 2) MSC Weather Stations in Northern Ontario

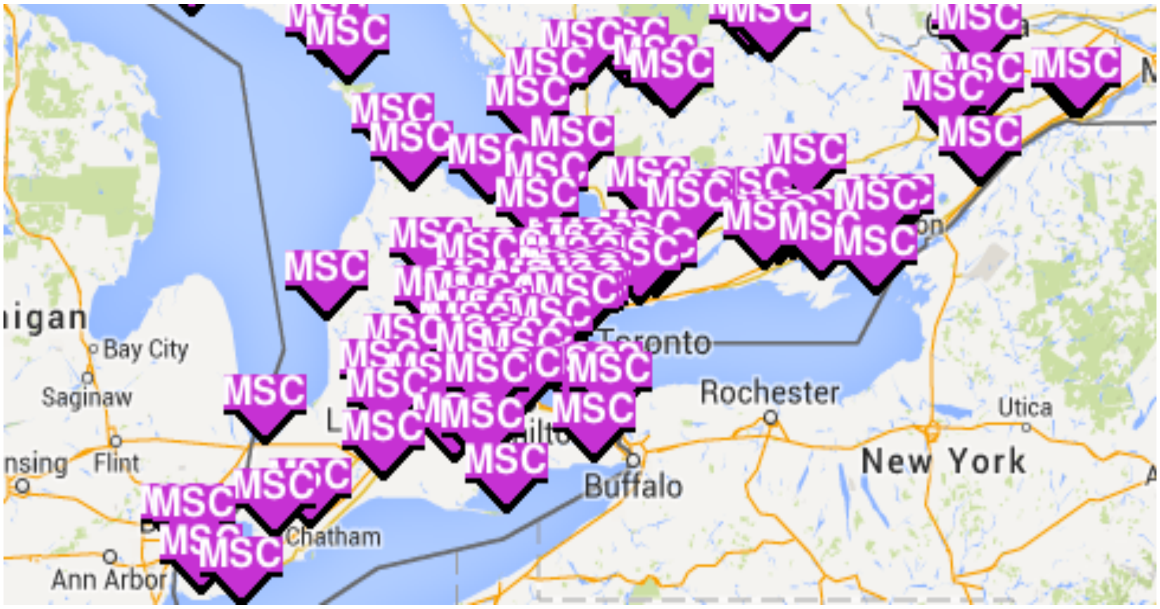


Figure 3) MSC Weather Stations in Southern Ontario

1.2 Outdated IDF Information

A revision of the 1990 IDF curves for Ontario was discussed because of administrative decisions in MTO. Concerns were raised since IDF cures were used in flood prevention on infrastructures and small watersheds, climate change may have an impact on the results (LIR, 2010). In 2008 – 2010, MTO collaborated with the University of Waterloo to develop a web-based tool for finding Intensity Duration Frequency (IDF) curves for precipitation events across Ontario. IDF curves provide the rainfall intensity (depth/time) of rainfall events for a combination of rainfall duration (time) and frequency on both regional and local scale. Peak rainfall intensities are important for highway drainage infrastructure design. Accurate rainfall data prevent over or under designing, as over designing is expensive with the added construction and material costs. Under designing will result in possible failure of the infrastructure and additional maintenance costs over time. This study marked the beginning of the MTO IDF curves renewal project.

1.3 Phase I IDF Lookup Website

Before Phase I of the IDF renewal project, peak rainfall intensities used for infrastructure designs were from data collected up to the year 1989 by Environment Canada. Previously, the MTO Drainage Management Manual provided IDF data for different regions in Ontario. These data were considered to be outdated and needed an update. The goal of Phase I was not only to update rainfall intensity data, but also to develop a more easy to use and comprehensive database for Ontario. The result of that is a web interface where a user can select a coordinate in Ontario and receive full IDF data for that particular location.

The development team had additional goals in mind when developing the Phase I IDF lookup website. Since weather stations are unevenly distributed in Ontario, rain gauge stations are scarce in the Northern region of Ontario, the website was designed to interpolate rain gauge data and convert them into IDF information. Developing an independent statistical method to derive IDF curves was crucial. Other than having accurate data, the website was designed to be user friendly, provided IDF tables and graphics in a methodical manner. The website was coded in such a way that it could be easily updated as IDF information will change in the future. The Phase I website allowed users to input latitude and longitude values within the Ontario Province boundary, and obtain IDF data for that particular location. The website provided IDF data such as figures showing the relationship between rainfall duration, intensity and the frequency of rainfall events. This could potentially save engineers half a day to a day of work for each project by presenting them with accurate IDF design values instantly.

1.4 Station Data Regression Analysis

Parameters A and B were used to calculate the values for the rainfall intensity. The rainfall data, provided by the National Climate Data Information Archive of Environment Canada, were collected from 125 stations across Ontario for different return periods. The basic equation for calculating rainfall intensity is:

Equation 1) Basic Rainfall Intensity Equation

$$R = \frac{A}{(T + C)^{B}}$$

where T is the rainfall duration (hours). A, B and C are parameters that vary between stations. The Meteorological Service of Canada (MSC) models IDF curves for each return period separately using the IDF parameters, A and B.

The relationship between rainfall intensity (R), rainfall duration (T) and parameters, A and B is

Equation 2) Basic Rainfall Intensity Equation Transformed

$$R = AT^{B}$$

Rainfall intensity is in the unit of depth per time, rainfall duration is in the unit of time, and parameters A and B's units are adjusted accordingly.

A basic regression formula was used to determine the possibility of a correlation between the IDF curve parameters and the station physiographic characteristics. (Equation 3)

Equation 3) Regression Formula

$$\hat{Y} = X_1 a + X_2 b_1 + X_3 b_2 + \ldots + X_8 b_7 + EPS$$

Where $\hat{Y}$ was the estimated value of the parameter, X_1, X_2, X_3 … X_8 were the *log* of the station physiographic characteristics (longitude, latitude, and elevation). a, b_1, b_2, b_3 … b_7 were the coefficients. By converting longitude and latitude from degree/minute to their minute *log* values and elevation from meters to its *log* values, sources of error for the $\hat{Y}$ estimates were reduced and ensured that the outcome stayed positive. Due to the irregular stations distribution in Ontario, the inverse-distance weighted interpolation and other methods were used to maintain result accuracy. In Phase I, the regression results for the stations had residuals similar to the estimated error in the station parameters; this confirmed that there is a relationship between the IDF parameter values and physiographic characteristics.

1.5 Ontario Data Regression Analysis

The Waterloo Multiple Physiographic Parameter Regression method is a modified version of the Square Grid method, developed by Dr. S. I. Solomon in late 1960's. The method divides an area into square grids, where each grid has its own physiographic characteristics. Regression equations were generated for each square grid using these parameters. Figure 4 to Figure 10 are visualizations of the physiographic characteristics parameters. The values for the parameters are represented in gray-scale, where the darker shade represented the higher value.

The physiographic parameters for the weather stations are as follows:

- *Elevation: Average elevation of the grid (m)*
- *Latitude: Latitude of the center of the grid (degree/minute)*
- *Longitude: Longitude of the center of the grid (degree/minute)*
- *Slope: The average elevation difference between the grids on either side of the station grid divided by the horizontal distance between the grids from North to South and from East to West*
- *Distance to Water: The distance of the center of the grid from either Hudson Bay or one of the Great Lakes.(km)*

- *Barrier height (towards the West): The difference between the elevation of the grid vs. the highest elevation of the landscape. Reset at large bodies of water. (m)*

A stepwise linear regression would regress multiple variables and eliminating the ones that were unimportant. The independent variable with the lowest objective function was first put into the regression. Each independent variable entered the regression separately. The process generated a set of equations that were used to calculate expected maximum precipitation for each rainfall duration and return period. It was necessary to verify the accuracy of the different interpolation techniques, since the WATMAPPR's station interpolated value might not be the measured value at the station. The root mean squared error (RMSE) was evaluated as a measure of fit. The RMSE was the square root of the mean of the squared difference between the measured values, interpolated values and the mean error (ME). The ME was the average of the net difference between the measured and interpolated values. The RMSE was evidence of the interpolation's accuracy and the ME demonstrates the bias of the interpolation.

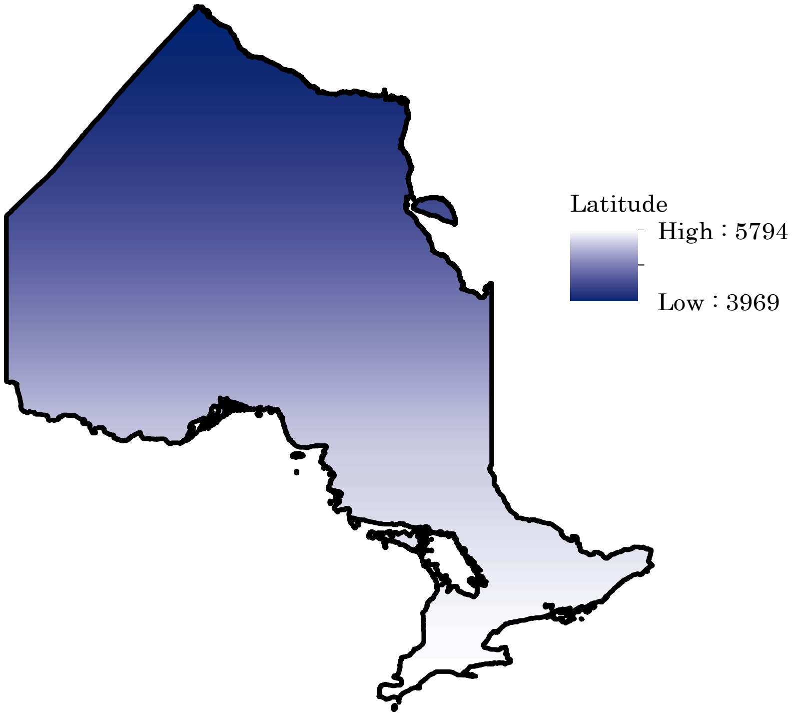


Figure 4) Latitude Parameter Visualization for Ontario

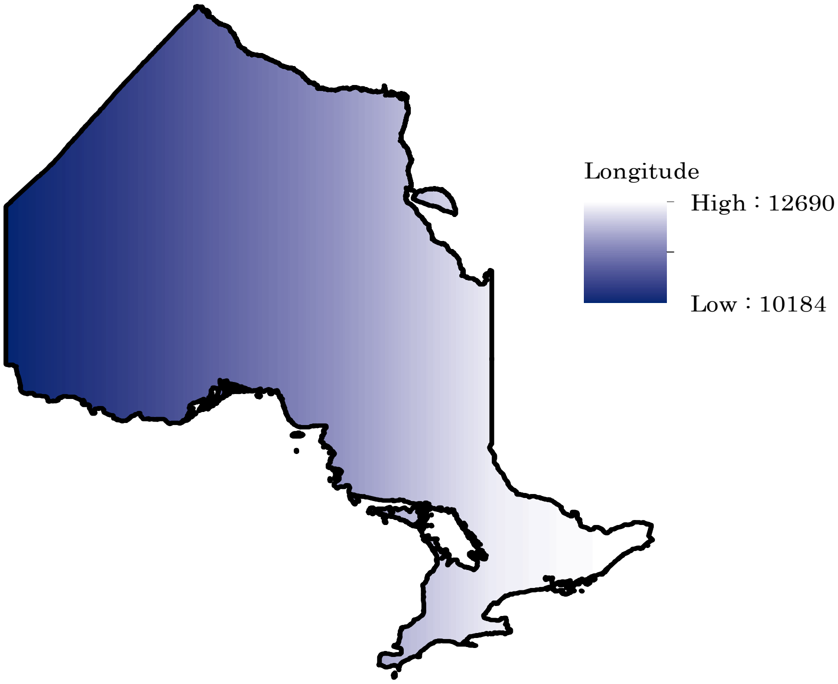


Figure 5) Longitude Parameter Visualization for Ontario

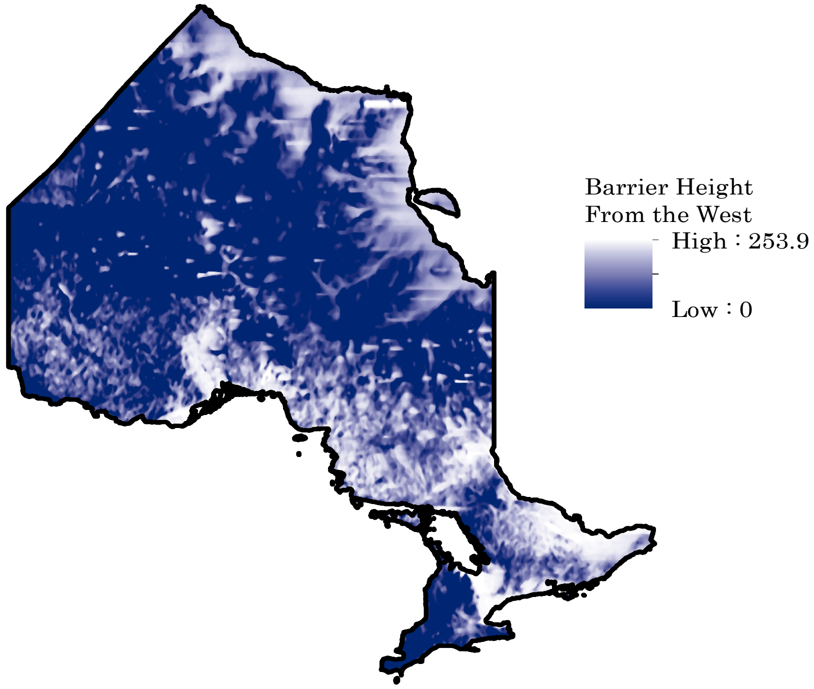


Figure 6) Barrier Height (m) Parameter Visualization for Ontario

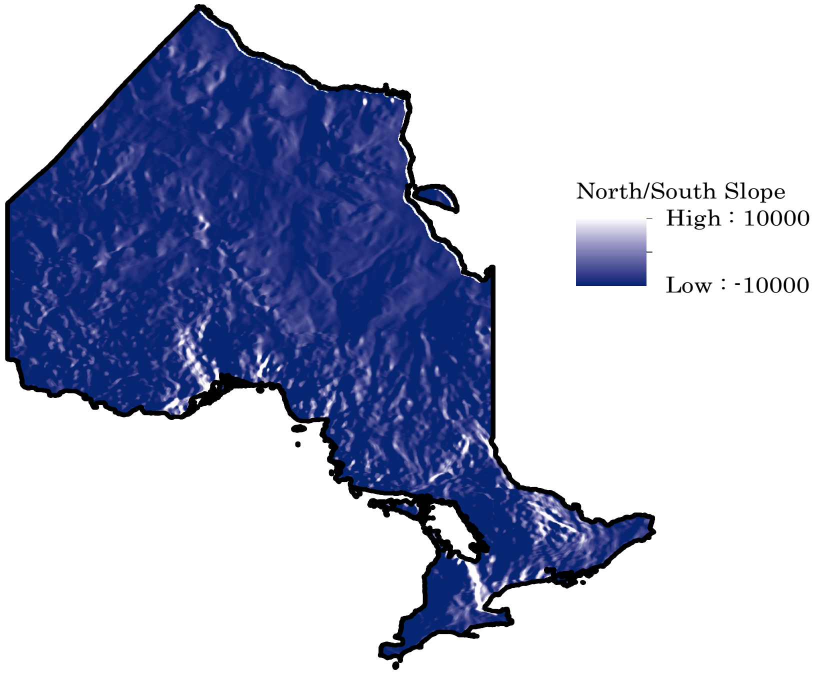


Figure 7) East/West Slope Parameter Visualization for Ontario

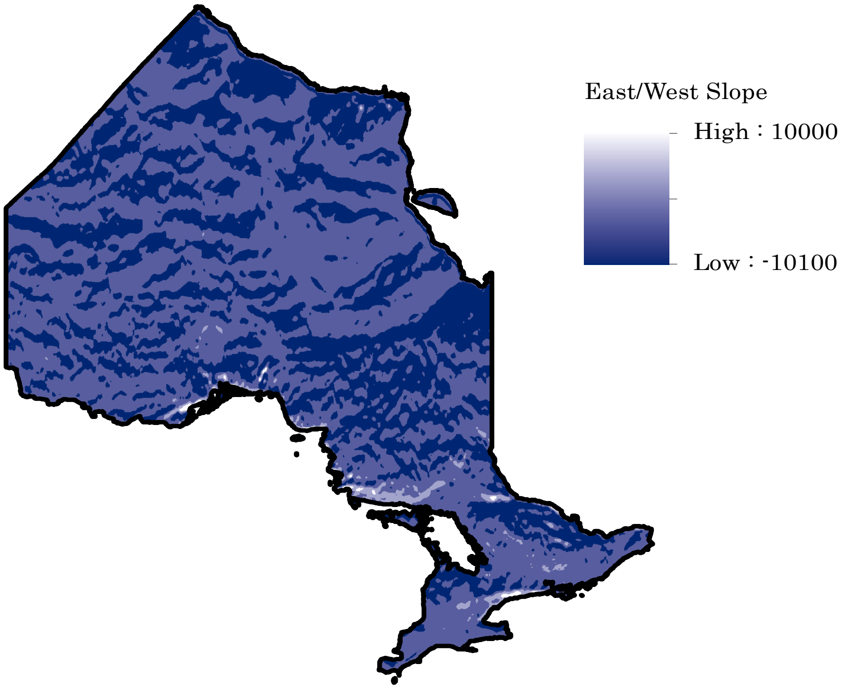


Figure 8) North/South Slope Parameter Visualization for Ontario

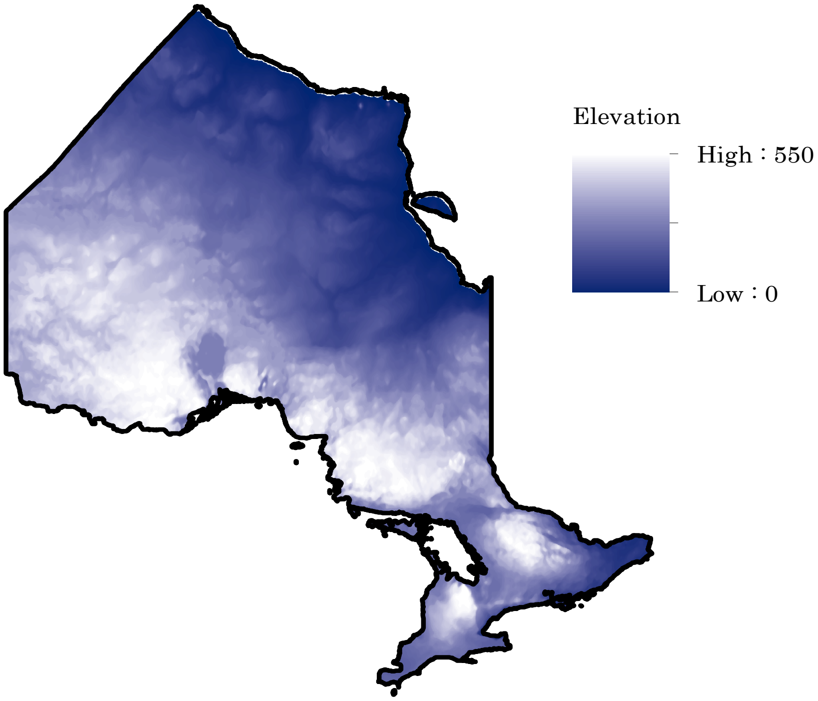


Figure 9) Elevation (m) Parameter Visualization for Ontario

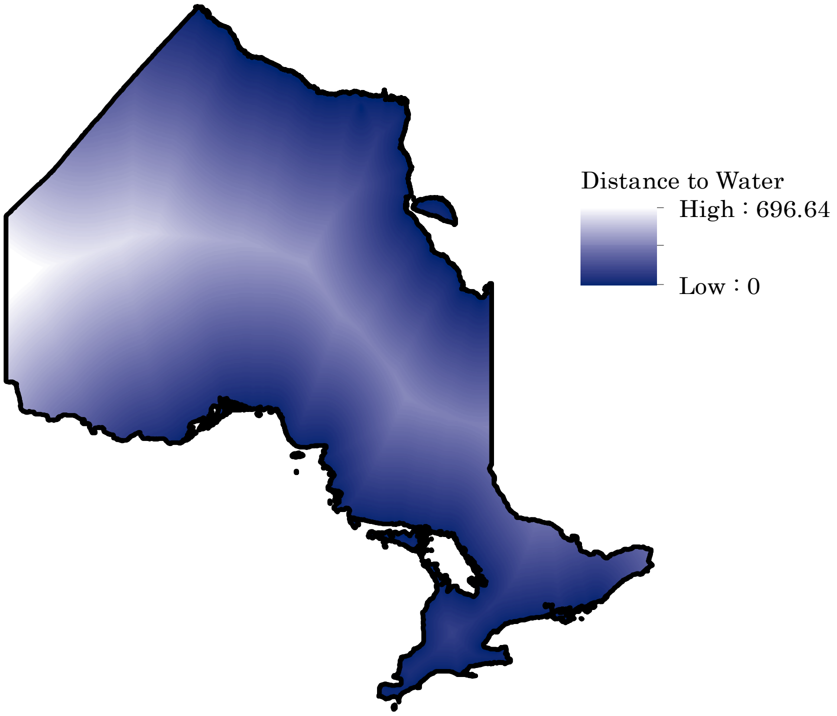


Figure 10) Distance to Water (km) Parameter Visualization for Ontario

Lake Superior and the borders of Ontario were areas with the largest errors when predicting the "A" and "B" parameters (Figure 11). Table 1 shows the regression coefficients, standard error, upper and lower bound of the 95% confidence limits for Ontario data.

Table 1) Regression Coefficients, Standard Error and Confidence Limits (ON)

Variable	Coefficients	Standard Error	Lower 95%	Upper 95%
Intercept	17.4720	3.4965	10.6168	24.3272
Longitude	- 0.0067	0.0003	- 0.0073	- 0.0062
Latitude	0.0195	0.0005	0.0184	0.0206
Barrier Height from the West	0.0076	0.0022	0.0034	0.0118
East/West Slope	- 0.0420	0.0034	- 0.0487	- 0.0353
North/South Slope	0.0012	0.0023	- 0.0033	0.0058
Elevation	0.0029	0.0013	0.0003	0.0054
Distance to Water	0.0059	0.0014	0.0031	0.0086

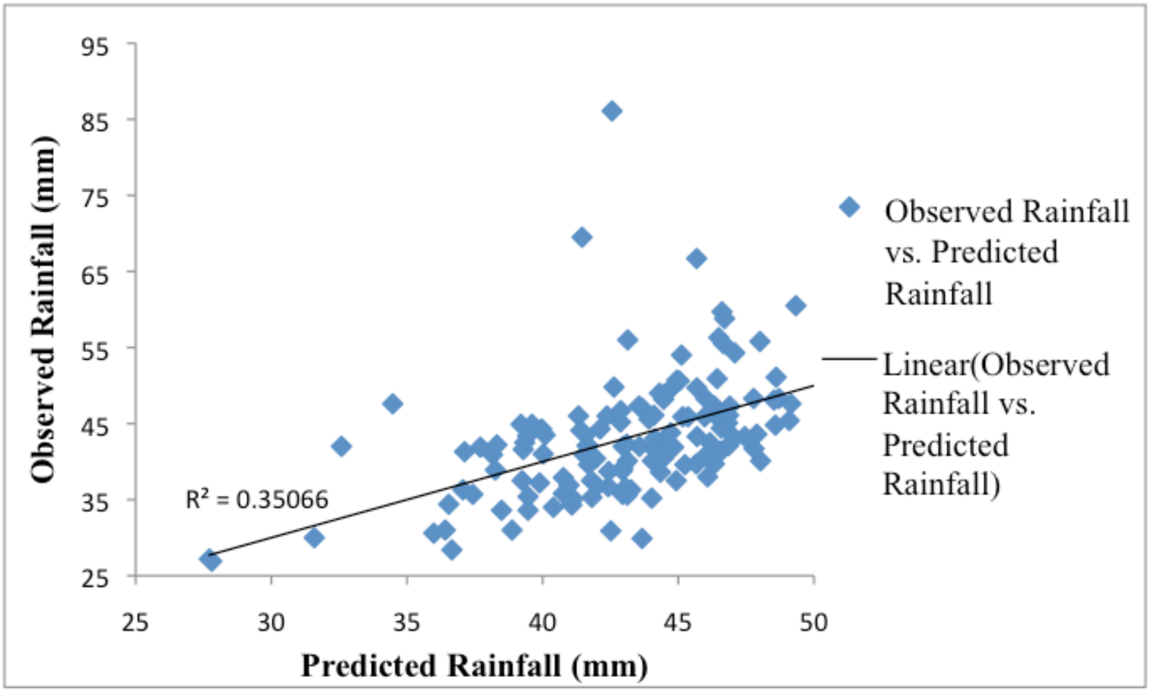


Figure 11) Maximum Rainfall Depth in Ontario Observed vs. Regression Prediction (1-hour Duration, 5 Year Return Period)

Chapter 2: MTO IDF Curves Update

2.1 Further Research

MTO started the revision of the IDF curves due to the concern for the impact of climate change would have on infrastructures after new data sets from AES were proposed. The goal of the continuing research (Phase II) was to invent a method to interpolate IDF data between Environment Canada weather stations and to precisely demonstrate the residual error as a result of the interpolation. A revision of the IDF curves was needed. The revision focused on the A and B parameters that were used to calculate rainfall intensities, which in turn were used to generate IDF curves. A method to interpolate IDF curve parameters between Environment Canada (EC) stations needed to be developed, since EC periodically updates IDF data at selected meteorological locations.

2.2 Defining Uncertainty

Figure 12 is an example of an IDF curve by Environment Canada. A typical standard error of an A coefficient was around 20 percent. The B coefficients used for calculations were the newest available values from Environment Canada, since they did not appear to vary in regards to weather station locations or return periods. The A parameters for Phase II were found by regression. The independent variables were the physiographic characteristics (station elevation, latitude, longitude, barrier height, slope X, slope Y, and distance to water) for the square grids in Phase I.

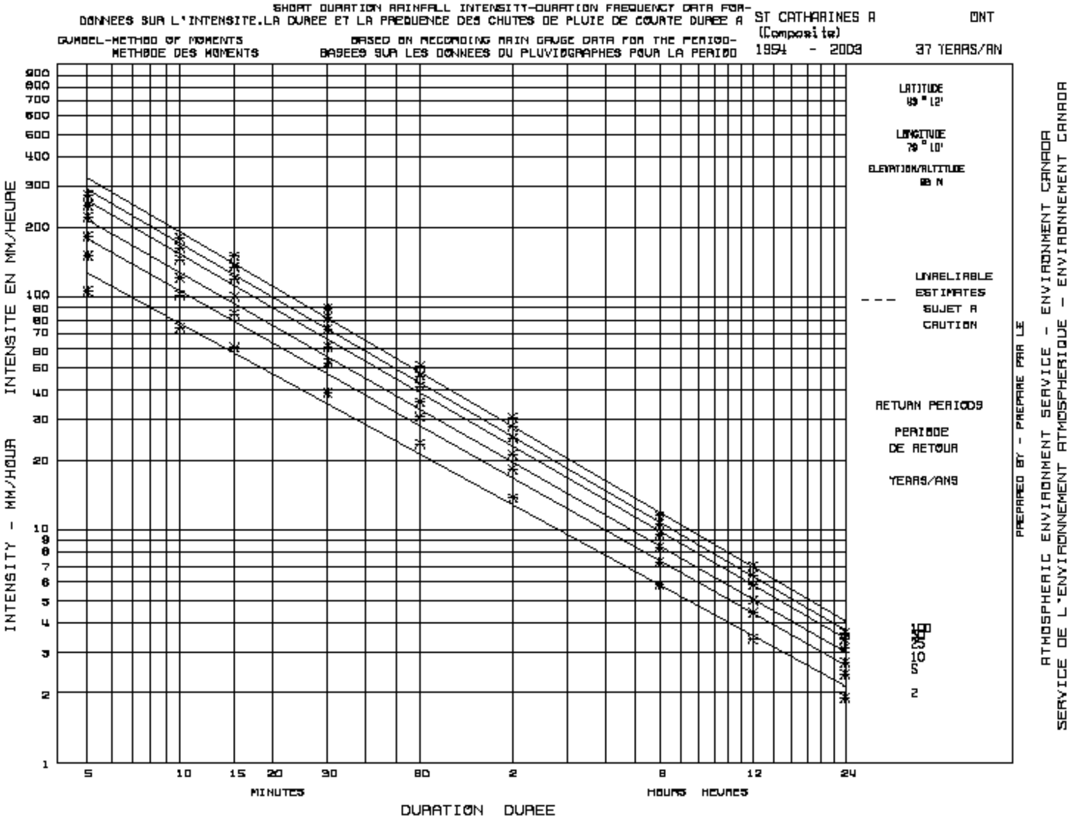


Figure 12) IDF Curve Example by Environment Canada

The Cartesian standard error (SE) was found using Equation 4:

Equation 4) Cartesian Standard Error

$$SE = 100 \times (10^{(SE \log < mj >)}) - 1$$

where mj is the station record length. This method minimizes the SE of the results, because the dependent variables are in a weighted *log* coordinate. Most of the SE in the results for the IDF curves was around a Cartesian 3 percent (SElog ≈ 0.0003), where the station SE values are usually around 15 percent. Since each weather station had a different length of weather records and a different amount of missing records, a weight factor was added to the regression variables, which was used to adjust for this issue.

2.3 Updated Station Data and Validation

The IDF Lookup website was undated in 2012. The number of Environment Canada weather stations to include in the study had increased from 125 to 141. Data from the new stations were including in the IDF regression analysis. Weather stations had different lengths of records. In Phase II, the lengths of records ranged from 11 years to 103 years. Stations with longer records should have a greater influence on the regression results than stations with short records. A slightly inefficient method to compensate for the various lengths of records would be to repeat a regression as many times as the station's recording years. i.e. If the station had 50 years of records, regression analysis was performed 50 times. A weighting factor to simulate this effect was developed.

2.3.1 Weight Factor Version 1

A weight factor was design in order to eliminate the need to perform regression analysis for each of the weather station's record year. A and B parameters were calculated by using the Environment Canada 2010 *log* version of the IDF equation. Based on the regional L-moment quantile algorithm (RFQA, 2005), the standard error (se) was assumed to be constant for all weather stations with a minimization of se^2/ms^2. Each station in the data set was prepared with Mse:

Equation 5) Phase II Weight Factor

$$Mse^2 = \sum se_j^{\,2} m_j^{\,2}$$

where M is the total number of weather stations, m is the number of records in weather station j. Figure 13 shows rainfall intensities for a 1-hour rainfall event for each weather station across Ontario with the weight factor. The standard error had lowered by about 20 percent.

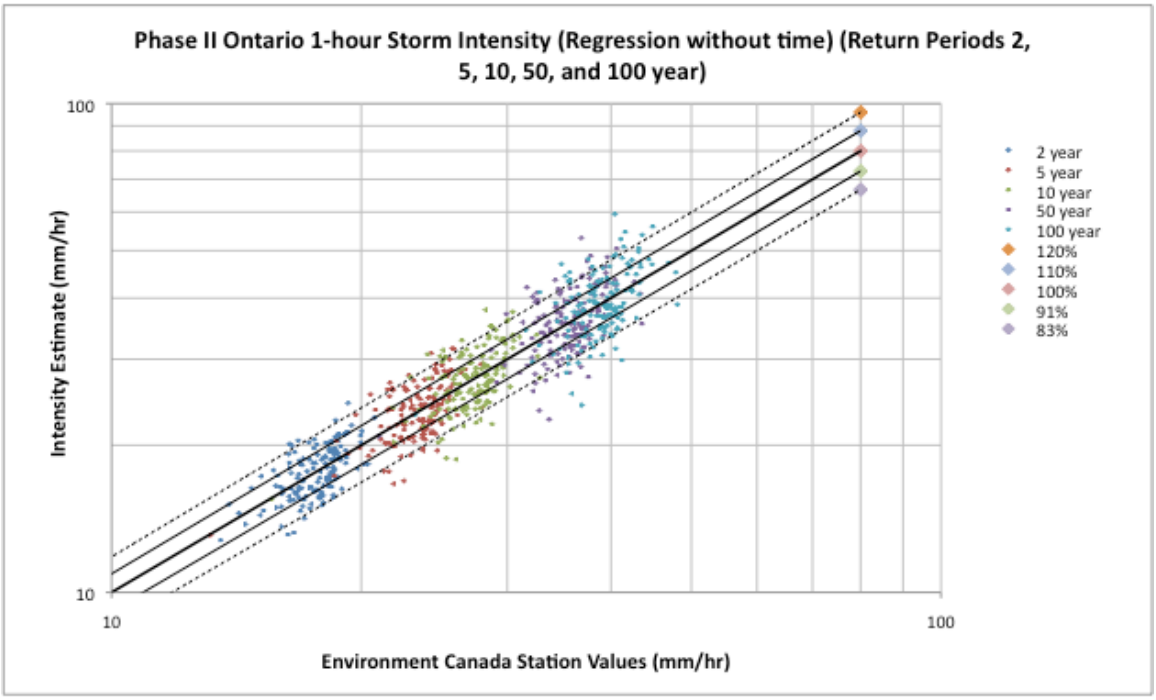


Figure 13) Phase II 1-hour Storm Estimated vs. Environment Canada Station Values

2.4 Confidence Limits

The regression results had a 95 percent confidence interval, which indicated that 95% of the time, the actual rainfall would be within the upper and lower bound of the predicted values. The upper and lower bound confidence limits were calculated as:

Equation 6) Upper and Lower Bound 95% Confidence Limit

$$\hat{y}_t \pm t_{\frac{\alpha}{2} n-k-1} s \sqrt{X_i^{\mathrm{T}} C^{-1} X_i}$$

where $\hat{y}_t$ is the predicted maximum rainfall, t is the t-distribution right tail probability, s is the standard error of the regression, α is one minus the confidence level, n is the total number of observations, k is the number of independent variables, X_i is a 1 X 7 column vector that is the difference between each independent variable and its mean for the ith observation, and C is the covariance matrix. The covariance matrix indicates the strength of connection between the independent variables in the regression. (Wiley et al, 1999)

Another important component in Phase II was the validation of the regression results. Figure 14 to 17 are comparisons of the “A” parameter between the predictions and Environment Canada Values for four different weather stations in Ontario. In figure 15 and 16, the red numbers indicate the Ottawa Sewer Design Guideline. Notice the 2012 MTO maximum rainfall designs are very close to the Ottawa design values.

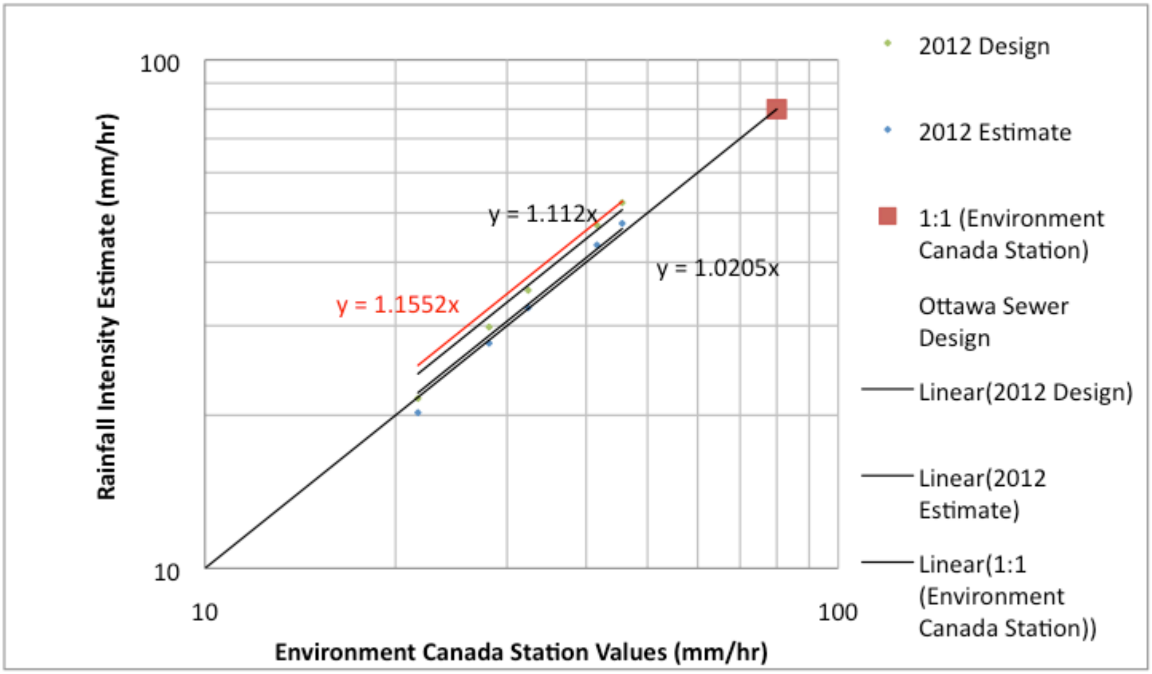


Figure 14) Ottawa RC "A" Coefficient Return Periods 2-100 Years

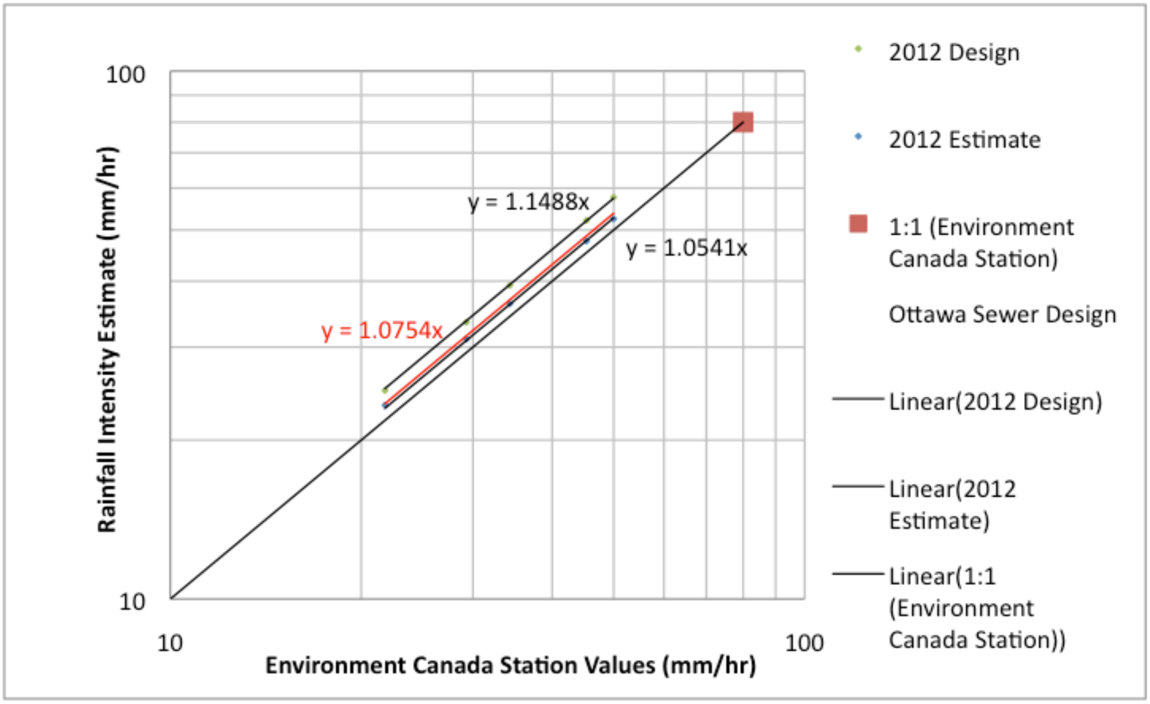


Figure 15) Ottawa Airport "A" Coefficient Return Periods 2-100 Years

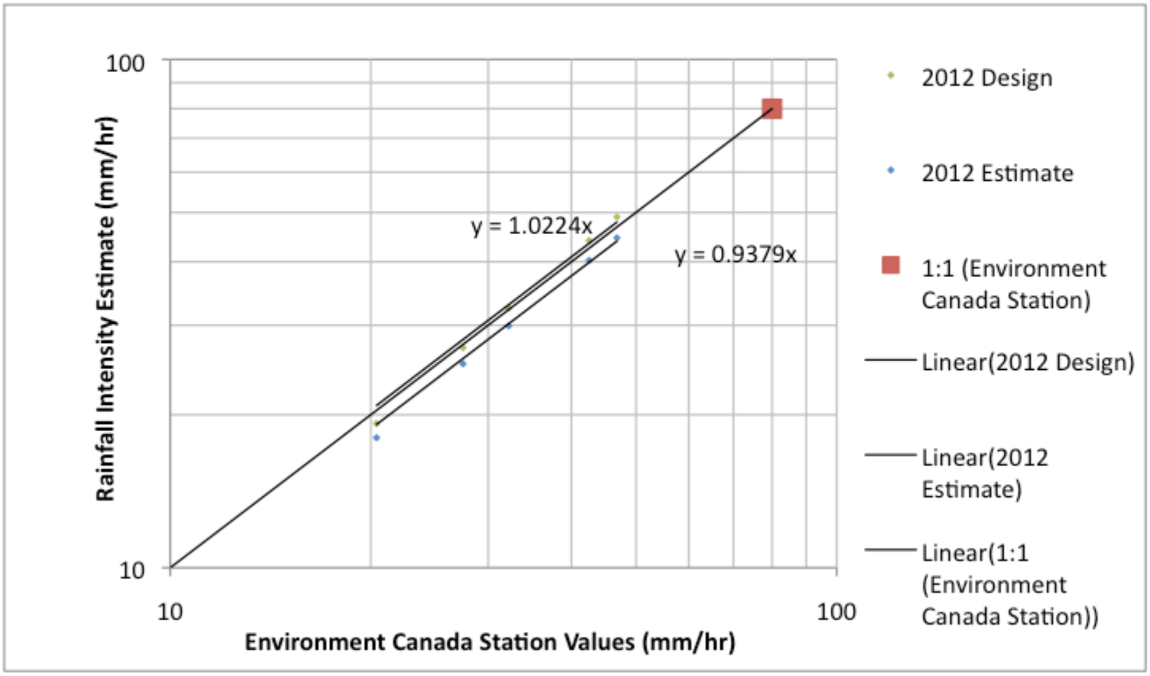


Figure 16) Armstrong Airport "A" Coefficient Return Periods 2-100 Years

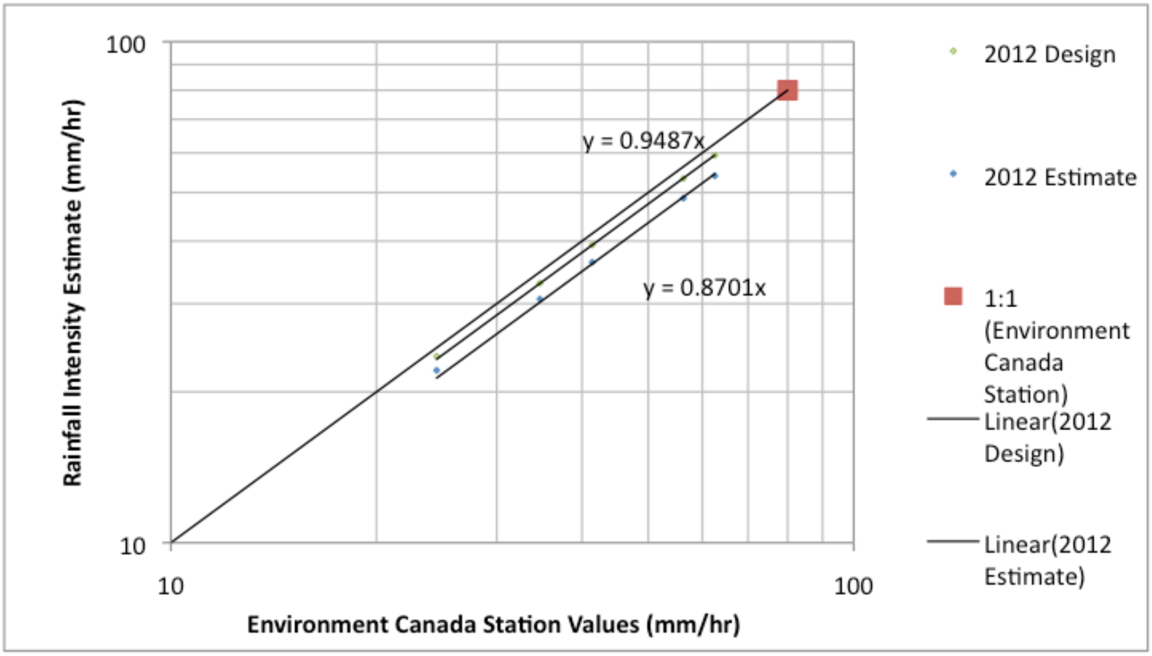


Figure 17) Kenora Airport "A" Coefficient Return Periods 2-100 Years

Phase I of the MTO IDF renewal project utilized the WATMAPPR method to interpolate IDF data from weather stations, in order to update IDF data and development a user-friendly IDF lookup tool. Phase II improved upon the existed work from Phase I, including more weather stations in Ontario, and implemented a weigh factor, which eliminated the need to repeatedly enter data for stations with longer records.

Chapter 3: Time Trend Estimation

3.1 Preparations for IDF Prediction Regression Analysis

"Development, Interpretation and Use of Rainfall Intensity-Duration-Frequency (IDF) Information: A Guideline for Canadian Water Resources Practitioners," a document developed by Canadian Standards Association, mentioned that one of the methods that had been applied to estimate the projected extreme precipitation is the extrapolation of trends. Post Phase II research used linear regression to characterize weather trends in historical data and the model was used to extend to future periods. (DIU, 2010) The "A" parameter for the equation: $R = AT^B$ can be found for future years by performing a regression analysis for the A parameters. The regression analysis must contain the average record year of the stations' weather records as an additional regression parameter. The actual average record years of the stations were difficult to find, as some of the stations were missing years of weather records. How the basic average year for each station was easily found with the equation:

Equation 7) Average Record Year of Weather Stations

$$y_{average} = \frac{y_2 + y_1}{2}$$

where $y_{average}$ was the average record year for each station, y_1 was the year when the station started to record weather data and y_2 was the year when the station stopped recording. A weight factor was used to adjust the regression parameter to simulate the effect of using the actual average record years.

3.1.1 Weight Factor Version 2 and Standard Error

The previous weight factor was updated to a more straightforward equation. It became the length of individual station record over the total lengths of stations. The change was made because it was assumed that the effect each station has on the regression result was proportional to the length of record of that station. This weight factor yielded very similar results to the previous one. The weight factor was:

Equation 8) Weight Factor Equation

$$weight = \frac{y_{lx}}{y_{l1} + y_{l2} + \ldots + y_{l151}}$$

where y_{lx} was the weather record length for a weather station, $y_{l1}+y_{l2}+\ldots+y_{151}$ was the sum of the weather record length for all weather stations. Each regression parameter was multiplied by the weight factor. Regression analysis was performed for each return period. The updated weight factor slightly improved the SE of the regression; its main purpose was to simplify the previously more complicated weight factor equation. The standard error of a regression describes the goodness of a fit, it is:

Equation 9) Standard Error of Regression

$$S.E. = \sqrt{\frac{SSR}{n-2}}$$

where SSR is the sum of the squared residuals and n is the sample size (Appendix A). For a relationship $y_i = b_0 + b_1 x_i$, SSR is:

Equation 10) Sum of the Squared Residuals

$$SSR = \sum (y_i - b_0 - b_1 x_i)^2$$

the standard error for the regressions for this study was lower than they were in phase I and phase II.

3.1.2 Regression Result Validation

Figure 19 shows the "A" coefficient regression results for all return periods for the average calendar years of the station records. The figure compares the value of predicted "A" coefficients and the recorded "A" coefficients. The thick solid black line represents the 1:1 line. Figure 18 shows that the regression analysis is an improvement from they were previously with the new weight factor (shown in Figure 12). About 90% of the predicted "A" parameters were within 20% of the Meteorological Service of Canada weather stations' recorded values. Regression analysis for the years 2012 and 2090 and validations for each of the year were performed in order to determine if a time trend relationship exist between the rainfall intensity and the physiological data. Individual "A" parameters regression figures for each return period are shown in Appendix B.

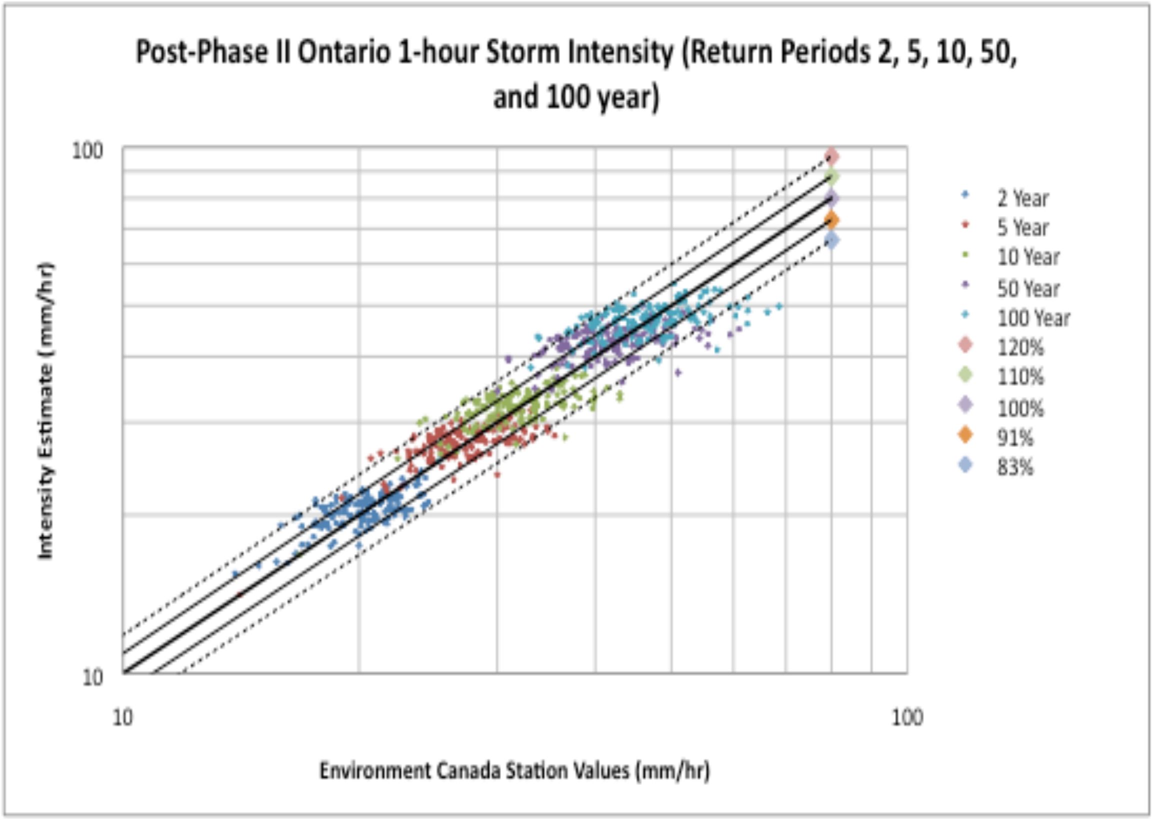
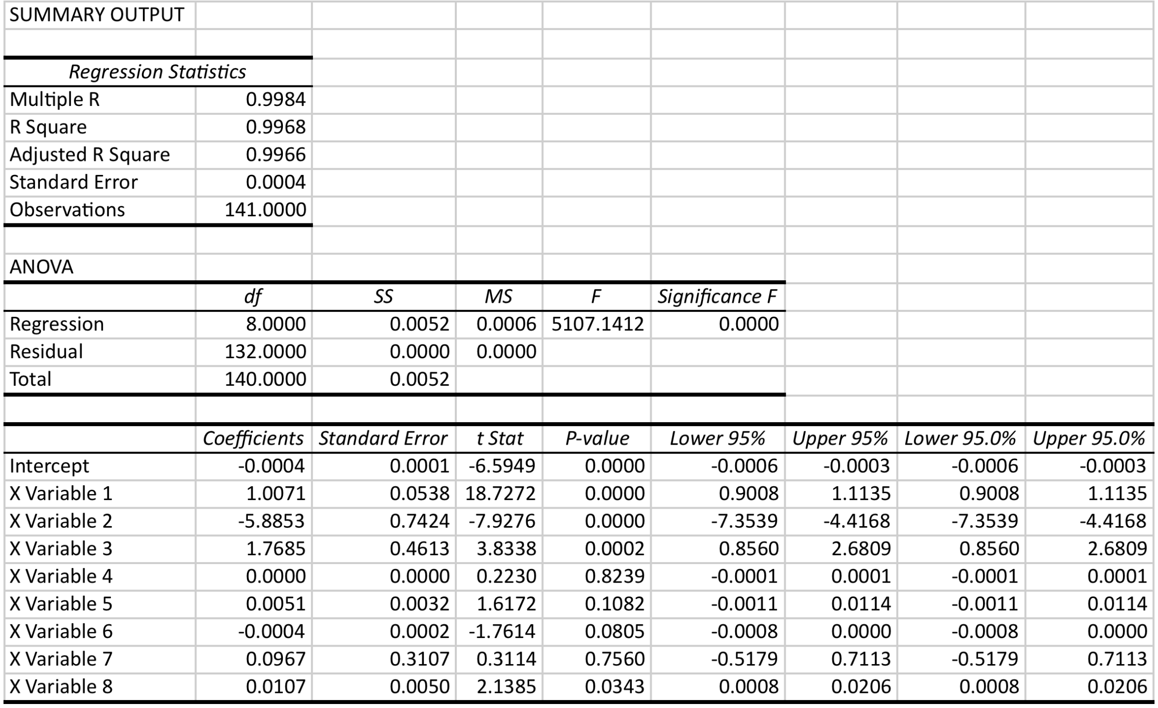


Figure 18) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year

3.2 Regression Analysis for Year 2012

The "A" parameters for future years could be found with the same technique. Table 2 is a sample regression result table for year 2012. Variables 1 – 8 are: average calendar year of station record (year), latitude, longitude, elevation (m), barrier height (m), slope Y, slope X and distance to water (km), respectively. For return periods 5, 10, 50 and 100 years, refer to Appendix C.

Table 2) Sample Regression Results 2-year Return Period for Year 2012



SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9984
R Square	0.9968
Adjusted R Square	0.9966
Standard Error	0.0004
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8.0000	0.0052	0.0006	5107.1412	0.0000
Residual	132.0000	0.0000	0.0000		
Total	140.0000	0.0052			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.0004	0.0001	-6.5949	0.0000	-0.0006	-0.0003	-0.0006	-0.0003
X Variable 1	1.0071	0.0538	18.7272	0.0000	0.9008	1.1135	0.9008	1.1135
X Variable 2	-5.8853	0.7424	-7.9276	0.0000	-7.3539	-4.4168	-7.3539	-4.4168
X Variable 3	1.7685	0.4613	3.8338	0.0002	0.8560	2.6809	0.8560	2.6809
X Variable 4	0.0000	0.0000	0.2230	0.8239	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0051	0.0032	1.6172	0.1082	-0.0011	0.0114	-0.0011	0.0114
X Variable 6	-0.0004	0.0002	-1.7614	0.0805	-0.0008	0.0000	-0.0008	0.0000
X Variable 7	0.0967	0.3107	0.3114	0.7560	-0.5179	0.7113	-0.5179	0.7113
X Variable 8	0.0107	0.0050	2.1385	0.0343	0.0008	0.0206	0.0008	0.0206

The average record years for the weather stations were substituted with the calendar year of the desire prediction. Figure 19 shows a regression analysis that was performed with average record years as 2012. Validation of the result was shown in section 2.2. Refer to Appendix C for individual figures for each return period.

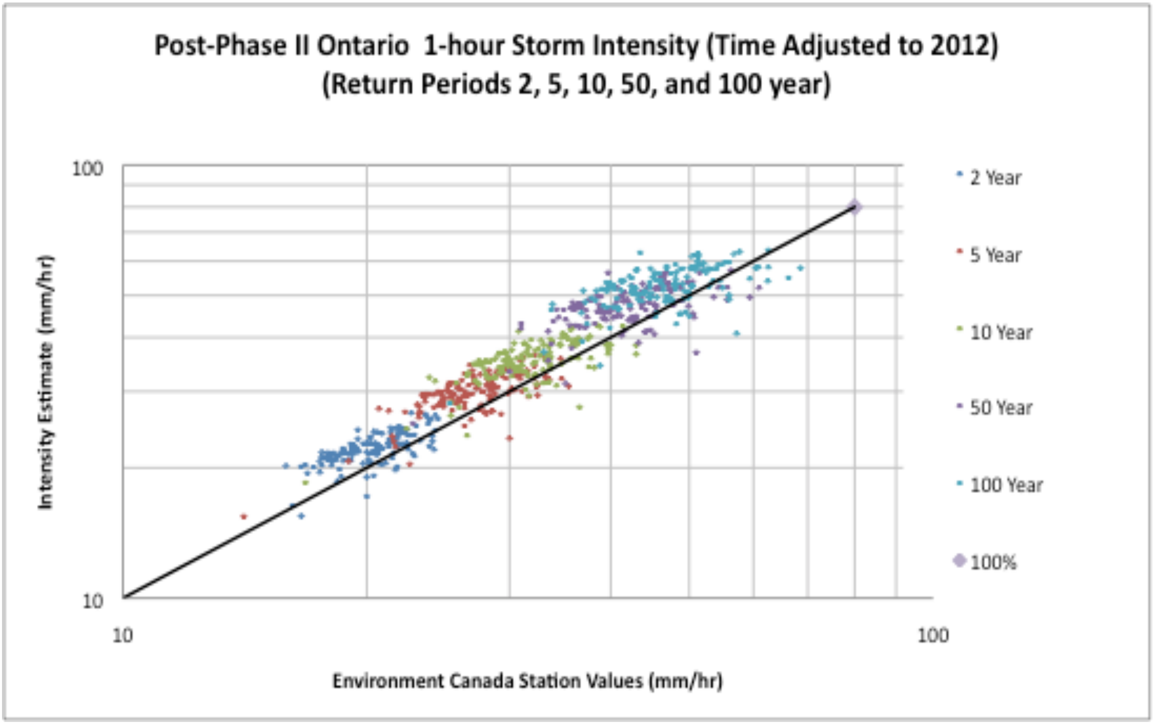


Figure 19) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year for 2012

3.3 Regression Validation Calendar Year 2012

3.3.1 National Oceanic and Atmospheric Administration Comparison

The Hydrometeorological Design Studies Center of the National Oceanic and Atmospheric Administration (NOAA) provides a precipitation estimate search engine named the Precipitation Frequency Data Server (PFDS). (Figure 20) (Figure 21) NOAA used empirical equations that were specially developed to calculate liquid precipitation frequency estimates. NOAA obtained the 90% confidence limits for the estimates by utilizing a Monte-Carlo simulation. PFDS delivers precipitation frequency, precipitation amount and other associate information based on the NOAA Atlas 14 documents. (PFA, 2013) The NOAA Atlas 14 is a 14-volume project, which include updated precipitation information for each state in the United States of America. As of 2013, NOAA Atlas 14 volumes 1 – 9 were completed.

The precipitation information for Michigan was updated in NOAA Atlas 14 volume 8, which was published in early 2013. The IDF curve for Detroit, Michigan was obtained using the PFDS. Detroit's IDF curve was used as a comparison with Windsor, Ontario's IDF curve produced by the regression analysis. The distance between Windsor and Detroit is less than 200 km; it is a short distance in regards to the location for an IDF curve which made the IDF curves comparable.

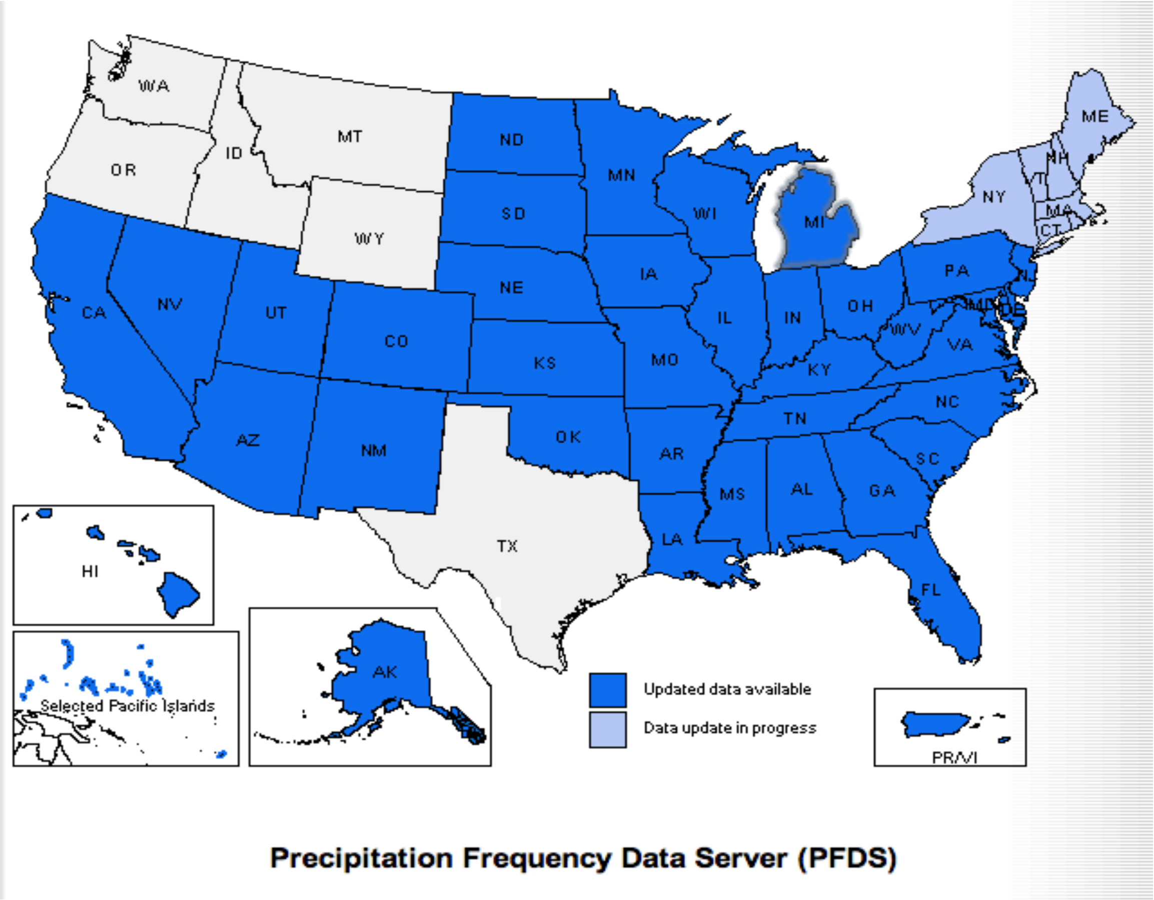
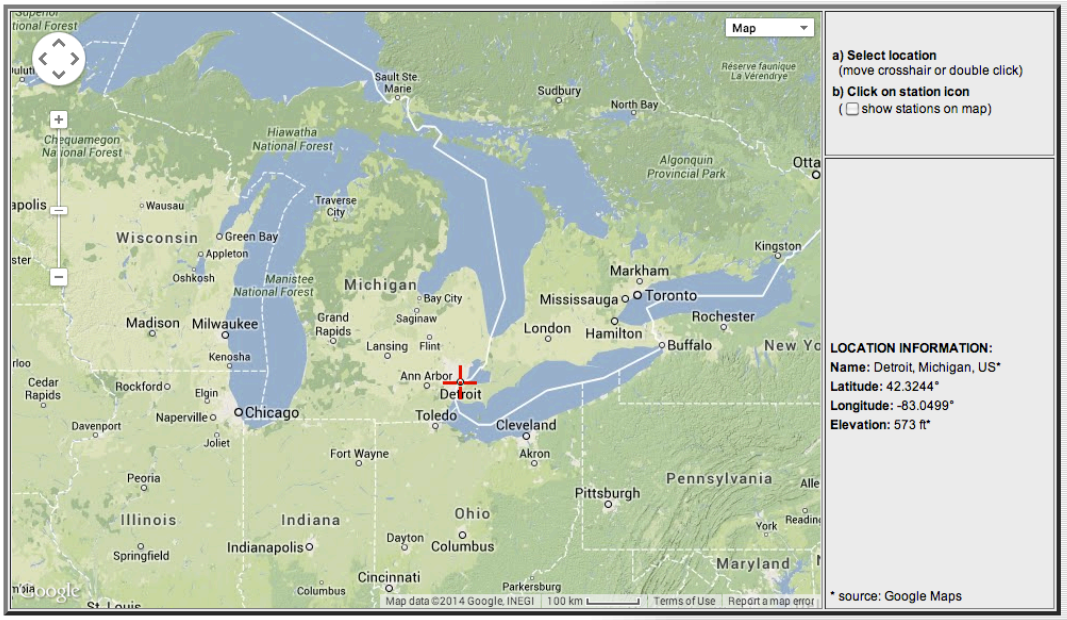


Figure 20) PFDS, An IDF Search Engine for the United States, on the NOAA Website



a) Select location
(move crosshair or double click)

b) Click on station icon
(☐ show stations on map)

LOCATION INFORMATION:
Name: Detroit, Michigan, US*
Latitude: 42.3244°
Longitude: -83.0499°
Elevation: 573 ft*

* source: Google Maps

Figure 21) IDF Location Selection on PFDS

Figure 22 is the IDF curve for a 1-hour storm duration for Detroit obtained from PFDS. The IDF information from PSDS was compared with the regression analysis for Windsor. (Figure 23) The blue curve represents the IDF curve for Detroit and the red represents the IDF curve for Windsor for a 2-year return period storm. The dotted lines are the 95% confidence limit for each of the IDF curve with their respective colors. The two curves are very similar without significant statistical difference. Figure 24 is the IDF comparison between Detroit and Windsor for a 25-year return period storm. Both IDF curves are very similar and the results are within each other's 95% confidence limit. (Figure 25)

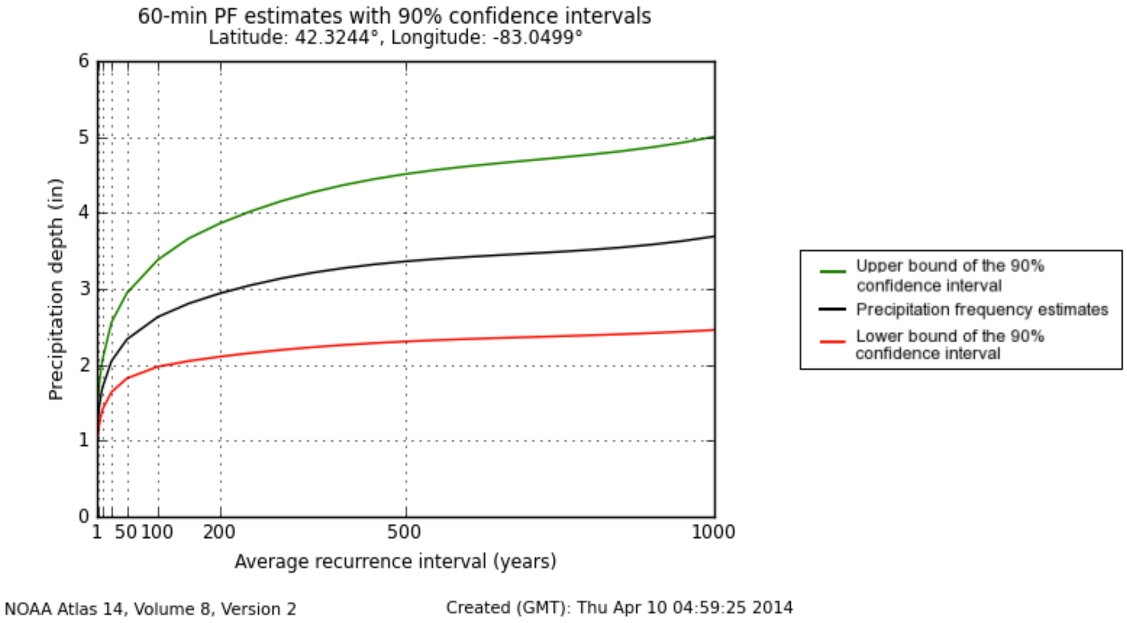


Figure 22) IDF Curve for an 1-hour Storm for Detroit on PFDS

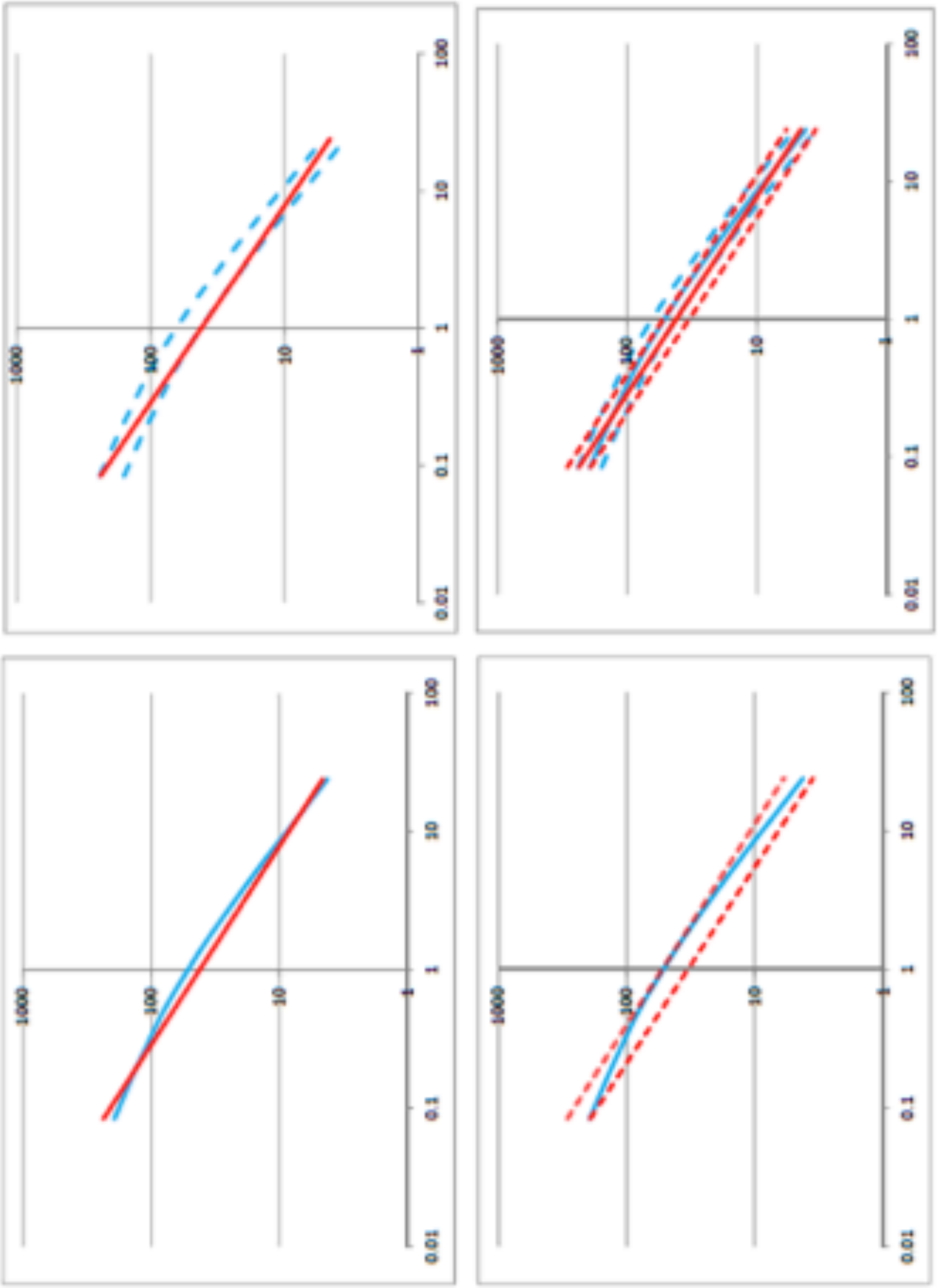


Figure 23) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Curves for 2-year Return Period Storms Comparison. Intensity (mm/hr) vs. Storm Duration (hrs)

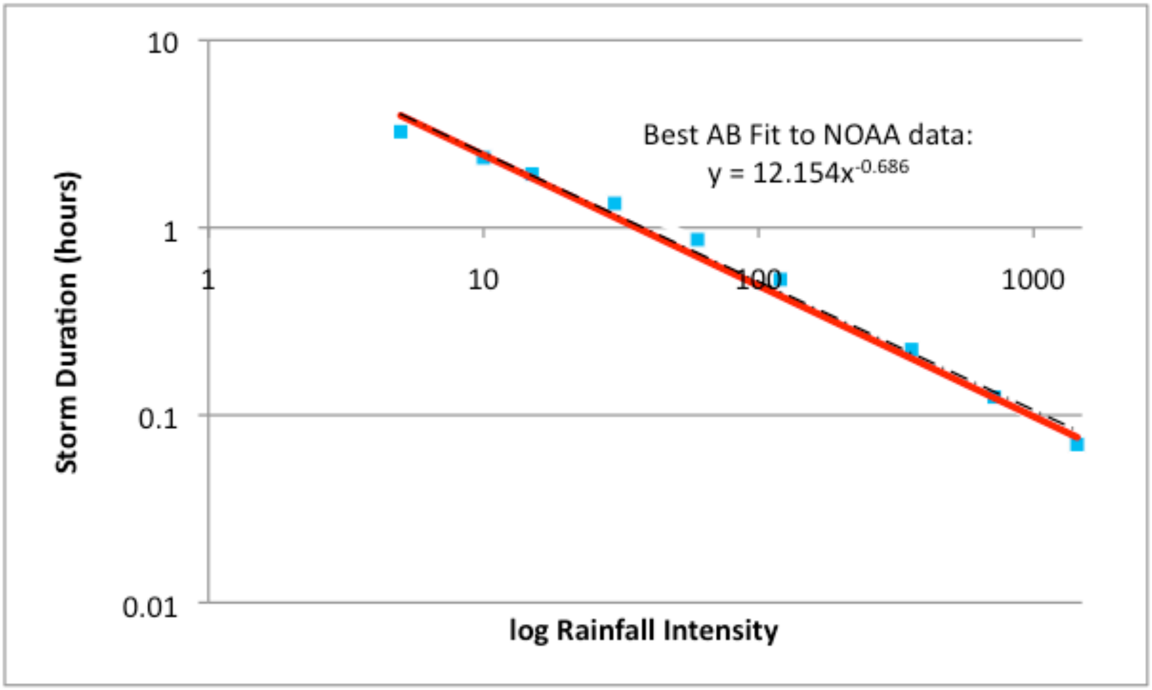


Figure 24) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Comparison for 25-year Return Period

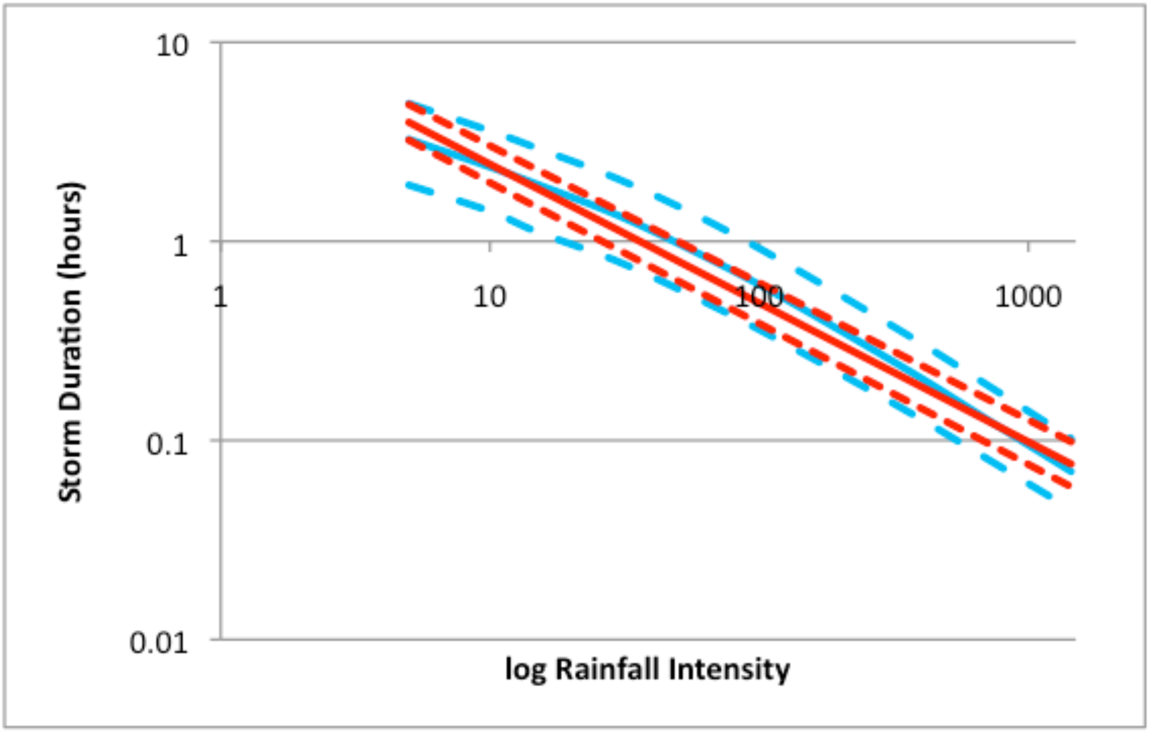


Figure 25) NOAA Detroit (Blue) and MTO Windsor (Red) IDF Comparison for 25-year Return Period (with Confidence Interval)

3.3 Regression Analysis for 2090 Design Values

One of the goals for this research was using regression analysis to predict IDF curves for 2090 for Ontario by studying past weather trends. The validation of the 2090 regression analysis is shown in section 3.4. Figure 26 shows the results of rainfall intensity prediction for a 1-hour rainfall event for 2090, which would be the IDF design values for projects with a standard 75 years design life. The regression analysis was performed with the average year of station records being 2090. The predicted precipitation intensity values (mm/hr) for 2090 are on the Y-axis and the design values obtained from Environment Canada are on the X-axis. The solid black curve is the 1:1 line. The dotted black lines are the upper and lower 20% boundaries. The lower boundaries were adjusted to 9 and 17% to keep they as the same ratio as the upper boundaries for a more appealing aesthetic since the figure is on a log scale. Rainfall intensities show a 20-30% increase from 2-100 year return periods, which is a reasonable amount when compared to other studies. These are encouraging results and a larger scale study with other return periods and storm durations can be done in the future. Refer to Appendix E for detail regression results for each return period and Appendix F for individual figures for each return period.

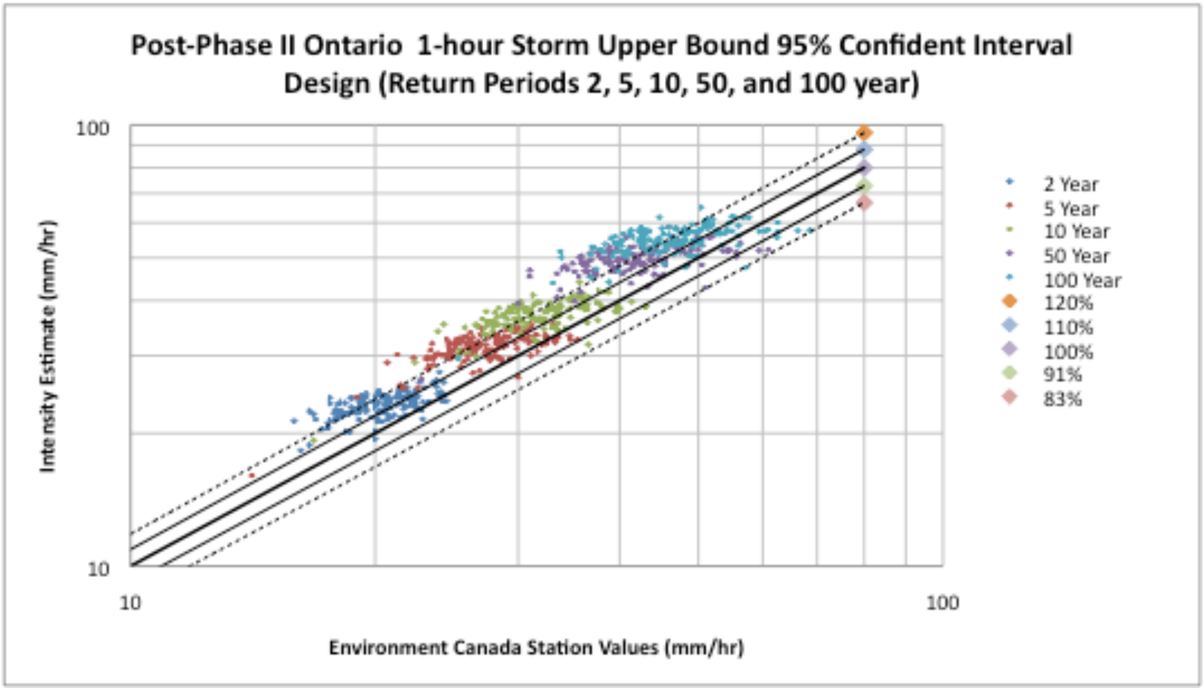


Figure 26) 1-hour Storm 2090 Regression Prediction for Ontario

3.4 Regression Validation Calendar Year 2090

3.4.1 McMaster Comparison

A journal named “Identification of the Effect of Climate Change on Future Design Standards of Drainage Infrastructure in Ontario.” (DPB, 2005) was published in 2005. In which Dr. Paulin Coulibaly and his colleagues discussed the increasing annual precipitation in Ontario and the effect it has on highway drainage infrastructure design. The study was performed using the downscaling method. The Grand River Region and the Kenora and Rainy River Region were the focus areas for the downscaling study. One station from each of the study area was selected for result comparison between the downscaling and the regression study. The four stations that were in the Grand River Region were Brantford, Stratford, Glen Allen and Woodstock. The Brantford weather station was selected randomly for comparing the result of the downscaling and the regression studies. Figure 27 is the McMaster University recorded 1-hour storm rainfall intensity downscaling estimates for the Brantford weather station from year 1970 to year 2090. Figure 28 is the Rainfall Frequency Atlas of Canada 1-hour storm intensity records and regression estimates for the Brantford weather station from year 1970 to 2090. Both of the studies predicted a rainfall intensity rate of a 33-75% increase for return periods 2 to 100 years.

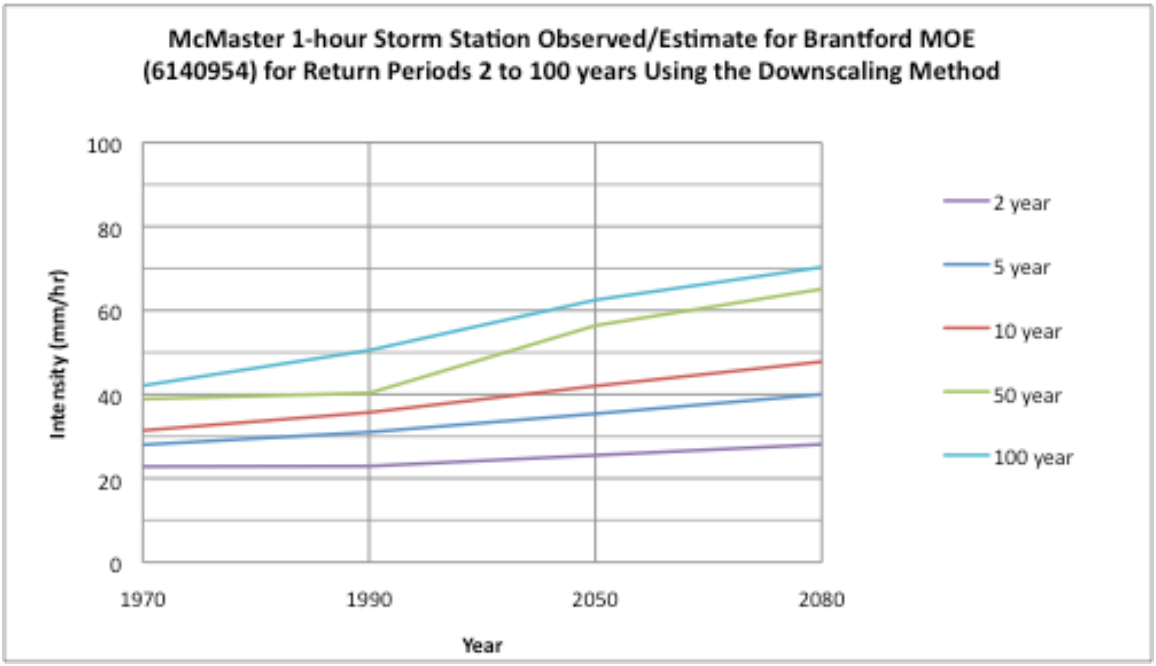


Figure 27) Brantford Weather Station 1-hour Storm Rainfall Intensities McMaster Records and Downscaling Prediction from 1970-2080

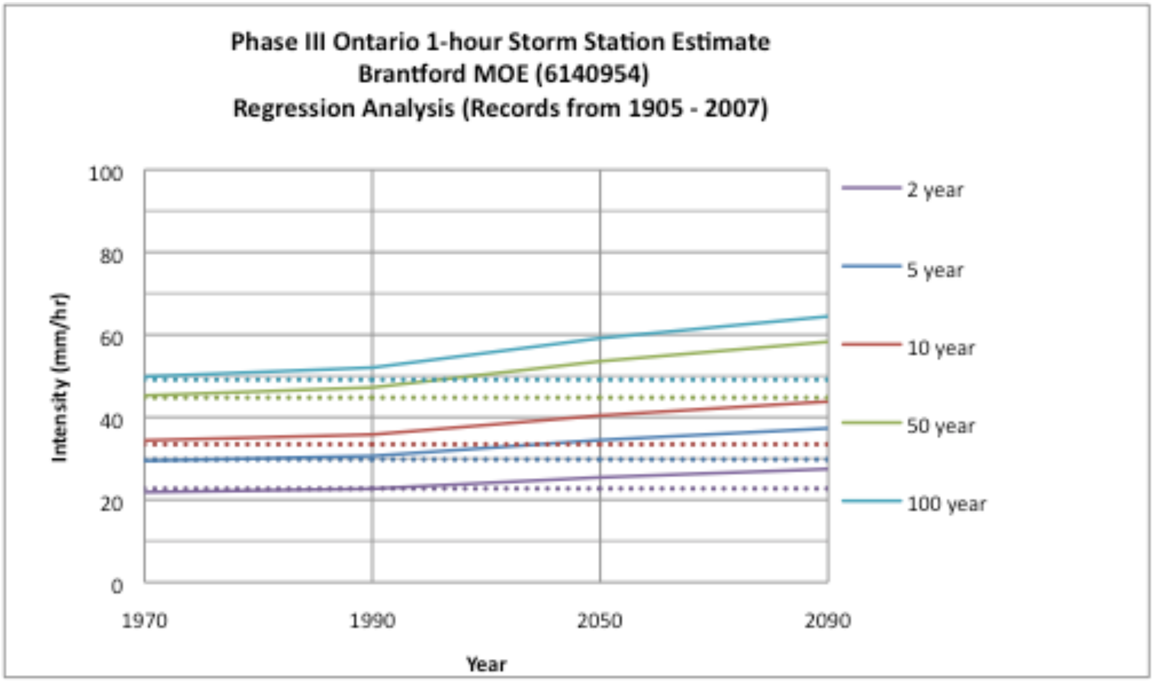


Figure 28) Brantford Weather Station 1-Hour Storm Rainfall Intensities Atlas of Canada Records and Regression Analysis Prediction from 1970-2090

Comparisons of the estimated rainfall intensity in 2050 and 2080 in Brantford between the McMaster downscaling study and the University of Waterloo regression study are shown in Figure 29 and Figure 30. The figures show that both the downscaling and regression studies predict a similar trend in rainfall intensity increase for Brantford. The downscaling study predicted a rainfall intensity of 25.5 mm/hr and the regression analysis predicted 25.4 mm/hr for a 2-year return period storm for 2050. The downscaling study predicted a rainfall intensity of 62.5 mm/hr and the regression analysis predicted 59.2 mm/hr for a 100-year return period storm for 2050, which is 5.5% lower than the downscaling study prediction. The downscaling study predicted a rainfall intensity of 28.1 mm/hr and the regression analysis predicted 26.9 mm/hr for a 2-year return period storm for 2080. The downscaling study predicted a rainfall intensity of 70.3 mm/hr and the regression analysis predicted 63.1 mm/hr for a 100-year return period storm for 2080, which is 10% lower than the downscaling study prediction. The regression results followed the general trend that was predicted by the downscaling study and had very comparable values.

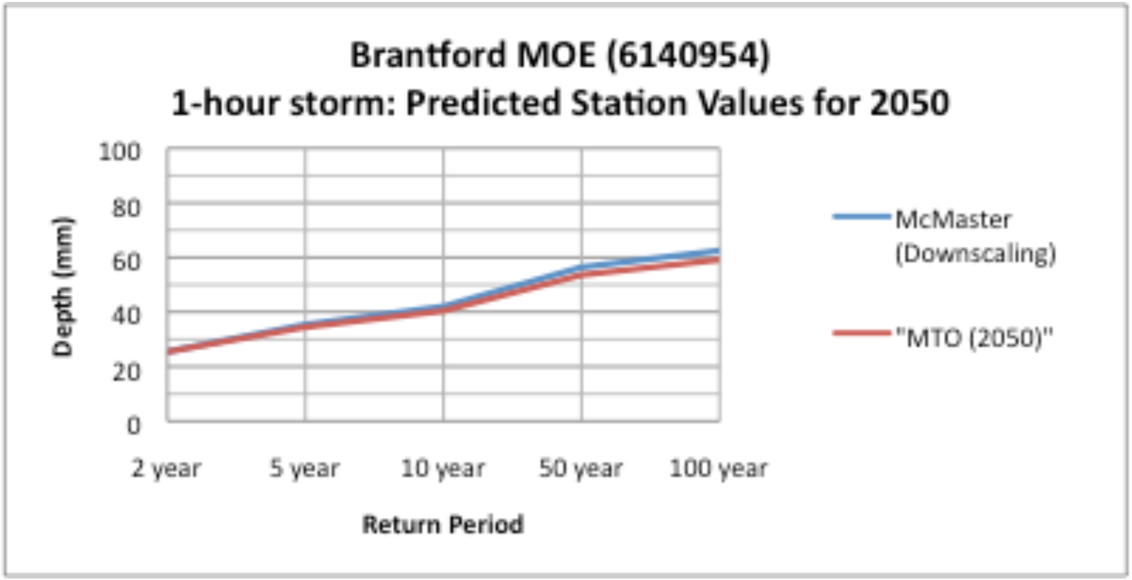


Figure 29) Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Brantford 2050

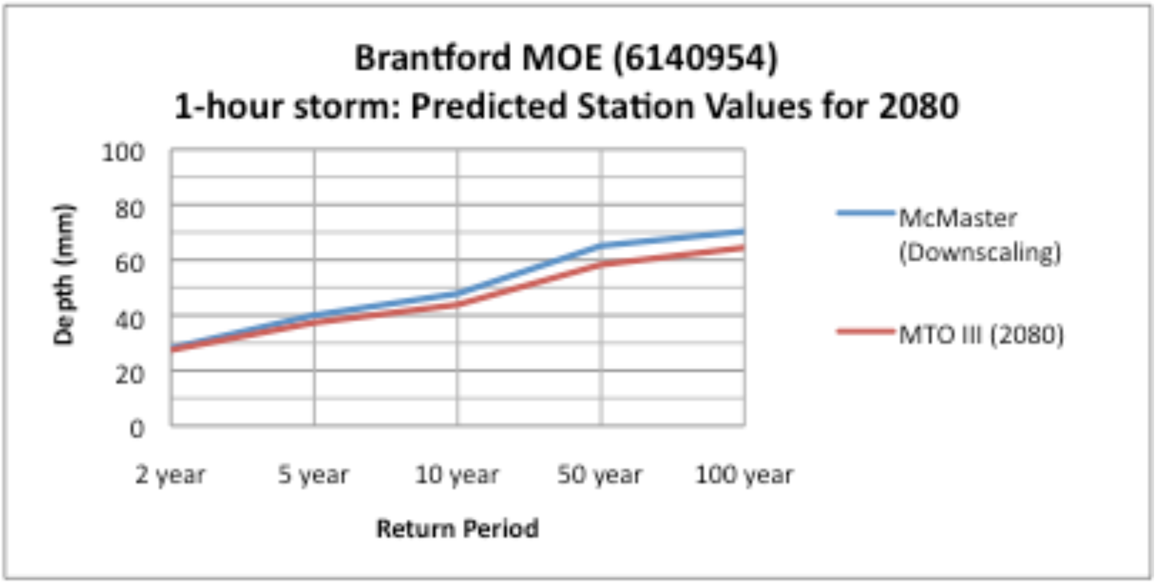


Figure 30) Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Brantford 2080

Rawson Lake was selected as a comparison between 2050 and 2080 1-hour rainfall intensity predictions for the downscaling study and the regression analysis, as Rawson Lake was one of the stations where the regression results had the largest difference when compared to the downscaling study.

Comparisons of the estimated rainfall intensity in 2050 and 2080 in Rawson Lake between the McMaster downscaling study and the University of Waterloo regression study are shown in Figure 31 and Figure 32. The downscaling study predicted a rainfall intensity of 23.8 mm/hr and the regression analysis predicted 22.7 mm/hr for a 2-year return period storm for 2050. The downscaling study predicted a rainfall intensity of 72 mm/hr and the regression analysis predicted 56 mm/hr for a 100-year return period storm for 2050, which is 22.3% lower than the downscaling study prediction. The downscaling study predicted a rainfall intensity of 24.5 mm/hr and the regression analysis predicted 24 mm/hr for a 2-year return period storm for 2080. The downscaling study predicted a rainfall intensity of 76.9 mm/hr and the regression analysis predicted 60 mm/hr for a 100-year return period storm for 2080, which is 22.1% lower than the downscaling study prediction. Even though the regression prediction is more than 20% lower than the downscaling study prediction, the percentage increase from 2012 to 2050 and 2080 prediction were comparable. Both the McMaster University downscaling study and the University of Waterloo regression analysis predicted a 10-13% increase in 1-hour duration rainfall intensity for 2050 and a 19-23%. Regression results followed the general trend that was predicted by the downscaling study.

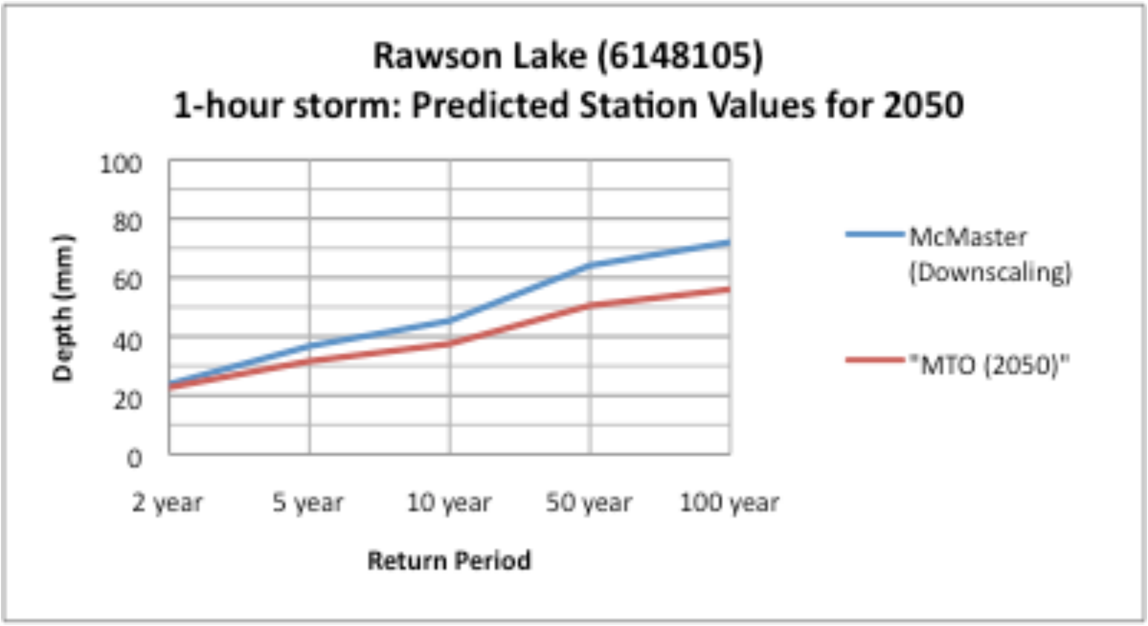


Figure 31)Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Rawson Lake 2050

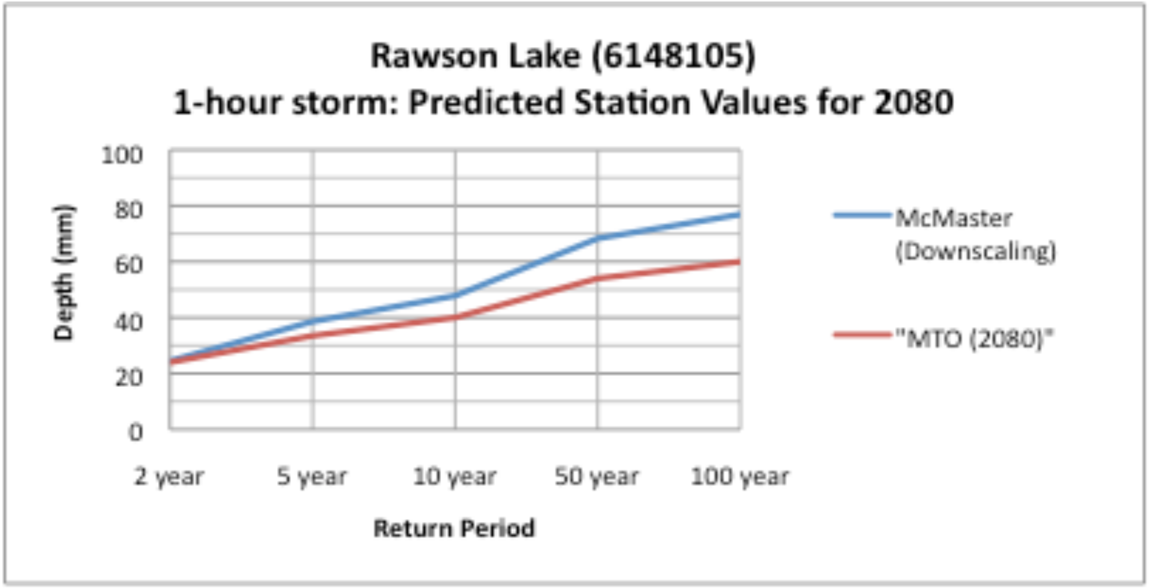


Figure 32)Rainfall Intensities for 2-100 Year Return Period Comparison Between Downscaling Study and Regression Analysis for Rawson Lake 2080

3.4.2 Environment Canada Climate Change Comparison

Dr. Viatcheslav. V. Kharin and Francis. W. Zwiers of Environment Canada published a journal named “Changes in the Extremes in an Ensemble of Transient Climate Simulation with a Couple Atmosphere-Ocean GCM“ in 2000. The journal was about the studies of three climate change simulations for the years 1900-2100. The simulations were performed with the global coupled model of the Canadian Centre for Climate Modeling and Analysis and extreme precipitation increase was predicted for everywhere on the globe. (CEE, 2000) Figure 33 shows the projected changes for 24-hour rainfall events for North America by the Canadian Centre for Climate Modeling and Analysis. The blue curve is the average recorded rainfall depth for 24-hour rainfall events in 1990. Predictions for 2055 and 2090 are the green and red curve, respectively. Figure 34 is the projected 1-hour rainfall events for Brantford, Ontario predicted by the regression analysis. The blue curve is the average recorded rainfall depth for 1-hour rainfall events in 1990. The values for rainfall depth are different in the two figures since the rainfall durations and the area of interest are different. However, comparisons can still be made about the rate of increase. Both projections predicted an increase in rainfall of 20-30% for a 2-year return period and an increase of. These results are very comparable without many statistical differences.

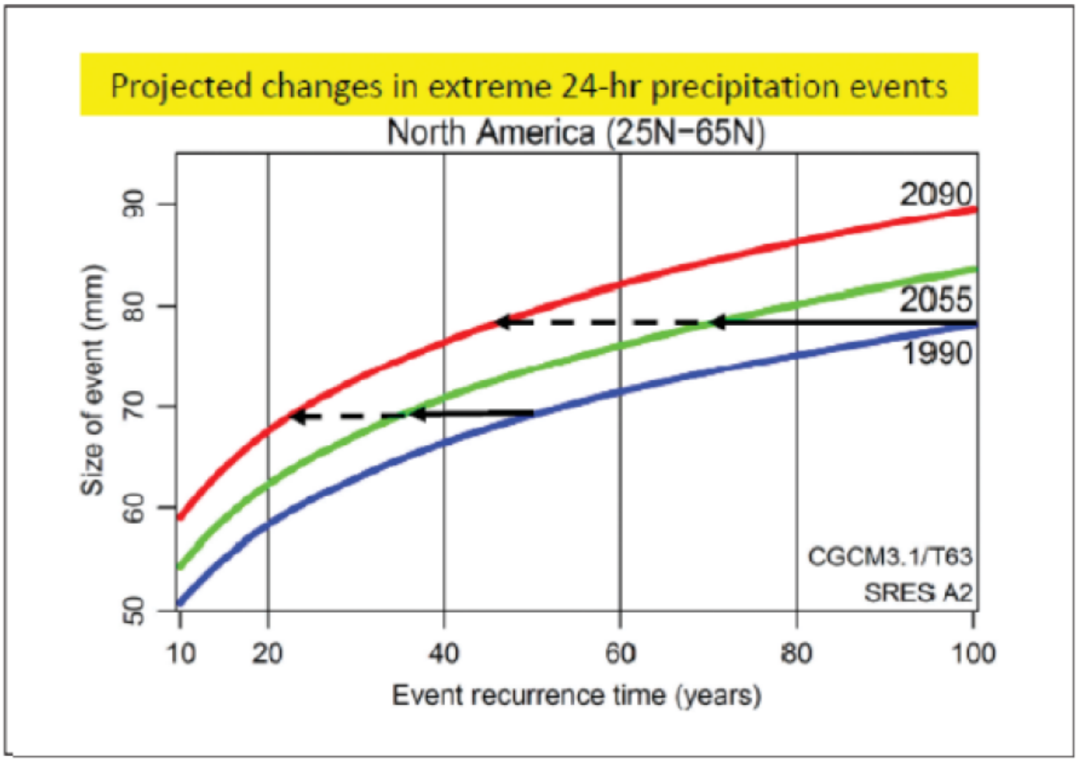


Figure 33) Environment Canada Rainfall Depth Prediction for 24-hour Rainfall Duration Event Based on the IPCC A2 Model

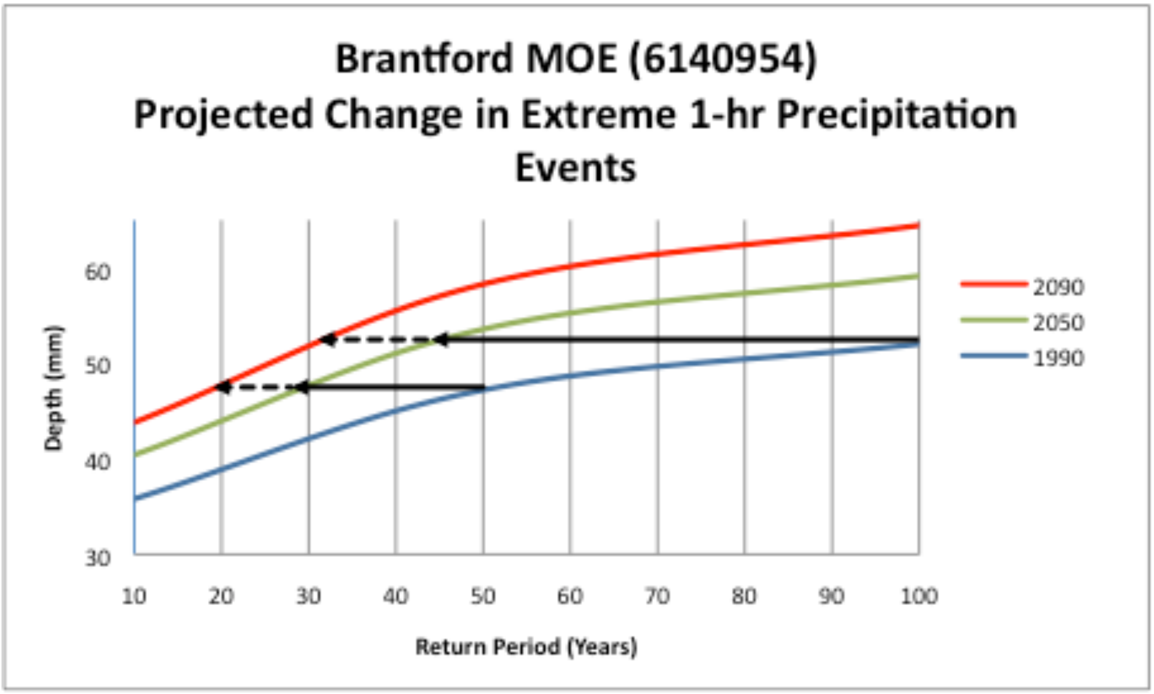
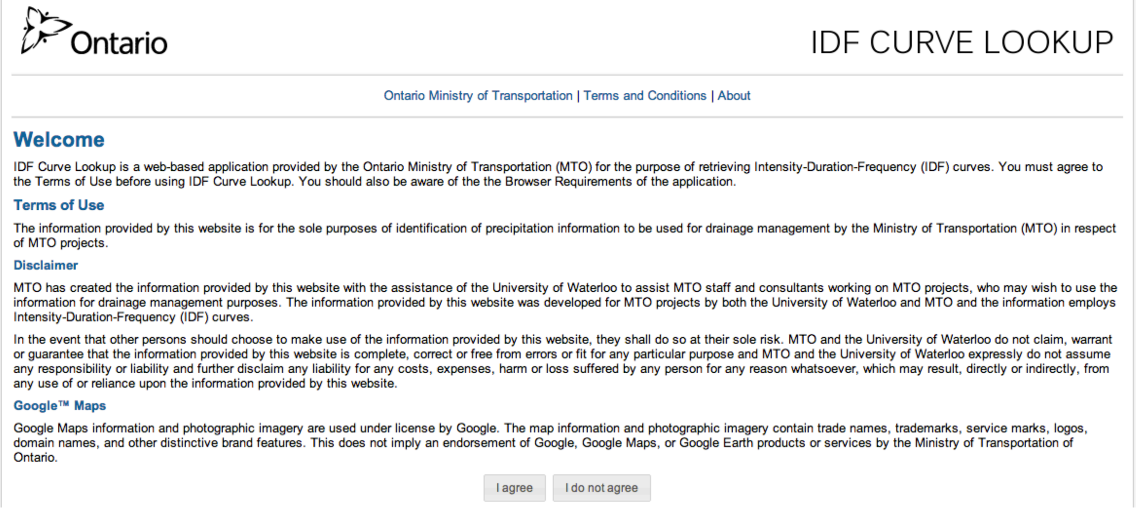


Figure 34) University of Waterloo IDF Regression 1-hour Storm Prediction for Brantford

3.5 New IDF Lookup Website

The IDF lookup website was updated in September 2013 with new interface and revised IDF information. The front page is Terms and Agreement, which informs the users that the website is used to identify precipitation information in Ontario and that the website was created with the assistance of the University of Waterloo (Figure 35).



Welcome

IDF Curve Lookup is a web-based application provided by the Ontario Ministry of Transportation (MTO) for the purpose of retrieving Intensity-Duration-Frequency (IDF) curves. You must agree to the Terms of Use before using IDF Curve Lookup. You should also be aware of the the Browser Requirements of the application.

Terms of Use

The information provided by this website is for the sole purposes of identification of precipitation information to be used for drainage management by the Ministry of Transportation (MTO) in respect of MTO projects.

Disclaimer

MTO has created the information provided by this website with the assistance of the University of Waterloo to assist MTO staff and consultants working on MTO projects, who may wish to use the information for drainage management purposes. The information provided by this website was developed for MTO projects by both the University of Waterloo and MTO and the information employs Intensity-Duration-Frequency (IDF) curves.

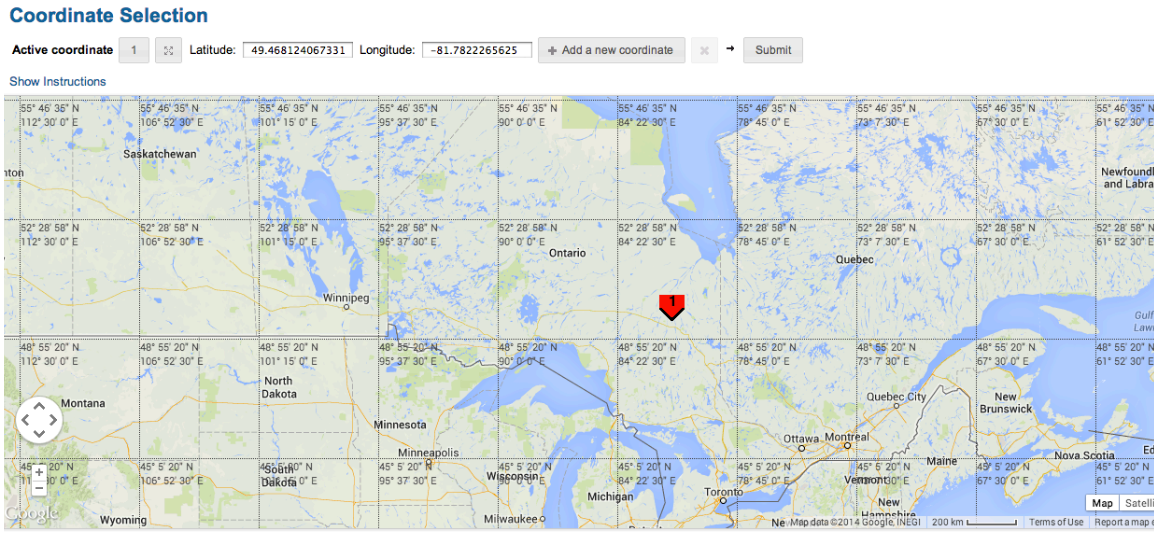
In the event that other persons should choose to make use of the information provided by this website, they shall do so at their sole risk. MTO and the University of Waterloo do not claim, warrant or guarantee that the information provided by this website is complete, correct or free from errors or fit for any particular purpose and MTO and the University of Waterloo expressly do not assume any responsibility or liability and further disclaim any liability for any costs, expenses, harm or loss suffered by any person for any reason whatsoever, which may result, directly or indirectly, from any use of or reliance upon the information provided by this website.

Google™ Maps

Google Maps information and photographic imagery are used under license by Google. The map information and photographic imagery contain trade names, trademarks, service marks, logos, domain names, and other distinctive brand features. This does not imply an endorsement of Google, Google Maps, or Google Earth products or services by the Ministry of Transportation of Ontario.

Figure 35) Front Page of the IDF Curve Lookup Website

The About section is updated with the feature of the website, the methodology of the study and information on the project team. After accepting the Terms and Agreements, the user will be brought to Coordinate Selection (Figure 36). IDF information can be obtained for any location in Ontario. The location of interest can be selected by clicking on the map or it can be found by entering the latitude and the longitude of the location.



Coordinate Selection

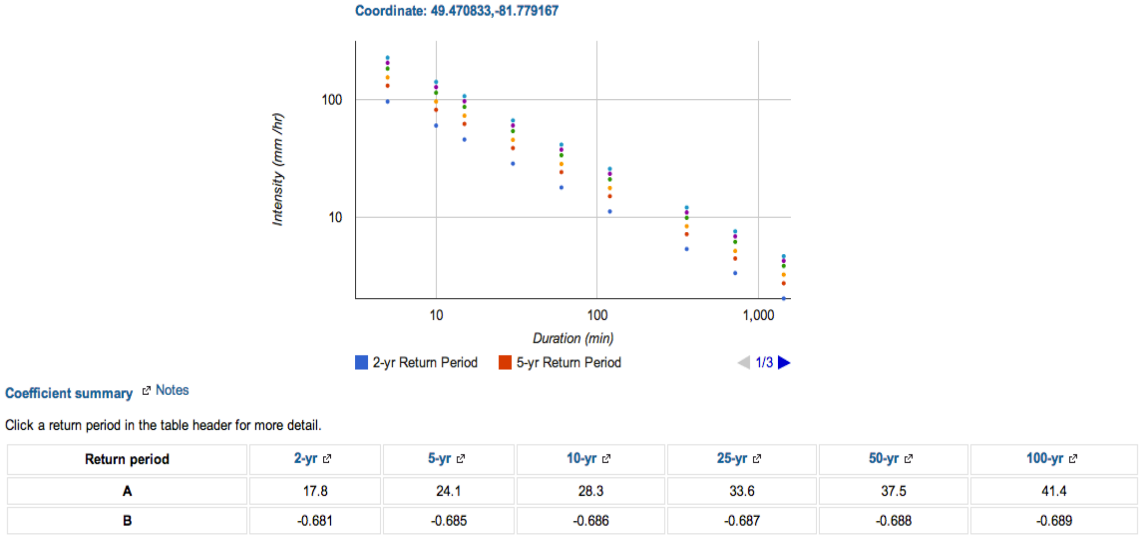
Active coordinate: 1

Latitude: 49.468124067331

Longitude: -81.7822265625

Figure 36) Location of Interest Selection on the IDF Lookup Website

Multiple locations can be selected by clicking "Add a new coordinate" and the system will interpolate the selected points for results. Up to 12 locations can be selected at the same time without noticeable slow down of the system. After the location(s) is selected, the system interpolates IDF data from MSC weather stations nearby. A sample of the output is shown as Figure ASDF. The output includes a figure showing relationship between the rainfall intensities (mm/hr), their corresponding return periods (years) and the rainfall duration (hr). The A and B coefficients for the $R = AT^B$ calculation are and rainfall intensity for all combination of return periods and rainfall durations are available in tables (Figure 37) (Figure 38).

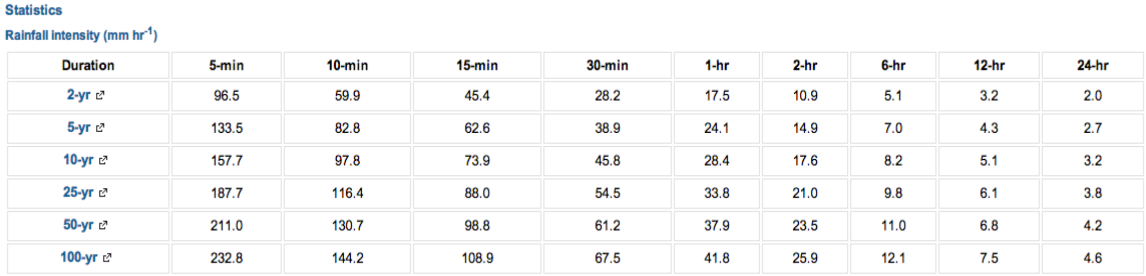


Coefficient summary Notes

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

Return period	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
A	17.8	24.1	28.3	33.6	37.5	41.4
B	-0.681	-0.685	-0.686	-0.687	-0.688	-0.689

Figure 37) Sample Output for Rainfall Intensity vs. Rainfall Duration And Table for "A" And "B" Coefficients for All Return Periods



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	96.5	59.9	45.4	28.2	17.5	10.9	5.1	3.2	2.0
5-yr	133.5	82.8	62.6	38.9	24.1	14.9	7.0	4.3	2.7
10-yr	157.7	97.8	73.9	45.8	28.4	17.6	8.2	5.1	3.2
25-yr	187.7	116.4	88.0	54.5	33.8	21.0	9.8	6.1	3.8
50-yr	211.0	130.7	98.8	61.2	37.9	23.5	11.0	6.8	4.2
100-yr	232.8	144.2	108.9	67.5	41.8	25.9	12.1	7.5	4.6

Figure 38) Sample Output for Rainfall Intensity for Each Return Period and Duration Combination

Individual return periods can be selected to generate a figure that shows depth (mm) or rainfall intensity vs. rainfall duration (Figure 39) (Figure 40). MSC weather station measurements can be put on the same figure for comparison purposes. The confidence limits for the rainfall intensities and depth are shown for the selected location (Figure 41). These different outputs allow the users to choose the desire result format.

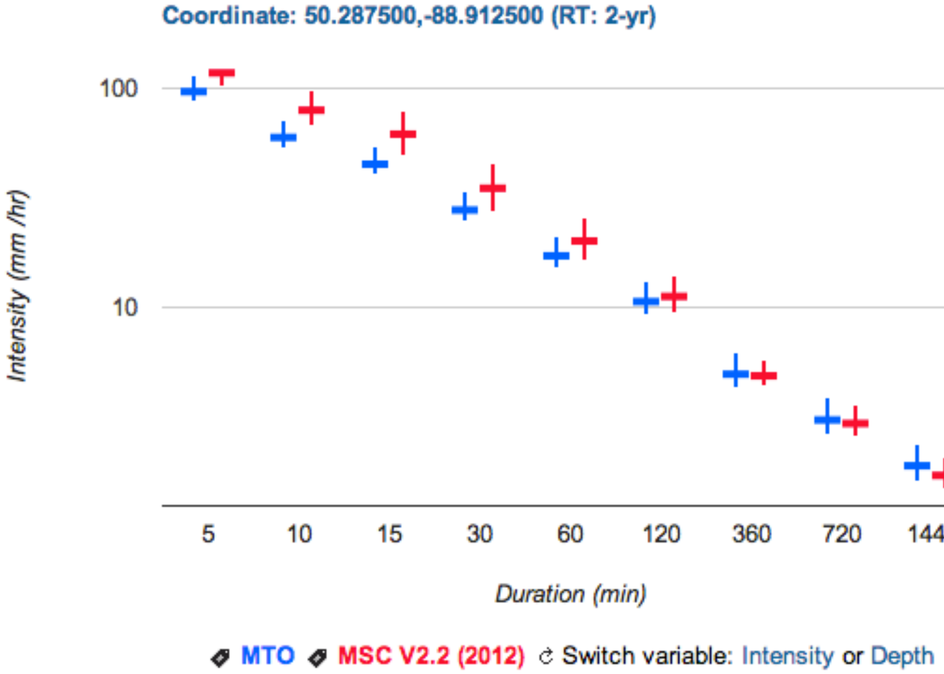


Figure 39) Sample Output Figure for Rainfall Intensity vs. Duration from the IDF Lookup Website

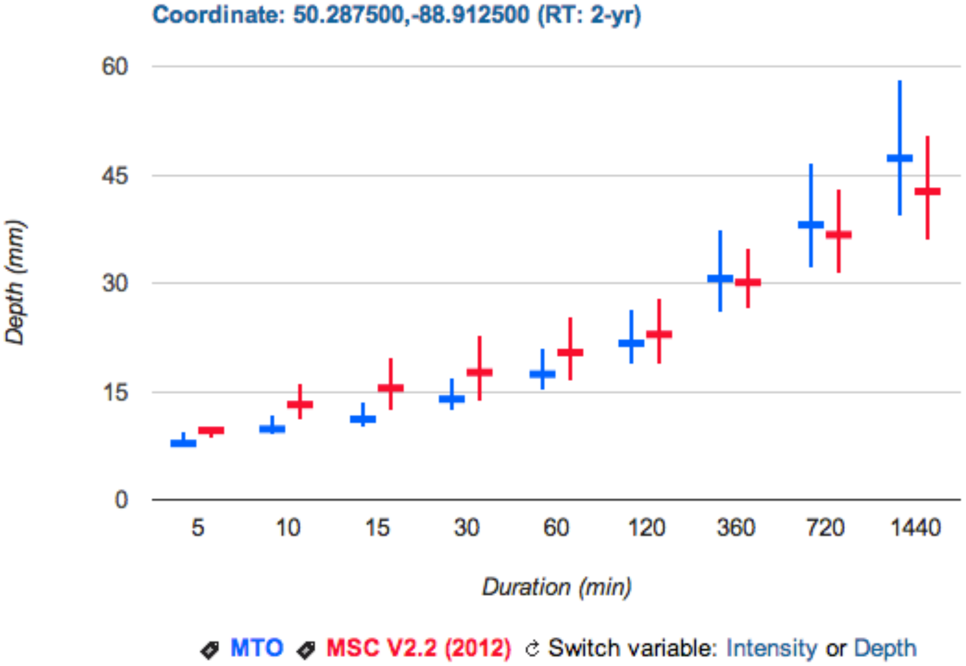
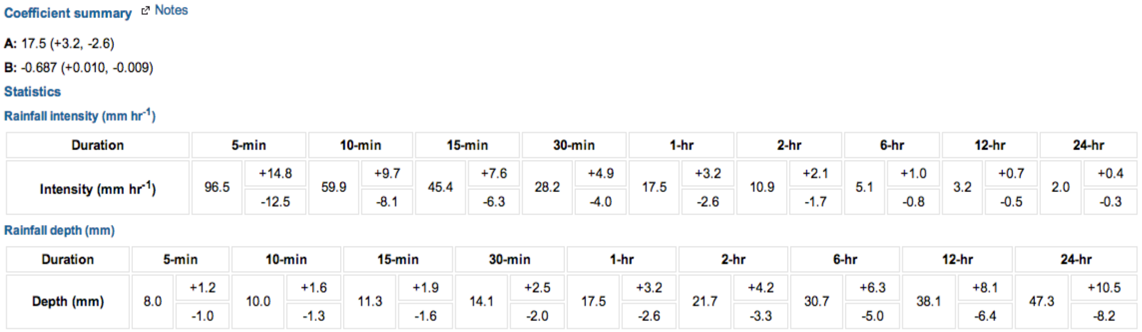


Figure 40) Sample Output Figure for Rainfall Depth vs. Duration from the IDF Lookup Website



Coefficient summary Notes

A: 17.5 (+3.2, -2.6)

B: -0.687 (+0.010, -0.009)

Statistics

Rainfall intensity (mm hr^{-1})

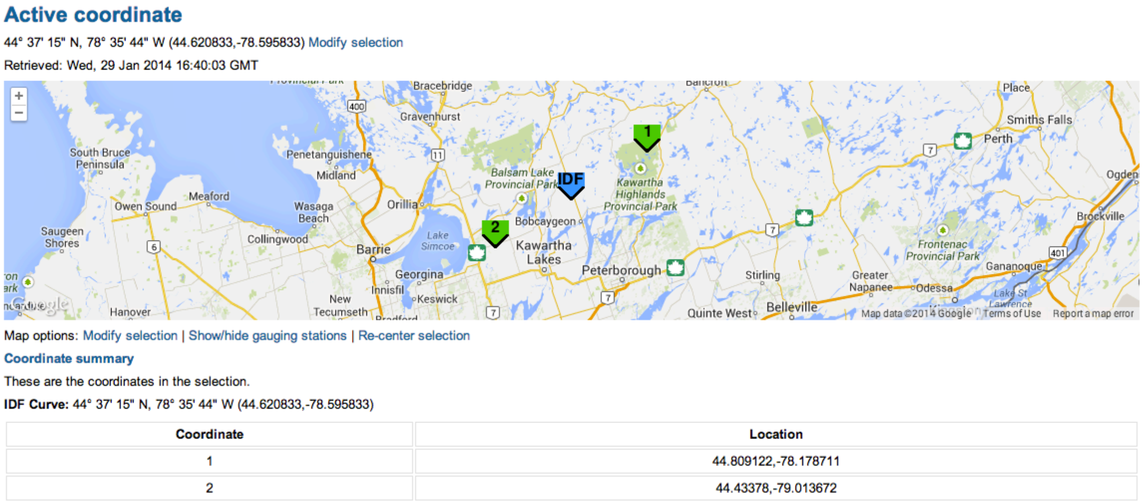
Duration	5-min		10-min		15-min		30-min		1-hr		2-hr		6-hr		12-hr		24-hr	
Intensity (mm hr^{-1})	96.5	+14.8	59.9	+9.7	45.4	+7.6	28.2	+4.9	17.5	+3.2	10.9	+2.1	5.1	+1.0	3.2	+0.7	2.0	+0.4
		-12.5		-8.1		-6.3		-4.0		-2.6		-1.7		-0.8		-0.5		-0.3

Rainfall depth (mm)

Duration	5-min		10-min		15-min		30-min		1-hr		2-hr		6-hr		12-hr		24-hr	
Depth (mm)	8.0	+1.2	10.0	+1.6	11.3	+1.9	14.1	+2.5	17.5	+3.2	21.7	+4.2	30.7	+6.3	38.1	+8.1	47.3	+10.5
		-1.0		-1.3		-1.6		-2.0		-2.6		-3.3		-5.0		-6.4		-8.2

Figure 41) Sample Output for "A" and "B" Parameters, Rainfall Intensity and Rainfall Depth from the IDF Lookup Website

When multiple locations are selected, the system interpolates the IDF data between the locations. Two locations are selected in Figure 42 as a demonstration. The coordinate map shows the two locations that are selected and the closest MSC weather stations from them. The outputs are the same as when a single point of interest is selected.



Active coordinate

44° 37' 15" N, 78° 35' 44" W (44.620833,-78.595833) Modify selection

Retrieved: Wed, 29 Jan 2014 16:40:03 GMT

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

Coordinate summary

These are the coordinates in the selection.

IDF Curve: 44° 37' 15" N, 78° 35' 44" W (44.620833,-78.595833)

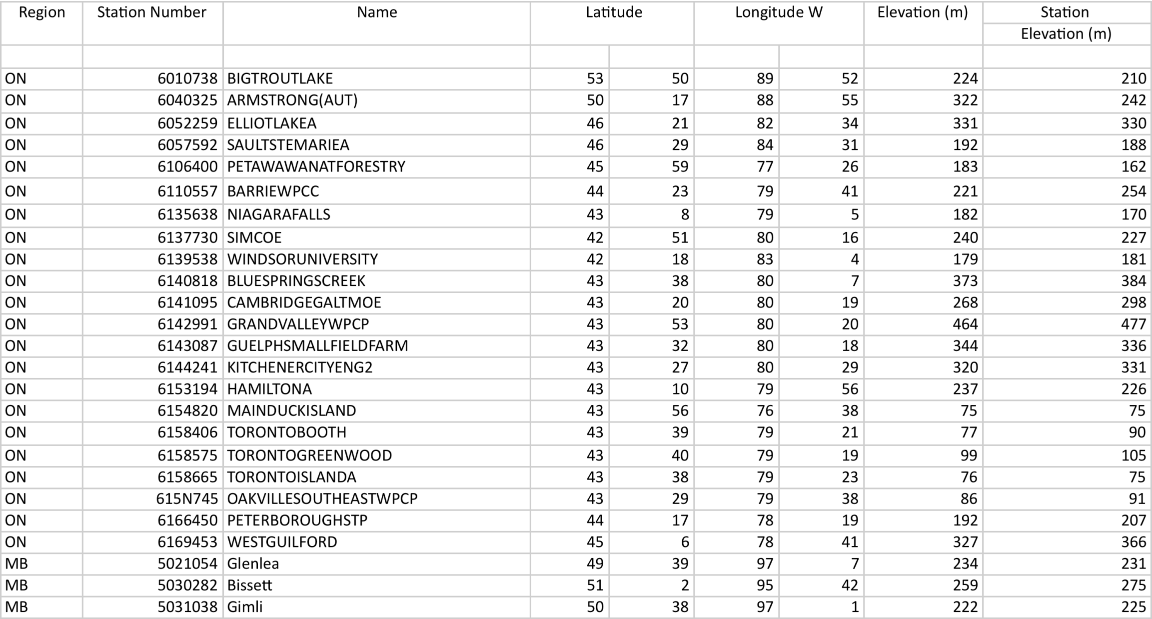
Coordinate	Location
1	44.809122,-78.178711
2	44.43378,-79.013672

Figure 42) Two Location Selected for A Sample Study on the IDF Lookup Website

3.6 Weather Data: Behind The Scene

Weather station data was stored as a .xlsx file. The file contained many components included geological information, weather records and rainfall intensity calculations for the weather stations. All of the information was stored in an orderly manner thus allow easy assess for possible researchers in the future. The geological information included the name and station number of the weather stations, the provinces of which the weather stations were located, the latitude, longitude and elevation of the weather stations. (Table 3)

Table 3) Geological Information for Sample Weather Stations



Region	Station Number	Name	Latitude		Longitude W		Elevation (m)	Station Elevation (m)
ON	6010738	BIGTROUTLAKE	53	50	89	52	224	210
ON	6040325	ARMSTRONG(AUT)	50	17	88	55	322	242
ON	6052259	ELLIOTLAKEA	46	21	82	34	331	330
ON	6057592	SAULTSTEMARIEA	46	29	84	31	192	188
ON	6106400	PETAWAWANATFORESTRY	45	59	77	26	183	162
ON	6110557	BARRIEWPCC	44	23	79	41	221	254
ON	6135638	NIAGARAFALLS	43	8	79	5	182	170
ON	6137730	SIMCOE	42	51	80	16	240	227
ON	6139538	WINDSORUNIVERSITY	42	18	83	4	179	181
ON	6140818	BLUESPRINGSCREEK	43	38	80	7	373	384
ON	6141095	CAMBRIDGEGALTMOE	43	20	80	19	268	298
ON	6142991	GRANDVALLEYWPCP	43	53	80	20	464	477
ON	6143087	GUELPHSMALLFIELDFARM	43	32	80	18	344	336
ON	6144241	KITCHENERCITYENG2	43	27	80	29	320	331
ON	6153194	HAMILTONA	43	10	79	56	237	226
ON	6154820	MAINDUCKISLAND	43	56	76	38	75	75
ON	6158406	TORONTOBOOTH	43	39	79	21	77	90
ON	6158575	TORONTOGREENWOOD	43	40	79	19	99	105
ON	6158665	TORONTOISLANDA	43	38	79	23	76	75
ON	615N745	OAKVILLESOUTHEASTWPCP	43	29	79	38	86	91
ON	6166450	PETERBOROUGHSTP	44	17	78	19	192	207
ON	6169453	WESTGUILFORD	45	6	78	41	327	366
MB	5021054	Glenlea	49	39	97	7	234	231
MB	5030282	Bissett	51	2	95	42	259	275
MB	5031038	Gimli	50	38	97	1	222	225

Recording information of the weather stations included the years when the weather stations started (Start Year) and stopped (End Year) recording weather data. The total years of the stations' records (Ny) were calculated as the difference of the starting and ending years. The number of calendar years

(Nr) excluding the years with missing records was included in order to find the percentage of years missing for each weather station, which was used to find the weight factor. (Table 4)

Table 4) Recording Information for Sample Weather Stations

Station Number	Name	Start Year	End Year	Ny	Nr	tbar	Total missing years	% Missing Year
6010738	BIGTROUTLAKE	1967	1992	26	26	1979.5	0	0
6040325	ARMSTRONG(AUT)	1969	1982	14	14	1975.5	0	0
6052259	ELLIOTLAKEA	1995	2006	12	12	2000.5	0	0
6057592	SAULTSTEMARIEA	1962	2006	45	45	1984	0	0
6106400	PETAWAWANATFORESTRY	1961	1994	34	34	1977.5	0	0
6110557	BARRIEWPCC	1979	2007	29	29	1993	0	0
6135638	NIAGARAFALLS	1965	1990	26	26	1977.5	0	0
6137730	SIMCOE	1962	1986	25	25	1974	0	0
6139538	WINDSORUNIVERSITY	1968	1979	12	12	1973.5	0	0
6140818	BLUESPRINGSCREEK	1967	1977	11	11	1972	0	0
6141095	CAMBRIDGEGALTMOE	1978	1992	15	15	1985	0	0
6142991	GRANDVALLEYWPCP	1976	1991	16	16	1983.5	0	0
6143087	GUELPHSMALLFIELDFARM	1954	1964	11	11	1959	0	0
6144241	KITCHENERCITYENG2	1955	1967	13	13	1961	0	0
6153194	HAMILTONA	1971	2003	33	33	1987	0	0
6154820	MAINDUCKISLAND	1966	1986	21	21	1976	0	0
6158406	TORONTOBOOTH	1966	1992	27	27	1979	0	0
6158575	TORONTOGREENWOOD	1966	1981	16	16	1973.5	0	0
6158665	TORONTOISLANDA	1971	1994	24	24	1982.5	0	0
615N745	OAKVILLESOUTHEASTWPCP	1965	1976	12	12	1970.5	0	0
6166450	PETERBOROUGHSTP	1965	1992	28	28	1978.5	0	0
6169453	WESTGUILFORD	1972	1987	16	16	1979.5	0	0
5021054	Glenlea	1967	2000	34	34	1983.5	0	0
5030282	Bissett	1969	1984	16	16	1976.5	0	0
5031038	Gimli	1964	1991	28	28	1977.5	0	0.000
6034075	KENORAA	1966	2004	39	38	1985	1	0.024
6041221	CARIBOUISLAND	1966	1988	23	22	1977	1	0.040

Finally, the rainfall intensity information is the A and B values used for the equation $R = AT^B$. The values listed are for the returning periods 2, 5, 10, 50 and 100 years. These values along with the other weather information were used for the regression analysis. (Table 5) (Table 6)

Table 5) “A” Coefficients Used in Equation $R=AT^B$ for Sample Weather Stations

Station Number	Name	Acoeff				
		2	5	10	50	100
6010738	BIGTROUTLAKE	16.2	21.7	25.4	33.5	36.9
6040325	ARMSTRONG(AUT)	20.4	27.5	32.2	42.5	46.8
6052259	ELLIOTLAKEA	22.9	31.1	36.5	48.5	53.5
6057592	SAULTSTEMARIEA	18.9	25.6	30.1	39.9	44.1
6106400	PETAWAWANATFORESTRY	18.7	26.4	31.5	42.8	47.5
6110557	BARRIEWPCC	21.3	28.5	33.3	43.7	48.1
6135638	NIAGARAFALLS	19.5	25.3	29.2	37.6	41.2
6137730	SIMCOE	21.4	28.9	33.8	44.6	49.1
6139538	WINDSORUNIVERSITY	23.6	31.1	36	46.8	51.3
6140818	BLUESPRINGSCREEK	22.9	31.1	36.5	48.3	53.2
6141095	CAMBRIDGEGALTMOE	22.1	29.1	33.7	43.8	48.1
6142991	GRANDVALLEYWPCP	20.6	26.8	30.8	39.7	43.5
6143087	GUELPHSMALLFIELDFARM	22.1	30.8	36.4	48.8	54
6144241	KITCHENERCITYENG2	24.3	31.5	36.3	47	51.4
6153194	HAMILTONA	22.4	30.5	35.8	47.5	52.5
6154820	MAINDUCKISLAND	18.1	24.6	28.8	38.2	42.2
6158406	TORONTOBOOTH	20.6	28.4	33.6	44.9	49.7
6158575	TORONTOGREENWOOD	19.1	26	30.6	40.5	44.7
6158665	TORONTOISLANDA	21.3	28.8	33.7	44.6	49.1
615N745	OAKVILLESOUTHEASTWPCP	20.3	25.9	29.7	37.9	41.3
6166450	PETERBOROUGHSTP	20	26.7	31.1	40.8	44.9
6169453	WESTGUILFORD	20.7	27.3	31.7	41.4	45.5
5021054	Glenlea	23.2	33.3	40	54.7	60.9
5030282	Bissett	18.3	24.2	28	36.5	40

Table 6) "B" Coefficients Used in Equation $R=AT^B$ for Sample Weather Stations

Station Number	Name	B exponent				
		2	5	10	50	100
6010738	BIGTROUTLAKE	-0.69	-0.695	-0.698	-0.701	-0.702
6040325	ARMSTRONG(AUT)	-0.765	-0.781	-0.788	-0.798	-0.801
6052259	ELLIOTLAKEA	-0.658	-0.669	-0.673	-0.68	-0.682
6057592	SAULTSTEMARIEA	-0.691	-0.685	-0.682	-0.678	-0.677
6106400	PETAWAWANATFORESTRY	-0.697	-0.696	-0.695	-0.695	-0.695
6110557	BARRIEWPCC	-0.707	-0.699	-0.695	-0.69	-0.689
6135638	NIAGARAFALLS	-0.668	-0.673	-0.676	-0.68	-0.681
6137730	SIMCOE	-0.688	-0.685	-0.684	-0.682	-0.681
6139538	WINDSORUNIVERSITY	-0.707	-0.704	-0.703	-0.701	-0.7
6140818	BLUESPRINGSCREEK	-0.685	-0.7	-0.707	-0.717	-0.72
6141095	CAMBRIDGEGALTMOE	-0.688	-0.678	-0.674	-0.667	-0.666
6142991	GRANDVALLEYWPCP	-0.705	-0.693	-0.687	-0.679	-0.676
6143087	GUELPHSMALLFIELDFARM	-0.707	-0.676	-0.664	-0.646	-0.64
6144241	KITCHENERCITYENG2	-0.814	-0.841	-0.855	-0.875	-0.881
6153194	HAMILTONA	-0.705	-0.697	-0.693	-0.688	-0.686
6154820	MAINDUCKISLAND	-0.678	-0.682	-0.684	-0.686	-0.687
6158406	TORONTOBOOTH	-0.72	-0.724	-0.725	-0.727	-0.728
6158575	TORONTOGREENWOOD	-0.718	-0.748	-0.76	-0.779	-0.784
6158665	TORONTOISLANDA	-0.723	-0.746	-0.756	-0.77	-0.774
615N745	OAKVILLESOUTHEASTWPCP	-0.684	-0.675	-0.671	-0.664	-0.663
6166450	PETERBOROUGHSTP	-0.697	-0.706	-0.709	-0.714	-0.716
6169453	WESTGUILFORD	-0.661	-0.651	-0.647	-0.641	-0.64
5021054	Glenlea	-0.708	-0.71	-0.71	-0.71	-0.711
5030282	Bissett	-0.666	-0.641	-0.63	-0.615	-0.61

Other geological information needed to perform the regression analysis included the barrier height, slope X and Y of the planes and the distance between the station location to a large body of water, typically Hudson Bay or the Great Lakes. The latitude and the longitude of the stations were converted to degrees from degrees and minutes. (Table 7) The latitude, longitude, slope X, slope Y and the distance to water were normalized to adjust to the common scale. (Table 8) The A parameters that were used for the regression analysis were converted into logarithmic values in order to minimize the standard error and prevent negative "A" parameter results (Table 9).

Table 7) Sample Geological Information

Station Number	Name				
		Barrier Height (m)	SlopeY	SlopeX	Distance to Water (km)
6010738	BIGTROUTLAKE	0	6	-21	372.73
6040325	ARMSTRONG(AUT)	173.9252	10	68	218.2888
6052259	ELLIOTLAKEA	22.104429	-32.7	84.3	24.331051
6057592	SAULTSTEMARIEA	33.946159	-38.7	0	2.8284271
6106400	PETAWAWANATFORESTRY	140.1967	17	97.3	235.59499
6110557	BARRIEWPCC	14.26584	-5	-7	43.382023
6135638	NIAGARAFALLS	42.212711	11.7	1.33	12.649111
6137730	SIMCOE	98.642227	19	24	13.416408
6139538	WINDSORUNIVERSITY	2.0748	-28	6.67	23.086792
6140818	BLUESPRINGSCREEK	0	-2	15	55.86591
6141095	CAMBRIDGEGALTMOE	27.200939	-7.67	64	62.289646
6142991	GRANDVALLEYWPCP	12.73682	-6	112	109.41663
6143087	GUELPHSMALLFIELDFARM	4.8650012	-40	6	74.632431
6144241	KITCHENERCITYENG2	34.407249	24.7	28	84.403793
6153194	HAMILTONA	7.3250022	-8.67	19	20.248457
6154820	MAINDUCKISLAND	154.2196	46.3	22.7	0
6158406	TORONTOBOOTH	89.568626	30.7	123	10
6158575	TORONTOGREENWOOD	24.88468	25	29.7	2
6158665	TORONTOISLANDA	96.267647	95.7	58	10.29563
615N745	OAKVILLESOUTHEASTWPCP	125.4565	5	76.7	2.236068
6166450	PETERBOROUGHSTP	55.108299	-57	20.3	42.190044
6169453	WESTGUILFORD	15.94162	-3	98.3	133.52153
5021054	Glenlea	0	0	0	697.81946
5030282	Bissett	3.483073	-33	13	672.05951
5031038	Gimli	5.6976008	24	8	753.7453
6034075	KENORAA	225	-28	6.67	454.49313

Table 8) Sample Geological Information After Normalization

Station Number	Name							
		Lat	Long	Elevation	Barrier Height	SlopeY	SlopeX	Distance to Water
6010738	BIGTROUTLAKE	0.000848	0.001416	1.191359	0.000000	-0.002442	-0.000037	0.015924
6040325	ARMSTRONG(AUT)	0.000427	0.000754	0.739254	0.010549	-0.002191	0.000064	0.005022
6052259	ELLIOTLAKEA	0.000337	0.000601	0.864063	0.001149	0.006142	0.000068	0.000480
6057592	SAULTSTEMARIEA	0.001268	0.002305	1.845952	0.006618	0.027259	0.000000	0.000209
6106400	PETAWAWANATFORESTRY	0.000948	0.001596	1.201833	0.020652	-0.009047	0.000221	0.013162
6110557	BARRIEWPCC	0.000780	0.001401	1.607244	0.001792	0.002270	-0.000014	0.002067
6135638	NIAGARAFALLS	0.000680	0.001246	0.964434	0.004755	-0.004762	0.000002	0.000540
6137730	SIMCOE	0.000649	0.001216	1.238272	0.010684	-0.007435	0.000040	0.000551
6139538	WINDSORUNIVERSITY	0.000308	0.000604	0.473925	0.000108	0.005259	0.000005	0.000455
6140818	BLUESPRINGSCREEK	0.000291	0.000534	0.921667	0.000000	0.000344	0.000011	0.001010
6141095	CAMBRIDGEGALTMOE	0.000394	0.000730	0.975344	0.001768	0.001801	0.000064	0.001535
6142991	GRANDVALLEYWPCP	0.000426	0.000779	1.665285	0.000883	0.001503	0.000120	0.002877
6143087	GUELPHSMALLFIELDFARM	0.000290	0.000535	0.806459	0.000232	0.006887	0.000004	0.001349
6144241	KITCHENERCITYENG2	0.000342	0.000634	0.938905	0.001938	-0.005026	0.000024	0.001803
6153194	HAMILTONA	0.000863	0.001599	1.627318	0.001047	0.004478	0.000042	0.001098
6154820	MAINDUCKISLAND	0.000559	0.000975	0.343661	0.014031	-0.015219	0.000032	0.000000
6158406	TORONTOBOOTH	0.000714	0.001299	0.530220	0.010478	-0.012975	0.000222	0.000444
6158575	TORONTOGREENWOOD	0.000423	0.000769	0.366572	0.001725	-0.006261	0.000032	0.000053
6158665	TORONTOISLANDA	0.000635	0.001155	0.392756	0.010010	-0.035951	0.000093	0.000406
615N745	OAKVILLESOUTHEASTWPCP	0.000316	0.000579	0.238272	0.006522	-0.000939	0.000062	0.000044
6166450	PETERBOROUGHSTP	0.000752	0.001329	1.264674	0.006685	0.024982	0.000038	0.001941
6169453	WESTGUILFORD	0.000437	0.000763	1.277766	0.001105	0.000751	0.000105	0.003510
5021054	Glenlea	0.001023	0.002001	1.713725	0.000000	0.000000	0.000000	0.038986
5030282	Bissett	0.000495	0.000928	0.960070	0.000241	0.008265	0.000014	0.017669
5031038	Gimli	0.000859	0.001646	1.374645	0.000691	-0.010519	0.000015	0.034679

Table 9) Sample log Values of "A" Parameters

Station Number	Name					
		log(2)	log(5)	log(10)	log(50)	log(100)
6010738	BIGTROUTLAKE	0.00659	0.00728	0.00766	0.00831	0.00854
6040325	ARMSTRONG(AUT)	0.00370	0.00407	0.00426	0.00461	0.00472
6052259	ELLIOTLAKEA	0.00325	0.00357	0.00373	0.00403	0.00413
6057592	SAULTSTEMARIEA	0.01225	0.01352	0.01419	0.01537	0.01578
6106400	PETAWAWANATFORESTRY	0.00915	0.01023	0.01078	0.01174	0.01207
6110557	BARRIEWPCC	0.00811	0.00888	0.00930	0.01002	0.01027
6135638	NIAGARAFALLS	0.00703	0.00765	0.00799	0.00859	0.00880
6137730	SIMCOE	0.00696	0.00764	0.00800	0.00863	0.00885
6139538	WINDSORUNIVERSITY	0.00328	0.00357	0.00372	0.00399	0.00409
6140818	BLUESPRINGSCREEK	0.00295	0.00324	0.00339	0.00366	0.00375
6141095	CAMBRIDGEGALTMOE	0.00410	0.00446	0.00465	0.00500	0.00513
6142991	GRANDVALLEYWPCP	0.00429	0.00466	0.00486	0.00522	0.00535
6143087	GUELPHSMALLFIELDFARM	0.00292	0.00323	0.00339	0.00367	0.00376
6144241	KITCHENERCITYENG2	0.00362	0.00391	0.00407	0.00436	0.00446
6153194	HAMILTONA	0.00942	0.01036	0.01084	0.01170	0.01200
6154820	MAINDUCKISLAND	0.00548	0.00606	0.00636	0.00690	0.00708
6158406	TORONTOBOOTH	0.00745	0.00824	0.00865	0.00937	0.00962
6158575	TORONTOGREENWOOD	0.00418	0.00462	0.00485	0.00525	0.00539
6158665	TORONTOISLANDA	0.00666	0.00732	0.00766	0.00827	0.00848
615N745	OAKVILLESOUTHEASTWPCP	0.00313	0.00338	0.00352	0.00377	0.00386
6166450	PETERBOROUGHSTP	0.00766	0.00840	0.00879	0.00948	0.00973
6169453	WESTGUILFORD	0.00430	0.00469	0.00490	0.00528	0.00541
5021054	Glenlea	0.00983	0.01096	0.01153	0.01251	0.01284
5030282	Bissett	0.00412	0.00452	0.00473	0.00510	0.00523
5031038	Gimli	0.00767	0.00846	0.00889	0.00962	0.00987

All independent variables were multiplied by the weight factor. The used of the weight factor was to adjust the regression parameters values so that they reflected the missing years for the weather stations. The regression analysis uses a set of factors to generate a relationship between those factors and a variable of interest. In this case, the factors were used to determine the rainfall intensity.

Conclusion

Phase I of the IDF renewal project replaced the old IDF information used for design values with regression analysis. Phase II of the IDF renewal project lowered the standard error of the regression and had more reasonable IDF information as the current design value standard (Figure 43).

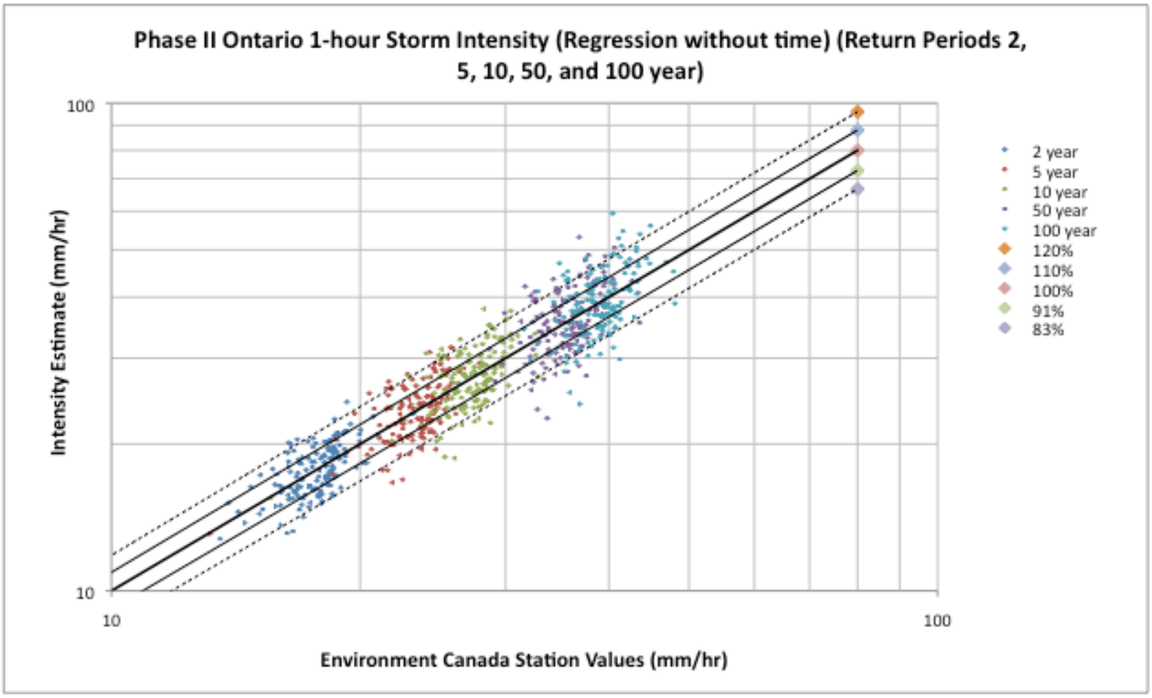


Figure 43) Phase II 1-hour Storm Estimated vs. Environment Canada Station Values

After Phase II of the IDF renewal project, research was being done on using the regression analysis to find a time trend for future weather predictions. 1-hour storm duration IDF curves, including return periods 2, 5, 10, 50 and 100 years, for 2012 and 2090 were produced as current IDF standards (figure 44) and possible design values for the future.

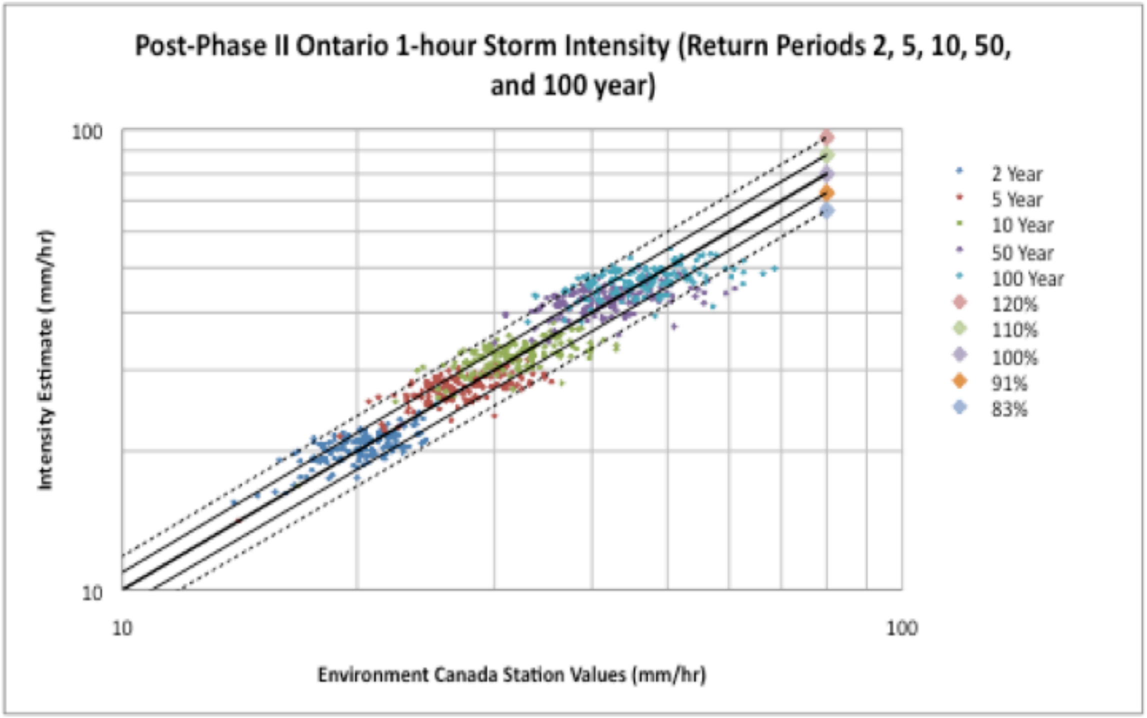
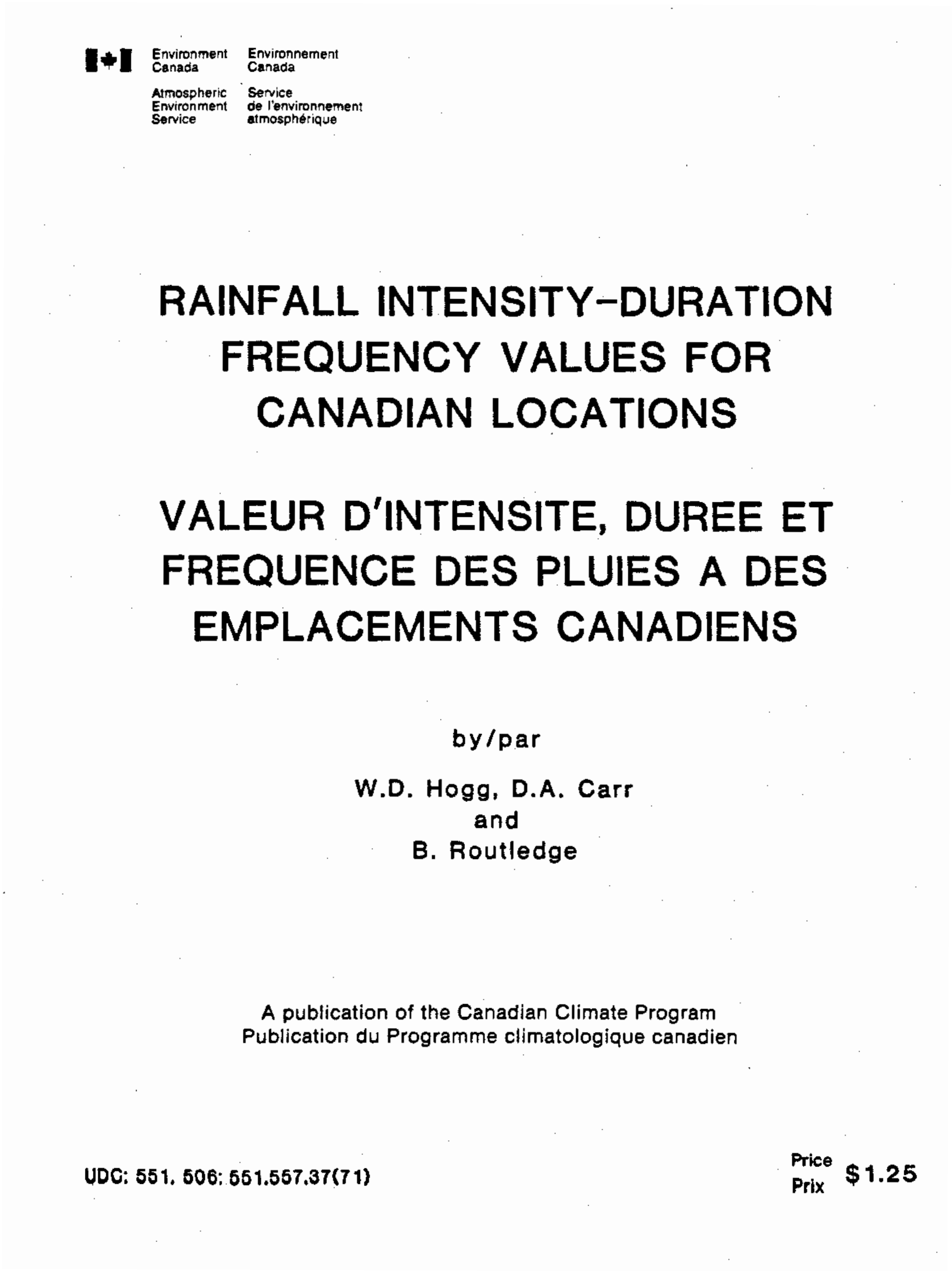


Figure 44) 1-hour Storm Intensities Regression for Return Periods 2, 5, 10, 50 and 100 year

The IDF curves obtained from the regression analysis was compared with weather information obtained from National Oceanic and Atmospheric Administration (NOAA). The comparison showed encouraging results as the IDF analysis regression curves for 2012 follow the same trend as the current IDF curves provided by NOAA with little statistical difference. The "IDF Lookup" website was developed as a user-friendly way for the public to access the IDF information for Ontario. The website allows users to select a single point or an area of interest for IDF curves in Ontario. The website interpolates points between known weather stations values to find the corresponding IDF information. This research was only a small display of what the regression analysis can do regarding IDF information predictions.

Further research can be done with other independent variables and as independent variables are available for other location, the scale of the regression can be national or even global.

Appendix A: Rainfall Intensity-Duration Frequency Values for Canadian Locations (pg 1-16)



Environment Canada / Environnement Canada

Atmospheric Environment Service / Service de l'environnement atmosphérique

RAINFALL INTENSITY-DURATION FREQUENCY VALUES FOR CANADIAN LOCATIONS

VALEUR D'INTENSITE, DUREE ET FREQUENCE DES PLUIES A DES EMPLACEMENTS CANADIENS

by/par

W.D. Hogg, D.A. Carr
and
B. Routledge

A publication of the Canadian Climate Program
Publication du Programme climatologique canadien

UDC: 551. 506: 551.557.37(71)

Price
Prix $1.25

CONTENTS/TABLE DES MATIÈRES

Page

1. Introduction/Introduction i

2. Rainfall Intensity/Intensités de pluies iv

   2.1 Duration Frequency Tables and Graphs/Courbes et tableaux de durée et de fréquence iv

3. Analysis Method/Méthode d'analyse viii

   3.1 Extreme Value Analysis/Analyse des valeurs extrêmes viii
   3.2 Adjustment to Partial Duration Series/Adaptation aux séries de durée partielle xi
   3.3 Other Statistical Analyses/Autres analyses statistiques xii

4. References/Références xiii

5. List of information centres/Liste des centres d'information xiv

6. Index of Stations/Index des stations 1

7. Index of Supplementary Stations/Index Supplémentaires Des Stations 15

RAINFALL INTENSITY-DURATION FREQUENCY VALUES FOR CANADIAN LOCATIONS

by

W.D. Hogg, D.A. Carr, B. Routledge

1. INTRODUCTION

Millions of dollars are spent each year in Canada on the design and construction of hydrological structures to carry water runoff from small catchments. These structures range in size from eavestroughs for roof drainage through road culverts and bridges to large, multi-million dollar storm sewer systems for urban areas. Unfortunately, since these structures are mostly on intermittent or very small watercourses, stream gauge data, on which to base the design, are not generally available.

In the absence of adequate streamflow information, the hydrological design engineer frequently turns to rainfall data to aid in the synthesis of peak flows. Rainfall records are frequently of longer duration and for more numerous locations than streamflow records. Although precipitation gauge records may not be representative of precipitation over large areas for individual storms, the general characteristics of precipitation usually vary in a regular manner. Thus, parameters like frequency of precipitation above a given value, can be transposed or interpolated to areas with no data.

VALEUR D'INTENSITÉ, DURÉE ET FRÉQUENCE DES PLUIES À DES EMPLACEMENTS CANADIENS

par

W.D. Hogg, D.A. Carr, B. Routledge

1. INTRODUCTION

Le Canada consacre chaque année des millions de dollars à la conception et à la construction de canalisations et autres structures d'évacuation des eaux. La taille et le coût de ces structures varient : il peut s'agir de simples gouttières tout comme de fossés et de leurs ponceaux ou d'importants réseaux d'égouts, de plusieurs millions de dollars, aménagés dans les zones urbaines en cas de pluies d'orage. Malheureusement, comme ces structures sont en générales établies pour des cours d'eau intermittents ou très petits, on dispose rarement de données de limnimètre sur lesquelles on peu baser les calculs pour les concevoir.

En l'absence de données adéquates sur l'écoulement, l'ingénieur, au niveau de la conception, utilise souvent les données pluviométriques pour calculer les débits de pointe. Fréquemment, les relevés pluviométriques couvrent une période plus longue et se rapportent à un nombre d'emplacements plus important que celui des relevés sur l'écoulement. Bien que, lors de tempêtes isolées, les relevés pluviométriques ne soient pas toujours représentatifs des précipitations dans de grandes régions, les caractéristiques des précipitations varient en général de façon assez régulière. On peut ainsi interpoler ou transposer, pour les régions où l'on ne dispose pas de données, certains paramètres comme la fréquence des précipitations au-dessus d'une valeur donnée.

Once the rainfall information is obtained, there are several techniques available to convert it into estimates of peak flow on a small watershed. Among these methods are several different hydrological computer models and the popular "rational method". To make use of the rainfall data, the design engineer must independently determine the duration of rainstorm which is significant to the watercourse in question. In general, the longer the basin the larger the duration critical for design. The specific duration is frequently chosen through "time of concentration" calculations or through similar formulae as described in any basic hydrology text (e.g. Bruce and Clark, 1966).

The design engineer must also select a frequency with which the capacity of the structure can be exceeded. This is usually expressed in terms of return period, which is the average interval between occurrences of events equalling or exceeding a given magnitude. For example, a 5-year return period event is one that is expected to be equalled or exceeded 20 times in 100 years or once every five years, on the average over a long period of time. The return period for the capacity of the structure must be selected so that the cost of the estimated damage, when the capacity is exceeded, does not outweigh the cost of increasing the size of the structure. Of course, other considerations such as public convenience and safety, and government regulations must also be taken into account.

To obtain the runoff or flow with a given return period, knowing only the rainfall with that return period, the assumption commonly made is that rainfall of a given frequency produces

Lorsqu'on possède les données pluviométriques, il existe plusieurs techniques pour en déduire le débit de pointe dans un petit bassin hydrographique. Par exemple, on peut utiliser divers modèles hydrologiques informatiques ou suivre la fameuse méthode "rationnelle". Pour utiliser les données pluviométriques, l'ingénieur doit déterminer la durée de la pluie affectant le cours d'eau considéré. En général, plus le bassin est grand, plus la durée du phénomène est critique du point de vue de la conception. On détermine souvent la durée spécifique à partir des valeurs du "temps de concentration" ou à l'aide de formules analogues, données dans n'importe quel ouvrage élémentaire d'hydrologie (p.ex. Bruce et Clark, 1966).

L'ingénieur doit aussi choisir la fréquence avec laquelle la capacité de la structure peut être dépassée. On l'exprime en général en termes de période de récurrence, c'est à dire : l'intervalle de temps moyen entre des manifestations d'amplitude égale ou supérieure à une amplitude donnée. Par exemple, en moyenne et à longue échéance, l'amplitude d'un phénomène dont la période de récurrence est de cinq ans sera vraisemblablement égalée ou dépassée 20 fois en 100 ans ou une fois tous les cinq ans. La période de récurrence pour la capacité de la structure doit être choisie de sorte que le coût des dommages anticipés si la capacité était dépassée soit inférieur au coût d'agrandissement de la structure. Bien entendu, il faut aussi tenir compte de la commodité et de la sécurité du public ainsi que des règlements gouvernementaux.

Pour connaître le ruissellement ou l'écoulement avec une période de récurrence donnée lorsque l'on ne dispose que des données pluviométriques sur cette période de récurrence, on assume streamflow of the same frequency. It should be realized that this is a fairly coarse assumption when the variability of antecedent moisture conditions and time distribution of rainfall events are considered.

The majority of stations with recording precipitation gauges in Canada are equipped with MSC tipping-bucket rain gauges (Meteorological Branch, 1952). This instrument has many advantages in simplicity and reliability of operation, but in common with other gauges of this type, it is prone to systematic errors or biases, especially at high rainfall rates. For this reason it is the practice in the Atmospheric Environment Service (AES) to adjust the data from the tipping-bucket gauges so that daily totals agree with the totals from the non-recording standard gauge operated at each recording gauge site. The ratio of standard gauge total to recording gauge total for the day has been used to adjust all of the tipping-bucket rainfall data.

The long duration recording gauge is a weighing gauge and, as operated by AES, does not have the same biases at high rainfall rates, but it does have reduced sensitivity and time resolution. For this reason reliable rainfall amounts for durations less than 30 minutes were not available from the long duration recording gauges. Adjustment factors are not applied to the long duration recording gauge data since the non-recording standard gauges are not operated at these remote sites.

en général que les pluies d'une fréquence donnée produisent des écoulements de même fréquence. Il ne faut pas oublier qu'il s'agit là d'une hypothèse très grossière si l'on considère la variabilité des conditions d'humidité et la distribution temporelle des précipitations pluviales.

La plupart des stations étudiées sont équipées de pluviomètres à augets basculeurs du Service météorologique canadien (Direction de la météorologie, 1952). Cet instrument présente plusieurs avantages car il est simple et fiable; toutefois, comme d'autres pluviomètres de ce type, il a tendance à donner systématiquement de fausses indications, surtout lorsque l'intensité des précipitations est élevée. Pour cette raison, le Service de l'environnement atmosphérique (SEA) rectifie les relevés des pluviomètres à augets basculeurs afin que les totaux journaliers concordent avec ceux des pluviomètres standard non enregistreurs dont chaque station pluviométrique est équipée. Pour corriger toutes les données des pluviomètres à augets basculeurs sur lesquelles est fondée cette étude, on a pris le rapport entre le total enregistré avec les pluviomètres standard et celui mesuré avec les pluviomètres.

Le pluviomètre enregistreur longue durée est un pluviomètre balance; tel qu'utilisé au SEA, il ne donne pas lieu aux mêmes erreurs que le pluviomètre à augets basculeurs lorsque l'intensité des précipitations est élevée; toutefois, sa sensibilité et sa résolution dans le temps sont réduites. Ce type de pluviomètre ne nous donne donc pas de données fiables sur la hauteur des pluies pour des périodes de moins de 30 minutes. Les données relevées par pluviomètres enregistreurs longue durée n'ont pas fait l'objet de rectification parce qu' il n'y a pas de pluivomètres standard non enregistreurs dans les stations éloignées.

2. RAINFALL INTENSITY

2.1 Duration Frequency Tables and Graph

For each station in Canada, with seven years or more recording rain gauge data, extreme value frequency analyses, for durations of 5 minutes to 24 hours, have been performed. The resulting information is shown on three separate tables (Tables 1, 2, 3) and a graph (Fig. 1) referred to as IDF Tabulations and IDF Curves. A brief explanation of these tables follows.

Table #1 - This table lists the maximum rainfall intensity for the durations of 5 min. to 24 hours for each year the station operated.

Summary values are shown for each duration for the following:

Mean Extreme
Standard Deviation
Years of Record
Coefficient of Skew
Coefficient of Kurtosis

It should be noted that the term 'annual' rainfall generally applies to the months April to October in most locations in Canada. During the winter months, most recording rain gauges are taken out of service.

Table #2 - The heading of this table contains the current station name, the climatological number; latitude, longitude and elevation. The remainder of the table is made up of two sections showing the rainfall durations (5 min. to 24 hours) and the return period values for: 2, 5, 10, 25, 50 and 100

2. INTENSITÉ DES PLUIES

2.1 Courbes et tableaux de durée et de fréquence

Pour chaque station du Canada pour laquelle on dispose d'au moins sept années de données fournies par des pluviographes, on a effectué des analyses de fréquences des extrêmes, pour des durées de 5 minutes à 24 heures. Les renseignements qui en découlent figurent sur les trois tableaux (tableaux 1, 2 et 3) et dans un graphique (figure 1) appelés tableaux et courbes IDF. Voici une brève explication de ces tableaux.

Tableau n° 1 - Ce tableau énumère l'intensité maximale des pluies pour des durées allant de 5 min à 24 h et ce, pour chacune des années pendant lesquelles la station a fonctionné.

Les valeurs récapitulatives correspondant à chaque durée figurent pour :

Moyenne des extrêmes
Écart type
Années d'observation
Coefficient de dissymétrie
Coefficient d'aplatissement

Notons que le terme de pluies "annuelles" s'applique en général, dans la plupart des emplacements du Canada, aux mois allant d'avril à octobre. Pendant les mois d'hiver, on ne se sert pas de la plupart des pluviographes.

Tableau n° 2 - L'en-tête de ce tableau comprend le nom actuel de la station, le numéro climatologique, la latitude, la longitude et l'altitude. Le reste du tableau comprend deux parties qui indiquent la durée des précipitations (de 5 min à 24 h) et les valeurs de la période de retour pour 2, 5, 10, 25, 50 years. The first section shows the expected total amount for each duration and return period. The second section expresses the expected value for each duration as a mean hourly rate of rainfall averaged over the duration in question, with 50% confidence limits.

<u>Table #3</u> - Indicates the results of the interpolation equation -

$$R = AT^B \qquad \ldots(3\text{-}1)$$

Values are shown for each return period (2 yrs. to 100 yrs) for the following statistics:

mean of intensity
standard deviation of intensity
standard error of estimate (R)
coefficient (A)
exponent (B)
mean of the percentage error.

Coefficients (A) and (B) are determined by taking the logarithm of the interpolation equation and performing a least squares fit. The resulting equation gives the best fit straight line on a log-log plot of intensity vs duration and is used as the interpolation line on the IDF graph (Fig. 1) For a given return period, the expected rainfall intensity for any duration can be obtained by substituting the appropriate values for (A), (B) and duration (T) into equation (3-1). For a few stations equation (3-1) is not suitable. In these cases a line with pronounced curvature is plotted on the IDF graph but the (A) and (B) in Table 3 is still presented as derived for equation (3-1). Manual interpolation from the graph is the preferable method when this occurs.

et 100 années. La première partie indique le total attendu pour chaque durée et période de retour. La seconde partie exprime la valeur attendue pour chaque durée. Il s'agit de la moyenne horaire de l'intensité des précipitations, calculée pour la durée en question, dans des limites de confiance de 50%.

<u>Tableau n° 3</u> - indique les résultats de l'équation d'interpolation -

Pour chaque période de récurrence (de 2 à 100 ans), ce tableau indique les valeurs des statistiques suivantes :

la moyenne de l'intensité
l'écart type de l'intensité
l'erreur type de l'estimation (R)
le coefficient (A)
l'exposant (B)
la moyenne de l'erreur de pourcentage.

Pour déterminer les coefficients (A) et (B), on calcule le logarithme de l'équation d'interpolation et on opère un ajustement par les moindres carrés. L'équation qui en résulte donne la droite la mieux ajustée sur un graphique bilogarithmique comparatif de l'intensité et de la durée et sert de ligne d'interpolation sur le graphique IDF (fig. 1). Pour une période de retour donnée, on peut obtenir, pour toute durée, l'intensité attendue des pluies en substituant la valeur appropriée au coefficient (A), à l'exposant (B) et à la durée T dans l'équation (3-1). Pour quelques stations, l'équation (3-1) ne convient pas. Dans ces cas-là, on trace une ligne de courbure prononcée sur le graphique IDF, mais les coefficients A et B du tableau 3 figurent toujours comme dérivées pour

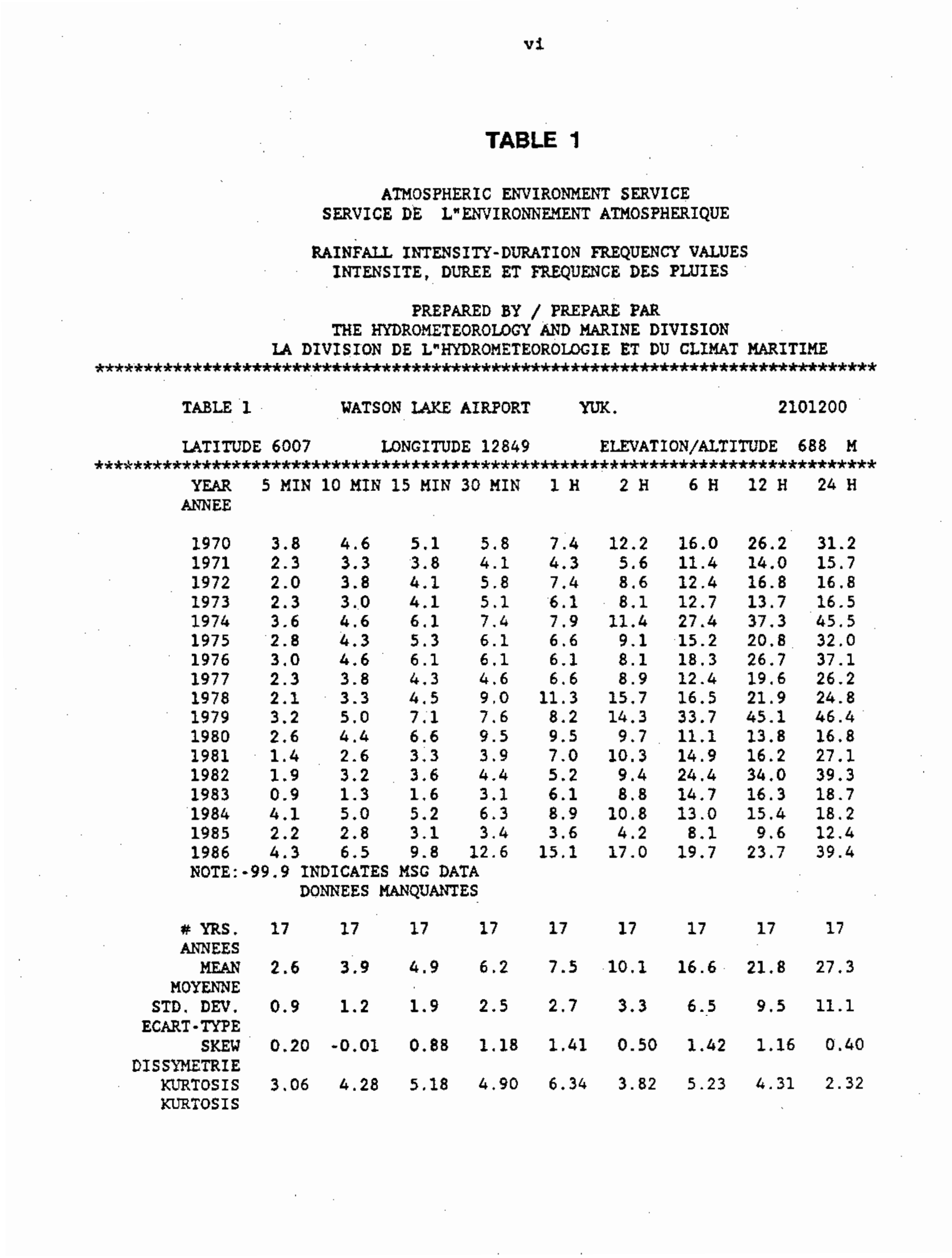


TABLE 1

ATMOSPHERIC ENVIRONMENT SERVICE
SERVICE DE L"ENVIRONNEMENT ATMOSPHERIQUE

RAINFALL INTENSITY-DURATION FREQUENCY VALUES
INTENSITE, DUREE ET FREQUENCE DES PLUIES

PREPARED BY / PREPARE PAR
THE HYDROMETEOROLOGY AND MARINE DIVISION
LA DIVISION DE L"HYDROMETEOROLOGIE ET DU CLIMAT MARITIME

TABLE 1 WATSON LAKE AIRPORT YUK. 2101200

LATITUDE 6007 LONGITUDE 12849 ELEVATION/ALTITUDE 688 M

YEAR ANNEE	5 MIN	10 MIN	15 MIN	30 MIN	1 H	2 H	6 H	12 H	24 H
1970	3.8	4.6	5.1	5.8	7.4	12.2	16.0	26.2	31.2
1971	2.3	3.3	3.8	4.1	4.3	5.6	11.4	14.0	15.7
1972	2.0	3.8	4.1	5.8	7.4	8.6	12.4	16.8	16.8
1973	2.3	3.0	4.1	5.1	6.1	8.1	12.7	13.7	16.5
1974	3.6	4.6	6.1	7.4	7.9	11.4	27.4	37.3	45.5
1975	2.8	4.3	5.3	6.1	6.6	9.1	15.2	20.8	32.0
1976	3.0	4.6	6.1	6.1	6.1	8.1	18.3	26.7	37.1
1977	2.3	3.8	4.3	4.6	6.6	8.9	12.4	19.6	26.2
1978	2.1	3.3	4.5	9.0	11.3	15.7	16.5	21.9	24.8
1979	3.2	5.0	7.1	7.6	8.2	14.3	33.7	45.1	46.4
1980	2.6	4.4	6.6	9.5	9.5	9.7	11.1	13.8	16.8
1981	1.4	2.6	3.3	3.9	7.0	10.3	14.9	16.2	27.1
1982	1.9	3.2	3.6	4.4	5.2	9.4	24.4	34.0	39.3
1983	0.9	1.3	1.6	3.1	6.1	8.8	14.7	16.3	18.7
1984	4.1	5.0	5.2	6.3	8.9	10.8	13.0	15.4	18.2
1985	2.2	2.8	3.1	3.4	3.6	4.2	8.1	9.6	12.4
1986	4.3	6.5	9.8	12.6	15.1	17.0	19.7	23.7	39.4

NOTE:-99.9 INDICATES MSG DATA
DONNEES MANQUANTES

# YRS. ANNEES	17	17	17	17	17	17	17	17	17
MEAN MOYENNE	2.6	3.9	4.9	6.2	7.5	10.1	16.6	21.8	27.3
STD. DEV. ECART-TYPE	0.9	1.2	1.9	2.5	2.7	3.3	6.5	9.5	11.1
SKEW DISSYMETRIE	0.20	-0.01	0.88	1.18	1.41	0.50	1.42	1.16	0.40
KURTOSIS KURTOSIS	3.06	4.28	5.18	4.90	6.34	3.82	5.23	4.31	2.32

TABLE 2

ATMOSPHERIC ENVIRONMENT SERVICE
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE

RAINFALL INTENSITY-DURATION FREQUENCY VALUES
INTENSITE, DUREE ET FREQUENCE DES PLUIES

****

TABLE 2 WATSON LAKE AIRPORT YUK. 2101200

LATITUDE 6007 LONGITUDE 12849 ELEVATION/ALTITUDE 688 M

****

RETURN PERIOD RAINFALL AMOUNTS (MM)
PERIODE DE RETOUR QUANTITIES DE PLUIE (MM)

DURATION DUREE	2 YR/ANS	5 YR/ANS	10 YR/ANS	25 YR/ANS	50 YR/ANS	100 YR/ANS	# YEARS ANNEES
5 MIN	2.5	3.3	3.9	4.5	5.1	5.6	17
10 MIN	3.7	4.7	5.4	6.3	7.0	7.6	17
15 MIN	4.6	6.3	7.4	8.8	9.8	10.8	17
30 MIN	5.8	7.9	9.4	11.2	12.6	13.9	17
1 H	7.0	9.4	11.0	13.0	14.5	16.0	17
2 H	9.6	12.5	14.4	16.9	18.7	20.5	17
6 H	15.5	21.3	25.1	29.9	33.5	37.1	17
12 H	20.3	28.7	34.3	41.3	46.5	51.7	17
24 H	25.5	35.3	41.8	50.0	56.1	62.2	17

RETURN PERIOD RAINFALL RATES EXPRESSED AS MM/HR
INTENSITE DE LA PLUIE PAR PERIODE DE RETOUR, EXPRIMEE EN MM/H
WITH 50% CONFIDENCE LIMITS / AVEC DES LIMITES DE CONFIANCE DE 50%

DURATION DUREE	2 YR/ANS	5 YR/ANS	10 YR/ANS	25 YR/ANS	50 YR/ANS	100 YR/ANS
5 MIN	29.8	39.7	46.3	54.6	60.7	66.8
	+/- 4.9	+/- 8.2	+/- 11.1	+/- 15.0	+/- 18.0	+/- 20.9
10 MIN	22.2	28.5	32.7	38.0	41.9	45.8
	+/- 3.1	+/- 5.3	+/- 7.1	+/- 9.6	+/- 11.5	+/- 13.3
15 MIN	18.5	25.1	29.5	35.0	39.1	43.2
	+/- 3.3	+/- 5.5	+/- 7.4	+/- 10.0	+/- 12.0	+/- 14.0
30 MIN	11.5	15.9	18.8	22.4	25.1	27.8
	+/- 2.2	+/- 3.6	+/- 4.9	+/- 6.6	+/- 7.9	+/- 9.2
1 H	7.0	9.4	11.0	13.0	14.5	16.0
	+/- 1.2	+/- 2.0	+/- 2.7	+/- 3.6	+/- 4.3	+/- 5.1
2 H	4.8	6.2	7.2	8.4	9.3	10.2
	+/- 0.7	+/- 1.2	+/- 1.6	+/- 2.2	+/- 2.6	+/- 3.1
6 H	2.6	3.5	4.2	5.0	5.6	6.2
	+/- 0.5	+/- 0.8	+/- 1.1	+/- 1.5	+/- 1.7	+/- 2.0
12 H	1.7	2.4	2.9	3.4	3.9	4.3
	+/- 0.3	+/- 0.6	+/- 0.8	+/- 1.1	+/- 1.3	+/- 1.5
24 H	1.1	1.5	1.7	2.1	2.3	2.6
	+/- 0.2	+/- 0.3	+/- 0.5	+/- 0.6	+/- 0.7	+/- 0.9

TABLE 3

ATMOSPHERIC ENVIRONMENT SERVICE
SERVICE DE L"ENVIRONNEMENT ATMOSPHERIQUE

RAINFALL INTENSITY-DURATION FREQUENCY VALUES
INTENSITE, DUREE ET FREQUENCE DES PLUIES

****

TABLE 3 WATSON LAKE AIRPORT YUK. 2101200

LATITUDE 6007 LONGITUDE 12849 ELEVATION/ALTITUDE 688 M

****

INTERPOLATION EQUATION / EQUATION D"INTERPOLATION: R = A * T ** B
R = RAINFALL RATE / INTENSITE DE LA PLUIE (MM /HR)
T = TIME IN HOURS / TEMPS EN HEURES

STATISTICS STATISTIQUES	2 YR ANS	5 YR ANS	10 YR ANS	25 YR ANS	50 YR ANS	100 YR ANS
MEAN OF R MOYENNE DE R	11.0	14.6	17.1	20.2	22.4	24.7
STD. DEV. R ECART-TYPE	10.2	13.5	15.7	18.5	20.6	22.6
STD. ERROR ERREUR STANDARD	1.2	1.6	1.9	2.3	2.6	3.0
COEFF. (A) COEFFICIENT (A)	7.3	9.9	11.6	13.7	15.3	16.9
EXPONENT (B) EXPOSANT (B)	-0.599	-0.589	-0.586	-0.582	-0.580	-0.578
MEAN % ERROR % D'ERREUR	4.1	5.1	5.8	6.4	6.7	7.0

FIGURE 1

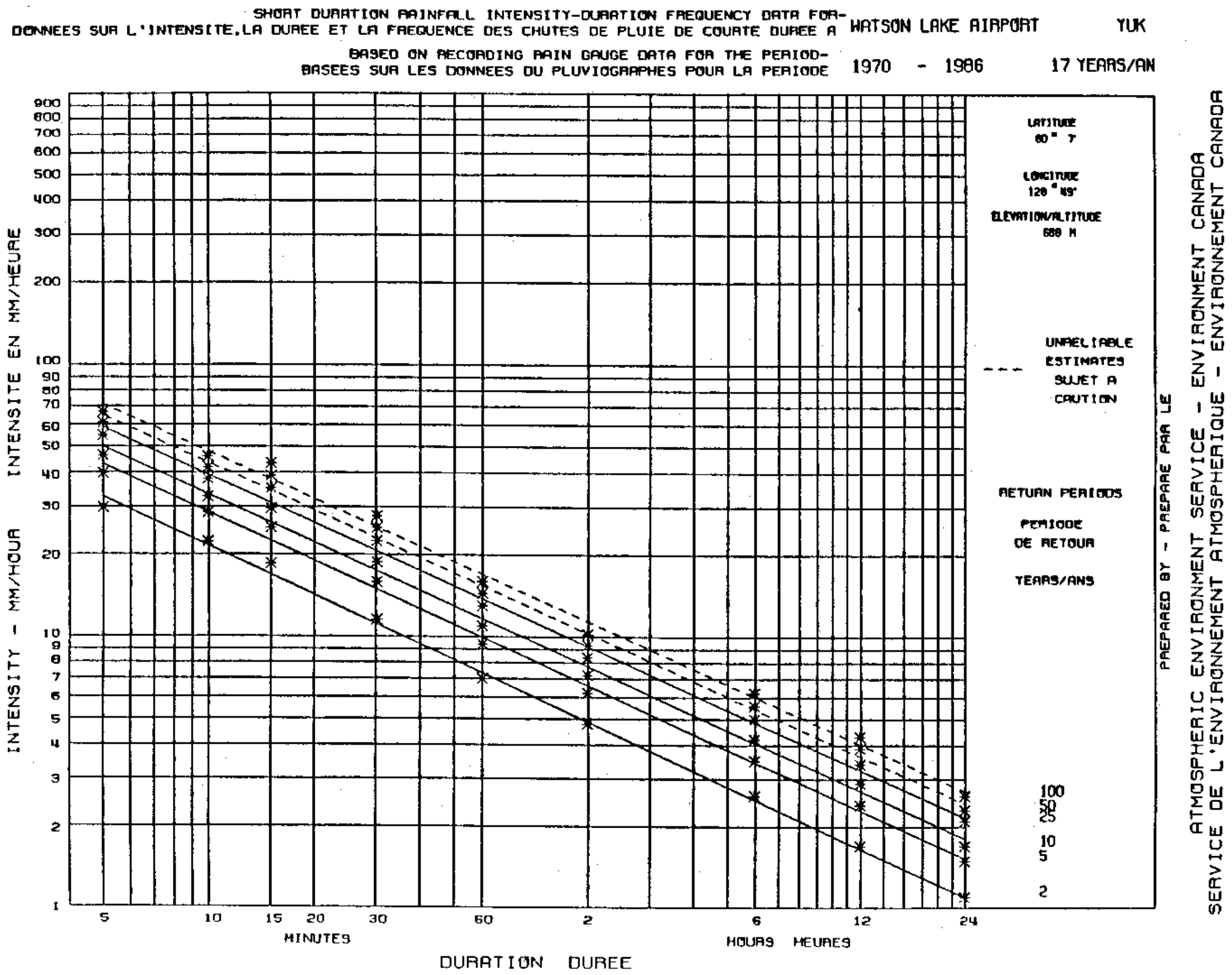

SHORT DURATION RAINFALL INTENSITY-DURATION FREQUENCY DATA FOR-
DONNEES SUR L'INTENSITE,LA DUREE ET LA FREQUENCE DES CHUTES DE PLUIE DE COURTE DUREE A
WATSON LAKE AIRPORT
YUK
BASED ON RECORDING RAIN GAUGE DATA FOR THE PERIOD-
BASEES SUR LES DONNEES DU PLUVIOGRAPHES POUR LA PERIODE
1970 - 1986
17 YEARS/AN
LATITUDE 60° 7'
LONGITUDE 128° 49'
ELEVATION/ALTITUDE 688 M
UNRELIABLE ESTIMATES
SUJET A CAUTION
RETURN PERIODS
PERIODE DE RETOUR
YEARS/ANS
100
50
25
10
5
2
INTENSITY - MM/HOUR
INTENSITE EN MM/HEURE
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
5
10
15
20
30
60
2
6
12
24
MINUTES
HOURS HEURES
DURATION DUREE
PREPARED BY - PREPARE PAR LE
ATMOSPHERIC ENVIRONMENT SERVICE - ENVIRONMENT CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE - ENVIRONNEMENT CANADA

Figure 1 - The Rainfall rates for 2, 5, 10, 25, 50, and 100 year return periods are plotted on log-log graphs. The horizontal axis indicates the rainfall durations from 5 minutes to 24 hours. The vertical axis indicates the rainfall rates in millimeters.

3. ANALYSIS METHOD

3.1 Extreme Value Analysis

Generally, the frequency of only the heavier rainfalls is of interest. To reduce data and processing requirements, techniques have been developed to derive these extreme rainfall frequencies by grouping the heavier rainfall events into special series. The series of all rainfall values above a selected base is referred to as a **partial or partial duration series.** The collection of the greatest event from each year is known as an **annual series.**

Determination of the frequency of extreme events is carried out by what are referred to as extreme value analysis procedures. The annual series is the one most commonly used in extreme value analysis for the sake of data availability, and because there is a theoretical basis for extrapolating annual series data beyond the duration of the record. This theory is based upon the assertion that annual maxima can be assumed to be the maxima of independent samples drawn from the population of all possible events. The assumption of independence is not

l'équation (1). Quand cette situation se présente, il est préférable de procéder à la main à une interpolation à partir du graphique.

Figure 1 - L'intensité des pluies pour les périodes de retour de 2, 5, 10, 25, 50 et 100 ans sont pointées sur les graphiques bilogarithmiques. L'axe horizontal indique les durées des précipitations, de 5 minutes à 24 heures. L'axe vertical indique l'intensité des précipitations, en millimètres.

3. MÉTHODE D'ANALYSE

3.1 Analyse des valeurs extrêmes

Généralement, seule la fréquence des pluies les plus abondantes présente un intérêt. Pour réduire les exigences en matière de données et de traitement des données, on a mis au point des méthodes pour dériver la fréquence de ces pluies extrêmes en les regroupant selon des séries spéciales : la série de toutes les pluies où la fréquence est supérieure à une fréquence de référence est appelée **série partielle ou de durée partielle**; l'ensemble des pluies maximales de chaque année est appelé **série annuelle.**

On détermine la fréquence des phénomènes extrêmes par la méthode appelée "analyse des valeurs extrêmes". C'est la série annuelle que l'on utilise le plus couramment pour cette analyse vu la disponibilité des données et parce qu'il existe une base théorique pour extrapoler les données des séries annuelles au delà de la durée du relevé. Cette théorie est fondée sur l'hypothèse que les maxima annuels peuvent être considérés comme les maxima des échantillons indépendants de la population de tous les phénomènes possibles. Cette notion "d'indépennecessarily valid for the partial series.

An incredible amount of effort has been expended in the past in an attempt to derive theoretical or empirical relationships, which would accurately describe the probability distributions of hydrological variables, with emphasis on low probability, long return period events. Pioneers in the field (Frechet, 1927, Fisher and Tippett, 1928) studied the distribution of extreme values and found that the distribution of the largest (or smallest) values, each of which is selected from independent samples, approaches a limiting (asymptotic) form as the sample size is increased. The type of limiting form depends on the type of the initial distribution. For three different types of initial distributions, three asymptotic extremal distributions can be derived. They are known as the Fisher-Tippett Types I, II and III distributions.

An easy method for applying the Type I distribution was developed by Gumbel (1954). As a result the Type I is commonly referred to as the Gumbel distribution. It is this distribution which is used by AES and most national meteorological services in the world (WMO, 1981) to describe the frequency of extreme rainfall events.

In the past, AES has used Gumbel's fitting method to fit the Gumbel distribution to extreme rainfall and other extreme value data. Numerous investigators have shown that this introduces a bias (e.g. Watt and Nozdryn-Plotnicki, 1980; Cunnane, 1978; and Lowery and Nash, 1970). The same investigators have shown that the method of moments and method of maximum likelihood are both nearly unbiased and more efficient fitting techniques. The maximum likeli-

dance" n'est pas nécessairement valable pour les séries partielles.

Dans le passé, on a fait des efforts considérables pour déduire des relations théoriques ou empiriques pouvant donner une description exacte des distributions de probabilité des variables hydrologiques, en mettant l'accent sur les phénomènes de faible probabilité et de longue période de retour. Les pionniers dans le domaine (Frechet, 1927, Fischer et Tippett, 1928) ont étudié la distribution des valeurs extrêmes et ont découvert que la distribution des valeurs les plus grandes (ou les plus petites), chacune sélectionnée dans des échantillons indépendants, tend vers une limite (asymptotique) lorsqu'on accroît la dimension de l'échantillon. Le type de limite dépend du type de distribution initiale. Pour trois différents types de distribution initiale, on peut dériver trois distributions asymptotiques extrêmes, appelées Types I, II, III de distributions Fischer-Tippett.

Gumbel (1954) a mis au point une méthode facile pour appliquer le type I de distribution. C'est pourquoi le type I est souvent appelé "distribution de Gumbel". C'est cette distribution que le SEA et la plupart des services météorologiques officiels (p.ex. OMM, 1981) utilisent pour décrire la fréquence des chutes de pluie extrêmement fortes.

Dans le passé, le SEA a utilisé la méthode d'ajustement de Gumbel pour adapter la distribution de Gumbel aux précipitations extrêmes et aux autres données extrêmes. De nombreux chercheurs ont montré que cette méthode introduit une erreur systématique (p.ex. Watt et Nozdryn-Plotnicki, 1980; Cunnane, 1978; Lowery et Nash, 1970). Ces mêmes chercheurs ont établi que la méthode des moments et celle des probabilités n'introduisent pratiquement pas hood method is considered marginally better but the differences are negligible. For these graphs the method of moments was used because of its simplicity and ease of implementation.

d'erreur et sont des techniques d'ajustement plus efficaces. La méthode du maximum de probabilité est considérée meilleure aux limites mais les différences sont négligeables. Pour les graphiques on a utilisé la méthode des moments à cause de sa simplicité et de sa facilité de mise en oeuvre.

The Gumbel double exponential distribution for annual extremes can be expressed as:

La distribution bi-exponentielle de Gumbel pour les extrêmes annuels peut s'exprimer par la formule :

$$X = \mu + K(T)\sigma \qquad \ldots (1)$$

where X is the exceedence value, μ and σ are the population mean and standard deviation of the annual extremes, T is return period and K(T) is defined by

où X représente l'excédent, μ et σ la moyenne de la population et l'écart-type des extrêmes annuels, T est la période de retour, et K(T) est défini par :

$$K(T) = -\frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\ln\frac{T}{T-1}\right) \qquad \ldots (2)$$

The most obvious and direct method of fitting the distribution to a sample of data is to use the sample mean ($\bar{X}$) and standard deviation (S) to estimate μ and σ of (1). Since $\bar{X}$ and S can be determined from the first and second moments of the data, this method is referred to as the method of moments. Thus, if n is the number of events in the sample, μ is estimated by

La méthode la plus évidente et la plus directe pour adapter la distribution à un ensemble de données est de prendre la moyenne de l'échantillon ($\bar{X}$) et l'écart-type (s) pour calculer μ et σ de l'équation (1). Puisque $\bar{X}$ et S peuvent être déterminés à partir du premier et du second moment des données, on appelle cette méthode la "méthode des moments". Donc, si "n" est le nombre de phénomènes dans un échantillon, μ est calculé par la formule :

$$\bar{X} = (\Sigma X)/n \qquad \ldots (3)$$

and σ by

et σ par la formule:

$$S = \sqrt{\Sigma\,(\bar{X}-X)^2/\,(n-1)} \qquad \ldots (4)$$

The new prediction equation then becomes:

La nouvelle équation de prévision devient donc :

$$X(T) = \bar{X} + K(T)\,S \qquad \ldots (5)$$

and using (2), (3), (4) and (5) the exceedance values for all return periods can be determined. To minimize duplication of effort the values of K(T) for commonly required return periods are tabulated.

En utilisant (2), (3), (4) et (5), on peut donc déterminer les excédents pour toutes les périodes de retour. Afin de minimiser les calculs répétitifs, on a mis sous forme de tableau les valeurs de K(T) pour les périodes de retour dont on a souvent besoin.

T	2 YR/ANS	5 YR/ANS	10 YR/ANS	25 YR/ANS	50 YR/ANS	100 YR/ANS
K(T)	-0.164	0.719	1.305	2.044	2.592	3.137

3.2 Adjustment to Partial Duration Series

3.2 Adaptation aux séries de durée partielle

Basing the analysis on the annual maximum series has major advantages in ease of analysis and in having a reasonably sound theoretical basis for extrapolation beyond the period of record. This analysis answers the question of the probability that the greatest annual amount will equal or exceed some value. However such a series ignores the 2nd and 3rd largest amounts in each year, and in some cases these may be greater than the maximum values of other years. The design engineer is often interested in the probability that a value greater than a given amount will occur within a given number of years, which is the type of result which arises from a partial duration series analysis.

Le fait que l'analyse soit fondée sur les séries annuelles de maxima présente plusieurs avantages majeurs : cela facilite l'analyse et permet d'avoir une base théorique relativement solide pour l'extrapolation au-delà de la période couverte par le relevé. Cette analyse permet de déterminer avec quelle probabilité la hauteur maximale annuelle sera égale ou supérieure à une certaine valeur. Néanmoins, ces séries ne tiennent pas compte des hauteurs de pluies classées en 2^{e} et 3^{e} positions et qui sont parfois supérieures aux hauteurs maximales enregistrées au cours d'autres années. En conception, l'ingénieur s'intéresse à la probabilité que se produise sur un nombre d'années donné, une valeur supérieure à une hauteur donnée (type de résultat obtenu à partir d'une analyse de série de durée partielle).

Fortunately there has been some empirical and theoretical work to find the relationship between extreme values estimated from both the annual maximum series and the partial duration series (Pugsley, 1981). These studies show that the estimates based on annual maxima are equal to those based on the partial duration series for return

Heureusement, des études empiriques et théoriques ont été faites pour établir la relation entre les valeurs extrêmes calculées à partir des séries de maxima annuels et des séries de durée partielle (Pugsley, 1981). Ces études montrent que les calculs basés sur les maxima annuels donnent des résultats semblables à ceux basés sur periods longer than 10 years. For shorter return periods the partial duration series results are higher than those obtained from the annual maximum series, by 14% for the 2-year return period, 4% for the 5-year return period and 1% for 10-year return period values. The values in the tables and graphs have not been adjusted to account for these differences.

3.3 Other Statistical Analyses

Supplemental to AES analyses, Howard (1979) reports on a statistical summary of rainfall data from 35 Canadian urban centres, produced for the Environmental Protection Service (EPS) for water pollution control design purposes. The results of the analyses consist of yearly tables summarizing events and statistical tables for storm rainfall depth, duration, average intensity and inter-event time. Statistical tables of moisture deficit estimates are also given. This data base could prove particularly useful to hydrological modellers. It is available from EPS Water Pollution Control Directorate, Ottawa, Ontario, K1A 1C8.

les séries de durée partielle pour des périodes de retour supérieures à 10 ans. Pour des périodes de retour plus courtes, les résultats des séries de durée partielle sont supérieurs à ceux obtenus à partir des séries de maxima annuels : de 14% pour une période de retour de 2 ans, de 4% pour une période de retour de 5 ans et de 1% pour une période de retour de 10 ans. Les valeurs de tableaux n'ont pas été corrigées pour tenir compte de ces différences.

3.3 Autres analyses statistiques

En supplément aux analyses du SEA, Howard (1979) fait rapport d'un sommaire statistique de données pluviométriques provenant de 35 centres urbains au Canada, établi pour le Service de la protection de l'environnement (SPE) aux fins du contrôle de la pollution des eaux. Les résultats de ces analyses sont présentés sous forme de tableaux annuels répertoriant les phénomènes et sous forme de tableaux statistiques pour la hauteur, la durée et l'intensité moyenne des pluies ainsi que pour la période inter-phénomènes. Les résultats comprennent aussi des tableaux statistiques des valeurs estimées du déficit de la teneur en eau. Cette base de données pourrait être très utile pour les modélisateurs en hydrologie; elle est disponible auprès du SPE, Direction générale du contrôle de la pollution de l'eau, Ottawa (Ont.), K1A 1C8.

Appendix B: “A” Coefficient Comparison Post Phase II Average Record Year

The black line represents the 1:1 line.

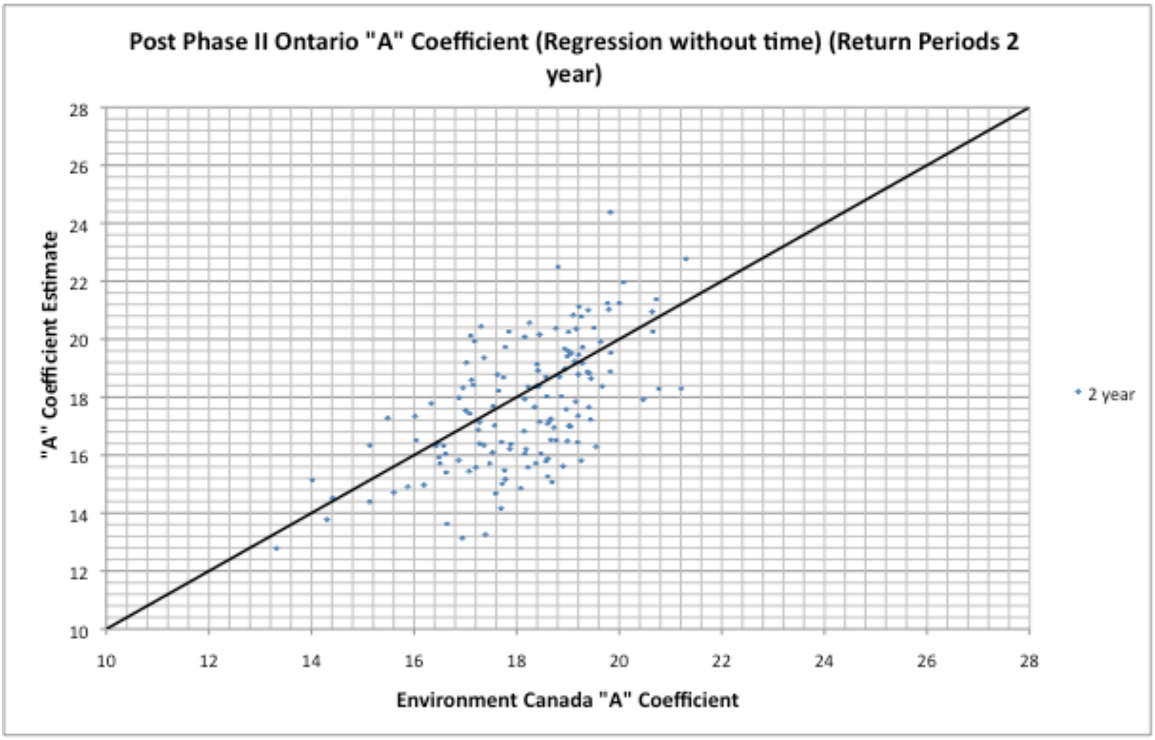


Figure 45) “A” Coefficient Regression Results for a 2-year Return Period

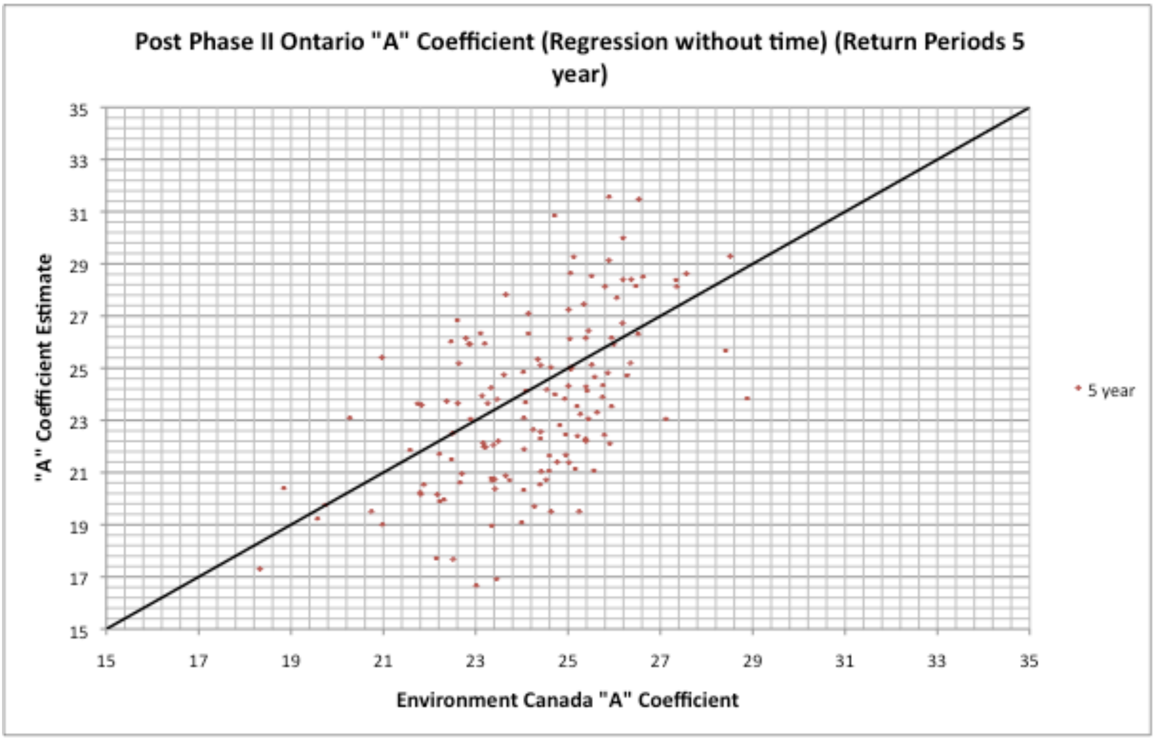


Figure 46) “A” Coefficient Regression Results for a 5-year Return Period

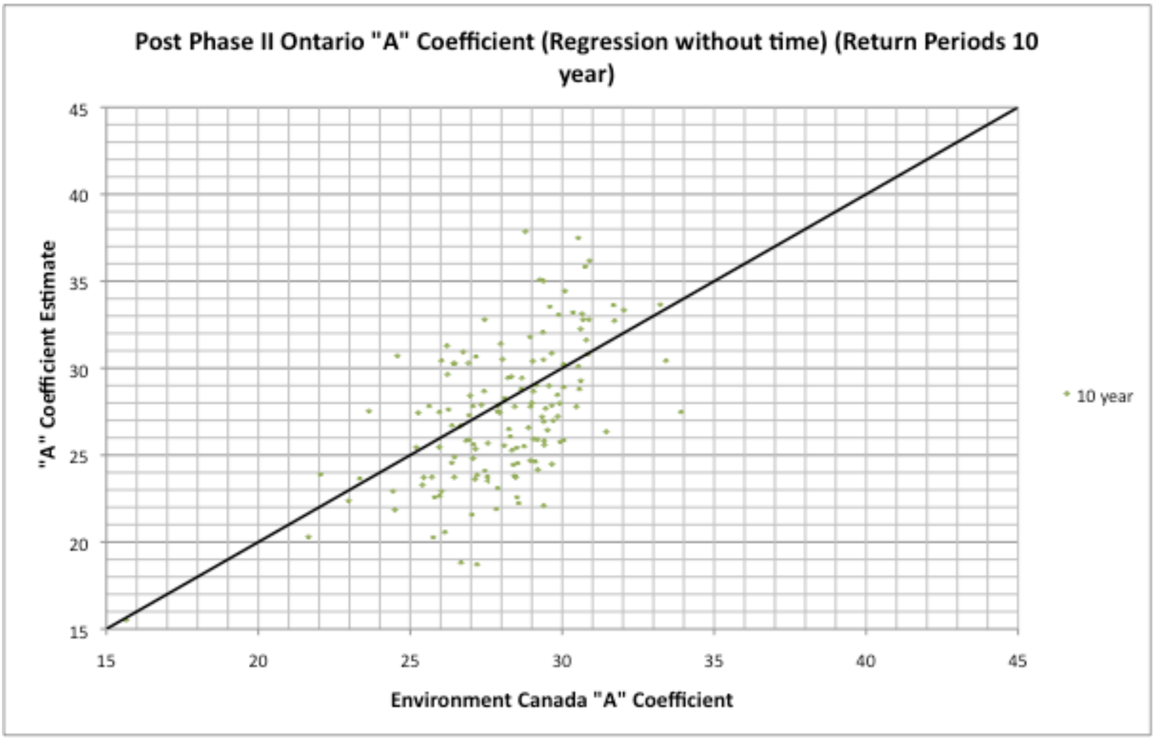


Figure 47) “A” Coefficient Regression Results for a 10-year Return Period

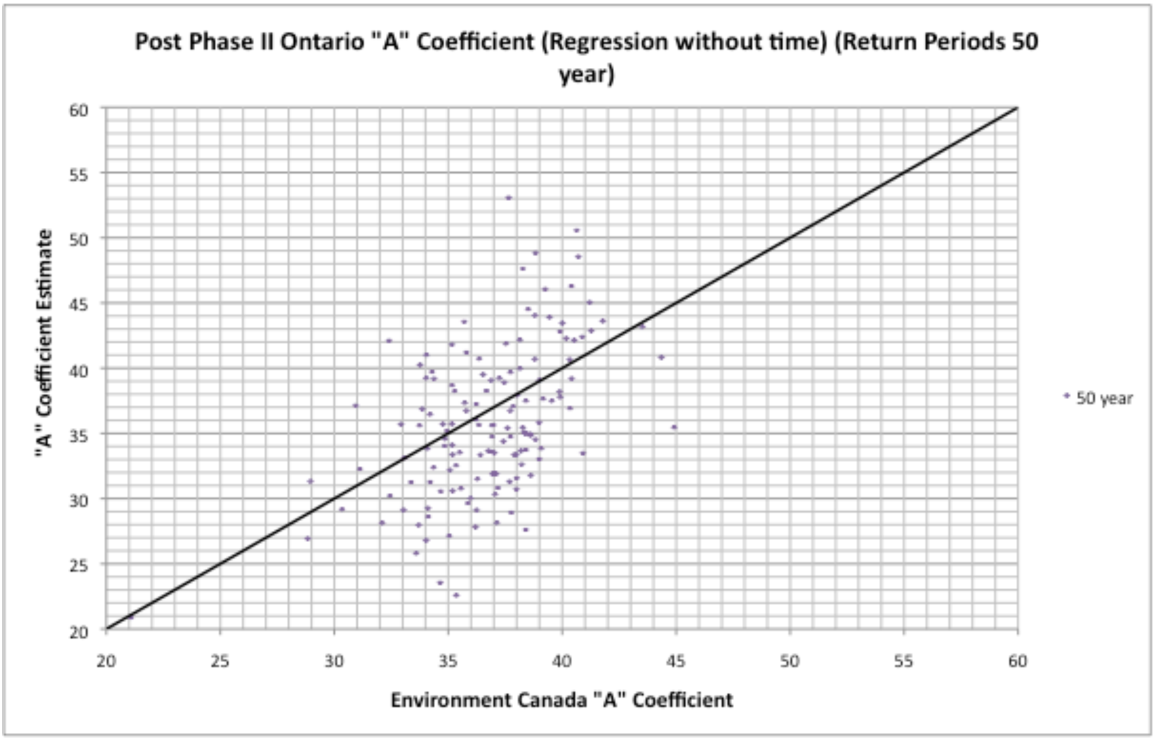


Figure 48) “A” Coefficient Regression Results for a 50-year Return Period

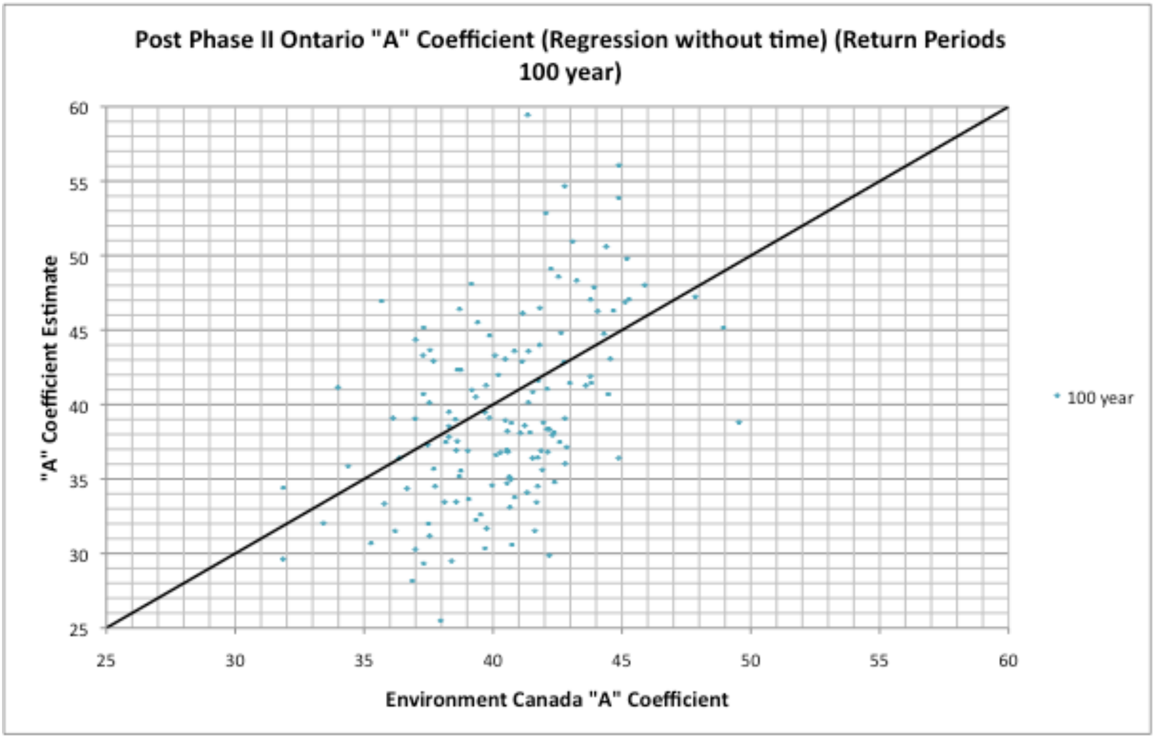


Figure 49) “A” Coefficient Regression Results for a 100-year Return Period

Appendix C: Detailed Regression Results for 2012

Regression results for time trend prediction for year 2012 for return periods 5, 10, 50 and 100 years. Variables 1 – 8 are: average year of record (year), latitude, longitude, elevation (m), barrier height (m), slope Y, slope X and distance to water (km), respectively.

Table 10) 5-Year Return Period Regression Result for 2012

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.9995							
R Square	0.9991							
Adjusted R Square	0.9915							
Standard Error	0.0004							
Observations	141.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	8.0000	0.0235	0.0029	17531.2734	0.0000			
Residual	133.0000	0.0000	0.0000					
Total	141.0000	0.0235						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.9852	0.0617	15.9781	0.0000	0.8632	1.1071	0.8632	1.1071
X Variable 2	-5.9988	0.8525	-7.0364	0.0000	-7.6851	-4.3125	-7.6851	-4.3125
X Variable 3	1.8387	0.5297	3.4710	0.0007	0.7909	2.8865	0.7909	2.8865
X Variable 4	0.0000	0.0000	-0.7380	0.4618	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0078	0.0036	2.1782	0.0312	0.0007	0.0150	0.0007	0.0150
X Variable 6	-0.0004	0.0002	-1.6848	0.0944	-0.0009	0.0001	-0.0009	0.0001
X Variable 7	-0.0696	0.3557	-0.1957	0.8451	-0.7732	0.6340	-0.7732	0.6340
X Variable 8	0.0103	0.0057	1.7847	0.0766	-0.0011	0.0216	-0.0011	0.0216

Table 11) 10-Year Return Period Regression Result for 2012

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9982
R Square	0.9964
Adjusted R Square	0.9962
Standard Error	0.0004
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8.0000	0.0046	0.0006	4583.2065	0.0000
Residual	132.0000	0.0000	0.0000		
Total	140.0000	0.0046			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.0005	0.0001	-6.8531	0.0000	-0.0006	-0.0003	-0.0006	-0.0003
X Variable 1	1.0075	0.0538	18.7234	0.0000	0.9010	1.1139	0.9010	1.1139
X Variable 2	-5.8754	0.7452	-7.8841	0.0000	-7.3495	-4.4012	-7.3495	-4.4012
X Variable 3	1.7771	0.4630	3.8380	0.0002	0.8612	2.6930	0.8612	2.6930
X Variable 4	0.0000	0.0000	0.2903	0.7720	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0050	0.0032	1.5813	0.1162	-0.0013	0.0113	-0.0013	0.0113
X Variable 6	-0.0004	0.0002	-1.7455	0.0832	-0.0008	0.0000	-0.0008	0.0000
X Variable 7	0.1010	0.3108	0.3248	0.7458	-0.5138	0.7158	-0.5138	0.7158
X Variable 8	0.0106	0.0050	2.1191	0.0360	0.0007	0.0205	0.0007	0.0205

Table 12) 50-Year Return Period Regression Result for 2012

SUMMARY OUTPUT

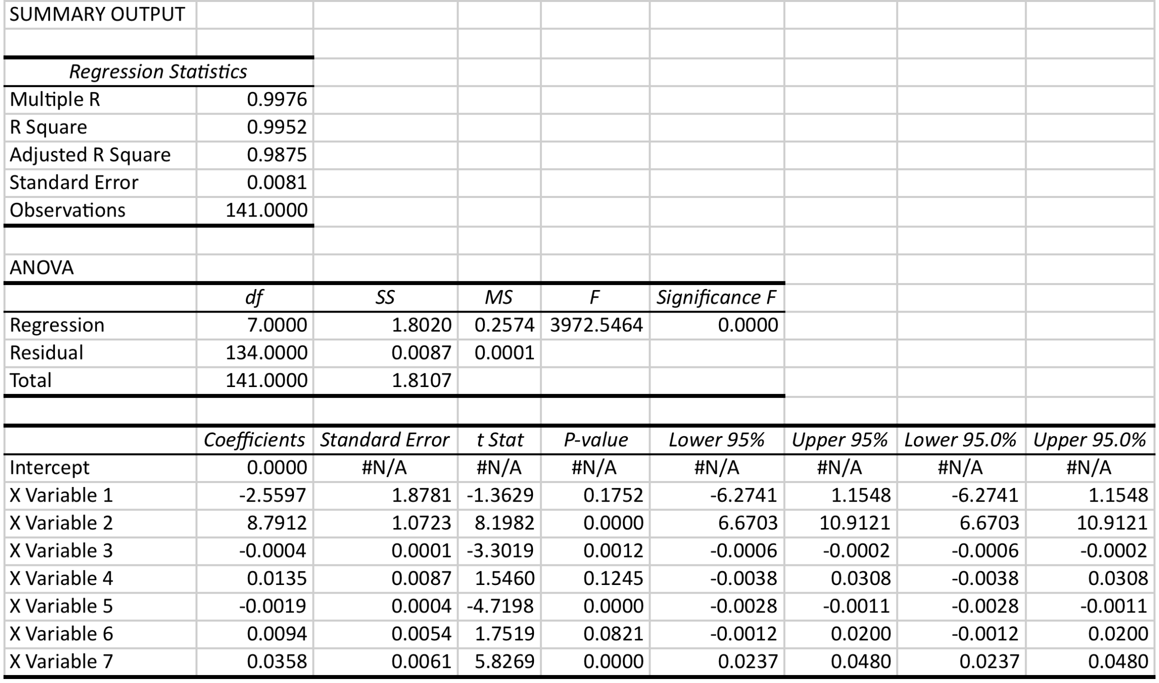
Regression Statistics	
Multiple R	0.9976
R Square	0.9952
Adjusted R Square	0.9875
Standard Error	0.0079
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7.0000	1.7113	0.2445	3933.5209	0.0000
Residual	134.0000	0.0083	0.0001		
Total	141.0000	1.7197			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-2.6481	1.8393	-1.4398	0.1523	-6.2858	0.9896	-6.2858	0.9896
X Variable 2	8.6561	1.0502	8.2426	0.0000	6.5791	10.7332	6.5791	10.7332
X Variable 3	-0.0004	0.0001	-3.3290	0.0011	-0.0006	-0.0002	-0.0006	-0.0002
X Variable 4	0.0131	0.0086	1.5298	0.1284	-0.0038	0.0300	-0.0038	0.0300
X Variable 5	-0.0019	0.0004	-4.7720	0.0000	-0.0027	-0.0011	-0.0027	-0.0011
X Variable 6	0.0091	0.0053	1.7322	0.0855	-0.0013	0.0195	-0.0013	0.0195
X Variable 7	0.0354	0.0060	5.8759	0.0000	0.0235	0.0473	0.0235	0.0473

Table 13) 100-Year Return Period Regression Result for 2012



SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.9976							
R Square	0.9952							
Adjusted R Square	0.9875							
Standard Error	0.0081							
Observations	141.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	7.0000	1.8020	0.2574	3972.5464	0.0000			
Residual	134.0000	0.0087	0.0001					
Total	141.0000	1.8107						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-2.5597	1.8781	-1.3629	0.1752	-6.2741	1.1548	-6.2741	1.1548
X Variable 2	8.7912	1.0723	8.1982	0.0000	6.6703	10.9121	6.6703	10.9121
X Variable 3	-0.0004	0.0001	-3.3019	0.0012	-0.0006	-0.0002	-0.0006	-0.0002
X Variable 4	0.0135	0.0087	1.5460	0.1245	-0.0038	0.0308	-0.0038	0.0308
X Variable 5	-0.0019	0.0004	-4.7198	0.0000	-0.0028	-0.0011	-0.0028	-0.0011
X Variable 6	0.0094	0.0054	1.7519	0.0821	-0.0012	0.0200	-0.0012	0.0200
X Variable 7	0.0358	0.0061	5.8269	0.0000	0.0237	0.0480	0.0237	0.0480

Appendix D: Post Phase II 1-hour Storm Intensity Comparison for 2012

The Black line represents the 1:1 line.

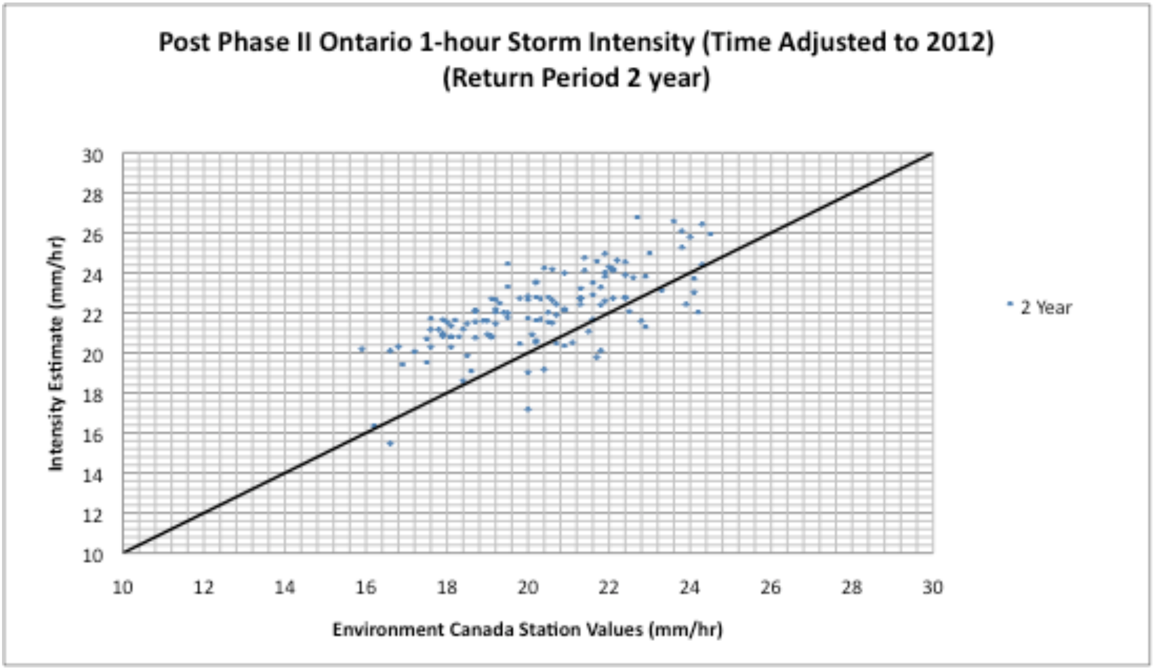


Figure 50) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 2-year Return Period for year 2012

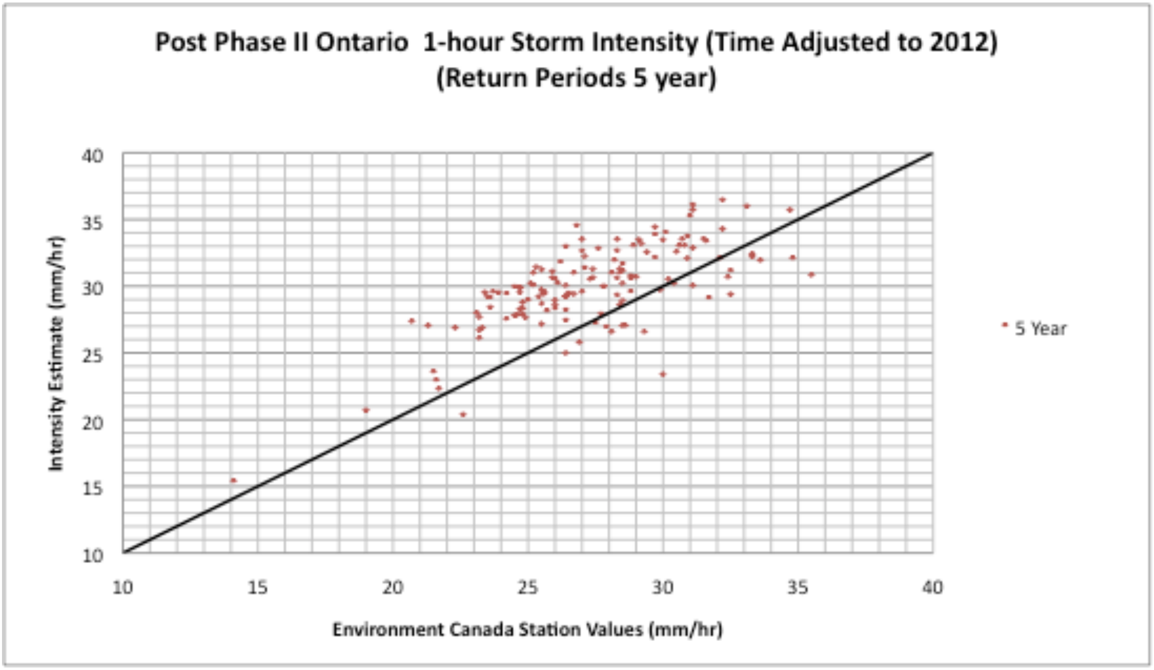


Figure 51)1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 5-year Return Period for year 2012

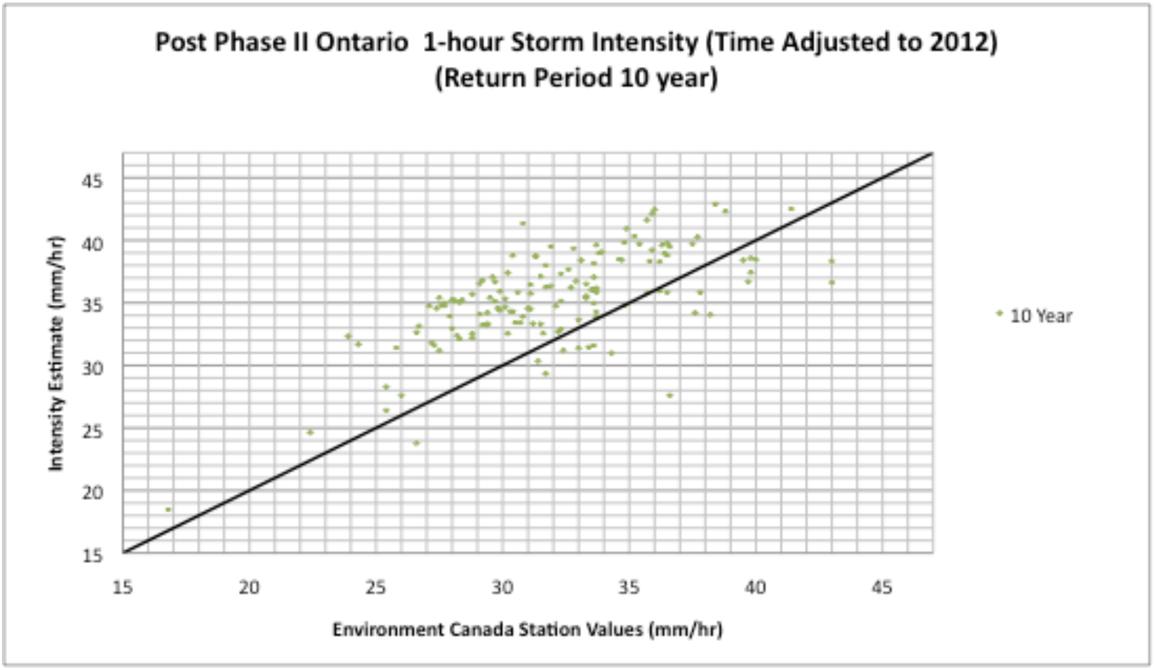


Figure 52) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 10-year Return Period for year 2012

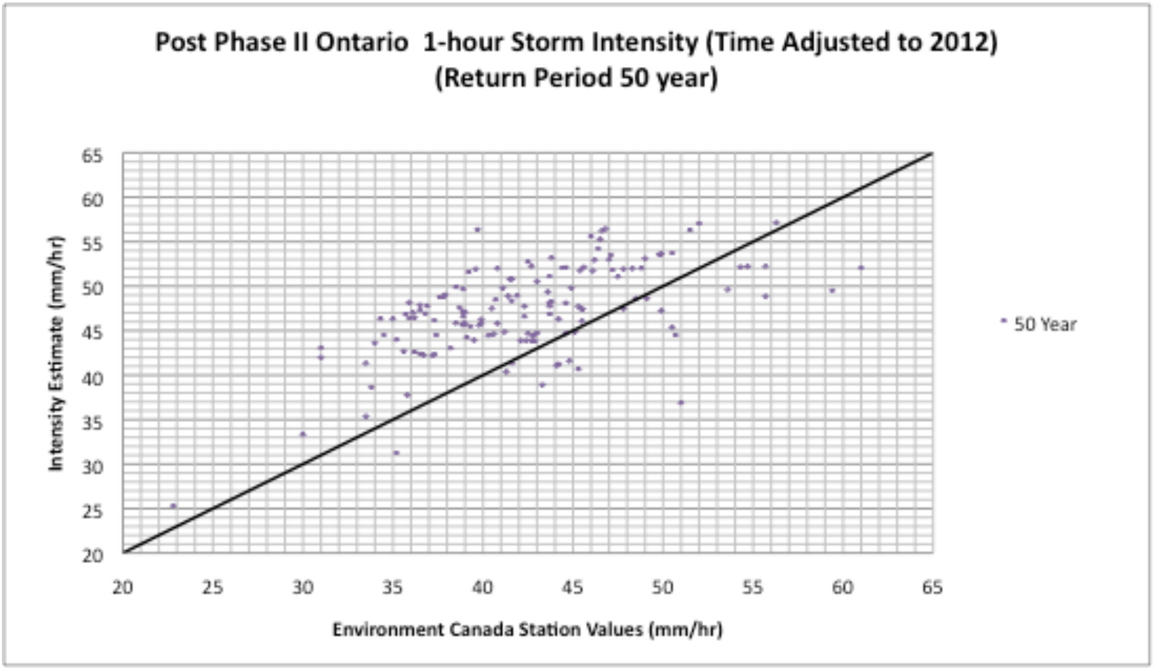


Figure 53) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 50-year Return Period for year 2012

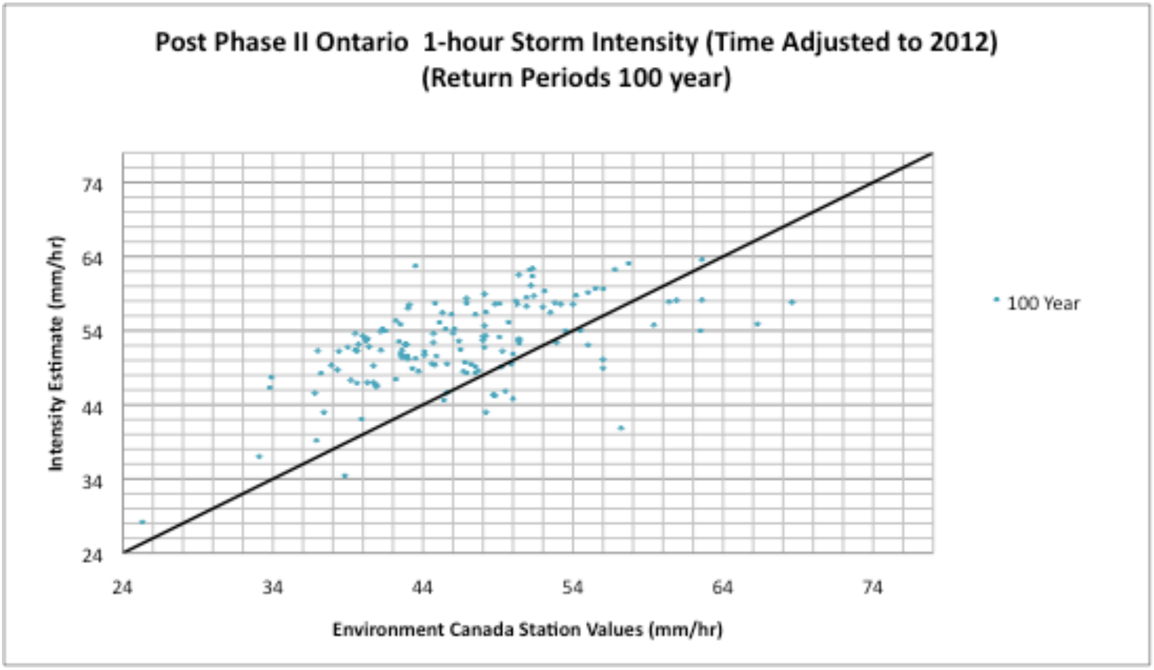


Figure 54) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 100-year Return Period for year 2012

Appendix E: Detailed Regression Results for 2090

Variables 1 – 8 are: average year of record (year), latitude, longitude, elevation (m), barrier height (m), slope Y, slope X and distance to water (km), respectively.

Table 14) 2-Year Return Period Regression Result for 2090

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9997
R Square	0.9995
Adjusted R Square	0.9919
Standard Error	0.0021
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8.0000	1.1054	0.1382	31649.1700	0.0000
Residual	133.0000	0.0006	0.0000		
Total	141.0000	1.1060			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.8089	0.0217	37.3198	0.0000	0.7660	0.8518	0.7660	0.8518
X Variable 2	-6.9315	0.5046	-13.7374	0.0000	-7.9295	-5.9335	-7.9295	-5.9335
X Variable 3	2.5298	0.3132	8.0765	0.0000	1.9103	3.1494	1.9103	3.1494
X Variable 4	0.0000	0.0000	-0.0831	0.9339	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	-0.0002	0.0023	-0.0868	0.9309	-0.0047	0.0043	-0.0047	0.0043
X Variable 6	-0.0006	0.0001	-5.0604	0.0000	-0.0008	-0.0003	-0.0008	-0.0003
X Variable 7	-0.0011	0.0014	-0.8191	0.4142	-0.0039	0.0016	-0.0039	0.0016
X Variable 8	0.0069	0.0017	4.1513	0.0001	0.0036	0.0102	0.0036	0.0102

Table 15) 5-Year Return Period Regression Result for 2090

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.9997							
R Square	0.9994							
Adjusted R Square	0.9918							
Standard Error	0.0025							
Observations	141.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	8.0000	1.3398	0.1675	27600.1706	0.0000			
Residual	133.0000	0.0008	0.0000					
Total	141.0000	1.3406						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.8303	0.0256	32.4922	0.0000	0.7797	0.8808	0.7797	0.8808
X Variable 2	-6.8815	0.5948	-11.5685	0.0000	-8.0580	-5.7049	-8.0580	-5.7049
X Variable 3	2.8732	0.3693	7.7806	0.0000	2.1428	3.6036	2.1428	3.6036
X Variable 4	0.0000	0.0000	0.0488	0.9612	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0007	0.0027	0.2451	0.8068	-0.0047	0.0060	-0.0047	0.0060
X Variable 6	-0.0005	0.0001	-3.9119	0.0001	-0.0008	-0.0003	-0.0008	-0.0003
X Variable 7	0.0002	0.0017	0.1036	0.9176	-0.0031	0.0034	-0.0031	0.0034
X Variable 8	0.0078	0.0020	3.9548	0.0001	0.0039	0.0117	0.0039	0.0117

Table 16) 10-Year Return Period Regression Result for 2090

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.9997							
R Square	0.9993							
Adjusted R Square	0.9918							
Standard Error	0.0027							
Observations	141.0000							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	8.0000	1.4716	0.1839	24608.2308	0.0000			
Residual	133.0000	0.0010	0.0000					
Total	141.0000	1.4726						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.8451	0.0284	29.7966	0.0000	0.7890	0.9012	0.7890	0.9012
X Variable 2	-6.8222	0.6602	-10.3333	0.0000	-8.1281	-5.5163	-8.1281	-5.5163
X Variable 3	3.0070	0.4099	7.3368	0.0000	2.1964	3.8177	2.1964	3.8177
X Variable 4	0.0000	0.0000	0.0494	0.9607	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0011	0.0030	0.3672	0.7141	-0.0048	0.0070	-0.0048	0.0070
X Variable 6	-0.0005	0.0001	-3.4798	0.0007	-0.0008	-0.0002	-0.0008	-0.0002
X Variable 7	0.0007	0.0018	0.3736	0.7093	-0.0029	0.0043	-0.0029	0.0043
X Variable 8	0.0081	0.0022	3.7070	0.0003	0.0038	0.0124	0.0038	0.0124

Table 17) 50-Year Return Period Regression Result for 2090

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9996
R Square	0.9992
Adjusted R Square	0.9917
Standard Error	0.0032
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8.0000	1.7183	0.2148	21244.2425	0.0000
Residual	133.0000	0.0013	0.0000		
Total	141.0000	1.7197			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.8796	0.0330	26.6669	0.0000	0.8144	0.9448	0.8144	0.9448
X Variable 2	-6.7755	0.7678	-8.8242	0.0000	-8.2943	-5.2568	-8.2943	-5.2568
X Variable 3	3.2021	0.4767	6.7177	0.0000	2.2593	4.1449	2.2593	4.1449
X Variable 4	0.0000	0.0000	0.0837	0.9334	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0016	0.0035	0.4654	0.6424	-0.0053	0.0085	-0.0053	0.0085
X Variable 6	-0.0005	0.0002	-2.8679	0.0048	-0.0008	-0.0002	-0.0008	-0.0002
X Variable 7	0.0013	0.0021	0.6324	0.5282	-0.0029	0.0056	-0.0029	0.0056
X Variable 8	0.0086	0.0025	3.3716	0.0010	0.0035	0.0136	0.0035	0.0136

Table 18) 100-Year Return Period Regression Result for 2090

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9996
R Square	0.9992
Adjusted R Square	0.9916
Standard Error	0.0033
Observations	141.0000

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8.0000	1.8092	0.2262	20467.7360	0.0000
Residual	133.0000	0.0015	0.0000		
Total	141.0000	1.8107			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.0000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	0.8951	0.0344	26.0385	0.0000	0.8271	0.9631	0.8271	0.9631
X Variable 2	-6.7561	0.8033	-8.4104	0.0000	-8.3450	-5.1672	-8.3450	-5.1672
X Variable 3	3.2410	0.4978	6.5106	0.0000	2.2564	4.2257	2.2564	4.2257
X Variable 4	0.0000	0.0001	0.0622	0.9505	-0.0001	0.0001	-0.0001	0.0001
X Variable 5	0.0018	0.0036	0.5081	0.6122	-0.0054	0.0090	-0.0054	0.0090
X Variable 6	-0.0005	0.0002	-2.7211	0.0074	-0.0008	-0.0001	-0.0008	-0.0001
X Variable 7	0.0015	0.0022	0.6696	0.5043	-0.0029	0.0059	-0.0029	0.0059
X Variable 8	0.0087	0.0027	3.2169	0.0016	0.0034	0.0141	0.0034	0.0141

Appendix F: Post Phase II 1-hour Storm Intensity Comparison for 2090

The black line is the 1:1 line. The red line indicates 120% of the Environment Canada values.

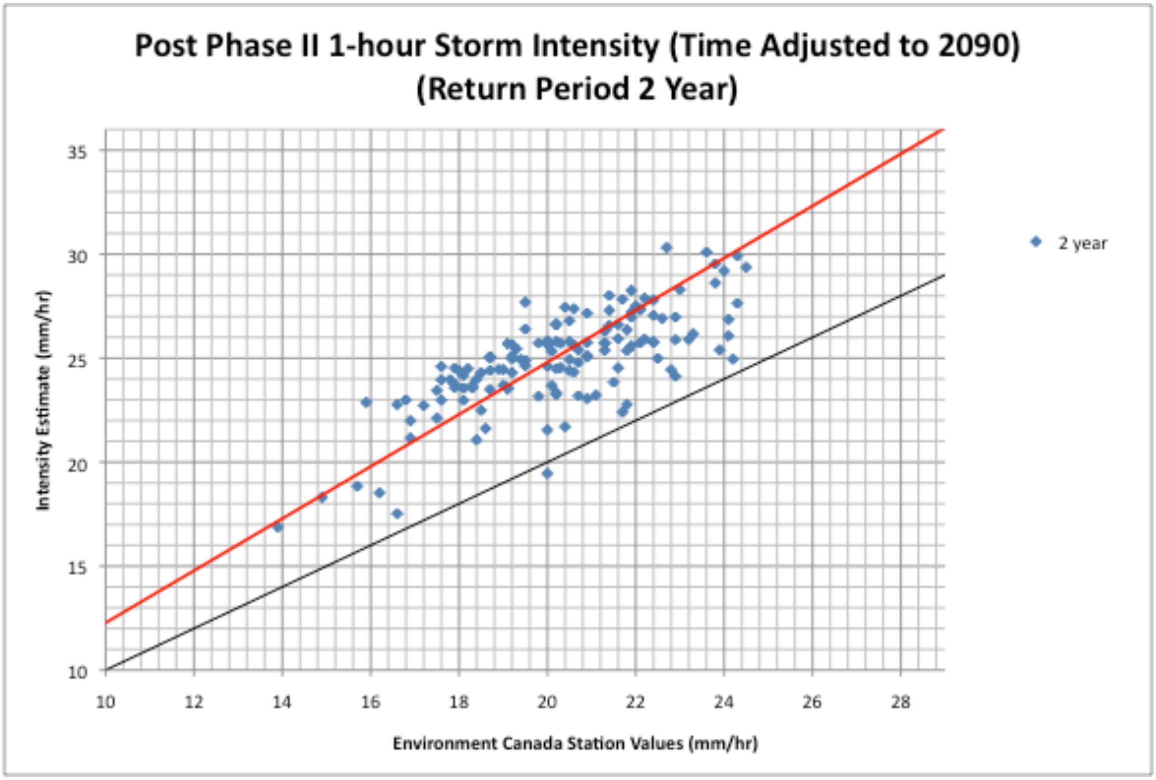


Figure 55) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 2-year Return Period for year 2090

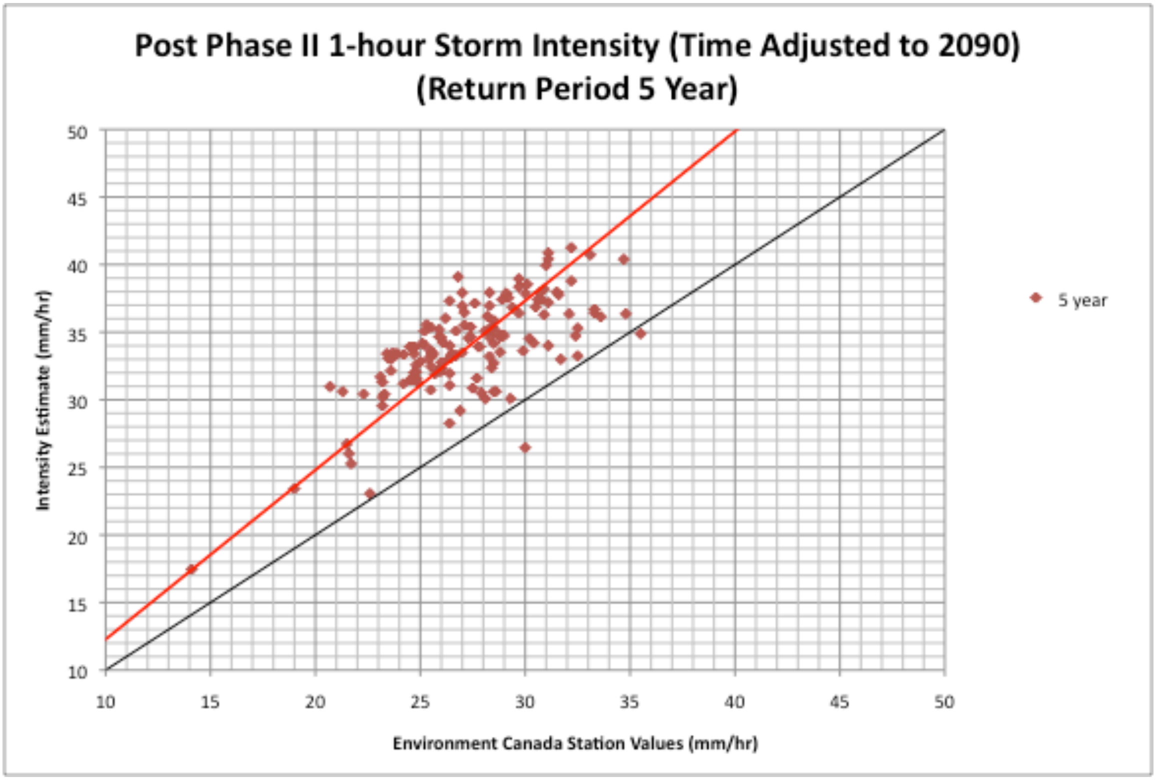


Figure 56) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 5-year Return Period for year 2090

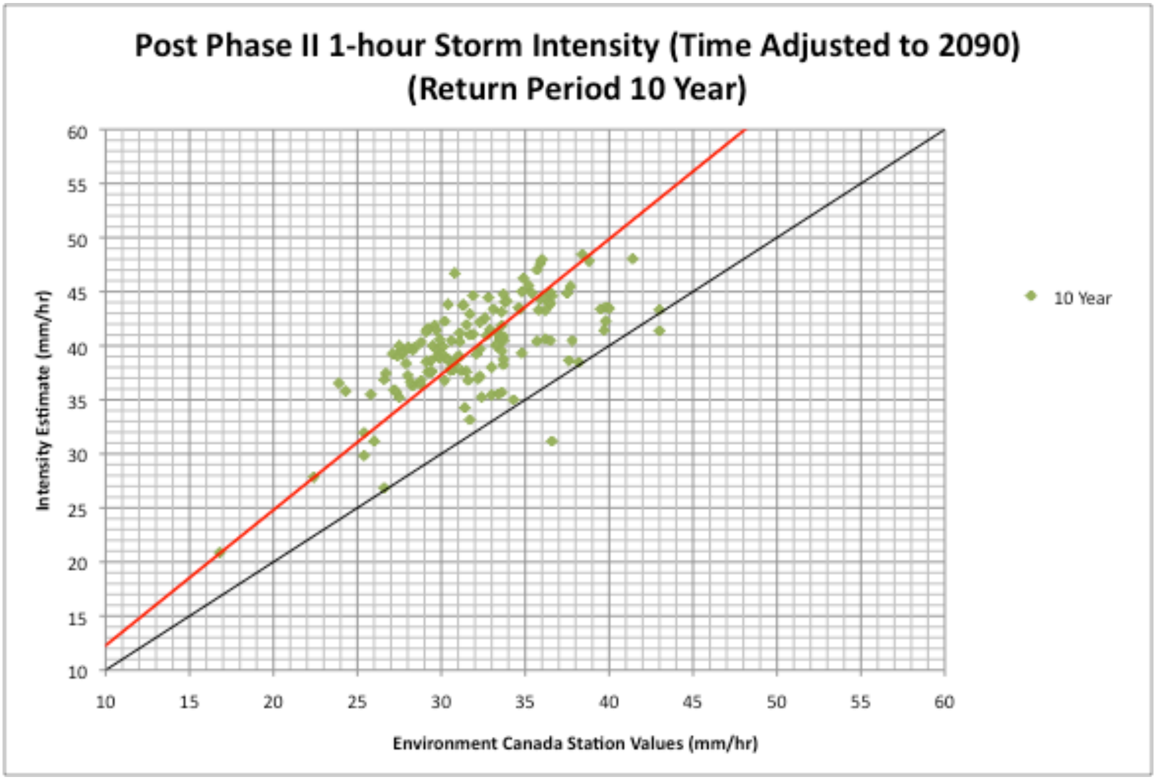


Figure 57) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 10-year Return Period for year 2090

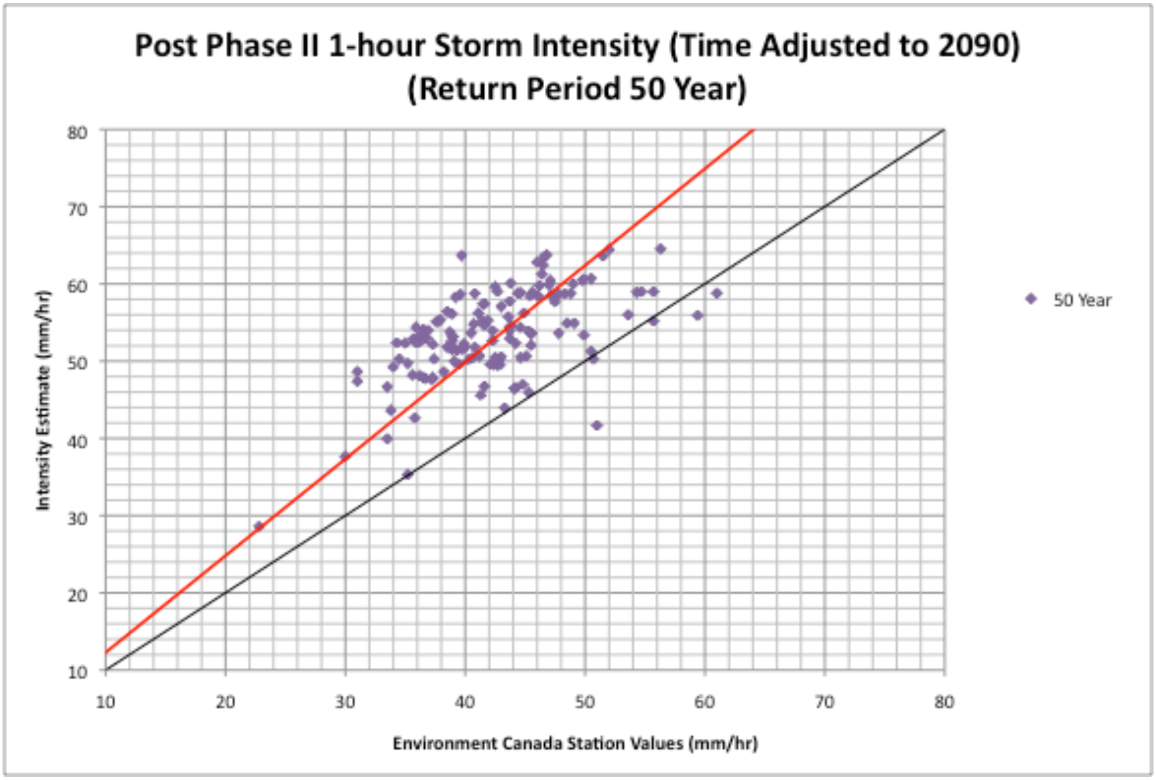


Figure 58) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 50-year Return Period for year 2090

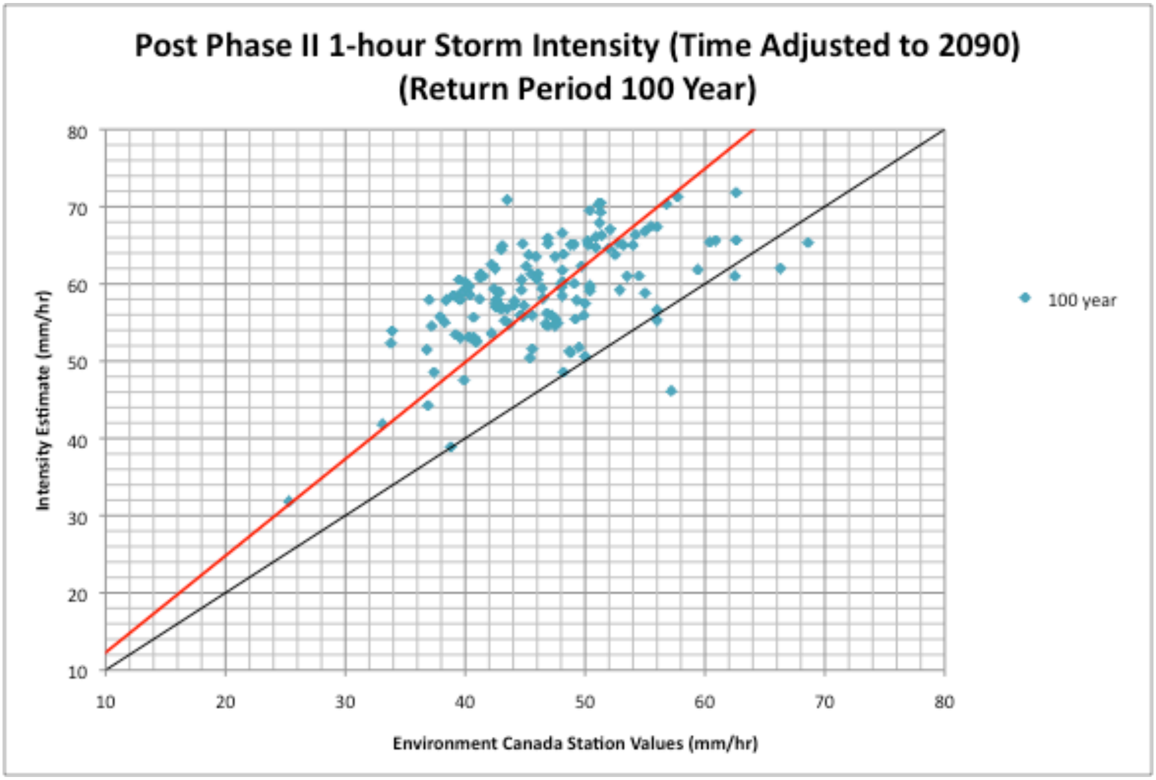


Figure 59) 1-hour Storm Rainfall Intensity Regression Prediction vs. EC Station Values for a 100-year Return Period for year 2090

Bibliography

(CEE, 2000) Kharin, Viatcheslav V., Francis W. Zwiers, 2000: Changes in the Extremes in an Ensemble of Transient Climate Simulations with a Coupled Atmosphere–Ocean GCM. *J. Climate*, **13**, 3760–3788.

(DIU, 2010) "Development, interpretation, and use of rainfall intensity-duration-frequency (IDF) information: Guideline for Canadian water resources practitioners." *Canadian Standard Association*. (2010): n. page. Print.

(DPB, 2005) Coulibaly, Paulin , and Xiaogang Shi . "Identification of the Effect of Climate Change on Future Design Standards of Drainage Infrastructure in Ontario." (2005): n. page. Web. 31 Mar. 2014.

(DPE, 2012)"Development of Projected Intensity-Duration-Frequency Curves for Welland, Ontario, Canada ." *AMEC Environment & Infrastructure* . (2012): n. page. Web. 14 Apr. 2014.

(LIR, 2010) Farghaly, Hani, and Muhammad Naeem. "Road Talk." *Let It Rain!* (2010): n. pag. Web.

(OCC, 2012) "Overview of Climate Change in Canada." *Natural Resources Canada*. N.p., 17 Oct 2012. Web. 9 Apr 2014.

(PFA, 2013) Perica, Sanja , Deborah Martin, et al. "Precipitation-Frequency Atlas of the United States ." *NOAA Atlas 14, U.S. Department of Commerce*. 8. (2013): n. page. Web. 10 Apr. 2014. <http://www.nws.noaa.gov/oh/hdsc/PF_documents/Atlas14_Volume8.pdf>.

(PFD, 2014) "PF Data Server Home." *NOAA's National Weather Service*. Hydrometeorological Design Study Center. Web. 8 Apr 2014. <http://dipper.nws.noaa.gov/hdsc/pfds/>.

(RLQA, 2005) Wallis, James, and J. R. M. Hosking. "Regional L-moment Quantile Algorithm." *Regional Frequency Analysis*. : Cambridge University Press, 2005. . Print.

(RMI, 2010) Soulis, Ric, Don Burn, and Frank Seglenieks. "Renewal of MTO I-D-F Curves" (2010): n. pag. Print.

(SLR, 2014) "Stepwise Linear Regression.". School of Geography, University of Leeds, n.d. Web. 5 Mar. 2014.

(TIR, 1999) Berlamont , J. . "THE INFLUENCE OF RAINFALL AND MODEL SIMPLIFICATION ON COMBINED SEWER SYSTEM DESIGN."*KATHOLIEKE UNIVERSITEIT LEUVEN*

(UAL, 2014) Ric Soulis et al. University of Waterloo. "IDF Curves – The Under Appreciated Legacy" University of Waterloo. PowerPoint. 2014.
(UIC, 2011) Taylor, Erin. "Updating IDF Climate Design Values for the Atlantic Provinces." *Ministry of Environment, Labour and Justice Government of PEI.* (2011): n. page. Web. 14 Apr. 2014.

(WFU, 2014) Cottrell, Allin. *Wfu.com.* N.p., n.d. Web. 6 Feb. 2014. <http://users.wfu.edu/cottrell/ecn215/regress.pdf>.

(WRR, 2011) Solaiman, Tarana A. , and Slobodan P. Simonovic . "Water Resources Research Report: Development of Probability Based Intensity-Duration Frequency Curves Under Climate Change." *THE UNIVERSITY OF WESTERN ONTARIO DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING.* (2011): n. page. Web. 6 Apr. 2014.