City of Guelph

City of Guelph – Ward One

Frequency Analysis of Maximum Rainfall and IDF Design Curve Update

Prepared for:
The Corporation of the City of Guelph
59 Carden Street
Guelph, Ontario
N1H 3A1

Prepared by:
Earth Tech Canada Inc.
101 Frederick Street, Suite 702
Kitchener, Ontario
N2H 6R2

May, 2007

P/N No. 96256

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FREQUENCY ANALYSIS OF MAXIMUM RAINFALL AND IDF DESIGN CURVE UPDATE FOR THE CITY OF GUELPH

1.0 INTRODUCTION

The City of Guelph is conducting a Stormwater Management Study and Environmental Assessment of the drainage system in Ward One of the city. The study will identify opportunities to improve the level of service of the existing drainage system and to reduce the level of flooding that is being experienced south of the CNR .The drainage improvements will be completed in conjunction with capital road works to Elizabeth Street between Stevenson Street and Victoria Road. The study identified the need to review and update the City's current Intensity Duration Frequency Design (IDF) curves. One of the reasons for recommending that the city undertake a rainfall analysis was that initial hydrologic modeling of low event storms (2 and 5 year) indicated that considerable surcharging of the storm sewer system in the upper catchment north of the CNR. This surcharging would have created localized surface ponding, however, there have been very few recorded incidences of nuisance flooding in this upper catchment area. Another reason for the investigation was that the current IDF design curves were derived from limited historical rainfall records (16years), for a meaningful analysis at least 25 to 30 years of data is recommended.

The city's current rainfall design curves were derived from approximately 16 years of rainfall records recorded at the University of Guelph Ontario Agricultural College Arboretum Rainfall Station. The rainfall analysis was completed in the early 1970's by the engineering firm of James F. MacLaren. The design curves were derived from a partial duration series of rainfall based on 16 years of rainfall records from 1954 to 1970. These curves have been used in the design of storm water infrastructure for existing and new developments within the City of Guelph. This report will review 43 years of records and generate an additional 7 years of missing rainfall records from the analysis of annual maximum rainfall from adjacent rainfall stations. The data will be used in a statistical rainfall frequency analysis model that will generate a distribution of rainfall intensities for various storm durations and storm recurrences (return periods). The model data will be used to develop updated intensity frequency duration (IDF) design curves that can be used for the sizing and modeling of various conveyance systems and stormwater management storage facilities. The analysis will also provide design curves for more frequent rainfall events used to size facilities to improve storm water quality. The report will provide some general discussion and recommendations for adapting the design curves to address global warming trends.

2.0 RAINFALL FREQUENCY ANALYSIS

2.1 Precipitation

Precipitation is a random event that cannot be predicted based on historical data. However, any given precipitation event has several distinct and independent characteristics which can be quantified as follows:

Intensity - Rainfall depth divided by the duration (mm/hr).
Duration - Length of time over which precipitation occurs (hours).
Frequency - Recurrence interval of events having the same duration and depth (mm).
Depth - Amount of precipitation occurring for the storm duration (mm)

A specified amount of rainfall depth may occur from many different combinations of intensities and durations. The peak intensity associated with each combination will vary widely. Also, storm events with the same intensity may have significantly different volumes and durations if the specified storm frequency (2-year, 10-year, 100-year) is different. It therefore, becomes critical for any regulatory criteria to specify the volume (or intensity) and the duration for a specified design frequency. Design Curves and synthetic storms will be discussed in the sections to follow.

2.2 Frequency

The frequency of a specified design storm can be expressed either in terms of ***exceedance probability*** or ***return period***.

Exceedance Probability is the probability that an event having a specified volume and duration will be exceeded in one time period, which is most often assumed to be one year.

Return Period is the average length of time between events having the same volume and duration.

If a storm of a specified duration and volume has a 1 percent chance of occurring in any given year, then it has an exceedance probability of .01 and a return period of 100 years. The return period concept is often misunderstood in that it implies that a 100-year flood will occur only once in a 100-year period. This will not always hold true because storm events cannot be predicted deterministically. Because storm events are random, the exceedance probability indicates that there is a finite probability (.01 for this example) that the 100-year storm may occur in any given year or consecutive years, regardless of the historic occurrence of that storm event.

TABLE 2.1 ***Variations of Rainfall Duration and Intensity for a Constant Volume***

Duration (*hr*)	Intensity (*mm/hr*)	Volume (*mm*)
0.5	30	15
1.0	15	15
1.5	10	15
6.0	2.5	15

TABLE 2.2 ***Variations of Rainfall Duration, Volume and Return Frequency for a Given Intensity***

Duration (*hr*)	Volume (*mm*)	Intensity (*mm/hr*)	Frequency (*years*)
1.0	15	15	2
2.0	30	15	25
3.0	45	15	50

2.3 Rainfall Records and Gauges

This report will complete an analysis of the annual maximum rainfall records for the City of Guelph to year 2003. The analysis will be used to generate updated Intensity Duration Frequency design curves that can be used in simple models (Rational Method) or more complex hydrologic models for the sizing of various stormwater infrastructure and management facilities. The annual maximum rainfall data for the City of Guelph and surrounding area were obtained from data collected by the Meteorological Services of Canada (MSC) Ontario Climate Center, an arm of Environment Canada. The department was formerly known as Atmospheric Environment Services (AEC). MSC collects meteorological data for all of Canada from a number of stations. The Guelph Turfgrass CS (Arboretum) rainfall gauge will be used for this analysis. It is located within the University of Guelph campus and has been in operation since 1954 (Hurricane Hazel) and 43 years of rainfall data has been collected to 2003. No records were available for 1974, 1975 and for 1992 to 1996 for this gauge. In order to provide a comparison of rainfall intensities and trends, two additional stations were included in the analysis. These were selected based on location, quality and continuity of the available data. Generally, a minimum of 30 years of records should be used for a rainfall frequency analysis. The additional data was obtained from MSC for the Waterloo Wellington Airport which has 31 years of records from 1971 to 2003 with missing records for 1999 and 2001. The third station at Fergus Shand Dam has 38 years of records from 1962 to 2003 with missing records for 1969,1971,1986 and 1995. The annual intensities are provided by MSC for 6 series of annual maximum intensities (2,5,10,25,50,100 year) and 9 standard rainfall durations ranging from 5minutes to 24hours. The selected stations, location and available

data for the annual maximum series of records are summarized in Table 2.3. Appendix A provides more detailed information and a statistical summary for these three Ontario stations used for this analysis as recorded by Atmospheric Environment Service (AES).

Table 2.3 Rainfall Gauge Sites, Annual Maximum Rainfall Intensities

Station Name	ID Number	Location Latitude / Longitude	Elevation (m)	Period Record
GUELPH TURFGRASS CS	6143069	4333 / 8013 Stone- Victoria Rd	328	1954-2003 42 years
WATERLOO WELLINGTON AIRPORT	6149387	4327 / 8023 RR 17 Fountain Street 3km s of Breslau	317	1971-2003 31 years
FERGUS SHAND DAM	6142400	4344 / 8020 Belwood Road Lake Belwood	418	1962-2003 38 years

The AEC statistical summary flags records that are considered to have intensities greater than a 100 year storm event. These are defined as *outliers* or data points that depart significantly from the main data trends. The location of the rainfall gauging stations is illustrated in Figure 2.1 The Guelph Turfgrass station is located between the other two rainfall gauges, approximately 22 km from the Fergus Shand Dam and 15 km from the Waterloo Airport.

Figure 2.1 Location of Rainfall Gauges

The Waterloo Airport rainfall volume records (mm) and the Guelph Turfgrass Station were reviewed for statistical trends (mean and standard deviation). The statistical summary of maximum annual rainfall for 9 durations (H, hours) where obtained from AES are

illustrated in Table 2.4. The mean and standard deviation showed good agreement between these two stations. The Waterloo Airport gauge was used to supplement missing or gap data for the Turfgrass station considering the relatively good agreement. Close proximity of the two stations was also another consideration. The Shand Dam in Fergus was not analyzed in detail but showed similar statistical characteristics to the other two stations. It was used to review general rainfall trends for data prior to 1971 for Waterloo Airport (1971-2003) and Guelph Turfgrass (1954-2003).

Table 2.4 Comparison of Guelph Turfgrass and Waterloo Airport Stations

Guelph Turfgrass Mean Values	9.5	13.4	16	20.4	24.2	28.4	37.1	42.3	49.8
Waterloo Airport Mean Values	9.2	12.9	15.9	21.4	26.7	32.1	41.1	47.0	54.7
Rainfall Duration Minutes	**5**	**10**	**15**	**30**	**60**	**120**	**360**	**720**	**1440**
Guelph Turfgrass SDEV	3.1	4.7	5.9	8.6	11.3	11.7	12.3	14.5	16.5
Waterloo Airport SDEV	2.9	4.4	5.5	9.2	14.7	17.2	18.6	18.3	18.5

AES analysis flags extreme values (100 year) based on the outcome of the Gumbel frequency analysis for various rainfall durations. The statistical analysis provides the maximum values that can be expected. The following observations of less frequent rainfall events were made from the raw AES rainfall data for all three stations and where 100 year exceedances where identified :

Table 2.5 Comparison of Less Frequent Rainfall Volumes(mm) for the 100 Year Rainfall at 3 Stations

	Guelph Turfgrass (TG)			Waterloo Airport (WA)			Fergus Shand Dam (SD)			Comments
Available Records	1954-2003 (43yrs)			1971-2003 (31yrs)			1962-2003 (37yrs)			Year- Denotes outliers (TG)
Missing Records	1974, 1975, 1992-1996			1999, 2001			1969,1971,1986,1995			na – record not available
Duration (hours)	6H	12H	24H	6H	12H	24H	6H	12H	24H	
Rainfall maximum	**75.8**	**87.9**	**101.5**	**99.5**	**104.5**	**112.6**	**100.8**	**107.1**	**120.7**	Maximum Annual Values from AES (mm) Gumbel
1954	50.3	83.1	**115.8**	na	na	na	na	na	na	24H high at TG max +, Hazel
1967	43.9	45.2	45.2	na	na	na	**111.0**	**113.5**	**116.8**	6H,12H SD max +, low at TG
1968	**79.9**	**79.9**	**79.9**	na	na	na	64.5	65.0	**117.6**	24H at SD just below max
1974	na	na	na	30.5	41.7	47.5	46.5	63.8	65.5	6H-24H at WA &SD agree
1975	na	na	na	**82.3**	**91.2**	**93.7**	35.3	42.2	44.7	6H-24H at WA below max
1982	**67.2**	**69.0**	**69.0**	**69.5**	**69.7**	**69.9**	29.2	31.2	34.0	6H-24H at WA &TG below max
1985	40.6	43.7	46.2	**88.8**	**89.4**	**89.7**	na	**81.2**	**81.2**	6H-24H at WA & TG below max

It should be noted that the 1968 records for Turfgrass where exceeded for the 1H, 2H not shown and the 6H. The 24H value of 79.9 when compared to the 117.6 at Shand Dam may suggest that the Turfgrass gauge may have failed to record the full 24H volume. No explanation is offered for the 1967 Turfgrass (low) when Shand Dam recorded an extreme event, other than the separation distance and spatial variation of the rainfall event.

The Guelph Turfgrass station has 7 years of missing records and the data from the Waterloo Airport can be used to fill in the gaps in data for the rainfall frequency analysis. This would include the 1974 records, which have good agreement with the adjacent Shand Dam. The1975 Airport record had 50% higher rainfall for 6H to 24H duration than Shand Dam. The missing data from 1992 to 1996 for the Turfgrass station can be supplemented with the Waterloo Airport rainfall data, which generally had good agreement with the Shand Dam rainfall (missing 1995 data) for all durations.

Looking at rainfall trends greater than 100 year maximum, Turfgrass had recorded the 1954 24H rainfall 115.8mm (Hurricane Hazel last 3 hours 112mm) exceeding the maximum 100 year of 101.5mm. Shand Dam had 1967 and 1968 24H values near the maximum annual of 120.7mm. Guelph station over the 43 years of records has had very few rainfall extreme events other than 1954 (Hazel) that exceeded the 100 year 24H maximum. The next highest record for Turfgrass was 1968, 1H, 2H exceedance and 6H to 24H where a rainfall of P=79.5mm would approximate equal to a 12H 50 year event and it's possible that the gauge failed.

The rainfall consolidated frequency analysis will use the existing and supplemental raw rainfall data to derive statistical data for each of the 9 durations and for the six recurrence intervals previously noted. This data will be "curvefit" using regression analysis (least squares fit) to derive the IDF parameters (a,b,c) for the City of Guelph Turfgrass station. A brief description of the process will be presented in the next section of this report.

3.0 CONSOLIDATED FREQUENCY ANALYSIS

Consolidated Frequency Analysis **(CFA)** is a statistical analysis program developed by Environment Canada in 1976 (updated 1988) for the analysis of both rainfall and flooding data from a network of stations. The program has a number of probability distributions that can be used for statistical analyses. The program has capabilities for the analysis of extreme data (outliers). There is a comprehensive reference manual prepared by Environment Canada Surveys and Information Systems that can be download from their website. CFA version 3.1 was used for this rainfall analysis using a three parameter log normal (3LN) distribution. It has been found that the inclusion of a third parameter will greatly improve the normalizing, hence the name, three parameter lognormal distribution.

Rainfall events can seldom be described by the standard normal distribution and more often the events are skewed. The transformations "*normalize*" the skewed distribution so that well known normal distribution properties can be used to draw statistical conclusions. The 3LN method is attractive since data can be extrapolated beyond the range of observed values to obtain values for less frequent events (greater than 100 years). The 3 parameter lognormal transformation (3LN) implies that the logarithms of the data set are normally distributed according to the equation $y = ln(x-a)$. The plotting position (exceedance probability, P) of the ranked data in this analysis uses the Hazen formula $P= (2r-1)/2n$ where, r is the rank or order (largest to smallest) of the data and n is the sample size or number or observations. The following is the generalized formula for deriving plotting position:

$$P = \frac{r - b}{n + 1 - 2b},$$

Where, r is the ordered rank of a sample value, n is the sample size, and b is a constant between 0 and 1, depending on the plotting method. A value of $b=0.5$ is used in the Hazen formula for plotting position. The Hazen formula tends to produce some what higher values for the probability than other statistical methods.

The following Tables 3.1 (a) and (b) provide a summary of the statistically derived (3LN) maximum annual rainfall volumes (mm) and intensities (mm/hr) for various durations and storm recurrences. This analysis is based on extending the 43 years of available data at the Turfgrass Station with an additional 7 years of data from the Waterloo Airport. The frequency analysis will be completed with and without outliers identified by the CFA program. The modified maximum annual rainfall volume dataset used for input in the CFA program is provided in Appendix A. A comparison of the results will be made both with and with out the extreme values (outliers). The limited number of outliers that have occurred for the Turfgrass station are not expected to change the results significantly. The data can also be extrapolated to produce more frequent events like the 1 year recurrence which can be useful for water quality evaluations. The 3LN statistical analysis can be extended to predict higher than 100 year recurrence interval with some caution. The rainfall depths or volumes (mm) used in the analysis were expressed as rainfall intensities (in mm/hr) using the corresponding value for each duration.

Table 3.1 (a) Consolidated Rainfall Frequency Analysis (3LN)

Guelph Turfgrass Station	Rainfall Volume (mm)										Outliers Included
	Recurrence Interval In Years										
Time (min)	1.003	1.05	1.25	2	5	10	20	25	50	100	200	500
5	1.22	4.22	6.71	9.41	12.2	13.7	14.8	15.0	16	16.7	17.3	17.9
10	3.78	6.51	9.12	12.5	16.8	19.6	22.2	22.7	25.4	27.8	30.1	33.0
15	5.16	7.99	10.9	14.8	20.2	23.9	27.6	28.4	32.6	36.4	40.3	45.6
30	7.17	10.3	13.6	18.5	26.1	31.7	37.7	39.2	46.4	53.7	61.7	73.5
60	10.3	13.1	16.2	21.2	29.7	36.6	44.6	46.7	57.1	68.4	81.7	103.0
120	13.4	16.4	19.8	25.3	34.6	42.3	51.0	53.3	64.9	77.4	92.2	116.0
360	19.2	23.0	27.3	33.9	44.9	53.6	63.4	65.9	78.4	91.7	107	131.0
720	20.0	25.3	31.0	39.5	52.6	62.7	73.4	76.0	89.1	102	117	139.0
1440	25.0	31.1	37.5	46.8	60.9	71.3	82.2	84.8	97.7	111	124	145

Table 3.1 (b) Consolidated Rainfall Frequency Analysis (3LN)

Guelph Turfgrass Station	Rainfall Intensity (mm/hr)										Outliers Included
	Recurrence in Interval Years										
Time (min)	1.003	1.05	1.25	2	5	10	20	25	50	100	200	500
5	14.6	50.6	80.5	112.9	146.4	164.4	177.6	180.0	192.0	200.4	207.6	214.8
10	22.7	39.1	54.7	75.0	100.8	117.6	133.2	136.4	152.4	166.8	180.6	198.0
15	20.6	32.0	43.6	59.2	80.8	95.6	110.4	113.7	130.4	145.6	161.2	182.4
30	14.3	20.6	27.2	37.0	52.2	63.4	75.4	78.3	92.8	107.4	123.4	147.0
60	10.3	13.1	16.2	21.2	29.7	36.6	44.6	46.7	57.1	68.4	81.7	103.0
120	6.7	8.2	9.9	12.7	17.3	21.2	25.5	26.7	32.5	38.7	46.1	58.0
360	3.2	3.8	4.6	5.7	7.5	8.9	10.6	11.0	13.1	15.3	17.8	21.8
720	1.7	2.1	2.6	3.3	4.4	5.2	6.1	6.3	7.4	8.5	9.8	11.6
1440	1.0	1.3	1.6	2.0	2.5	3.0	3.4	3.5	4.1	4.6	5.2	6.0

Tables 3.1 (a) and (b) are based on extending the records for the Turfgrass Station from 43 years to 49 years and includes the outliers. Tables 3.2 (a) and (b) provide the results of the 3LN analysis without the outliers which exclude the1954 24H, 1968 1H & 2H and the 1982 2H data.

The 3LN analysis can be compared to the Gumbel Extreme Value (GEV) analysis which is provided with the MSC (AES) data. It has been shown by Chow that the Gumbel distribution is essentially a lognormal with constant skewness. In the comparison there is very good agreement for lower frequency events and in general the 3LN analysis generates somewhat higher values for the 50 year and 100 year rainfall volumes for durations greater than 2H.

Table 3.2 (a) Consolidated Rainfall Frequency Analysis (3LN)

Guelph Turfgrass Station	Rainfall Volume (mm)											Outliers removed
	Recurrence Interval in Years											
Time (min)	1.003	1.05	1.25	2	5	10	20	25	50	100	200	500
5	1.22	4.22	6.71	9.41	12.2	13.7	14.8	15.0	16	16.7	17.3	17.9
10	3.78	6.51	9.12	12.5	16.8	19.6	22.2	22.7	25.4	27.8	30.1	33
15	5.16	7.99	10.9	14.8	20.2	23.9	27.6	28.4	32.6	36.4	40.3	45.6
30	7.17	10.3	13.6	18.5	26.1	31.7	37.7	39.2	46.4	53.7	61.7	73.5
60	9.75	12.9	16.2	21.1	28.6	34.3	40.2	41.6	48.7	55.9	63.6	75
120	12.6	16.1	19.8	25	32.6	38.1	43.7	45.0	51.6	57.9	64.6	74.1
360	19.2	23	27.3	33.9	44.9	53.6	63.4	65.9	78.4	91.7	107	131
720	20	25.3	31	39.5	52.6	62.7	73.4	76.0	89.1	102	117	139
1440	23.8	30.7	37.5	46.7	59.3	67.7	75.9	77.7	86.7	94.8	103	114

Table 3.2 (b) Consolidated Rainfall Frequency Analysis (3LN)

Guelph Turfgrass Station	Rainfall Intensity (mm/hr)											Outliers removed
	Recurrence Interval in Years											
Time (min)	1.003	1.05	1.25	2	5	10	20	25	50	100	200	500
5	14.6	50.6	80.5	112.9	146.4	164.4	177.6	180.0	192.0	200.4	207.6	214.8
10	22.7	39.1	54.7	75.0	100.8	117.6	133.2	136.4	152.4	166.8	180.6	198.0
15	20.6	32.0	43.6	59.2	80.8	95.6	110.4	113.7	130.4	145.6	161.2	182.4
30	14.3	20.6	27.2	37.0	52.2	63.4	75.4	78.3	92.8	107.4	123.4	147.0
60	9.8	12.9	16.2	21.1	28.6	34.3	40.2	41.6	48.7	55.9	63.6	75.0
120	6.3	8.1	9.9	12.5	16.3	19.1	21.9	22.5	25.8	29.0	32.3	37.1
360	3.2	3.8	4.6	5.7	7.5	8.9	10.6	11.0	13.1	15.3	17.8	21.8
720	1.7	2.1	2.6	3.3	4.4	5.2	6.1	6.3	7.4	8.5	9.8	11.6
1440	1.0	1.3	1.6	1.9	2.5	2.8	3.2	3.2	3.6	4.0	4.3	4.8

4.0 INTENSITY-DURATION-FREQUENCY CURVES

4.1 IDF Design Curves

The Meteorological Service of Canada (MSC) rainfall station data can be statistically analyzed to produce updated Intensity-Duration-Frequency (IDF) curves. In this report the three parameter lognormal (3LN) distribution was used to derive the intensities. The IDF relationship and curves provide a distribution of maximum rainfall values that can be expected for given durations. The derivation of IDF curves and parameters requires the transformation of raw precipitation intensities for a series of annual maximum values for various durations (e.g. 5, 10, 15 min).The adjustments of these recorded annual extreme values are transformed using statistical relationships. These statistics provide the probability of different rainfall intensities occurring for different durations (5, 10, 15, 30 minutes and 1, 2, 6, 12, 24 hours) and are valid for a specific location that are analyzed. Each IDF curve represents a certain frequency of recurrence or a certain return period expressed in terms of years. They are based on the available period of rainfall records with longer records providing a better statistical fit and representation. There are a number of empirical relationships that are used to derive the IDF curves and synthetic design storms, the most popular being the Keifer and Chu (1957) known as the Chicago Method

$$i = a / (t+b)^{c}, \text{ where}$$

i *= average rainfall intensity (mm/hr or in/hr)*
td *= storm duration (minutes)*
a,b,c *= constants dependent on units used and return frequency*

The method requires selection of parameter r (where 0 < r < 1) which defines the time to peak t_p ,which is a point when the rainfall intensity is a maximum within the selected storm duration td. Typically values **of** $r=t_p/t_d$,, **0.3 to 0.5** (i.e. storm peaks at 30% to 50% of the duration) are used to distribute the rainfall intensities. The values of a, b and c are derived from the statistical rainfall frequency analysis for a particular duration and recurrence or return period that is being used for the design of water resources structures.

The rational method uses a single point on the IDF design curves to obtain an average intensity for a duration that is equal to the time of concentration of the catchment to optimize the peak flow value. Other methods such as the SCS methods generalize the rainfall data taken from the IDF curves and create mass rainfall distributions for various percentiles and regions. These synthetic storm patterns are used in various hydrologic models to generate hydrographs and peak flow rates for various storm recurrences. There are a number of other distributions that can also be used and selected by the water resources modeler.

Updated IDF curves for the City of Guelph were developed using rainfall data collected by Meteorological Services Canada (MSC) Environment Canada formerly AES for the

Guelph Turfgrass Station. Supplemental data from the adjacent Waterloo Airport was not significantly different when compared statistically (Table 1.2). This annual maximum data was used to fill in missing years and to extend the Turfgrass records from 43 years to 49 years. The City of Guelph's current IDF relationships and curves for various return periods were derived from 16 years of records at the Arboretum at the Guelph Agricultural College. These were completed for the City of Guelph by James F. MacLaren consulting engineers in the early 1970's and needed updating.

The empirical relationship that was used to derive the IDF curves and synthetic design storms was that proposed by Keifer and Chu (1957) also known as the Chicago Method in the form of equation previously described.

$$i = a / (t_d + b)^{c}$$, where

i = average rainfall intensity (mm/hr)
t_d = storm duration (minutes)
a,b,c = constants dependent on units used and return frequency

The updated IDFdesign parameters that are being recommended for the City of Guelph are summarized in Table 4.1 for various return periods from one year to 100 year. The rainfall intensities in the Rational Method of design are based on using a storm duration equal to the time of concentration. The following is an example of the equation for the updated IDF relationship for a one year return period for the City of Guelph:

$$i = \frac{316.91}{(t_d + 6.18)^{0.7562}}$$

Table 4.1 Summary of Updated Intensity Duration Frequency (IDF) Parameters for the City of Guelph

	Recurrence Interval in Years						
	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
a	316.91	509.17	835.70	1129.90	1710.72	2499.69	3811.79
b	6.18	2.15	3.84	5.61	9.09	13.33	19.09
c	.756	.764	.799	.818	.851	.883	.925

Note: parameters a & b rounded to two decimal places, c value to 3 decimal places. Based on 49 years of records to 2003 for the Guelph Turfgrass Station

A comparison of the updated IDF curves (49 years of record, 3LN) with those currently being used by the City of Guelph (16 years of record) for a 60 minute duration indicates that the updated IDF curves rainfall intensities are generally lower. The rainfall intensities are respectively 17% and 20% lower for low event storms (2 and 5 year),19% and 16%

lower for mid-range storms (10 and 25 year) and 11.5% and 5.5% lower for less frequent storm (50 and100 year) than those currently being used by the City of Guelph.

Although not detailed in this report, a comparison was also made between statistical methods using the standard Gumbel Extreme Value (GEV) used by MSC and the 3LN method used to derive the parameters in this report. In general, there is good agreement with more frequent storm events (2 to 10 year) and the 3LN will tend to produce higher values 10 to 5% for less frequent storms respectively (50 and 100 year) than the GEV method.

All comparisons were based on using a 60 minute duration and percentages will vary for other durations. This provides some sense of the deviation that can be expected from the statistical model selected. This information will be used to address possible adjustments that could be made when looking at global warming rainfall trends.

A graphical representation of the updated IDF curves being proposed for the City of Guelph will be presented. The parameters were derived from the Consolidated Frequency Analysis 3LN and the least squares regression analysis Miduss Curvefit (Alan A, Smith Inc.). The proposed design curves can be plotted on log-log paper. An example of the updated one year IDF design curve for the City of Guelph is shown in Figure 4.1. Also for comparison Figure 4.2 (a) and (b) shows the updated 2 year curve plotted with the city's current design curve. The rainfall intensities for the current IDF curves were found to be 17% higher than the updated for a one year event and generally about 15% higher for the 5 and 10 year storms.

The updated IDF design curves for the City of Guelph for storm recurrences from 1-year to 100-year including curve fit data and the IDF parameters are shown in Appendix A.

Time (hr)	(min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	4.22	50.6	4.26	51.06
	10	6.52	39.1	6.43	38.61
	15	8.00	32.0	7.87	31.50
	30	10.30	20.6	10.50	21.01
1.00	60	13.10	13.1	13.31	13.31
2.00	120	16.40	8.2	16.34	8.17
3.00	180			18.26	6.09
4.00	240			19.71	4.93
6.00	360	22.80	3.8	21.90	3.65
12.00	720	25.20	2.1	26.09	2.17
18.00	1080			28.87	1.60
24.00	1440	31.20	1.3	31.00	1.29

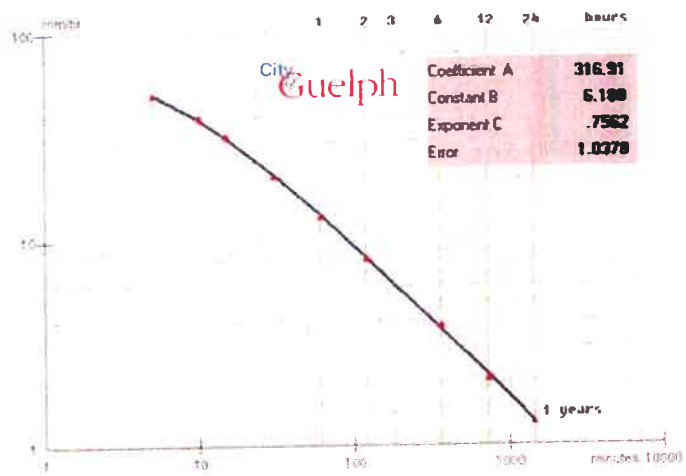

Figure 4.1 Intensity Duration Frequency Updated Design Curve 1-Year (3LN)

Current 2 year

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5.00	9.12	109.44	9.11	109.36
	10.00	13.52	81.12	13.52	81.10
	15.00	16.32	65.28	16.32	65.27
	30.00	21.22	42.44	21.22	42.44
1.00	60.00	26.14	26.14	26.15	26.15
2.00	120.00	31.18	15.59	31.20	15.60
3.00	180.00	.00	.00	34.28	11.43
4.00	240.00	.00	.00	36.56	9.14
6.00	360.00	39.90	6.65	39.92	6.65
12.00	720.00	46.20	3.85	46.18	3.85
18.00	1080.0	.00	.00	50.21	2.79
24.00	1440.0	53.28	2.22	53.25	2.22

Updated 2 year

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5.00	9.41	112.9	9.45	113.39
	10.00	12.50	75.0	12.60	75.62
	15.00	14.80	59.2	14.53	58.11
	30.00	18.50	37.0	17.98	35.96
1.00	60.00	21.20	21.2	21.73	21.73
2.00	120.00	25.40	12.7	25.95	12.97
3.00	180.00		.00	28.68	9.56
4.00	240.00		.00	30.77	7.69
6.00	360.00	34.20	5.7	33.94	5.66
12.00	720.00	39.60	3.3	40.07	3.34
18.00	1080.0		.00	44.13	2.45
24.00	1440.0	48.00	2.0	47.25	1.97

Figure 4.2 (a) Comparison of Current City 2 Year IDF Design Curve with Updated 2 Year Curves

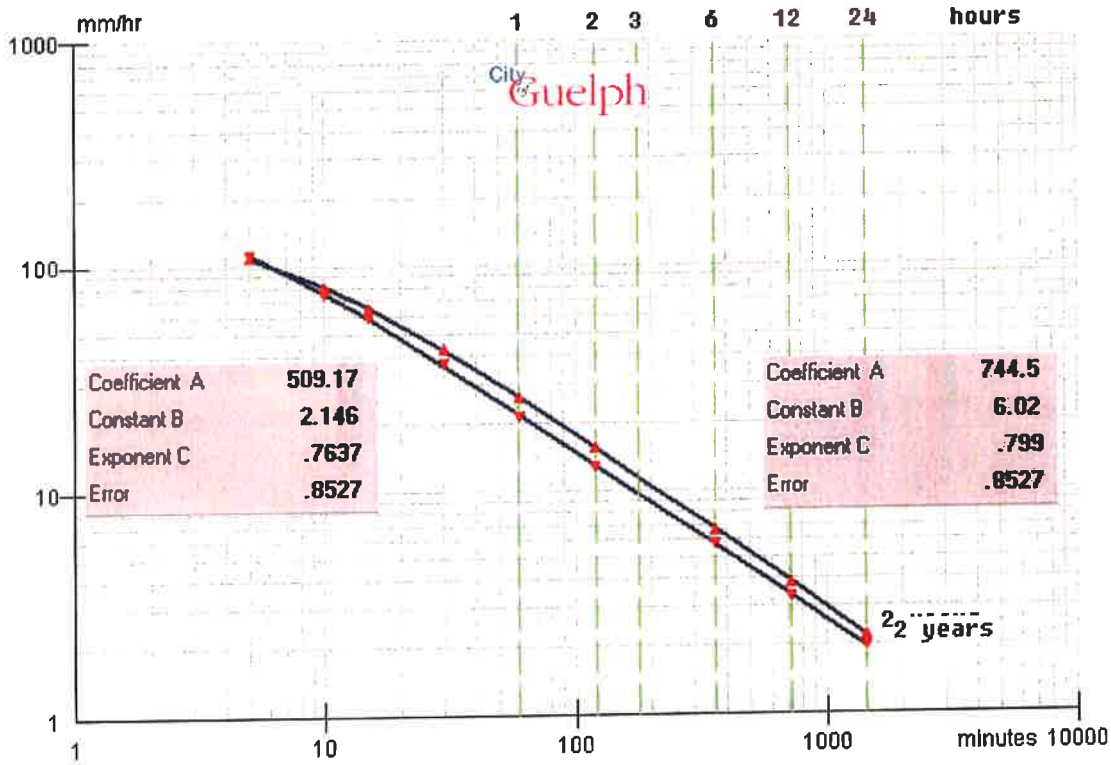

Figure 4.2 (b) Comparison of City Current 2 Year IDF Design Curve with Updated 2 Year

The statistical analysis was based on the recording rain gauge at the Turfgrass Station for 42 years of records and 7 years of missing records derived from the Waterloo Airport.

The updated IDF design curves being recommended for the City of Guelph for all storm recurrences are shown in Figure 4.3.The IDF parameters derived from the frequency analysis and least squares fit are also summarized in the previous Table 4.1.

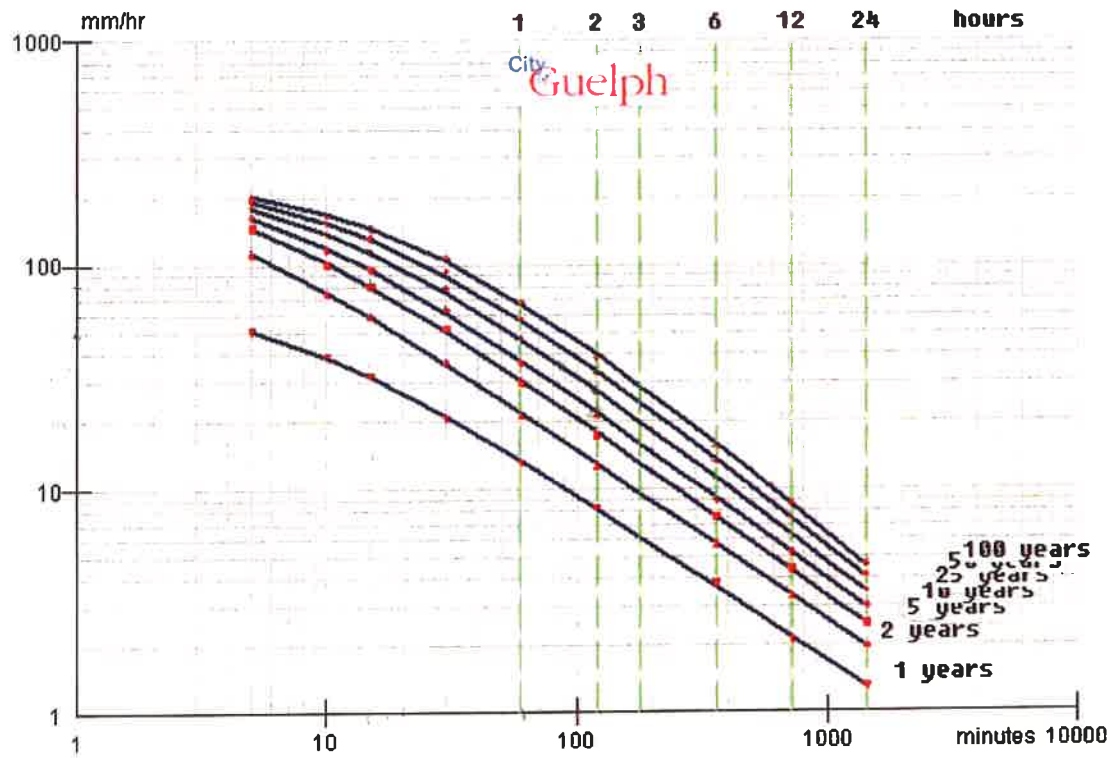

Figure 4.3 Updated IDF Design Curves for the City of Guelph For a various Storm Recurrences Updated to 2003

The Miduss Curvefit program also calculates the total rainfall volume from the CFA intensities used to derive the IDF parameters for various recurrences and duration. These durations are typically used in hydrologic modeling depending on response time of the catchment. Typically for a storm duration 2 to 3 times the catchment response is used and higher values (6 to 12 hours) for the design of stormwater management ponds including sediment and erosion control. A storm duration of 3H for a 1 year event would typically be used for the evaluation and sizing of facilities for stormwater quality improvements. The rainfall volumes can also be used in for derivation of the distribution of synthetic storms, Chicago, SCS or Huff storms.

The annual maximum rainfall volumes are summarized for 1H, 2H, 6H, 2H and 24H durations for various recurrences in Table 4.2 The table also shows both the values from the 3LN analysis and from the AES Gumbel analysis for comparison. A third comparison of rainfall volume can also be made with the Rainfall Frequency Atlas which uses the Gumbel series, however, only a 6 hour duration is available from the atlas. The point rainfall volume (X_T) can be derived knowing the mean volume (X) and adding this to a frequency factor (K) for various recurrences, this value times the standard deviation (S). The equation takes the form $X_T = X + KS$. The parameters for the City of Guelph for a 6 hour duration have been estimated from the rainfall atlas contours. A mean rainfall volume of **X=42mm** and **S=19mm** were used for the city. These will be used as general guide for comparing the results of the 3LN frequency analysis and GEV. The 6 hour maximum rainfall volumes (mm) from the atlas are highlighted in blue.

Table 4.2 Summary of Rainfall Volumes (mm) for various Storm Durations and Recurrences Comparing Statistical Methods

Rainfall Volumes (mm)														
Recurrence in years														
Duration	1		2		5		10		25		50		100	
Hours	3LN	GEV	3LN	GEV	3LN	GEV	3LN	GEV	3LN	GEV	3LN	GEV	3LN	GEV
1H	13.3	na	21.7	22.3	30.2	32.3	36.9	39.0	46.5	47.3	56.4	53.6	67.0	59.3
2H	16.4	na	25.9	26.4	35.6	36.8	43.54	43.7	54.6	52.4	66.5	58.8	79.5	65.2
6H	21.9	na	33.9	35.1	45.1	46.0	54.4	53.2	66.9	62.3	80.4	69.1	94.4	75.8
12H	26.1	na	40.1	40.0	52.1	52.8	62.2	61.3	75.0	72.1	88.6	80.0	101.8	87.9
24H	31.0	na	47.3	47.1	60.0	61.7	70.8	71.3	83.6	83.5	96.9	92.5	108.5	101.5
6H Atlas	na		39		55		67		81		91		102	

There is generally good agreement between the statistical methods for lower events up to and including the 25 year recurrence. The 3LN rainfall volumes are somewhat higher than the GEV for higher event storms (50 years and 100 years). The 3LN 6H and 12H rainfall volumes for the 50 and 100 year is respectively about 15 to 25 % higher than for the GEV distribution. The GEV rainfall volumes were obtained directly from the statistical analysis of AES records for the Turfgrass Station. The 3LN rainfall values are derived from the IDF curvefit parameters and also shown in Figures A-1 to A-6.

The rainfall volumes from this analysis can be compared to those derived from the city's current IDF relationships for various recurrences and storm durations. This is illustrated in Figure 4.3. In general the new rainfall volumes or depths are lower than current by approximately 10 to 15%. This trend changes for the longer durations approximately at the 25 year recurrence and up to the 100 year, where the new volumes are somewhat

Table

higher than the city's IDF curves. A comparison of the current and new rainfall volumes is shown in ~~Figure~~ 4.3. The rainfall volumes for the new IDF curves are somewhat higher than the current city curves by 5 to 7% for the 50 and 100 year storm for 12 and 24 hour durations. The statistical analysis for the new IDF curves included the extreme values or outliers.

Table 4.3 Summary of Rainfall Volumes (mm) for various Storm Durations and Recurrences Comparing Current City IDF and New

Rainfall Volumes (mm)														
Recurrence in years														
Duration	1		2		5		10		25		50		100	
Hours	Curr	New	Curr	New	Curr	New	Curr	New	Curr	New	Curr	New	Curr	New
.5H	10.5	na	21.21	17.98	30.46	25.07	37.29	30.40	44.85	37.73	51.25	44.87	57.64	52.05
1H	13.31	na	26.14	21.74	37.60	30.20	45.72	36.88	55.63	46.46	63.63	56.39	71.69	66.98
2H	16.34	na	31.19	25.95	43.89	35.57	52.73	43.36	64.20	54.57	73.24	66.53	82.35	79.48
3H	18.26	na	34.28	28.69	47.26	38.91	56.29	47.25	68.27	59.15	77.65	71.89	87.08	85.57
6H	21.90	na	39.92	33.95	52.74	45.11	61.75	54.28	74.06	66.94	83.66	80.43	93.25	94.34
12H	26.09	na	46.19	40.08	58.12	52.08	66.80	61.97	78.92	74.99	88.43	88.63	97.84	101.77
24H	31.00	na	53.28	47.26	63.63	60.00	71.73	70.52	83.32	83.57	92.53	96.91	101.55	108.52

The rainfall volumes for the new curves may be used for simulation modeling should the city wish to retain their current IDF parameters for Rational Method design of storm sewers.

4.2 Regulatory Storm

Hurricane Hazel (October 14 and 15,1954) or the Regional Storm is a historical rainfall event that affected the Greater Toronto area and is considered the extreme rainfall event characteristic to Southwestern Ontario. The storm is used for the delineation of regulatory floodlines by the Conservation Authorities in Ontario for watersheds within the affected zone (Central and Western Ontario). The storm created considerable flooding damage and was preceded by low intensity rainfall (73mm in the first 36hours) that saturated the ground depleting potential infiltration. It has been estimated that nearly 90% of the rainfall was converted to runoff. The main part of the storm (36th to 48th hours) produced an additional 212mm of rainfall in12 hours with approximately 50% of this total falling within the last 3 hours of the storm. When applying the 12 hour part of the storm, wet antecedent moisture conditions should be used to simulate the 73mm of initial rainfall.

The rainfall volume of 212 mm that fell over last 12 hours is approximately two times greater than a 100-year storm event for long-duration (12 and 24hour) maximum annual precipitation recorded at the Guelph Turfgrass station. The largest hourly intensities for the last 3hours of this storm were 53, 38, 13 mm/hr (112 mm of rainfall). For rainfall lasting 3 hours, the rainfall volume of 112mm is in general terms approximately equal to a 250-year rainfall event if interpolated (for 3hours) from our dataset. The 6H values from the Climatic Atlas which characterizes more Regional values tends towards the higher values for this two recurrences which leans to accepting the higher 3LN values.

5.0 CLIMATE CHANGE AND DESIGN IMPACTS

As part of the development of design storms, a brief literature review was conducted to assess the potential increase in rainfall due to climate change. Although there is no consensus in the literature regarding whether climate change has already resulted in higher rainfall or whether climate change will, in fact, even result in higher rainfall at all, there is some support among researchers for a 15% increase in rainfall depth in Canada (Hengeveld, 2000, Ciarmatiori et al, 2000, Watt et al, 2003).

Faced with a potential increase in 15% in rainfall depth, the following recommendations are made.

a. Storm Sewer Design

The only implication on storm sewer design is that the new IDF curves may result in a smaller level of service than originally intended.

For example, since a 5-year storm is roughly 15-20% larger than a 2-year storm, climate change may effectively decrease the level of service of some pipes from 5 years to 2 years.

Similarly, climate change may effectively decrease the level of service of a pipe designed for a 2 year storm to something slightly less than 2 years. However, since the pipes typically have some reserve capacity based on the requirement to use standard pipe sizes, and since there is ultimately no problem with a slightly lower level of service, the recommendation is to make no allowance in storm sewer design for the potential effects of global warming. In addition the City has indicated that they will likely retain the current IDF curves which will are generally 15% higher than the new and in this way account for the potential global warming increases. The level of surcharging and the connectivity of private drains would need to be looked at to determine impacts and develop management schemes to reduce the impact. In some cases capacity upgrades may be necessary to convey the increased flow rate. In general the differences may also be within the tolerances of the model used to design the facility.

b. Stormwater Management Facility - Water Quality Design

The sizing of permanent pool volumes and extended detention volumes for water quality design of stormwater management facilities, are based on Table 3.1 of the MOE Stormwater Management Practices Planning and Design Manual. Since a design storm is not used when applying this Table, the change in design rainfall due to global warming may not change how the ponds are designed. More rainfall may cause runoff to bypass the facilities slightly more often, but the long-term operation may not be significantly impaired. Since the only impact is a small potential increase in uncontrolled runoff due to increased bypass, it is not recommended to change the water quality design until such time as the MOE revises Table 3.1.

c. Conveyance Design and Flood Control

Quantifying potential impacts on flood control due to utilization of larger design storms is made complex because of the use of different storms for pre-development, existing, short term, and long term situations. Redrawing flood elevations and revising hydrologic calculations for existing conditions is an extremely complex task. As a result, the preferred approach is not to change the design storm, but to make *over-control of flow* an objective where appropriate to address potential for climate change. It is recommended that all stormwater management facilities target a release rate of 85% of pre-development rates for the 100-year storm to offset potential impacts of global warming on flooding potential. This would have to be reviewed with respect to new and existing IDF curves that are adopted by the City. Retaining the current IDF curves would make allowances for the global warming. Existing facilities reduced outflow rate, storage capabilities and any hydraulic surcharging would have to be reviewed.

6.0 BENEFITS AND SHORTFALLS

The city has indicated that they would prefer to retain the existing IDF curves and higher values. ETC is providing our comments on this approach. This would allow make an appropriate allowance for global warming trends and simplifies overall design for new stormwater systems and also for the redesign or replacement of older infrastructure. The benefits and shortfalls of retaining the current IDF curves and rainfall volumes can be summarized as follows.

6.1 Benefits

- Rational Method of sewer design for new facilities and replacement of aging infrastructure will be consistent
- Provides a margin of safety for subjective selection of various design parameters for hydrologic modeling
- Provides a margin of safety for the design of stormwater management facilities
- Provides reserve capacity for global warming trends indicating increasing rainfall volumes and intensity of storm events
- Previous and new watershed and sub-watershed hydrologic study, Master Plans, hydraulic studies findings remain valid

6.2 Shortfalls

- Computer modeling simulations using mass curve or Chicago distribution used for verification, validation and comparison of monitored flows not representative
- Additional capital costs for new infrastructure or replacement and oversizing of stormwater detention facilities for less frequent events

7.0 SUMMARY AND CONCLUSIONS

The characterization of precipitation frequency is an important component in hydrologic investigations and engineering design. MSC has collected annual maximum precipitation data at various locations within and near the City of Guelph. The longest period of records (43 years) is within the city and the adjacent stations provide some sense of the spatial distribution for comparison in assessing the frequency of annual maximum precipitation. The MSC data set identifies periods of missing records and also extreme events that have occurred. The data compiled for this study indicate that maximum precipitation values for 3 particular years generally were much greater than those for the other years because of extremely large rainfall amounts associated with storms in 1954 (24H),1968 (1&2H) and 1982 (2H) (,refer to data set table A-1 in Appendix A. The presence of these unusually large values not consistent with trends (outliers) will tend to influence statistical results. To determine the effects of large events storms, the annual maximum values were computed for two data sets, the full set and one which excluded the extreme values.

A comparison of rainfall values with and without ouliers was completed. It can bee seen that the differences in rainfall volume or intensity appears in the duration series that were removed. The 1H and 2H data (1968), the 2H (1982), the 2 &4H 1954 and the 24H (1954) were deleted from the data set to review differences. It's recommended that the City that the results with outliers in should be used to derive the IDF curves.

The city has indicated that they will be retaining current IDF Curves. ETC recommended that the IDF curve figure be annotated to show the review of available (49 years, to 2002) records has been completed and are generally lower in value. The city are retaining current higher curves to account for the potential global warming trends. The City should continue to update their IDF curves and suggest that this be completed in 5 years.

Respectfully Submitted,

Earth Tech Canada

Joseph P. Falcone, M. Eng., P. Eng
Senior Project Manager

Appendix A

Rainfall Analysis Data and IDF Curves

Table A-1 Modified AES Rainfall Records, Guelph Turfgrass which includes Missing Data

ANNUAL MAXIMUM RAINFALL DATASET
TURFGRASS STATION, CITY OF GUELPH — **1954-2003**

STATION	Year	5M	10M	15M	30M	1H	2H	6H	12H	24H
6143069	1954	6.3	12.2	17.3	22.6	23.9	25.1	50.3	83.1	[illegible]
6143069	1955	12.7	15.0	15.7	18.3	21.6	26.9	28.7	39.1	46.5
6143069	1956	8.9	12.2	13.5	17.8	19.8	30.5	37.1	57.7	66.3
6143069	1957	6.9	9.1	9.9	12.7	16.5	19.0	30.5	32.5	51.3
6143069	1958	11.4	14.7	16.0	17.8	19.6	21.1	35.6	53.8	58.7
6143069	1959	7.4	8.9	10.4	12.7	15.0	18.5	26.2	27.2	27.2
6143069	1960			15.0	19.6	19.8	19.8	28.2	32.8	44.7
6143069	1961	7.9	12.4	13.2	16.8	20.1	31.5	37.8	37.8	50.0
6143069	1962	10.9	11.4	14.2	15.5	22.4	27.7	31.7	33.3	54.4
6143069	1963	9.4	13.2	15.5	18.5	19.8	22.1	27.4	31.7	34.8
6143069	1964	11.4	16.8	22.1	32.3	43.7	43.7	45.0	45.0	51.6
6143069	1965	11.9	15.0	17.3	17.8	17.8	19.0	30.0	35.8	45.5
6143069	1966	3.6	4.8	6.9	10.2	15.0	27.9	45.5	45.7	55.1
6143069	1967	6.9	9.1	11.2	14.7	23.1	33.0	43.9	45.2	45.2
6143069	1968	12.7	19.0	25.7	40.9	[illegible]	[illegible]	79.5	79.5	79.5
6143069	1969	3.6	6.1	8.1	9.1	11.9	21.1	46.2	46.2	46.2
6143069	1970	9.1	15.0	18.3	26.9	30.7	31.7	33.5	33.8	34.3
6143069	1971	12.7	25.4	30.5	39.4	39.4	42.2	60.7	61.0	61.0
6143069	1972	7.9	10.9	12.7	15.5	20.8	22.4	27.2	30.2	49.3
6143069	1973	9.4	9.9	11.7	18.3	22.1	27.2	31.2	32.3	33.3
6149387	1974	7.6	7.9	8.9	12.4	14.0	15.7	30.5	41.7	47.5
6149387	1975	11.7	15.5	17.3	22.9	26.9	50.5	82.3	91.2	93.7
6143069	1976	5.3	7.4	10.2	12.2	13.7	21.1	40.1	65.8	70.6
6143069	1977	11.2	16.8	21.6	22.4	22.4	22.4	22.6	22.6	38.6
6143069	1978	10.1	12.9	13.2	13.4	15.4	17.7	22.9	26.6	35.7
6143069	1979	11.7	12.0	12.0	14.7	18.7	25.7	37.2	38.4	42.5
6143069	1980	12.7	16.1	17.2	17.4	18.0	21.6	33.3	43.1	48.6
6143069	1981	5.9	10.1	13.7	17.2	17.8	21.2	27.1	35.5	49.6
6143069	1982	10.1	20.2	28.7	46.3	55.8	[illegible]	69.5	69.7	69.8
6143069	1983	9.1	10.9	12.2	13.6	13.8	17.8	28.8	34.8	35.0
6143069	1984	13.0	17.7	21.7	23.7	23.9	24.7	26.7	26.7	41.6
6143069	1985	11.6	13.0	19.4	30.5	30.5	30.5	40.6	43.7	46.2
6143069	1986	15.7	19.7	22.5	29.2	29.8	34.0	50.6	62.5	63.8
6143069	1987	8.6	10.5	10.5	13.4	18.5	23.2	34.7	43.4	53.7
6143069	1988	10.1	17.4	24.2	32.3	33.2	51.5	52.9	52.9	53.4
6143069	1989	3.9	6.8	7.2	7.4	9.8	12.7	21.0	28.6	37.4
6143069	1990	11.4	16.7	19.7	23.2	30.3	33.5	39.6	41.1	41.6
6143069	1991	8.4	10.4	11.1	16.1	21.7	30.9	45.6	57.0	62.6

Table A-1 Cont'd

ANNUAL MAXIMUM RAINFALL DATASET **1954-2003**
TURFGRASS STATION, CITY OF GUELPH

6149387	1992	6.8	8.5	12.3	17.7	23.7	28.3	29.9	45.1	58.0
6149387	1993	10.8	12.0	16.8	23.0	25.6	26.6	37.0	37.8	38.5
6149387	1994	7.9	9.0	12.3	18.1	18.5	22.2	34.4	40.0	42.6
6149387	1995	15.9	21.0	27.8	42.6	44.8	47.4	47.8	47.8	47.8
6149387	1996	5.2	10.0	12.0	14.8	15.3	17.1	34.1	50.2	57.7
6143069	1997	13.6	15.0	15.6			28.2	28.4	28.4	29.2
6143069	1998	7.8	10.2	12.2	18.0	24.4	28.4	29.6	29.6	54.0
6143069	1999	12.2	23.6	26.4	28.0	29.6	30.6	38.8	43.0	48.2
6143069	2000	8.2	14.6	17.6	23.2	26.8	27.6	31.2	36.2	41.6
6143069	2001	5.4	9.2	10.6	17.2	19.6	22.2	29.4	36.0	36.6
6143069	2002	15.0	21.4	24.8	24.8	24.8	24.8	31.4	31.4	43.8
6143069	2003	5.6	8.6	10.4	12.8	17.8	20.2	21.0	25.8	27.4

- Data from Waterloo/Wellington A
- No data available from adjacent stations
- Outlier identified by CFA

DATASET REPRODUCED FROM AES RECORDS AND MISSING RECORDS SUPPLEMENTED FROM WATERLOO AIRPORT STATION

City of Guelph

Intensity Duration Frequency Design Curves

(Based on 49 years of rainfall records at Turfgrass Station, Guelph)
(1954-2003)

Time (hr)	(min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	4.22	50.6	4.26	51.06
	10	6.52	39.1	6.43	38.61
	15	8.00	32.0	7.87	31.50
	30	10.30	20.6	10.50	21.01
1.00	60	13.10	13.1	13.31	13.31
2.00	120	16.40	8.2	16.34	8.17
3.00	180			18.26	6.09
4.00	240			19.71	4.93
6.00	360	22.80	3.8	21.90	3.65
12.00	720	25.20	2.1	26.09	2.17
18.00	1080			28.87	1.60
24.00	1440	31.20	1.3	31.00	1.29

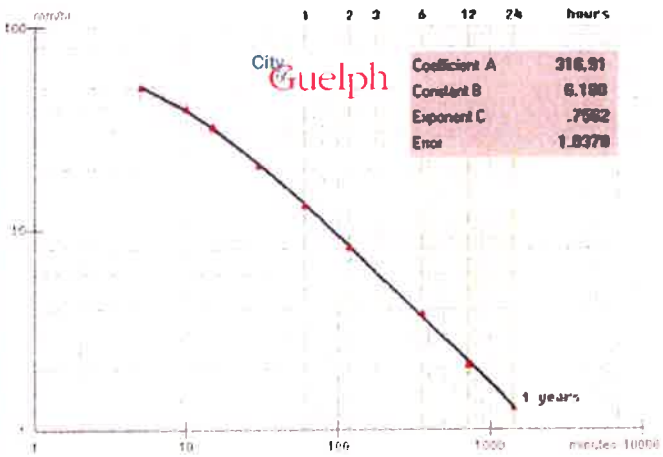

Figure A-1 IDF Design Curve for 1-Year Recurrence (3LN)

Time (hr)	(min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5.00	9.41	112.92	9.46	113.55
	10.00	12.50	75.00	12.61	75.63
	15.00	14.80	59.20	14.52	58.10
	30.00	18.50	37.00	17.97	35.94
1.00	60.00	21.20	21.20	21.72	21.72
2.00	120.00	25.40	12.70	25.93	12.97
3.00	180.00	.00	.00	28.67	9.56
4.00	240.00	.00	.00	30.76	7.69
6.00	360.00	34.20	5.70	33.94	5.66
12.00	720.00	39.60	3.30	40.08	3.34
18.00	1080.0	.00	.00	44.15	2.45
24.00	1440.0	48.00	2.00	47.28	1.97

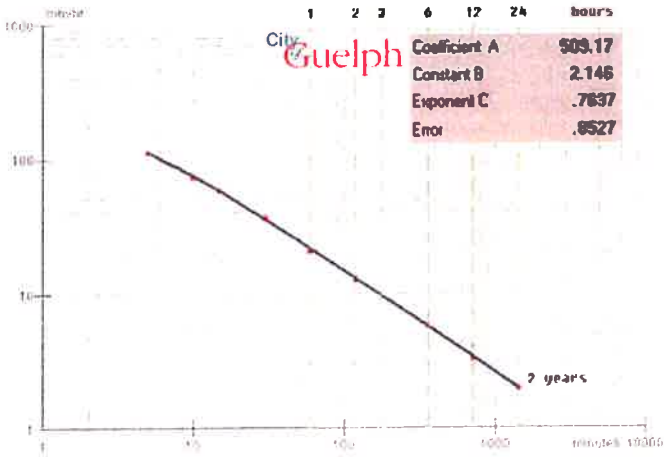

Figure A-2 IDF Design Curve for 2-Year Recurrence (3LN)

City of Guelph

Intensity Duration Frequency Design Curves

(Based on 49 years of rainfall records at Turfgrass Station, Guelph)
(1954-2003)

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5.00	12.20	146.4	12.21	146.52
	10.00	16.80	100.80	17.07	102.42
	15.00	20.20	80.80	20.01	80.05
	30.00	26.10	52.2	25.07	50.14
1.00	60.00	29.70	29.7	30.20	30.20
2.00	120.00	34.60	17.3	35.57	17.79
3.00	180.00		.00	38.91	12.97
4.00	240.00		.00	41.40	10.35
6.00	360.00	45.00	7.50	45.11	7.52
12.00	720.00	52.80	4.4	52.08	4.34
18.00	1080.0		.00	56.58	3.14
24.00	1440.0	60.00	2.5	60.00	2.50

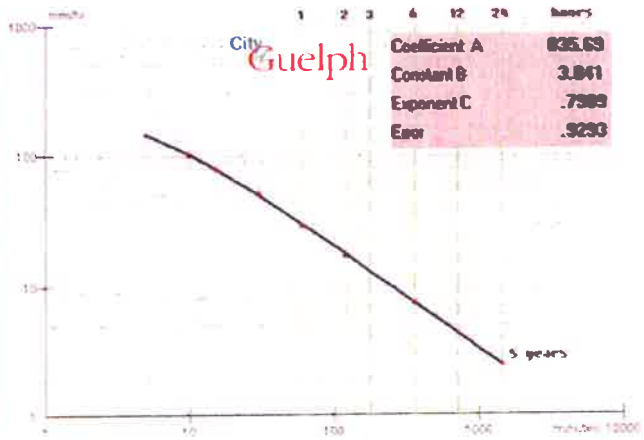

Figure A-3 IDF Design Curve for 5- Year Recurrence (3LN)

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	13.70	164.4	13.65	163.80
	10	19.60	117.6	19.91	119.48
	15	23.90	95.6	23.80	95.21
	30	31.70	63.4	30.44	60.89
1.00	60	36.60	36.6	36.95	36.95
2.00	120	42.40	21.2	43.46	21.73
3.00	180			47.37	15.79
4.00	240			50.24	12.56
6.00	360	53.40	8.9	54.43	9.07
12.00	720	62.40	5.2	62.16	5.18
18.00	1080			67.08	3.73
24.00	1440	72.00	3.0	70.77	2.95

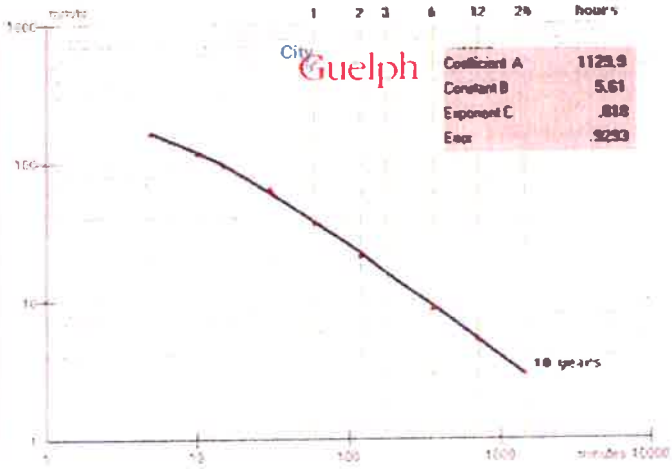

Figure A-4 IDF Design Curve for 10Year Recurrence (3LN)

City of Guelph

Intensity Duration Frequency Design Curves

(Based on 49 years of rainfall records at Turfgrass Station, Guelph)
(1954-2003)

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	15.00	180.0	14.99	179.85
	10	22.73	136.4	23.15	138.88
	15	28.42	113.7	28.48	113.93
	30	39.15	78.3	37.73	75.45
1.00	60	46.70	46.7	46.46	46.46
2.00	120	53.40	26.7	54.58	27.29
3.00	180			59.15	19.72
4.00	240			62.37	15.59
6.00	360	66.00	11.0	66.94	11.16
12.00	720	75.60	6.3	74.99	6.25
18.00	1080			79.93	4.44
24.00	1440	84.00	3.5	83.57	3.48

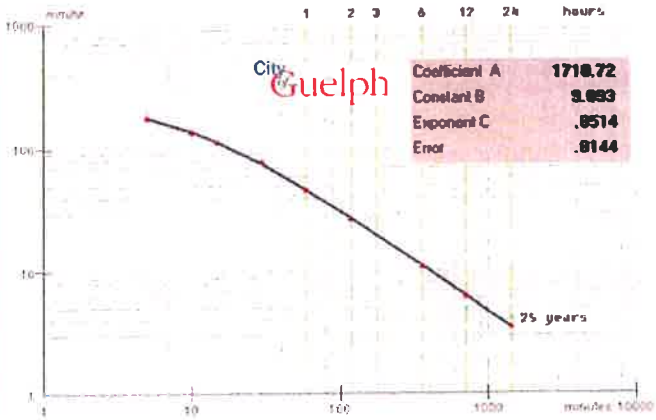

Figure A-5 IDF Design Curve for 25-year Recurrence (3LN)

Time (hr)	Time (min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	16.00	192.0	15.98	191.77
	10	25.40	152.4	25.83	154.99
	15	32.60	130.4	32.64	130.57
	30	46.40	92.8	44.87	89.73
1.00	60	57.10	57.1	56.39	56.39
2.00	120	65.00	32.5	66.53	33.27
3.00	180			71.89	23.96
4.00	240			75.50	18.88
6.00	360	78.60	13.1	80.43	13.40
12.00	720	88.80	7.4	88.63	7.39
18.00	1080			93.44	5.19
24.00	1440	98.40	4.1	96.91	4.04

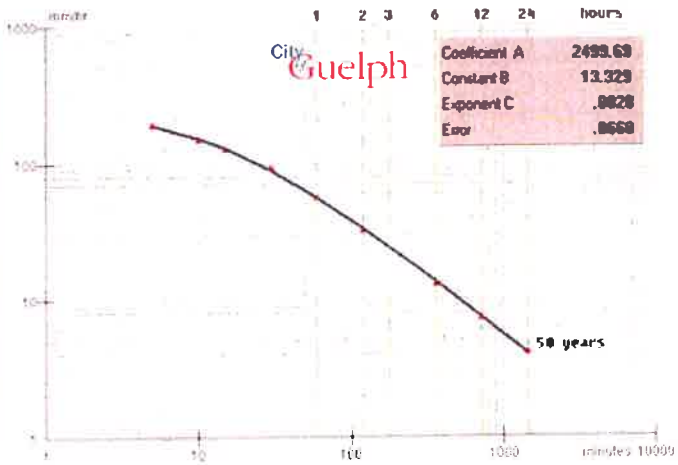

Figure A-6 IDF Design Curve for 50-year Recurrence (3LN)

City of Guelph

Intensity Duration Frequency Design Curves

(Based on 49 years of rainfall records at Turfgrass Station, Guelph)
(1954-2003)

Time (hr)	(min)	Depth (mm)	Intensity (mm/hr)	Computed Depth	Computed Intensity
	5	16.70	200.4	16.76	201.07
	10	27.80	166.8	28.15	168.89
	15	36.40	145.6	36.46	145.85
	30	53.70	107.4	52.05	104.11
1.00	60	68.40	68.4	66.98	66.98
2.00	120	77.40	38.7	79.48	39.74
3.00	180		.00	85.57	28.52
4.00	240		.00	89.43	22.36
6.00	360	91.80	15.3	94.35	15.72
12.00	720	102.00	8.5	101.78	8.48
18.00	1080		.00	105.77	5.88
24.00	1440	110.40	4.6	108.53	4.52

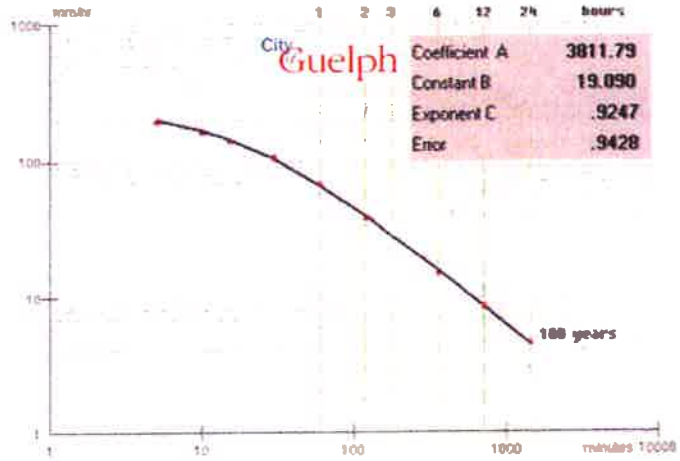

Figure A-7 IDF Design Curve for 100-year Recurrence (3LN)

Appendix B

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