RAINFALL DISTRIBUTION IN THE CITY OF ST. JOHN'S: TEMPORAL DISTRIBUTION, SPATIAL VARIATION, FREQUENCY ANALYSIS, AND TROPICAL STORM GABRIELLE

DAVID WADDEN

Your file Votre référence
ISBN: 0-612-84047-6
Our file Notre référence
ISBN: 0-612-84047-6

RAINFALL DISTRIBUTION IN THE CITY OF ST. JOHN'S:

Temporal Distribution, Spatial Variation, Frequency Analysis, and Tropical Storm Gabrielle

By

©David Wadden

A Thesis Submitted to the

School of Graduate Studies

in Partial Fulfilment of the

Requirements for the Degree of

Master of Engineering

FACULTY OF ENGINEERING AND APPLIED SCIENCE

MEMORIAL UNIVERSITY OF NEWFOUNDLAND

AUGUST, 2002

ST. JOHN'S NEWFOUNDLAND

ABSTRACT

The evaluation of rainfall distribution throughout the City of St. John's, Newfoundland, was performed: to investigate the temporal distribution of rainfall across the City; to compare the spatial variations of concurrent rainfall events at the City's three rain gage stations, to determine the most appropriate probability distribution for the frequency analysis of rainfall; to update the IDF curves for the City of St. John's; and to analyze the extreme rainfall event of September 19, 2001, which resulted from Tropical Storm Gabrielle.

The temporal distribution of rainfall in the City of St. John's was examined resulting in the determination of a family of probability curves (10% through 90%), which related percent storm rainfall to percent storm duration, for both single station rain gages and the Network Mean. The method utilized was similar to **Huff (1967)** except that storms were not grouped by the quartile which had the most rainfall accumulation but instead all storms were analyzed as a single group. The analysis indicated that the temporal distribution for the Network Mean was similar to the results obtained for each of the single station rain gages and that it was appropriate to represent the time distribution of rainfall, across the City of St. John's, by a Network Mean distribution that was applicable for all storm durations. The proposed Network Mean distribution was then compared to the AES Mean, Huff, and SCS temporal distributions. It was concluded that the 20% Network Mean distribution was the most appropriate for the City of St. John's in all cases except the 12-hour event where the AES Mean distribution should be used.

The spatial variation of rainfall was analyzed using concurrent rainfall events, from the City's Windsor Lake, Ruby Line, and Blackler Avenue rain gage stations. The analyses indicated that the spatial variation of rainfall fluctuated across the City on a storm by storm basis and that, on average, the rainfall depths were greater in the Northeast at Windsor Lake. It was also shown that the data from the AES rain gage at the St. John's Airport could be combined with the data from Windsor Lake to provide an extended database for IDF analysis.

The frequency analysis of annual extremes for the combined database of Windsor Lake and St. John's Airport was performed. The results indicated that the previously assumed AES Extreme Value Type 1 (EV1) distribution was no longer appropriate for the frequency analysis of annual rainfall extrema and that the Lognormal (LN) distribution was the best fit. Updated IDF curves were prepared, based on the combined database and the LN distribution, and it was found that the new curves, on average, gave slightly higher rainfall intensities for various return periods and durations.

The rainfall event of September 19, 2001, resulting from Tropical Storm Gabrielle, was also examined. The temporal distribution of rainfall across the City for this event was uniform and best represented by the AES 12 hour distribution. The rainfall generated by Tropical Storm Gabrielle varied across the City with a maximum difference of 61.9mm between stations. The frequency analysis of this event indicated that the 2-hour, 6-hour, 12-hour, and 24-hour rainfall maxima all exceeded the 100 year return period.

ACKNOWLEDGMENTS

The author wishes to express his appreciation and gratitude to Dr. Leonard Lye for his suggestions, expertise, and guidance throughout the course of this work. In addition, the author would like to recognize Mr. Arthur Cheeseman and Mr. Walter Mills for their interest, comments, and continuous support in the research.

The author expresses his gratitude to the staff of the City of St. John's Municipal Government and to Council for their support throughout the duration of the research.

Finally, the author wishes to express his unending thanks to his wife, Jacqueline Lee McGrory, for her patience and endurance throughout the 7-year period of the research.

CONTENTS

List of Tables

LIST OF FIGURES

ABBREVIATIONS

$1000m^3$	=	1000 cubic metres
AD	=	Anderson-Darling
AES	=	Atmospheric Environment Service
Bp	=	Beta-p probability distribution
Bk	=	Beta-k probability distribution
CDA	=	Canadian Department of Agriculture
C.I.	=	Confidence intervals
cm	=	Centimetres
cms	=	Cubic Metres per Second
CN	=	Curve Number
EV1	=	Extreme Value Type 1 probability distribution
$F(x)$	=	Specified cumulative probability distribution
$F_n(x)$	=	Empirical cumulative probability distribution
GG	=	Generalized Gamma probability distribution
GNO	=	Generalized Normal probability distribution
GP	=	Generalized Pareto probability distribution
HEC-HMS	=	Hydrologic Engineering Centre - Hydrologic Modeling System
i	=	rank
IDF	=	Intensity-Duration-Frequency
KS	=	Kolomorgov-Smirnov
km	=	kilometres
km/h	=	kilometres per hour
L-moment	=	Linear moment
LG	=	Logistic probability distribution
LLG	=	Loglogistic probability distribution
LN	=	Lognormal probability distribution
LN3	=	3-Parameter Lognormal probability distribution

LP3	=	LogPearson Type 3 probability distribution
LS	=	Least Squares Estimators
MLE	=	Maximum Likelihood Estimators
m	=	metres
mm	=	millimetres
mm/hr	=	millimetres per hour
MUN	=	Memorial University of Newfoundland
MW	=	Mann-Whitney
μ	=	location
N	=	Normal Probability Distribution
n	=	Sample Size
N/A	=	Not Available
p, q	=	Sample sizes for MW test
p_i	=	Probability for rank i
P3	=	Pearson Type 3 probability distribution
PPCC	=	Probability Plot Correlation Coefficient
Q	=	Flow
Q-Q	=	Quartile-Quartile
R	=	Revfeim probability distribution
σ	=	scale
SCS	=	Soil Conservation Service
SWMM	=	Storm Water Management Model
TN	=	Transnormal probability distribution
TP40	=	Technical Publication No. 40
U_i	=	Order Statistic
USACE	=	United States Army Corps of Engineers
V	=	Volume
WAK	=	Wakeby probability distribution
WMO	=	World Meteorological Organization

$\psi(t)$	=	Anderson-Darling weight function
Z_i	=	Reduced variate

CHAPTER 1

INTRODUCTION

1.0 Background

The purpose of this thesis is: to investigate the temporal distribution of rainfall across the City of St. John's; to compare the spatial variations of concurrent rainfall events at the City's three rain gage stations, to determine the most appropriate probability distribution for the Intensity-Duration-Frequency (IDF) analysis of rainfall; to update the IDF curves for the City of St. John's; and to analyze the extreme rainfall event of September 19, 2001, resulting from Tropical Storm Gabrielle.

The City of St. John's is located on the Avalon Peninsula at latitude 47° 37' and longitude 52° 44' on the eastern side of the island of Newfoundland, Canada, as shown in **Figure 1.0** below.

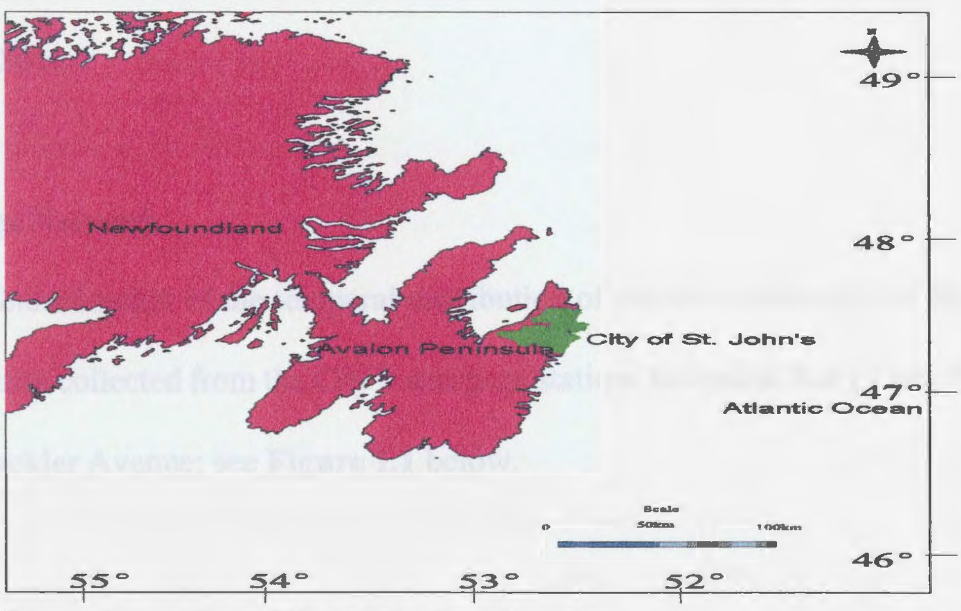


Figure 1.0: City of St. John's Location Map

Much like other mid-latitude areas, Newfoundland has considerable seasonality. During Winter months low pressure systems off the south of Greenland cause prevailing winds from the west to blow over Eastern Newfoundland. Winter storms track from the South moving in a North-Easterly direction across the Avalon Peninsula. Winter storms diminish in the Spring but easterly air flow patterns and offshore icebergs/ice packs create cool, foggy weather in the St. John's area. In the summer subtropical air masses strengthen and generate prevailing South-Westerly winds. Storms continue to track from the South but tend to be weaker given the reduction in air mass from the subtropics. In the Fall, low pressures begin to strengthen in the North and the subtropic influence diminishes. Storms from the South continue to travel across the Avalon Peninsula occasionally of hurricane or tropical storm magnitude **(Robertson et al, 1993)**. The City has a population of 99,181, based on the 2001 Census, and encompasses an area of approximately 478 km^2. The greater part of the City of St. John's lies below elevation **190** m; however, some hills to the south reach elevations higher than **230** m.

1.1 Rain Gage Network

The determination of the temporal distribution of rainfall for the City of St. John's are based on data collected from the City's rain gage stations located at Ruby Line, Windsor Lake, and Blackler Avenue; see **Figure 1.1** below.

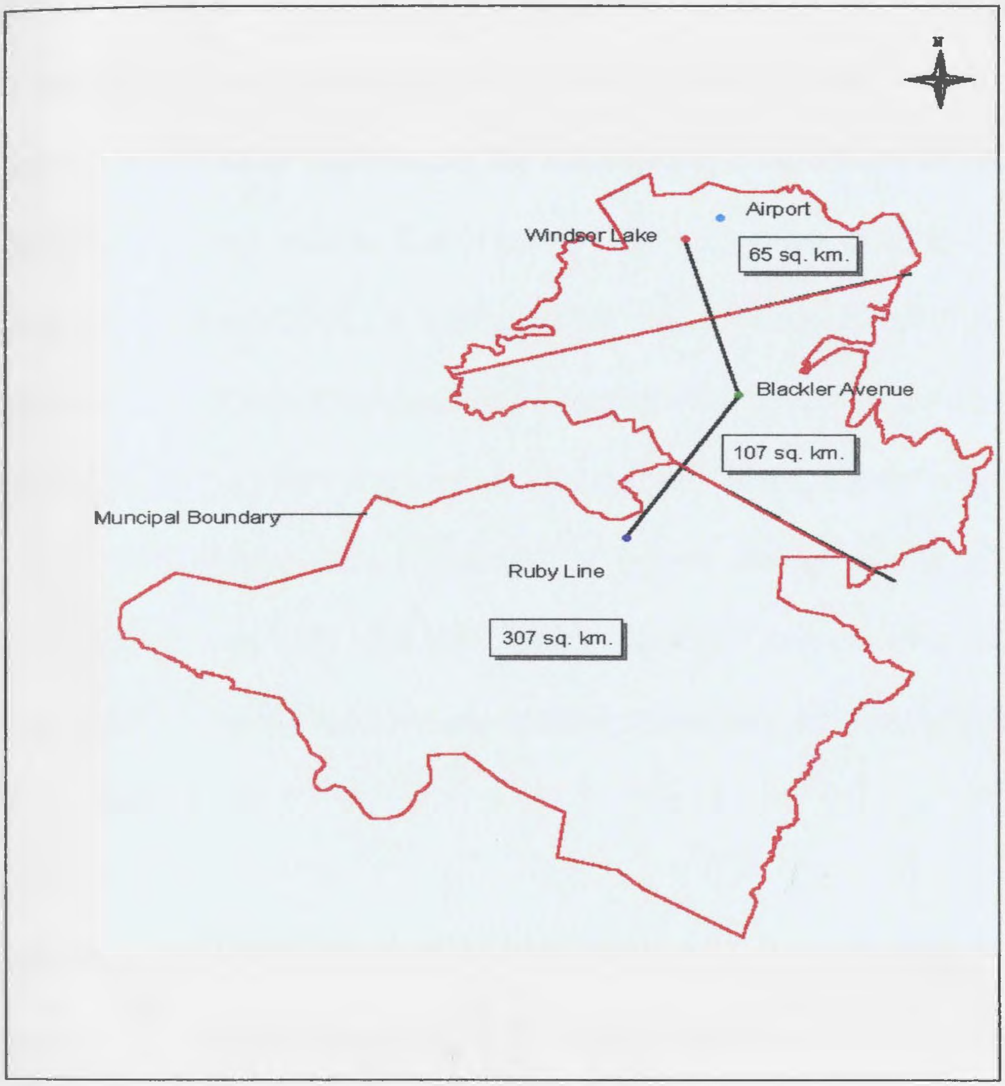


Figure 1.1: City of St. John's Rain Gage Network

The Ruby Line station, located in the Southwest area of the City, has approximately 4.5 years of data between 1997 and 2001. The City of St. John's commenced its continuous rainfall monitoring program in March 1997 with the installation of a Met One tipping bucket rain gage at this location. The gage has a sensitivity of 0.1mm and data is recorded and archived for each minute of rainfall. In December 1998 a Met One tipping bucket rain gage was installed at Windsor Lake in the northern sector of the City. The Windsor Lake station is located approximately 1.6-km southwest of the Atmospheric Environment Service (AES) operated St. John's Airport station. The Windsor Lake station has three years of data collected between 1999 and 2001. A tipping bucket rain gage was installed at Blackler Avenue in December 1999 which has continued to operate to the present collecting two years of data to date. Each of the City's rain gages is insulated and heated, during winter months, allowing for a 12-month operation. Electronic dataloggers totalize rainfall in 1-minute increments on a continuous basis with 100% battery backup in case of power failure. The gages are calibrated on a yearly basis and are checked periodically with a standard rain gage to verify daily totals.

1.2 Rainfall Data

Up until 1997, rainfall monitoring in the City had been done on a continuous basis by AES at the St. John's Airport Station (see **Figure 1.1**). AES collected continuous rainfall data at the Airport up until the end of 1996 using a tipping bucket rain gage with data recorded and archived in 5-minute intervals. Since 1997 AES have been collecting rainfall data with a Fisher and Porter rain gage and data has been archived every six hours. The City of St. John's Engineering Department had some concerns when AES reduced the rainfall recording interval from five minutes to six hours, the sparser database having an obvious impact on the City's ability to accurately model rainfall / runoff events using computer models. The City made a decision in late 1996 to commence its own rainfall monitoring program, on a continuous basis, using tipping bucket rain gages linked to City computers through telemetry.

One of the objectives of operating its own rainfall monitoring program was the eventual updating of the IDF curves that the City currently used for engineering design. The present IDF curves were developed in 1990 from annual rainfall maxima at the St. John's Airport recorded in 1949 and 1961 to 1990. These curves had not been updated in 12 years and concerns had been raised about their applicability throughout the entire 478 km^2 area of the City. Annual extreme data were provided to the City by AES for 1991 to 1996 and the annual maxima were calculated. Given the close proximity of the Windsor Lake station to the Airport station, approximately 1.6-km, the statistical plausibility of combining the annual maxima data from the two locations was considered in order to increase the number of years of the Windsor Lake database for IDF analysis. **Hogg (1982)** indicated that AES assumed an Extreme Value Type 1 (EV1) distribution for annual rainfall maxima in determining the Airport IDF curves. It was decided to incorporate the verification of this assumption into the research.

This thesis uses the rainfall data from Ruby Line, Windsor Lake, and Blackler Avenue to analyze the temporal and spatial distributions of rainfall across the City of St. John's. The Airport data was used in combination with the Windsor Lake data to evaluate the appropriate probability distribution for annual maxima and for updating IDF curves. Other rain gages located at St. John's West (CDA) and Memorial University (MUN) were not used in the analysis because the data was not concurrent with the City's data or was unavailable.

1.3 Objectives

The objectives of this thesis are the following:

(1) the analysis of the temporal rainfall characteristics and spatial variability for the City of St. John's utilizing the tipping bucket rainfall data from Ruby Line, Windsor Lake, and Blackler Avenue;

(2) the comparison of daily rainfall depths at the City's Windsor Lake gage with the AES rain gage at St. John's Airport in order to determine if the two data sets can be combined.

(3) the frequency analysis of annual rainfall maxima using a combined database from the St. John's Airport and Windsor Lake;

(4) the evaluation of the September 19, 2001, rainfall event which resulted from Tropical Storm Gabrielle.

1.4 Thesis Outline

This chapter discussed the background and rationale for the thesis. Chapter 2 investigates the temporal distribution of rainfall, and Chapter 3 analyzes the spatial variability of rainfall. The frequency analysis of rainfall is investigated in Chapter 4. Tropical Storm Gabrielle is discussed and interpreted in Chapter 5. Chapter 6 presents the conclusions and recommendations from the research.

CHAPTER 2

Temporal Distribution of Rainfall

2.0 Background

An understanding of the temporal distribution of rainfall throughout the City of St. John's is necessary for the design of waterways, bridges, major culverts, storm sewers and flood plains. Several researchers have investigated the temporal distribution of rainfall in other areas of North America; some are described below.

Huff (1967) considered an 11-year rainfall database (1955-1966) over 1000-km^2 area. He studied rural Illinois where the topography ranged from 200m to 280m above mean sea level and a large percentage of the significant rainfall events were thunderstorms. From the Illinois rainfall data, Huff found that temporal distributions could best be expressed as a family of probability curves which related the percentage of storm rainfall to the percentage of storm duration. Storms were grouped by the quartile which had the most rainfall accumulation and these groupings became known as the "Huff curves".

SCS (1975) developed four 24-hour rainfall distributions (Types I, II, III, and IA) to represent various regions of the United States. The distributions were dimensionless plots of time, in hours, versus cumulative percent of the 24-hour rainfall. For any given location within the United States, the hydrologist could determine the 24-hour total rainfall, based on local IDF curves, and subsequently distribute the rainfall in time using the appropriate SCS rainfall distribution. To represent the different geographic areas of the United States SCS proposed: Type I and IA distributions for the Pacific maritime climate which have wet winters and dry summers; Type III for the Gulf of Mexico and Atlantic coastal areas which are subject to long duration tropical storms; and Type II for the remainder of the United States. The storms differ from each other in terms of intensity and time of peak rainfall. The Type 1A event is the least intense of the distributions having its peak occur in the 8th hour of the storm with a magnitude approximately equal to 10% of the total rainfall accumulation. The Type I event receives a peak of 25 % of the total rainfall accumulation in the 10th hour of the storm. Type II and Type III distributions are the most intense rainfall events having their peaks occur in the 12th hour with accumulations of 45% and 40%, respectively, of the total rainfall.

Hogg (1980) analyzed 25 years of data (1951-1975) from 35 Canadian stations extracting 900 1-hour storms and 1050 12-hour storms. Hogg conducted a similar analysis to **Huff's (1967)** method with a slight modification in that only 1-hour and 12-hour rainfall events were investigated and time distributions were not grouped according to quartile. Hogg found that the 1-hour and 12-hour time distributions for the British Columbia coast were more similar to the Maritime Provinces than either the Prairies or Southern Ontario. Hogg attributed this to the similar marine-type climates of the British Columbia Coast and the Eastern Canadian Coast which have more pronounced topographic variations and higher mean annual precipitation than either Southern Ontario or the Prairies which have continental climates, relatively flat topography, and lower mean annual precipitation.

Hogg (1982) noted that computer modeling with storm water simulation programs was sensitive to the manner in which rainfall was distributed in time and that calculated peak flows were significantly affected by the selected rainfall temporal distribution. He considered 46 Canadian rain gage stations, with a 25-year database (1951-1975), where 1,100 1-hour and 1,250 12-hour storms were examined. Hogg proposed an exponential time distribution with the distribution peak coinciding with the mean time of peak rainfall and the remainder of the rainfall, on either side of the peak, being fitted exponentially. The new distribution was called the "AES Mean" distribution. He developed a simple rainfall/runoff model to compare other well known temporal distributions (i.e., Huff and SCS) with the AES Mean curves and determined that the AES Mean distribution provided the best results for 1-hour and 12-hour storms. **Hogg's (1982)** research demonstrated that runoff was maximized by temporal distributions with the largest slope. This is characteristic of rainfall events which have a large portion of the precipitation concentrated over a short period of time. Hogg concluded that site specific time distributions were more appropriate producing lower root mean square errors. However, Hogg added that it was not very practical to have separate time distributions for every locality and determined that the AES Mean distribution and the Huff 3rd Quartile distribution were the most appropriate temporal distributions for Atlantic Canada. The City of St. John's presently uses the AES Mean 1-hour and 12-hour temporal distributions, proposed by Hogg, for engineering design.

Loukas and Quick (1996) considered a mountainous 180-km^2 watershed in coastal

British Colombia analyzing six stations (1983-1990) located 100m to 1,800m above mean sea level. They found that the time distribution of storms was not affected by elevation, storm type, storm duration, or storm rainfall depth. Loukas and Quick concluded that one set of time probability curves, based on the average of all storms at all elevations, was appropriate.

Peyron et al (2002) proposed an optimum 1-hour temporal distribution for Southern Quebec through the analysis of 199 rainfall events between 1943 and 1994. Their research was compared to several popular temporal distributions, including the 1-hour AES Mean distribution, by computer modeling different urban drainage basins using the Environmental Protection Agency's Storm Water Management Model (SWMM). The 1-hour AES Mean distribution was found to underestimate runoff volume by as much as 30% where as Peyron's proposed distribution provided accurate estimates of both runoff and volume.

In analyzing network and site specific rainfall time distributions for the City of St. John's, this thesis developed a variation of **Huff's (1967)** method whereby the temporal distribution was described by a family of probability curves calculated from a single group of events instead of storms grouped by quartile. The Network Mean temporal distribution was based on rainfall events from the Ruby Line, Windsor Lake, and Blackler Avenue rain gage stations that had an average total accumulation greater than or equal to 12mm. A rainfall event was defined as a storm that was separated by 6-hours or more from preceding and succeeding rainfall.

2.1 Network Mean Temporal Distribution

The evaluation of the Network Mean temporal distribution for the City of St. John's was performed utilizing the average time distributions of 77 rainfall events, recorded concurrently at Windsor Lake, Blackler Avenue and Ruby Line, between 1999 and 2001 (see **Appendix A**). The duration of the storms analyzed ranged from 2 hours to 72 hours and the average total rainfall ranged between 12mm and 111.1mm. Adopting **Huff's (1967)** methodology, the average time distribution for each rainfall event was made dimensionless by expressing storm rainfall and storm duration as cumulative percentages to allow direct comparison. For each rainfall event, the percent cumulative rainfall that occurred in the first 10% of the total event duration was ranked in descending order and probability of exceedances were calculated for 10% through to 90%. This procedure was repeated for the 20% through to 90% durations yielding a family of probability curves to represent the Network Mean temporal distribution. **Figure 2.0** below indicates the percent cumulative rainfall for the various percent storm durations and probability of exceedances (10% to 90%), and **Table 2.0** tabulates the information. The first entry in **Table 2.0** is interpreted as 10% of the storm events in the City of St. John's deposited at least 13% of the total storm rainfall in the 10% duration of the event. Similarly, 90% of the events deposited 0.5% or less of the storm rainfall in the 10% duration of the event. The temporal distributions are expressed as probabilities because the distribution can vary from storm to storm.

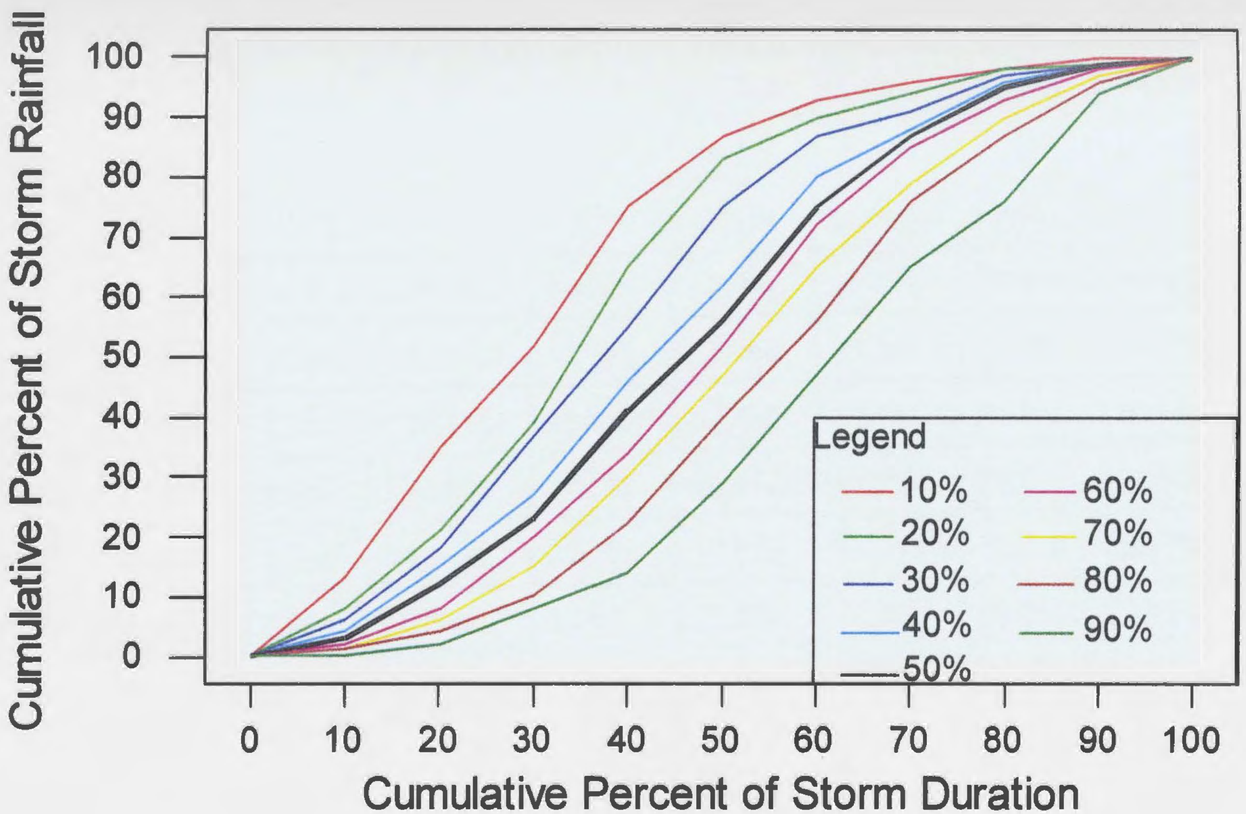


Figure 2.0: Network Mean Temporal Distribution Probability Curves

Table 2.0: Percent Cumulative Rainfall - Network Mean Temporal Distribution											
	Percent Storm Duration										
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Probability of Exceedance	**10%**	13.0%	35.3%	51.8%	75.4%	87.0%	92.9%	96.4%	99.6%	99.6%	100.0%
	20%	8.1%	21.4%	38.7%	64.5%	83.4%	89.8%	94.3%	97.8%	99.3%	100.0%
	30%	5.5%	17.7%	36.6%	55.4%	74.7%	86.6%	91.4%	96.9%	99.1%	100.0%
	40%	4.0%	14.7%	27.5%	46.3%	62.2%	80.0%	88.4%	95.9%	98.9%	100.0%
	50%	2.8%	11.9%	22.6%	41.3%	55.9%	75.5%	86.6%	94.6%	98.6%	100.0%
	60%	2.2%	8.2%	20.1%	33.8%	52.4%	71.7%	84.8%	93.2%	98.3%	100.0%
	70%	1.5%	5.6%	14.8%	30.0%	46.7%	64.9%	79.5%	89.9%	97.3%	100.0%
	80%	1.0%	4.3%	10.5%	22.3%	39.5%	56.4%	76.3%	86.7%	96.5%	100.0%
	90%	0.5%	2.5%	7.6%	13.9%	28.9%	46.7%	65.0%	76.1%	94.2%	100.0%

The 20% Network Mean temporal distribution, for example, would be that denoted in the second row of **Table 2.0**.The physical meaning of this distribution is that there is a 20% probability that the 20% Network Mean time distribution of rainfall could be exceeded for any of the storm durations between 10% and 90%. The family of probability distribution curves, shown in **Figure 2.0**, allows the user to select the curve most applicable for the intended application. **Huff (1967)** indicated that the median (50%) time distribution was the most useful statistic but added that the other extreme probabilities could maximize runoff. For example, the 20% Network Mean temporal distribution has the steepest slope and, based on **Hogg's (1982)** research, this distribution would be expected to maximize runoff.

This thesis differs from **Huff's (1967)** work in that time distribution probability curves are not classified by the quartile of the storm having the most rainfall accumulation. This research investigated classifying the probability curves by triads, quartiles, and pentiles and found that there was no advantage to that approach because rainfall events of a given duration were found in all classes. The grouping of time distribution probability curves by triads involved classifying events as 1st, 2nd, or 3rd triad storms depending on if the majority of rainfall accumulation fell within the 0%-33%, 34%-66%, or 67%-100% durations, respectively. Classification by quartiles or pentiles would similarly see time distribution probability curves grouped by quarters or fifths, respectively. The grouping of time distributions by storm duration was also investigated and it was concluded that time distributions noted in short duration storms were also observed in long duration events rendering this type of grouping impractical. This rationale is supported by **Hogg's (1982)** research whereby there is little difference between the AES Mean 1-hour and 12-hour time distributions based on the St. John's Airport data. **Loukas and Quick (1996)** noted that Huff's primary reason for classification by quartiles was due to the nonuniform nature of thunderstorm rainfall events, whereas Loukas and Quick's research dealt with rainfall along Coastal British Columbia where most precipitation is produced by frontal systems, which have low to medium intensities and long durations. **Hogg (1980)** has indicated that the time distribution of rainfall for Atlantic Canada is similar to British Columbia.

2.2 Site Specific Temporal Distributions

The purpose of analyzing the individual rain gage station temporal distributions was to demonstrate that the Network Mean time distribution was representative of all rain gage stations operated by the City of St. John's and that site specific temporal distributions were unnecessary. This was accomplished by establishing site specific temporal distributions for Ruby Line, Windsor Lake, and Blackler Avenue, and comparing each to the Network Mean distribution.

2.2.1 Ruby Line Station Temporal Distribution

The Ruby Line station temporal distributions were generated from 145 rainfall events between 1997 and 2001 (see **Appendix B**). The duration of the storms ranged from 2-hours to 74-hours and the total storm rainfall had a spread of 12mm to 128.4mm. **Appendix C** tabulates the percent cumulative rainfall for the various percent storm durations and probability of exceedances (10% to 90%) and this information is plotted below in **Figure 2.1.** The probability curves in **Figure 2.1** are visually similar to those in the Network Mean temporal distributions (**Figure 2.0**). The most notable differences are: the Network Mean 20% and 30% probability curves which peak earlier than Ruby Line; the Ruby Line 40% and 90% probability curves which peak before the Network Mean distributions; and the 50%, or median, probability curves which are practically identical. A statistical comparison is carried out in Section 2.3.

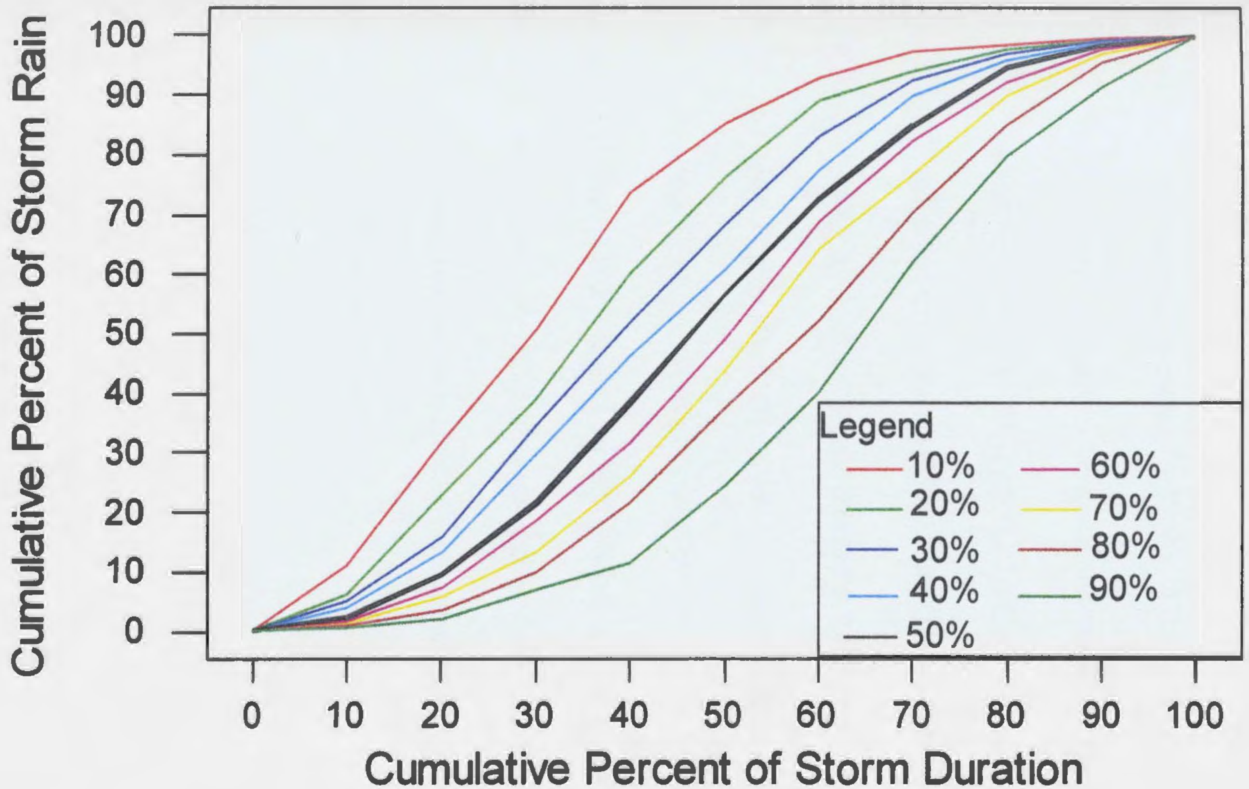


Figure 2.1: Ruby Line Temporal Distribution Probability Curves

2.2.2 Windsor Lake Station Temporal Distribution

For the Windsor Lake station time distribution, 88 rainfall events between 1999 and 2001 (see **Appendix D**) were selected. The duration of the storms ranged from 1-hour to 103-hours and the total storm rainfall ranged between 12mm and 119.7mm. The percent cumulative rainfall for the various percent storm durations were tabulated in **Appendix E** for probability of exceedances (10% to 90%) and this information is graphically displayed below in **Figure 2.2.** Visually there were some significant differences between Windsor Lake and the Network Mean temporal distributions (**Figure 2.0**). The Network Mean probability curves appeared to peak much sooner than the Windsor Lake curves. In particular, the Network Mean 30% probability curve was almost identical to the Ruby Line 20% probability curve. The exceptions were the 10% and 90% probability curves which appeared visually similar. The Kolmogorov-Smirnov (KS) two-sample test is used in Section 2.3 to ascertain whether or not the Network Mean and Windsor Lake temporal distributions were statistically similar for probabilities 10% through 90%.

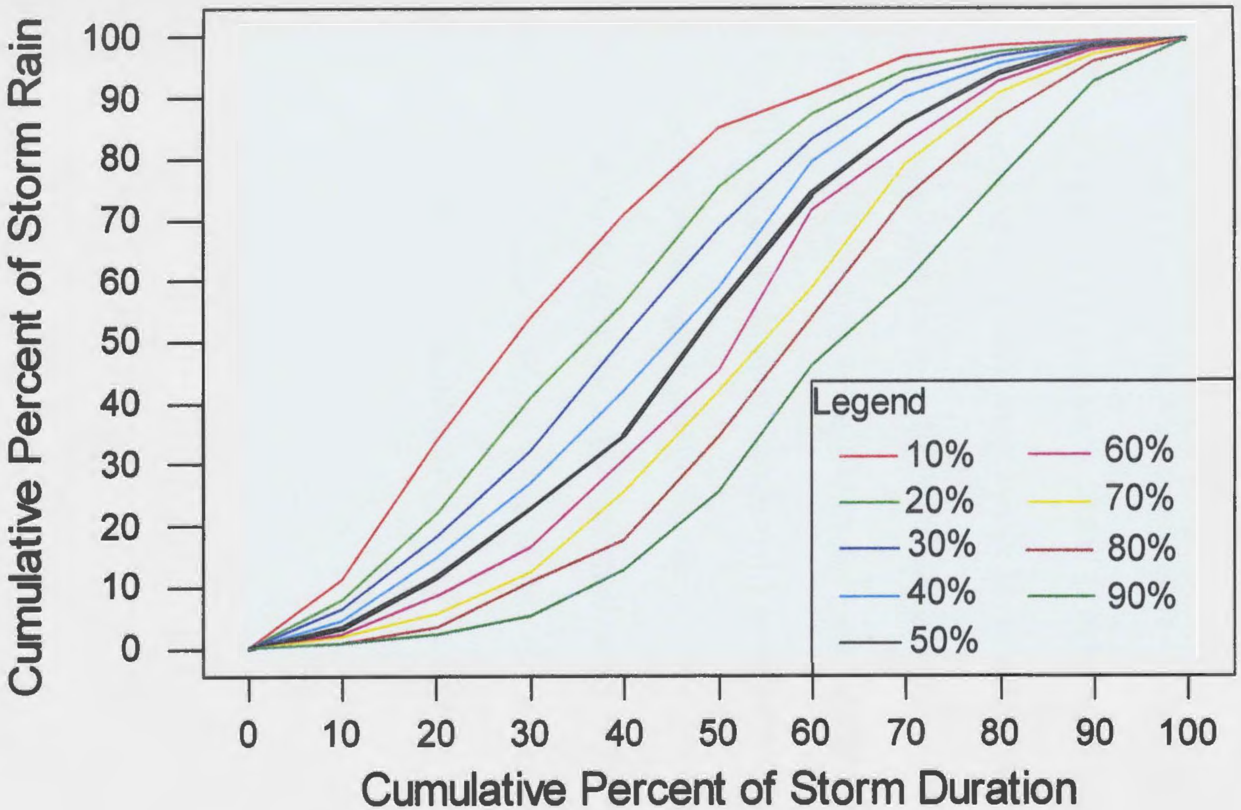


Figure 2.2: Windsor Lake Temporal Distribution Probability Curves

2.2.3 Blackler Avenue Station Temporal Distribution

The temporal distributions for Blackler Avenue were assembled using 51 rainfall events between 2000 and 2001 (see **Appendix F**) from that station. The duration of the storms ranged from 2-hours to 37-hours and the total storm rainfall had a dispersion of 12mm to 54.9mm. **Appendix G** lists the percent cumulative rainfall for the various percent storm durations and probability of exceedances (10% to 90%) which are plotted in **Figure 2.3** below. When compared visually with the Network Mean temporal distributions (**Figure 2.0**), Blackler Avenue appeared to vary the most significantly compared to the other individual sites. For probabilities 10% through 90%, the peak rainfall for the Network Mean distributions precedes the Blackler Avenue distributions. Most notable are the 20% and 90% probability curves for the Network Mean which precede Blackler Avenue by as much as 10% of the storms duration. For example, for a 10-hour rainfall event the 90% Network Mean temporal distribution could peak one hour prior to that calculated by the 90% Blackler Avenue distribution. The statistical significance of this, if any, is determined in Section 2.3.

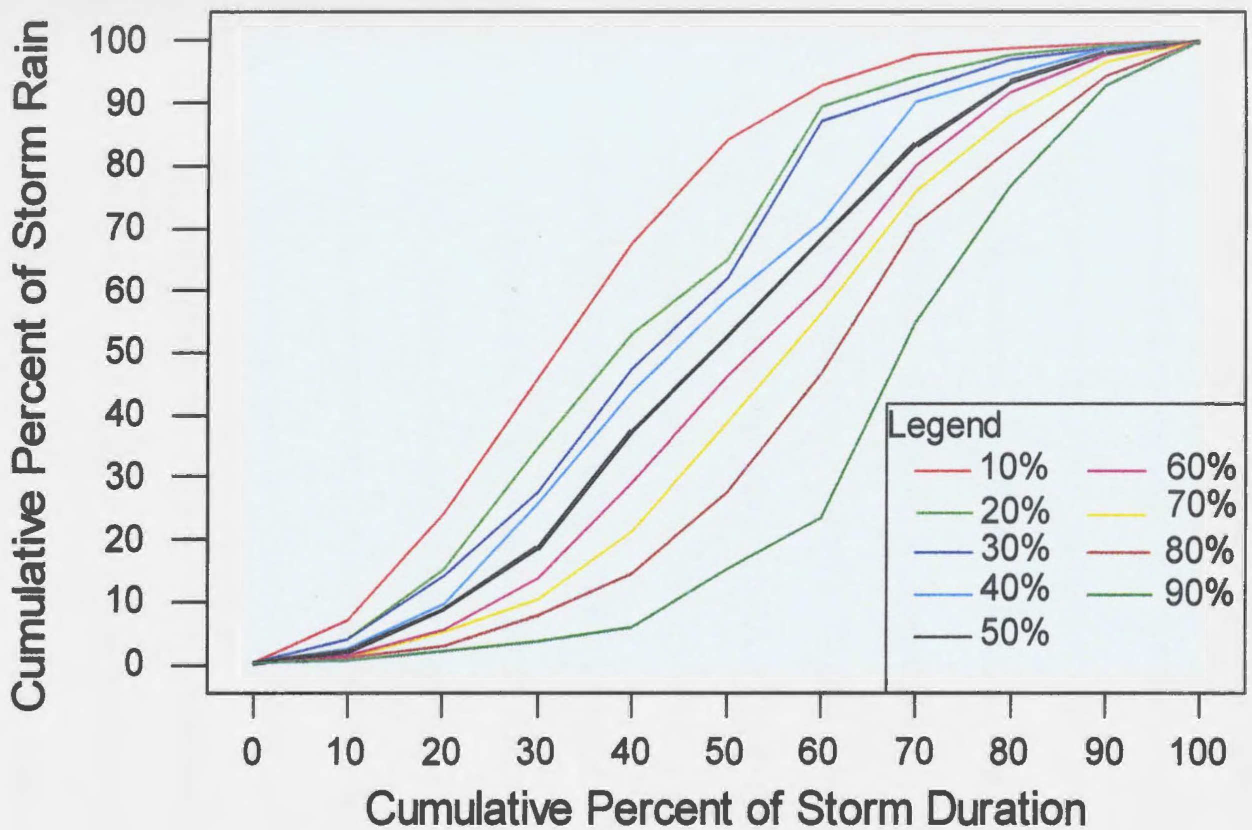


Figure 2.3: Blackler Avenue Temporal Distribution Probability Curves

2.3 Comparison of Network Mean and Site Specific Temporal Distributions

Figure 2.4 below illustrates a comparison of the 10%, 50%, and 90% probability curves from each of the distributions in Section 2.1 and 2.2. The 10% and 50% probability curves appear to be very similar for each distribution. The 90% probability curve for Blackler Avenue seems to deviate somewhat from the other curves and this anomaly may due to the short record at the Blackler Avenue station. The Kolmogorov-Smirnov (KS) two-sample test **(Afifi and Azen, 1979)**, which tests for significant differences between two independent cumulative frequency distributions, was used to statistically compare the temporal distributions. The KS test confirmed (see **Appendix H**) that there were no significant differences at the 5% level between the Network Mean and site specific temporal distributions, for the various probability levels 10% through 90%, and it was concluded that time distribution of rainfall across the City of St. John's could best be represented by a Network Mean temporal distribution. **Loukas and Quick (1996)** arrived at a similar conclusion for their study in British Colombia where they determined that one set of probability curves, based on the average of all storms at all elevations, was appropriate for their 180-km^2 study area. The Network Mean temporal distribution is compared to the AES Mean, Huff, and SCS temporal distributions in the following sections to determine which distributions are appropriate for the St. John's area. The rationale for selecting a given temporal distribution is based on its relevance to local climatic conditions and its ability to maximize runoff.

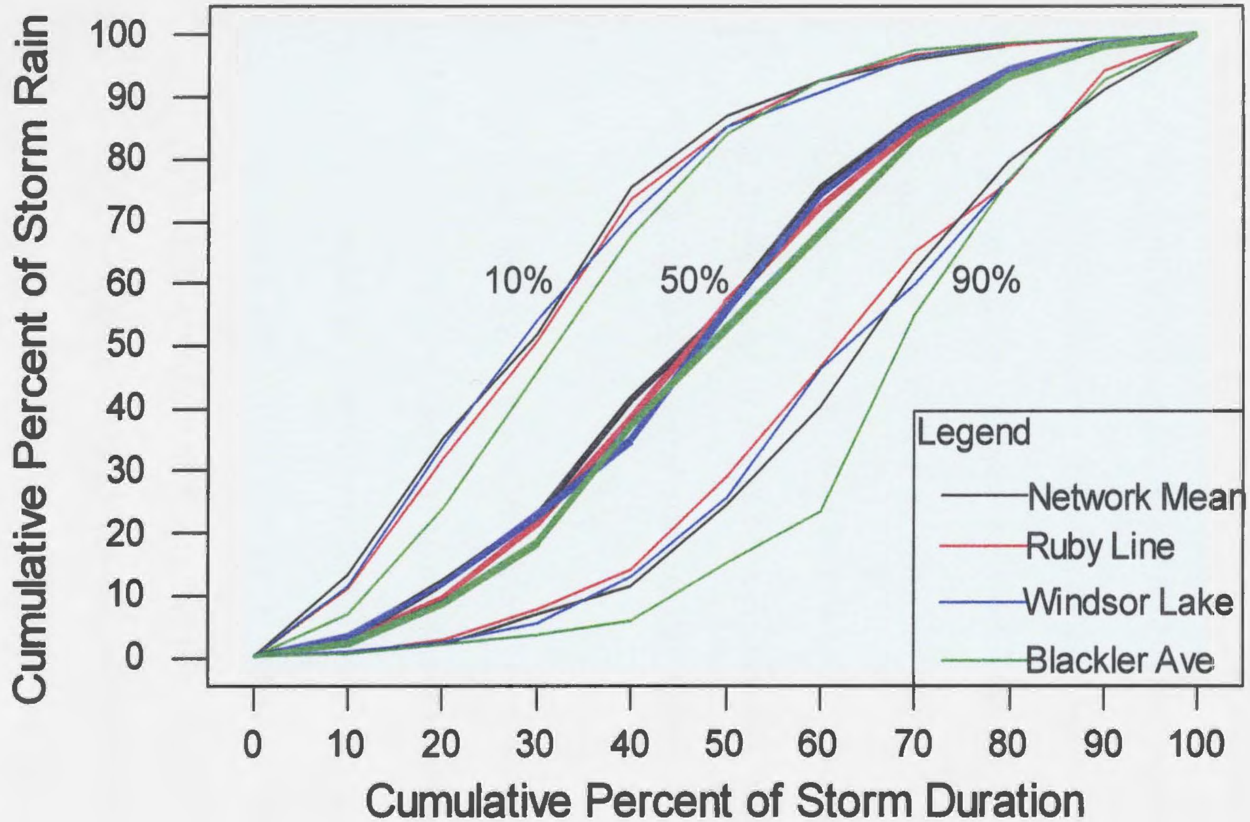


Figure 2.4: Comparison of Network and Site Specific Probability Curves

2.4 Comparison of Network Mean and AES Temporal Distributions

The 1-hour and 12-hour AES Mean temporal distributions are the standard time distributions utilized by the City of St. John's in engineering design. The comparison of these distributions with the Network Mean distributions is very important in terms of the City's future applications of temporal distributions. The AES Mean temporal distributions were converted to dimensionless distributions in order to compare them with the Network Mean temporal distributions as indicated in **Figure 2.5**. The 1-hour and 12-hour AES Mean temporal distributions appear to be similar in shape to the 20% Network Mean time distribution but they lag this curve by approximately 5% and 10%, respectively. Given the similar shapes of these distributions, it might be expected that the 20% Network Mean temporal distribution would generate runoff rates similar to those generated by the AES Mean distributions.

The Network Mean and AES Mean distributions were compared by modeling each of them in the Hydrologic Engineering Center's - Hydrologic Modeling System (HEC-HMS) **(United States Army Corps of Engineers, 2001)** to determine which distribution maximizes storm water runoff. HEC-HMS is a digital computer program, written by the United States Army Corps of Engineers, which simulates the precipitation/runoff processes in urban and rural watersheds. Several test models were created within HEC-HMS, using the Soil Conservation Service (SCS) hydrograph method, to check the sensitivity of model parameters and confirm which distribution maximized runoff. Drainage areas between 1- and 1000-hectares were modeled with curve numbers (CN) ranging between 60 and 95, rainfall

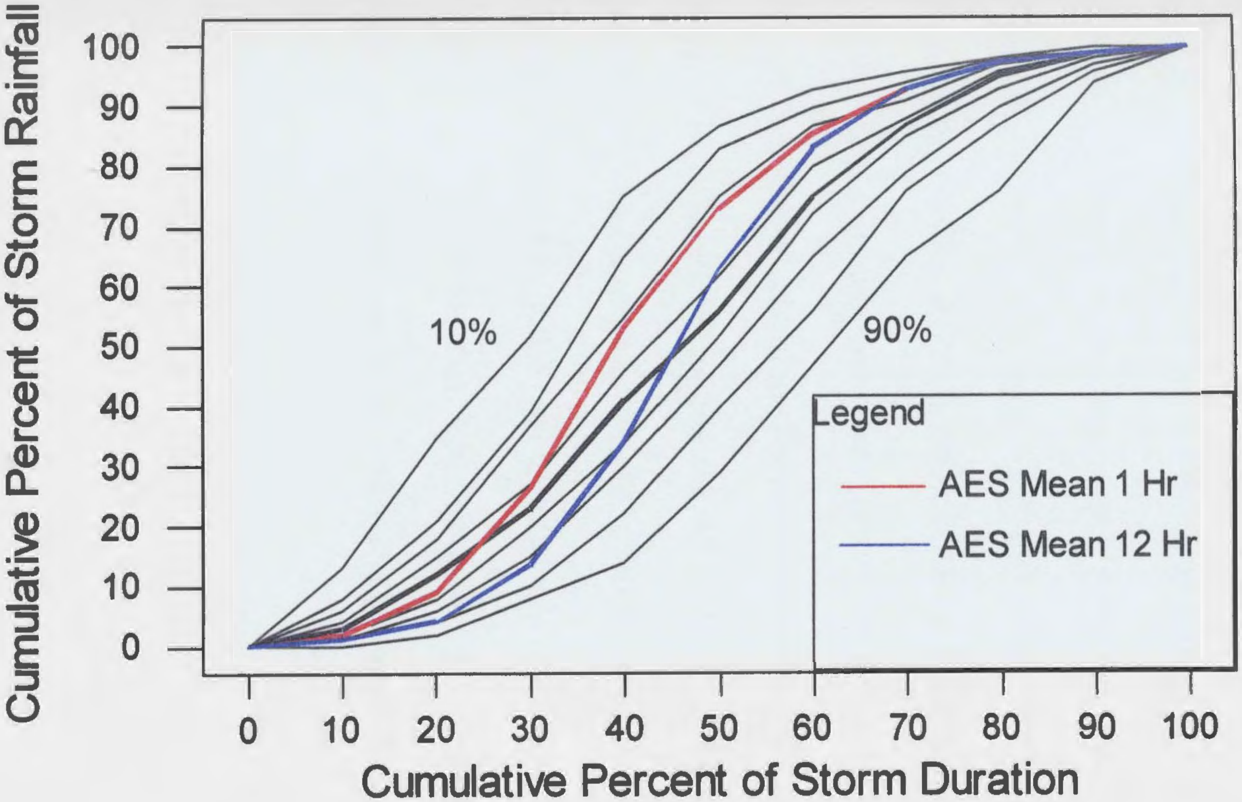


Figure 2.5: Comparison of Network and AES Probability Curves

intensities from 15 mm/hr to 75 mm/hr, and time of concentrations between 10 minutes and 6 hours. **Tables 2.1** and **2.2** compare the results of the Network Mean distributions to the AES Mean 1-hour and 12-hour distributions, respectively, for a 100-hectare site where: the time of concentration was 50 minutes, the CN was 80, and a rainfall intensity of 15mm/hr was applied to each of the temporal distributions. In the case of the 1-hour rainfall event the 10% and 20% Network Mean distributions generated higher flows and volumes than the AES Mean distribution; however, the AES Mean distribution created the highest runoff for the 12-hour rainfall event followed by the 20% Network Mean distribution. The Network Mean 10%, 20%, and 30% distributions produced larger volumes than the AES Mean distribution. The volumes vary between distributions because within the SCS method runoff rate is a function of infiltration. The model parameters were varied, within the ranges previously mentioned, to investigate the sensitivity of the HEC-HMS results and no significant changes were noted in the performance of the various temporal distributions. **Peyron et al (2002)** concluded from their research that the influence of catchment shape, size, and imperviousness was not significant in the performance of a selected design storm.

Table 2.1: HEC-HMS comparison of Network Mean and AES Mean 1-Hour Distributions

	10%	20%	30%	40%	50%	60%	70%	80%	90%	AES
Q (cms)	0.021	0.017	0.013	0.011	0.009	0.008	0.005	0.004	0.003	0.016
V ($1000m^3$)	0.012	0.008	0.005	0.003	0.003	0.002	0.001	0.001	0.001	0.007

Table 2.2: HEC-HMS comparison of Network Mean and AES Mean 12-Hour Distributions

	10%	20%	30%	40%	50%	60%	70%	80%	90%	AES
Q (cms)	7.54	8.30	6.85	6.35	6.78	6.69	6.14	6.68	6.02	9.76
V ($1000m^3$)	120.88	120.63	120.38	120.17	119.9	119.62	118.61	117.83	115.54	120.19

2.5 Comparison of Network Mean and Huff Temporal Distributions

The Huff distributions are plotted below, along with the Network Mean temporal distribution for probability levels 10% through 90%, in **Figure 2.6. Hogg (1982)** recommended the Huff 3rd quartile distribution for Atlantic Canada as an alternative to the AES Mean distributions. Using HEC-HMS and the model parameters noted in Section 2.4, the Huff distributions were compared to the 10% and 20% Network Mean distributions and the AES Mean distribution and the results are displayed in **Tables 2.3** and **2.4.** For the 1-hour rainfall event the 10% and 20% Network Mean distributions generated higher flows and volumes than the AES Mean and Huff distributions. The AES Mean distribution created the highest runoff for the 12-hour rainfall event, and the 10% and 20% Network Mean distributions maximized runoff.

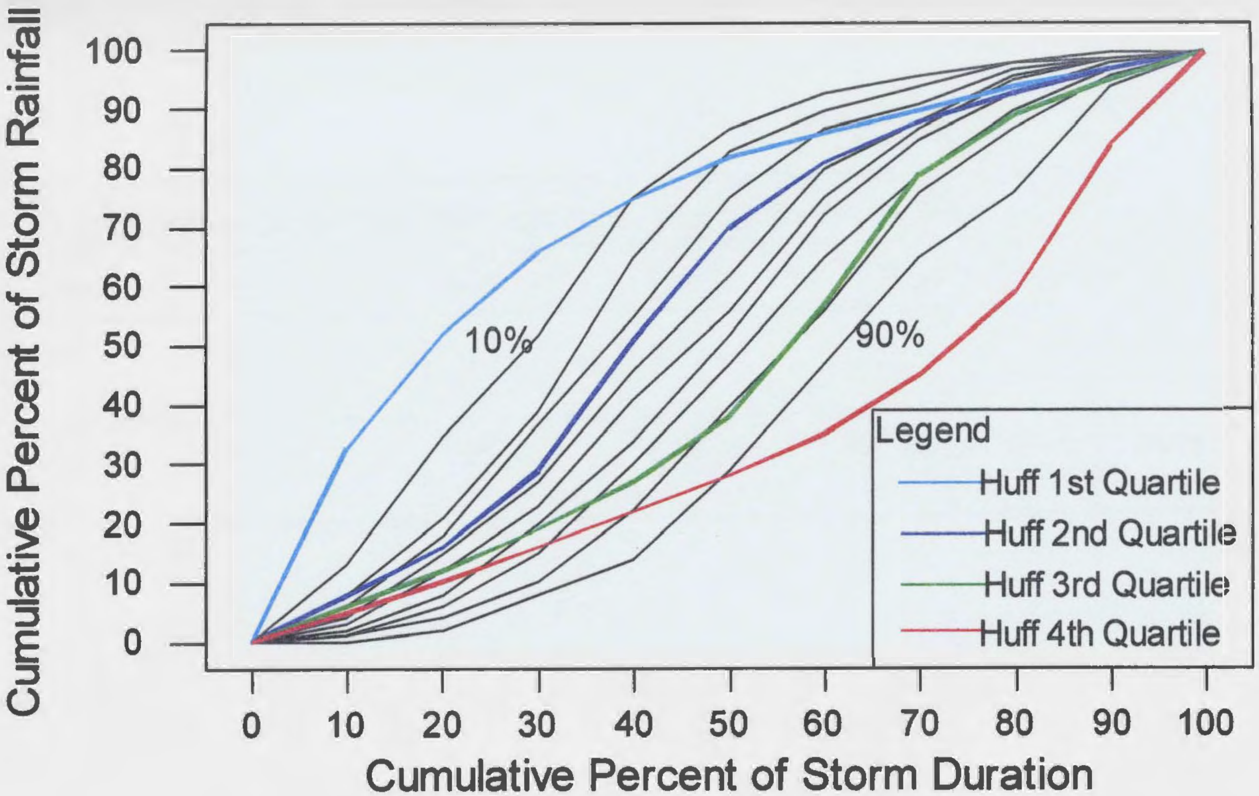


Figure 2.6: Comparison of Network and Huff Probability Curves

Table 2.3: HEC-HMS comparison of 1-Hour Network Mean and Huff Distributions

	10%	20%	AES	Huff 1	Huff 2	Huff 3	Huff 4
Q (cms)	0.021	0.017	0.016	0.010	0.008	0.004	0.001
V ($1000m^3$)	0.012	0.008	0.007	0.004	0.003	0.001	0.001

Table 2.4: HEC-HMS comparison of 12-Hour Network Mean and Huff Distributions

	10%	20%	AES	Huff 1	Huff 2	Huff 3	Huff 4
Q (cms)	7.54	8.30	9.76	6.41	6.82	7.44	8.38
V ($1000m^3$)	120.88	120.63	120.19	118.58	118.53	116.74	106.62

2.6 Comparison of Network Mean and SCS Temporal Distributions

Using HEC-HMS and the model parameters noted in Section 2.4, the SCS distributions were compared to the 10% and 20% Network Mean distributions and the results are listed in **Table 2.5.** The SCS distributions are plotted below, along with the Network Mean temporal distributions for probability levels 10% through 90%, in **Figure 2.7**. Similar to the AES Mean temporal distributions, the SCS 24-hour distributions were converted to dimensionless distributions in order to make them comparable with the Network Mean distributions. The Type III distribution which was recommended by **SCS (1975)** for Atlantic Coastal areas does not fit any of the Network Mean distributions nor do any of the other SCS distributions. The steep slopes of the SCS curves would suggest that the majority of rainfall falls over a short duration within the overall storm event and intuitively the appropriateness of these curves for St. John's is questionable. The SCS distributions generated significantly more runoff than either of the Network Mean distributions. However, the Network Mean distributions produce slightly higher volumes.

Table 2.5: HEC-HMS comparison of 24 Hour 10% & 20% Network Mean and SCS Distributions						
	10%	20%	SCS 1	SCS 2	SCS 3	SCS IA
Q (cms)	8.44	9.62	15.25	14.33	13.12	9.29
V (1000m^3)	293.20	292.98	291.71	291.72	292.66	288.87

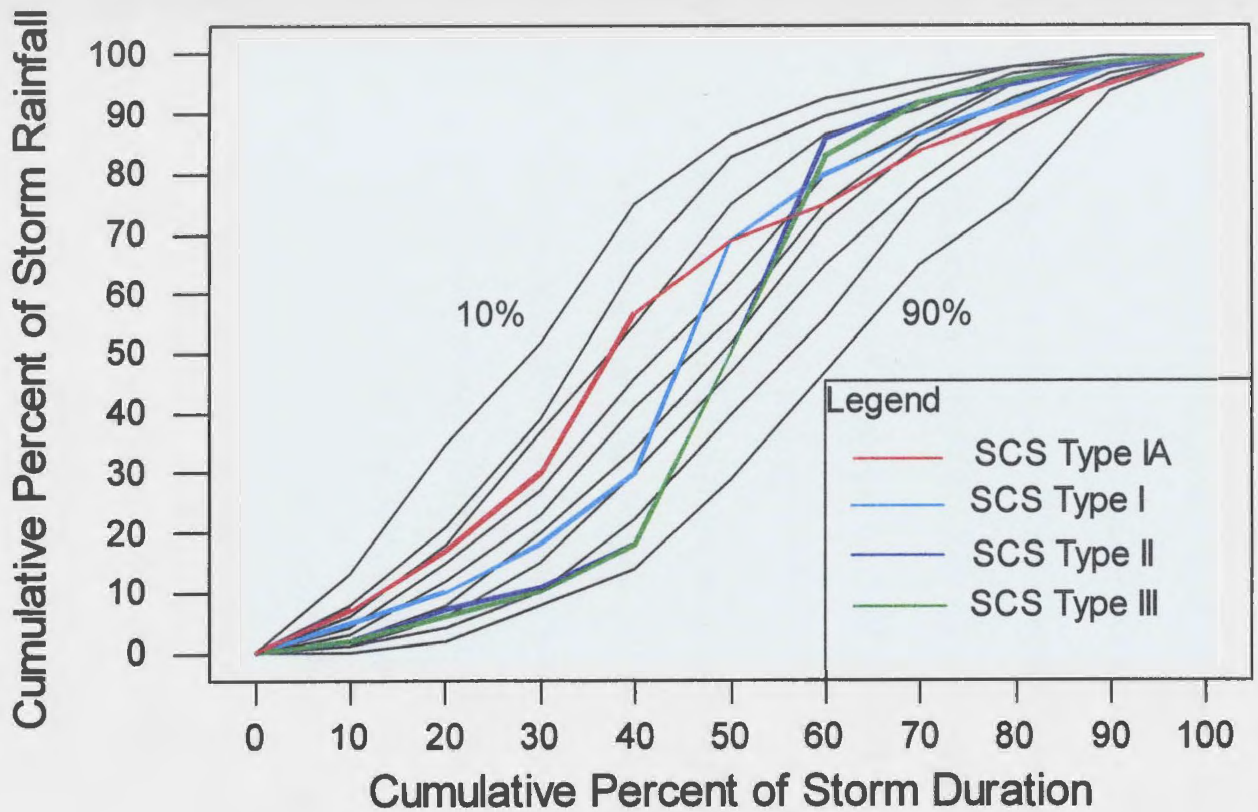


Figure 2.7: Comparison of Network and SCS Probability Curves

2.7 Discussion

A literature review indicated that a simple empirical method devised by **Huff (1967)** had been applied over the years by other researchers with good success. The method involved selecting several storms that exceeded a required depth threshold and determining a family of empirical probability curves that related percent storm rainfall to percent storm duration. **Hogg (1980)** applied the methodology to the Atlantic Provinces but in later research, **Hogg (1982)**, opted for an exponential temporal distribution which maximized runoff for the 1-hour and 12-hour events. **Loukas and Quick (1996)** demonstrated that one set of average temporal distribution probability curves, based on **Huff's (1967)** method, was applicable over a large area of coastal British Columbia for all durations. Using **Huff's (1967)** methodology and **Loukas and Quick's (1996)** approach, this thesis investigated temporal rainfall distributions for individual rain gage stations as well as an overall Network Mean distribution. It was concluded that the Network Mean distribution was statistically similar to the site specific temporal distributions for all durations. The Network Mean distribution was then compared to the AES, Huff, and SCS temporal distributions using the SCS hydrograph method in HEC-HMS. The 20% Network Mean temporal distribution generated a larger runoff than the AES mean 1-hour distribution but not the AES mean 12-hour distribution. The Network Mean distribution also generated larger volumes than the AES mean distributions. The approach taken for the Network Mean distribution makes it applicable for all durations whereas the AES mean distributions are exclusive to the 1-hour and 12-hour events. The Network Mean distribution generated larger flows than the Huff 3rd quartile distribution which was recommended for Atlantic Canada by **Hogg (1982)**. The other Huff distributions also generated lower flows than the Network Mean distribution with the exception of the Huff 4th quartile distribution for the 12-hour event which created slightly larger flows. The Huff distributions are based primarily on thunderstorms in Illinois and for practical purposes are not applicable to the City of St. John's. Finally, the Network Mean distribution was compared to the SCS curves for the 24-hour rainfall event. In each case the SCS distributions generated significantly more runoff than the Network Mean distributions; however, the Network Mean distributions produced larger volumes. The Type III SCS distribution which was recommended by **SCS (1975)** for the Atlantic coastal areas is for all intents and purposes not appropriate for the St. John's area. While it maximizes runoff, given that the distribution was designed for the United States, the Type III SCS distribution may lead to the unnecessary over design of hydrologic/hydraulic structures.

CHAPTER 3

Spatial Variation of Rainfall

3.0 Background

Knowledge of the spatial variation of rainfall is important when modeling river systems and catchments where the areas are large and the rainfall distribution is not uniform. This phenomenon has been well studied in North America and in other areas of the world. **Berndtsson and Niemczynowicz (1986)** studied rainfall variability for a 2-year period in Northern Tunisia over a 19.2-km^2 area. Spatial correlation structures were used to describe the rainfall variations. **Loukas and Quick (1996)** examined the spatial variation in coastal British Colombia by comparing the ratio of the values of various storm features at each station to values at a base station in Vancouver Harbour.

The locations of the City's rain gages and their respective catchments, as defined by Theissen polygons, are shown in **Figure 2.0**. The Windsor Lake gage (elevation 159m), located in the northeast sector of the City, monitors rainfall over a 65-km^2 catchment which includes: Windsor Lake watershed, Broad Cove River watershed, and parts of Outer Cove Brook, Stick Pond Brook, Coaker's Meadow Brook, Virginia River, and Rennies River. The Blackler Avenue gage (elevation 110m), located in the City's center, collects rainfall over a 107-km^2 area which includes: Mundy Pond Brook, Learys Brook, Waterford River, and South Brook. The Windsor Lake and Blackler Avenue rain gages are separated by approximately 7.2 km. The Ruby Line gage (elevation 159m), positioned in the southwest corner of the City, records rainfall over a 307-km^2 watershed and includes: Waterford River, South Brook, Doyles River, Cochrane Pond Brook, and Raymonds Brook. The distance between the Blackler Avenue and Ruby Line rain gages is approximately 7.5-km. The St. John's Airport rain gage (elevation 131m) is also indicated in **Figure 2.0** approximately 1.6-km northeast of the Windsor Lake gage.

The spatial variation of rainfall between the Windsor Lake and St. John's Airport gages was investigated to determine if concurrent daily data from the two stations could be combined for IDF analysis. The spatial variability of rainfall for the City's rain gages was then probed briefly from an annual and monthly perspective, and later the variability of rainfall was investigated in more detail on a rainfall event basis.

3.1 Comparison of Windsor Lake and St. John's Airport Rain Gages

The Windsor Lake and St. John's Airport rain gages have operated concurrently from 1999 to 2001. Daily rainfall totals from these sites were compared to determine if the spatial variation of rainfall at the two sites was similar. Days that recorded snow were not compared given that Windsor Lake recorded total precipitation (mm) whereas the St. John's Airport converted measured snow depth (cm) to an equivalent depth of rainfall (mm). Given that the City is primarily interested in rainfall extremes, only daily totals which exceeded 20mm were considered. **Figure 3.0** below plots the daily rainfall from Windsor Lake versus that from the St. John's Airport. The 45-degree line indicated in the plot represents the theoretical

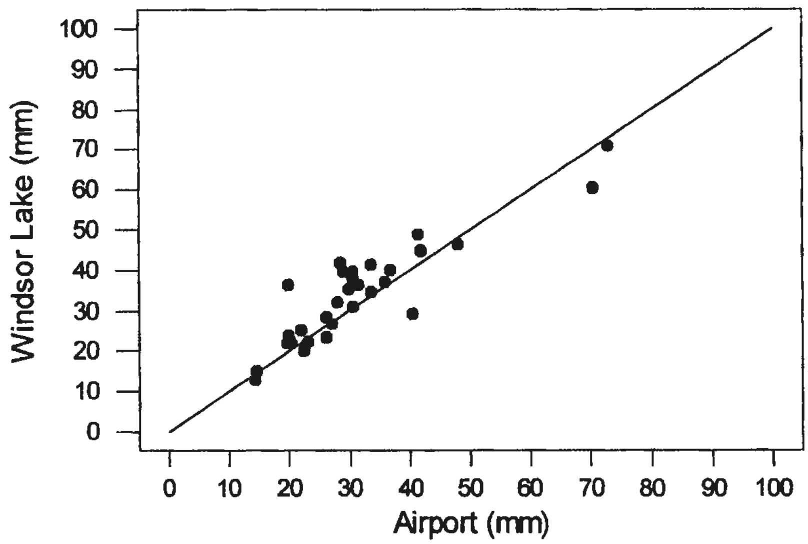


Figure 3.0: Daily Rainfall (>20mm) - Windsor Lake v. Airport

plot for two sites whose rainfall depths are identical for all days. The daily rainfall from both sites appear to follow the 45-degree line. The Airport has a mean daily rainfall (>20mm) of 33.9mm and a standard deviation of 12.2mm compared to Windsor Lake which has a mean of 31.4mm and a standard deviation of 12.8mm. The correlation coefficient for the daily rainfall in **Figure 3.0** is 0.9 which indicates a strong correlation and suggests that the spatial variation of rainfall at both locations is homogenous. **Berndtsson and Niemczynowicz (1986)** found that stations separated by a distance of about 1km displayed a significant correlation, around 0.8 to 0.9, for daily rainfall data. They discovered that a high correlation was maintained between stations separated by distances up to 2-3 km, beyond that the correlation gradually decreased with distance.

3.2 Annual Variability of Rainfall

The total annual rainfall for the City's rain gage network is shown below in Table 3.0.

Table 3.0: Annual Rainfall for City of St. John's Rain Gage Network

Year	Windsor Lake (mm)	Ruby Line (mm)	Blackler Avenue (mm)
1997	N/A	785.9 *	N/A
1998	N/A	1601.0	N/A
1999	1539.9	1530.0	N/A
2000	1440.4	1438.4	926.7 **
2001	1376.6	1293.9	1102.7

* 137 days not available.
** 59 days not available.

The database for total annual rainfall is not of sufficient length to allow any detailed analysis. Comparisons of the annual totals for Ruby Line and Windsor Lake between 1999 and 2000 appear similar; however, Windsor Lake recorded 82.7mm more than Ruby Line in 2001. The Blackler Avenue site recorded its first complete year of rainfall data in 2001 indicating 273.9mm and 191.2mm less than Windsor Lake and Ruby Line, respectively. A comparison of the spatial variation of monthly total rainfall was subsequently investigated.

3.3 Monthly Variability of Rainfall

The monthly rainfall totals for each station, between 1999 and 2001, are listed in **Appendix I** and plotted below in **Figure 3.1.**

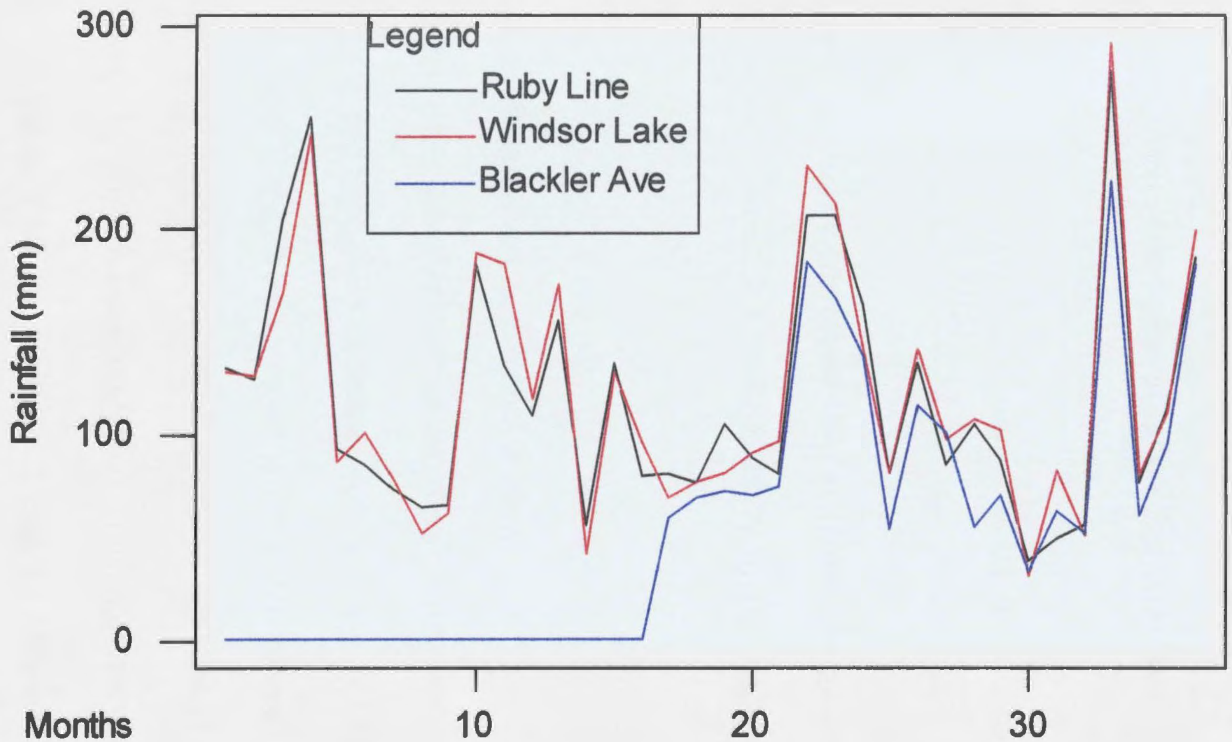


Figure 3.1: Monthly Totals (1999-2001)

The variation of monthly data for each station appears to be similar, with Blackler Avenue recording slightly less than the other stations. The correlation coefficient (n=36) between Ruby Line and Windsor Lake is 0.965 for the period 1999 to 2001. Between May 2000 and 2001, the correlation matrix for the three stations is shown in **Table 3.1**

Table 3.1: Correlation Matrix for Monthly Rainfall Data

n = 24	Ruby Line	Windsor Lake
Windsor Lake	0.978	
Blackler Avenue	0.961	0.969

The monthly data are highly correlated indicating that the spatial variation of rainfall is consistent on a monthly basis. An analysis of the spatial variation of individual rainfall events follows.

3.4 Variability of Rainfall for Individual Events

The spatial variation of rainfall on an annual basis cannot be ascertained due to the shortness of record and the spatial differences of monthly data appears to be insignificant for the short database. IDF curves, however, are based on the maxima of individual rainfall events and, therefore, the spatial variation of rainfall for individual events is important in determining if the City's IDF curves, which are based on the St. John's Airport station, are applicable across the entire City. **Tables 3.2** and **3.3** below list the annual maxima at Windsor Lake for 2000 and 2001, respectively, along with the associated maximums of Ruby

Line and Blackler Avenue for the given dates.

Table 3.2: Windsor Lake 2000 Annual Maxima Comparison					
Duration	**Date**	**Time**	**Windsor (mm)**	**Ruby (mm)**	**Blackler (mm)**
5 Min.	Sep 17	15:14	4.0	3.1	4.7
10 Min.	Sep 17	15:09	7.3	4.8	7
15 Min.	Aug 10	22:29	9.1	3.1	6
30 Min.	Mar 18	03:53	13.3	14.4	13.9
1 Hour	Mar 18	03:43	21.9	20.5	19.9
2 Hour	Mar 18	03:39	29.9	31.1	28.7
6 Hour	Oct 3	22:08	43.3	38.7	40.3
12 Hour	Oct 29	06:28	59.0	39.9	32.6
24 Hour	Oct 29	00:00	70.5	49.5	40.9

Table 3.3: Windsor Lake 2001 Annual Maxima Comparison					
Duration	**Date**	**Time**	**Windsor (mm)**	**Ruby (mm)**	**Blackler (mm)**
5 Min.	Jul 25	09:40	4.9	0	0
10 Min.	Jul 25	09:37	6.4	0	0
15 Min.	Jul 12	19:20	9.0	6.1	10.9
30 Min.	Jul 12	19:07	16.3	9	17.6
1 Hour	Jul 12	18:54	24.8	11	24.4
2 Hour	Jul 12	18:13	29.4	12.2	25.8
6 Hour	Sep 14	19:17	49.8	51.9	33.4
12 Hour	Sep 14	13:51	50.4	53.1	33.7
24 Hour	Apr 2	15:01	58.0	58.1	21.4

Tables 3.2 and **3.3** demonstrate that the distribution of rainfall across the City of St. John's varies. For example, in 2000 the 5-minute annual maxima at Windsor Lake was 4.0mm compared with Blackler Avenue which recorded a 4.7mm 5-minute maximum on September 17, 2000. When calculating the City's IDF curves, based on the Windsor Lake/St. John's Airport data, the larger 5-minute maximum at Blackler Avenue is not taken into account. Variations such as this over the entirety of the Windsor Lake/St. John's Airport database may lead to situations where the IDF curves underestimate rainfall of a given return period for other parts of the City.

The variations noted in **Tables 3.2** and **3.3** are examined further in the rainfall events of September 17, 2000, and July 12, 2001, as these events produced higher annual maxima at Blackler Avenue than Windsor Lake.

3.4.1 Spatial Variation of September 17, 2000, Rainfall Event

The majority of rainfall at the City's rain gage stations fell over a 2-hour period on September 17, 2000. **Figure 3.2** plots in time the 5-minute intervals of the rainfall event between 15:00 and 17:00. **Figure 3.2** indicates that Ruby Line received its highest peak (3.1mm) at 15:05 compared to Blackler Avenue (4.7mm) and Windsor Lake (4.0mm) at 15:15. **Table 3.2** indicated that the 5-minute annual maximum for Windsor Lake was 4.0mm which occurred on September 17, 2000. The 5-minute maximum for the rainfall event at Blackler Avenue was 17.5% higher than Windsor Lake whereas the 5-minute maximum at

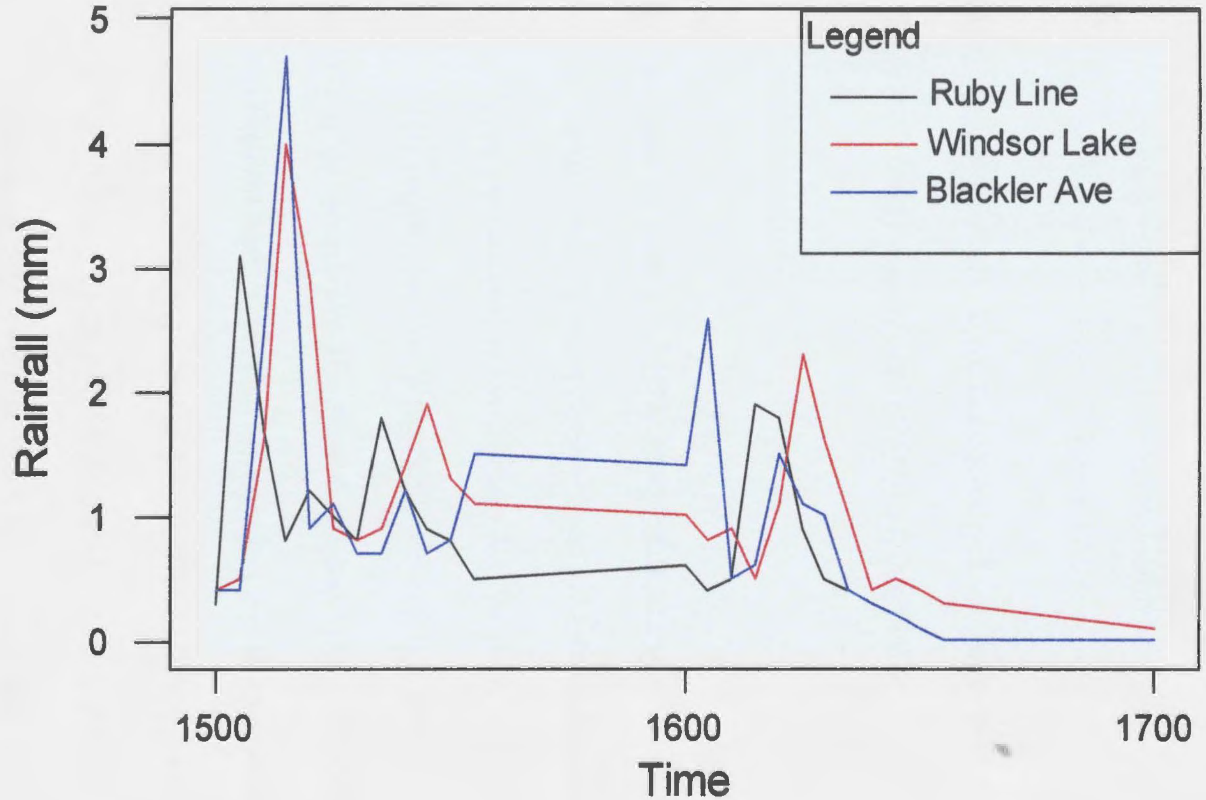


Figure 3.2: Time Series Plot (5 min. maxima) - September 17, 2000

Ruby Line was 22.4% lower than Windsor Lake. The correlation matrix for the time series plot in **Figure 3.2,** based on 5-minute interval data, is indicated in **Table 3.4**.

Table 3.4: Correlation Matrix for 2 Hour Rainfall Event - September 17, 2000		
n = 25	Ruby Line	Windsor Lake
Windsor Lake	0.143	
Blackler Avenue	0.147	0.709

Table 3.4 indicates that the Ruby Line data does not correlate well with the other stations. However, there is a relatively good correlation between Windsor Lake and Blackler Avenue for this event.

3.4.2 Spatial Variation of July 12, 2001, Rainfall Event

The July 12, 2001, rainfall event commenced at 18:00 and continued until 21:00. The 30-minute rainfall intervals are plotted in **Figure 3.3** for each of the City's rain gages. The 30-minute rainfall depths for the Windsor Lake and Blackler Avenue gages, shown in **Figure 3.3,** appear to be practically identical whereas Ruby Line differs both in space and time. Ruby Line's highest peak (9.0mm) occurred at 19:00 compared to Blackler Avenue (17.6mm) and Windsor Lake (16.3mm) at 19:30. **Table 3.3** indicated that the 30-minute annual maximum for Windsor Lake was 16.3mm which occurred on July 12, 2001. The 30 minute maximum for the rainfall event at Blackler Avenue was 8.0% higher than Windsor Lake whereas the same event at Ruby Line was 44.8% lower than Windsor Lake.

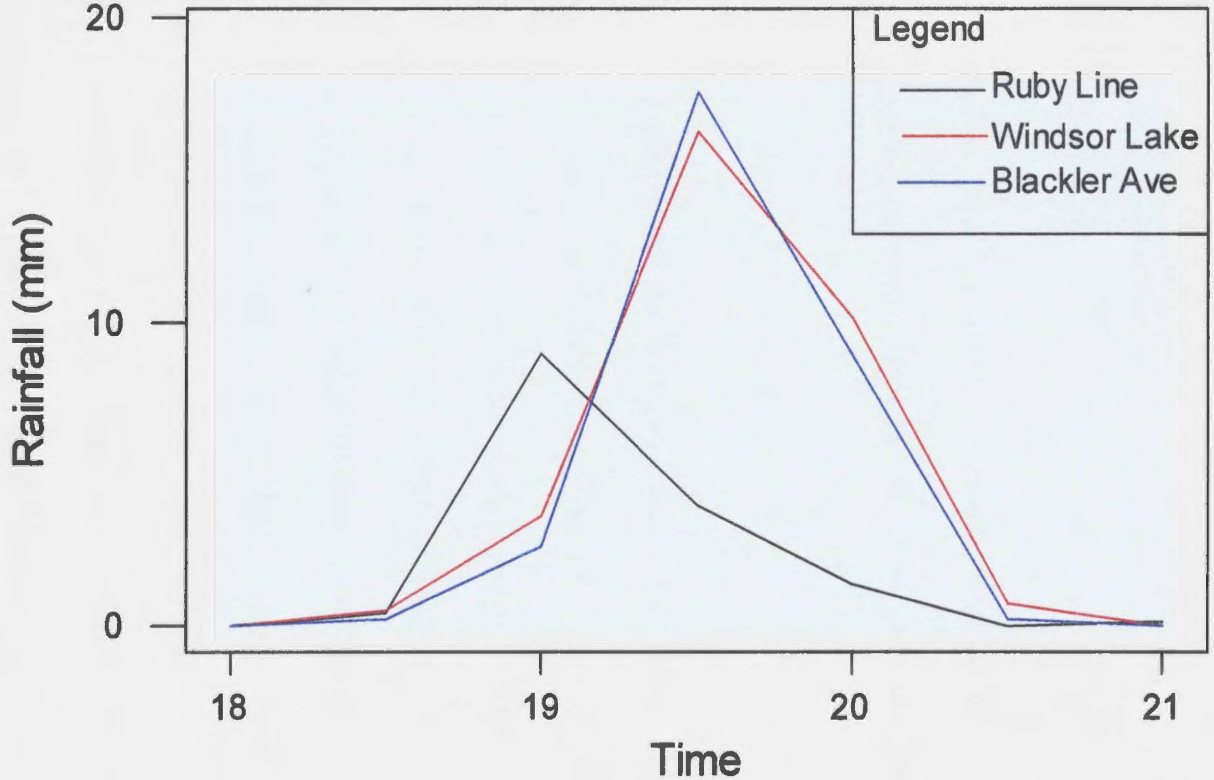


Figure 3.3: Time Series Plot (30 min. maxima) - July 12, 2001

The correlation matrix for the time series plot in **Figure 3.3,** based on 30-minute interval data, is indicated in **Table 3.5.**

Table 3.5: Correlation Matrix for 3 Hour Rainfall Event - July 12, 2001		
n = 7	Ruby Line	Windsor Lake
Windsor Lake	0.355	
Blackler Avenue	0.322	0.993

Table 3.5 confirms that there is a poor correlation between Ruby Line and the other stations and reaffirms the strong correlation between Windsor Lake and Blackler Avenue.

3.5 Discussion

The close proximity of the Windsor Lake and St. John's Airport stations intuitively suggests that the rainfall accumulations at both sites may be similar. A comparison of extreme daily events exceeding 20mm at each station both visually and statistically confirmed this. The correlation structure of the data for the daily rainfall events exceeding 20mm was very strong substantiating **Berndtsson and Niemczynowicz's (1986)** findings that a high correlation is maintained between stations up to about 2-3 km. The short annual concurrent record (1999-2001) for the Ruby Line, Windsor Lake, and Blackler Avenue rain gage stations suggests that rainfall is non-uniformly distributed across the City of St. John's but no conclusions can be drawn at that level. Monthly totals for the same period appear to be highly correlated between each station refuting the initial suggestion but it is likely the summation of rainfall on a monthly basis will balance any spatial irregularities for shorter durations. The spatial variation of rainfall for a given rainfall event becomes important when performing precipitation frequency analysis **(Maidment, 1993)** over a large area where more than one set of IDF curves may be appropriate. Since annual maxima are derived from individual rainfall events it seemed appropriate to select those events at Windsor Lake, between 1999 and 2001, which generated annual maxima and conduct a comparison with Ruby Line and Blackler Avenue. **Tables 3.2** and **3.3** demonstrates some significant variations for various storms. In particular, the rainfall events of September 17, 2000, and July 12, 2001, were analyzed and the variations in the accumulation of rainfall between Windsor Lake and the other City gages ranged between 8% and 44.8%. The short three year concurrent record is suggestive but more data needs to be collected and the issue revisited in the future.

CHAPTER 4

Frequency Analysis of Annual Rainfall Maxima

4.0 Background

The frequency analysis of annual rainfall maxima from the St. John's Airport was performed in the early 1970s by Newfoundland Design Associates Limited for a 12-year record from 1964 to 1975 **(personal communication: Reg Babstock,2002)**. The Extreme Value Type 1 distribution (EV1) was assumed and applied to annual rainfall extremes to develop IDF curves. In 1982, AES published IDF curves for the St. John's Airport, with annual maxima for 1949 and from 1961 to 1981, based on the assumption that the data followed an EV1 distribution. Subsequent IDF curves were published by AES in 1984, 1986, and 1990. Since the early 1970s the City of St. John's has used rainfall IDF curves to calculate the average design rainfall intensity for a given exceedance probability and duration for storm sewer design. The City's current practice is to use the upper 95% confidence limit rainfall intensity in the design of various hydrologic and hydraulic projects. Two of the objectives of this thesis were to revisit the appropriateness of using the EV1 distribution and to produce a current set of IDF curves.

4.1 Rainfall Data

AES have annual maxima recorded for 1949 and 1961 to 1996. As previously shown in Chapter 3 the St. John's Airport data can be combined with the Windsor Lake database, 1999 to 2001, to produce a 40-year record as shown in **Appendix J.** Annual rainfall maxima are usually stationary **(Maidment, 1993)** implying that the statistical parameters of the data, such as the mean and variance, remain constant throughout time. To verify this assumption, the Mann-Whitney (MW) Test **(Rao and Hamed, 2000)** was applied to the annual rainfall maxima and the data was found to be homogenous and stationary. Using the MW test, the data was essentially split into two samples of size p and q, with $p \leq q$, and the null hypothesis that the two samples originated from the same population was tested. Autocorrelation analysis was also used to confirm stationarity where the correlation was found to decrease with lag time.

4.2 Annual Rainfall Maxima Frequency Analysis

There have been many attempts by other researchers to fit various probability distributions to annual rainfall extremes. **Bruce (1959)** applied the EV1 distribution to 9 stations across Canada to analyze annual rainfall maxima but there was no indication of attempts to fit other distributions and good-of-fit tests were not performed. **Baghitathan and Shaw (1978)** examined 19 stations throughout Sri Lanka fitting the EV1 distribution to annual maximum rainfall depths using MLE and confirming goodness-of-fit by the chi-squared test; however, other probability distributions were not examined. **Aron et al (1987)** applied the LP3 distribution to partial duration rainfall maxima in Pennsylvania to determine IDF curves for that State. **Aron et al (1987)** compared the results with the national TP-40 rainfall contour maps but no goodness-of-fit tests were utilized and no other probability distributions were considered. **Wilks (1993)** considered nine probability distributions [Beta-p (Bp), Beta-k (Bk), Revfeim (R), Generalized Gamma (GG), Generalized Pareto (GP), Generalized Extreme Value (GEV), Transnormal (TN), Three-Parameter Lognormal (LN3), and Extreme Value Type 1 (EV1)] for analysis of annual and partial duration rainfall maxima throughout the Eastern United States. The Bk distribution was found to be the best fit for annual rainfall maxima based on visual comparison of quartile-quartile (Q-Q) plots, fitted by maximum likelihood estimators (MLE), and bootstrap resampling extrapolations. Wilks noted that the EV1 distribution significantly underestimated probabilities associated with larger return period events. **Burlando (2002)** examined eight distributions [Generalized Gamma (GG), Generalized Normal (GNO), Generalized Extreme Value (GEV), Extreme Value Type 1 (EV1), Logpearson Type 3 (LP3), Pearson Type 3 (P3), Generalized Pareto (GP), and Wakeby (WAK)] to describe annual rainfall maxima in Malaysia and recommended the GEV distribution, fitted by L-moments, using the Probability Plot Correlation Coefficient (PPCC) goodness-of-fit test and bootstrap resampling extrapolations. Burlando noted that Malaysia's current practice was to assume an EV1 distribution for IDF curves. The EV1 distribution had also been assumed by AES **(Hogg, 1982)** to fit annual rainfall maxima at St. John's Airport resulting in the 1990 IDF curves which are presently used by the City of St. John's.

Tao et al (2002) considered 9 probability distributions [Beta-p (Bp), Beta-k (Bk), Generalized Normal (GNO), Generalized Extreme Value (GEV), Extreme Value Type 1 (EV1), Logpearson Type 3 (LP3), Pearson Type 3 (P3), Generalized Pareto (GP), and Wakeby (WAK)] to represent 5-minute and 1-hour annual rainfall maxima in Southern Quebec. Using visual comparisons and several goodness-of-fit tests the GEV distribution was recommended as the most appropriate.

Several goodness-of-fit tests have been suggested in the literature which assess whether or not an observed data-set belongs to a given probability distribution. **Chow et al (1988)** outlined a procedure for the Chi-squared test whereby the relative frequencies of the observed data are compared to the expected values for a proposed probability distribution. For a chosen significance level, the null hypothesis that a proposed probability distribution fits the observed data is accepted if the calculated Chi-squared statistic is below a critical limiting value. **Onoz and Bayazit (1995)** indicated that the Chi-squared test is not appropriate for frequency analysis and noted that the results of the test are significantly affected by interval selection and distribution parameter estimation errors. **Afifi and Azen (1979)** described the KS test where a D-statistic is calculated based on the maximum absolute difference between the data cumulative probability distribution function and the proposed cumulative probability distribution. For a chosen significance level, the null hypothesis that a proposed probability distribution fits the observed data is accepted if the calculated D- statistic is above a critical limiting value. **Chowdhury et al (1991)** suggested that the KS test is not applicable when the parameters of the probability distribution are estimated from the observed data which **Cunnane (1989)** states is usually the case. **Anderson and Darling (1952)** proposed a goodness-of-fit procedure to assess if an empirical cumulative probability distribution $F_n(x)$, based on observed data, is drawn from a specified cumulative probability distribution F(x). If $\psi(t)$ is some preassigned weight function then Anderson and Darling proposed the following statistic.

$$W_n^2 = n\int_{-\infty}^{\infty}\left[F_n(x) - F(x)\right]^2 \psi\left[F(x)\right]dF$$

Lewis (1961) defined an equivalent form of the statistic as

$$W_n^2 = -n - \frac{1}{n}\sum_{i=1}^{n}\left[(2i-1)\ln U_{(i)} + (2(n-1)+1)\ln\left(1 - U_{(i)}\right)\right]$$

where U_i is the order statistic of a data sample of size n from a population with the uniform (0,1) distribution. **Bury (1999)** described a modified Anderson and Darling test as follows,

$$A_m = -\left\{n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\left[\ln\left(W_{(i)}\right) + \ln\left(1 - W_{(n-i+1)}\right)\right]\right\}\left(1 + \frac{0.75}{n} + \frac{2.25}{n^2}\right)$$

where W_i is the cumulative normal distribution $(x_i - \mu)/\sigma$ and the equation is modified to account for the sample size, n. Several references; such as **Ahmad et al (1988), Sinclair and Spurr (1988), Onoz and Bayazit (1995), Ben-Zvi and Azmon (1997)**, and **Bury(1999)** recommend the Anderson Darling goodness-of-fit test and this method has been adopted for this thesis.

Five 2-parameter probability distributions [Normal (N), Lognormal (LN), Extreme

Value Type 1 (EV1), Logistic (LG), and Loglogistic (LLG)] and four 3-parameter distributions [Generalized Pareto (GP), Generalized Logistic (GLG), Generalized Normal (GNO) and Generalized Extreme Value (GEV)] were investigated in this thesis for the frequency analysis of annual maxima rainfall, from Windsor Lake and St. John's Airport. The distribution parameters were estimated using the Least Squares (LS), MLE, and L-moments methods and the goodness-of-fit was evaluated using the Anderson-Darling (AD) statistic. Based on a visual inspection of the probability plots of the 9 distributions and results from the AD statistic, the 2-parameter LN distribution was determined to be the most appropriate for modeling annual rainfall maxima using L-moments parameter estimation. **Table 4.0** below shows the parameter estimates for the LS, MLE, and L-moments methods.

Table 4.0: Lognormal Distribution Parameter Estimates

	MLE		LS		L-moments	
Duration	**Location**	**Scale**	**Location**	**Scale**	**Location**	**Scale**
5 min	1.529	0.390	1.529	0.400	1.526	0.391
10 min	1.922	0.348	1.922	0.359	1.916	0.364
15 min	2.169	0.344	2.169	0.354	2.162	0.364
30 min	2.527	0.319	2.527	0.328	2.520	0.341
1 hr	2.872	0.299	2.872	0.307	2.867	0.311
2 hr	3.182	0.310	3.182	0.318	3.178	0.331
6 hr	3.714	0.252	3.714	0.258	3.711	0.263
12 hr	3.961	0.232	3.961	0.238	3.957	0.247
24 hr	4.136	0.241	4.139	0.247	4.132	0.257

The probability plot, based on the 2-parameter LN distribution, for the 5-minute annual rainfall extrema is shown in **Figure 4.0** below. In this graph, the reduced variate, z_i, is calculated using $z_i = 5.0633\left[p_i^{0.135} - \left(1 - p_i\right)^{0.135}\right]$ where p_i is the probability value assigned to the ordered annual rainfall extrema using Blom's plotting position. The reduced variate is plotted against the natural logarithms of the 5-minute annual extrema indicating by the straight line fit that the 2-parameter LN distribution is an appropriate choice. The location and scale parameters for the 2-parameter LN distribution were calculated using **Hosking's (1990)** method of L-moments which compare well with the MLE and LS parameter estimates in **Table 4.0.** The LN distribution with L-moments parameters had an Anderson-Darling (AD) statistic of 0.686 compared with 0.701 and 0.760 for the same distribution with the MLE or LS parameter estimates, respectively. The lower the AD statistic the better the fit which in the case of the 2-parameter LN probability plot, for 5-minute annual extrema, is best represented by L-moment parameters. **Figure 4.0** also shows the upper and lower 95% confidence intervals which are calculated based on the location and scale parameters. The probability plots for the 2-parameter LN distribution using the L-moments parameter estimation method are contained in **Appendix K.** Based on the 2-parameter LN distribution, the new IDF curves for the Windsor Lake/Airport area are plotted in **Figure 4.1** at the upper 95% confidence limit and this information is also tabulated in **Appendix** L.

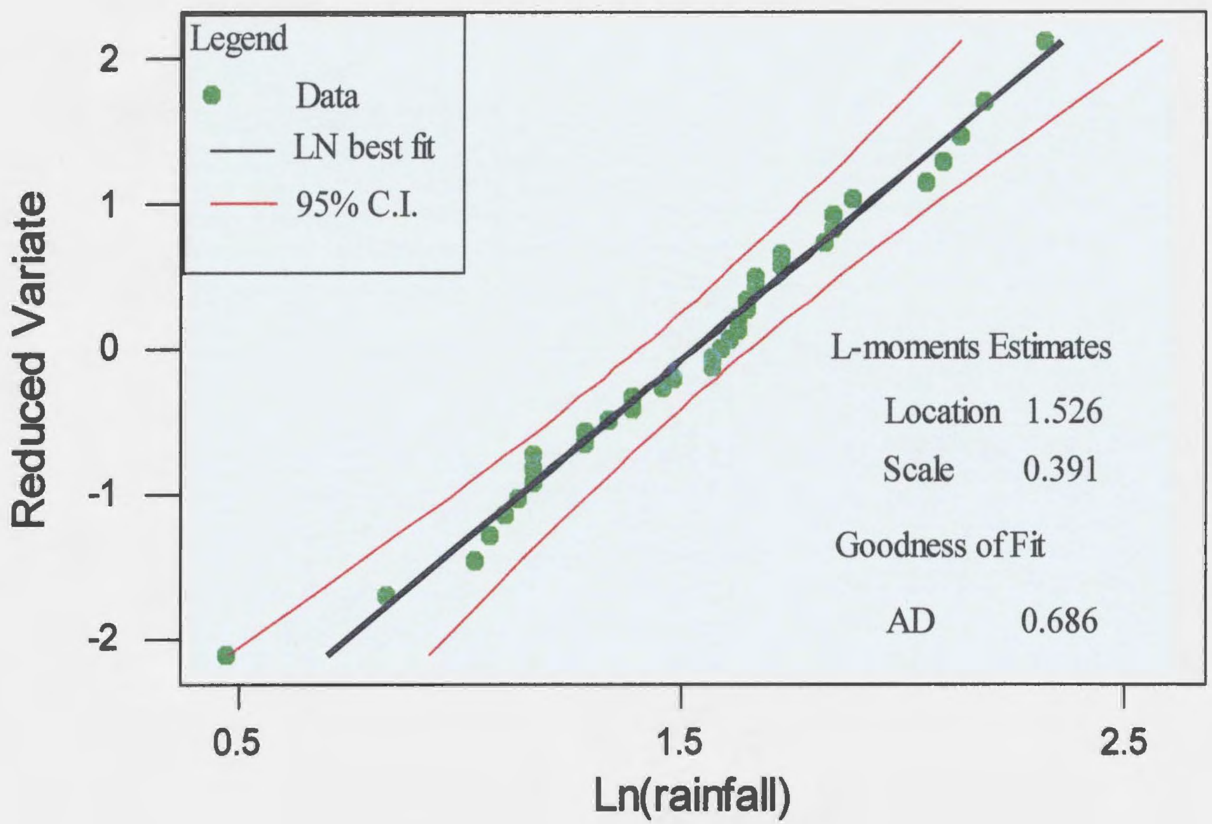


Figure 4.0: Lognormal Probability Plot for 5 Minute Annual Extrema

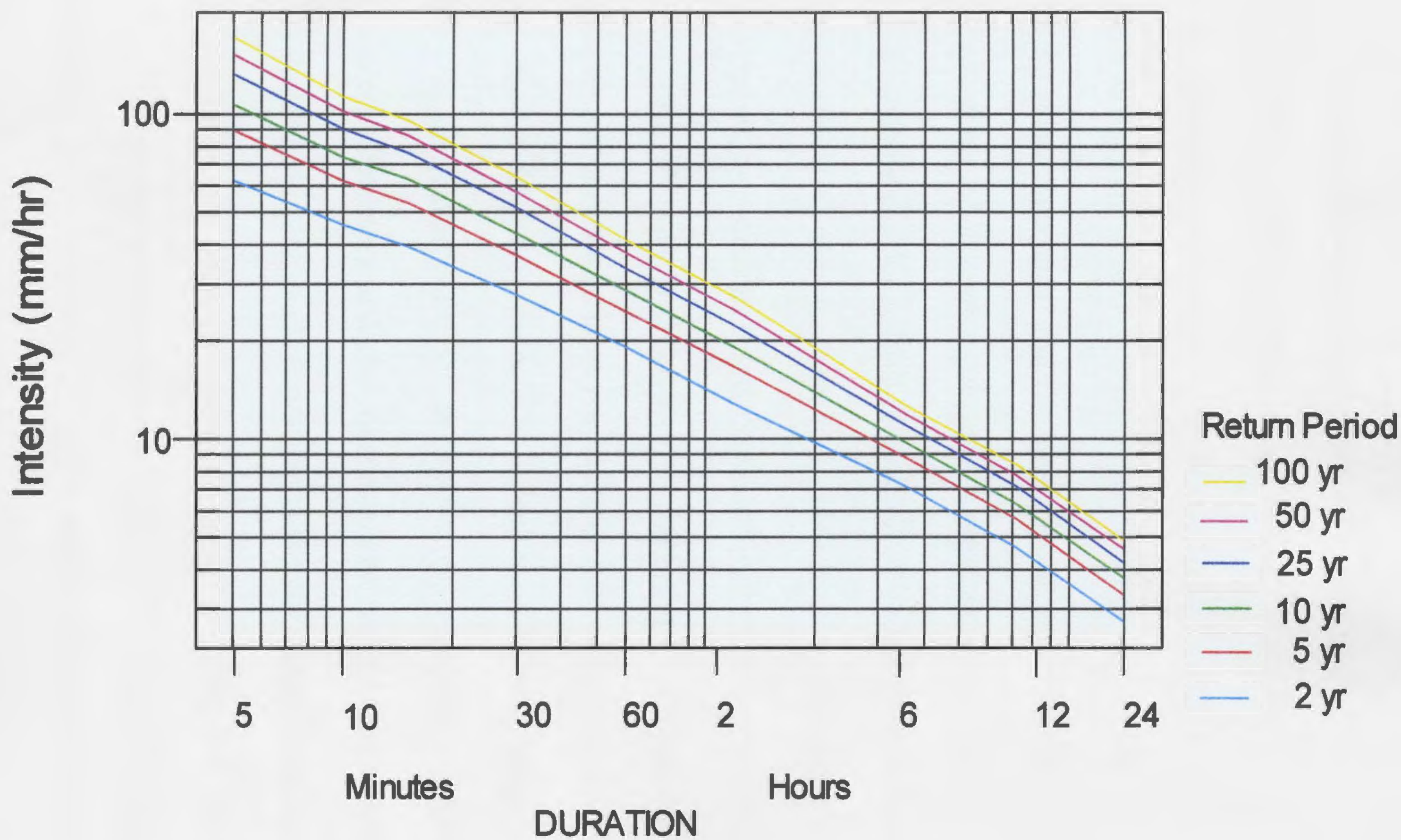


Figure 4.1: Windsor Lake/St. John's Airport IDF Curves for 95% Confidence Interval

4.3 Discussion

The literature indicates several researchers **[Bruce (1959), Baghitathan and Shaw (1978), and Hogg (1982)]** who have assumed an Extreme Value Type 1 (EV1) probability distribution when performing a frequency analysis of annual rainfall maxima. The literature also notes other investigators who have tried a variety of well-known, popular distributions with no apparent general consensus. The same can be said for the estimation of distribution parameters and goodness-of-fit testing. The end result appears to be that the methodology that works best for a particular location is the most appropriate method for that location.

Using a combined 40-year data base of annual extremes, from the Windsor Lake and St. John's Airport rain gage stations, it was proposed to develop a new set of IDF curves for the City of St. John's. The data was checked for stationarity and homogeneity using the Mann-Whitney and autocorrelation tests, respectively. The results indicated that there were no trends in the data. A frequency analysis of the extremes found that the 2-parameter LN distribution was the most appropriate for all durations in representing the data based on L-moments parameter estimators and the Anderson-Darling goodness-of-fit test. The 2-parameter LN distribution is a good choice for modeling annual extremes given that its sample space is positive, its shape naturally fits hydrologic data, and it is well known to engineers. The EV1 distribution did not fit any of the cases examined and performed poorly confirming that the original assumption of an EV1 distribution is no longer applicable. This is quite interesting given that the literature mentions so many examples where the EV1 distribution is assumed outright as the appropriate distribution for the frequency analysis of rainfall. Based on the 2-parameter LN distribution, a new set of IDF curves was calculated at the upper 95% confidence interval. These curves were compared to the 1990 AES IDF curves and were found to have, on average, marginal increases for most durations.

CHAPTER 5

TROPICAL STORM GABRIELLE

5.0 Background

Tropical Storm Gabrielle originated as a Tropical Depression in the Gulf of Mexico on September 11, 2001 (see **Figure 5.0**), and by September 13, 2001, it had reached Tropical Storm status. Gabrielle passed over the State of Florida on September 14, 2001, tracking Northeast across the Atlantic Ocean. On September 17, 2001, the storm was upgraded to Hurricane status with winds in excess of 110 km/h tracking approximately 450-km East of North Carolina but by September 18, 2001, it had been downgraded to Tropical Storm status approximately 750-km east of Virginia. The storm then veered North-Northeast and by early morning on September 19, 2001 was tracking approximately 100-km Southeast of the Avalon Peninsula, Newfoundland. Heavy rainfalls commenced over St. John's approximately 2:00a.m. on September 19, 2001, and by 2:00p.m. the majority of rainfall was complete. Over a 12-hour period 146.6mm, 132.5mm, and 113.1mm fell at the Windsor Lake, Ruby Line, and Blackler Avenue rain gage stations, respectively, causing massive flooding throughout the City of St. John's. The following sections investigate the temporal distribution of the storm, the variations in rainfall accumulation, and the intensity of the rainfall.

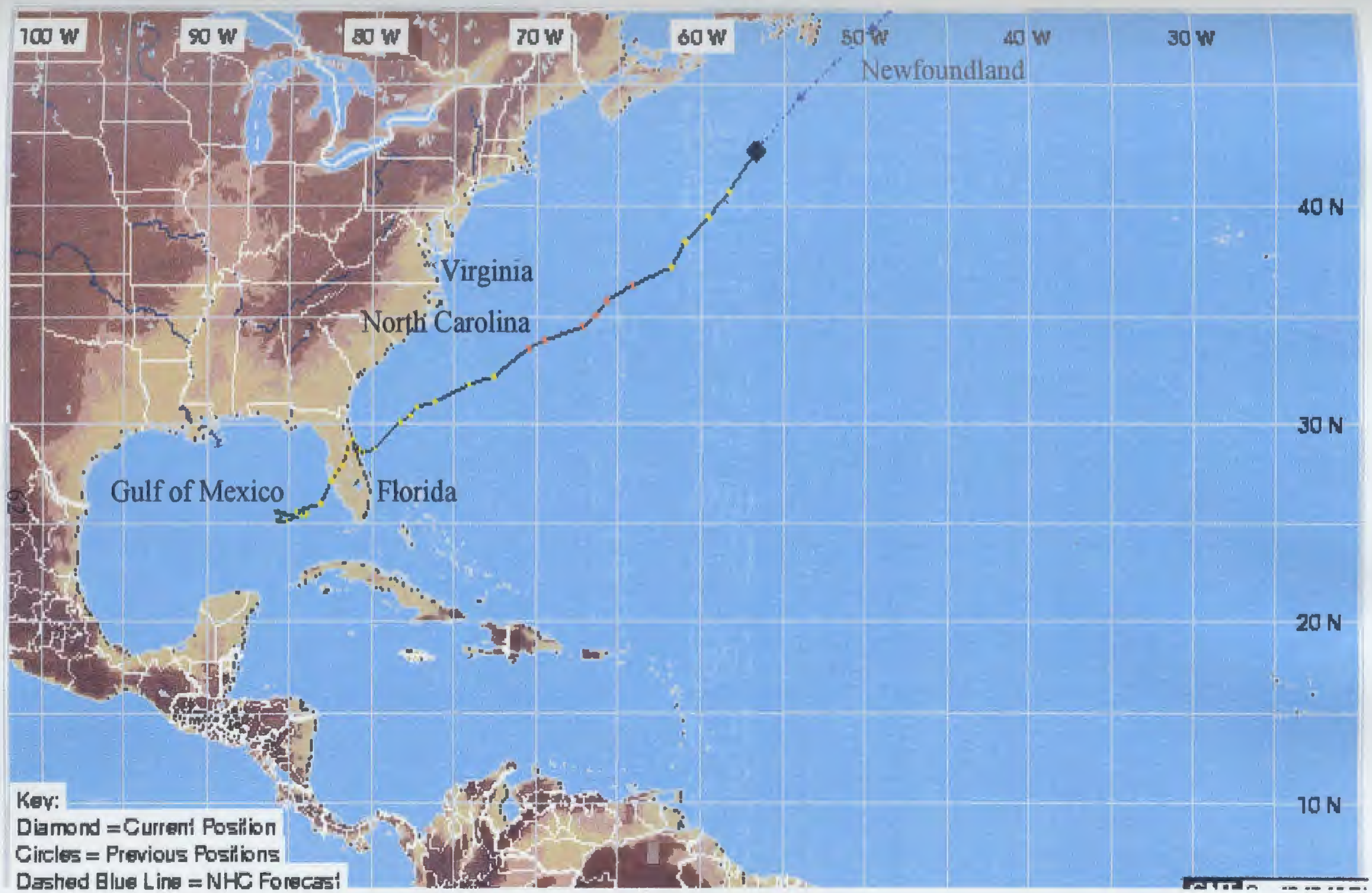


Figure 5.0: Track of Tropical Storm Gabrielle (source: moreweather.com)

5.1 Temporal Distribution of Tropical Storm Gabrielle

Figure 5.1 below plots the Network Mean temporal probability distributions (10%-90%) from Chapter 2 with the observed temporal distributions of Tropical Storm Gabrielle at the City's rain gage stations. The graph plots cumulative percent storm rainfall versus cumulative percent storm duration. The temporal distribution of Tropical Storm Gabrielle appears to be similar at Ruby Line and Windsor Lake; however, these storms seem to lag Blackler Avenue by approximately 30-minutes to 1-hour. Gabrielle deposited approximately 70% of its total rainfall in the 2nd quartile of the storm and this type of temporal distribution does not closely fit the Network Mean patterns. **Figure 5.2** below plots the AES Mean 12-hour time distribution with the Gabrielle distributions and the average September 19, 2001, temporal distribution of Ruby Line, Windsor Lake, and Blackler Avenue. Ruby Line and Windsor Lake are similar to the AES Mean12-hour distribution with the exception of the third quartile, whereas Blackler Avenue differs slightly from the AES Mean distribution for the first half of Tropical Storm Gabrielle.

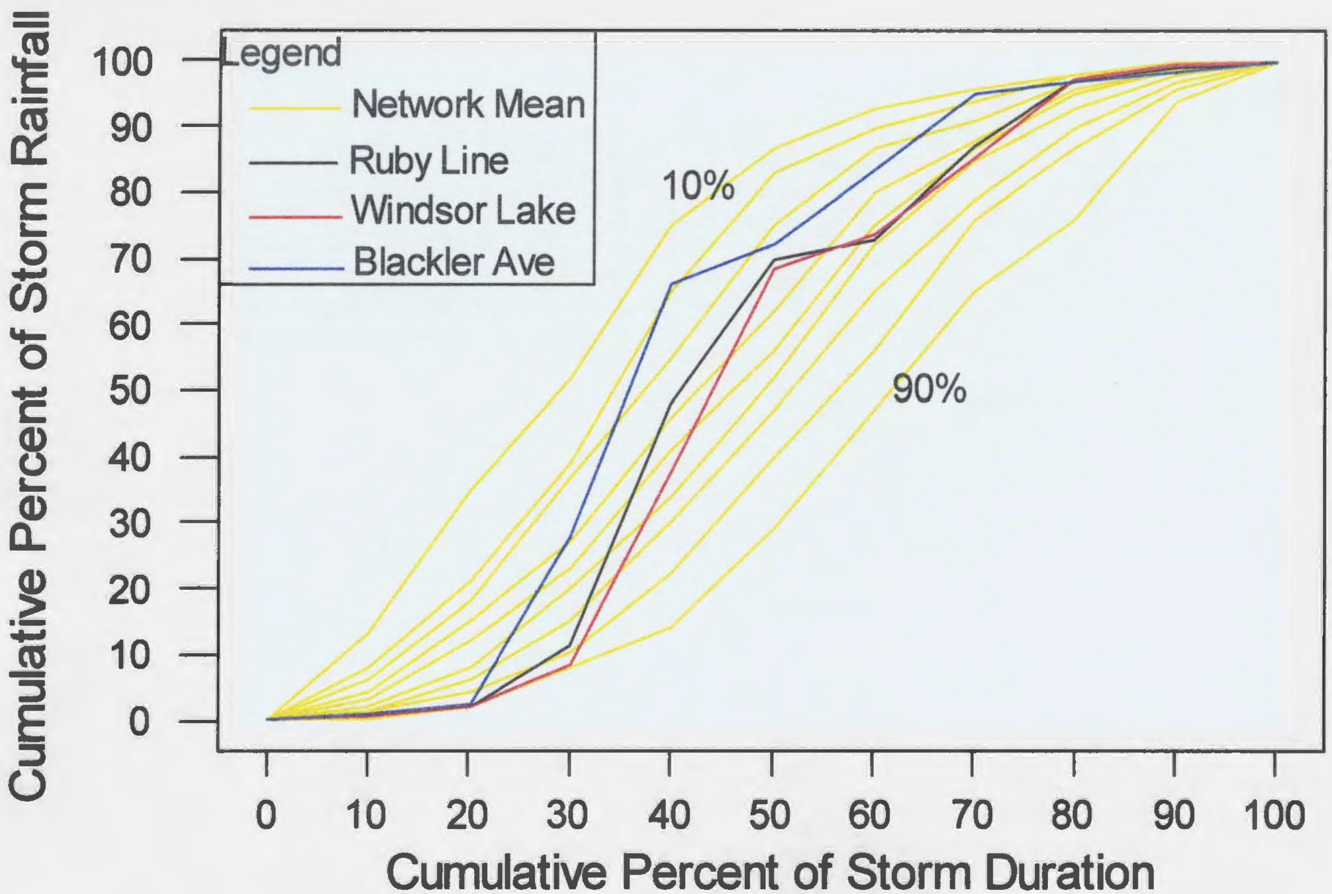


Figure 5.1: Comparison of Tropical Storm Gabrielle to Network Distributions

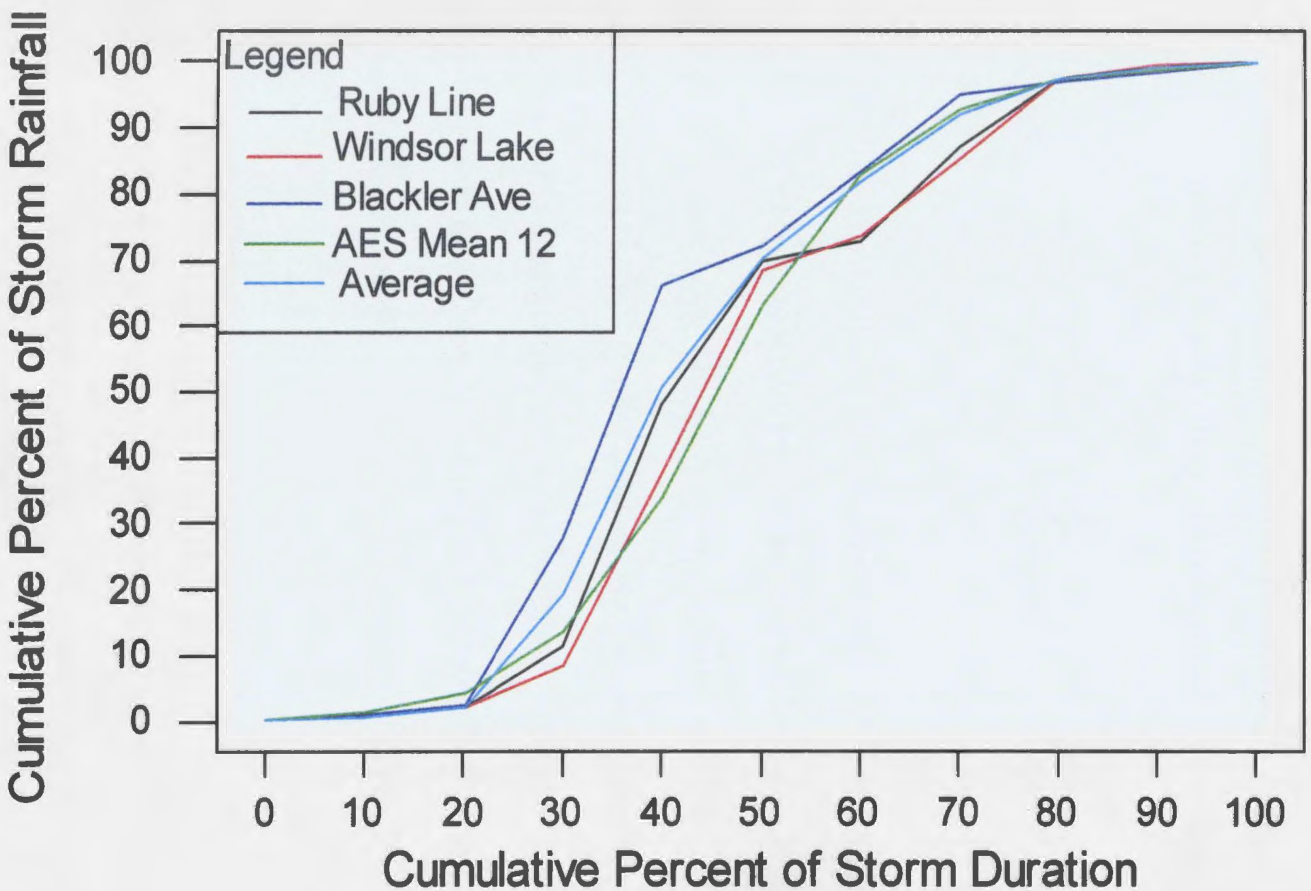


Figure 5.2: Comparison of Tropical Storm Gabrielle to AES Mean 12 Hour

The Huff distributions were also compared with Tropical Storm Gabrielle but were found to differ significantly. Using the HEC-HMS model and parameters from Chapter 2, the temporal distributions in **Figure 5.2** were compared for runoff maximization in **Table 5.0** below.

Table 5.0: HEC-HMS comparison of Gabrielle and AES Mean 12-Hour Distributions					
	Ruby Line	Windsor Lake	Blackler Ave	Average	AES
Q (cms)	9.8	10.3	10.5	8.9	9.8
V ($1000m^3$)	120.7	120.8	119.9	120.5	120.2

Table 5.0 indicates that the temporal distribution at Blackler Avenue maximized runoff and that the Windsor Lake temporal distribution maximized volume. The HEC-HMS model calculated similar runoffs for the AES Mean 12-hour distribution and the temporal distribution recorded at Ruby Line but modeling of the temporal distributions recorded at Windsor Lake and Blackler Avenue generated runoffs 5% and 8% lower, respectively. The average distribution of Ruby Line, Windsor Lake, and Blackler Avenue for September 19, 2001, generated the least runoff.

5.2 Spatial Variation of Tropical Storm Gabrielle

Figure 5.3 below shows the mass curve plots of the Ruby Line, Windsor Lake, and Blackler Avenue rain gage data for September 19, 2001. **Figure 5.3** indicates that between midnight and 5:00a.m. the Ruby Line station received the most rainfall and the accumulations at Windsor Lake and Blackler Avenue are identical. As Tropical Storm Gabrielle tracked Northeast of St. John's, the rainfall depths after 5:00a.m. increased at Windsor lake and Ruby Line, respectively, and were relatively higher than Blackler Avenue. This spatial pattern continued for the remainder of the storm. An interesting observation is that Blackler Avenue, which is midway between Ruby Line and Windsor Lake, received less rainfall than the other stations. The depth of rainfall, for the 12-hour duration, at Blackler Avenue was 33.5mm and 19.4mm less than that recorded at Windsor Lake and Ruby Line, respectively, for the same time period. This is a significant accumulation difference which impacted on the degree of subsequent flooding that was experienced across the City of St. John's as a result of Tropical Storm Gabrielle. The City of St. John's received more than 1,100 flood damage claims as a result of Gabrielle, most of which were concentrated in the northeastern sector of the City within the Windsor Lake rain gage catchment. **Richards (2001)** reported total rainfall depths for Gabrielle of 175.0mm, 118.6mm, and 129.0mm at Memorial University (MUN), St. John's Airport, and St. John's West CDA, respectively. **Figure 5.4** shows the locations of all six gages along with the total depths recorded on September 19, 2001. The inclusion of the three additional gages from Memorial University, St. John's Airport, and St. John's West CDA confirms that the spatial variation of rainfall was not uniform across the City as can be seen in **Figure 5.4.**

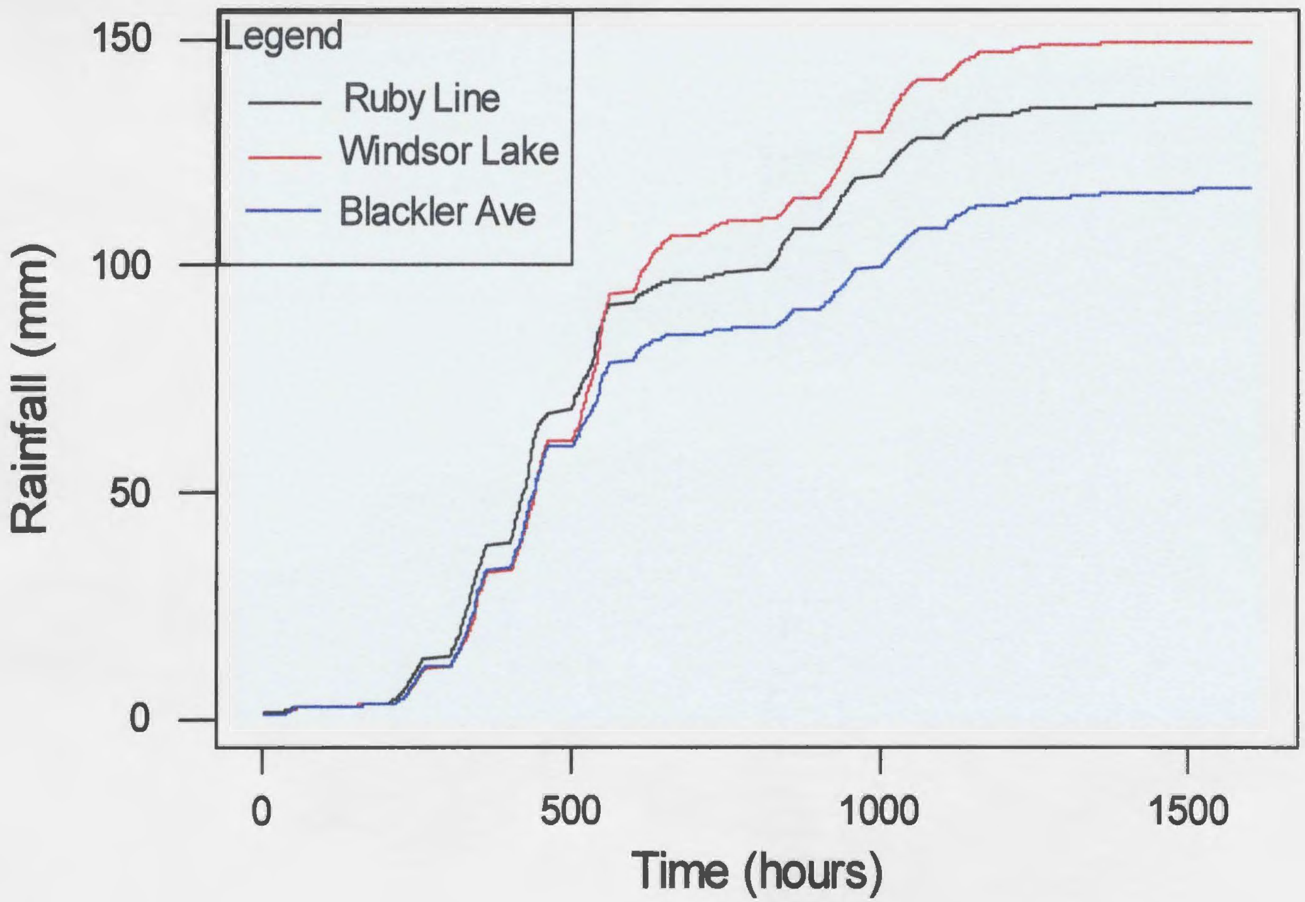


Figure 5.3: Mass Curve Plots - Tropical Storm Gabrielle

Figure 5.4: Spatial Variation of Rainfall Accumulation, Tropical Storm Gabrielle

5.3 Rainfall Intensity

Figure 5.5 below plots the hyetographs of the City's rain gages for September 19, 2001. The most intense rainfall fell between 3:00a.m. and 6:00a.m. depositing 78.4mm, 82.8mm, and 67.6mm at Ruby Line, Windsor Lake, and Blackler Avenue, respectively. **Table 5.1** below lists the maximum rainfall intensities for each City rain gage resulting from Tropical Storm Gabrielle and compares them to the IDF curves for the 100-year return period.

Table 5.1: Maximum Rainfall Intensities - Tropical Storm Gabrielle

Duration	Ruby Line (mm/hr)	Windsor Lake (mm/hr)	Blackler Ave (mm/hr)	100 Year IDF (mm/hr)	100 Year IDF 95% CI (mm/hr)
5 Min.	62.4	60.0	39.6	136.8	175.2
10 Min.	52.8	57.0	36.6	94.8	118.8
15 Min.	45.2	47.6	34.4	81.2	101.6
30 Min.	37.4	39.2	30.8	55.0	67.8
1 Hour	33.0	33.7	27.3	36.2	43.8
2 Hour	**28.1**	**31.0**	24.9	25.9	31.7
6 Hour	**16.0**	**17.9**	**13.9**	12.6	14.7
12 Hour	**11.1**	**12.3**	**9.5**	7.8	9.0
24 Hour	**5.6**	**6.2**	**4.9**	4.7	4.5

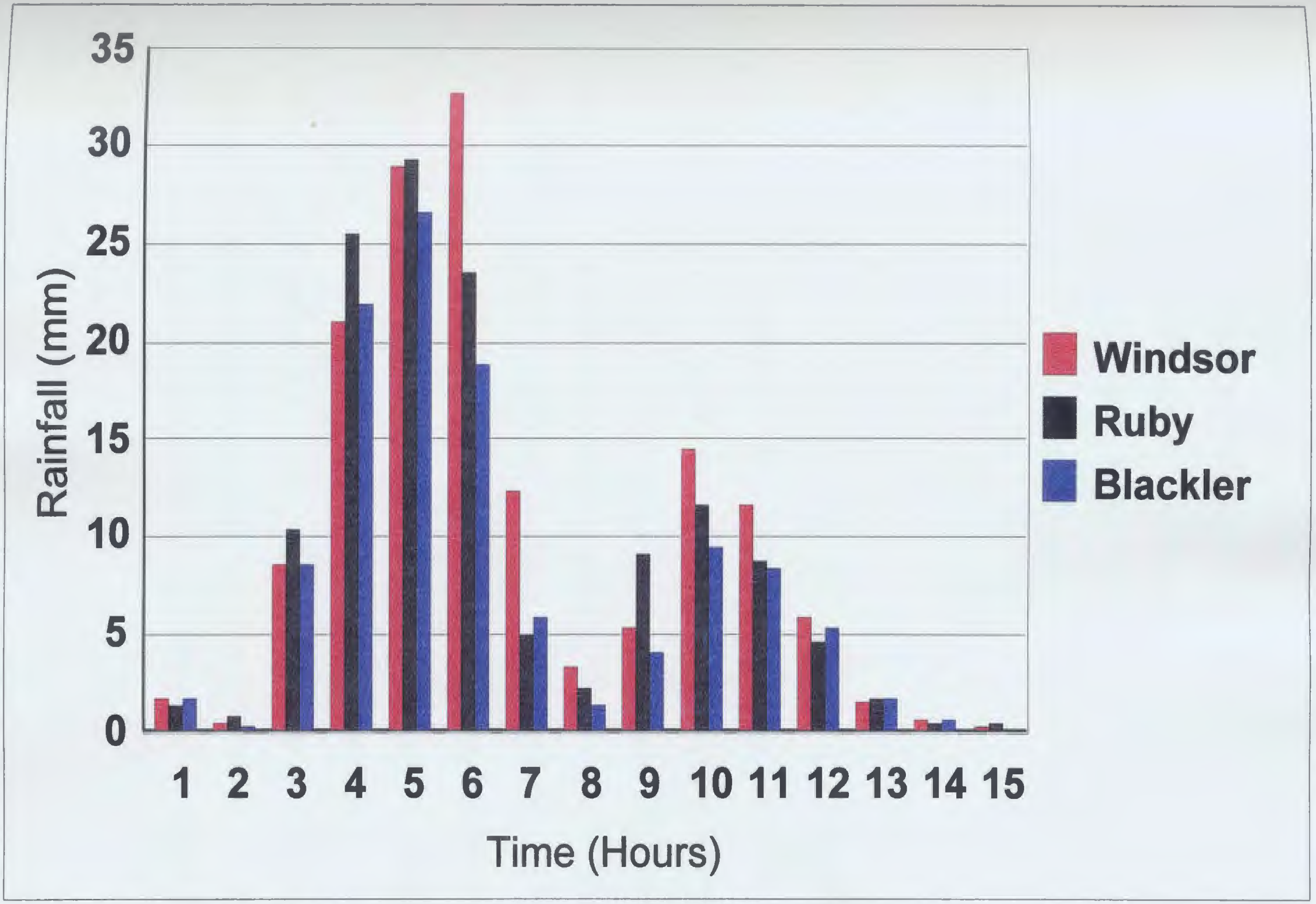


Figure 5.5: Tropical Storm Gabrielle Hyetographs

Table 5.1 indicates that Tropical Storm Gabrielle exceeded the 100-year return period for the 2-, 6-, 12-, and 24-hour durations at Ruby Line and Windsor Lake and for the 6-, 12-, and 24-hour durations at Blackler Avenue. The 100-year return period rainfall at the 95% confidence interval level was also exceeded for the 2-, 6-, 12-, and 24-hour durations at Windsor Lake; the 6-, 12-, and 24-hour durations at Ruby Line; and the 12-hour duration at Blackler Avenue.

5.4 Discussion

Tropical Storm Gabrielle tracked 100-km southeast of the Avalon Peninsula, Newfoundland, causing massive flooding throughout the City of St. John's. The temporal distribution of the rainfall across the City was fairly consistent approximately following the AES Mean 12-hour distribution. The Network Mean distributions, determined from an analysis of the City's rain gage network in Chapter 2, did not closely fit the observed temporal distributions of Tropical Storm Gabrielle as well as the AES 12-hour distribution. The database for the Network Mean distributions does not include many 12-hour events with large accumulations which results in the AES 12-hour distribution better representing the temporal distribution of Gabrielle. As the City collects further data this may change. The observed temporal distribution at Blackler Avenue was found to generate the most runoff when modeled in HEC-HMS and compared to Ruby Line, Windsor Lake, AES Mean 12-hour, and an average distribution of Gabrielle over the City's three rain gages. The rainfall accumulation distributed by Tropical Storm Gabrielle across the City of St. John's varied significantly from station to station. When compared to the three stations (MUN, St. John's CDA, and Airport) noted by **Richards (2001)** the spatial distribution ranged between 113.1mm and 175.0mm. The mean total rainfall over the six rain gage stations was 135.8mm with a standard deviation of 22.46mm. The rainfall intensities calculated for Ruby Line, Windsor Lake, and Blackler Avenue all stations exceeded the 100-year rainfall for the 6-, 12-, and 24-hour durations. Ruby Line and Windsor Lake also exceeded the 100-year rainfall for the 2-hour duration. It is important to note that for some durations the 100-year 95% confidence interval rainfall was also exceeded. This confirmed that Tropical Storm Gabrielle was larger than the 100-year event and, as noted by **Richards (2001)**, it was the worst rainfall since 1876.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.0 Conclusions

The conclusions, grouped by the Chapter, are as follows:

Temporal Distribution of Rainfall

(1) **Huff's (1967)** method was applied to rainfall events from the Ruby Line, Windsor Lake, and Blackler Avenue rain gage stations that equaled or exceeded depths of 12mm and site specific temporal distributions were calculated for probabilities ranging between 10% and 90%. A Network Mean temporal distribution was also developed and compared to the site specific temporal distributions. It was determined that the temporal distribution of rainfall across the City of St. John's could best be represented by the 20% Network Mean distribution.

(2) The AES Mean 12-hour distribution maximizes runoff when compared to the Network Mean temporal distributions using a theoretical HEC-HMS rainfall/runoff model. The Network Mean distributions generated larger runoff rates at the 10% and 20% probability levels than the AES Mean 1-hour temporal distribution. The same results arose when comparisons were made to the Huff temporal distributions.

(3) The SCS 24-hour distributions created higher runoff rates than the Network

Mean distributions using the above referenced rainfall/runoff model.

Spatial Variation of Rainfall

(4) Concurrent daily rainfall events from Windsor Lake and St. John's Airport that equaled or exceeded 20mm were compared and it was determined that the station data were highly correlated and that the annual extreme records could be combined for IDF analysis.

(5) The annual and monthly rainfall data records were too short in length for satisfactory analysis.

(6) The comparison of maxima from each rain gage station for specific rainfall events indicated that rainfall varied spatially across the City. A longer record, however, was required for a more detailed analysis.

Frequency Analysis of Annual Maxima

(7) The 40-year record of annual extremes from the combined Windsor Lake/St. John's Airport database was found to be stationary and homogenous.

(8) The 2-Parameter Lognormal (LN) probability distribution was found to best fit the data using L-moment parameter estimates and the Anderson-Darling test.

(9) Based on the 2-Parameter LN distribution a new set of IDF curves was

produced for the City of St. John's which gave, on average, slightly higher rainfall intensities than those given by the AES (1990) IDF curves.

Tropical Storm Gabrielle

(10) Tropical Storm Gabrielle had a temporal distribution that was very similar to the AES Mean 12-hour distribution.

(11) The Network Mean temporal distributions were not representative of the time distributions observed within Tropical Storm Gabrielle.

(12) The observed temporal distributions of Gabrielle at Ruby Line, Windsor Lake, and Blackler Avenue all generated larger runoff rates than any other theoretical time distribution when using the above referenced HEC-HMS rainfall/runoff model.

(13) The spatial variation of rainfall Tropical Storm Gabrielle across the City of St. John's was nonuniform. There was a 61.9mm difference in total accumulation between the Blackler Avenue gage and a private site located at Memorial University (MUN).

(14) Tropical Storm Gabrielle exceeded the 100-year return period for the 2-, 6-, 12-, and 24-hour return periods.

(15) Tropical Storm Gabrielle is the worst rainfall event to affect the City of St. John's since rainfall data collection began in 1876.

6.1 Recommendations

(1) The proposed Network Mean temporal distributions should be used for all durations except the 12-hour event in which case the AES Mean 12-hour distribution should be used.

(2) The Network Mean temporal distributions should be recalculated in 2007 when more data will be available.

(3) The proposed IDF curves should be used for the entire City of St. John's until the issue of spatial variation is revisited in 2007. At that time a set of IDF curves can be created for Ruby Line and subsequently compared to Windsor Lake/St. John's Airport. As well, more analysis of available data for redeveloping IDF curves should be done for the Windsor Lake/St. John's Airport database. In particular, the 6-hour data from the St. John's Airport and the St. John's CDA can be analyzed from 1996 as well as any data prior to 1961 for the St. John's Airport.

(4) The City of St. John's should continue to monitor rainfall and consider expanding its rain gage network in order to better quantify the temporal distributions and spatial variations of rainfall.

References

Afifi, A.A. and S.P. Azen (1979), *Statisitical Analysis - A Computer Oriented Approach*, 2nd. Ed., Academic Press.

Ahmad, M.I., C.D. Sinclair, and B.D. Spurr (1988), "Assessment of flood frequency models using empirical distribution function statistics", *Water Resource Research*, 24(8): 1323-1328.

Anderson, T.W., and D.A. Darling (1952), "Asymptotic theory of certain goodness-of-fit criteria based on stochastic processes", *Annals of Mathematical Statistics*, 23: 193-212.

Aron, G., D.J. Wall, E.L. White, and C.N. Dunn (1987), "Regional Rainfall Intensity-Duration-Frequency Curves For Pennsylvania", *Water Resources Bulletin*, 23(3): 479-485.

Babstock, Reginald (2002), personal communication, Newfoundland Design Associates Ltd.

Baghirathan, R.B. and E.M. Shaw (1978), "Rainfall Depth-Duration-Frequency Studies For Sri Lanka", *Journal of Hydrology*, 37: 223-239.

Ben-Zvi, A. and B. Azmon (1997), "Joint use of L-moment diagram and goodness-of-fit test: a case study of diverse series", *Journal of Hydrology*, 198: 245-259.

Berndtsson, R. and J. Niemezynowicz (1986), "Spatial and temporal characteristics of high-intensive rainfall in Northern Tunisia", *Journal of Hydrology*, 87: 285-298.

Bruce, J.P. (1959), "*Rainfall Intensity-Duration-Frequency Maps for Canada*",Meteorological Branch, Department of Transport, Canada.

Burlando, P. (2002), *Water Science & Technology: Rainfall in Urban Areas*, IWA Publishing.

Bury, K. (1999), *Statisitical Distributions in Engineering*, Cambridge University Press.

Chow, V.T., D.R. Maidment, and L.W. Mays (1988), *Applied Hydrology*, McGraw-Hill Inc.

Chowdhury, J.U., J.R. Stedinger, and L-H Lu (1991), "Goodness-of-fit tests for regional generalized extreme value flood distributions", *Water Resources Research*, 27(7): 1765-1776.

Cunnane, C. (1989), *Statistical Distributions For Flood Frequency Analysis*, World Meteorological Organization.

Hogg, W.D. (1980), "*Time Distribution of Short Duration Storm Rainfall in Canada*", AES, Downsview, Ontario.

Hogg, W.D. (1982), "*Distribution of Rainfall With Time: Design Considerations*", AES, Downsview, Ontario.

Hosking, J.R.M. (1990), "L-moments: analysis and estimation of distributions using linear combinations of order statistics", *Journal of the Royal Statistical Society*, 52(1): 105-124.

Huff, F.A. (1967), "Time Distribution of Rainfall in Heavy Storms", *Water Resources Research*, 3(4): 1007-1019.

Lewis, P.A.W. (1961), "Distribution of the Anderson-Darling Statistic", *Annals of Mathematical Statistics*, 32: 1118-1124.

Loukas, A. and M.C. Quick (1996), "Spatial and temporal distribution of storm precipitation in southwestern British Columbia", *Journal of Hydrology*, 174: 37-56.

Maidment, D. (1993), *Handbook of Hydrology*, MacGraw-Hill Inc.

Onoz, B. and M. Bayazit (1995), "Best-fit distributions of largest available flood samples", *Journal of Hydrology*, 167: 195-208.

Peyron, N., V-T-V Nguyen, and G. Rivard (2002), "An optimal design storm pattern for urban runoff estimation in Southern Quebec", *Annual Conference of the Canadian Society for Civil Engineering*, Montreal, June 2002.

Rao A.R. and K.H. Hamed (2000), *Flood Frequency Analysis*, CRC Press.

Richards, W. (2001), "*Rainfall in Newfoundland Due to Tropical Storm Gabrielle*", Atlantic Climate Centre.

Robertson, A., S. Porter, and G. Brodie (1993), *"Climate and Weather of Newfoundland and Labrador*", Creative Printers, St. John's, NF.

SCS (1975), "*Urban Hydrology for Small Watersheds, TR-55*", United States Department of Agriculture.

Sinclair, C.D. and B.D. Spurr (1988), "Approximations to the distribution function of the Anderson-Darling test statistic", *Journal of American Statistical Association*, 83.

Tao, D.Q., V-T-V Nguyen, and A. Bourque (2002), "On selection of probability distributions for representing extreme precipitation in Southern Quebec", *Annual Conference of the Canadian Society for Civil Engineering*, Montreal, June 2002.

United States Army Corps of Engineers (2001), "*Hydrologic Modeling System HEC-HMS: User's Manual*", Version 2.1.

Wilks, D.S. (1993), "Comparison of Three-Parameter Probability Distributions for Representing Annual Extreme and Partial Duration Precipitation Series", *Water Resources Research*, 29(10): 3543-3549.

APPENDIX A

NETWORK MEAN TEMPORAL DISTRIBUTION RAINFALL EVENTS

Network Mean Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
1	Jul 12/01	2	22.50	0%	3%	14%	43%	68%	94%	100%	100%	100%	100%
2	Jun 8/00	5	12.30	4%	15%	37%	49%	55%	67%	74%	83%	97%	100%
3	March 30/99	5	11.60	3.5%	14.7%	22.1%	30.3%	44.2%	64.9%	85.3%	98.7%	99.6%	100.0%
4	Aug 10/00	6	13.90	2%	27%	85%	87%	87%	89%	96%	97%	99%	100%
5	Jan 16/99	6	16.80	1%	2%	5%	23%	48%	76%	85%	93%	99%	100%
6	Sep 17/00	6	27.60	0%	0%	3%	40%	67%	94%	98%	98%	99%	100%
7	May 25/00	6	15.80	2%	5%	8%	11%	17%	36%	59%	76%	96%	100%
8	Aug 8/00	7	16.20	2%	6%	20%	33%	57%	77%	87%	95%	100%	100%
9	Apr 19/01	7	12.90	1.3%	4.7%	4.9%	7.8%	52.1%	93.3%	96.4%	97.9%	99.0%	100.0%
10	Oct 8/00	8	16.80	44%	44%	44%	46%	47%	47%	47%	47%	55%	100%
11	Mar 16/99	8	30.40	0.0%	0.8%	4.4%	11.2%	27.0%	46.1%	76.4%	92.1%	97.9%	100.0%
12	Mar 10/01	8	20.20	1%	8%	20%	33%	52%	73%	88%	94%	98%	100%
13	Dec 27/01	8	31.30	0%	2%	12%	31%	49%	71%	87%	97%	100%	100%
14	Sept 2/01	8	14.60	3%	35%	46%	56%	69%	74%	87%	94%	99%	100%
15	Mar 23-24/01	8	12.10	2%	2%	10%	23%	51%	72%	73%	75%	99%	100%
16	Aug 28/01	8	15.80	2%	14%	65%	80%	91%	94%	99%	99%	100%	100%
17	Sept 14/01	8	45.70	0%	2%	28%	31%	40%	53%	74%	90%	99%	100%
18	May 23/99	9	12.60	1.2%	4.8%	23.5%	60.6%	78.5%	89.2%	96.8%	98.0%	98.0%	100.0%
19	Dec 29/01	9	14.20	0%	3%	10%	22%	44%	67%	87%	96%	99%	100%
20	Oct 19/00	9	23.20	8%	21%	37%	46%	60%	75%	90%	99%	100%	100%
21	Jun 7/00	9	13.00	6%	18%	37%	63%	88%	92%	94%	99%	100%	100%
22	Aug 25/01	9	15.80	1%	5%	20%	73%	83%	86%	91%	99%	100%	100%
23	Dec 26/01	10	25.20	1%	1%	3%	5%	14%	37%	69%	88%	98%	100%
24	Jun 3/00	10	13.30	1%	4%	15%	38%	57%	86%	93%	97%	97%	100%
25	Oct 7/01	10	15.80	1%	6%	33%	48%	58%	65%	78%	86%	98%	100%
26	June 29/99	11	38.60	5.2%	5.6%	10.5%	21.5%	28.9%	47.0%	77.7%	98.4%	99.6%	100.0%
27	Dec 12-13/00	11	29.50	3%	6%	8%	16%	38%	48%	76%	96%	99%	100%
28	July 14/99	11	12.20	7.4%	10.7%	18.9%	56.1%	79.9%	88.1%	93.4%	96.3%	98.8%	100.0%
29	Feb 22-23/99	12	23.70	3%	16%	30%	42%	76%	90%	92%	94%	99%	100%
30	Nov 11-12/01	12	22.30	1%	6%	16%	37%	52%	64%	78%	89%	98%	100%
31	Sep 27/00	12	17.70	6%	18%	39%	75%	84%	92%	97%	98%	99%	100%
32	Feb 15/01	12	40.40	0%	1%	2%	5%	9%	14%	40%	74%	99%	100%
33	May 28/99	12	17.10	0.3%	3.8%	12.6%	28.4%	45.0%	75.7%	86.3%	92.7%	99.1%	100.0%
34	Mar 14/01	12	32.20	1%	3%	5%	12%	32%	54%	79%	96%	100%	100%
35	Jun 30/00	13	16.80	5%	18%	22%	30%	51%	70%	85%	88%	94%	100%
36	April 10/99	13	14.40	3.5%	13.2%	17.4%	23.3%	31.3%	49.7%	58.7%	72.9%	96.2%	100.0%

Network Mean Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
37	Nov 5/01	13	25.60	11%	39%	43%	47%	53%	82%	85%	97%	99%	100%
38	Dec 29/99	14	14.70	2%	7%	12%	27%	43%	64%	75%	89%	97%	100%
39	Sep 24/00	14	15.70	2%	5%	14%	29%	40%	45%	61%	73%	98%	100%
40	Dec 7-8/00	15	35.10	2%	6%	10%	21%	52%	76%	93%	99%	99%	100%
41	May 21-22/99	15	22.40	13.0%	43.6%	71.6%	74.5%	75.4%	75.4%	75.4%	75.6%	93.7%	100.0%
42	Jan 20/01	15	12.30	2%	9%	19%	31%	45%	57%	78%	89%	97%	100%
43	Dec 15/00	16	16.70	1%	4%	15%	40%	67%	83%	87%	88%	93%	100%
44	Dec 22/01	16	30.60	3%	15%	23%	27%	38%	59%	85%	97%	99%	100%
45	May 26-27/99	16	20.80	0.5%	8.2%	39.5%	55.4%	55.9%	55.9%	58.3%	61.7%	75.2%	100.0%
46	May 24/00	16	13.90	8%	18%	25%	33%	53%	80%	89%	95%	99%	100%
47	Dec 19/01	17	45.20	2%	12%	26%	41%	59%	74%	83%	95%	99%	100%
48	Jun 17-18/99	17	16.60	3.9%	12.4%	17.8%	21.5%	28.1%	35.0%	43.5%	76.1%	98.2%	100.0%
49	Nov 18/00	17	31.40	4%	15%	27%	45%	62%	87%	91%	96%	99%	100%
50	June 19/99	17	17.10	23%	67%	73%	77%	85%	91%	94%	94%	96%	100%
51	Nov 7/01	17	29.20	1%	3%	8%	19%	37%	56%	90%	93%	94%	100%
52	Oct 3-4/00	18	55.60	1%	14%	44%	67%	79%	88%	90%	93%	94%	100%
53	Nov 27-28/00	18	32.30	7%	17%	38%	53%	65%	80%	90%	96%	99%	100%
54	Mar 24/01	19	20.10	2%	7%	10%	13%	20%	41%	65%	87%	87%	100%
55	Feb 6-7/99	20	30.40	6%	17%	38%	51%	52%	76%	97%	98%	99%	100%
56	July 27-28/99	21	33.90	4.0%	20.8%	38.1%	64.5%	81.4%	89.8%	94.2%	97.6%	99.4%	100.0%
57	Dec 23/00	21	15.60	6%	26%	37%	62%	89%	95%	97%	97%	99%	100%
58	Nov 14-15/99	22	71.80	6%	21%	37%	60%	75%	79%	82%	90%	99%	100%
59	Oct 30/01	22	40.90	4%	11%	21%	37%	52%	70%	84%	97%	98%	100%
60	Nov 8/00	24	20.60	2%	5%	5%	7%	9%	16%	87%	98%	99%	100%
61	Sept 27/01	24	36.90	5%	10%	34%	58%	83%	87%	87%	95%	99%	100%
62	Jan 10-11/99	26	68.00	10%	21%	32%	45%	61%	77%	87%	93%	98%	100%
63	April 5-6/99	26	31.70	3.9%	26.9%	49.8%	67.9%	87.0%	92.9%	95.7%	97.6%	98.6%	100.0%
64	Nov 5-6/00	29	43.50	2%	9%	23%	50%	60%	63%	64%	73%	96%	100%
65	Nov 11/00	31	20.00	1%	2%	11%	14%	17%	65%	76%	77%	79%	100%
66	Jul 31/00	34	33.80	8%	26%	27%	45%	68%	75%	84%	96%	97%	100%
67	Dec 1-2/99	36	24.10	16.4%	51.5%	69.9%	73.9%	90.7%	91.7%	93.2%	94.6%	95.2%	100.0%
68	April 13-14/99	38	50.50	21.6%	56.0%	67.5%	81.6%	84.2%	87.0%	94.4%	97.8%	98.9%	100.0%
69	Oct 28-29/00	39	66.30	11%	19%	20%	21%	31%	66%	82%	95%	99%	100%
70	Mar 17-19/00	44	67.90	1%	7%	23%	77%	90%	95%	96%	98%	99%	100%
71	Feb 27-28/01	46	35.60	3%	15%	18%	34%	54%	83%	88%	88%	95%	100%
72	April 3/01	47	49.60	9%	15%	36%	68%	89%	94%	96%	98%	98%	100%

Network Mean Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
73	Oct 4-6/99	50	43.60	20.0%	20.5%	33.1%	47.6%	74.7%	81.2%	85.2%	85.7%	91.9%	100.0%
74	Dec 1-3/00	51	19.70	19%	39%	63%	76%	84%	90%	91%	94%	97%	100%
75	Mar 11-14/99	57	105.25	12.4%	22.7%	25.7%	37.8%	46.4%	63.0%	77.1%	84.8%	95.3%	100.0%
76	Dec 14-16/99	57	50.30	4%	13%	24%	46%	65%	72%	80%	90%	97%	100%
77	April 28-30/99	72	111.10	13.0%	30.9%	51.8%	87.5%	89.3%	91.6%	95.4%	96.3%	98.6%	100.0%

APPENDIX B

RUBY LINE TEMPORAL DISTRIBUTION RAINFALL EVENTS

Ruby Line Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
1	Jul 12/01	2	12.3	0.0%	4.1%	31.7%	86.2%	87.8%	98.4%	99.2%	99.2%	99.2%	100.0%
2	Feb 13/98	5	16.8	3.0%	6.0%	11.9%	25.0%	41.1%	61.9%	76.2%	89.3%	94.0%	100.0%
3	Oct 10/99	5	15.9	1.9%	2.5%	12.6%	27.0%	41.5%	55.3%	70.4%	89.9%	95.6%	100.0%
4	Mar 30/99	5	13.3	6.0%	15.8%	21.1%	30.1%	45.1%	64.7%	85.0%	98.5%	99.2%	100.0%
5	Sep 30/97	5	12.7	0.8%	1.6%	7.1%	14.2%	30.7%	45.7%	81.9%	92.1%	100.0%	100.0%
6	Feb 27/99	5	15.2	0.0%	5.9%	10.5%	11.2%	13.2%	36.8%	63.8%	80.9%	92.8%	100.0%
7	Aug 16/99	6	12.0	0.0%	3.3%	3.3%	3.3%	21.7%	83.3%	83.3%	84.2%	84.2%	100.0%
8	Jan 16/99	6	18.5	1.1%	2.7%	5.9%	22.2%	46.5%	73.5%	82.2%	90.8%	98.4%	100.0%
9	Jul 6/98	6	15.7	0.0%	4.5%	26.1%	52.9%	65.0%	69.4%	72.6%	84.7%	99.4%	100.0%
10	Aug 28/01	6	16.1	1%	2%	50%	64%	78%	90%	93%	97%	99%	100%
11	Dec 27/01	7	29.7	0.3%	2.7%	12.8%	36.7%	57.2%	70.0%	86.2%	96.3%	99.3%	100.0%
12	Aug 25-26/98	7	21.5	30.7%	47.0%	63.7%	77.7%	91.6%	96.7%	97.2%	97.2%	99.5%	100.0%
13	Aug 8/00	7	14.2	0.7%	6.3%	24.6%	35.2%	64.1%	83.1%	93.0%	96.5%	100.0%	100.0%
14	Nov 28/99	7	14.7	8.8%	32.0%	51.0%	76.2%	95.9%	96.6%	99.3%	99.3%	99.3%	100.0%
15	Apr 10/98	7	14.1	0.0%	7.8%	19.9%	30.5%	55.3%	66.7%	83.0%	98.6%	100.0%	100.0%
16	Dec 18/98	7	14.4	0.7%	4.2%	11.1%	27.1%	37.5%	74.3%	85.4%	94.4%	99.3%	100.0%
17	May 17/97	7	13.4	0.7%	8.2%	14.9%	26.1%	35.1%	69.4%	92.5%	97.8%	99.3%	100.0%
18	Feb 17/01	7	13.1	3.8%	11.5%	18.3%	26.7%	39.7%	51.9%	58.8%	73.3%	96.2%	100.0%
19	Sep 2/01	7	12.2	2%	33%	51%	54%	57%	71%	74%	87%	93%	100%
20	Apr 19/01	7	14.2	2%	6%	6%	11%	54%	94%	97%	99%	99%	100%
21	Dec 29/01	8	15.1	1%	3%	9%	24%	44%	62%	70%	89%	99%	100%
22	Jul 18-19/98	8	15.1	0.7%	6.6%	34.4%	73.5%	78.1%	85.4%	86.8%	99.3%	99.3%	100.0%
23	Mar 16/99	8	27.6	0.0%	0.7%	4.3%	12.3%	27.5%	45.7%	75.4%	90.2%	97.5%	100.0%
24	Jan 31/98	8	46.2	2.7%	8.2%	18.7%	36.3%	63.7%	89.0%	96.2%	98.4%	98.9%	100.0%
25	Jan 19/99	8	15.0	1.3%	5.3%	10.0%	13.3%	34.7%	50.7%	84.0%	97.3%	99.3%	100.0%
26	May 3/00	8	12.8	0.8%	7.0%	23.4%	38.3%	53.9%	71.9%	89.8%	96.1%	99.2%	100.0%
27	May 10/97	8	20.0	0.5%	1.0%	8.5%	17.5%	37.5%	54.0%	83.0%	96.0%	99.0%	100.0%
28	Oct 14-15/99	8	33.7	0.3%	4.5%	5.0%	5.3%	7.7%	34.4%	63.2%	86.6%	100.0%	100.0%
29	Aug 24-25/01	9	20.0	4.0%	9.0%	76.5%	82.5%	94.0%	99.5%	100.0%	100.0%	100.0%	100.0%
30	Feb 29/00	9	21.2	0.5%	1.4%	7.1%	8.0%	9.9%	33.0%	83.5%	85.8%	98.6%	100.0%
31	Mar 10-11/01	9	21.0	0.5%	7.6%	20.5%	37.1%	60.0%	81.0%	90.5%	96.7%	99.5%	100.0%
32	Feb 20/98	9	21.6	2.3%	11.1%	37.0%	61.1%	74.5%	83.3%	91.7%	97.7%	99.5%	100.0%
33	Oct 19/00	9	29.2	9.4%	23.8%	40.1%	47.5%	60.9%	74.3%	89.1%	99.0%	99.5%	100.0%
34	Jan 25-26/98	10	27.9	2.2%	6.1%	19.4%	30.8%	41.6%	71.0%	88.9%	96.1%	97.1%	100.0%
35	Jun 29/99	10	35.4	9.3%	9.3%	14.1%	24.3%	32.5%	40.1%	62.1%	89.0%	99.7%	100.0%
36	Jan 27/01	10	12.3	1%	13%	31%	50%	68%	83%	92%	98%	99%	100%

Ruby Line Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
37	Jul 5/98	10	25.2	8.3%	8.7%	8.7%	11.1%	17.1%	74.2%	90.1%	90.1%	91.3%	100.0%
38	Oct 7/01	10	18.0	1.1%	6.7%	36.7%	51.7%	58.9%	65.6%	77.8%	86.1%	98.9%	100.0%
39	Jan 8/00	10	16.1	1%	6%	19%	32%	45%	69%	94%	96%	99%	100%
40	Apr 30/00	11	13.5	3.0%	15.6%	23.0%	31.9%	45.9%	73.3%	90.4%	94.1%	94.8%	100.0%
41	Dec 17/98	11	26.2	1.1%	9.2%	13.4%	24.0%	55.0%	72.5%	84.7%	94.7%	98.9%	100.0%
42	Nov 11-12/01	11	26.5	1.5%	7.2%	15.8%	41.1%	49.4%	59.6%	72.5%	80.8%	98.5%	100.0%
43	Jun 23/97	11	15.3	2.0%	2.0%	7.8%	7.8%	7.8%	39.9%	44.4%	55.6%	84.3%	100.0%
44	Jul 4/97	11	12.8	2.3%	2.3%	3.9%	4.7%	10.2%	21.9%	63.3%	82.0%	98.4%	100.0%
45	Jul 9/98	11	31.6	0.9%	3.5%	21.2%	58.5%	75.9%	96.8%	98.7%	99.4%	99.7%	100.0%
46	Apr 26-27/97	12	25.2	1.2%	4.0%	7.1%	25.0%	42.9%	50.8%	63.1%	93.7%	99.2%	100.0%
47	May 28/99	12	17.9	0.6%	3.9%	14.0%	24.6%	44.1%	76.0%	85.5%	91.1%	99.4%	100.0%
48	Feb 23/99	12	24.1	3.3%	17.0%	31.1%	47.7%	80.5%	89.2%	91.7%	93.8%	99.2%	100.0%
49	Sep 23/99	12	12.1	2.5%	3.3%	15.7%	20.7%	70.2%	85.1%	94.2%	97.5%	99.2%	100.0%
50	Mar 5/00	12	13.3	2.3%	10.5%	30.8%	57.9%	63.9%	70.7%	72.9%	80.5%	98.5%	100.0%
51	Nov 5-6/01	12	24.9	2.8%	26.9%	30.5%	33.3%	39.0%	64.3%	82.3%	91.6%	98.4%	100.0%
52	Oct 2/98	12	21.1	0.5%	0.5%	9.0%	28.0%	30.8%	64.5%	65.9%	70.1%	98.1%	100.0%
53	Dec 26/01	12	27.1	0%	1%	3%	3%	6%	24%	65%	97%	100%	100%
54	Oct 8/00	13	20.5	1.0%	44.4%	46.3%	48.8%	49.3%	49.3%	54.1%	99.0%	99.0%	100.0%
55	Aug 1/98	13	12.1	0.8%	0.8%	13.2%	28.9%	43.0%	52.9%	69.4%	95.0%	99.2%	100.0%
56	Sep 27/00	13	15.9	0.6%	11.9%	23.3%	64.2%	79.2%	88.7%	96.9%	97.5%	98.1%	100.0%
57	Dec 15/00	13	13.5	3.0%	5.2%	21.5%	48.1%	81.5%	93.3%	97.8%	97.8%	97.8%	100.0%
58	Jun 3/00	13	14.4	2.1%	3.5%	15.3%	45.1%	75.7%	93.1%	97.9%	99.3%	99.3%	100.0%
59	Nov 15/00	13	12.9	0.8%	14.0%	34.1%	58.9%	63.6%	71.3%	82.9%	98.4%	99.2%	100.0%
60	Feb 15/01	14	38.6	0%	1%	2%	5%	9%	24%	52%	84%	99%	100%
61	Dec 29/99	14	13.9	3.6%	7.2%	12.9%	24.5%	39.6%	70.5%	78.4%	89.9%	97.8%	100.0%
62	Nov 15-16/98	14	27.6	5.1%	18.8%	39.5%	61.6%	82.6%	97.5%	98.6%	98.6%	98.9%	100.0%
63	Nov 21/98	14	39.3	1.3%	6.4%	12.5%	21.4%	33.8%	56.0%	76.6%	93.9%	99.5%	100.0%
64	Dec 30/97	14	36.7	0.5%	2.5%	11.4%	46.0%	59.7%	76.8%	93.2%	93.7%	97.3%	100.0%
65	Jun 30/00	14	17.3	0.6%	11.0%	20.2%	26.0%	45.1%	68.8%	80.9%	86.7%	94.2%	100.0%
66	Dec 12-13/00	14	33.1	4.2%	6.3%	11.8%	36.9%	54.4%	91.5%	97.6%	99.1%	99.1%	100.0%
67	Apr 21/00	14	12.0	6.7%	25.8%	40.8%	58.3%	75.0%	92.5%	97.5%	99.2%	99.2%	100.0%
68	Dec 22/01	14	30.2	6%	19%	25%	28%	32%	50%	69%	91%	99%	100%
69	Apr 4/98	15	32.6	0.3%	1.2%	3.7%	8.9%	42.9%	65.3%	73.0%	84.7%	95.1%	100.0%
70	Mar 14-15/01	15	27.3	1.1%	3.3%	11.0%	33.0%	59.0%	89.0%	96.7%	98.2%	99.3%	100.0%
71	Jun 27/98	15	12.7	0.8%	2.4%	29.1%	61.4%	81.1%	90.6%	94.5%	97.6%	98.4%	100.0%
72	Dec 7-8/00	15	39.8	1.5%	5.8%	10.1%	21.4%	49.5%	72.9%	92.7%	98.5%	99.7%	100.0%

Ruby Line Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
73	Feb 21-22/98	16	17.2	18.6%	60.5%	76.2%	76.7%	76.7%	78.5%	90.1%	95.3%	97.7%	100.0%
74	May 30-31/01	16	29.9	0.3%	5.0%	12.7%	17.1%	26.4%	27.1%	50.8%	67.9%	95.7%	100.0%
75	Jan 20/00	16	32.1	4%	25%	57%	85%	91%	93%	93%	94%	96%	100%
76	Sep 24/97	16	21.4	6.1%	17.3%	36.0%	54.2%	62.6%	81.3%	89.7%	98.1%	99.1%	100.0%
77	Nov 20-21/97	16	40.7	10.1%	28.5%	39.1%	57.2%	68.8%	81.6%	93.6%	96.3%	98.0%	100.0%
78	Nov 17-18/00	16	33.4	5.1%	15.0%	24.9%	44.3%	59.3%	77.2%	91.6%	96.1%	99.1%	100.0%
79	Dec 1-2/97	16	24.1	15.8%	27.0%	32.0%	40.7%	44.8%	45.6%	46.5%	47.7%	69.7%	100.0%
80	Dec 18-19/01	17	41.0	3.9%	15.4%	32.2%	49.3%	65.9%	77.3%	88.0%	96.1%	99.5%	100.0%
81	Nov 7/01	17	27.4	2%	4%	9%	23%	39%	61%	91%	95%	96%	100%
82	Oct 30-31/98	17	33.2	40.1%	70.2%	81.6%	88.6%	88.9%	89.2%	89.5%	90.1%	91.9%	100.0%
83	Apr 8/98	17	57.5	2.1%	7.7%	22.4%	46.1%	77.2%	92.0%	92.9%	95.3%	98.6%	100.0%
84	Aug 18-19/98	17	26.4	1.5%	18.9%	47.7%	75.8%	76.5%	76.9%	78.8%	90.2%	96.2%	100.0%
85	Sep 28-29/98	17	22.8	2.2%	8.8%	13.6%	50.4%	57.9%	76.3%	80.7%	82.5%	91.2%	100.0%
86	Mar 23-24/01	18	15.8	3.8%	9.5%	13.3%	17.1%	22.8%	39.2%	55.7%	79.7%	84.2%	100.0%
87	Nov 27-28/00	18	33.0	5.2%	13.9%	30.6%	43.3%	60.0%	77.9%	86.4%	90.9%	96.7%	100.0%
88	Mar 6/98	18	29.0	2.8%	14.1%	23.8%	31.7%	43.8%	51.4%	62.8%	69.0%	85.9%	100.0%
89	Oct 3-4/00	18	55.5	1.8%	15.0%	42.7%	66.3%	76.4%	83.8%	85.9%	92.3%	93.9%	100.0%
90	Oct 5-6/97	18	33.3	8.1%	26.1%	37.2%	48.0%	56.8%	70.3%	84.4%	92.2%	97.9%	100.0%
91	Sep 23/98	18	50.2	0.2%	1.4%	9.2%	40.8%	46.4%	52.2%	64.1%	75.3%	88.8%	100.0%
92	Dec 28/97	19	29.0	2.8%	13.8%	31.0%	49.3%	54.8%	61.4%	74.1%	87.9%	97.2%	100.0%
93	Sep 17/00	19	28.7	1.4%	1.7%	5.2%	7.7%	8.0%	8.4%	9.4%	40.4%	97.2%	100.0%
94	Jul 1-2/98	19	56.0	1.8%	15.9%	17.9%	21.1%	70.2%	96.3%	96.6%	96.6%	96.8%	100.0%
95	Nov 1/98	19	22.8	0.4%	18.9%	37.7%	43.0%	49.1%	65.4%	70.6%	71.1%	75.0%	100.0%
96	Oct 23-24/99	19	18.3	2.7%	23.0%	41.0%	63.9%	85.8%	91.3%	93.4%	94.5%	97.8%	100.0%
97	Nov 27-28/97	19	31.8	4.1%	12.3%	26.1%	48.1%	64.5%	82.7%	97.2%	98.1%	98.7%	100.0%
98	Apr 10-11/00	20	13.1	0.8%	2.3%	5.3%	16.0%	24.4%	27.5%	35.9%	60.3%	85.5%	100.0%
99	Feb 6-7/99	20	31.7	6.0%	17.7%	38.8%	53.6%	53.9%	77.6%	96.8%	97.5%	98.4%	100.0%
100	Jun 1-2/98	20	34.4	5.5%	8.1%	14.0%	15.4%	40.1%	42.2%	68.3%	95.6%	96.5%	100.0%
101	Jul 16/01	20	12.7	7%	9%	9%	49%	76%	80%	80%	83%	98%	100%
102	Jul 27-28/99	20	33.0	4.8%	19.7%	34.5%	58.8%	79.1%	90.0%	92.7%	97.0%	99.4%	100.0%
103	Sep 24-25/00	20	16.9	3.6%	14.8%	32.0%	40.8%	56.8%	86.4%	97.0%	97.6%	98.2%	100.0%
104	Jun 7-8/00	21	25.2	4.0%	24.6%	44.8%	51.2%	51.6%	51.6%	52.0%	58.7%	84.9%	100.0%
105	Oct 13-14/98	22	32.6	1.5%	5.2%	13.8%	31.0%	50.3%	70.2%	85.9%	95.1%	98.5%	100.0%
106	Nov 14-15/99	22	72.5	5.0%	22.2%	36.8%	60.6%	74.3%	77.2%	80.1%	89.5%	98.9%	100.0%
107	Oct 30-31/01	22	40.6	6%	12%	21%	38%	53%	70%	83%	95%	96%	100%
108	Sep 10-11/98	22	23.7	1.7%	8.0%	11.0%	11.8%	13.5%	22.8%	41.4%	93.2%	95.4%	100.0%

Ruby Line Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
109	May 26-27/99	23	24.5	2.4%	2.9%	3.3%	5.7%	35.1%	58.8%	59.2%	62.0%	66.5%	100.0%
110	Oct 18-19/99	24	54.1	2.4%	15.3%	31.6%	36.8%	40.3%	56.0%	73.9%	97.2%	99.6%	100.0%
111	May 27/98	24	20.4	0.5%	1.5%	6.9%	16.7%	75.5%	94.6%	96.6%	97.1%	97.5%	100.0%
112	Nov 8/00	24	21.0	4.8%	6.7%	7.6%	10.0%	13.3%	20.5%	77.6%	98.1%	98.6%	100.0%
113	Apr 24-25/99	25	20.8	4.8%	18.7%	32.2%	49.5%	73.1%	92.8%	93.7%	96.2%	96.6%	100.0%
114	Apr 5/99	25	39.6	4.3%	25.3%	47.7%	61.6%	88.4%	95.5%	97.5%	98.5%	99.5%	100.0%
115	Jun 18-19/99	25	19.9	9.0%	9.5%	9.5%	31.2%	66.3%	72.4%	89.9%	91.5%	91.5%	100.0%
116	Sep 27/01	25	41.4	4%	8%	35%	71%	86%	88%	90%	98%	99%	100%
117	Jul 13-14/97	26	27.0	7.8%	11.9%	23.3%	23.3%	24.4%	39.6%	56.7%	81.9%	94.1%	100.0%
118	Oct 16-17/98	28	88.4	0.5%	1.7%	9.7%	22.7%	44.8%	80.9%	92.4%	97.4%	99.5%	100.0%
119	Jan 21-22/00	29	30.8	25.0%	67.5%	68.5%	68.5%	70.5%	81.8%	96.8%	97.4%	99.7%	100.0%
120	Jul 11-12/00	30	17.1	5.3%	5.8%	6.4%	8.8%	32.2%	80.7%	80.7%	84.8%	94.2%	100.0%
121	Sep 13-15/01	30	55.4	1.1%	1.6%	2.2%	2.5%	3.6%	4.2%	4.2%	29.1%	67.7%	100.0%
122	Jan 10-11/99	31	67.6	1.0%	5.0%	21.3%	31.8%	48.4%	67.0%	83.6%	89.2%	96.7%	100.0%
123	Oct 6-7/98	31	21.9	16.0%	25.1%	33.8%	43.4%	64.8%	81.3%	90.0%	94.5%	99.1%	100.0%
124	May 24-25/00	31	34.9	7.2%	14.6%	35.5%	49.6%	53.6%	54.2%	54.2%	54.4%	59.3%	100.0%
125	Dec 1-2/00	31	27.1	10.7%	26.2%	44.3%	62.7%	80.8%	87.1%	92.6%	95.6%	97.0%	100.0%
126	Nov 5-6/00	31	41.7	5.3%	14.4%	29.5%	54.2%	60.4%	62.1%	64.0%	90.4%	98.3%	100.0%
127	Apr 13-14/99	33	54.1	19.2%	47.7%	64.0%	76.2%	80.8%	82.6%	86.5%	94.8%	98.7%	100.0%
128	May 16-18/98	34	98.8	11.0%	30.0%	40.2%	52.7%	75.1%	91.4%	96.6%	98.8%	99.6%	100.0%
129	Sep 5-6/98	34	38.1	5.5%	16.8%	40.2%	63.5%	65.1%	65.6%	76.6%	82.4%	97.9%	100.0%
130	Oct 4-6/99	35	35.0	17.7%	18.3%	18.3%	28.9%	45.7%	51.7%	84.3%	92.0%	97.4%	100.0%
131	Dec 1-2/99	36	25.8	14.3%	38.4%	59.3%	65.1%	91.9%	93.0%	93.8%	95.0%	95.3%	100.0%
132	Oct 28-29/00	37	62.2	9.3%	19.5%	21.1%	21.9%	33.6%	62.9%	78.0%	93.4%	99.5%	100.0%
133	Oct 16-17/97	38	69.4	1.3%	47.4%	74.5%	86.0%	94.8%	98.0%	98.8%	99.1%	99.4%	100.0%
134	Jul 30-31/00	39	52.7	4.7%	14.2%	29.6%	31.9%	58.1%	67.7%	78.4%	93.4%	94.3%	100.0%
135	Aug 28-30/00	40	31.7	5.0%	35.6%	35.6%	56.2%	58.0%	67.8%	73.8%	84.9%	96.8%	100.0%
136	Mar 2-4/98	43	23.7	3.8%	9.7%	48.1%	60.3%	64.6%	67.1%	68.4%	70.5%	74.7%	100.0%
137	Aug 30-31/97	46	50.3	11.7%	51.5%	89.3%	89.5%	90.1%	90.5%	90.9%	91.5%	97.4%	100.0%
138	Feb 27/01	46	39.2	2%	13%	16%	31%	53%	79%	83%	83%	94%	100%
139	Apr 2-4/01	49	64.2	1%	8%	20%	37%	67%	88%	93%	96%	99%	100%
140	Dec 13-16/99	58	48.6	5%	9%	19%	40%	61%	68%	76%	86%	95%	100%
141	Mar 17-19/00	58	79.5	0.5%	1.6%	3.5%	20.1%	78.0%	90.7%	95.0%	96.6%	98.5%	100.0%
142	Sep 9-11/97	61	35.2	28.1%	54.8%	70.7%	77.6%	85.5%	86.9%	89.8%	94.9%	96.3%	100.0%
143	Mar 11-14/99	64	128.4	17%	27%	36%	43%	56%	72%	84%	95%	99%	100%
144	Apr 28-30/99	72	102.8	16.1%	32.8%	55.2%	88.0%	90.4%	92.2%	96.0%	96.4%	98.5%	100.0%

Ruby Line Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
145	Nov 10-13/00	74	25.8	5%	31%	34%	42%	43%	50%	83%	95%	98%	100%

APPENDIX C

PERCENT CUMULATIVE RAINFALL

RUBY LINE TEMPORAL DISTRIBUTION

Appendix C: Percent Cumulative Rainfall - Ruby Line Temporal Distribution

		Percent Storm Duration									
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Probability of Exceedance	**10%**	11.0%	32.0%	50.8%	73.5%	85.5%	93.0%	97.2%	98.6%	99.5%	100.0%
	20%	6.0%	23.0%	39.1%	60.3%	76.4%	89.2%	93.8%	97.6%	99.3%	100.0%
	30%	4.8%	15.9%	34.4%	51.7%	68.3%	83.1%	92.4%	96.9%	99.2%	100.0%
	40%	3.8%	13.0%	29.6%	46.1%	60.9%	77.6%	89.7%	95.7%	98.9%	100.0%
	50%	2.4%	9.3%	21.5%	38.3%	56.6%	72.5%	85.0%	94.6%	98.5%	100.0%
	60%	1.6%	7.2%	18.3%	31.7%	49.4%	68.9%	82.3%	92.1%	97.8%	100.0%
	70%	1.1%	5.8%	13.2%	26.1%	44.1%	64.3%	76.6%	89.9%	96.8%	100.0%
	80%	0.7%	3.5%	9.7%	21.4%	37.5%	52.2%	70.2%	84.8%	95.3%	100.0%
	90%	0.5%	2.0%	6.9%	11.2%	24.4%	40.1%	62.1%	79.7%	91.5%	100.0%

APPENDIX D

WINDSOR LAKE TEMPORAL DISTRIBUTION RAINFALL EVENTS

Windsor Lake Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
1	Oct 8/00	1	10.4	8.7%	15.4%	28.8%	59.6%	77.9%	90.4%	99.0%	100.0%	100.0%	100.0%
2	Aug 10/00	3	15.4	0.0%	0.0%	0.6%	0.6%	1.3%	5.8%	18.8%	29.9%	91.6%	100.0%
3	July 12/01	3	29.4	0.0%	3.1%	10.9%	32.0%	62.9%	88.4%	100.0%	100.0%	100.0%	100.0%
4	Jan 16/99	5	15.1	1.3%	6.6%	27.2%	50.3%	74.8%	84.8%	92.1%	96.0%	99.3%	100.0%
5	Feb 27/99	6	15.7	0.0%	5.7%	10.8%	10.8%	31.2%	54.1%	86.0%	98.1%	100.0%	100.0%
6	May 25/00	6	14.3	0.0%	2.1%	5.6%	14.0%	19.6%	45.5%	70.6%	95.8%	100.0%	100.0%
7	Sep 17/00	6	30.6	0.0%	0.3%	2.6%	35.9%	64.1%	91.2%	96.4%	97.7%	99.3%	100.0%
8	Sep 5/00	7	17.1	0.6%	8.8%	16.4%	25.7%	38.0%	43.3%	48.0%	55.0%	74.3%	100.0%
9	Aug 8/00	7	19.4	2.6%	6.2%	17.0%	31.4%	54.6%	73.2%	81.4%	93.8%	99.5%	100.0%
10	Jan 21/00	7	35.8	4.2%	9.8%	20.1%	31.8%	52.2%	79.6%	91.1%	99.4%	99.7%	100.0%
11	Jun 8/00	7	12.8	8.6%	38.3%	53.1%	60.2%	72.7%	87.5%	97.7%	98.4%	100.0%	100.0%
12	Sep 14-15/01	7	50.3	1.8%	22.1%	26.8%	33.0%	43.7%	60.2%	78.3%	92.6%	99.2%	100.0%
13	Sep 23-24/01	7	13.4	2.2%	3.0%	5.2%	28.4%	37.3%	77.6%	80.6%	81.3%	84.3%	100.0%
14	Mar 16/99	7	33.1	0.9%	4.8%	8.5%	23.0%	38.7%	61.3%	85.8%	95.5%	98.5%	100.0%
15	Feb 6/01	8	13.2	15.2%	34.1%	47.7%	56.8%	68.9%	87.9%	97.0%	99.2%	99.2%	100.0%
16	Jun 7/00	8	13.3	6.8%	16.5%	33.8%	46.6%	87.2%	94.0%	95.5%	97.0%	99.2%	100.0%
17	Mar 10-11/01	8	16.3	0.6%	3.1%	12.3%	23.3%	45.4%	71.8%	90.2%	95.7%	98.2%	100.0%
18	Sep 2/01	8	19.6	2.6%	34.2%	42.3%	60.2%	72.4%	79.6%	91.3%	95.4%	98.5%	100.0%
19	Dec 29/01	8	13.8	1.4%	4.3%	10.9%	26.8%	38.4%	71.7%	82.6%	91.3%	97.1%	100.0%
20	Feb 17/01	8	18.2	1.1%	3.3%	9.3%	18.1%	29.7%	47.3%	64.3%	76.9%	97.8%	100.0%
21	Dec 27/01	8	33.1	0.0%	0.3%	1.5%	7.9%	30.2%	53.5%	73.7%	92.7%	98.8%	100.0%
22	Oct 20/99	9	26.2	8.0%	19.5%	32.4%	42.0%	57.6%	74.4%	88.9%	98.5%	100.0%	100.0%
23	Oct 19/00	9	26.2	8.0%	19.5%	32.4%	42.0%	57.6%	74.4%	88.9%	98.5%	100.0%	100.0%
24	Jan 8/00	9	15.7	1.9%	6.4%	12.7%	17.8%	37.6%	59.9%	94.9%	98.7%	100.0%	100.0%
25	Jan 16/01	9	12.2	3.3%	18.0%	34.4%	58.2%	75.4%	86.1%	90.2%	95.1%	98.4%	100.0%
26	May 23/99	10	14.0	0.7%	0.7%	1.4%	5.0%	27.9%	63.6%	84.3%	95.7%	99.3%	100.0%
27	Oct 7/01	10	15.1	2.0%	5.3%	28.5%	41.7%	55.6%	62.9%	79.5%	88.7%	98.7%	100.0%
28	Dec 26/01	11	25.6	0.4%	0.8%	2.0%	3.1%	8.2%	27.0%	59.0%	94.5%	99.2%	100.0%
29	Apr 30/00	11	15.7	1.9%	19.7%	29.9%	38.9%	51.6%	75.2%	95.5%	99.4%	99.4%	100.0%
30	May 28/99	11	16.3	1%	4%	30%	34%	67%	80%	88%	94%	99%	100%
31	Feb 23/99	11	23.2	2.6%	12.5%	27.2%	33.6%	56.9%	81.0%	92.7%	93.5%	95.7%	100.0%
32	Dec 12-13/00	11	22.9	2.2%	5.7%	9.2%	17.0%	39.3%	51.1%	78.6%	96.5%	99.1%	100.0%
33	Mar 14-15/01	12	30.5	1.6%	3.3%	3.9%	8.5%	27.2%	47.5%	79.7%	97.4%	99.7%	100.0%
34	Feb 15/01	12	33.6	0.6%	2.1%	3.6%	9.8%	16.7%	24.4%	51.2%	79.5%	98.2%	100.0%
35	Jun 3/00	12	13.5	1.5%	5.2%	29.6%	54.8%	85.2%	94.1%	95.6%	99.3%	99.3%	100.0%
36	Jul 14/99	12	13.1	9.2%	12.2%	22.1%	53.4%	74.8%	83.2%	90.8%	95.4%	98.5%	100.0%

Windsor Lake Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
37	Jun 29/99	12	41.9	1.7%	2.1%	8.1%	19.3%	29.6%	56.8%	94.7%	98.8%	99.8%	100.0%
38	Dec 7-8/00	12	36.8	2.4%	6.8%	10.3%	13.3%	23.4%	44.3%	67.7%	87.0%	95.4%	100.0%
39	Jan 20/01	12	12.5	4.0%	12.0%	23.2%	32.8%	45.6%	56.8%	76.0%	92.8%	98.4%	100.0%
40	Apr 10/99	13	17.1	1.2%	8.8%	12.3%	17.5%	25.1%	46.2%	56.7%	72.5%	96.5%	100.0%
41	Apr 21/00	14	21.3	6.6%	23.5%	46.0%	54.9%	77.9%	93.9%	98.1%	99.1%	99.5%	100.0%
42	Mar 5/00	14	15.5	3.2%	11.6%	23.2%	36.8%	47.1%	54.2%	57.4%	76.1%	96.1%	100.0%
43	Dec 23/00	14	14.3	6.3%	17.5%	42.0%	51.7%	62.2%	73.4%	96.5%	97.9%	99.3%	100.0%
44	Feb 28/99	14	14.2	7.7%	36.6%	61.3%	73.2%	78.9%	84.5%	89.4%	97.2%	99.3%	100.0%
45	Dec 15/00	14	12.4	3.2%	5.6%	25.0%	56.5%	90.3%	96.0%	96.8%	96.8%	99.2%	100.0%
46	Dec 29/99	14	15.4	1.3%	6.5%	11.7%	29.2%	45.5%	58.4%	72.1%	89.0%	96.8%	100.0%
47	Jun 30/00	14	17.5	6.3%	20.6%	28.0%	37.7%	58.9%	84.0%	89.1%	90.9%	98.9%	100.0%
48	Sep 24-25/00	14	15.4	0.6%	3.2%	15.6%	28.6%	42.9%	49.4%	63.6%	76.6%	98.7%	100.0%
49	Sep 27/00	14	22.4	0.4%	1.8%	13.8%	34.8%	79.9%	85.7%	94.6%	97.3%	98.2%	100.0%
50	May 24/00	15	14.6	4.1%	11.6%	16.4%	19.9%	33.6%	74.0%	86.3%	94.5%	99.3%	100.0%
51	May 21-22/99	15	23.4	11.1%	35.0%	78.2%	81.6%	82.5%	82.5%	82.5%	82.5%	94.9%	100.0%
52	Dec 22/01	15	33.4	5.7%	18.0%	22.8%	27.5%	34.4%	56.0%	80.2%	95.2%	97.9%	100.0%
53	Dec 19/01	15	41.5	5.3%	14.0%	27.0%	42.4%	57.3%	73.7%	80.7%	92.5%	97.6%	100.0%
54	May 26-27/99	15	17.8	2.2%	28.7%	44.4%	53.4%	53.4%	53.4%	56.7%	60.7%	75.8%	100.0%
55	Nov 27-28/00	16	36.4	6.3%	13.2%	32.7%	46.7%	61.3%	79.9%	86.3%	96.4%	98.9%	100.0%
56	Nov 7/01	16	30.4	3.0%	6.2%	8.2%	22.0%	41.1%	56.6%	87.5%	90.1%	92.1%	100.0%
57	Jan 20/00	16	38.4	4.4%	20.6%	47.4%	76.6%	91.1%	94.3%	95.1%	95.8%	96.4%	100.0%
58	Jun 17-18/99	17	18.8	2.1%	10.1%	15.4%	18.6%	25.5%	29.8%	43.6%	75.0%	97.9%	100.0%
59	Apr 10-11/00	17	14.1	3.5%	5.0%	12.1%	12.8%	20.6%	28.4%	45.4%	75.9%	96.5%	100.0%
60	Oct 3-4/00	17	56.5	4.8%	25.1%	57.7%	72.0%	85.5%	92.7%	92.9%	93.3%	94.7%	100.0%
61	Nov 17-18/00	17	27.2	3.7%	12.5%	24.3%	43.0%	58.5%	83.5%	88.2%	91.9%	97.1%	100.0%
62	Feb 6-7/99	18	29.1	9.6%	19.6%	38.8%	49.1%	49.8%	71.8%	96.9%	98.6%	99.3%	100.0%
63	Mar 24-25/01	19	20.1	4.0%	9.5%	11.9%	13.9%	19.4%	39.3%	62.7%	88.6%	89.1%	100.0%
64	Nov 5-6/01	20	27.6	0.7%	1.1%	1.8%	2.2%	44.6%	49.3%	61.6%	84.1%	98.9%	100.0%
65	Oct 30/01	20	48.1	1.9%	8.5%	17.9%	31.2%	44.9%	63.0%	75.9%	91.3%	99.6%	100.0%
66	Dec 7/99	21	12.0	6.7%	20.0%	35.8%	50.8%	75.0%	75.0%	75.8%	79.2%	85.0%	100.0%
67	Jul 27-28/99	21	34.8	7.2%	30.7%	49.7%	72.7%	87.4%	90.8%	96.0%	97.7%	99.4%	100.0%
68	Aug 28/01	22	19.9	6.5%	8.0%	8.0%	8.0%	56.8%	86.4%	97.0%	98.5%	99.0%	100.0%
69	Nov 5-6/00	24	47.4	6.8%	13.5%	29.7%	54.4%	66.2%	72.2%	73.4%	74.5%	86.7%	100.0%
70	Jun 19/99	25	20.1	18.4%	18.4%	18.9%	61.2%	85.6%	89.1%	95.5%	97.5%	98.0%	100.0%
71	Apr 5-6/99	25	23.7	9.3%	32.1%	55.3%	70.9%	83.5%	88.2%	92.8%	96.2%	96.6%	100.0%
72	Jan 10-11/99	31	69.7	0.7%	3.4%	19.1%	27.0%	43.8%	64.7%	83.5%	89.1%	97.4%	100.0%

Windsor Lake Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
73	Sep 26-28/01	31	37.8	0.8%	1.9%	11.9%	29.6%	58.2%	81.5%	83.1%	87.0%	98.7%	100.0%
74	Nov 6-7/99	33	47.8	11.3%	24.1%	60.0%	68.4%	72.8%	74.9%	98.7%	99.4%	99.6%	100.0%
75	Apr 2-3/01	34	60.7	5.6%	11.4%	15.2%	31.0%	47.9%	78.7%	92.1%	97.0%	99.3%	100.0%
76	Dec 1-2/99	35	22.4	26.3%	74.1%	83.0%	83.9%	89.7%	90.2%	92.9%	94.2%	95.5%	100.0%
77	Jul 31/00	37	32.0	3.1%	8.7%	24.7%	27.5%	65.3%	77.2%	83.4%	98.1%	99.1%	100.0%
78	Apr13-14/99	37	46.5	29.5%	61.3%	71.4%	85.2%	87.3%	89.0%	94.6%	97.0%	98.3%	100.0%
79	Oct 28-30/00	39	84.9	9.4%	15.1%	16.7%	17.4%	25.4%	59.2%	79.4%	93.9%	98.9%	100.0%
80	Oct 29-31/99	39	84.9	9.4%	15.1%	16.7%	17.4%	25.4%	59.2%	79.4%	93.9%	98.9%	100.0%
81	Feb 27-28/01	45	39.8	4.3%	17.3%	21.9%	38.7%	56.3%	87.7%	91.7%	92.0%	96.7%	100.0%
82	Oct 4-6/99	49	45.6	24.1%	25.2%	37.9%	52.4%	71.7%	80.9%	85.7%	87.1%	91.9%	100.0%
83	Dec 1-3/00	52	24.7	22.7%	38.5%	54.3%	67.2%	76.1%	85.0%	88.3%	91.1%	95.1%	100.0%
84	Mar 17-19/00	54	71.9	0.8%	1.4%	3.2%	15.9%	42.0%	83.4%	92.1%	95.5%	97.9%	100.0%
85	Dec 14-16/99	55	52.3	5.4%	16.3%	28.5%	49.5%	67.3%	73.8%	82.6%	91.6%	97.3%	100.0%
86	Mar 11-14/99	56	82.8	13%	16%	21%	36%	44%	63%	76%	84%	93%	100%
87	Apr 28-30/99	75	119.7	11%	31%	59%	87%	88%	92%	95%	97%	99%	100%
88	Nov 8-12/00	103	55.2	3%	39%	41%	44%	53%	58%	60%	67%	93%	100%

APPENDIX E

PERCENT CUMULATIVE RAINFALL

WINDSOR LAKE TEMPORAL DISTRIBUTION

Percent Cumulative Rainfall - Windsor Lake Temporal Distribution

		Percent Storm Duration									
		10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Probability of Exceedance	**10%**	11.2%	34.1%	54.3%	70.9%	85.5%	90.8%	96.8%	98.8%	99.8%	100.0%
	20%	8.0%	22.1%	40.9%	56.5%	75.4%	87.5%	94.9%	97.9%	99.3%	100.0%
	30%	6.5%	18.4%	32.4%	50.8%	68.9%	83.5%	92.7%	97.0%	99.3%	100.0%
	40%	4.4%	15.1%	27.2%	42.0%	58.9%	79.6%	90.2%	95.8%	99.0%	100.0%
	50%	3.3%	11.6%	22.8%	34.8%	55.6%	74.4%	86.3%	94.5%	98.7%	100.0%
	60%	2.2%	8.5%	16.7%	31.0%	45.6%	71.7%	82.6%	92.8%	98.2%	100.0%
	70%	1.7%	5.7%	12.3%	25.7%	42.0%	59.2%	79.4%	91.1%	97.3%	100.0%
	80%	0.9%	3.4%	10.8%	17.8%	34.4%	54.2%	73.7%	87.0%	96.4%	100.0%
	90%	0.6%	2.1%	5.2%	12.8%	25.4%	46.2%	59.8%	76.6%	92.8%	100.0%

APPENDIX F

BLACKLER AVENUE TEMPORAL DISTRIBUTION RAINFALL EVENTS

Blackler Avenue Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
1	July 12/01	2	25.8	0.0%	1.2%	8.1%	36.0%	64.7%	97.7%	99.6%	100.0%	100.0%	100.0%
2	Jun 8/00	5	12.4	0.0%	11.3%	27.4%	46.0%	50.0%	66.1%	73.4%	80.6%	92.7%	100.0%
3	Sep 17/00	5	26.3	0.0%	5.3%	43.7%	67.7%	95.4%	99.2%	99.6%	99.6%	99.6%	100.0%
4	Aug 10-11/00	6	15.0	0.7%	20.0%	83.3%	84.7%	84.7%	90.7%	94.7%	94.7%	97.3%	100.0%
5	May 25/00	6	17.7	2.8%	8.5%	10.7%	14.1%	29.9%	58.2%	80.2%	98.9%	100.0%	100.0%
6	Dec 27/01	7	31.2	0.3%	1.6%	7.4%	24.4%	46.2%	58.7%	80.4%	92.3%	99.0%	100.0%
7	Apr 19/01	7	14.4	0.7%	3.5%	3.5%	5.6%	47.2%	93.8%	96.5%	97.9%	98.6%	100.0%
8	Aug 8/00	7	14.9	2.0%	5.4%	19.5%	33.6%	54.4%	77.2%	88.6%	94.0%	99.3%	100.0%
9	Sep 14-15/01	7	33.7	2.1%	31.8%	34.4%	38.0%	44.5%	56.4%	76.6%	91.4%	98.8%	100.0%
10	Dec 29/01	8	13.7	0.7%	2.2%	6.6%	19.7%	29.9%	56.9%	70.8%	88.3%	97.8%	100.0%
11	Oct 19/00	8	23.1	6.1%	15.2%	33.3%	46.3%	52.4%	66.2%	77.5%	93.9%	99.6%	100.0%
12	Sep 2/01	8	12.1	0.0%	28.9%	46.3%	49.6%	62.0%	66.9%	81.0%	91.7%	100.0%	100.0%
13	Oct 8/00	8	15.8	55.7%	56.3%	56.3%	59.5%	60.1%	60.1%	60.1%	60.1%	67.1%	100.0%
14	Mar 10-11/01	8	23.4	1.3%	14.5%	29.5%	44.0%	62.0%	77.8%	90.2%	95.3%	98.3%	100.0%
15	Jun 3/00	9	12.5	4.0%	7.2%	25.6%	47.2%	64.8%	89.6%	94.4%	95.2%	95.2%	100.0%
16	Dec 26/01	9	23.1	0.4%	1.7%	2.6%	4.8%	11.7%	32.9%	57.1%	83.1%	95.7%	100.0%
17	Jun 7/00	9	12.7	4.7%	15.0%	34.6%	58.3%	88.2%	92.9%	94.5%	98.4%	99.2%	100.0%
18	Aug 24-25/01	9	16.3	1.2%	6.7%	13.5%	75.5%	85.9%	87.7%	91.4%	98.8%	100.0%	100.0%
19	Oct 7/01	10	14.4	0.7%	4.9%	34.7%	51.4%	59.7%	66.7%	77.1%	84.0%	97.2%	100.0%
20	May 17-18/01	11	13.0	3.1%	4.6%	15.4%	53.1%	58.5%	70.0%	88.5%	92.3%	98.5%	100.0%
21	Feb 15/01	11	49.2	0.2%	0.8%	1.8%	3.3%	3.3%	10.2%	39.2%	76.6%	99.6%	100.0%
22	Sep 27/00	12	15.1	6.6%	19.9%	41.1%	74.2%	84.1%	94.0%	98.0%	98.7%	99.3%	100.0%
23	Jun 30/00	13	15.8	3.8%	17.7%	20.3%	28.5%	52.5%	70.9%	85.4%	88.0%	94.3%	100.0%
24	Sep 24-25/00	13	15.2	0.7%	9.2%	16.4%	32.2%	38.8%	46.7%	63.8%	77.6%	98.0%	100.0%
25	Nov 5-6/01	14	25.1	23.1%	49.0%	51.4%	57.0%	64.9%	84.1%	92.4%	96.8%	98.8%	100.0%
26	May 30-31/01	14	25.5	5.1%	8.6%	10.2%	20.8%	22.4%	25.1%	60.0%	82.7%	96.5%	100.0%
27	Dec 12-13/00	14	33.2	3.9%	6.9%	10.2%	37.3%	55.1%	90.1%	97.6%	99.1%	99.1%	100.0%
28	Mar 17-18/00	15	54.5	0.4%	2.2%	3.7%	9.7%	17.4%	23.5%	31.9%	46.1%	89.5%	100.0%
29	Mar 14-15/01	15	39.5	1.3%	3.5%	12.2%	34.4%	64.6%	89.4%	98.2%	99.2%	99.2%	100.0%
30	Dec 22/01	16	28.2	0.7%	6.4%	17.7%	22.3%	26.2%	48.6%	75.2%	94.7%	98.2%	100.0%
31	Aug 28/01	16	14.0	1.4%	2.1%	2.9%	2.9%	2.9%	12.1%	83.6%	97.1%	97.9%	100.0%
32	Dec 15/00	16	24.1	1.7%	2.1%	10.8%	18.7%	50.2%	69.3%	75.9%	75.9%	88.8%	100.0%
33	Nov 7/01	16	29.9	2.3%	5.4%	6.7%	21.1%	43.1%	68.2%	92.0%	93.6%	95.0%	100.0%
34	Dec 18-19/01	16	53.2	2.8%	13.9%	26.3%	39.5%	55.1%	74.6%	80.1%	92.3%	98.3%	100.0%
35	Nov 17-18/00	17	33.6	3.9%	14.9%	27.1%	44.9%	61.9%	88.4%	92.0%	97.0%	99.1%	100.0%
36	Mar 23-24/01	17	24.4	2.5%	4.9%	9.0%	12.7%	29.9%	45.1%	70.9%	86.9%	90.6%	100.0%

Blackler Avenue Temporal Distribution Rainfall Events

No.	Date	Duration	Rain (mm)	10.00%	20.00%	30.00%	40.00%	50.00%	60.00%	70.00%	80.00%	90.00%	100.00%
37	Nov 27-28/00	17	27.5	8.4%	17.5%	42.5%	58.9%	62.5%	70.5%	82.2%	93.5%	98.9%	100.0%
38	Dec 7-8/00	17	28.9	2.4%	4.8%	9.3%	37.4%	81.7%	90.7%	96.2%	97.2%	99.0%	100.0%
39	Oct 3-4/00	18	54.9	1.3%	13.8%	45.7%	68.1%	79.8%	88.9%	90.3%	94.2%	94.2%	100.0%
40	Oct 30/01	19	33.3	3.6%	10.2%	18.3%	29.1%	42.3%	56.2%	71.2%	82.3%	97.0%	100.0%
41	Jan 20/01	20	13.8	1.4%	9.4%	21.7%	34.1%	46.4%	69.6%	92.8%	97.8%	99.3%	100.0%
42	Dec 23/00	20	20.6	2.4%	10.7%	17.5%	43.7%	78.2%	90.3%	94.2%	94.7%	97.6%	100.0%
43	Jul 11/00	20	12.4	0.8%	8.9%	9.7%	9.7%	10.5%	10.5%	12.1%	28.2%	65.3%	100.0%
44	Nov 8/00	21	18.9	2.1%	2.6%	2.6%	3.2%	3.7%	13.2%	92.6%	98.4%	98.9%	100.0%
45	Sep 27/01	21	32.4	3.7%	9.0%	22.2%	47.8%	77.2%	87.0%	89.2%	89.8%	92.9%	100.0%
46	Nov 11/00	24	13.8	0.7%	1.4%	5.1%	13.8%	15.2%	18.8%	21.7%	85.5%	97.1%	100.0%
47	Oct 4-5/00	25	41.5	1.7%	6.5%	26.5%	49.6%	53.3%	54.2%	54.7%	65.3%	94.2%	100.0%
48	Apr 2-3/01	26	21.6	0.9%	1.4%	3.2%	5.6%	23.1%	56.0%	92.1%	93.1%	97.7%	100.0%
49	Jul 30-31/00	30	21.2	3.8%	13.2%	31.1%	40.6%	41.0%	60.8%	83.5%	91.5%	94.3%	100.0%
50	Feb 27-28/01	31	25.3	0.8%	3.2%	16.2%	17.0%	27.3%	39.9%	54.5%	76.7%	94.9%	100.0%
51	Oct 28-29/00	37	51.7	12.0%	24.0%	25.5%	25.7%	34.0%	66.0%	81.2%	92.8%	99.0%	100.0%

APPENDIX G

PERCENT CUMULATIVE RAINFALL

BLACKLER AVENUE TEMPORAL DISTRIBUTION

Percent Cumulative Rainfall - Blackler Avenue Temporal Distribution

		Percent Storm Duration									
Prob. of Exceed.		**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
	10%	6.6%	24.0%	45.7%	67.7%	84.1%	92.9%	97.6%	98.9%	99.6%	100.0%
	20%	3.9%	15.2%	34.6%	53.1%	64.9%	89.6%	94.4%	97.9%	99.3%	100.0%
	30%	3.6%	13.8%	27.4%	47.2%	62.0%	87.0%	92.1%	96.8%	99.0%	100.0%
	40%	2.4%	9.4%	25.5%	43.7%	58.5%	70.9%	90.2%	94.7%	98.8%	100.0%
	50%	2.0%	8.5%	18.3%	37.3%	52.5%	68.2%	83.6%	93.5%	98.3%	100.0%
	60%	1.3%	5.4%	13.5%	29.1%	46.2%	60.8%	80.2%	91.7%	97.6%	100.0%
	70%	0.8%	4.8%	10.2%	21.1%	38.8%	56.4%	75.9%	88.0%	96.5%	100.0%
	80%	0.7%	2.6%	7.4%	14.1%	27.3%	46.7%	70.8%	82.7%	94.3%	100.0%
	90%	0.3%	1.7%	3.5%	5.6%	15.2%	23.5%	54.7%	76.6%	92.7%	100.0%

APPENDIX H

KOLMOGOROV-SMIRNOV TEST FOR 10%-90% PROBABILITY CURVES

Kolomogorov Smirnov Test - 10 % Probabilities								
10% Network	10% Ruby	D	10% Network	10% Windsor	D	10% Network	10% Depot	D
0.130	0.110	0.019	0.130	0.112	0.018	0.130	0.066	0.064
0.353	0.320	0.033	0.353	0.341	0.012	0.353	0.240	0.113
0.518	0.508	0.010	0.518	0.543	0.024	0.518	0.457	0.061
0.754	0.735	0.019	0.754	0.709	0.045	0.754	0.677	0.077
0.870	0.855	0.015	0.870	0.855	0.016	0.870	0.841	0.029
0.929	0.930	0.001	0.929	0.908	0.021	0.929	0.929	0.000
0.964	0.972	0.008	0.964	0.968	0.004	0.964	0.976	0.012
0.984	0.986	0.001	0.984	0.988	0.004	0.984	0.989	0.004
0.996	0.995	0.000	0.996	0.998	0.002	0.996	0.996	0.000
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.000	0.000
	Dmax	0.033		Dmax	0.045		Dmax	0.113
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 20 % Probabilities								
20% Network	20% Ruby	D	20% Network	20% Windsor	D	20% Network	20% Depot	D
0.081	0.060	0.020	0.081	0.080	0.000	0.081	0.0392	0.041
0.214	0.230	0.016	0.214	0.221	0.007	0.214	0.1515	0.062
0.387	0.391	0.003	0.387	0.409	0.022	0.387	0.3465	0.041
0.645	0.603	0.042	0.645	0.565	0.081	0.645	0.5308	0.115
0.834	0.764	0.070	0.834	0.754	0.080	0.834	0.6494	0.184
0.898	0.892	0.007	0.898	0.875	0.023	0.898	0.8960	0.002
0.943	0.938	0.005	0.943	0.949	0.006	0.943	0.9440	0.001
0.978	0.976	0.002	0.978	0.979	0.001	0.978	0.9792	0.001
0.993	0.993	0.000	0.993	0.993	0.000	0.993	0.9928	0.001
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.070		Dmax	0.081		Dmax	0.184
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 30 % Probabilities								
30% Network	30% Ruby	D	30% Network	30% Windsor	D	30% Network	30% Depot	D
0.055	0.048	0.007	0.055	0.065	0.010	0.055	0.0360	0.019
0.177	0.159	0.018	0.177	0.184	0.007	0.177	0.1384	0.039
0.366	0.344	0.021	0.366	0.324	0.041	0.366	0.2742	0.092
0.554	0.517	0.038	0.554	0.508	0.046	0.554	0.4720	0.082
0.747	0.683	0.064	0.747	0.689	0.057	0.747	0.6198	0.127
0.866	0.831	0.035	0.866	0.835	0.032	0.866	0.8704	0.004
0.914	0.924	0.011	0.914	0.927	0.013	0.914	0.9213	0.008
0.969	0.969	0.001	0.969	0.970	0.001	0.969	0.9681	0.001
0.991	0.992	0.001	0.991	0.993	0.002	0.991	0.9904	0.001
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.064		Dmax	0.057		Dmax	0.127
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 40 % Probabilities								
40% Network	40% Ruby	D	40% Network	40% Windsor	D	40% Network	40% Depot	D
0.040	0.038	0.002	0.040	0.044	0.004	0.040	0.0243	0.016
0.147	0.130	0.017	0.147	0.151	0.004	0.147	0.0942	0.052
0.275	0.296	0.021	0.275	0.272	0.003	0.275	0.2553	0.020
0.463	0.461	0.002	0.463	0.420	0.044	0.463	0.4369	0.026
0.622	0.609	0.013	0.622	0.589	0.034	0.622	0.5846	0.037
0.800	0.776	0.024	0.800	0.796	0.004	0.800	0.7089	0.091
0.884	0.897	0.013	0.884	0.902	0.018	0.884	0.9017	0.018
0.959	0.957	0.002	0.959	0.958	0.001	0.959	0.9466	0.012
0.989	0.989	0.000	0.989	0.990	0.001	0.989	0.9881	0.001
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.024		Dmax	0.044		Dmax	0.091
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 50 % Probabilities								
50% Network	50% Ruby	D	50% Network	50% Windsor	D	50% Network	50% Depot	D
0.0282	0.0240	0.004	0.0282	0.0326	0.004	0.0282	0.0201	0.008
0.1186	0.0932	0.025	0.1186	0.1164	0.002	0.1186	0.0847	0.034
0.2259	0.2148	0.011	0.2259	0.2275	0.002	0.2259	0.1832	0.043
0.4134	0.3828	0.031	0.4134	0.3482	0.065	0.4134	0.3735	0.040
0.5590	0.5656	0.007	0.5590	0.5563	0.003	0.5590	0.5253	0.034
0.7547	0.7252	0.029	0.7547	0.7443	0.010	0.7547	0.6823	0.072
0.8659	0.8496	0.016	0.8659	0.8630	0.003	0.8659	0.8357	0.030
0.9462	0.9457	0.000	0.9462	0.9453	0.001	0.9462	0.9345	0.012
0.9858	0.9849	0.001	0.9858	0.9868	0.001	0.9858	0.9829	0.003
1.0000	1.0000	0.000	1.0000	1.0000	0.000	1.0000	1.0000	0.000
	Dmax	0.031		Dmax	0.065			0.072
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 60 % Probabilities								
60% Network	60% Ruby	D	60% Network	60% Windsor	D	60% Network	60% Depot	D
0.022	0.016	0.005	0.022	0.022	0.001	0.022	0.0128	0.009
0.082	0.072	0.010	0.082	0.085	0.003	0.082	0.0537	0.028
0.201	0.183	0.018	0.201	0.167	0.034	0.201	0.1350	0.066
0.338	0.317	0.021	0.338	0.310	0.029	0.338	0.2913	0.047
0.524	0.494	0.030	0.524	0.456	0.068	0.524	0.4615	0.063
0.717	0.689	0.028	0.717	0.717	0.000	0.717	0.6085	0.109
0.848	0.823	0.025	0.848	0.826	0.022	0.848	0.8023	0.046
0.932	0.921	0.011	0.932	0.928	0.004	0.932	0.9174	0.015
0.983	0.978	0.005	0.983	0.982	0.001	0.983	0.9757	0.007
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.030		Dmax	0.068		Dmax	0.109
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 70 % Probabilities								
70% Network	70% Ruby	D	70% Network	70% Windsor	D	70% Network	70% Depot	D
0.015	0.011	0.004	0.015	0.017	0.002	0.015	0.0079	0.007
0.056	0.058	0.002	0.056	0.057	0.001	0.056	0.0484	0.007
0.148	0.132	0.016	0.148	0.123	0.025	0.148	0.1020	0.046
0.300	0.261	0.038	0.300	0.257	0.042	0.300	0.2107	0.089
0.467	0.441	0.026	0.467	0.420	0.047	0.467	0.3882	0.079
0.649	0.643	0.007	0.649	0.592	0.057	0.649	0.5638	0.086
0.795	0.766	0.028	0.795	0.794	0.001	0.795	0.7593	0.035
0.899	0.899	0.001	0.899	0.911	0.012	0.899	0.8797	0.019
0.973	0.968	0.005	0.973	0.973	0.000	0.973	0.9647	0.008
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.038		Dmax	0.057		Dmax	0.089
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 80 % Probabilities								
80% Network	80% Ruby	D	80% Network	80% Windsor	D	80% Network	80% Depot	D
0.010	0.007	0.004	0.010	0.009	0.001	0.010	0.0069	0.004
0.043	0.035	0.008	0.043	0.034	0.008	0.043	0.0265	0.016
0.105	0.097	0.008	0.105	0.108	0.003	0.105	0.0737	0.031
0.223	0.214	0.009	0.223	0.178	0.045	0.223	0.1412	0.082
0.395	0.375	0.020	0.395	0.344	0.051	0.395	0.2727	0.123
0.564	0.522	0.043	0.564	0.542	0.022	0.564	0.4671	0.097
0.763	0.702	0.061	0.763	0.737	0.026	0.763	0.7080	0.055
0.867	0.848	0.019	0.867	0.870	0.003	0.867	0.8275	0.040
0.965	0.953	0.011	0.965	0.964	0.001	0.965	0.9434	0.021
1.000	1.000	0.000	1.000	1.000	0.000	1.000	1.0000	0.000
	Dmax	0.061		Dmax	0.051		Dmax	0.123
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

Kolomogorov Smirnov Test - 90 % Probabilities								
90% Network	90% Ruby	D	90% Network	90% Windsor	D	90% Network	90% Depot	D
0.0048	0.0047	0.000	0.0048	0.0060	0.001	0.0048	0.0032	0.002
0.0249	0.0196	0.005	0.0249	0.0208	0.004	0.0249	0.0173	0.008
0.0764	0.0686	0.008	0.0764	0.0522	0.024	0.0764	0.0347	0.042
0.1386	0.1118	0.027	0.1386	0.1277	0.011	0.1386	0.0556	0.083
0.2889	0.2444	0.044	0.2889	0.2544	0.034	0.2889	0.1522	0.137
0.4673	0.4011	0.066	0.4673	0.4620	0.005	0.4673	0.2349	0.232
0.6501	0.6215	0.029	0.6501	0.5978	0.052	0.6501	0.5470	0.103
0.7613	0.7975	0.036	0.7613	0.7662	0.005	0.7613	0.7663	0.005
0.9418	0.9146	0.027	0.9418	0.9275	0.014	0.9418	0.9274	0.014
1.0000	1.0000	0.000	1.0000	1.0000	0.000	1.0000	1.0000	0.000
	Dmax	0.066		Dmax	0.052		Dmax	0.232
	Dcrit	0.409		Dcrit	0.409		Dcrit	0.409

APPENDIX I

MONTHLY RAINFALL SUMMARIES

Monthly Rainfall Summaries			
Month/Year	Ruby Line	Windsor Lake	Blackler Avenue
Jan/99	132.4	130.6	n/a
Feb/99	127.3	127.8	n/a
Mar/99	205.4	168.8	n/a
Apr/99	255.7	246.6	n/a
May/99	93.2	86.8	n/a
Jun/99	85.2	101.2	n/a
Jul/99	73.6	77.5	n/a
Aug/99	64.3	51.1	n/a
Sep/99	65.9	61.7	n/a
Oct/99	183.0	188.2	n/a
Nov/99	133.8	182.8	n/a
Dec/99	110.2	116.8	n/a
Jan/00	156.1	173.4	n/a
Feb/00	56.4	41.5	n/a
Mar/00	135.1	130.2	n/a
Apr/00	80.0	95.3	n/a
May/00	81.6	68.8	59.2
Jun/00	76.6	77.3	68.7
Jul/00	105.4	81.0	72.7
Aug/00	88.7	90.9	70.0
Sep/00	80.8	96.6	75.1
Oct/00	207.8	231.7	183.9
Nov/00	207.0	212.7	166.5
Dec/00	162.9	141.0	138.2
Jan/01	81.3	81.2	53.5
Feb/01	135.4	141.4	113.7
Mar/01	85.0	97.8	101.2
Apr/01	105.7	107.1	54.6
May/01	88.2	102.1	70.5
Jun/01	38.2	31.0	32.4
Jul/01	49.6	82.2	62.7
Aug/01	55.8	50.8	51.3
Sep/01	279.0	291.7	223.8
Oct/01	77.2	80.5	60.0
Nov/01	112.6	110.8	95.9
Dec/01	185.9	200.0	183.1

APPENDIX J

COMBINED ANNUAL MAXIMA RAINFALL DATA

WINDSOR LAKE / ST. JOHN'S AIRPORT

Combined Annual Maxima Rainfall Data for Windsor Lake / St. John's Airport									
Year	**5min**	**10min**	**15min**	**30min**	**1 hr**	**2 hr**	**6 hr**	**12 hr**	**24 hr**
1949	8.9	8.9	10.2	17.5	28.2	52.6	61.7	62.0	63.5
1961	3.0	4.3	5.3	6.9	8.6	13.5	25.7	35.6	38.6
1962	2.8	4.6	4.6	8.1	13.0	20.6	33.8	54.9	59.7
1963	10.2	11.2	11.7	13.7	18.5	23.6	40.9	62.3	57.9
1964	4.3	6.9	7.9	11.2	19.3	28.2	54.9	72.6	77.5
1965	5.3	7.4	9.9	13.0	17.8	19.6	32.3	51.8	59.7
1966	8.4	13.2	17.0	25.4	29.7	43.7	48.5	64.5	85.3
1967	2.3	3.8	5.3	9.9	10.9	16.3	29.5	44.4	58.4
1968	6.3	12.7	13.7	14.7	17.5	22.4	41.9	55.1	61.7
1969	5.6	7.1	8.4	8.6	11.7	19.0	30.7	34.5	48.3
1970	5.6	7.1	10.7	15.2	16.3	19.6	42.4	62.5	87.4
1971	6.3	10.4	14.5	16.0	19.0	22.1	34.3	41.1	77.7
1972	4.8	5.3	6.6	10.9	15.0	20.6	47.8	72.6	89.2
1973	5.3	6.9	7.9	10.4	16.5	30.0	49.5	65.8	67.1
1974	3.6	5.6	6.3	9.9	16.3	22.4	42.4	53.3	72.9
1975	8.1	10.4	12.2	17.8	19.0	19.6	46.5	71.9	82.3
1976	3.6	4.8	6.1	8.4	12.7	19.0	33.8	42.2	53.6
1977	3.8	5.6	7.6	11.7	17.5	23.4	38.6	40.4	41.4
1978	4.0	5.9	7.4	7.6	12.9	13.1	27.1	37.6	43.0
1979	3.2	4.2	5.9	10.2	16.2	18.1	29.3	41.9	49.2
1980	3.2	6.1	7.4	12.2	17.4	23.9	33.6	41.6	69.8
1981	n/a	n/a	n/a	n/a	15.0	22.4	46.7	72.5	82.6
1982	5.1	9.0	12.9	17.1	24.5	35.9	80.3	82.4	84.0
1983	1.6	3.2	4.8	9.6	19.2	26.5	47.3	52.8	54.7
1984	5.0	9.9	13.0	21.5	27.1	36.6	61.0	74.0	75.3
1985	5.2	7.1	9.8	11.3	14.1	18.5	36.0	54.9	82.9

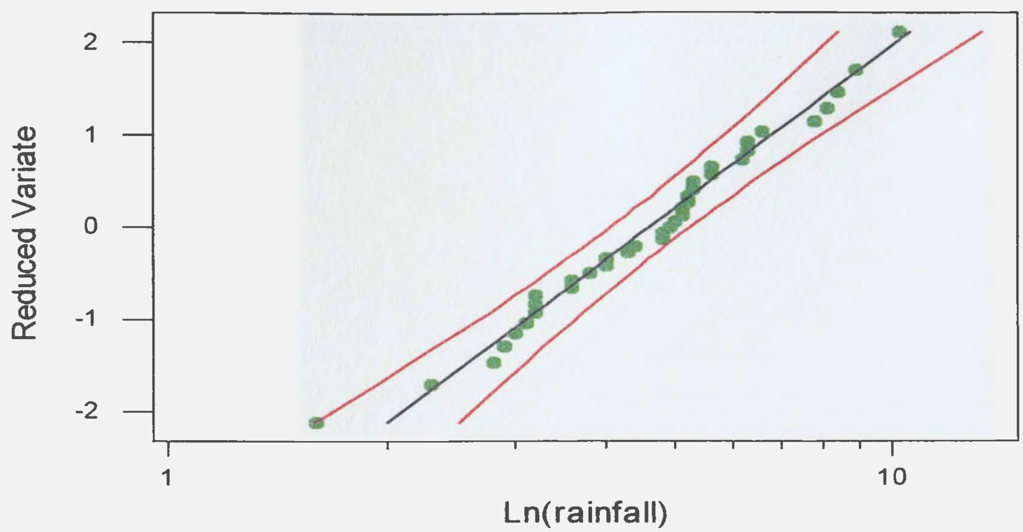
Combined Annual Maxima Rainfall Data for Windsor Lake / St. John's Airport (cont.)									
Year	**5min**	**10min**	**15min**	**30min**	**1 hr**	**2 hr**	**6 hr**	**12 hr**	**24 hr**
1986	3.1	3.1	7.2	14.3	23.3	27.9	40.2	58.9	70.6
1987	5.1	5.1	8.6	16.2	23.5	24.2	30.6	36.6	46.8
1988	6.6	6.6	13.2	17.4	23.4	25.9	44.8	45.8	49.0
1989	2.9	2.9	6.2	8.0	10.9	19.7	43.4	51.6	51.6
1990	n/a	n/a	n/a	n/a	n/a	n/a	43.5	n/a	83.4
1991	7.8	11.4	15.9	23.3	28.8	29.5	51.2	51.6	51.8
1992	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	48.2
1993	4.4	7.0	7.6	11.5	20.0	31.3	47.5	49.3	51.2
1994	6.2	9.1	10.3	12.6	12.8	14.8	24.4	36.4	67.5
1995	5.2	7.3	14.5	16.6	27.6	46.7	53.3	58.1	58.7
1996	4.8	6.2	7.4	10.2	15.4	27.2	40.2	44.0	44.4
1999	3.2	3.2	7.5	8.9	15.2	25.3	42.1	63.1	99.6
2000	4.0	4.0	9.1	13.3	21.9	29.9	43.3	59.0	70.5
2001	5.0	5.0	11.9	19.6	33.7	61.9	107.3	147.7	149.6

APPENDIX K

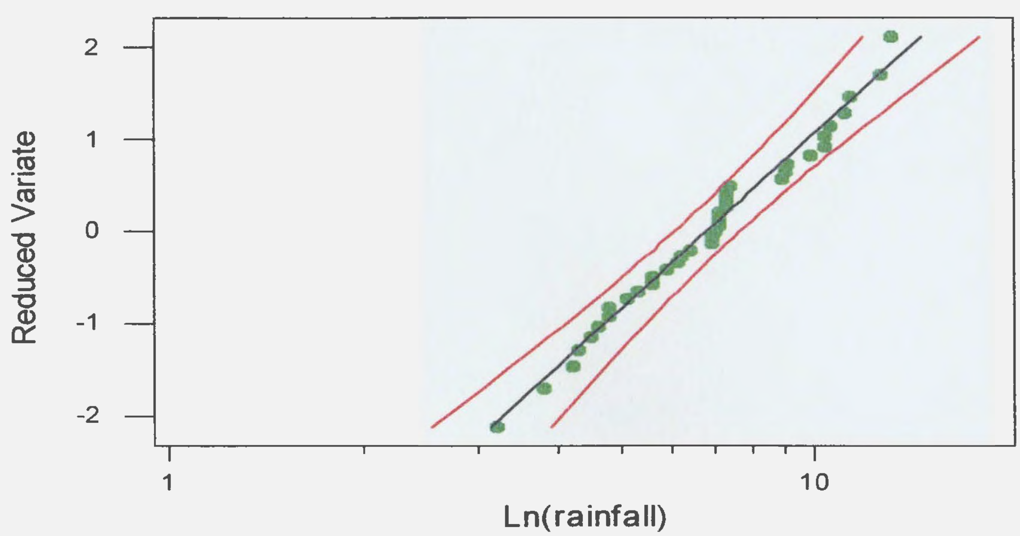
LOGNORMAL PROBABILITY PLOTS

FOR L-MOMENT ESTIMATORS

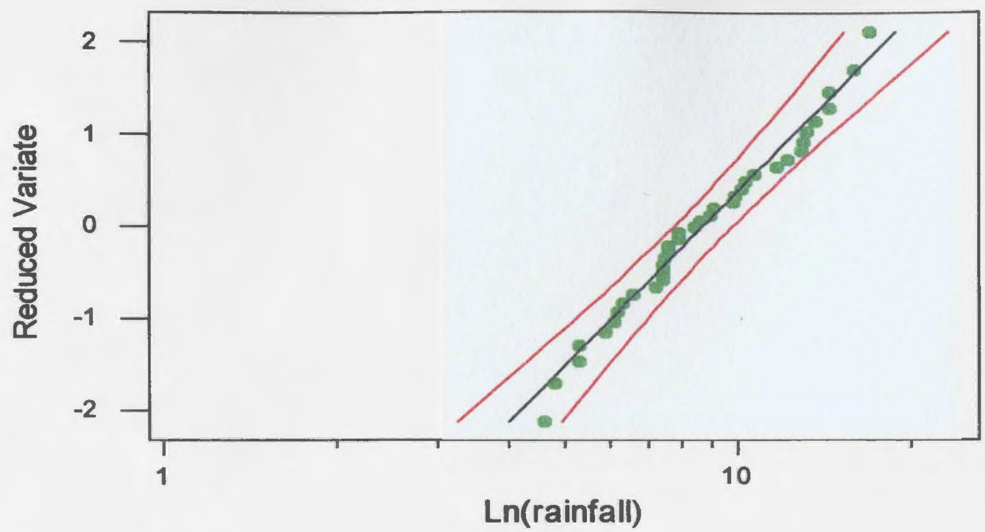
Lognormal Probability Plot for 5-Minute Annual Extrema



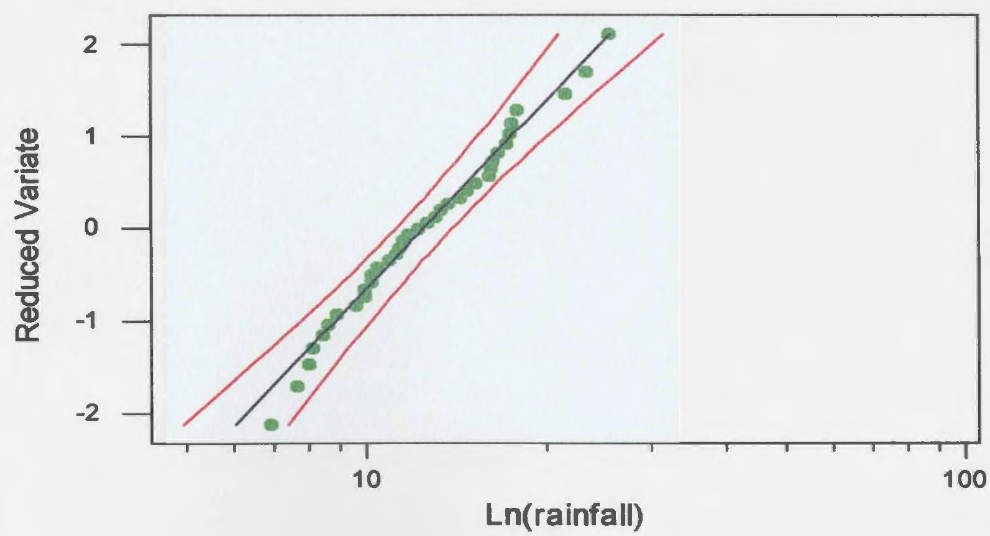
Lognormal Probability Plot for 10-Minute Annual Extrema



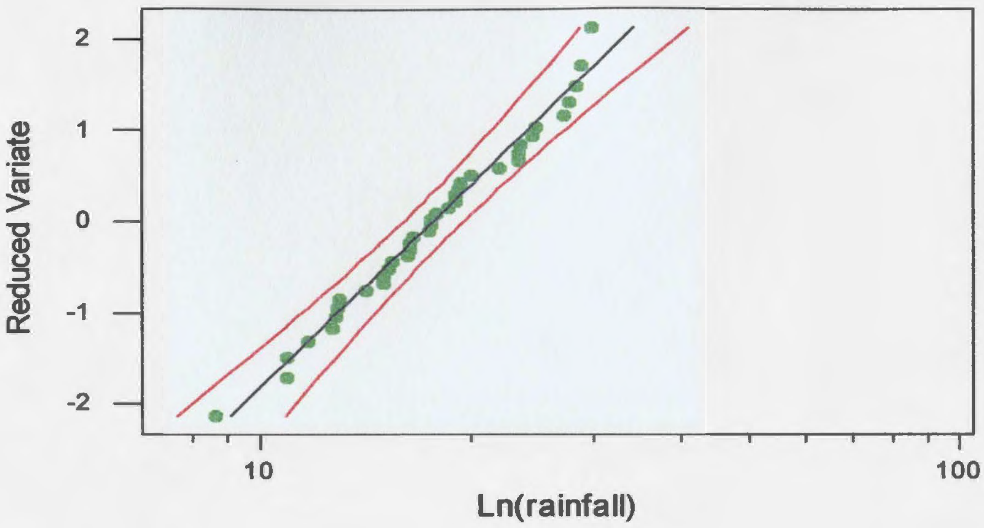
Lognormal Probability Plot for 15-Minute Annual Extrema



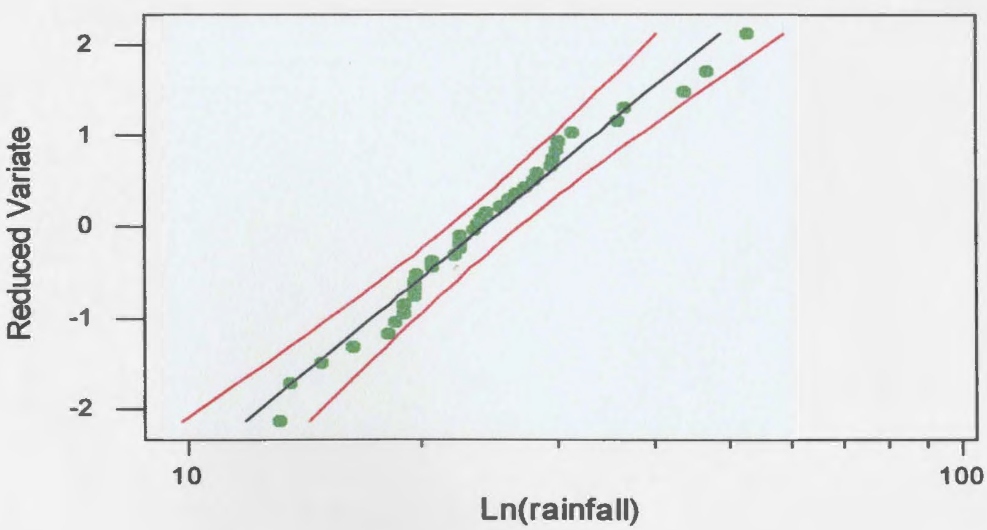
Lognormal Probability Plot for 30-Minute Annual Extrema



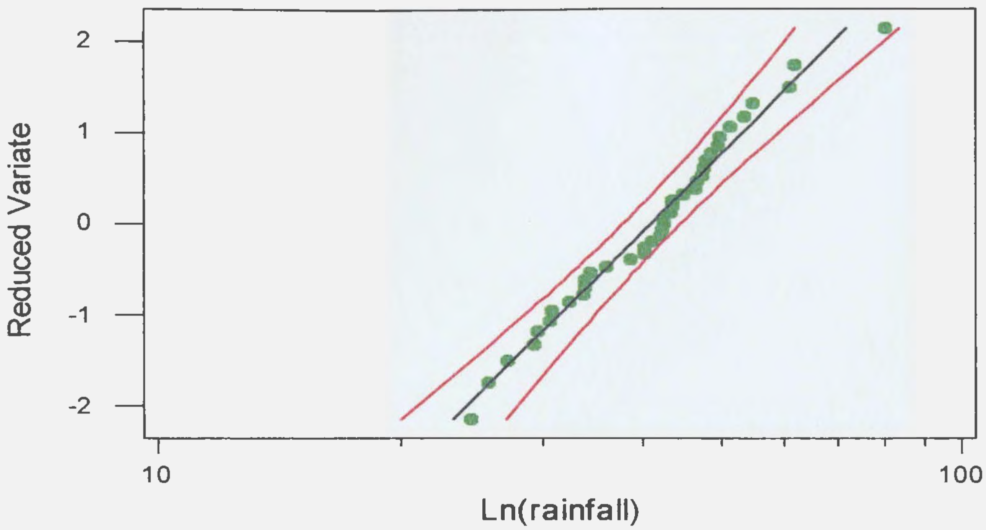
Lognormal Probability Plot for 1-Hour Annual Extrema



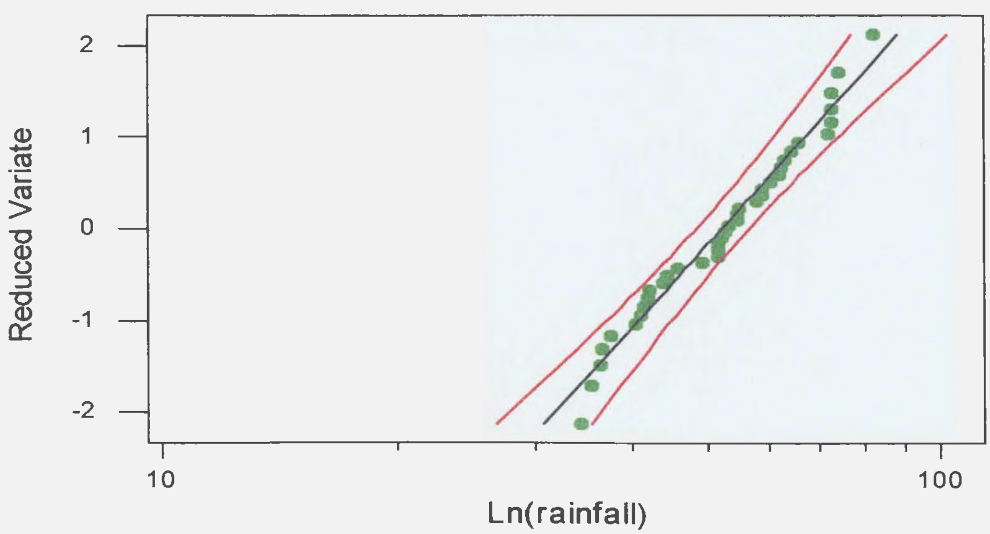
Lognormal Probability Plot for 2-Hour Annual Extrema

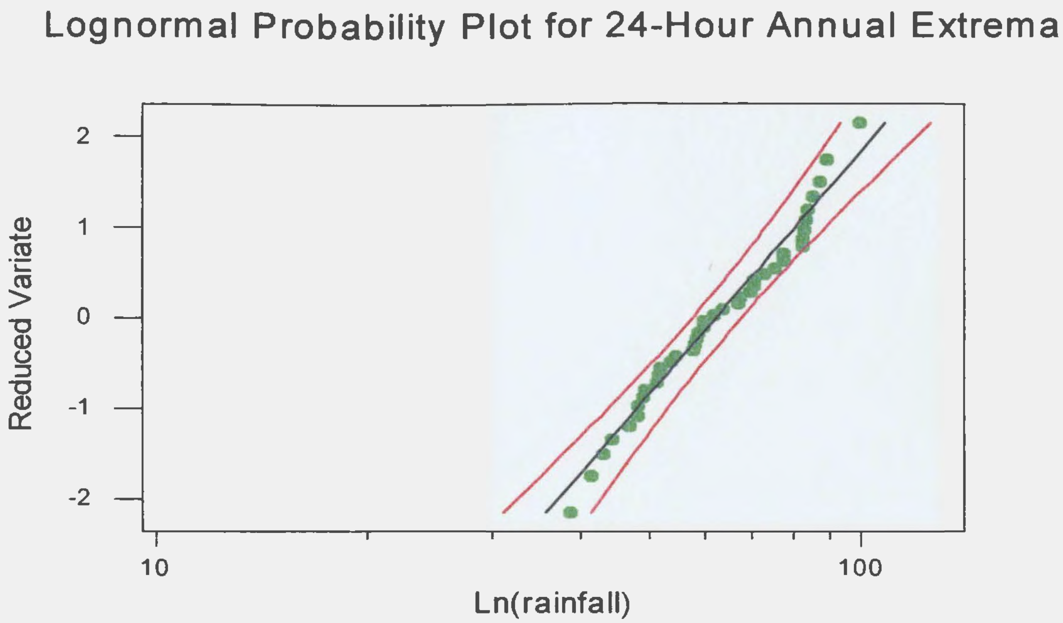


Lognormal Probability Plot for 6-Hour Annual Extrema



Lognormal Probability Plot for 12-Hour Annual Extrema




Lognormal Probability Plot for 24-Hour Annual Extrema
Reduced Variate
2
1
0
-1
-2
10
100
Ln(rainfall)

APPENDIX L

IDF CURVE DATA

WITH 95% CONFIDENCE INTERVALS

IDF CURVE DATA WITH 95% CONFIDENCE INTERVALS							
Duration	**Intensity (mm/hr)**	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**
5 min.	I	4.6	6.4	7.6	9.1	10.3	11.4
	Lower 95% C.I.	4.1	5.5	6.4	7.5	8.2	9.0
	Upper 95% C.I.	5.2	7.4	9.0	11.2	12.8	14.6
10 min.	I	6.8	9.2	10.8	12.8	14.3	15.8
	Lower 95% C.I.	6.0	8.1	9.2	10.7	10.7	12.6
	Upper 95% C.I.	7.6	10.6	12.7	15.5	17.6	19.8
15 min.	I	8.7	11.8	13.9	16.5	18.4	20.3
	Lower 95% C.I.	7.7	10.3	11.8	13.6	14.9	16.2
	Upper 95% C.I.	9.8	13.5	16.2	19.8	22.6	25.4
30 min.	I	12.4	16.6	19.2	22.6	25.0	27.5
	Lower 95% C.I.	11.1	14.6	16.6	19.0	20.6	22.2
	Upper 95% C.I.	13.9	18.8	22.3	26.9	30.4	33.9
1 hr.	I	17.6	22.9	26.2	30.3	33.3	36.2
	Lower 95% C.I.	15.9	20.4	22.9	25.9	28.0	30.0
	Upper 95% C.I.	19.4	25.6	29.9	35.5	39.6	43.8
2 hr.	I	24.0	31.7	36.7	42.8	47.3	51.8
	Lower 95% C.I.	21.6	28.0	31.8	36.2	39.3	42.3
	Upper 95% C.I.	26.7	35.8	42.2	50.6	57.0	63.4
6 hr.	I	40.9	51.0	57.3	64.8	70.1	75.4
	Lower 95% C.I.	37.7	46.3	51.2	56.8	60.7	64.3
	Upper 95% C.I.	44.4	56.2	64.0	73.9	81.1	88.3
12 hr.	I	52.3	64.4	71.8	80.7	86.9	93.0
	Lower 95% C.I.	48.4	58.8	64.6	71.2	75.7	79.9
	Upper 95% C.I.	56.6	70.6	79.9	91.4	99.9	108.2
24 hr.	I	62.3	77.3	86.6	97.6	105.6	113.2
	Lower 95% C.I.	57.5	70.5	77.8	86.0	91.7	97.1
	Upper 95% C.I.	67.5	84.8	96.4	110.8	121.5	131.9