NIWA
Taihoro Nukurangi

Review of the frequency of high intensity rainfalls in Christchurch

NIWA Client Report: CHC2009-139
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Review of the frequency of high intensity rainfalls in Christchurch

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Executive Summary

Rainfall depth-duration-return period relations are derived for Christchurch from a database of nearly 8100 stationary and serially independent annual maxima of 10 durations ranging from 0.17 to 72 hours. Depth-return period relations at each rainfall station are modelled by Extreme Value Type I frequency distributions. L-moment analysis shows that Christchurch is a single homogeneous region and a 4-parameter Kappa frequency distribution is used to model dimensionless rainfall depth-return period data in this area using median values of annual maxima. The depth-duration relation has a constant spatial pattern for rainfalls up to about 12 hours duration but increasingly resembles the mean annual pattern for longer durations. Area reduction factors derived in the United Kingdom may be used in Christchurch. These findings are similar to those of earlier work by Pearson (1992) and Griffiths and Pearson (1993) using mean values of annual maxima, although current predicted rainfall depths are on average about 25% lower than earlier values because the more recent rainfall pattern has been less stormy. No evidence of the influence of the Interdecadal Pacific Oscillation and the El Niño Southern Oscillation on climate variability was found in the longer rainfall records of annual daily maxima: nor was any trend due to human induced climate change detected. Some guidelines are given, however, for dealing with the potential impact of human induced climate change.

1. Introduction

Christchurch City Council and Environment Canterbury requested that a review be undertaken of the frequency of high intensity rainfalls in Christchurch. The purpose of the review is to update previous studies by Pearson (1992) and Griffiths and Pearson (1993) by including rainfall records collected since that earlier work, as well as incorporating records now available from additional raingauges.

The methodology used herein for estimating the areal and frequency distributions of potential storm rainfalls from point measurements made under a particular climatic regime is similar to that of Pearson (1992).

Our analysis involves six steps. First, median annual maximum rainfalls are computed for ten durations ranging from 0.17 hr to 72 hr for each rainfall station in the area with the appropriate data. Second, the spatial distribution of median annual maximum 24 hr rainfall is mapped and a model derived to predict median rainfall for other durations at a point, using the map or otherwise. Third, rainfall depth-return period relations are derived for the durations of the first step for all rainfall stations. A comparison is then made at some stations between these relations and those predicted by the computer package, HIRDS (High Intensity Rainfall Design System, Version 2), described by Thompson (2002).

Fourth, a regional frequency analysis is undertaken to determine dimensionless frequency factors, or multipliers, for eight durations and differing return periods. Fifth, area reduction factors are derived to predict the areal distribution of rainfalls from point values. Sixth, some long term rainfall records of annual daily maxima are examined for evidence of climate variability and change, and guidelines are given for dealing with potential future climate change.

The aim of the review is to provide design rainfalls for hydrologic use in Christchurch.

2. Rainfall data

Rainfall data for this study came from both automatic and manual raingauges operated by Christchurch City Council, Environment Canterbury and the Meteorological Service of New Zealand. Details about these raingauges are given in Table 2.1 and Table 2.2, and their locations are shown in Figure 1.

The time series of annual maximum daily rainfalls for the two rainfall stations having the longest records - Christchurch Gardens and Christchurch Airport (Figure 2) - were

Table 2.1: Details of automatic raingauge records (see locations in Figure 1)

Number	Location	Start	End	Years with gaps	Length (yr)	Recorder resolution
323605	42A Peraki St, Kaiapoi	1988	2008		21	1 h, 15 min from 2001
324501	Christchurch Airport	1955	2008	1995-2001	47	<6 min
324606	Harbour Rd, Brooklands	1987	2008		22	15 min
324607	Lower Styx Rd	1987	2008		22	15 min
324608	PS62, Tyrone St	1982	2008		27	1 h, 15 min from 1988
324609	Burwood Hospital	1962	2002		41	1 h
324610	Firestone, Papanui	1981	2008	1988-1990	25	6 min, 15 min from 2008.
325403	PS80, Templeton	1990	2008		19	1 h
325507	College of Education	1965	2008		44	1 h, 15 min
325508	Wigram Retention Basin	1995	2008		14	15 min
325510	Halswell Retention Basin	1980	2008	1990	28	15 min
325601	Christchurch Gardens	1962	2008		47	1 h
325611	Cashmere Valley	1963	1975		13	1 h
325617	Horseshoe Lake PS205	1987	2008		22	15 min
325618	PS42, Sparks Rd	1968	2008		41	1 h, 15 min from 1988, 5 min from 2007
325619	Tunnel Rd	1962	2008		47	1 h, 15 min from 1987
325620	Huntsbury Reservoir	1969	2002		34	1 h
325621	Bowenvale Flume	1989	2008		20	15 min
325622	Mid Bowenvale	1988	2002		15	1 h
325623	St Albans	1967	1981		15	1 h
325708	Oxidation Pond No. 6	1987	2002		16	1 h
325711	Van Asch St, Sumner	1968	2008	2004	40	1 h
326610	Hoon Hay Valley	1962	1985	1977	23	1 h
326611	Coopers Knob	1990	2008	1993	18	7.5 min
326616	Upper Bowenvale	1989	2008		20	1 h

Table 2.2: Details of manual raingauge records

Number	Site name	Start	End	Years with gaps	Length (yr)
324501	Christchurch Airport	1946	2008		63
324601	Waimakariri Bridge	1948	1994	1950-1953	43
324603	Windsor	1978	1996	1992	18
325401	Paparua Prison Farm	1925	1983	1941-1967	32
325502	Wigram Aero	1938	1968	1963	30
325504	Prebbleton	1970	2008		29
325601	Christchurch Gardens	1899	2008		110
325602	Cashmere Hills	1892	1975		84
325603	Shirley	1940	2008	1952	68
325703	Bromley	1962	1989		28
325704	Mt Pleasant	1964	1993		30
325705	Horotane	1950	1985	1974,1981,1982	33
325801	Godley Head Light	1936	1989		54
326301	Burham Sewage	1954	2004	1992, 2000-2002	47
326401	Lincoln	1881	1987	1884-1885	105
326402	Lincoln Broadfield	1972	1999		28
326501	Otahuna	1904	1956		53
326601	Allandale	1917	1973		57
326602	Living Springs	1978	2006	1985	28
326607	Governors Bay	1990	2008		19
326701	Lyttelton Harbour	1966	2008	1980-1992,2004	29
326702	Purau	1963	1983		21
327501	Greenpark	1957	2008		52
327603	Gebbies Pass	1949	1977		29

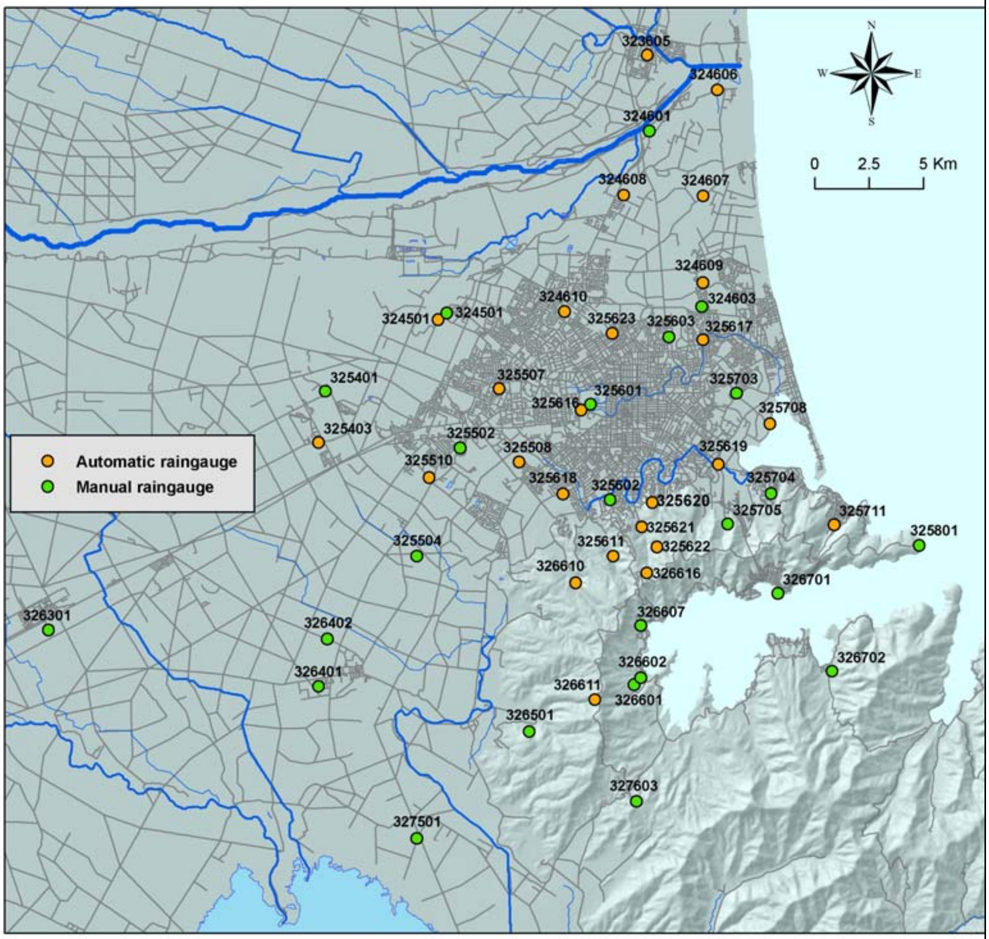


Figure 1: **Locations of raingauges.**

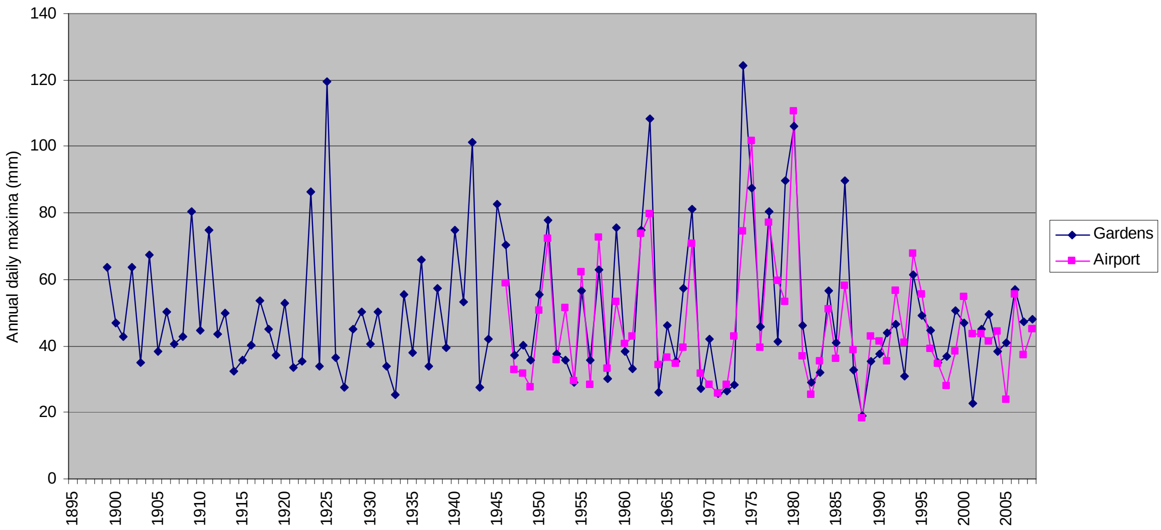


Figure 2: **Time series of annual maximum daily rainfalls for Christchurch Gardens and Christchurch Airport.**

examined for evidence of non-stationarity and serial correlation. For both records no evidence of trend, periodicity, persistence or shifts was found by inspection and by using statistical tests. Specifically, test statistics computed using the two records included the Spearman rank order correlation coefficient and, for a split sample, the Mann-Whitney test for location difference and the Wald-Wolfowitz runs test for any difference. In all cases the null hypothesis was accepted at the 0.05 significance level. This means that each record can be assumed to be stationary and composed of independent values. It is of interest to note that Withers and Pearson (1991) came to a similar conclusion using other statistical tests.

Figure 2 shows periods of different lengths where annual maxima tend to be persistently high or low. These runs are a normal feature of rainfall time series. Probability distributions for the number and length of such runs, above median rainfall and less than median rainfall, have been calculated for 3-monthly rainfalls at Christchurch Gardens by Griffiths (1990).

3. Analysis

3.1. Christchurch storm rainfalls

Heavy rainfalls in Christchurch result from depressions, with centres south and south-east of South Island producing south-westerly frontal rain with preceding thunderstorms, and with centres north to east of South Island producing north-easterly to south-easterly rain. Falls of more than 100 mm of rain in 24 hours are not unusual and up to 170 mm in 18 hours has been recorded. Tomlinson (1978) describes a very local, intense, short duration thunderstorm near Wigram Aerodrome in 1975 which yielded 30 mm in 0.5 hr. Detailed records of severe storms from 1963 to 1986 are reviewed by Pearson (1992). Since then no storms of comparable significance have occurred apart from another short duration thunderstorm near Wigram Aerodrome in January 2009 which yielded 39 mm in 0.5 hr. Also worthy of note is a storm in October 2000 in which 133 mm of rain was recorded in 12 hrs at the Upper Bowenvale Valley gauge (326616, Figure 1).

3.2. Rainfall depth-duration relations

Median annual maximum rainfalls for durations of 0.17, 0.33, 0.5, 1, 3, 6, 12, 24, 48 and 72 hr were extracted from the data (Median value is a more robust statistic to use than mean value for non-normal data). Half hour maxima from 15 minute recorders were multiplied by 1.07 to convert from fixed time maxima (Tomlinson 1980, p.7). Likewise, hourly maxima were multiplied by 1.14. Tables 3.1 and 3.2 list the median annual maximum values. The normal mean annual rainfall for the 30 yr normal period 1971-2000 is also given in Table 3.2. Pearson (1992) presents tables similar to Tables

3.1 and 3.2 herein but lists mean rather than median annual maximum rainfalls for the various durations between 0.5 and 72 hr. Table 3.3 gives a comparison between mean annual rainfall values calculated by Pearson (1992) and those of this study for 1 and 24 hr durations. The values of Pearson (1992) are on average 5.7% higher for a 1 hr duration and 5.0% higher for a 24 hr duration. This result is to be expected as the rainfall record since about 1990, post-dating Pearson (1992), is relatively quiet with no large storms.

Correlations between rainfall stations with automatic raingauges were calculated for 1 and 24 hr annual maximum rainfalls. Pearson correlation coefficients were all positive for the 1 hr data and all coefficients exceeded 0.6 for the 24 hr data. Pearson (1992) obtained a similar result.

The spatial pattern or distribution of median annual maximum rainfalls of 24 hr duration (multiplied by 1.14 to convert from fixed time maxima) is displayed in Figure 3 along with isolines drawn by hand. (Note that in drawing the isolines, the Lyttelton gauge totals have been ignored because the data are not reliable.) This pattern closely resembles the pattern of normal mean annual rainfall shown in Figure 6. (Note also that we drew isolines in Figures 3 and 6 only to illustrate a similar pattern. Isoline construction is rather subjective and we believe this or any other spatial interpolation method is best left to the user.) But for durations shorter than 24 hr this resemblance diminishes. In fact, the standard deviations of the median annual maximum rainfalls increase little for durations of 0.5 to about 12 hrs, that is, the median annual maximum rainfall can be taken as approximately uniform for these durations. This behaviour allows the development of a simple non-linear model of rainfall depth-duration relations for durations between 0.5 and 24 hr. For details of the model see Pearson (1992). It is assumed that the median value of the median 0.5 hr rainfalls (which from Table 3.1 is 7.3 mm) is a constant value over Christchurch that gradually develops into the 24 hr duration isolines in Figure 3 as duration extends from 0.5 to 24 hr. For the model a power law is adopted

$$P_m = aD^b \qquad (1)$$

$$0.5 \leq D \leq 24\ hr$$

in which P_m is median annual maximum rainfall and D is duration. Using the median 0.5 hr value of 7.3 mm as one boundary condition (P_m = 7.3, D = 0.5), and the median annual maximum 24 hr value, P_{24}, given in Figure 3 as the other ($P_m = P_{24}$, D = 24) we find from Equation 1 that

$$b = ln(P_{24} / 7.3)/ln48 \qquad (2)$$

and

$$a = P_{24} / 24^b \qquad (3)$$

Table 3.1: Median annual maximum rainfalls for ten different durations determined from automatic raingauges.

Site number	Site name	Start	End	Median annual maximum rainfall (mm)									
				0.17 h	0.33 h	0.50 h	1 h	3 h	6 h	12 h	24 h	48 h	72 h
323605	42A Peraki St, Kaiapoi	1988	2008	no data	no data	no data	10.5	18.7	28.6	42.8	52.1	60.6	73.5
324501	Christchurch Airport	1955	2008	3.9	6.2	7.7	11.7	18.1	28.1	38.8		see daily table	
324606	Harbour Rd, Brooklands	1987	2008	no data	no data	6.8	9.5	17.3	26.9	41.4	54.5	59.5	67.8
324607	Lower Styx Rd	1987	2008	no data	no data	7.9	10.7	17.6	27.7	39.7	48.6	62.2	68.6
324608	PS62, Tyrone St	1982	2008	no data	no data	6.8	10.9	19.1	26.1	37.2	51.6	61.4	68.4
324609	Burwood Hospital	1962	2002	no data	no data	no data	13.3	21.1	28.0	37.1	46.7	56.8	70.5
324610	Firestone, Papanui	1981	2008	4.5	6.0	7.0	9.8	20.4	31.6	43.2	50.6	56.0	68.2
325403	PS80, Templeton	1990	2008	no data	no data	no data	10.0	18.5	26.6	37.4	49.6	59.0	64.6
325507	College of Education	1965	2008	no data	no data	6.5	11.2	20.1	29.3	41.8	52.3	60.4	70.6
325508	Wigram Retention Basin	1995	2008	no data	no data	7.3	9.1	17.4	27.3	40.2	53.0	58.1	60.9
325510	Halswell Retention Basin	1980	2008	no data	no data	9.3	12.4	19.4	29.2	38.4	46.3	59.0	65.5
325601	Christchurch Gardens	1962	2008	no data	no data	no data	10.9	21.0	30.4	44.4		see daily table	
325611	Cashmere Valley	1963	1975	no data	no data	no data	16.0	27.6	37.7	42.5	67.9	83.4	86.5
325617	Horseshoe Lake PS205	1987	2008	no data	no data	7.6	9.9	18.6	24.9	38.0	54.1	58.3	64.8
325618	PS42, Sparks Rd	1968	2008	no data	no data	7.1	11.4	22.5	30.4	43.1	59.8	72.6	75.5
325619	Tunnel Rd	1962	2008	no data	no data	8.1	11.9	23.1	32.8	44.4	56.0	65.9	74.8
325620	Huntsbury Reservoir	1969	2002	no data	no data	no data	12.3	23.4	35.9	47.3	61.5	77.5	87.9
325621	Bowenvale Flume	1989	2008	no data	no data	8.0	10.9	21.8	34.6	49.4	66.1	88.1	92.4
325622	Mid Bowenvale	1988	2002	no data	no data	no data	11.4	21.4	35.8	53.0	68.0	75.8	88.0
325623	St Albans	1967	1981	no data	no data	no data	11.4	20.9	29.9	42	44.8	58.3	79.8
325708	Oxidation Pond No. 6	1987	2002	no data	no data	no data	11.4	19.0	26.8	37.2	49.0	51.3	54.7
325711	Van Asch St, Sumner	1968	2008	no data	no data	no data	11.6	20.6	30.8	43.3	49.8	60.9	67.6
326610	Hoon Hay Valley	1962	1985	no data	no data	no data	13.7	23.3	35.1	45.2	57.3	75.0	86.8
326611	Coopers Knob	1990	2008	no data	no data	6.1	9.1	18.3	29.1	41.1	55.5	73.0	75.8
326616	Upper Bowenvale	1989	2008	no data	no data	no data	12.9	26.3	39.8	57.8	74.5	93.5	105

Table 3.2: Median annual maximum rainfalls 24-hr, 48-hr and 72-hr rainfall, and normal annual rainfall (1971-2000) determined from manual raingauges.

Site number	Site name	Start	End	Median annual maximum rainfall (mm) 24 h	48 h	72 h	Normal mean annual rainfall (mm) 1971-2000
324501	Christchurch Airport	1946	2008	47.0	59.8	68.4	630
324601	Waimakariri Bridge	1948	1994	46.7	58.9	67.6	598
324603	Windsor	1978	1996	43.0	55.8	69.0	-
325401	Paparua Prison Farm	1925	1983	57.6	66.9	79.0	609
325502	Wigram Aero	1938	1968	46.2	63.7	69.7	607
325504	Prebbleton	1970	2008	46.3	57.0	64.9	654
325601	Christchurch Gardens	1899	2008	50.5	64.2	70.9	653
325602	Cashmere Hills	1892	1975	58.1	70.6	81.1	695
325603	Shirley	1940	2008	47.3	58.3	64.5	587
325703	Bromley	1962	1989	46.2	55.1	66.6	602
325704	Mt Pleasant	1964	1993	51.9	68.5	77.0	699
325705	Horotane	1950	1985	55.6	67.4	72.6	677
325801	Godley Head Light	1936	1989	50.7	62.6	68.1	587
326301	Burham Sewage	1954	2004	51.3	61.2	64.5	646
326401	Lincoln	1881	1987	49.2	64.1	69.3	666
326402	Lincoln Broadfield	1972	1999	43.3	53.5	60.7	652
326501	Otahuna	1904	1956	61.1	85.1	87.9	786
326601	Allandale	1917	1973	69.5	87.7	104	874
326602	Living Springs	1978	2006	63.5	83.5	99.3	908
326607	Governors Bay	1990	2008	70.7	96.3	96.7	938
326701	Lyttelton Harbour	1966	2008	51.0	59.9	61.9	575
326702	Purau	1963	1983	82.1	117	137	844
327501	Greenpark	1957	2008	44.4	56.6	61.3	628
327603	Gebbies Pass	1949	1977	68.4	85.6	95.7	804

Table 3.3: Comparison between mean annual rainfall values of Pearson (1992) and this study for 1 and 24 hr durations.

		Pearson (1992)		This study		Percent differences	
Number	**Location**	**1 hr**	**24 hr**	**1 hr**	**24 hr**	1 hr	**24 hr**
323605	42A Peraki St, Kaiapoi			11.7	55.9		
324501	Christchurch Airport	14.1	58.9	13.0	53.1	-7.9	-9.9
324601	Waimakariri Br		62.6		54.7		-12.6
324603	Windsor		53.8		51.0		-5.3
324606	Harbour Rd, Brooklands			10.4	50.9		
324607	Lower Styx Rd			11.9	52.7		
324608	PS62, Tyrone St	12.4	45.3	11.9	50.5	-4.2	11.5
324609	Burwood Hospital	15	60	13.8	59.2	-8.0	-1.3
324610	Firestone, Papanui			12.8	50.8		
325401	Paparua Prison Farm		66.3		58.1		-12.3
325403	PS80, Templeton			10.1	48.4		
325502	Wigram Aero		57.3		53.6		-6.5
325504	Prebbleton		62.6		52.8		-15.7
325507	College of Education (Riccarton)			12.2	55.1		
325508	Wigram Retention Basin			9.5	48.7		
325510	Halswell Retention Basin			12.2	50.3		
325601	Christchurch Gardens	15.1	61.6	14.0	56.9	-7.1	-7.7
325602	Cashmere Hills		75.1		67.3		-10.4
325603	Shirley		59.7		54.7		-8.3
325611	Cashmere Valley	15.4	65.6	16.6	69.3	7.9	5.7
325617	Horseshoe Lake PS205			10.7	55.1		
325618	PS42, Sparks Rd	14.4	62.5	13.3	60.8	-7.9	-2.8
325619	Tunnel Rd	14.1	67.3	13.2	64.8	-6.1	-3.7
325620	Huntsbury Reservoir	13.8	68.1	13.0	69.9	-5.6	2.6
325621	Bowenvale Flume			11.8	70.7		
325622	Mid Bowenvale			11.2	74.1		
325623	St Albans	15.6	61.1	12.2	61.1	-21.8	0.0
325703	Bromley		64.0		61.6		-3.8
325704	Mt Pleasant		64.3		60.4		-6.0
325705	Horotane		57.8		61.7		6.7
325708	Oxidation Pond No. 6			9.7	51.5		
325711	Van Asch St, Sumner	12.4	58.7	11.9	56.8	-4.1	-3.3
325801	Godley Head Light		56.3		53.6		-4.8
326301	Burham Sewage				55.9		
326401	Lincoln		55.1		55.6		1.0
326402	Lincoln Broadfield				48.2		
326501	Otahuna				69.6		
326601	Allandale		76.3		78.7		3.1
326602	Living Springs		102.3		72.6		-29.0
326607	Governors Bay				70.7		
326610	Hoon Hay Valley	14.8	63.1	15.0	65.7	1.7	4.1
326611	Coopers Knob (ECan)			9.7	57.4		
326616	Upper Bowenvale			13.7	85.4		
326701	Lyttelton Harbour		66.7		56.5		-15.3
326702	Purau		99.4		108.3		9.0
327501	Greenpark		53.7		48.9		-8.9
327603	Gebbies Pass		89.4		71.8		-19.7
			average % increase			-5.7	-5.0
			median % increase			-6.1	-4.8

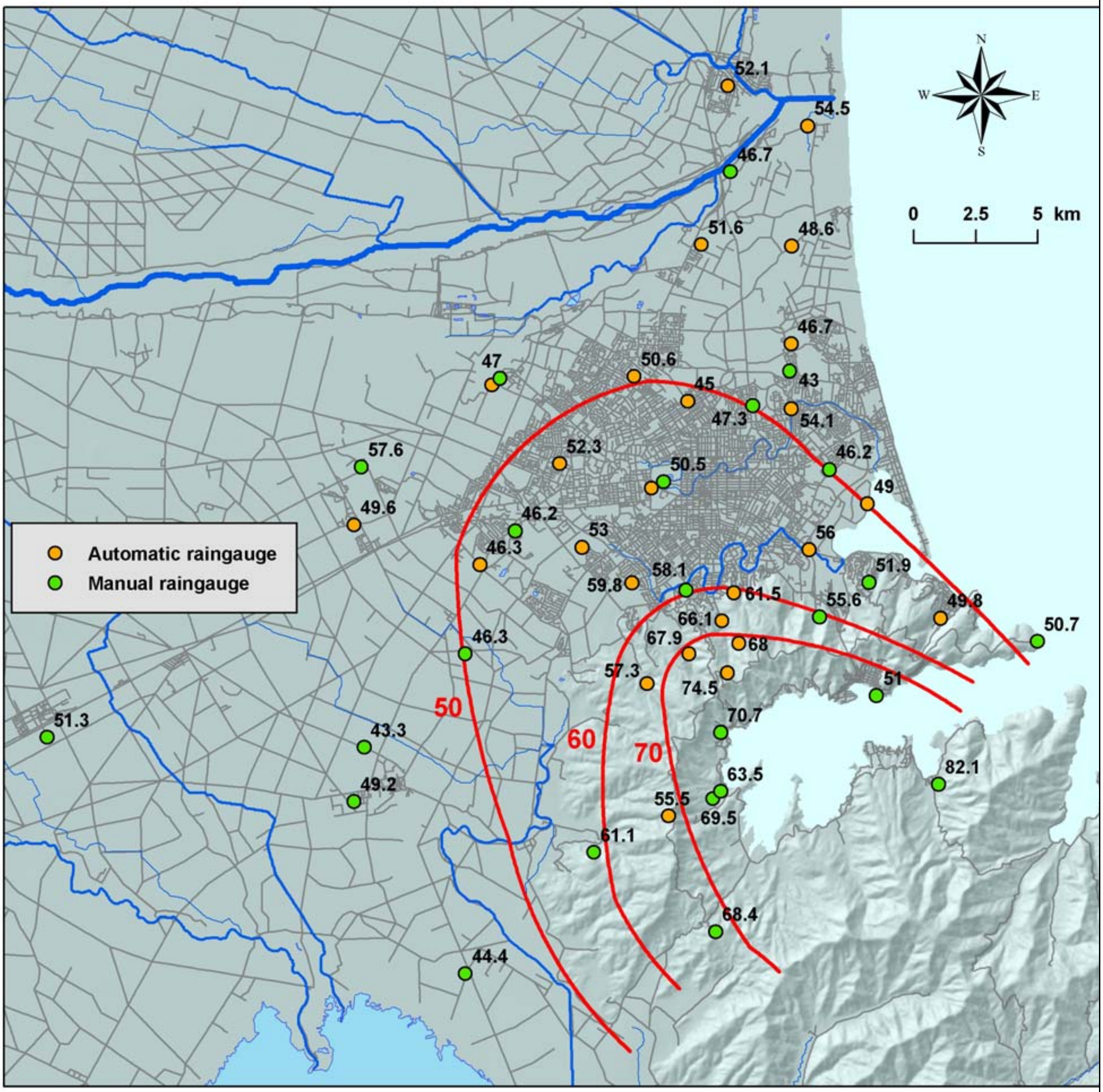


Figure 3: **Median annual maximum 24-hr rainfall (mm) and isolines (mm). (Note that in drawing the isolines, the Lyttelton gauge totals have been ignored because the data are not reliable.)**

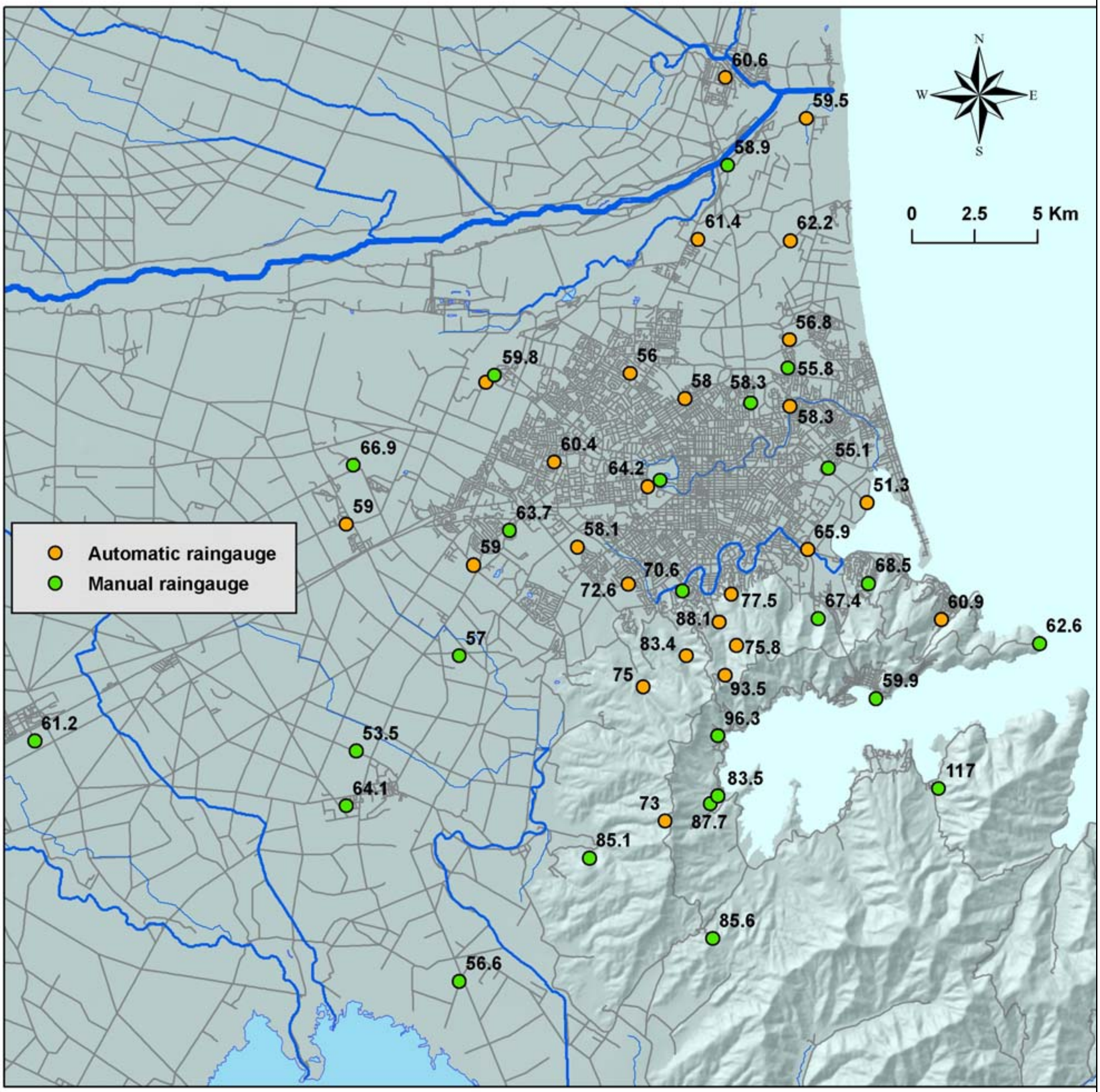


Figure 4: **Median annual maximum 48-hr rainfall (mm).**

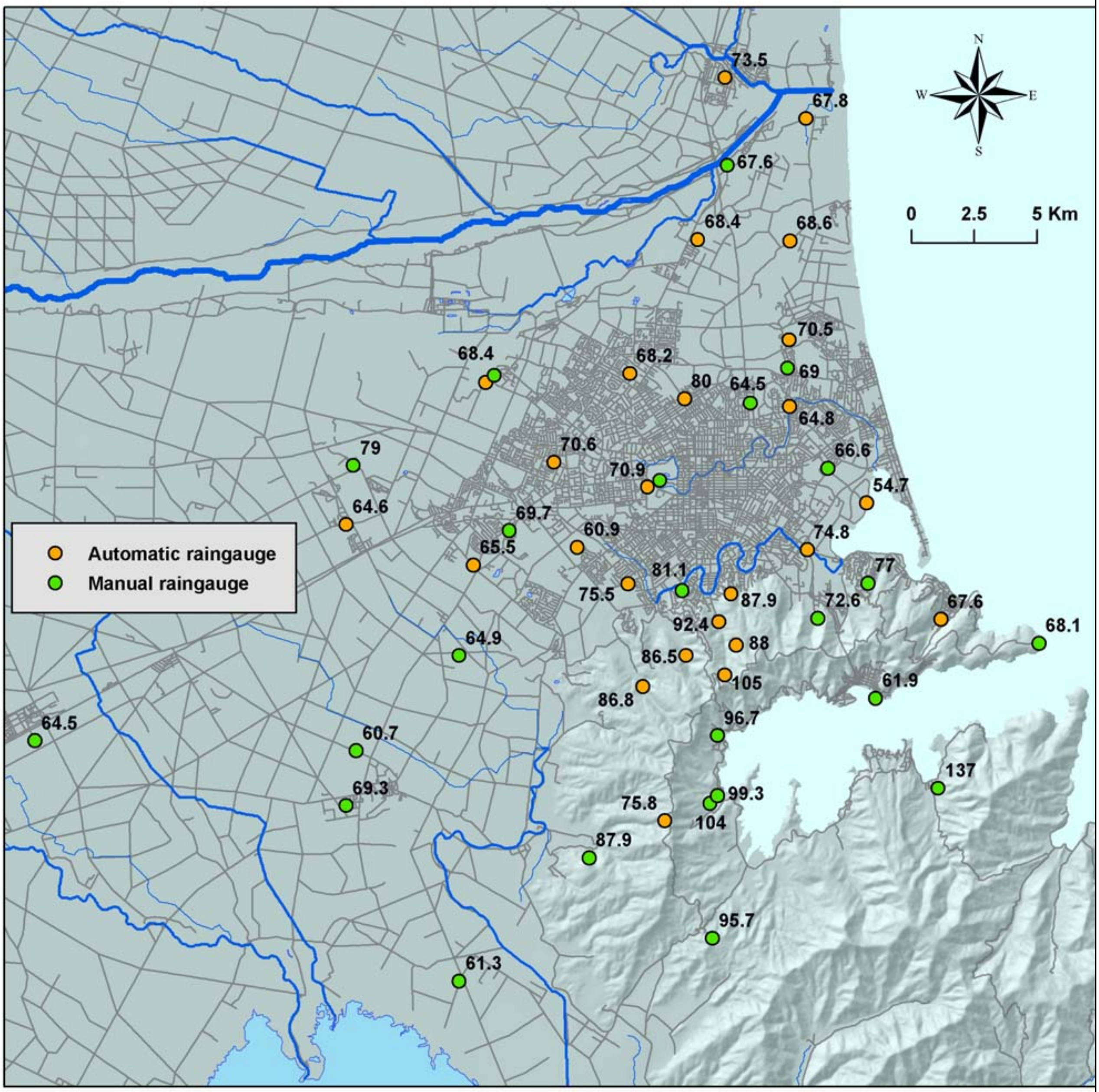


Figure 5: **Median annual maximum 72-hr rainfall (mm).**

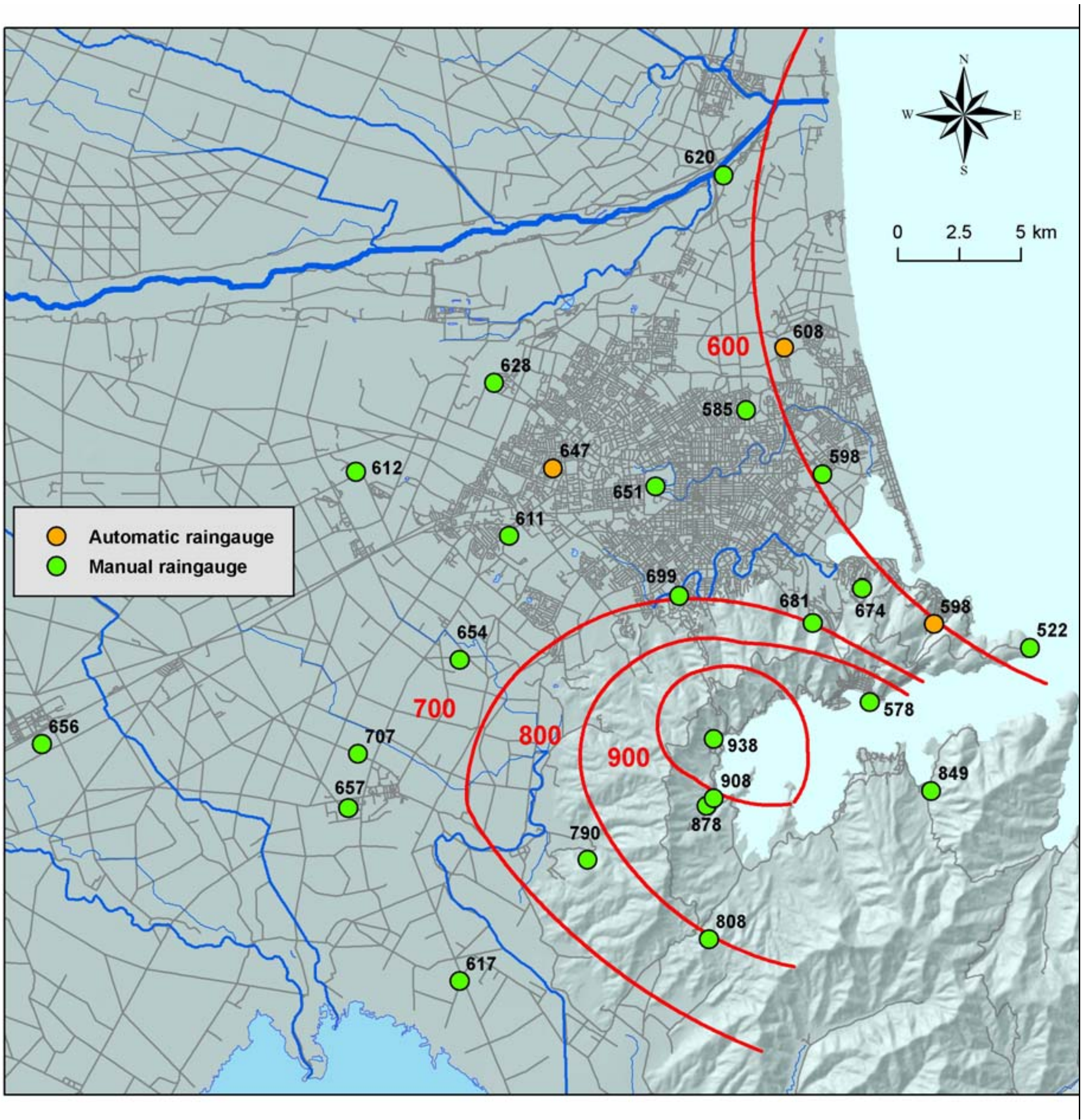


Figure 6: Normal mean annual rainfall (mm) (1971-2000) and isolines (mm). (Note that in drawing the isolines, the Lyttelton gauge totals have been ignored because the data are not reliable.)

Where median annual maximum rainfalls greater than 24 and up to 72 hr duration are of concern, Figures 3, 4 and 5 may be used to interpolate rainfall depths. One method of doing this for a given location is to plot 24, 48 and 72 hr rainfall depth values for a given duration obtained from Figures 3 to 5 against their respective durations and then fit a line through the three values. The resulting graph may then be used to read off rainfall depths for any intermediate duration.

3.3. Rainfall depth-return period relations

Extreme Value Type I (EV1) distributions were fitted by the method of probability weighted moments to the median annual maximum data for 8 durations. As in Pearson (1993) the Gringorten plotting position was employed. Results for Christchurch Gardens and Christchurch Airport are shown in Figure 7. Using the hypotheses tests of Hosking et al. (1985) it was found that of the 254 fits, 222 displayed EV1 behaviour, 24 EV2 and 8 EV3: the EV2 and EV3 behaviour was exhibited at a mix of sites and for varying durations with no apparent pattern. Steeper EV1 lines occur at each rainfall station as duration increases; and for fixed durations, steeper EV1 lines correspond to stations where normal mean annual rainfall is higher.

A comparison was made at three rainfall stations – Christchurch Gardens, Christchurch Airport and Van Asch Street, Sumner (Table 2.1) – between rainfall depths predicted by the High Intensity Rainfall Design System (HIRDS) and those predicted by analysis of station data herein. It can be seen from Figure 8 that for all durations and return periods at the three sites the performance of HIRDS is generally quite good.

3.4. Regional frequency analysis

Regional frequency analysis was employed to obtain dimensionless rainfall depth-return period relations for all durations and for any location in Christchurch, using rainfall data from all stations (Tables 2.1 and 2.2).

In previous work by Pearson (1992) and Griffiths and Pearson (1993) based on L-moments (Hosking 1990; Hosking and Wallis 1993), it was found that the Christchurch area could be treated as one homogenous region and that the 4-parameter Kappa distribution (Miekle 1973) provided a good fit to the dimensionless rainfall data. The Kappa cumulative distribution function, *F*, is given by

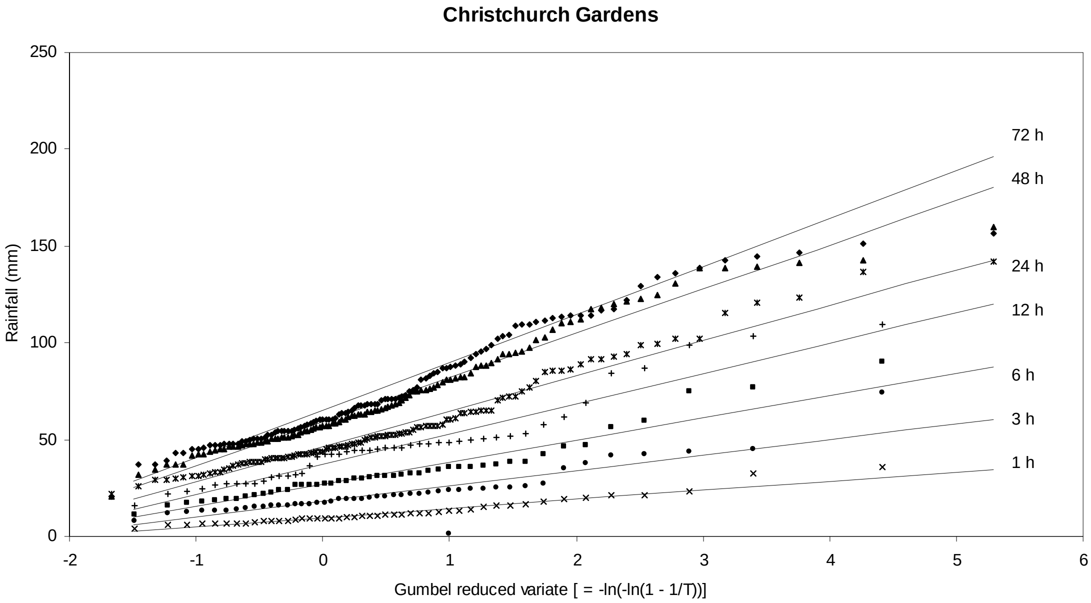
$$F = \{1 - h\{1 - [(k(P/P_m) - u)/a]\}^{1/k}\}^{1/h} \qquad (4)$$

or

$$P/P_m = u + (a/k)\{1 - [(1 - F^h)/h]^k\} \qquad (5)$$

where F = 1- (1/T), T is return period and P is rainfall depth. This function was fitted to the data of this study (Figure 9) yielding parameter estimates of u = 0.896, a = 0.308, k = -0.108 and h = -0.0992.

To test for homogeneity the V statistics of Hosking and Wallis (1993) were computed and their values confirm that Christchurch can be viewed as one homogeneous region.



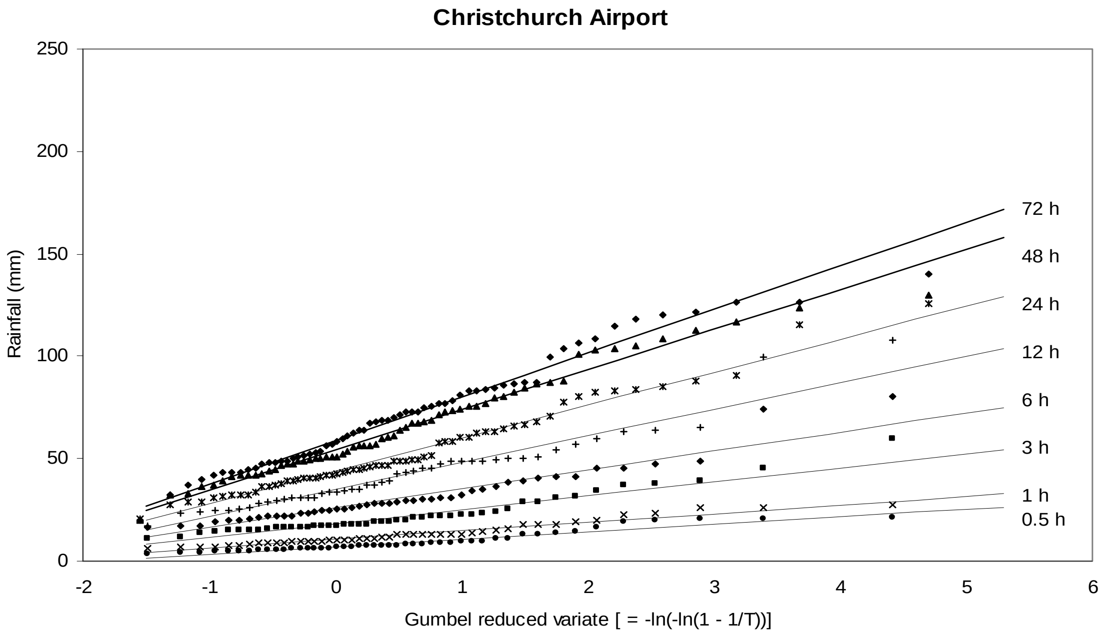
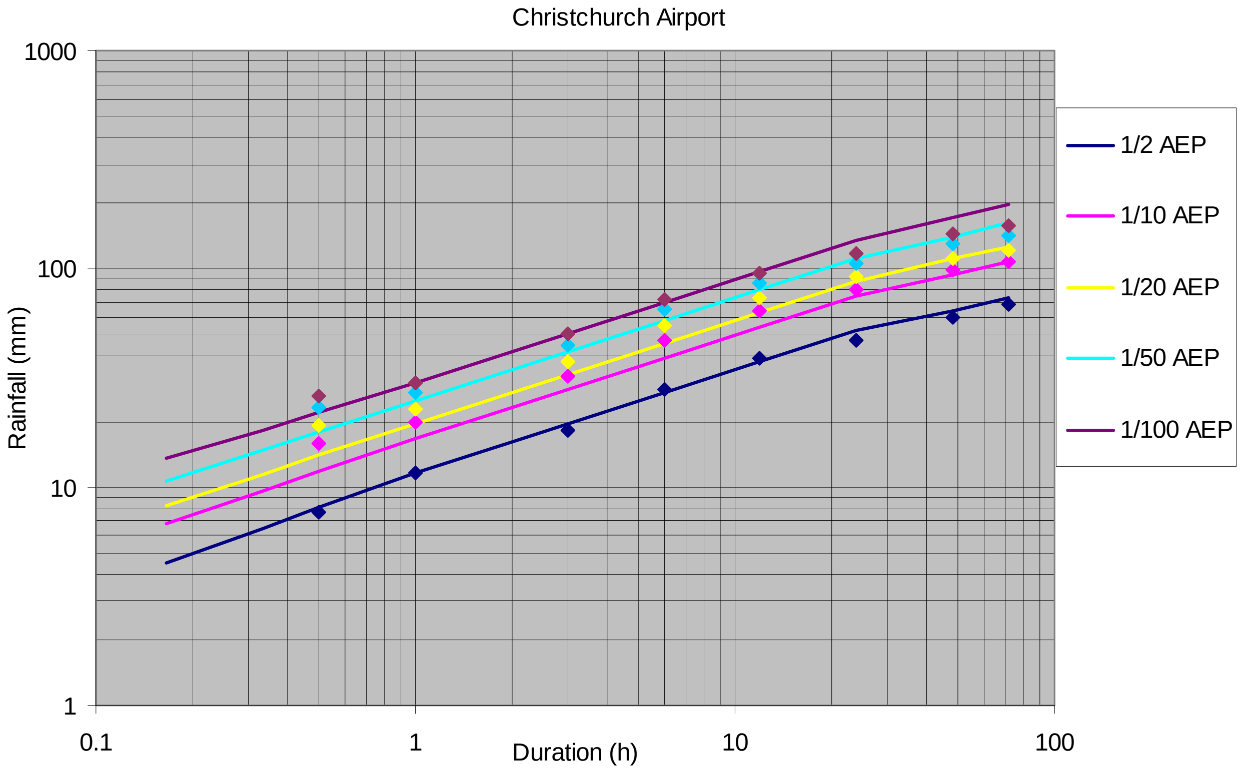
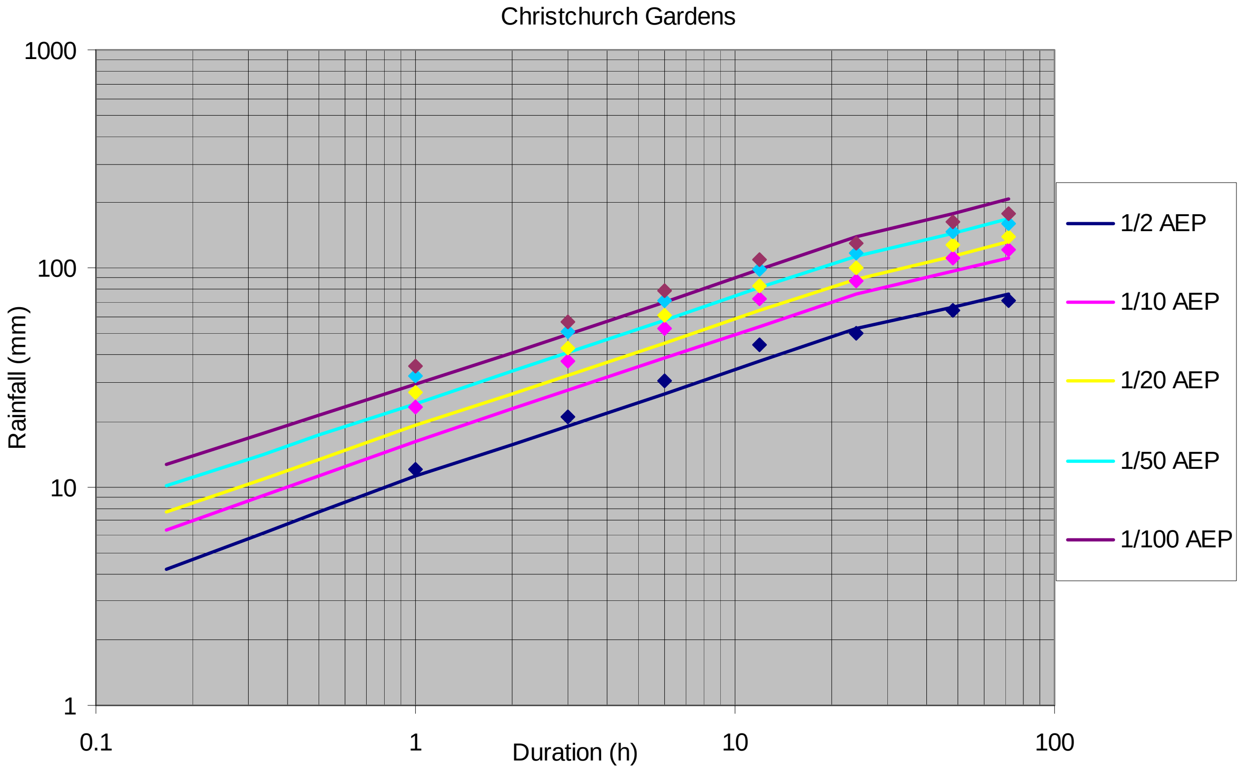


Figure 7: EV1 frequency plots for annual maximum rainfall series for Christchurch Gardens and Christchurch Airport (Table 2.1)


Christchurch Airport
1000
100
10
1
Rainfall (mm)
0.1
1
10
100
Duration (h)
1/2 AEP
1/10 AEP
1/20 AEP
1/50 AEP
1/100 AEP


Christchurch Gardens
1000
100
10
1
Rainfall (mm)
0.1
1
10
100
Duration (h)
1/2 AEP
1/10 AEP
1/20 AEP
1/50 AEP
1/100 AEP

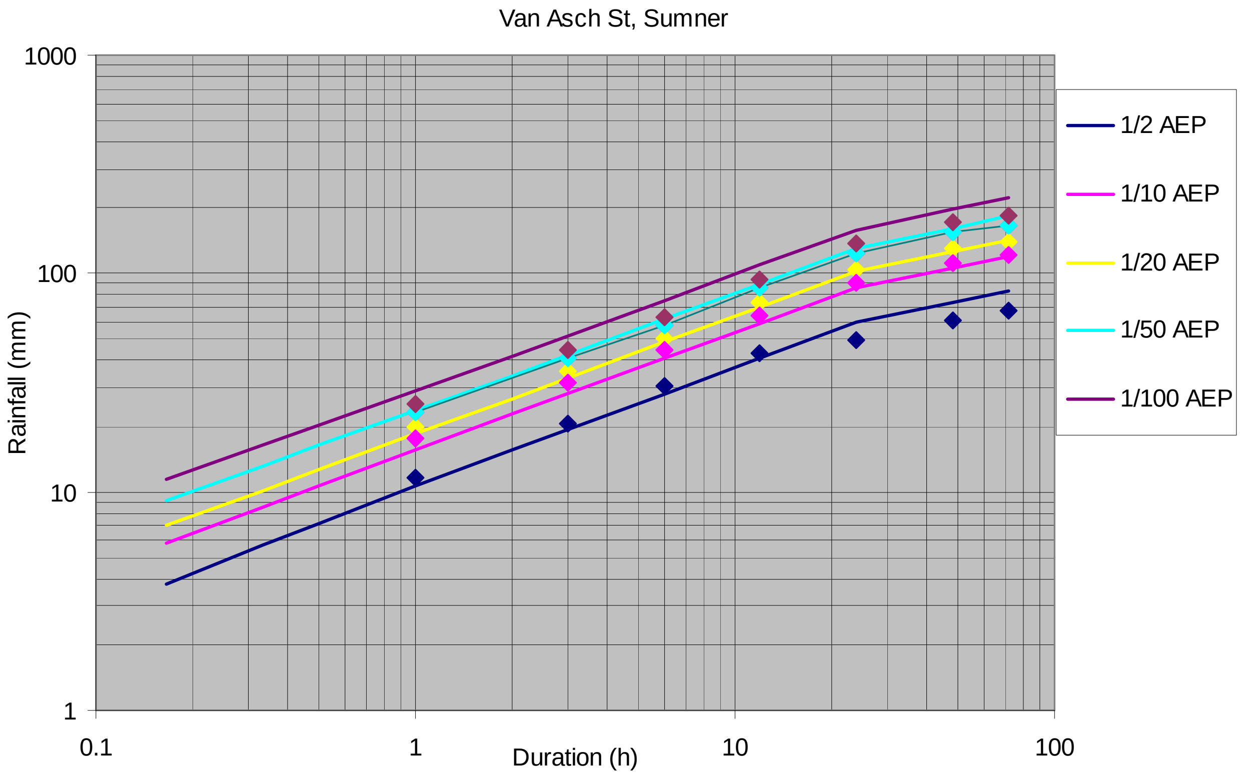


Figure 8: **Rainfall depth-duration-return period relations for Christchurch Airport, Christchurch Gardens and Van Asch St, Sumner (Table 2.1) predicted by HIRDS (solid lines) compared with values (diamonds) estimated in this study using recorded rainfall data.**

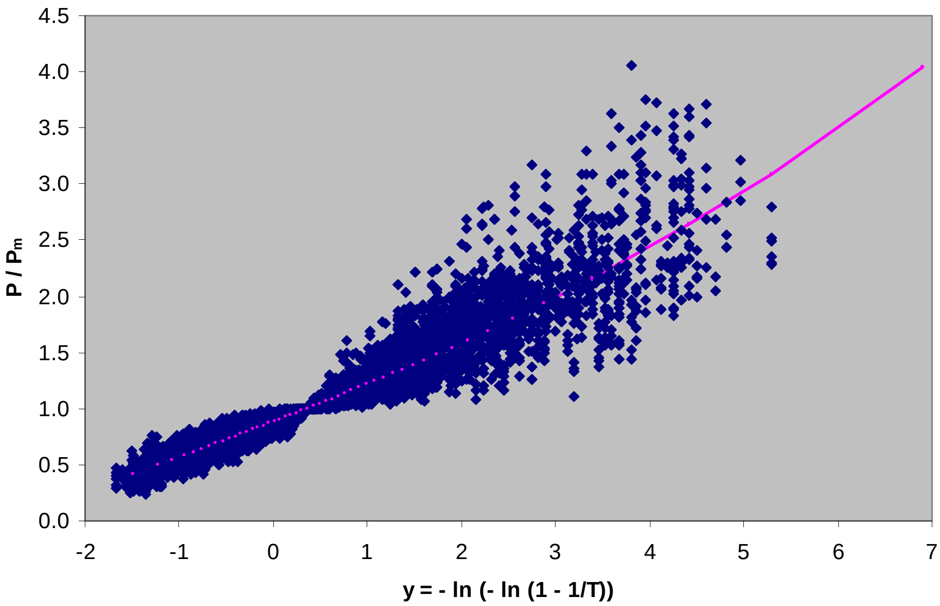


Figure 9: **Dimensionless regional Kappa frequency relation based on 8087 annual maximum events (Table 3.4)**

Table 3.4 lists dimensionless frequency factors or multipliers for different durations and return periods together with average values for each return period. The factors may be used to predict rainfall depth of a given duration and return period from a given median annual maximum value.

Table 3.4: Dimensionless frequency factors for 0.5 to 72 hrs duration and return periods. Note that the factors are made dimensionless using median rainfall.

Return period T (yrs)	2	3	5	10	20	50	100	200	500	1000
Gumbel reduced variate y = -ln(-ln(1-1/T))	0.367	0.579	1.50	2.25	2.97	3.90	4.60	5.30	6.21	6.91
Dimensionless rainfall depth P/P_m	1.00	1.07	1.39	1.68	1.97	2.39	2.73	3.09	3.62	4.05

The regional frequency approach does not allow systematic calculation of standard errors. Nevertheless, with regional procedures errors are usually proportional to $1/\sqrt{nN}$, where n is average record length and N is the number of records. Based on this result we estimate limits of ±20% to standard errors for rainfall depths of return periods less than 2000 years.

The form of the Kappa curve in Figure 9 suggests that the distribution of median annual maxima at rainfall stations would be better modelled by an EV2 distribution rather than EV1, as fitted in Section 3.3, at least at stations with long records such as Christchurch Airport and Christchurch Gardens. We found that for short durations (0.5, 3, 6 hr) at Airport and for 1, 3 and 24 hr at Gardens, an EV2 distribution is a better fit than an EV1 but otherwise not. Further work is needed to understand this seemingly patternless behaviour.

Finally, Pearson (1992) also lists dimensionless frequency factors for various return periods as per Table 3.4 but uses mean annual maximum rainfall rather than median annual maximum rainfall, as in Table 3.4 to non-dimensionalise the values. Table 3.5 compares the factors of Pearson (1992) with those computed in this study. For each given return period our values are less than those of Pearson (1992) probably because of the influence of more recent rainfall records available to us, which are less stormy than the earlier record analysed in Pearson (1992).

3.5. Area reduction factors

Pearson (1992) conducted a random check using the catchment of the Avon River at Gloucester Street Bridge to see if standard area reduction factors (ARF) for temperate zone climates derived by the Natural Environment Research Council (NERC 1975) are applicable to Christchurch. Both Tomlinson (1980) and Pearson (1992) recommend that NERC (1975) ARF values be used.

Table 3.5: Comparison between dimensionless frequency factors of Pearson (1992) and this study based on mean annual maximum rainfall. Applies for durations of 0.5 to 72 hrs.

Return period T (yrs)	10	20	50	100	200	500	1000
Dimensionless rainfall depth (non-dimensionalised using mean annual maximum rainfall. (Pearson (1992)	1.64	1.95	2.37	2.699	3.02	3.46	3.80
Dimensionless rainfall depth (non-dimensionalised using mean annual maximum rainfall (This study).	1.53	1.80	2.18	2.49	2.82	3.62	3.70

To confirm this recommendation an exploratory assessment of some of the storms recorded over the Avon River was undertaken. This involved the following steps:

- dates of the six largest floods recorded since 1980 were identified;
- peak rainfalls at the times of these floods for four raingauges within the 32 km^2 catchment were extracted for durations ranging from 1 to 24 hr;
- peak rainfalls in the same year for the same duration were extracted;
- the ratio of the rainfall at the time of the flood to the peak rainfall for the same duration in the same year was calculated; and
- the average ratio for each duration was compared with NERC (1975) recommendations.

A sample of the data is given in Table 3.6, while Table 3.7 lists the average ratios of total storm depth to annual maximum depths for the 1986 event in Table 3.6 and for five other Avon storms.

Lastly, Table 3.8 compares ARF values for a 38 km^2 catchment for various durations given by Faulkner (1999) with the average values derived herein. The results are considered to be sufficiently close to endorse the NERC (1975) or, more recently, Faulkner (1999) recommendations. A plot of ARF values as a function of area and duration is given in Figure 10.

Table 3.6: Sample of storm data for ARF calculations

Gauge		Peak rainfall depth (mm) during flood of 13 Mar 1986 Duration (hr)					Annual maximum rainfall (mm) (1986) Duration (hr)				
		1	3	6	12	24	1	3	6	12	24
325601	Airport	10.9	28.3	46.0	56.8	58.9	13.0	29.1	48.8	56.9	65.7
324610	Firestone	12.4	25.8	48.0	55.4	64.2	12.4	25.8	48.0	62.0	89.8
325507	College of Edn	13.3	32.0	51.0	59.8	62.8	13.8	32.0	51.0	60.3	85.5
325616	Gardens	21.0	42.3	59.9	69.2	73.5	21.0	42.3	59.9	69.2	99.0

Table 3.7: Averages of ratios of total storm rainfall depth to annual maximum rainfall depth

Flood date (yyyymmdd)	Average ratio Duration (hr)				
	1	3	6	12	24
19860313	0.95	0.99	0.99	0.97	0.77
19910628	0.65	0.86	0.93	0.97	0.90
19990717	0.92	0.99	0.99	1.00	1.00
20060512	0.63	0.72	0.90	0.99	0.94
20070730	0.85	0.98	1.00	1.00	0.97
20080731	0.49	0.65	0.81	0.79	0.81

Table 3.8: Average ARF values for Avon catchment compared with Faulkner (1999) recommendations.

	Average ratio Duration (hr)				
	1	3	6	12	24
Avon catchment, average for six floods	0.75	0.87	0.93	0.95	0.90
UK ARF recommended	0.86	0.91	0.94	0.95	0.96

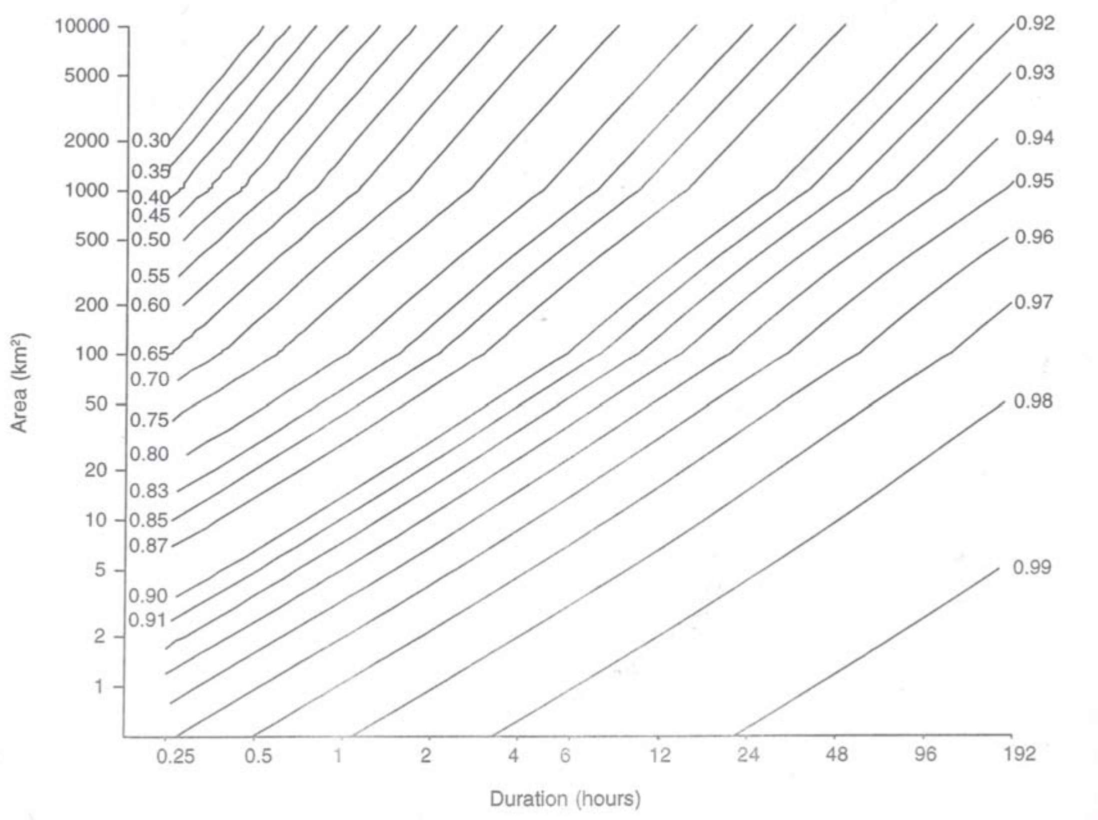


Figure 10: Areal reduction factors based on Faulkner (1999).

3.6. Climate variability and change

In addition to the Christchurch Airport and Christchurch Garden sites two others – Hororata and Lincoln - with long term rainfall records were examined for evidence of trend, periodicity, persistence and shifts in annual daily maxima (Figure 11). The same visual inspections and statistical tests were carried out as described in Section 2 above, with the result that each record can be assumed to be stationary and composed of independent values, as found for Christchurch Airport and Christchurch Gardens. We checked the series closely for any visual evidence of trends as well as the influence of the Interdecadal Pacific Oscillation and El Niño Southern Oscillation. From this we infer that although the rainfall regime has been quite variable since records began its behaviour has not changed significantly.

Any effects of climate change induced by humans will be superimposed on this natural variability. To provide guidance on assessing the impacts of these effects, the Ministry for the Environment has produced a manual (MfE 2008) based in part on the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC 2007).

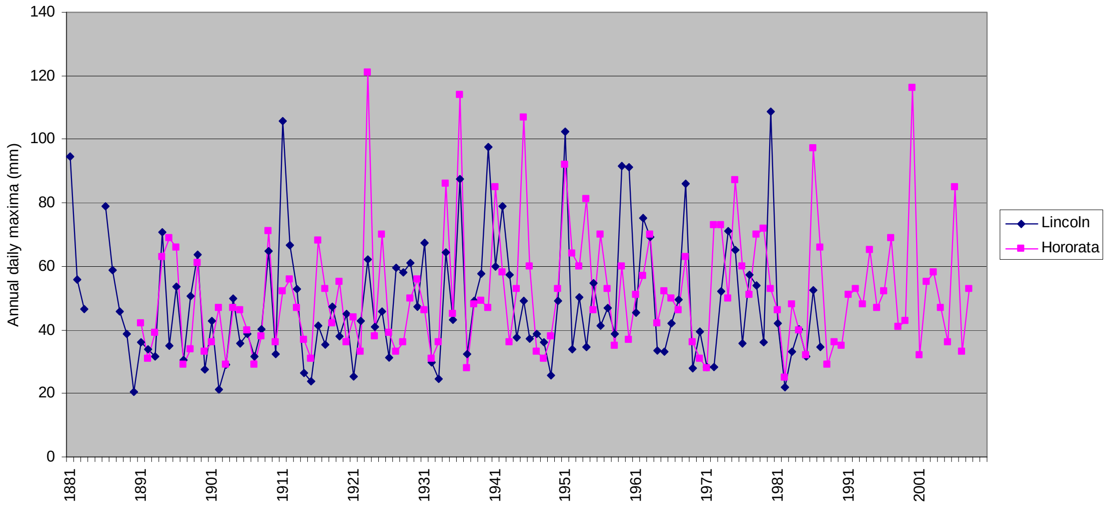


Figure 11: **Times series of annual daily maximum rainfall for Lincoln (Site No. 326401) and Hororata (Site No. 315901)**

Projections of global climate for the coming century vary depending upon which greenhouse gas emission scenario (from potentially low emissions, e.g. the B2 SRES scenario, to potentially high emissions, e.g. the A1FI SRES scenario) is used in the model run. A low emission scenario will result in less temperature change compared with a high emission scenario. The specifications of Global Climate Models (GCMs) being run at institutions around the world also varies slightly and thus the projections of global climate change for the same emission scenario vary depending upon the GCM being used. As a result, global climate projections are always presented as a range of likely changes rather than a single value (see Figure 2.1 and Tables 2.2 to 2.5 in MfE (2008)).

A range of projections rather than a single value can be difficult for a practitioner to deal with. Rather than making a single "best guess", using the mid-range value for instance, it is suggested that the user evaluate the impacts of several climate change projections within the range. As a minimium, it is suggested that low, middle and high projections within the range are analyzed and the impacts evaluated. Depending upon the "impact model" it may be possible to make several runs such as multiple GCM runs for multiple emission scenarios and produce a statistical distribution of the likely impacts.

The user must then carefully consider the output from the impact model runs using a risk-based framework. For considerations of impacts which are deemed to have a "medium risk" effect on society (e.g. coastal flooding of poor quality agricultural land), the user may decide to adopt an adaptation strategy allowing for a 50% probability of protection from coastal flooding (based on the range of projected impacts). For consideration of impacts which are deemed to have a "high risk" effect on society (e.g. urban flooding), the user may decide on adaptation strategies to cope with the full range of projected impacts - or beyond. The costs of implementing the various adaptation strategies also need to be evaluated and balanced against the risk and cost of the impacts.

From the viewpoint of the designer of an urban stormwater system, for instance, in Christchurch the potential impact of climate change on rainfall depth is one of several sources of uncertainty along with population changes and new developments in on-site storage, for example, which need to be incorporated in sound hydrologic design.

Historic designs based on Pearson (1992) mean annual maximum rainfall depths will be more conservative than those based on this study because the mean annual values of Pearson (1992) are about 5% higher than those obtained herein; and his dimensionless frequency factors or multipliers (Table 3.4) are about 7% higher as well. When these differences are propagated through predictive formulae (Equations 1 to 4) based on data in Figures 3 to 5, the result is that predicted rainfall depths of Pearson (1992) and Griffiths and Pearson (1993) are, on average, about 25% higher than those estimated using this study.

4. Examples

To show how the analysis of Section 3 may be applied, two examples are given of calculating design rainfall depths in Christchurch. These cover the three basic design situations – 0.5 hr duration, between 0.5 hr and 24 hr duration, and between 24 hr and 72 hr duration.

4.1. Example 1

Problem:

Obtain a design rainfall depth at the centroid of the Buxton Terrace sub-catchment (63.4 km^2) of the Heathcote River for a 0.5 hr duration, 200 yr storm.

Solution:

For a 0.5 hr duration the median annual maximum rainfall is taken to be uniform over Christchurch with a median value of 7.3 mm (Table 3.1). The 200 yr dimensionless rainfall multiplier is 3.09 (Table 3.4) so the 200 yr, 0.5 hr point estimate is 22.6 mm. The areal reduction factor for an area of 63.4 km^2 and 0.5 hr is 0.76 (Figure 10) so the 200 yr, 0.5 hr areal estimate for Buxton Terrace is 17.1 mm.

4.2. Example 2

Problem:

Obtain a design rainfall depth at the centroid of the Gloucester Street sub-catchment (38 km^2) of the Avon River for a 12 hr and a 36 hr duration, 50 yr storm.

Solution:

From Figure 3 the median annual maximum 24 hr rainfall at the centroid is 52 mm. Substitution of this value into Equations 1, 2 and 3 yields b = 0.507, a = 10.38 and P_m = 36.6 mm as the median annual maximum 24 hr rainfall. The multiplier for a 50 yr event from Table 3.4 is 2.39 which gives a point rainfall depth of 87.4 mm. For a catchment area of 38 km^2 the areal reduction factor is 0.960 (Figure 10) so the required rainfall depth for a 12 hr duration is 84 mm.

From Figures 3, 4 and 5, rainfall depths for 24 hr, 48 hr and 72 hr durations obtained by visual inspection are 51, 62 and 71 mm respectively. Plotting these values against their durations and interpolating gives a 36 hr depth of 57 mm. Multiplying this by 2.39 for a 50 yr event and 0.96 for areal reduction as above yields the required rainfall depth for a 36 hr duration of 137 mm.

5. Conclusions and recommendations

The main conclusions of this study are:

- Statistical analysis indicates that time series of annual maxima recorded at rainfall stations in Christchurch are stationary and serially independent.

- Extreme value Type I distributions may be used to model rainfall depth-return period relations for durations from 0.5 to 72 hr.

- Christchurch forms a single homogeneous hydrological region for the relationship between dimensionless rainfall depth and return period. A 4-parameter Kappa distribution provides an excellent fit to the data which extends up to a return period of 2000 years.

- The spatial pattern of 24 hr and longer duration median annual maximum rainfalls is similar to the pattern of mean annual rainfall over Christchurch. This resemblance weakens as durations decrease; below about 12 hr the spatial distribution is approximately uniform.

- A check using the Avon Catchment indicates that area reduction factors derived in the United Kingdom may be used to infer areal rainfall of given duration and return period from point rainfall of the same duration and return period.

- Statistical analysis of long term rainfall records of annual daily maxima revealed no evidence of either trend, periodicity, persistence or shifts in the time series or the influence of the Interdecadal Pacific Oscillation and El Niño Southern Oscillation.

- To allow for the potential effect of human induced climate change on future rainfall depths, it is recommended that the Ministry for the Environment guidelines be followed and that possible impacts of a range of projections be evaluated. Selection of design rainfall depths will involve consideration and balancing of the risks and costs of projected impacts.

- It is recommended that the data and relationships presented in this report be used in design, because the analysis is based on all rainfall records available to date and is specific to Christchurch.

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