ANALYSIS AND USE OF URBAN RAINFALL DATA IN CANADA

by

Charles Howard & Associates Ltd.
Professional Engineers

for the

Water Pollution Control Directorate
Environmental Protection Service
Environment Canada

Report No. EPS 3-WP-79-4
July 1979

REVIEW NOTICE

This report has been reviewed by the Water Pollution Control Directorate, Environmental Protection Service, and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute recommendation or endorsement for use.

Cat. No. En 43-3/79-4
ISBN 0-662-10672-5
BEAUREGARD PRESS LIMITED

ABSTRACT

Rainfall data available for 35 Canadian urban centres were analysed and are summarized in this report. This information has been assembled as a guide to engineers involved in the design of urban runoff and pollution control facilities.

The results of the rainfall storm event analyses consist of yearly tables summarizing each rainfall event, and statistical tables for four rainfall storm event characteristics: storm depth (total volume); storm duration (length of event); average storm intensity (depth divided by duration), and storm inter-event time (the length of time without rain preceding the event). Statistical tables of moisture deficit estimates are also given. The tables summarizing rainfall events provide a quick reference for the design engineer in choosing either specific events, series of events or years of data for design studies. The statistical tables provide information for the calculation of the probability and return period for specific storm events.

The calculation of accurate probability and return periods depends on an understanding of the physical system and the important characteristics of a particular rainfall event. In many practical design situations, the joint probability of two or more rainfall event characteristics is required to accurately calculate the return period. The significance of the independence of rainfall event characteristics in these calculations is presented as an appendix to this report.

RÉSUMÉ

Le présent rapport comporte une analyse et un résumé des données sur les pluies dans 35 régions urbaines du Canada. Il veut servir de guide aux ingénieurs municipaux qui s'occupent des systèmes de canalisation des eaux de ruissellement et des installations de lutte contre la pollution.

L'analyse des données sur les pluies lors d'orages est présentée sous forme de tableaux annuels résumant chaque précipitation et de tableaux statistiques établis en fonction de quatre caractéristiques: hauteur de précipitation (volume de pluie au total); durée de précipitation; intensité moyenne de précipitation (hauteur par rapport à la durée) et fréquence de précipitation (temps sans pluie avant chaque précipitation.) On retrouve également des tableaux statistiques comportant des estimations de l'indice d'assèchement du sol. Les tableaux des précipitations constituent un outil de référence facile d'accès pour les ingénieurs-concepteurs qui, au cours de leur travail, ont besoin de données sur des précipitations précises, sur des séries de précipitations ou des données portant sur plus d'une année. Les tableaux statistiques, eux, fournissent des données utiles pour le calcul des probabilités et de la fréquence de certaines précipitations.

Le calcul exact des probabilités et de la fréquence est fonction d'une bonne compréhension du système physique et des caractéristiques importantes d'une précipitation quelconque. Dans bien des travaux pratiques de planification, il faut posséder des données sur les probabilités de deux caractéristiques ou plus pour calculer exactement la fréquence des pluies. L'annexe au présent rapport fait ressortir l'importance de l'indépendance des caractéristiques dans ces calculs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Rainfall data are widely used in the planning, design and analysis of storm runoff and pollution control facilities in urban areas when direct measurements of runoff are not available. These rainfall data are available for computer processing as daily and hourly rainfall totals, and as continuous strip charts for manual processing from the Atmospheric Environment Service, Environment Canada. This report discusses the analysis and use of the hourly averaged rainfall data. The analysis includes a summary of individual events and the statistics of related characteristics from 35 Canadian cities. This information can be used directly for many design applications; for others, specific events can be identified which require the more detailed, but less convenient, strip charts.

Sources of data have been identified and limitations are discussed. The use of the statistical results to develop estimates of the return periods for certain rainfall characteristics is explained. For runoff calculations, additional considerations are involved which are not discussed here, but the return period for any particular rainfall event of interest can be estimated from the present work.

2 DESCRIPTION OF HOURLY RAINFALL DATA

Hourly rainfall data are available from the Atmospheric Environment Service, Environment Canada, on computer cards or magnetic tape. The data are reported in hourly volumes resulting in 24 entries for each day. In some areas of Canada, the gauges are operated for as few as six months per year, while in other areas they are operated year-round. At present, there are hundreds of continuous recording rain gauges operating in Canada. It was beyond the scope of this work to analyze and present all of the recorded data. The present investigation analyzed data from the urban rainfall stations given in Table 1* for each year of the period of record.

The hourly rainfall data are obtained by analyzing the charts of continuously recording rain gauges. In some respects, the hourly rainfall data obtained do not accurately represent the recorded rainfall sequence, as shown in Figure 1. The depth or volume of rainfall is accurately represented by the hourly data; however, the starting and ending time for the rainfall is not. Using the arbitrary clock hour reporting system, the length or duration of a rainfall event, taken from hourly rainfall data, will be generally longer than actually occurred. For recorded rainfall events lasting at least two hours, this error will average one hour, while for recorded events lasting one hour, the error will be 0.5 hours. Therefore, the imprecision introduced by the reporting procedure must be considered when using the hourly data.

---

* The results for specific cities may be obtained by writing:
Chief - Municipal Division
Water Pollution Control Directorate
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

TABLE 1 HOURLY RAINFALL DATA STATIONS ANALYZED

Province	City	Period of Record
British Columbia	Victoria	1960-74
	Vancouver	1961-74
	Vancouver UBC	1960-74
	N. Vancouver	1965-74
	Langley	1972-74
	Kamloops	1965-74
Alberta	Edmonton	1960-74
	Calgary	1961-74
	Lethbridge	1960-74
Saskatchewan	Saskatoon	1960-74
	Regina	1961-74
	Moose Jaw	1960-74
Manitoba	Brandon	1960-74
	Dauphin	1960-74
	Winnipeg	1961-74
Ontario	Kitchener	1962-66
	London	1962-66
	Niagara Falls	1966-71
	Ottawa	1966-73
	Sault Ste. Marie	1966-74
	Thunder Bay	1960-74
	Toronto	1960-74
	Windsor	1961-74
Quebec	Montreal	1960-73
	Quebec City	1962-72
	Sherbrooke	1962-72
New Brunswick	Fredericton	1960-71
	Moncton	1960-74
	Saint John	1960-74
Nova Scotia	Halifax	1960-71
	Sydney	1961-74
P.E.I.	Charlottetown	1968-71
Newfoundland	St. John's	1964-70
Yukon	Whitehorse	1960-74
N.W.T.	Yellowknife	1964-74

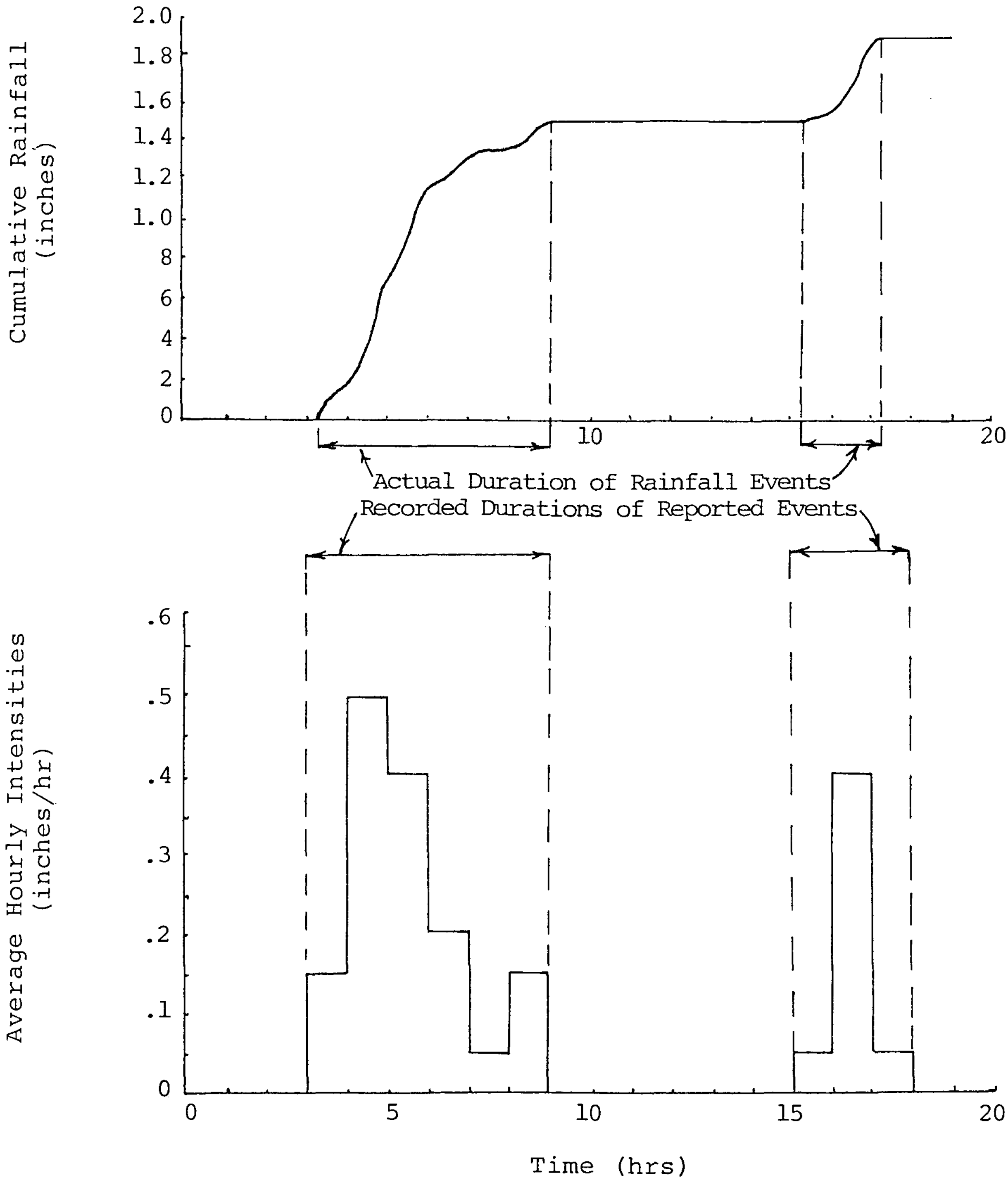

FIGURE 1 COMPARISON OF CONTINUOUS HOURLY RAINFALL CHART AND REPORTED HOURLY RAINFALL DATA

3 METHOD OF STORM EVENT ANALYSIS

The purposes of analyzing recorded hourly rainfall data are:

1) to concisely present the sequence of historical rainfall data, which can be used by engineers in the design of urban runoff facilities; and
2) to facilitate the calculation of the return periods of design events to evaluate the risk and/or economic viability of a project.

The first step in the analysis is to identify storm events and to determine the characteristics of each event. It is then possible to calculate the probability of, for example, an average storm intensity of one inch/hour being equalled or exceeded for the period of record. Knowing the average annual number of events, the corresponding return period can also be calculated.

The storm event analysis procedure is as follows:

Step 1 Define a minimum time without rain which separates independent storm events. The time without rain which separates two adjacent storm events is called the inter-event time.

Step 2 Identify storm events and the characteristics of each event. Consider the typical hourly rainfall sequence in Figure 2a. Using a minimum inter-event time of one hour, the rainfall has been grouped into events in Figure 2b.

A characterization of each event is provided by the:

a) duration
b) depth (total volume)
c) average intensity, and
d) inter-event time (the elapsed rain-free period preceding the event).

The characteristics for the rainfall sequence shown in Figures 2a and 2b are summarized in Table 2.

Definition of an independent storm event is crucial to the accurate determination of the probability of recurrence and the return period. It was beyond the scope of this work to study this aspect of storm analysis completely. For the purpose of this study, a minimum inter-event time of one hour was chosen to separate independent events.

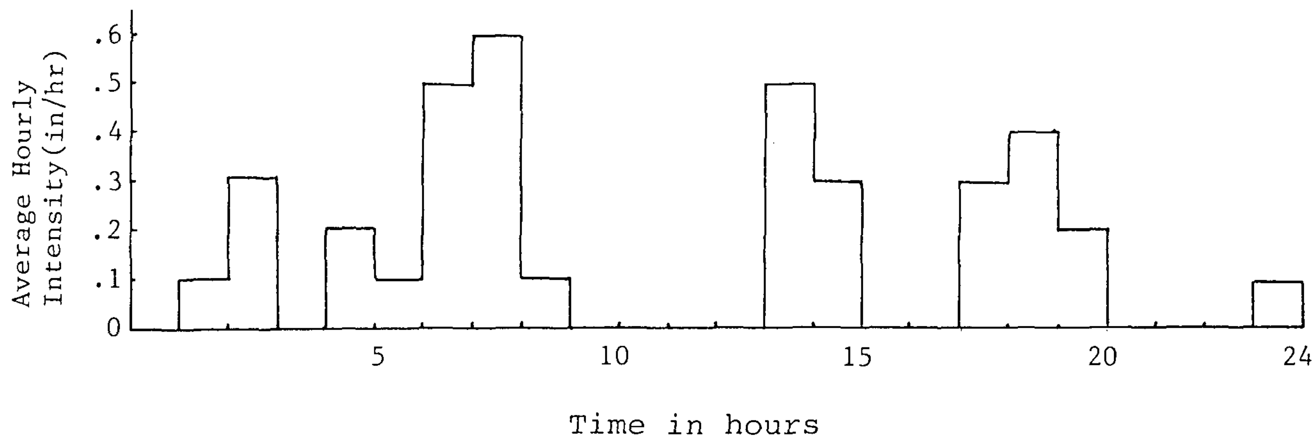

FIGURE 2a TYPICAL HOURLY RAINFALL SEQUENCE

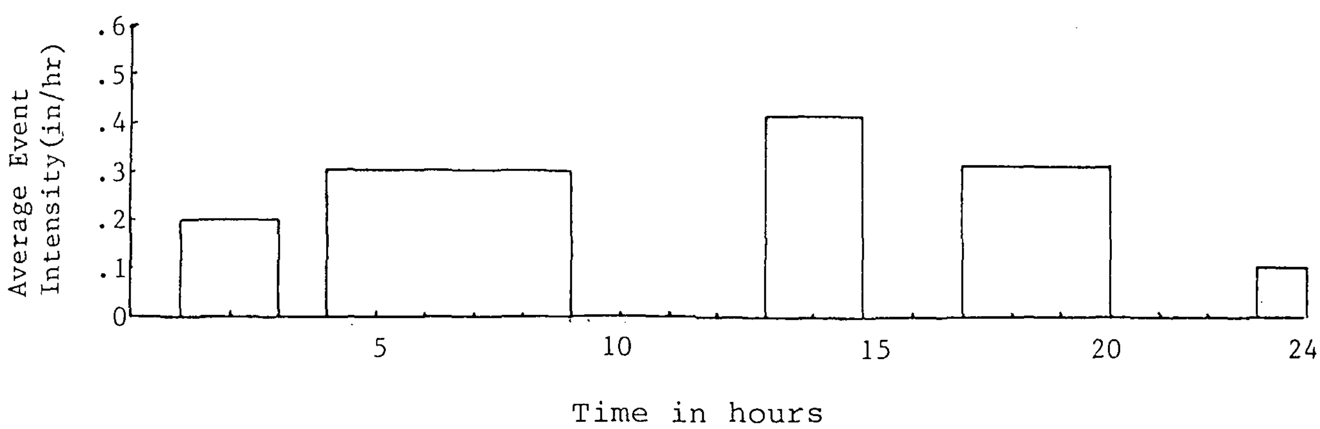

FIGURE 2b STORM EVENTS RESULTING FROM ANALYSIS USING A MINIMUM INTER-EVENT TIME OF ONE HOUR

TABLE 2 SUMMARY OF RAINFALL EVENT CHARACTERISTICS (FIGURES 2a AND 2b)

Event	Depth (in)	Duration (h)	Inter-event Time (h)	Average Intensity (in/h)
1	0.40	2	-	0.20
2	1.50	5	1	0.30
3	0.80	2	4	0.40
4	0.90	3	2	0.30
5	0.10	1	3	0.10

The minimum interval time of one hour was chosen because:

a) Rainfall data are reported at minimum intervals of one hour on a country-wide basis (more detailed data are not available).

b) Urban watersheds can have relatively short response times, in some cases less than an hour. A one-hour period without rain will, therefore, be important in watershed response and facility operation. If a longer minimum inter-event were used, periods without rain would be included within events.

c) Display of the storm events obtained using a one-hour minimum inter-event time provides the most detailed information to the user of the individual storm results.

d) Statistics for longer minimum inter-event time definitions can be calculated using the one-hour definition results, but not the reverse.

e) The statistical independence of the rainfall storm event characteristics is not greatly affected by the choice of a minimum inter-event time as low as one hour.

4 HOW TO USE TABLES OF RAINFALL EVENTS

The purpose of the following discussion is to assist the user of the hourly rainfall analysis in reading and using the tables of rainfall storm events.

Descriptive information for the analysis is printed at the beginning of the results (Figure 3). This information includes:

a) the name of the city and the Atmospheric Environment station number(s) used in the analysis,
b) the starting and ending year of the analysis, and the starting and ending month for each year analyzed,
c) the two equations used to give a running estimate of moisture deficit, and
d) a list of years not used in the analysis.

The rainfall storm events are listed in chronological order by year. Table 3 is a sample printout of rainfall data.

At the end of each year (Table 3), the maximum, minimum and average values are printed. The inter-event time for the first event of the year, 0.00, is not included in this calculation.

A summary of storm analyses results for all years is printed following the last year of storm analysis (Table 4). The first portion of the summary presents the averages of all parameters analyzed in the period of record. The second portion of the summary presents parameters (the reciprocal of the mean) which can be used to define a theoretical frequency distribution for each rainfall characteristic.

4.1 Comments

For the first storm event in each year, the inter-event time is not defined and is printed as zero (0.00). If the value of this inter-event time is of interest, it may be calculated from the printed tables.

The moisture deficit, columns 8 and 9, Table 3, is only a rough estimate and is printed as a guide. The exponential equation (Table 3) assumes that as "T", the inter-event time, becomes very large, the moisture deficit approaches six inches of water. This assumption must be examined when working in areas where soil conditions indicate some other maximum. The printed moisture deficit results can be scaled easily

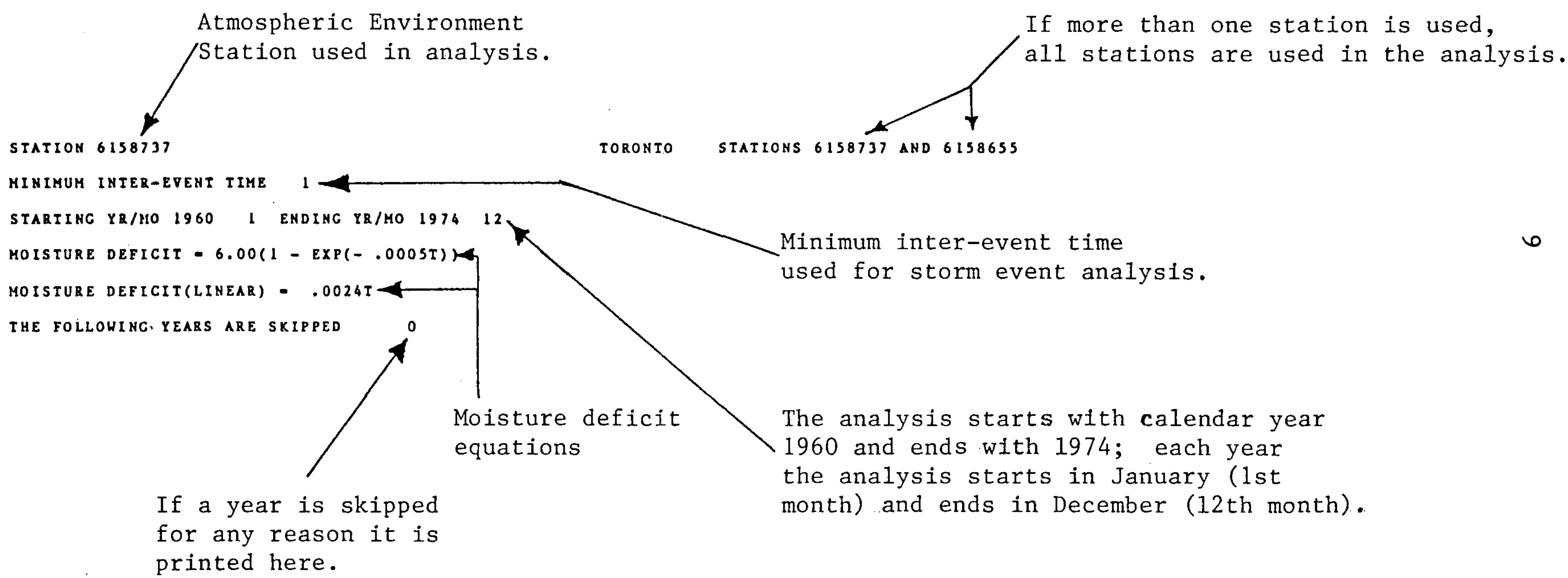

FIGURE 3 GENERAL DATA FOR ANALYSIS

TABLE 3 SAMPLE PRINTOUT OF RAINFALL STORM EVENTS

TORONTO STATIONS 6158737 AND 6158655 MINIMUM INTER-EVENT TIME... 1 HOURS

YEAR	MONTH	DAY	STARTING TIME	STORM DEPTH	STORM DURATION	STORM INTENSITY	PRECEDING INTER EVENT TIME	MOISTURE DEFICIT	(LINEAR)
1960	1	2	19	.19	3.00	.0633	0.00	.12	.10
1960	1	2	23	.02	1.00	.0200	1.00	.00	.00
1960	1	3	1	.06	3.00	.0200	1.00	.00	.00
1960	1	3	5	.01	1.00	.0100	1.00	.00	.00
1960	1	3	19	.01	1.00	.0100	13.00	.04	.03
1960	1	3	24	.02	1.00	.0200	4.00	.04	.03
1960	1	12	16	.71	10.00	.0710	207.00	.61	.51
1960	1	13	3	.18	5.00	.0360	1.00	.00	.00
1960	1	13	12	.05	1.00	.0500	4.00	.01	.01
1960	2	5	23	.57	9.00	.0633	562.00	1.47	1.35
1960	2	6	13	.03	1.00	.0300	5.00	.91	.79
1960	2	6	15	.06	2.00	.0300	1.00	.89	.76
1960	2	6	19	.03	1.00	.0300	2.00	.83	.71
1960	3	30	6	.01	1.00	.0100	1258.00	3.23	3.70
1960	3	30	19	.01	1.00	.0100	12.00	3.23	3.72
1960	3	31	5	.09	1.00	.0900	9.00	3.24	3.73
1960	3	31	11	.17	5.00	.0340	5.00	3.15	3.65
1960	4	3	13	.02	1.00	.0200	69.00	3.09	3.65
1960	4	3	18	.11	2.00	.0550	4.00	3.07	3.63
1960	4	3	23	.05	2.00	.0250	3.00	2.97	3.53
1960	4	4	3	.05	1.00	.0500	2.00	2.92	3.49
1960	4	4	7	.05	1.00	.0500	3.00	2.87	3.44
1960	4	8	1	.03	1.00	.0300	89.00	2.96	3.61
1960	4	8	20	.04	2.00	.0200	18.00	2.96	3.62
1960	4	8	23	.01	1.00	.0100	1.00	2.92	3.58
1960	4	9	7	.01	1.00	.0100	7.00	2.92	3.59
1960	4	13	9	.01	1.00	.0100	97.00	3.06	3.81
1960	4	13	11	.02	2.00	.0100	1.00	3.05	3.81
1960	4	14	15	.01	1.00	.0100	26.00	3.07	3.85
1960	4	15	18	.02	2.00	.0100	26.00	3.10	3.90
1960	4	15	21	.01	1.00	.0100	1.00	3.08	3.88
1960	4	16	16	.16	3.00	.0533	18.00	3.09	3.92
1960	4	16	20	.01	1.00	.0100	1.00	2.94	3.76
1960	4	17	2	.08	3.00	.0267	5.00	2.93	3.76
1960	4	17	7	.01	1.00	.0100	2.00	2.86	3.68
1960	4	17	21	.10	3.00	.0333	13.00	2.87	3.71
1960	4	18	1	.01	1.00	.0100	1.00	2.77	3.61
1960	4	21	14	.15	3.00	.0500	84.00	2.89	3.80
1960	4	21	19	.01	1.00	.0100	2.00	2.75	3.65
1960	4	22	22	.25	2.00	.1250	26.00	2.78	3.71
1960	4	24	1	.01	1.00	.0100	25.00	2.57	3.52
1960	4	24	24	.18	2.00	.0900	22.00	2.60	3.56
1960	4	25	7	.10	1.00	.1000	5.00	2.43	3.39
1960	4	25	12	.10	3.00	.0333	4.00	2.33	3.30
1960	4	26	4	.07	1.00	.0700	13.00	2.26	3.23
1960	4	26	7	.19	4.00	.0475	2.00	2.19	3.17
1960	4	26	13	.02	1.00	.0200	2.00	2.01	2.98
1960	4	30	11	.04	1.00	.0400	93.00	2.17	3.19
1960	4	30	13	.01	1.00	.0100	1.00	2.13	3.15
1960	4	30	19	.57	6.00	.0950	5.00	2.13	3.15
1960	5	11	10	.15	6.00	.0250	249.00	2.08	3.18
1960	5	12	12	.01	1.00	.0100	20.00	1.97	3.08
1960	5	12	21	.20	4.00	.0500	8.00	1.98	3.08
1960	5	13	7	.02	2.00	.0100	6.00	1.79	2.90

TABLE 3 (continued)

TORONTO STATIONS 6158737 AND 6158655 MIMIMUM INTER-EVENT TIME... 1 HOURS

YEAR	MONTH	DAY	STARTING TIME	STORM DEPTH	STORM DURATION	STORM INTENSITY	PRECEDING INTER EVENT TIME	MOISTURE DEFICIT	(LINEAR)
1960	5	17	11	.01	1.00	.0100	98.00	1.97	3.11
1960	5	17	14	.05	1.00	.0500	2.00	1.97	3.11
1960	5	17	18	.01	1.00	.0100	3.00	1.92	3.07
1960	5	18	1	.27	5.00	.0540	6.00	1.92	3.07
1960	5	20	4	.53	5.00	.1060	46.00	1.75	2.91
1960	5	22	9	.14	6.00	.0233	48.00	1.34	2.50
1960	5	22	24	.09	1.00	.0900	9.00	1.22	2.38
1960	5	23	22	.04	2.00	.0200	21.00	1.18	2.34
1960	5	24	7	.01	1.00	.0100	7.00	1.16	2.32
1960	5	25	9	.01	1.00	.0100	25.00	1.21	2.37
1960	5	25	13	.01	1.00	.0100	3.00	1.20	2.36
1960	5	28	11	.01	1.00	.0100	69.00	1.36	2.52
1960	5	30	17	.04	2.00	.0200	53.00	1.47	2.64
1960	5	31	2	.01	1.00	.0100	7.00	1.44	2.61
1960	5	31	4	.20	7.00	.0286	1.00	1.44	2.60
1960	5	31	13	.01	1.00	.0100	2.00	1.24	2.41
1960	5	31	15	.01	1.00	.0100	1.00	1.23	2.40
1960	6	2	15	.09	2.00	.0450	47.00	1.33	2.50
1960	6	2	19	.01	1.00	.0100	2.00	1.25	2.42
1960	6	14	7	.01	1.00	.0100	275.00	1.85	3.07
1960	6	14	9	.45	6.00	.0750	1.00	1.84	3.06
1960	6	14	19	.04	3.00	.0133	4.00	1.40	2.62
1960	6	15	4	.11	4.00	.0275	6.00	1.38	2.60
1960	6	16	22	.56	6.00	.0933	38.00	1.36	2.58
1960	6	17	7	.01	1.00	.0100	3.00	.80	2.02
1960	6	17	13	.05	2.00	.0250	5.00	.81	2.03
1960	6	17	19	.01	1.00	.0100	4.00	.77	1.99
1960	6	23	19	.26	3.00	.0867	143.00	1.12	2.32
1960	6	24	5	.38	2.00	.1900	7.00	.88	2.08
1960	6	28	23	.02	2.00	.0100	112.00	.80	1.96
1960	6	29	3	.01	1.00	.0100	2.00	.78	1.95
1960	6	29	5	.18	3.00	.0600	1.00	.77	1.94
1960	7	3	10	.03	2.00	.0150	98.00	.85	2.00
1960	7	9	14	.45	1.00	.4500	146.00	1.19	2.32
1960	7	13	10	1.73	4.00	.4325	91.00	.97	2.09
1960	7	18	14	.62	4.00	.1550	120.00	.35	.64
1960	7	22	16	.71	2.00	.3550	94.00	.28	.25
1960	7	26	20	.13	3.00	.0433	98.00	.29	.24
1960	7	26	24	.04	2.00	.0200	1.00	.16	.11
1960	7	30	13	.38	2.00	.1900	83.00	.36	.27
1960	8	2	24	.16	2.00	.0800	81.00	.24	.19
1960	8	3	6	.02	2.00	.0100	4.00	.09	.04
1960	8	7	18	.05	2.00	.0250	106.00	.38	.28
1960	8	9	19	.12	2.00	.0600	47.00	.46	.34
1960	8	9	22	.01	1.00	.0100	1.00	.34	.22
1960	8	10	1	.01	1.00	.0100	2.00	.34	.22
1960	8	10	3	.04	2.00	.0200	1.00	.33	.21
1960	8	10	7	.01	1.00	.0100	2.00	.29	.18
1960	8	14	19	.40	1.00	.4000	107.00	.58	.42
1960	8	14	23	.61	6.00	.1017	3.00	.19	.03
1960	8	20	13	.01	1.00	.0100	128.00	.37	.31
1960	8	21	17	.01	1.00	.0100	27.00	.44	.36
1960	8	22	7	.01	1.00	.0100	13.00	.46	.38
1960	8	22	19	.09	1.00	.0900	11.00	.48	.40

TABLE 3 (continued)

TORONTO STATIONS 6158737 AND 6158655 MIMIMUM INTER-EVENT TIME... 1 HOURS

YEAR	MONTH	DAY	STARTING TIME	STORM DEPTH	STORM DURATION	STORM INTENSITY	PRECEDING INTER EVENT TIME	MOISTURE DEFICIT	(LINEAR)
1960	8	29	18	.01	1.00	.0100	166.00	.84	.71
1960	9	23	2	.02	2.00	.0100	583.00	2.14	2.10
1960	9	26	18	.12	3.00	.0400	86.00	2.28	2.28
1960	9	30	3	.11	4.00	.0275	78.00	2.31	2.35
1960	10	2	7	.80	6.00	.1333	48.00	2.29	2.36
1960	10	5	20	.01	1.00	.0100	79.00	1.66	1.75
1960	10	6	1	.18	3.00	.0600	4.00	1.66	1.75
1960	10	6	7	.01	1.00	.0100	3.00	1.49	1.57
1960	10	15	22	.03	2.00	.0150	230.00	1.97	2.11
1960	10	16	2	.05	2.00	.0250	2.00	1.94	2.09
1960	10	19	15	.01	1.00	.0100	83.00	2.06	2.24
1960	10	19	18	.08	5.00	.0160	2.00	2.05	2.23
1960	10	20	1	.01	1.00	.0100	2.00	1.98	2.16
1960	10	22	20	.14	4.00	.0350	66.00	2.10	2.31
1960	10	23	1	.26	5.00	.0520	1.00	1.96	2.17
1960	10	23	7	.01	1.00	.0100	1.00	1.70	1.91
1960	10	23	16	.02	2.00	.0100	8.00	1.71	1.92
1960	10	23	19	.02	1.00	.0200	1.00	1.69	1.90
1960	10	23	21	.02	1.00	.0200	1.00	1.68	1.89
1960	10	31	17	.58	8.00	.0725	187.00	2.04	2.31
1960	11	1	3	.04	2.00	.0200	2.00	1.47	1.74
1960	11	1	17	.07	3.00	.0233	12.00	1.45	1.73
1960	11	3	2	.02	1.00	.0200	30.00	1.45	1.73
1960	11	3	12	.01	1.00	.0100	9.00	1.45	1.73
1960	11	3	20	.01	1.00	.0100	7.00	1.46	1.74
1960	11	8	19	.02	1.00	.0200	118.00	1.71	2.01
1960	11	8	21	.01	1.00	.0100	1.00	1.69	1.99
1960	11	9	1	.01	1.00	.0100	3.00	1.69	1.99
1960	11	9	7	.01	1.00	.0100	5.00	1.69	1.99
1960	11	9	16	.32	10.00	.0320	8.00	1.70	2.00
1960	11	10	7	.01	1.00	.0100	5.00	1.39	1.69
1960	11	14	20	.21	3.00	.0700	108.00	1.62	1.94
1960	11	15	9	.54	6.00	.0900	10.00	1.43	1.76
1960	11	15	17	.35	5.00	.0700	2.00	.90	1.22
1960	11	16	1	.08	7.00	.0114	3.00	.56	.88
1960	11	16	9	.02	1.00	.0200	1.00	.48	.80
1960	11	22	24	.02	1.00	.0200	158.00	.88	1.16
1960	11	27	23	.01	1.00	.0100	118.00	1.16	1.42
1960	11	28	1	.02	1.00	.0200	1.00	1.15	1.42
1960	11	28	4	.01	1.00	.0100	2.00	1.13	1.40
1960	11	28	7	.01	1.00	.0100	2.00	1.13	1.40
1960	11	28	10	.02	2.00	.0100	2.00	1.12	1.39
1960	11	28	20	.28	4.00	.0700	8.00	1.12	1.39
1960	11	29	3	.01	1.00	.0100	3.00	.85	1.12
1960	11	29	7	.01	1.00	.0100	3.00	.85	1.11
MAXIMUM VALUES				1.73	10.00	.4500	1258.00	3.24	3.92
MINIMUM VALUES				.01	1.00	.0100	1.00	.00	.00
AVERAGE VALUES				.12	2.29	.0440	50.05	1.55	2.09

TABLE 4 SUMMARY OF STORM ANALYSES

TORONTO STATIONS 6158737 AND 6158655 MINIMUM INTER-EVENT TIME... 1 HOURS

AVERAGE ANNUAL INDEPENDENT STORMS... 137.1333

TOTAL NUMBER OF STORMS ANALYZED... 2057

AVERAGE ANNUAL PRECIPITATION ... 21.197

AVERAGE ANNUAL RAINFALL PERIOD(HOURS).... 7413.9

AVERAGE STORM DURATION= 2.65 HOURS

AVERAGE STORM INTENSITY= .05 INCHES/HOUR

AVERAGE STORM DEPTH= .15 INCHES

AVERAGE PRECEEDING INTER-EVENT TIME= 51.80 HOURS

AVERAGE MOISTURE DEFICIENCY PRIOR TO BEGINNING OF STORM= 1.27 INCHES (LINEAR = 1.99 INCHES)

DERIVED PROBABILITY DISTRIBUTION PARAMETERS

STORM DURATION,LAMBDA... .37792

STORM INTENSITY,BETA... 20.23173

STORM DEPTH,ZETA... 6.46937

PRECEDING INTER-EVENT TIME,PSI... .01931

PRECEDING MOISTURE DEFICIENCY,MU... .7863 (LINEAR = .5030)

with the appropriate estimated maximum deficit to make them applicable to the new conditions. For example, if the maximum moisture deficit was estimated to be four inches, the moisture deficit for the first storm event in 1960 (Table 3) would become:

$$\frac{4}{6} \times 0.10 = 0.07 \text{ inches.}$$

If the rate of depletion represented by the coefficient, 0.0005 (Table 4), is considered inappropriate to a specific situation, the moisture deficit must be recalculated using the information printed in the storm event summary tables (i.e., Table 4).

The linear moisture deficit calculation is included to indicate the sensitivity of the moisture deficit results to specific assumptions in the form of the moisture deficit equation and its coefficients. In using the linear equation, a maximum possible moisture deficit of 6.0 inches was also assumed.

4.2 Use of the Tables

The tables of rainfall storm events provide a relatively concise summary of the entire rainfall history for a climatological station. They provide a quick reference for identifying storms and sequences of storms which may be of interest in the design of a runoff control facility. Where single storm events are of prime interest, a copy of the continuous strip chart of the rain gauge record from the Atmospheric Environment Service, Environment Canada, will provide additional detail of the storm event.

Where a mass balance simulation of a design is required, the storm event tables can be used to identify critical sequences of events. A simulation of the runoff control system can then be made by hand calculation or with the assistance of a computer.

Where a full year of data is required for detailed simulation, a representative year can be chosen by comparing the annual means and extremes for rainfall characteristics to the means for the entire period. In this way, some appreciation of typical results of a one-year simulation can be obtained.

It should be noted that all recorded hourly precipitation data were used in the preparation of the storm event analyses for this report. No differentiation was made between recorded frozen or freezing and unfrozen precipitation. Care should be taken in using the storm results for periods when the temperature is usually below freezing. If a particular event is in question, the maximum and minimum temperatures for the day(s) of the event should be checked.

5 TABLES OF STATISTICS

5.1 Reading the Tables

Statistical summary tables for each of the four storm event characteristics (depth, duration, intensity and inter-event time), and the two methods of calculating moisture deficit are printed at the end of hourly storm event analyses. All of the frequency tables are in the same format and should be read as follows (Tables 5 through 10):

Column	Heading	
1	INTERVAL FROM	the lower limit of the interval,
2	INTERVAL TO	the upper limit of the interval,
3	PLOT POSN	the plotting position for the interval (midway between the upper and lower limits),
4	PLOT POSN/AV	the plotting position, column 3, divided by the means of the continuous distribution (printed between the lines of asterisks below the table),
5	PERCENTAGE FREQ.	the percentage frequency of occurrence in the interval, defined by columns 1 and 2,
6	PERCENTAGE CUM.	the cumulative frequency of values less than and including the interval,
7	PROBABILITY DENSITY	the probability density of the interval (the frequency of the interval as a fraction divided by the width of the interval), and
8	NO. OF VALUES	the number of events during the interval.

In most frequency tables, the first line has the word "IMPULSE" written in column 1. "IMPULSE" is a concentration of probability at a single value; in the case of these tables, at the minimum (0.01" depth, 1.0 h duration, 0.01 in/h intensity, and 0 h inter-event time). The impulse for the inter-event time occurs at 0.0 h rather than 1.0 h because the inter-event time of the first event in a year is assigned an inter-event time of zero. The impulse is calculated and printed when a large number of events fall at the

TABLE 5 STATISTICAL SUMMARY OF STORM DEPTH - TORONTO

FREQUENCY ANALYSIS OF STORM DEPTH MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		.01		27.03	27.03		556.
.01	.14	.08	.37	44.24	71.27	3.3514534	910.
.14	.27	.21	1.00	12.15	83.42	.9207290	250.
.27	.41	.34	1.63	5.64	89.06	.4272182	116.
.41	.54	.47	2.27	3.35	92.42	.2541212	69.
.54	.67	.60	2.90	2.87	95.28	.2172920	59.
.67	.80	.74	3.54	1.36	96.65	.1031216	28.
.80	.93	.87	4.17	.97	97.62	.0736583	20.
.93	1.07	1.00	4.80	.49	98.10	.0368292	10.
1.07	1.20	1.13	5.44	.63	98.74	.0478779	13.
1.20	1.33	1.26	6.07	.58	99.32	.0441950	12.
1.33	1.46	1.40	6.71	.10	99.42	.0073658	2.
1.46	1.59	1.53	7.34	.24	99.66	.0184146	5.
1.59	1.73	1.66	7.98	.05	99.71	.0036829	1.
1.73	1.86	1.79	8.61	.10	99.81	.0073658	2.
1.86	1.99	1.92	9.24	.05	99.85	.0036829	1.
1.99	2.12	2.06	9.88	.05	99.90	.0036829	1.
2.12	2.25	2.19	10.51	0.00	99.90	0.0000000	0.
2.25	2.39	2.32	11.15	.05	99.95	.0036829	1.
2.39	2.52	2.45	11.78	0.00	99.95	0.0000000	0.
2.52	2.65	2.58	12.42	.05	100.00	.0036829	1.

* *

MAX = 2.65 MIN = .01 MEAN = .21 STD. DEV. = .28

* *

MEAN OF THE TOTAL DISTRIBUTION = .1546

TABLE 6 STATISTICAL SUMMARY OF STORM DURATION - TORONTO

FREQUENCY ANALYSIS OF STORM DURATION MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		1.00		45.70	45.70		940.
1.00	2.10	1.55	.38	22.36	68.06	.2032969	460.
2.10	3.20	2.65	.66	10.26	78.32	.0932514	211.
3.20	4.30	3.75	.93	6.56	84.88	.0596632	135.
4.30	5.40	4.85	1.20	4.28	89.16	.0388916	88.
5.40	6.50	5.95	1.48	3.21	92.37	.0291687	66.
6.50	7.60	7.05	1.75	2.04	94.41	.0185619	42.
7.60	8.70	8.15	2.02	1.46	95.87	.0132585	30.
8.70	9.80	9.25	2.29	1.07	96.94	.0097229	22.
9.80	10.90	10.35	2.57	.78	97.72	.0070712	16.
10.90	12.00	11.45	2.84	.78	98.49	.0070712	16.
12.00	13.10	12.55	3.11	.34	98.83	.0030936	7.
13.10	14.20	13.65	3.39	.19	99.03	.0017678	4.
14.20	15.30	14.75	3.66	.10	99.12	.0008839	2.
15.30	16.40	15.85	3.93	.29	99.42	.0026517	6.
16.40	17.50	16.95	4.20	.10	99.51	.0008839	2.
17.50	18.60	18.05	4.48	.24	99.76	.0022097	5.
18.60	19.70	19.15	4.75	.15	99.90	.0013258	3.
19.70	20.80	20.25	5.02	0.00	99.90	0.0000000	0.
20.80	21.90	21.35	5.30	.05	99.95	.0004419	1.
21.90	23.00	22.45	5.57	.05	100.00	.0004419	1.

* *

MAX = 23.00 MIN = 1.00 MEAN = 4.03 STD. DEV. = 2.99

* *

MEAN OF THE TOTAL DISTRIBUTION = 2.6461

TABLE 7 STATISTICAL SUMMARY OF STORM INTENSITY - TORONTO

FREQUENCY ANALYSIS OF STORM INTENSITY MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		.01		32.04	32.04		659.
.01	.09	.05	.73	52.89	84.93	6.6952614	1088.
.09	.17	.13	1.89	10.60	95.53	1.3415138	218.
.17	.25	.21	3.05	2.48	98.01	.3138404	51.
.25	.33	.29	4.21	.73	98.74	.0923060	15.
.33	.41	.37	5.37	.34	99.08	.0430761	7.
.41	.48	.44	6.54	.63	99.71	.0799985	13.
.48	.56	.52	7.70	.05	99.76	.0061537	1.
.56	.64	.60	8.86	.10	99.85	.0123075	2.
.64	.72	.68	10.02	.05	99.90	.0061537	1.
.72	.80	.76	11.18	.05	99.95	.0061537	1.
.80	.88	.84	12.34	0.00	99.95	0.0000000	0.
.88	.96	.92	13.50	0.00	99.95	0.0000000	0.
.96	1.04	1.00	14.67	0.00	99.95	0.0000000	0.
1.04	1.12	1.08	15.83	0.00	99.95	0.0000000	0.
1.12	1.20	1.16	16.99	0.00	99.95	0.0000000	0.
1.20	1.27	1.23	18.15	0.00	99.95	0.0000000	0.
1.27	1.35	1.31	19.31	0.00	99.95	0.0000000	0.
1.35	1.43	1.39	20.47	0.00	99.95	0.0000000	0.
1.43	1.51	1.47	21.64	0.00	99.95	0.0000000	0.
1.51	1.59	1.55	22.80	.05	100.00	.0061537	1.

* *

MAX = 1.59 MIN = .01 MEAN = .07 STD. DEV. = .09

* *

MEAN OF THE TOTAL DISTRIBUTION = .0494

TABLE 8 STATISTICAL SUMMARY OF STORM INTER-EVENT TIME - TORONTO

FREQUENCY ANALYSIS OF INTER-EVENT TIME MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		.00		.73	.73		15.
.00	65.15	32.58	.63	75.16	75.89	.0115361	1546.
65.15	130.30	97.73	1.89	12.25	88.14	.0018804	252.
130.30	195.45	162.88	3.14	5.83	93.97	.0008954	120.
195.45	260.60	228.03	4.40	2.82	96.79	.0004328	58.
260.60	325.75	293.18	5.66	1.41	98.20	.0002164	29.
325.75	390.90	358.33	6.92	.58	98.78	.0000895	12.
390.90	456.05	423.48	8.18	.24	99.03	.0000373	5.
456.05	521.20	488.63	9.43	.19	99.22	.0000298	4.
521.20	586.35	553.78	10.69	.19	99.42	.0000298	4.
586.35	651.50	618.93	11.95	.19	99.61	.0000298	4.
651.50	716.65	684.08	13.21	.05	99.66	.0000075	1.
716.65	781.80	749.23	14.47	0.00	99.66	0.0000000	0.
781.80	846.95	814.38	15.72	.05	99.71	.0000075	1.
846.95	912.10	879.53	16.98	.05	99.76	.0000075	1.
912.10	977.25	944.68	18.24	0.00	99.76	0.0000000	0.
977.25	1042.40	1009.83	19.50	0.00	99.76	0.0000000	0.
1042.40	1107.55	1074.98	20.75	.10	99.85	.0000149	2.
1107.55	1172.70	1140.13	22.01	0.00	99.85	0.0000000	0.
1172.70	1237.85	1205.28	23.27	0.00	99.85	0.0000000	0.
1237.85	1303.00	1270.43	24.53	.15	100.00	.0000224	3.

* *

MAX = 1303.00 MIN = .00 MEAN = 51.80 STD. DEV. = 101.94

* *

MEAN OF THE TOTAL DISTRIBUTION = 51.4176

TABLE 9 STATISTICAL SUMMARY OF MOISTURE DEFICIT (EXPONENTIAL FUNCTION) - TORONTO

FREQUENCY ANALYSIS OF MOISTURE DEFICIT MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		.00		2.04	2.04		42.
.00	.22	.11	.09	12.69	14.73	.5845321	261.
.22	.44	.33	.25	9.09	23.82	.4188027	187.
.44	.65	.55	.42	9.33	33.16	.4300006	192.
.65	.87	.76	.59	8.99	42.15	.4143235	185.
.87	1.09	.98	.75	7.54	49.68	.3471359	155.
1.09	1.31	1.20	.92	7.49	57.17	.3448963	154.
1.31	1.52	1.41	1.09	7.44	64.61	.3426567	153.
1.52	1.74	1.63	1.26	6.32	70.93	.2911462	130.
1.74	1.96	1.85	1.42	6.56	77.49	.3023442	135.
1.96	2.17	2.07	1.59	4.18	81.67	.1926044	86.
2.17	2.39	2.28	1.76	4.18	85.85	.1926044	86.
2.39	2.61	2.50	1.93	2.92	88.77	.1343752	60.
2.61	2.82	2.72	2.09	2.58	91.35	.1186981	53.
2.82	3.04	2.93	2.26	2.19	93.53	.1007814	45.
3.04	3.26	3.15	2.43	1.60	95.14	.0739064	33.
3.26	3.48	3.37	2.59	1.46	96.60	.0671876	30.
3.48	3.69	3.58	2.76	1.22	97.81	.0559897	25.
3.69	3.91	3.80	2.93	1.17	98.98	.0537501	24.
3.91	4.13	4.02	3.10	.73	99.71	.0335938	15.
4.13	4.34	4.24	3.26	.29	100.00	.0134375	6.

* *

MAX = 4.34 MIN = .00 MEAN = 1.30 STD. DEV. = .98

* *

MEAN OF THE TOTAL DISTRIBUTION = 1.2718

TABLE 10 STATISTICAL SUMMARY OF MOISTURE DEFICIT (LINEAR FUNCTION) - TORONTO

FREQUENCY ANALYSIS OF LINEAR MOISTURE DEFICIT MINIMUM INTER-EVENT TIME... 1 HOURS

INTERVAL FROM	TO	PLOT POSN.	PLOT POSN/AV	PERCENTAGE FREQ.	CUM.	PROBABILITY DENSITY	NO. OF VALUES
IMPULSE		.00		1.94	1.94		40.
.00	.33	.17	.08	15.12	17.06	.4603308	311.
.33	.66	.50	.24	9.53	26.59	.2901120	196.
.66	.99	.82	.41	7.97	34.56	.2427468	164.
.99	1.32	1.15	.57	8.22	42.78	.2501476	169.
1.32	1.64	1.48	.73	5.88	48.66	.1790998	121.
1.64	1.97	1.81	.89	6.22	54.89	.1894609	128.
1.97	2.30	2.14	1.05	7.24	62.13	.2205444	149.
2.30	2.63	2.47	1.22	5.49	67.62	.1672585	113.
2.63	2.96	2.79	1.38	3.69	71.32	.1124924	76.
2.96	3.29	3.12	1.54	4.96	76.28	.1509767	102.
3.29	3.62	3.45	1.70	5.30	81.58	.1613378	109.
3.62	3.94	3.78	1.86	5.83	87.41	.1776196	120.
3.94	4.27	4.11	2.03	3.60	91.01	.1095321	74.
4.27	4.60	4.44	2.19	1.75	92.76	.0532859	36.
4.60	4.93	4.76	2.35	2.38	95.14	.0725280	49.
4.93	5.26	5.09	2.51	1.65	96.79	.0503256	34.
5.26	5.59	5.42	2.67	1.02	97.81	.0310834	21.
5.59	5.91	5.75	2.84	1.51	99.32	.0458851	31.
5.91	6.24	6.08	3.00	.53	99.85	.0162818	11.
6.24	6.57	6.41	3.16	.15	100.00	.0044405	3.

* *

MAX = 6.57 MIN = .00 MEAN = 2.03 STD. DEV. = 1.56

* *

MEAN OF THE TOTAL DISTRIBUTION = 1.9880

minimum. These events are not included in the calculation of the frequency for the first interval.

Following the frequency analysis table, the maximum (MAX), minimum (MIN), mean (MEAN) and standard deviation (STD. DEV.) are printed. If the frequency tables contain an impulse, this mean does not include those events occurring at the impulse. The mean of all data, including the impulse, is printed on the last line of the table. The difference between the two means therefore, results from the number and magnitude of events at the impulse.

5.2 Determination of Probability and Return Periods

The cumulative frequency data, column 6, provides the most convenient method for determining the probability and return period of an event. Initially, the particular storm event characteristic or characteristics of interest must be identified.

For example, let us take the storm event starting on the 10th hour, 13th day, 7th month of 1960, Table 3. This event is characterized by:

a) a depth of 1.73 inches,
b) a duration of 4 hours,
c) an intensity of 0.4325 inches/hour, and
d) a preceding inter-event time of 91 hours.

Using the statistical summary tables, the probability and return period of each of these characteristics can be calculated. To simplify the procedure, the cumulative frequency curves can be plotted, for example as in Figure 4. The cumulative frequency of the impulse is plotted as a vertical straight line at the value of the impulse and the cumulative frequency for each interval at the upper limit of each interval. A curve may then be drawn through the plotted points.

The drawing of a smooth curve or a stepped curve is illustrated by Figures 5 through 8, where the cumulative frequency curves have been plotted using each of the over 2000 events analyzed for Toronto. The plotting position for each event was determined by sorting the data and ranking each value. The plotting position was then calculated using the general equation:

$$pp = m/(n + 1)$$

where:
- pp is the plotting position in probability, (less than or equal, $\leq$);
- m is the rank of the value; and
- n is the total number of values being plotted

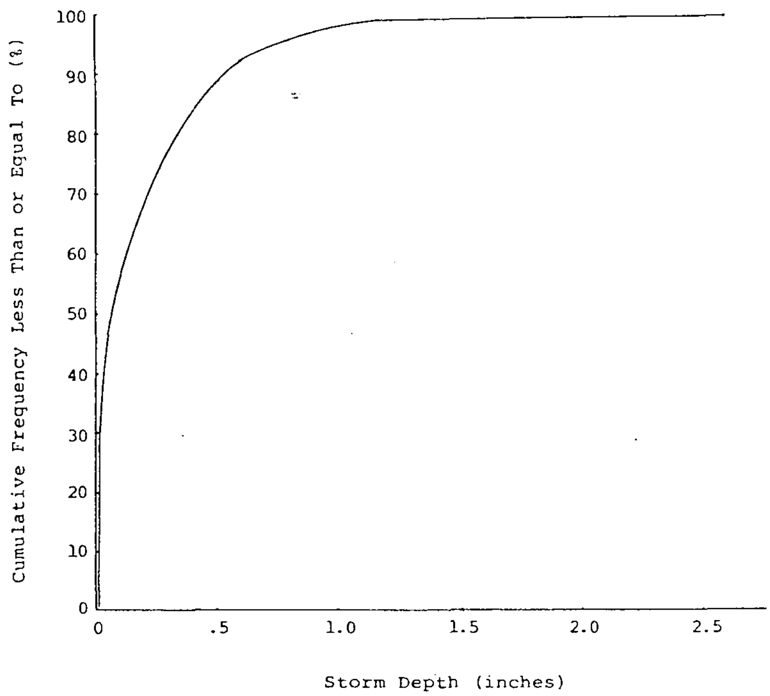

FIGURE 4 CUMULATIVE FREQUENCY DISTRIBUTION FOR STORM DEPTHS FROM FREQUENCY TABLES - TORONTO

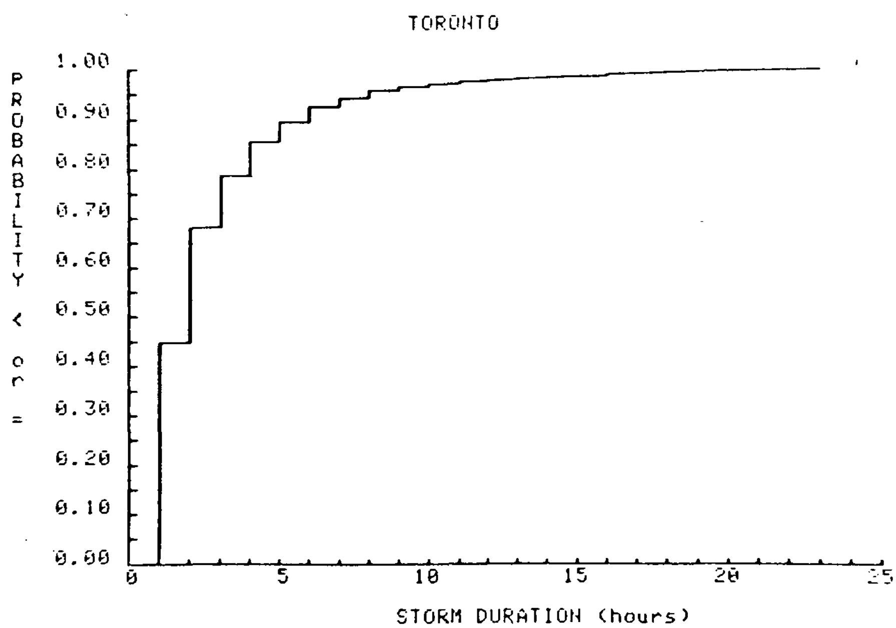

FIGURE 5 CUMULATIVE FREQUENCY DISTRIBUTION OF STORM DURATIONS BY PLOTTING EACH EVENT - TORONTO

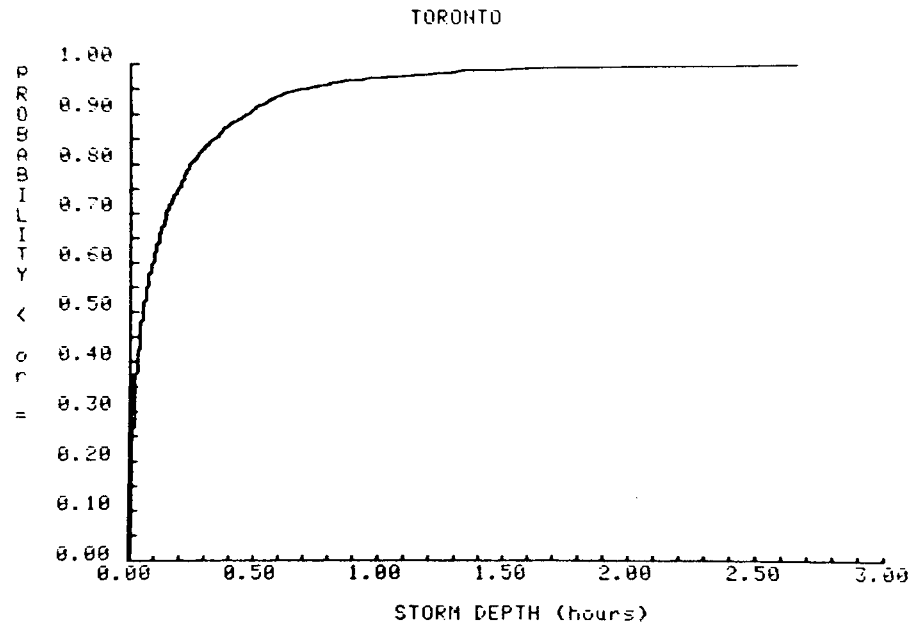

FIGURE 6 CUMULATIVE FREQUENCY DISTRIBUTION OF STORM DEPTHS BY PLOTTING EACH EVENT - TORONTO

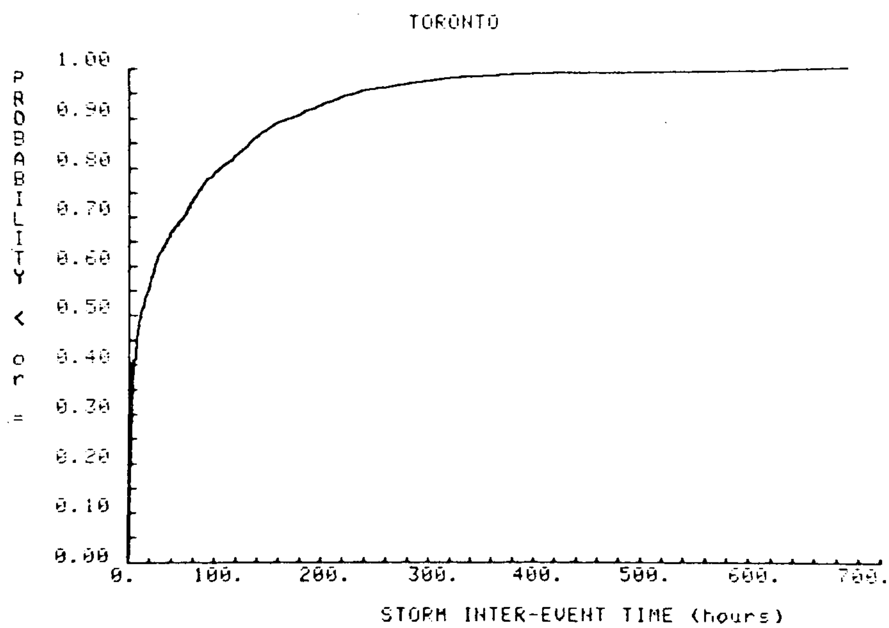

FIGURE 7 CUMULATIVE FREQUENCY DISTRIBUTION OF STORM INTER-EVENT TIMES BY PLOTTING EACH EVENT - TORONTO

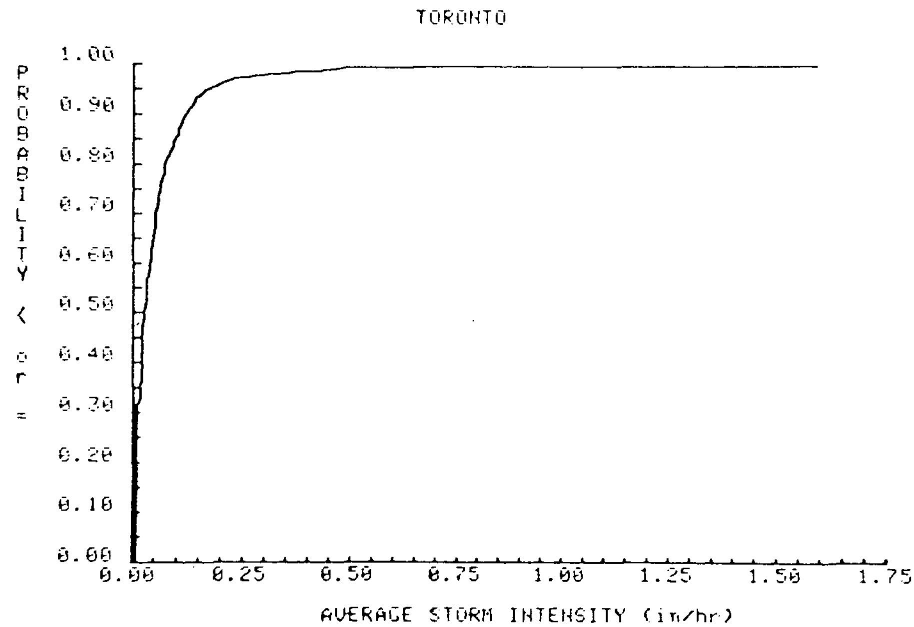

FIGURE 8 CUMULATIVE FREQUENCY DISTRIBUTION OF STORM INTENSITY BY PLOTTING EACH EVENT - TORONTO

The step-like shape of the plot for storm durations reflects the one-hour reporting interval of the data i.e., it is not possible to have durations other than in intervals of one hour; therefore, there is no probability associated with durations of, for example, 1.5 hours.

From the cumulative frequency tables (or a plot of the tables), the probability less than or equal to a given value can be determined. The probability greater than or equal to a given value and the corresponding return period is sometimes of interest. This probability (Prob $a \geq a_o$) is the complement of the probability less than or equal to (Prob $a \leq a_o$). The return period is the reciprocal of the product of this probability and the average annual number of events. Table 11 summarizes these calculations for the example storm event. The return period for the event varies from 2.5 years (on the average every 2.5 years) to 0.05 years (20 times a year), depending on the characteristic chosen. It is, therefore, very important to understand the nature of the physical system and which rainfall characteristic or characteristics are important to the design before assigning a return period to a storm event.

TABLE 11 CALCULATION OF PROBABILITY AND RETURN PERIOD FOR EXAMPLE STORM

Rainfall Characteristics	% Cumulative[1] Prob. ($a \leq a_o$)	% Cumulative[2] (Prob. ($a \geq a_o$)	Return[3] Period
Depth	99.71	0.29	2.51 yr
Duration	84.88	15.12	0.05 yr
Intensity	99.26	0.74	1.00 yr
Inter-event Time	84.56	15.44	0.05 yr

1 From cumulative frequency table or graph

2 Cumulative probability ($a \geq a_o$) = 100 - cumulative probability ($a \leq a_a$)

3 Return period = 100/(θ x P)

where: θ is the average annual number of independent events. (For Toronto, the average annual number of independent events was 137.13, with a minimum inter-event time of one hour separating independent events, Table 4) and

P is the cumulative probability greater than or equal to a given value.

Practical engineering design is often concerned with more than one rainfall characteristic. For example, storage utilization and spills depend on both the event volumes and the preceding inter-event times. In calculating the return period of a flood peak, the joint probability of the occurrence of an intensity and a duration sufficient to create a steady flow is of interest. If intensity and duration are independent (see Appendix), the two probabilities can be multiplied together to calculate the joint probability. For the example storm:

Prob (intensity $\geq$ 0.43 and duration > 4)

= prob (intensity $\geq$ 0.43 • prob duration $\geq$ 4)

= 0.74 x 15.12 - 11.19%.

The return period of a peak flow caused by this event would be:

Return period = 100/(11.19 x 137.13)

= 0.07 or about 14 times/year.

A similar calculation would be required for runoff control systems where storage was available. In this case, the joint probability of storm volumes and inter-event times would be of prime importance.

In summary, it cannot be over-emphasized that care must be taken to understand the dynamics of the runoff control system and which characteristics of rainfall events are of prime importance to the system. It is impossible to calculate a correct return period for a design event without this understanding. The independence of rainfall storm events and their characteristics (Appendix) are additional factors not considered in detail in this work.

As pointed out in Section 4, no differentiation was made in the example storm analysis between liquid and frozen precipitation. In using the statistical summary tables, this must be kept in mind. It may be necessary to recalculate the tables in specific instances.

APPENDIX

Independence of Rainfall Characteristics

APPENDIX

Independence of Rainfall Characteristics

The physical independence of storm events, as referred to briefly in Section 3, must be assured to permit the correct calculation of the return period of events. This Appendix deals with the statistical independence of rainfall characteristics which is important to the calculation of the joint probability of two or more rainfall characteristics.

Independence of the rainfall characteristics is important because it enables the joint probability to be calculated from the marginal distributions of the individual characteristics. That is, the probability of a duration greater than some value given an intensity greater than some value is the product of the two individual probabilities. If, for example, intensity and duration were not independent variables it would be necessary to develop a full probability surface to enable correct calculation of the joint probability.

Developing an adequate three-dimensional probability surface requires enormous amounts of data. The frequency distribution of, for example, intensities given a duration of one hour must be calculated. This procedure must then be repeated for all durations. Difficulties arise because, for very long durations, there will be very few events to define the frequency distribution of intensity.

For the purpose of this work, all rainfall data were analyzed with a minimum inter-event time of one hour. In some cases, the correlation among rainfall characteristics obtained using an inter-event time of one hour suggest they are not independent (Tables A-1 through A-6). The change in the correlation between rainfall characteristics as a function of the minimum inter-event time is shown in Figures A-1 through A-6 for Winnipeg. By choosing a minimum inter-event time of about five hours, storm intensity and duration become effectively independent (Figure A-2).

Statistically, two variables are not independent until the correlation is zero. However, for many practical engineering applications, a correlation coefficient slightly greater than zero can indicate independence. Confidence limits can be calculated for the regression line and the correlation coefficient to quantify this approach.

A summary of the correlation between rainfall characteristics for selected cities (Moncton, Montreal, Sydney, Toronto, Vancouver and Winnipeg) is presented in Tables A-1 through A-6.

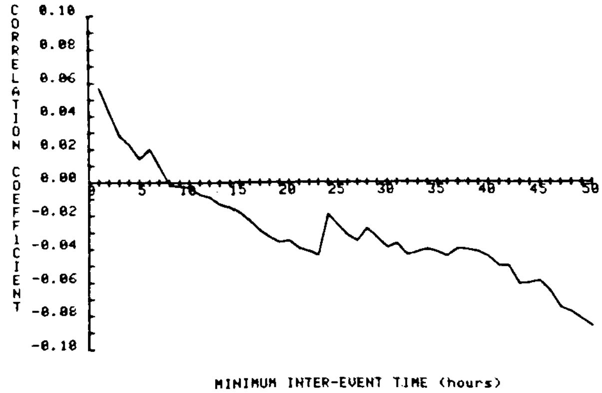

FIGURE A-1 CORRELATION OF STORM DEPTH AND INTER-EVENT TIME - WINNIPEG

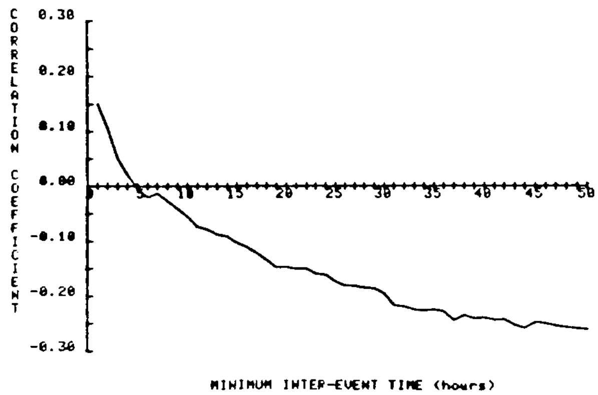

FIGURE A-2 CORRELATION OF STORM INTENSITY AND STORM DURATION - WINNIPEG

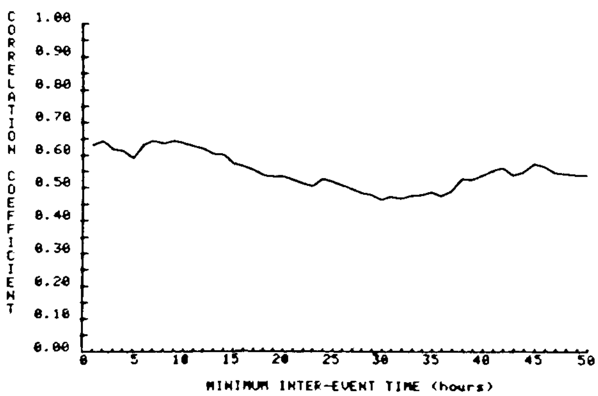

FIGURE A-3 CORRELATION OF STORM DURATION AND STORM DEPTH - WINNIPEG

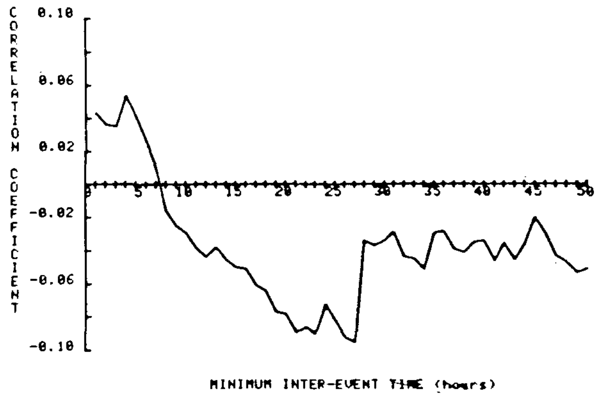

FIGURE A-4 CORRELATION OF STORM DURATION AND INTER-EVENT TIME - WINNIPEG

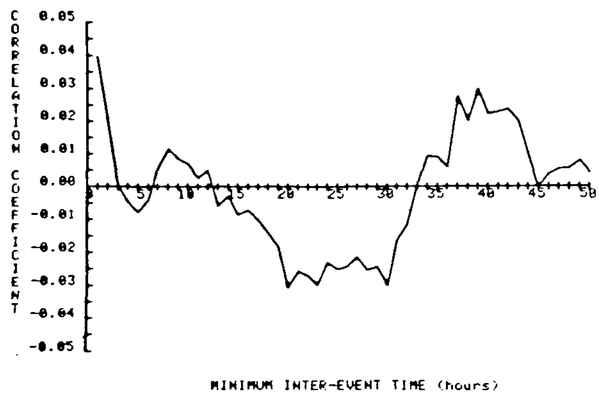

FIGURE A-5 CORRELATION OF STORM INTENSITY AND INTER-EVENT TIME - WINNIPEG

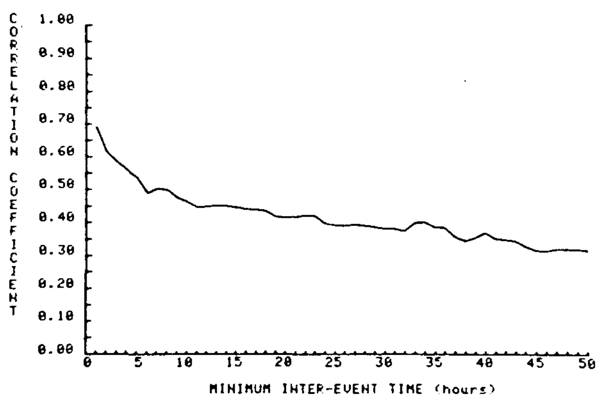

FIGURE A-6 CORRELATION OF STORM DEPTH AND STORM INTENSITY - WINNIPEG

TABLE A-1 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - MONCTON

	MINIMUM INTER-EVENT TIME, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.21	0.13	0.08	0.04	0.02	-0.05	-0.15	-0.17	-0.22	-0.23
2 Duration - Inter-event Time	0.04	0.03	0.04	0.05	0.03	0.03	0.0	-0.00	0.04	0.06
3 Depth - Inter-event Time	0.07	0.06	0.06	0.08	0.07	0.05	0.02	0.01	0.01	-0.01
4 Depth - Intensity	0.57	0.51	0.48	0.46	0.45	0.41	0.34	0.28	0.23	0.17
5 Duration - Depth	0.77	0.77	0.75	0.73	0.71	0.69	0.61	0.62	0.61	0.63
6 Intensity - Inter-event Time	0.11	0.09	0.08	0.08	0.08	0.05	0.05	0.05	-0.04	-0.05

TABLE A-2 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - MONTREAL

	MINIMUM INTER-EVENT TIME, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.10	0.03	-0.00	-0.03	-0.06	-0.12	-0.19	-0.22	-0.25	-0.25
2 Duration - Inter-event Time	0.10	0.12	0.12	0.12	0.10	0.05	-0.01	-0.01	-0.04	-0.05
3 Depth - Inter-event Time	0.06	0.06	0.05	0.05	0.04	0.01	-0.02	-0.02	-0.04	-0.04
4 Depth - Intensity	0.63	0.57	0.52	0.48	0.46	0.38	0.33	0.29	0.21	0.13
5 Duration - Depth	0.69	0.68	0.67	0.68	0.66	0.63	0.60	0.60	0.68	0.71
6 Intensity - Inter-event Time	0.00	0.02	-0.03	-0.04	-0.04	-0.04	-0.04	-0.03	-0.04	-0.02

TABLE A-3 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - SYDNEY

	MINIMUM INTER-EVENT TIME, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.4	0.34	0.27	0.22	0.17	0.05	-0.11	-0.16	-0.23	-0.24
2 Duration - Inter-event Time	0.07	0.04	0.03	0.04	0.04	-0.02	0.01	0.09	0.07	0.01
3 Depth - Inter-event Time	0.08	0.07	0.06	0.05	0.05	0.01	-0.04	-0.02	-0.03	-0.04
4 Depth - Intensity	0.68	0.67	0.63	0.60	0.57	0.50	0.38	0.29	0.24	0.15
5 Duration - Depth	0.83	0.80	0.78	0.77	0.76	0.74	0.68	0.68	0.66	0.68
6 Intensity - Inter-event Time	0.10	0.12	0.11	0.12	0.10	0.11	0.04	0.03	-0.00	0.02

TABLE A-4 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - TORONTO

	MINIMUM INTER-EVENT TIME, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.10	0.05	0.01	-0.03	-0.04	-0.07	-0.15	-0.19	-0.23	-0.24
2 Duration - Inter-event Time	0.03	0.05	0.05	0.06	0.05	0.01	0.03	-0.01	0.02	0.02
3 Depth - Inter-event Time	0.03	0.04	0.04	0.05	0.04	0.05	0.06	0.04	0.04	0.03
4 Depth - Intensity	0.65	0.57	0.55	0.52	0.51	0.48	0.37	0.30	0.24	0.22
5 Duration - Depth	0.66	0.67	0.65	0.64	0.63	0.63	0.61	0.60	0.60	0.60
6 Intensity - Inter-event Time	0.02	0.00	-0.01	-0.02	-0.01	0.01	0.00	0.02	-0.01	0.00

TABLE A-5 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - VANCOUVER

	MINIMUM INTER-EVENT TIME, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.41	0.34	0.27	0.23	0.19	0.02	-0.11	-0.13	-0.14	-0.16
2 Duration - Inter-event Time	0.04	0.04	0.03	0.01	-0.00	-0.01	0.01	0.02	-0.03	-0.06
3 Depth - Inter-event Time	0.03	0.04	0.03	0.02	0.00	-0.01	0.00	0.03	-0.00	-0.03
4 Depth - Intensity	0.59	0.57	0.55	0.53	0.50	0.38	0.19	0.11	0.11	0.06
5 Duration - Depth	0.87	0.85	0.83	0.82	0.80	0.79	0.81	0.84	0.85	0.86
6 Intensity - Inter-event Time	0.02	0.03	0.03	0.03	0.03	0.01	-0.05	-0.03	0.03	0.02

TABLE A-6 CORRELATION OF RAINFALL CHARACTERISTICS FOR DIFFERENT INTER-EVENT TIMES - WINNIPEG

	MINIMUM INTER-EVENT TIMES, HOURS									
Correlation	1	2	3	4	5	10	20	30	40	50
1 Intensity - Duration	0.15	0.11	0.05	0.02	0.00	-0.06	-0.15	-0.20	-0.24	-0.26
2 Duration - Inter-event Time	0.04	0.04	0.04	0.05	0.04	-0.03	-0.08	-0.03	-0.03	-0.05
3 Depth - Inter-event Time	0.06	0.04	0.03	0.02	0.01	0.00	-0.04	-0.04	-0.04	-0.09
4 Depth - Intensity	0.69	0.62	0.59	0.56	0.54	0.47	0.42	0.38	0.37	0.32
5 Duration - Depth	0.63	0.64	0.62	0.61	0.59	0.64	0.54	0.47	0.54	0.54
6 Intensity - Inter-event Time	0.04	0.02	0.00	-0.00	-0.01	0.01	-0.03	-0.03	0.02	0.00