Development of Design Rainfalls for Selwyn District

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Contents

1 Introduction

Selwyn District Council is developing a strategy for designing and managing its stormwater networks. This strategy aims to ensure the security, resilience, and sustainability of the network when affected by extreme rainfalls and predicted climate change. Fundamental to the development of this strategy is a review of design rainfalls. It is possible that different design rainfall standards have been used for different components of the stormwater system depending on when they were designed and built. This can pose problems with regard to connectivity when the downstream elements of the system have been designed for smaller flows than the upstream network.

Some organisations have adopted HIRDS in the absence of site-specific design rainfall tables. Analysis has shown, however, that rainfall data derived from actual measurements are considerably more reliable than those from HIRDS. This has significant implications with respect to both cost and risk when any 'errors' are passed on to design and operational activities. For example, over-estimation of flows leads to over-design and therefore unwarranted costs. Likewise, under-estimation of flows can lead to an increased risk of failure.

A series of design rainfall tables have therefore been developed using local rainfall information. These tables have been adjusted to account for the impact of predicted climate change through to the 2040s and 2090s. Such a review is consistent with recently released climate change scenarios; and requirements under the Local Government Act (2002) and the Resource Management Act (1991).

Development of the design rainfall tables, together with additional information such as typical storm hyetographs and the spatial and temporal variability in rainfall across the Selwyn District, will assist in infrastructure planning. It will also allow more robust analysis and design which will help to ensure sustainable development.

Spatial variability of rainfall was determined using all rainfall stations that have at least 10 years of data with daily resolution (i.e. 24 hours). Approximately 55 sites were found within, or close to, the Selwyn District. The mean annual rainfalls (MAR) of these sites were used to interpolate a MAR surface for the district. Using this MAR surface six rainfall zones were defined.

Developing design rainfall tables requires data with a minimum temporal resolution of ten minutes. This criterion severely limits the data available for analysis. Data from all rain gauges with at least 10 years of record and 15-min or better resolution were used. From the 55 rainfall sites in Selwyn District, 14 met the above criteria. The strong orographic control on rainfall results in significant differences in rainfall, particularly in a West-East direction across the district (Figure 1.1). Thus, the accuracy of the design rainfall tables which are based on site-specific data, may be compromised when applied to wider areas. To overcome this problem a series of Thiessen polygons containing scale factors were defined. These allow the site-specific data from the rain gauges to be scaled appropriately to any location in the district.

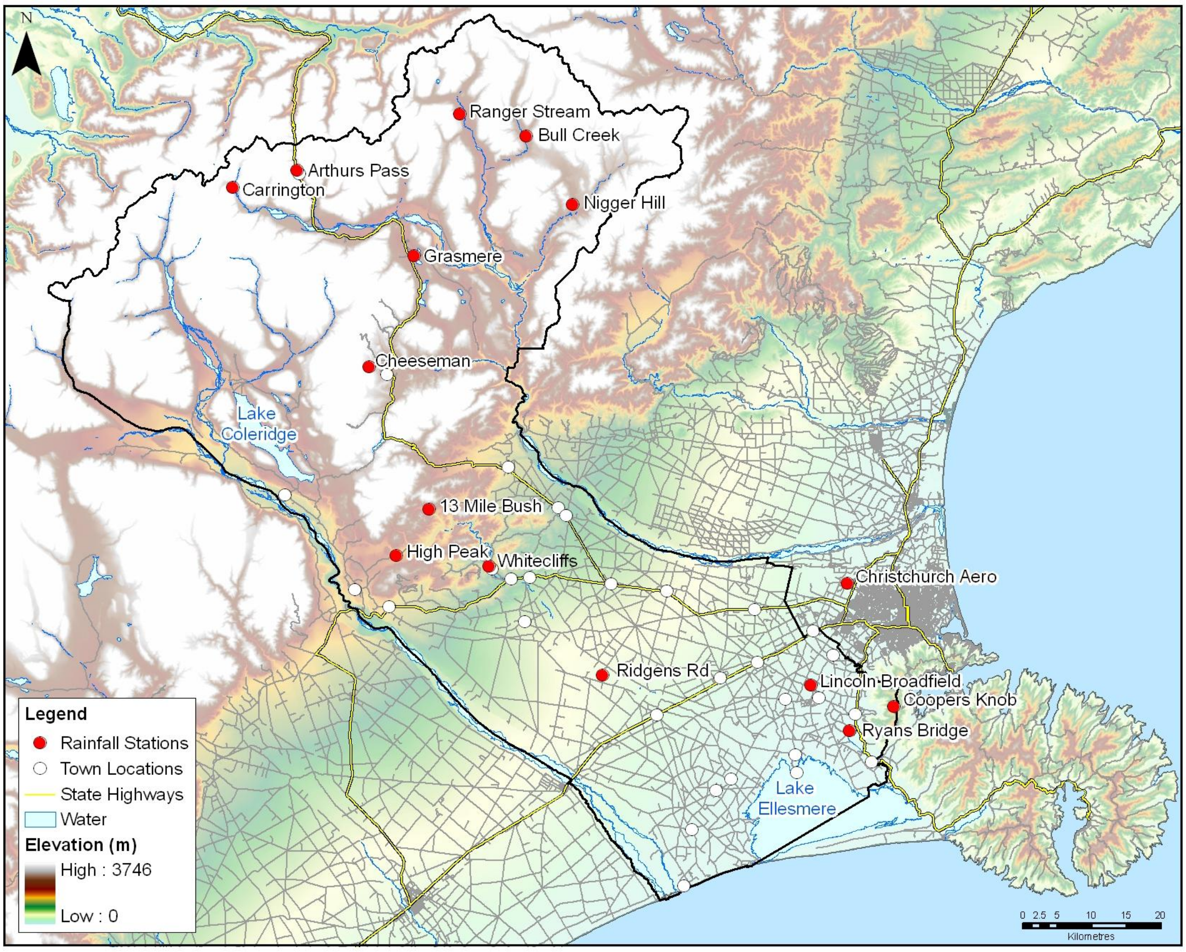

Figure 1.1 **Location of the townships and smaller than 15-min resolution data within the Selwyn District.**

2 Review of weather sequences

2.1 Canterbury Region

The Canterbury Region lies in the zone of mid-latitude westerlies where the weather is dominated by a succession of lows (depressions) and highs (anticyclones) which progress generally eastwards. However, the positions of these pressure features are highly variable. This affects the subtleties of the weather experienced at a specific location.

The climate of the Canterbury Region, including Selwyn District, is dominated by the effects of the high mountain ranges on the prevailing westerly airflow. It is thought that the influence of large scale topography on flow patterns extends to a height of at least 1500m. This affects both the pressure and airflow patterns, strongly distorting them (Ryan, 1987).

Easterlies, north-easterlies and south-westerlies are reasonably common on the plains as illustrated by Figure 2.1 and Table 2.1. Ryan (1987) suggests that the southerly components predominate in winter, while the northerly and easterly components are more dominant in summer. This is because of the more southerly path of the highs in summer, and the more frequent penetration of cold air into these latitudes during winter. However, for much of the time the surface wind regime is controlled by local circulations rather than by the flow of free air (Ryan, 1987). For example, the Selwyn River tends to flood under north-easterly conditions because of the alignment of the catchment relative to the movement of these weather systems.

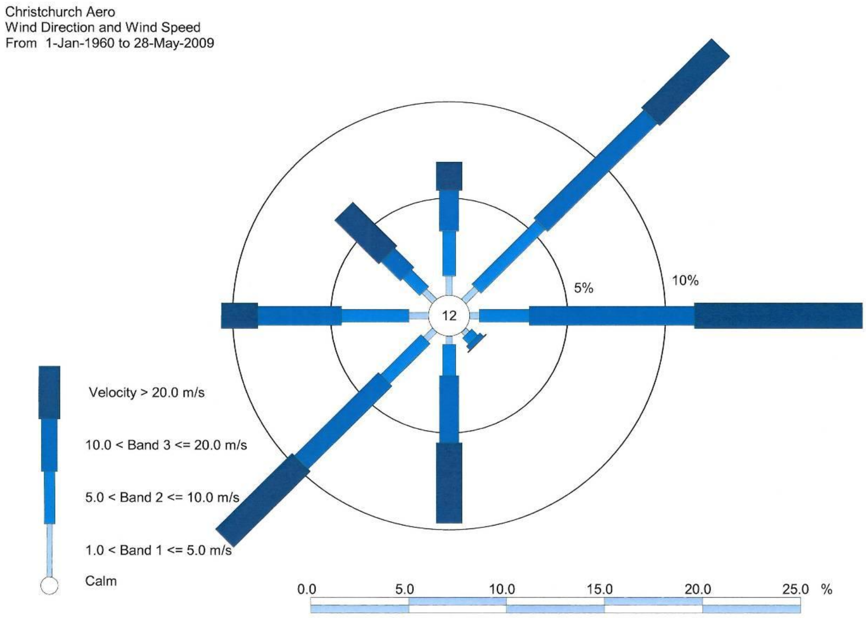

Figure 2.1 Christchurch Aero wind rose showing the wind speed and direction.

Table 2.1 Christchurch Aero wind direction and wind speed (1960-2009).

Christchurch Aero	Band 1 (1-5m/s)	Band 2 (5-10m/s)	Band 3 (10-20m/s)	Band 4 (>20m/s)	Total
North (337.5-22.4)	1.0	2.3	2.1	1.5	6.9
North East (22.5-67.4)	0.9	4.6	7.9	5.1	18.5
East (67.5-112.4)	0.5	2.6	8.4	8.6	20.0
South East (112.5-157.4)	0.2	0.4	0.3	0.0	1.0
South (157.5-202.4)	0.4	1.6	3.5	4.1	9.6
South West (202.5-247.4)	0.7	2.9	6.1	5.5	15.2
West (247.5-292.4)	1.0	3.4	4.3	1.9	10.6
North West (292.5-337.4)	0.7	1.2	1.4	3.2	6.6
Total	5.5	19.1	33.9	29.9	88.3
Percentage Calm					11.7

Many upland areas in the Selwyn District have maximum surface wind speeds in spring, while winter generally has the slowest mean monthly winds. However, near the coast the maximum wind speed is greater in the summer months when the sea breeze and thermal influences are strongest.

2.2 Main weather patterns in Selwyn District

2.2.1 Airflow between north-east and south-east

Surface south-easterlies are very rare except when channelled by valleys (Table 2.1). If there is an anticyclone to the south or east of the country cloud may be low, often with drizzle. In a cyclonic situation there may be heavy rain over the area with deep snow in winter (Ryan, 1987).

2.2.2 Airflow between south east and south west

Southerly airflows are unstable as they contain cold air travelling over a relatively warm sea. When the flow is anticyclonic there is extensive low cloud with frequent light showers. With cyclonic flow, the convection is stronger and significant snowfalls can occur in winter and spring. In the summer, heavy afternoon showers may develop. The passage of an active cold front brings very strong south or south-west winds; and a 2-6 hour delay in rainfall after the front passes.

2.2.3 Airflow between south-west and west

With strong flows of polar air, the wind is south-west over the whole district except where channelling occurs in some river gorges. The weather is usually fine with occasional coastal showers. In many cases, usually in spring and summer, the south-westerlies are reasonably shallow. These systems are often associated with minor frontal disturbances in west to south-west airstreams.

2.2.4 Airflow between west and north-north-west

This is a complicated case where the low level air flow patterns are determined by the topography, strength, and stability of the flow; and over the plains, by the extent of separation of the upper flow from the ground surface. When the flow is light and stable there is a strong resistance to ascend over the ranges. However, with strong unstable flow, there is little resistance to ascent, and the wind is north-west over the whole district.

There is strong diurnal variation in wind strength especially in winter when a nocturnal inversion often forms over the plains. When this happens, the shallow layer of cold dense air near the ground drifts down-slope. This katabatic wind follows the natural drainage of the ground independently of wind flow above the inversion. The wind rose for the Arthur’s Pass shows this katabatic wind effect (Figure 2.2). This wind rose also shows that the surface wind regime is dominated by the local conditions; and the topographic channelling of the wind rather than the flow in the free air (Ryan, 1987). This effect of topography on the wind flow at Arthur’s Pass is further highlighted in Table 2.2.

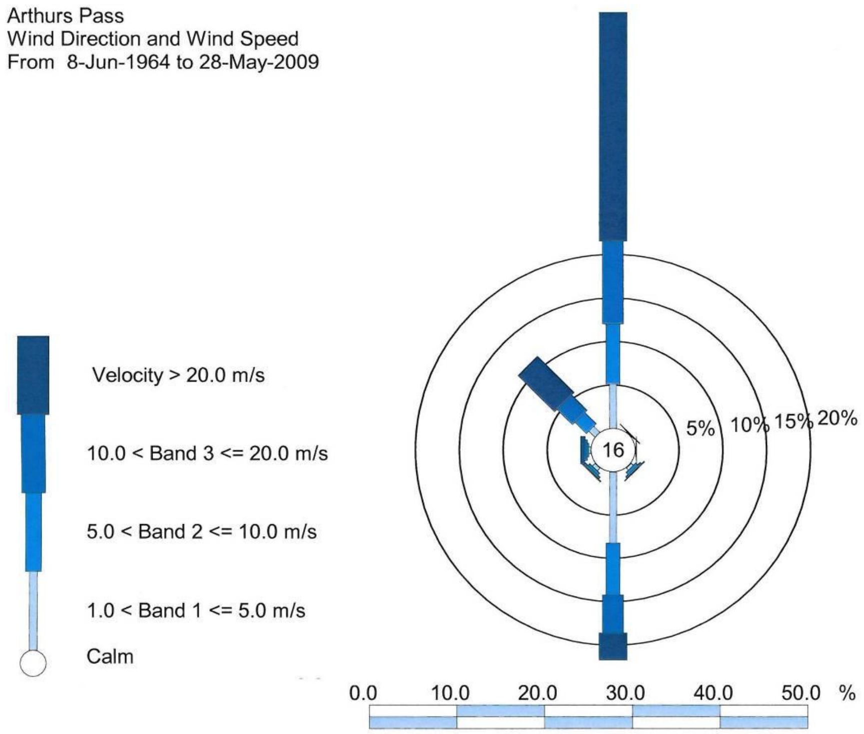

Figure 2.2 Arthur's Pass wind rose showing the frequencies of both direction and speed.

Table 2.2 Arthur's Pass wind direction and wind speed (1964-2009).

Arthur's Pass	Band 1 (1-5m/s)	Band 2 (5-10m/s)	Band 3 (10-20m/s)	Band 4 (>20m/s)	Total
North (337.5-22.4)	5.1	6.9	9.5	26.4	47.9
North East (22.5-67.4)	0.1	0.0	0.0	0.0	0.2
East (67.5-112.4)	0.1	0.0	0.0	0.0	0.1
South East (112.5-157.4)	0.3	0.3	0.2	0.1	1.0
South (157.5-202.4)	8.2	6.0	4.4	3.1	21.7
South West (202.5-247.4)	0.4	0.3	0.2	0.2	1.1
West (247.5-292.4)	0.2	0.2	0.3	0.5	1.2
North West (292.5-337.4)	1.0	1.8	2.5	5.9	11.2
Total	15.5	15.6	17.2	36.1	84.5
Percentage Calm					15.5

2.2.5 Airflow between north-north west and north-east

When surface winds are northerly, they are seldom strong. The weather is often fine and warm, especially in summer (Figure 2.1). However, along the coast sea breezes can set in causing temperatures to be several degrees colder than those further inland.

2.3 Precipitation patterns

The dominant wind directions strongly influence the rainfall pattern across the Selwyn District. Generally rainfall decreases east from the Southern Alps towards the coast. This is caused by the sheltering effect of the mountains on the prevailing rain-bearing west to north-west airflows (Figure 4.1). Precipitation forms and falls as the air rises up the western flanks of the mountains. Down-gradient of the mountains cloud and rain dissipate rapidly; but there is a considerable ‘spillover’ of precipitation and snow for about 10-20km east of the main divide. On the east coast, rainfall is mostly associated with on-shore air flow. A lot of the rain on the plains, and near the coast, is associated with south to south-west flows (25%). Consequently, there is an area west of the foothills near Lake Coleridge that is sheltered from both this rain, and orographic spillover from the Southern Alps. This is the driest part of the district but it contains limited population outside of the Lake Coleridge community.

In the Selwyn District coastal areas receive more rainfall in the late autumn and winter, and least during the spring and summer. Not a lot of rainfall falls in this area during the spring/summer months because of the high frequency of westerlies during these seasons. Further inland, in the high country and near the mountains, most rainfall occurs in spring from orographic spillover caused by the number of disturbed westerlies (Ryan, 1987). Therefore, near the mountains rainfall is dominated by the westerly flows, but on the plains it is dominated by easterly flows (Figure 2.1).

From the eastern foothills to the coast flooding mostly occurs with easterly and southerly winds. Extreme rainfalls are modest when compared with the rest of New Zealand. However, the many small catchments still flood following consecutive showers which occur when disturbances in west or south-west airstreams move across the area. A slow-moving disturbance in a north-easterly airstream can also give heavy rain in the east of the district.

3 Climatic cycle effects on rainfall

3.1 Interdecadal Pacific Oscillation

The Interdecadal Pacific Oscillation (IPO) is a climatic fluctuation in atmospheric and sea surface temperatures (SST) in the Pacific Basin that operates over a time scale of decades. Studies have shown that in some areas of New Zealand there is a strong correlation between heavy rainfall and flooding and the IPO phases. This results in successive ‘benign’ and ‘active’ phases in flooding that occur in conjunction with negative and positive phases of the IPO respectively. A positive phase persisted from 1922-1945, and again from 1977-1999; while from 1946-1976 the IPO was in a negative phase. The IPO is currently in a negative phase and so the incidence of heavy rainfall is likely to be less than the long-term average (Figure 3.1). The positive phase is most commonly associated with higher frequency and intensity of El Niño-like conditions, while the negative phase is associated with a prevalence of La Niña patterns. For example, more El Niño episodes occurred during the period 1978 to 1999 than the previous three decades which saw more La Niña (McKerchar & Henderson, 2003). This is evident in Figure 3.2.

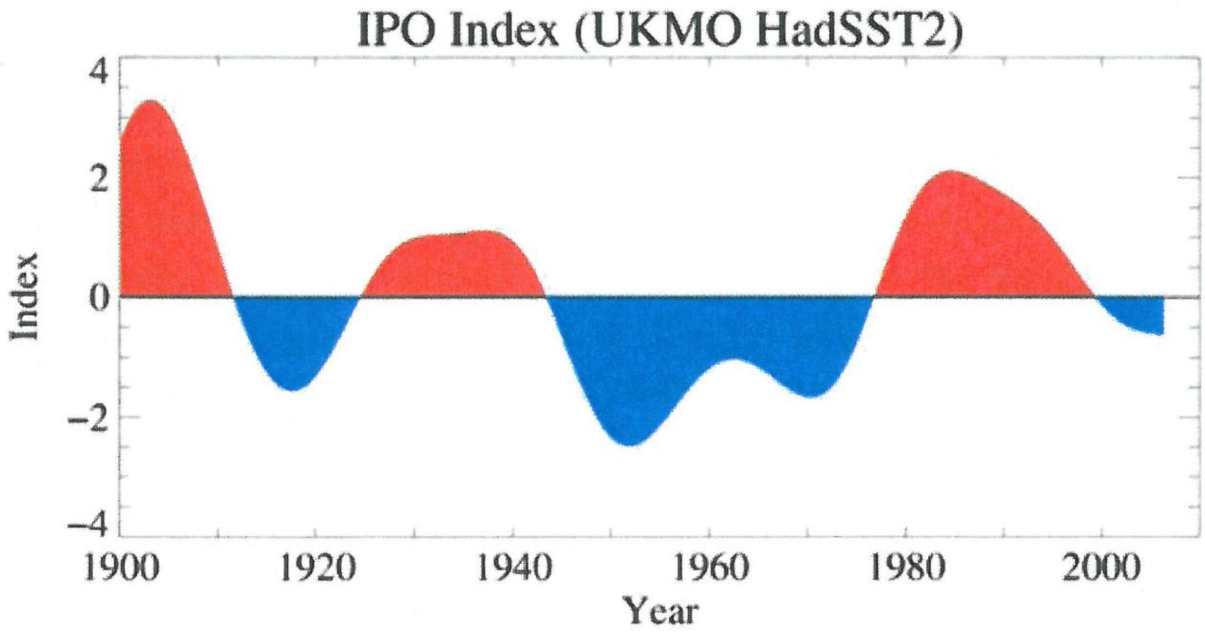

Figure 3.1 **The Interdecadal Pacific Oscillation for the period 1900 to 2006 (MfE, 2009). The positive (red) phases correlate with higher incidences and more extreme El Niño episodes. Negative (blue) phases correlate with La Niña events in Figure 3.2.**

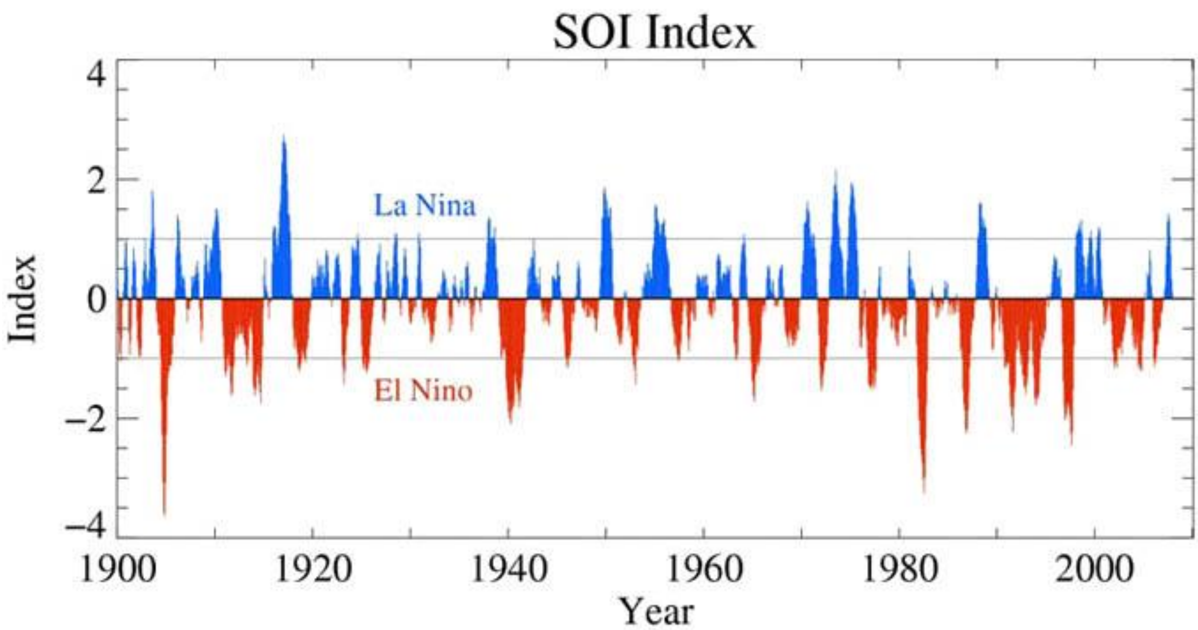

Figure 3.2 **The Southern Oscillation Index for the period 1900 to 2006. The positive and negative peaks depict La Niña and El Niño events respectively (NIWA, 2009).**

3.2 El Niño – Southern Oscillation

The El Niño – Southern Oscillation (ENSO) is a global climate phenomenon that is triggered by changes in the ocean-atmosphere system in the tropical Pacific. These changes are measured by the pressure difference between Tahiti and Darwin known as the Southern Oscillation Index (SOI).

El Niño, the negative phase in the SOI index, occurs when the westerly trade winds soften and warmer sea surface temperatures (SSTs) occur off the coast of South America. Characteristically, during El Niño New Zealand experiences stronger and more frequent westerly winds, and lower SSTs. During summer months this can lead to higher rainfall in south-western parts of the South Island, and drought conditions in the east. These conditions also bring more benign weather in the north and east of the North Island. During winter the wind becomes dominant from the south, leading to overall colder conditions (NIWA, 2009). El Niño conditions generally bring colder temperatures which are more noticeable in the North Island in all but the summer months (Kidson and Renwick, 2002).

Alternatively La Niña, the positive SOI phase, occurs when strengthened trade winds and colder SST in the eastern Pacific extend further west than usual. La Niña years tend to have a weaker effect on the climate of New Zealand; with more north-westerly winds and typically warmer temperatures over the whole country (NIWA, 2009). Higher rainfall is experienced in the north and eastern part of the North Island during summer, while the south and south-west of the South Island can experience drier conditions. Above average rainfall occurs in the other seasons in all areas except on the east coast of both islands which have normal or below average rainfall (Kidson and Renwick, 2002).

The inter-annual ENSO events vary in strength, can last from several months to several years, and tend to occur three to seven years apart (NIWA, 2009). Figure 3.2 shows the occurrence of the ENSO events from 1900-2006. More recently a La Niña event occurred during the summer of 2006-2007 and an El Niño event during the summer of 2007-2008 (NOAA, 2009).

3.3 Effects of climate oscillations on Selwyn District

Research shows that El Niño events generally account for 25% of the variation in seasonal rainfall and temperature. This is significant enough to warrant management and planning for such climate episodes (NIWA, 2009).

Higher areas in Selwyn District such as Arthur's Pass, situated within the Southern Alps, can expect higher than average rainfall during El Niño phases. McKerchar & Henderson (2003) confirmed a 9% increase in rainfall between 1978-1999 in the South Island's south and south-west. This corresponded to a shift in the IPO to a positive phase. Drought conditions are more likely towards the coast during these phases because of the orographic effect of the mountains on the westerly and south-westerly air flows. This situation occurred in Canterbury during the El Niño event of 1997-1998 (Environment Canterbury, 2003).

Selwyn District is more likely to receive average rainfall during La Niña years as it has a weak effect on the east coast of the South Island. Droughts still occur in south Canterbury in both El Niño and La Niña phases (NIWA, 2009).

3.4 Effect of climate oscillations on rainfall records

The effect of these climate oscillations has the potential to bias any rainfall record used in analysis. This is not a major issue with long-term records that include a number of both El Niño and La Niña phases. The effects of both phases are apparent in a long record and will therefore be included in the results of any statistical analysis. However, when a rainfall record coincides largely with one or other of the phases the data may be biased. The record may reflect either increased (El Niño) or decreased rainfall (La Niña).

When assessing the variability in rainfall across the Selwyn District, the potential effect of different periods of record at various rain gauges must be considered. In some cases only relatively short rainfall records exist. The potential effect of climatic oscillations on the representativeness of these data to longer term rainfall patterns must also be assessed. Short records can be biased and reflect periods of either higher or lower rainfall.

4 Spatial variability

Spatial variability of rainfall across the Selwyn District was determined using all rainfall stations that have at least 10 years of data with daily resolution. Approximately 55 sites were found within, or close to, the Selwyn District (Figure 4.1). Using the mean annual rainfall (MAR) from these sites, a MAR surface for the district was interpolated using a Kriging method (Figure 4.1). Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of data points. It assumes that the distance or direction between the rainfall points reflects a spatial correlation that can be used to explain variation in the surface. Kriging then fits a mathematical function to a specified number of points to determine an output value at each location. Kriging was therefore used to produce a grid of approximately 400m cells across the Selwyn District. Each cell contained an estimate of the MAR at that location.

Using this MAR surface six rainfall zones were defined (Figure 4.1). The Selwyn plains were split into three zones. The ‘red zone’ correlates to the least amount of rainfall; 550-649mm per year. The ‘orange zone’ relates to 650-749mm per year; and the yellow zone shows a MAR between 750 and 999mm. The Selwyn upland area is also split into three zones. The green zone has a MAR of 1000-2000mm; the light blue zone a MAR of 2000-4000mm; and the dark blue zone correlates to a MAR of 4000-6291mm.

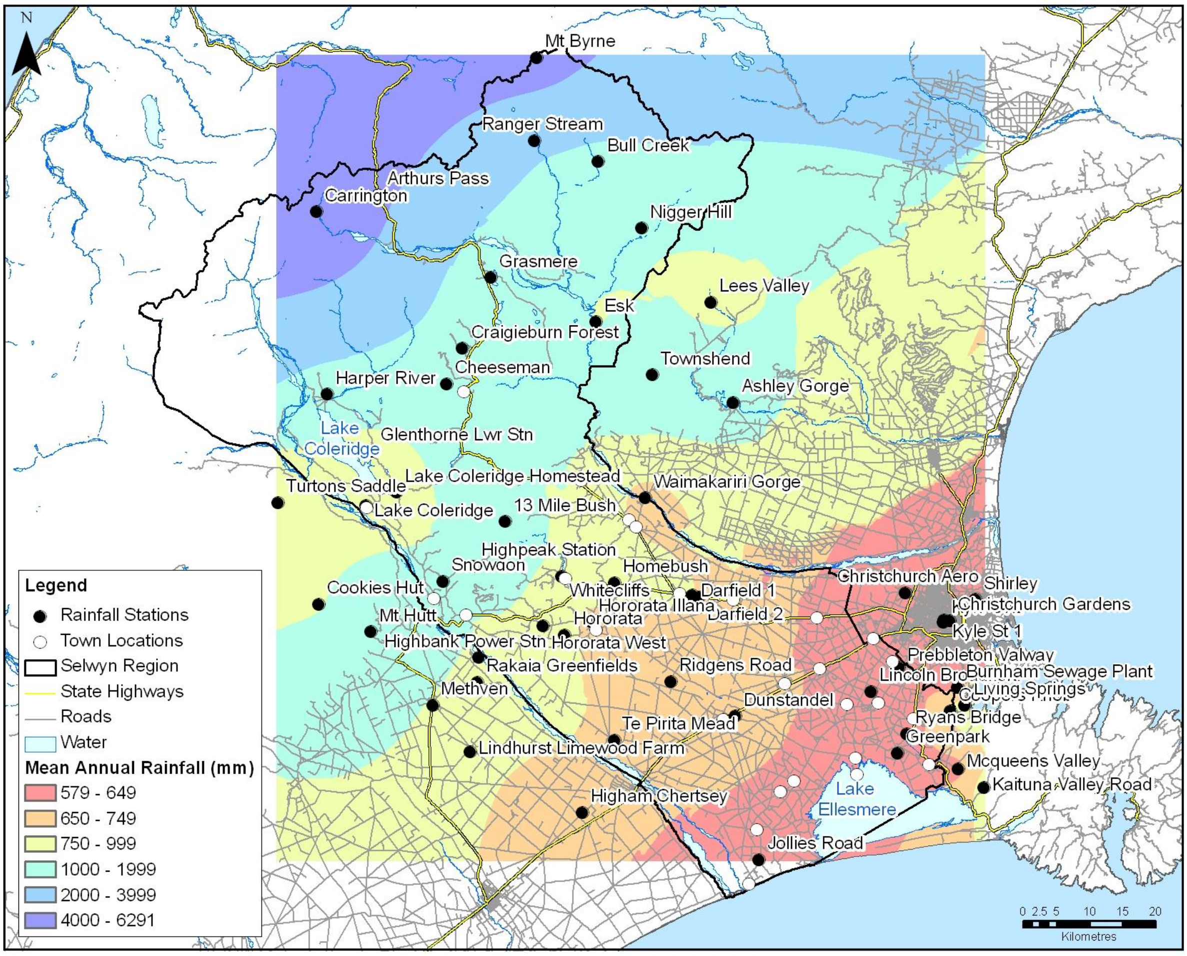

Figure 4.1 **Sites close to or within the Selwyn District with greater than 10 years of daily rainfall data. The rainfall (mm) surface shows the MAR for the district, derived from the individual rainfall stations using Kriging.**

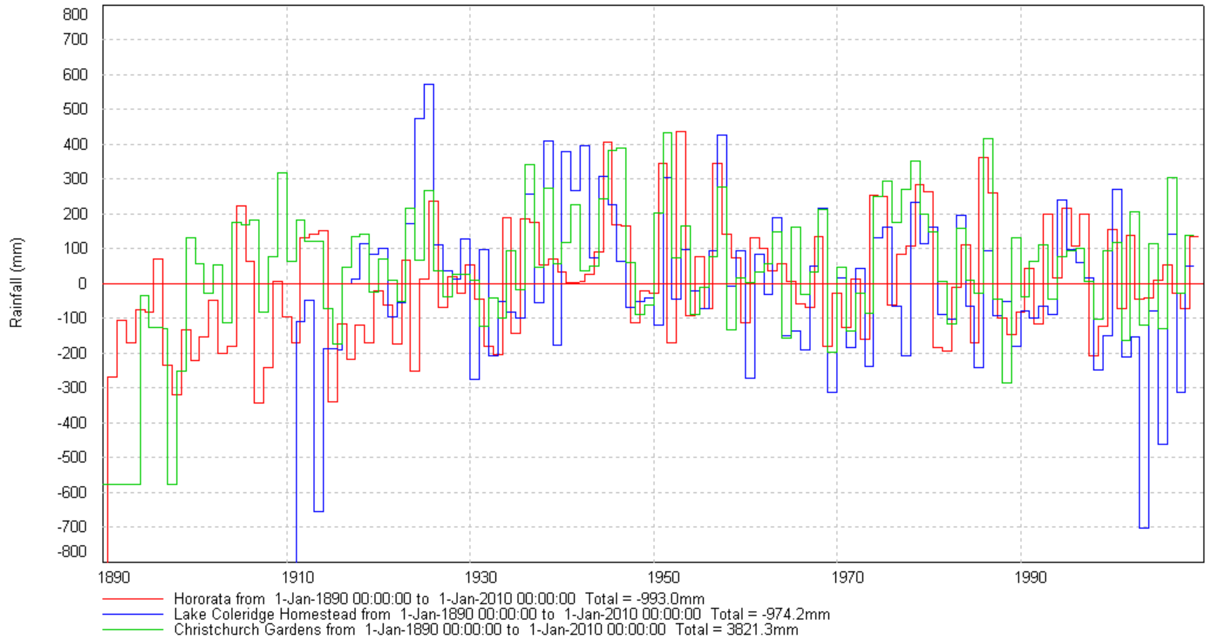

Figure 4.2 Variability about the long-term mean annual rainfall (mm).

Three spatially separated stations with long daily rainfall records were used to assess the variation in annual precipitation about the long-term mean (Figure 4.2). Annual precipitation varies significantly by up to 700mm, however, the fluctuations are short lived. Random variability is apparent about the mean rainfall but there seems to be no indication of cyclic behaviour or consistent trends. This suggests that climate oscillations are likely to have a relatively minor affect on rainfall across the Selwyn District.

5 Temporal variability within zones

5.1 Rainfall sites

The temporal variability of rainfall across the Selwyn District was determined using data from all rain gauges with at least 10 years of record and 15-min or better resolution. From the 55 rainfall sites in Selwyn District, 14 meet the above criteria (Figure 5.1 and Table 5.1). Each of the six MAR zones specified above has at least one rainfall site; the 1000-2000mm zone has five rainfall stations. This zone (Zone 4) covers a large area with variable rainfall. It was therefore considered appropriate to use data from more than one site to characterise rainfall in the zone.

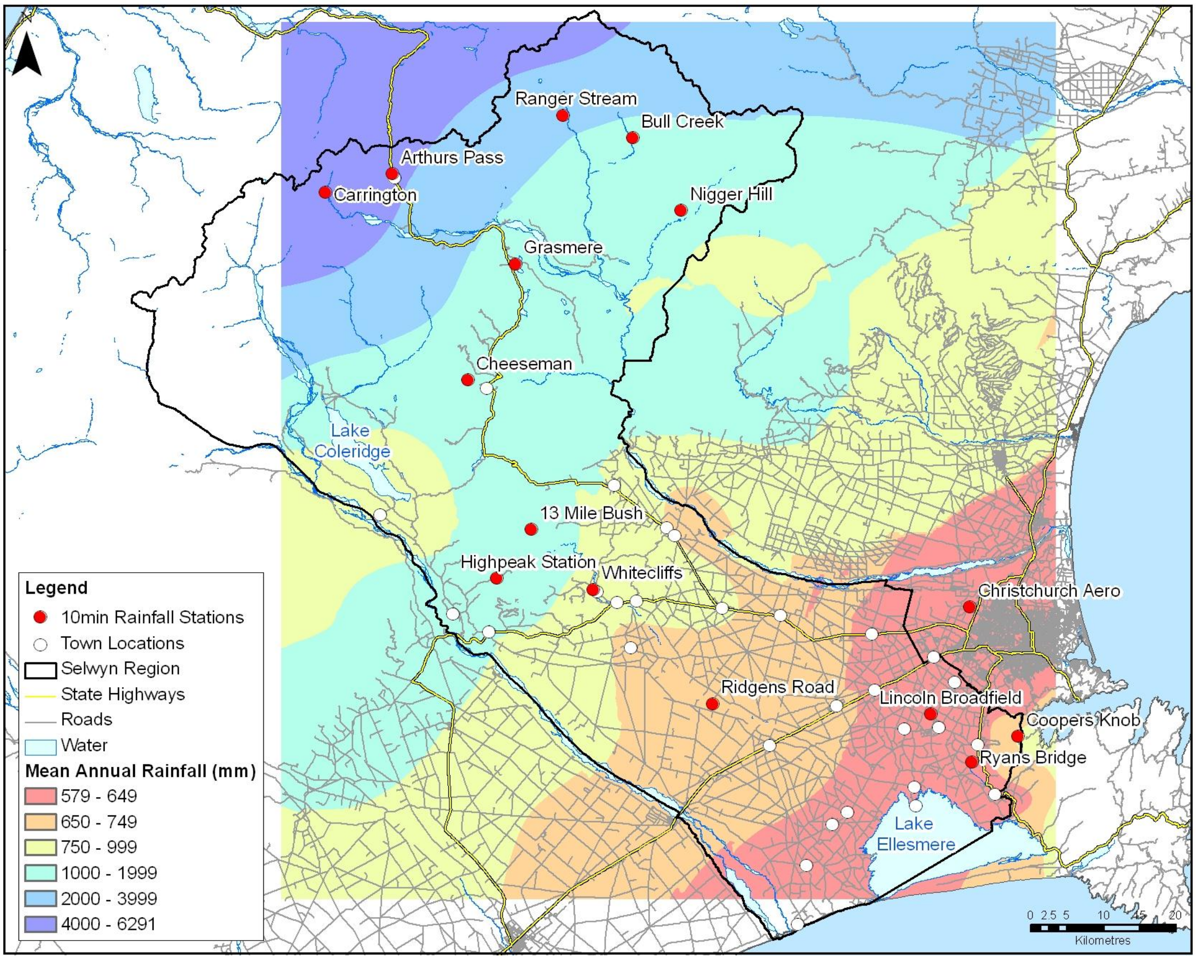

Figure 5.1 Location of the townships and rainfall sites with greater than 15-min resolution data.

Table 5.1 Details of the 14 rainfall sites with high resolution data.

	Rainfall (mm)				NZMS 260		
	Mean Annual	Median Annual	Max Annual	Max Daily	Northings	Eastings	Elevation (m)
Arthurs Pass	4387	4520	5886	346	5806373	2392657	750
Bull Creek	1557	1460	2145	132	5811234	2425904	745
Carrington	6314	5885	8031	326	5803656	2383433	823
Cheeseman	1276	1185	1758	111	5777701	2403167	880
Christchurch Aero	623	605	1020	106	5772500	2446100	37
Coopers Knob	768	797	1014	70.5	5757038	2411890	400
Grasmere	1028	1050	1440	70.5	5793644	2409599	600
Highpeak Station	1128	1120	1140	294	5750031	2407099	457
Lincoln Broadfield	602	657	863	70.5	5731298	2467445	18
13 Mile Bush	1152	1210	1407	133	5728295	2479314	488
Nigger Hill	1066	1100	1444	112	5801225	2432696	790
Ranger Stream	2369	2235	3204	193	5814380	2416251	625
Ridgens Road	653	686	818	101	5732728	2437129	120
Ryans Bridge	594	599	886	70.5	5724792	2472950	8
Whitecliffs	918	935	1136	162	5748672	2420470	280

5.2 Scaling temporal distributions

One of the difficulties when using rainfall data is that the information relates essentially to only a single point. As such these data are affected by both the location factors relating to the rain gauge, and the rainfall characteristics associated with any storm event. Therefore, while the data may be ‘accurate’ for the particular point at which it was collected, how it reflects wider rainfall variability is largely unknown. This inter-site variability tends to become smoothed and more regular when averaged over longer time periods (e.g., yearly data). This is why MAR surfaces provide a good indication of general trends in rainfall across an area. However, the highly site-specific response of individual rain gauges is a major issue when analysing short duration rainfall events. This problem is compounded when using short periods of record that may not reflect the entire spectrum of rainfall depths and durations. Extreme rainfall depths recorded over short durations at a particular gauge may simply reflect the fact that the rain gauge was affected by the most extreme elements of a storm event. A very different pattern may have been recorded even a few hundred metres away from that particular rain gauge.

Having more than one rainfall site within a specific zone can therefore cause problems as to which data are ‘correct’. To provide a mechanism for scaling the temporal design rainfall distributions, a number of Thiessen polygons were defined across the Selwyn District using the 14 rain gauges with good temporal records. Thiessen polygons are constructed by dividing the area equally between adjacent rain gauges. This means that each polygon defines a representative area associated with each rain gauge.

Using this method, Selwyn District was divided into 14 representative polygons. The MAR map was then ‘clipped’ to these Thiessen polygons so that each polygon contains the appropriate MAR information. Each polygon also contains a rainfall station with a specific MAR. This value was used to divide the MAR of each cell in the polygon to produce a ‘scale factor’ for each cell within the 14 polygons. Thus, at the rainfall station the scale factor is one. Cells with a MAR less than the rainfall station will have a scale factor less than one. Cells with a greater MAR will have a scale factor greater than one. Using these scale factors, the design rainfalls derived from the higher temporal resolution stations can be scaled appropriately across the relevant polygon (Figure 5.2).

The use of Thiessen polygons provides a standard method for scaling the design rainfalls for a specific site to adjacent areas. However, this methodology does not overcome the problem of rainfall data at a specific site being biased by either short records or extreme events. In fact, it is possible that the use of Thiessen polygons actually compounds this problem by extrapolating any ‘errors’ in the design rainfall distributions across a wider area.

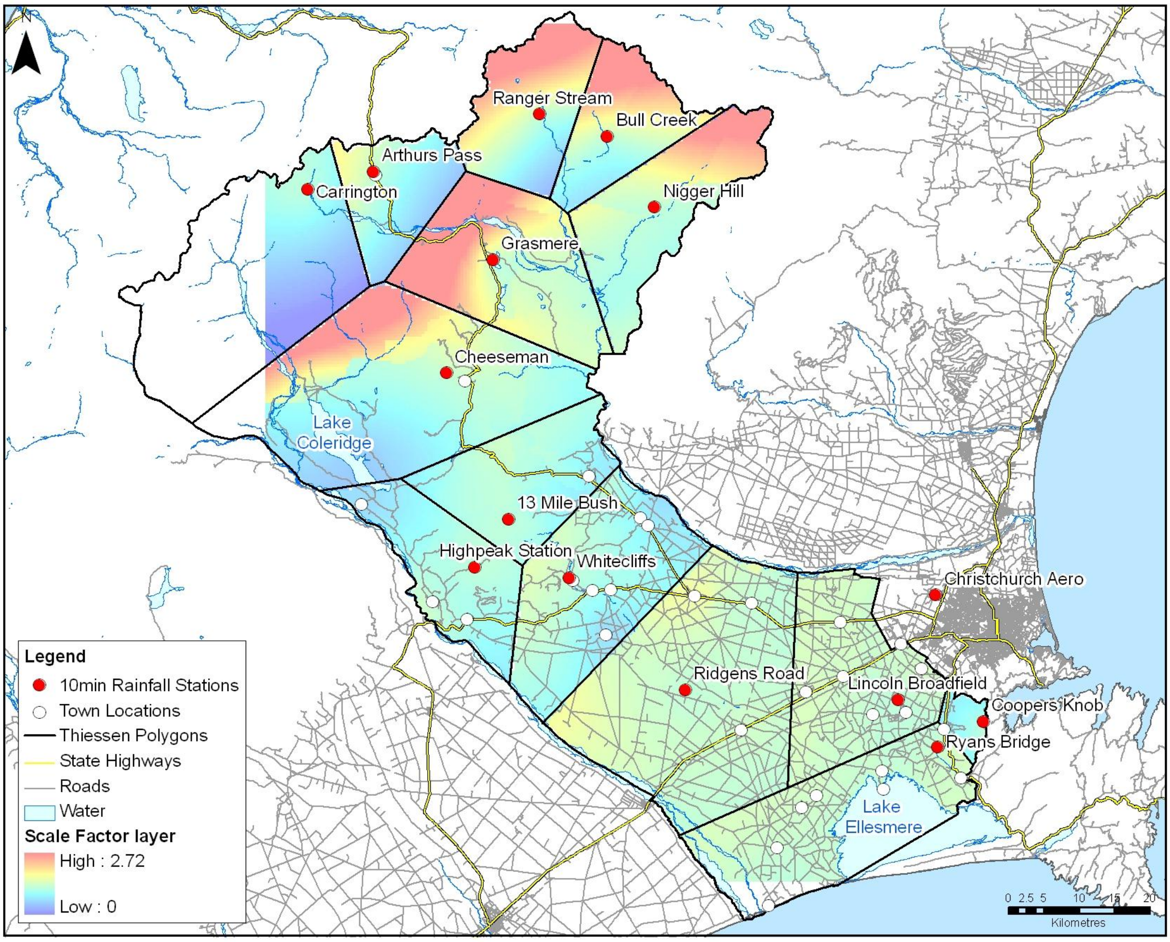

Figure 5.2 The 14 Thiessen polygons showing the scale factors for each polygon area.

Table 5.2 lists the scale factors needed to scale the rainfall gauges for each township in the Selwyn District. The scale factors for all communities except those related to Christchurch Aero were derived by interpolation of the MAR surface. Those communities related to Christchurch Aero have scale factors derived by dividing the MAR of this site by the MAR of each of the townships.

Because of the relatively uniform rainfall across much of the District the scale factors are generally close to 1.0. In fact, the use of a single specific design rainfall distribution for each polygon should not generate significant errors. Any errors are likely to be within the uncertainty of the actual design rainfall distribution.

Table 5.2 The scale factors for each township within the Selwyn District.

Rainfall Gauge	Township	Scale Factor
Arthurs Pass	Arthurs Pass	0.99
Cheeseman	Castle Hill	1.02
Highpeak Station	Lake Coleridge	0.72
	Terrace Downs	1.01
	Windwhistle	0.92
Lincoln Broadfield	West Melton	1.07
	Templeton	1.05
	Rolleston	1.06
	Burnham	1.09
	Prebbleton	1.07
	Springston	1.02
	Lincoln	1.00
13 Mile Bush	Springfield	0.83
Ridgens Road	Darfield	1.20
	Kirwee	1.02
	Dunstandel	1.05
Coopers Knob	Tai Tapu	1.02
Ryans Bridge	Motukarara	1.06
	Upper Selwyn Huts	1.02
	Lower Selwyn Huts	1.02
	Doyleston	1.05
	Leeston	1.05
	Southbridge	1.03
Whitecliffs	Whitecliffs	1.00
	Sheffield	0.83
	Waddington	0.82
	Glentunnel	0.92
	Coalgate	0.91
	Hororata	0.76
Christchurch Aero	West Melton	1.03
	Templeton	1.02
	Rolleston	1.03
	Burnham	1.06
	Prebbleton	1.03
	Springston	0.99
	Lincoln	0.96
	Tai Tapu	0.98
	Motukarara	1.01
	Upper Selwyn Huts	0.96
	Lower Selwyn Huts	0.98
	Doyleston	1.01
	Leeston	1.01
	Southbridge	0.98

6 Design rainfall tables

6.1 Rainfall measurements

Design rainfall tables are developed by undertaking frequency analyses of maximum rainfall depths over intervals of 10-mins, 20-mins, 30-mins, 1-hr, 2-hrs 6-hrs, 12-hrs and 24-hrs. Three types of statistical distributions were assessed (Gumbel, Pearson 3 (PE3) and GEV) for how well they modelled the actual rainfall depth data. The most appropriate distribution was then used to estimate rainfall depths for storm events of specific durations and return periods.

In general, the longer duration rainfall events approximate one of the standard statistical distributions. Therefore the model provides reliable estimates of the frequency and magnitude of specific storm events. There is considerably more scatter in the data for short duration storms. In a few cases it is difficult to find a statistical distribution that provides a realistic model of the data. In these situations some subjectivity is required in selecting an appropriate model. The criteria adopted in this study were:

- The distribution that provided the best-fit through all the data points;
- The distribution with the most realistic shape;
- The distribution that provides the closest approximation to the extreme values; and
- The average of the distributions.

While this process might appear to be subjective, in most cases the choice of a specific statistical distribution results in relatively minor differences in the estimated depth-duration-frequency table.

Using this technique, design rainfall tables were developed for:

a) Arthur's Pass (Table 6.1)

b) Bull Creek (Table 6.2)

c) Carrington (Table 6.3)

d) Cheeseman (Table 6.4)

e) Christchurch Aero (Table 6.5)

f) Coopers Knob (Table 6.6)

g) Grasmere (Table 6.7))

h) Highpeak Station (Table 6.8)

i) Lincoln Broadfield (Table 6.9)

j) 13 Mile Bush (Table 6.10)

k) Nigger Hill (Table 6.11)

l) Ranger Stream (Table 6.12)

m) Ridgens Road (Table 6.13)

n) Ryans Bridge (Table 6.15)

o) Whitecliffs (Table 6.16)

The results of the frequency distributions, and all the analyses, are contained in Appendix A.

Frequency analyses are traditionally performed on a 12-month partition. That is, only the largest value of each year is plotted, and the most appropriate statistical distribution is fitted to these values. The Whitecliffs and Ridgens Road sites had only 15-min data. Therefore these data needed to be interpolated to derive 10-min storm duration rainfall depths. The 15, 20, 30-min data, and the 1, 2, 6, 12 and 24-hour rainfall events, were plotted in Excel. The equation was then found for each ARI (r^2=0.99) and the 10-min storm duration rainfalls calculated.

Table 6.1 lists the design rainfall table derived from the Arthur's Pass rainfall record from January 1955 to May 2009. It also includes the type of distribution used for each frequency analysis.

Table 6.1 Arthurs Pass design rainfall table (1955-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*GEV*	*GEV*	*PE3*	*PE3*
2.33	7.1	12.2	16.9	28.3	49.0	106.7	160.8	225.9
5	9.7	15.5	20.6	33.5	57.5	125.2	189.2	265.7
10	12.1	18.4	23.5	37.4	63.8	139.1	211.5	296.6
20	14.4	21.2	26.2	41.0	69.2	151.6	232.1	324.9
50	17.5	24.8	29.7	45.4	75.6	166.6	257.7	359.9
100	19.9	27.4	32.2	48.6	80.0	177.1	276.3	385.2

Table 6.2 lists the design rainfall table derived from the Bull Creek rainfall record from November 1962 to July 2009. It also includes the type of distribution used for each frequency analysis.

Table 6.2 Bull Creek design rainfall table (1962-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	2.7	4.5	5.9	9.4	15.5	34.1	52.7	80.4
5	4.2	6.6	8.4	12.8	20.1	43.8	65.2	99.4
10	5.3	8.1	10.1	15.0	23.1	50.4	74.0	114.0
20	6.3	9.4	11.6	16.8	25.5	56.0	81.6	127.4
50	7.5	10.9	13.3	18.9	28.1	62.5	90.5	143.8
100	8.3	11.9	14.5	20.3	29.9	66.9	96.7	155.7

Table 6.3 lists the design rainfalls for Carrington. The Gumbel distribution fits the data best for the 10 and 20-min durations whereas the PE3 distribution fits better for all other storm durations.

Table 6.3 Carrington design rainfall table (1989-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Gumbel*	*Gumbel*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	8.9	14.5	19.7	34.5	58.8	129.4	194.4	281.9
5	10.7	17.1	23.1	38.6	66.3	146.7	219.4	319.4
10	12.0	19.3	25.9	41.0	70.9	158.9	236.9	347.4
20	13.4	21.3	28.5	42.9	74.4	169.4	251.9	372.5
50	15.1	24.0	32.0	44.8	78.2	181.7	269.5	403.0
100	16.4	26.0	34.5	46.0	80.5	190.1	281.5	425.0

Table 6.4 lists the design rainfalls for Cheeseman. Here, a partition of 1-month was used rather than 12-months as it provides a more reliable distribution of data. The Gumbel distribution fits best for the 2-hr and 24-hr storm durations and the PE3 distribution fits the 12-hr event best. The GEV was the best fit for all other storm durations.

Table 6.4 Cheeseman design rainfall table (1990-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*GEV*	*GEV*	*GEV*	*GEV*	*Gumbel*	*GEV*	*PE3*	*Gumbel*
2.33	4.2	7.1	9.5	14.3	22.2	43.6	62.7	79.3
5	5.5	9.1	11.9	16.9	25.9	51.7	75.0	94.9
10	6.8	11.1	14.2	19.1	28.9	58.2	84.7	107.6
20	8.5	13.3	16.8	21.3	31.8	64.6	93.9	119.8
50	11.1	16.8	20.6	24.2	35.5	72.8	105.7	135.5
100	13.6	19.9	24.0	26.5	38.2	79.0	114.4	147.3

Table 6.5 shows the Christchurch Aero design rainfall table for the years 1955 to 2009. The Pearson (PE3) distribution fitted the data better for the 2-hr, 6-hr and 12-hr intervals. The Gumbel distribution was a better fit for the short duration storms, and the 1-hr and 24-hr storms.

Table 6.5 Christchurch Aero design rainfall table (1955-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Gumbel*	*Gumbel*	*Gumbel*	*Gumbel*	*PE3*	*PE3*	*PE3*	*Gumbel*
2.33	4.4	6.9	8.5	12.0	16.3	27.8	39.2	51.8
5	6.2	9.7	11.7	15.9	22.1	36.1	51.0	66.9
10	7.7	11.9	14.2	19.0	27.2	44.1	61.5	79.3
20	9.1	14.1	16.7	22.0	32.3	53.1	72.5	91.1
50	10.9	16.9	19.9	25.9	38.8	66.8	89.0	106.3
100	12.3	19.0	22.2	28.8	43.8	78.9	101.0	117.8

Table 6.6 shows the design rainfalls for the Coopers Knob site between April 1990 and July 2009. The PE3 distribution fits the 10-30-mins, 1-hr and 24-hr events; the Gumbel distribution fits the 2-hr and 12-hour storm durations; and the GEV distribution fits the 6-hr storm duration.

Table 6.6 Coopers Knob design rainfall table (1990-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*Gumbel*	*GEV*	*Gumbel*	*PE3*
2.33	3.5	5.4	6.9	10.2	14.8	29.5	42.1	60.0
5	4.6	6.8	8.4	11.5	16.4	34.4	49.7	70.7
10	5.6	7.9	9.6	12.4	17.7	38.3	55.8	78.1
20	6.5	8.9	10.7	13.0	19.0	42.0	61.8	84.3
50	7.8	10.2	12.1	13.8	20.6	46.7	69.4	91.4
100	8.7	11.1	13.0	14.3	21.8	50.2	75.2	96.2

Table 6.7 lists the design rainfalls for the Grasmere site from December 1988 to August 2009. It also includes the type of distribution that best fits the data. All three distributions were used for particular storm durations with the GEV distribution used for the larger, longer storm durations.

Table 6.7 Grasmere design rainfall table (1988-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*Gumbel*	*PE3*	*GEV*	*GEV*	*GEV*
2.33	2.7	4.3	5.9	10.3	16.4	35.1	48.4	64.6
5	3.9	5.7	7.5	11.8	18.6	40.6	55.9	75.8
10	5.2	7.6	9.2	13.0	20.3	44.1	60.9	82.9
20	6.8	9.7	11.1	14.2	21.9	46.8	64.9	88.5
50	9.0	12.9	13.7	15.7	23.7	49.6	69.2	94.2
100	10.7	15.4	15.8	16.8	25.1	51.3	71.8	97.5

Table 6.8 shows the design rainfalls for the Highpeak Station (High Peak) rainfall site for the years between December 1987 and March 2009. The PE3 distribution fitted the data best for all the smaller durations from 10-mins to 2-hrs, and also the 24-hr storm event. The GEV distribution fitted best for the 6-hour event, while the Gumbel distribution fits the 12-hr storm duration best.

Table 6.8 Highpeak Station design rainfall table (1987-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*GEV*	*Gumbel*	*PE3*
2.33	5.1	7.7	9.4	13.0	19.7	34.1	49.5	62.0
5	6.8	10.5	13.0	17.2	25.7	43.1	65.2	88.4
10	8.0	12.6	16.1	20.6	30.7	50.3	78.2	111.7
20	9.2	14.6	19.0	23.9	35.6	57.2	90.5	134.8
50	10.6	17.1	22.8	28.1	41.8	65.9	106.5	164.9
100	11.6	18.9	25.6	31.3	46.4	72.4	118.5	187.6

Table 6.9 lists the design rainfalls for the Lincoln Broadfield site. It also includes the type of distribution used for each frequency analysis, which is PE3 for all storm durations.

Table 6.9 Lincoln Broadfield design rainfall table (2000-2009) (rainfall depths are in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	6.1	8.0	9.4	12.1	16.2	27.8	35.7	42.6
5	7.9	10.6	11.9	16.1	21.2	36.2	47.1	55.8
10	9.0	12.5	13.5	19.0	25.0	42.6	56.5	67.1
20	9.9	14.0	14.7	21.5	28.5	48.3	65.5	78.0
50	10.9	15.9	16.5	24.6	32.8	55.3	76.8	92.0
100	11.6	17.1	17.6	26.7	35.8	60.2	85.2	102.5

Table 6.10 lists the design rainfalls for 13 Mile Bush. For nearly all the storm intervals, the Pearson (PE3) distribution fitted the data best. However, the Gumbel distribution provided a better fit for the 2-hr storm duration.

Table 6.10 13 Mile Bush design rainfall table (1988-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*Gumbel*	*PE3*	*PE3*	*PE3*
2.33	5.6	8.9	10.9	14.4	21.2	35.4	47.5	64.0
5	8.2	12.8	15.3	19.3	25.8	42.8	60.7	86.4
10	10.6	16.4	19.3	23.9	29.5	48.8	72.1	106.2
20	13.0	19.9	23.3	28.4	33.1	54.4	83.2	125.7
50	16.2	24.5	28.5	34.5	37.7	61.5	97.7	151.2
100	18.6	28	32.5	39.0	41.2	66.7	108.4	170.4

Table 6.11 shows the design rainfall for Nigger Hill between January 1960 and July 2009. Here, the PE3 distribution provides the best fit for all but one storm duration. The GEV distribution fitted the 6-hour rainfall duration best.

Table 6.11 Nigger Hill design rainfall table (1960 to 2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*GEV*	*PE3*	*PE3*
2.33	2.1	3.8	5.1	8.4	13.7	28.9	44.6	65.0
5	5.2	7.3	8.8	12.6	18.4	38.1	58.0	82.9
10	8.4	10.5	11.9	15.7	21.5	44.4	68.0	97.7
20	11.8	13.7	15.0	18.5	24.1	49.6	77.0	111.8
50	16.5	17.9	18.9	21.9	26.9	55.3	87.9	129.8
100	20.1	21.1	21.7	24.4	28.9	58.9	95.7	143.0

Table 6.12 lists the design rainfalls for Ranger Stream using data from September 1978 to July 2009. The PE3 distribution provides the best fit for all but one storm duration. The 30-min event has a best fit to the GEV distribution.

Table 6.12 Ranger Stream design rainfall table (1978-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*PE3*	*PE3*	*GEV*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	5.0	8.5	11.2	18.5	30.2	63.4	97.7	130.9
5	7.2	11.0	13.8	22.1	36.2	78.6	119.7	160.3
10	9.6	13.4	16.0	24.7	40.5	90.4	136.2	183.7
20	12.2	15.8	18.2	27.0	44.4	101.4	151.1	205.4
50	16.0	18.9	21.4	29.7	48.9	115.0	169.2	232.7
100	18.9	21.3	23.8	31.7	52.1	124.8	182.1	252.5

Table 6.13 lists the design rainfall for the Ridgens Road rainfall site. The PE3 distribution fits all the data best except the 10-min rainfall event. Here, since the data were originally measured in 15-min intervals, the 10-min event needed to be interpolated. This was done by plotting each ARI and finding the equation of the best fit line. This equation was then used to estimate the 10-min rainfall. The r^2 value of the best fit line was never less than 0.98 providing accurate data interpolation.

Some of the rainfall values are much higher than expected, especially since this rain gauge is on the plains. This is caused by a large storm event (15/11/04) skewing the distributions to high rainfall depths. A close look at the rainfall recorded during this particular storm event suggests that the data are accurate, and that such a high magnitude storm did in fact occur. Although the rainfall record is only 19 years long, it would appear that this period happens to contain an extremely high-magnitude low-frequency event. The short record means that this large event biases all the estimates of the various design rainfalls. As the record gets longer, and assuming that this large event is not exceeded, the various estimates will gradually reduce.

To avoid the bias caused by this extreme event, which it is believed results in unrealistic rainfall depth duration estimates, a design rainfall table was also derived excluding this event from the analysis. The resulting values appear more consistent with the expected pattern of rainfall, and the results from other sites with similar exposure (Table 6.14). Appendix A (Figures A.89-A.96) show the frequency analyses for Ridgens Road. It is suggested that this design rainfall table should be used in future planning and design.

Table 6.13 Ridgens Road design rainfall table (1990-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Interpolated*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*Gumbel*
2.33	3.4	4.6	6.8	9.3	14.3	26.2	38.8	50.5
5	7.2	9.6	12.7	15.3	20.6	33.0	46.0	62.5
10	12.6	16.1	19.6	22.3	26.7	39.0	51.3	72.2
20	19.3	23.8	27.3	30.0	33.0	45.0	55.9	81.6
50	29.7	35.1	38.1	41.0	41.4	52.9	61.4	93.7
100	38.3	44.1	46.7	47.9	49.7	58.8	65.2	102.7

Table 6.14 Ridgens Road design rainfall table (1990-2009) without the 15/11/09 storm event (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Interpolated*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	3.8	5.3	7.3	9.9	14.6	25.6	38.4	50.7
5	5.6	7.8	10.5	13.1	18.0	30.5	45.1	62.7
10	7.4	10.2	13.4	15.9	20.9	34.5	49.9	72.2
20	9.2	12.6	16.2	18.6	23.6	38.3	53.9	81.1
50	11.7	15.7	19.9	22.2	27.1	43.1	58.5	92.5
100	13.6	18.1	22.7	24.8	29.8	46.6	61.5	100.8

Table 6.15 shows the design rainfalls for Ryans Bridge. The 10-min data for this site was also interpolated using regression equations. The r^2 value was 0.99 for all trendlines at this location.

Table 6.15 Ryans Bridge design rainfall table (1996-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Interpolated*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*
2.33	3.7	5.2	6.5	8.9	12.8	23.7	32.7	41.1
5	5.2	7.1	8.6	11.6	17.0	29.7	41.5	51.2
10	6.6	8.9	10.5	14.4	21.4	35.6	49.6	59.9
20	8.0	10.7	12.4	17.5	26.0	41.5	57.7	68.5
50	10.0	13.1	14.9	21.8	32.4	49.5	68.5	79.5
100	11.6	14.9	16.8	25.2	37.3	55.6	76.8	87.8

Table 6.16 shows the design rainfalls for Whitecliffs between May 1988 and August 2009. As with the Ridgens Road site, the 10-min data were interpolated and the r^2 values were all 0.98 or higher. The PE3 distribution was found to fit the data best for all rainfall durations except the 12-hour event where the Gumbel distribution was more appropriate.

Table 6.16 Whitecliffs design rainfall table (1988-2009) (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hr**	**2-hrs**	**6-hrs**	**12-hrs**	**24-hrs**
Distribution	*Interpolated*	*PE3*	*PE3*	*PE3*	*PE3*	*PE3*	*Gumbel*	*PE3*
2.33	4.9	6.4	8.1	12.2	19.2	34.8	46.2	55.9
5	6.5	8.8	11.3	15.9	23.9	40.2	56.5	75.4
10	8.0	11.1	14.2	19.2	27.6	43.7	64.9	94.4
20	9.6	13.3	17.1	22.5	31.1	46.5	72.9	114.2
50	11.8	16.2	21.0	26.8	35.3	49.8	83.4	141.1
100	13.3	18.4	23.9	30.0	38.3	51.9	91.2	161.8

6.2 HIRDS

HIRDS is an acronym for *H*igh *I*ntensity *R*ainfall *D*esign *S*ystem. It is a generalised procedure to obtain spatially and temporally consistent depth-duration-frequency design rainfalls for New Zealand. *HIRDS* Version 1 was a computer-based program, developed in 1992 to allow a quick and consistent determination of high intensity design rainfall depths (and associated standard errors) over mainland New Zealand, by simply supplying geographical coordinates. Apart from incorporating additional data from archives held by NIWA and local territorial authorities, the various revisions of *HIRDS* use more robust estimation techniques associated with regional frequency analysis. Results from HIRDS for each of the sites are listed in Table 6.17-6.31. Note that HIRDS does not provide results for the 5-year return period storm.

Table 6.17 HIRDS design rainfall table for Arthurs Pass (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	7.9	13.0	17.4	28.7	44.7	90.2	140.5	218.8
5								
10	12.2	18.8	24.3	37.7	58.7	118.6	184.8	287.9
20	14.6	22.0	28.0	42.3	65.8	113.0	207.2	322.8
50	18.7	27.2	33.9	49.4	77.0	155.6	242.4	377.8
100	22.8	32.2	39.5	55.9	87.2	176.2	274.6	427.9

When compared to the design rainfalls derived for this study the HIRDS estimates are greater for all storm durations at Arthurs Pass. Thus, they might be considered more conservative since they predict greater rainfalls. However, the use of the higher values from HIRDS is also likely to result in over-design and added cost. The difference between the rainfall measurements gets greater with increasing storm duration. The HIRDS 24-hour storm (100 ARI) is 42.7mm larger (11%) than the site-specific value.

Table 6.18 HIRDS design rainfall table for Bull Creek (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.0	7.9	10.4	16.4	25.0	48.9	74.7	114.0
5								
10	7.8	11.7	14.9	22.3	33.8	65.4	99.2	150.3
20	9.6	14.0	17.5	25.7	38.8	74.6	112.7	170.4
50	12.8	18.1	22.2	31.4	47.2	90.2	135.7	204.1
100	16.3	22.4	27.0	37.1	55.6	105.6	158.3	237.2

As with the Arthurs Pass site, the HIRDS estimates are larger than the site-specific rainfall values at Bull Creek. This occurs for all average recurrence intervals and for all storm durations. At the 24-hour, 100 ARI duration event the HIRDS estimate is 81.5mm higher (52%) than that derived from site-specific data.

Table 6.19 HIRDS design rainfall table for Carrington (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	9.7	16.2	21.8	36.5	56.3	111.8	172.4	265.8
5								
10	15.1	23.6	30.7	48.0	74.0	147.0	226.7	349.6
20	18.2	27.7	35.4	53.8	82.9	164.8	254.1	391.9
50	23.5	34.4	43.0	62.9	97.0	192.7	297.1	458.2
100	28.8	40.8	50.1	71.2	109.8	218.1	336.3	518.6

At the Carrington site, HIRDS predicts consistently higher rainfall values for all storm durations. Here, HIRDS has a value 93.6mm greater (22%) than the site-specific rainfall values for the 100yr, 24-hour storm duration.

Table 6.20 HIRDS design rainfall table for Cheeseman (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.5	7.0	9.1	14.2	21.3	40.4	60.5	90.7
5								
10	7.0	10.3	13.0	19.3	28.8	54.5	81.5	121.9
20	8.5	12.3	15.2	22.0	32.9	62.2	93.0	138.9
50	11.2	15.7	19.1	26.7	39.6	75.2	112.3	167.5
100	14.1	19.2	23.0	31.3	46.7	88.0	131.1	195.4

Rainfall at Cheeseman shows no consistent pattern between the HIRDS and site-specific rainfall measurements. However, HIRDS estimates are generally larger for most ARI's. The HIRDS ARI 100 yrs, 24-hour storm is 48.1mm larger than the value derived from the rainfall record.

Table 6.21 HIRDS design rainfall table for Christchurch Aero (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.5	6.5	8.1	11.7	16.2	27.1	37.5	51.9
5								
10	6.8	9.6	11.8	16.7	23.1	38.8	53.7	74.5
20	8.2	11.5	14	19.6	27.2	45.6	63.2	87.7
50	10.7	14.8	17.9	24.7	34.3	57.6	80	110.9
100	13.5	18.3	22	30	41.7	70.1	97.2	134.9

Results from Christchurch Aero show no consistent pattern between the HIRDS and site-specific rainfall measurements; although HIRDS is generally larger for the 1-24-hr storms. Although the data are generally similar, the HIRDS 100yr, 24-hour storm is 17.1mm larger than that derived from the site-specific data.

Table 6.22 HIRDS design rainfall table for Coopers Knob (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.8	5.7	7.2	10.8	16.0	30.1	44.7	66.4
5								
10	5.8	8.5	10.6	15.6	23.2	43.4	64.4	95.7
20	7.0	10.2	12.7	18.5	27.4	51.2	76.1	112.9
50	9.2	13.2	16.4	23.5	34.9	65.1	96.6	143.3
100	11.6	16.5	20.2	28.7	42.6	79.6	118.0	174.9

Comparisons of the site-specific and HIRDS design rainfalls at Coopers Knob show that the HIRDS data are higher for all recurrence intervals and duration periods. The HIRDS 24-hour (100 ARI) duration event is 78.7mm larger (82%).

Table 6.23 HIRDS design rainfall table for Grasmere (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.8	6.1	8.0	12.9	19.4	37.0	55.7	83.8
5								
10	5.9	9.0	11.5	17.6	26.3	49.8	74.6	111.7
20	7.2	10.7	13.5	20.1	30.1	56.8	84.9	126.8
50	9.5	13.7	17.0	24.5	36.4	68.5	102.1	152.0
100	12.0	16.8	20.5	28.7	42.6	79.9	118.7	176.5

As with most other sites, the HIRDS estimates at Grasmere are larger than the site-specific rainfall values. This occurs for all recurrence intervals, and all durations. For the 100-yr, 24-hour duration event the HIRDS estimate is 79mm higher (81%) than that derived from the site-specific data.

Table 6.24 HIRDS design rainfall table for Highpeak Station (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.0	6.1	7.9	12.1	17.5	31.3	45.2	65.2
5								
10	6.3	9.2	11.5	16.8	24.1	42.9	61.7	88.7
20	7.7	11.0	13.6	19.4	27.9	49.5	71.1	102.0
50	10.3	14.3	17.3	24.1	34.5	60.9	87.2	124.8
100	13.2	17.8	21.3	28.8	41.1	72.4	103.4	147.7

Comparisons for the Highpeak Station site show that the site-specific rainfall values are larger than the HIRDS values; thus, the measured values are actually more conservative. The site-specific values are larger for nearly all durations and ARI's except the 2-yr ARI and the 24-hour storm duration.

Table 6.25 HIRDS design rainfall table for Lincoln Broadfield (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.2	6.1	7.5	10.9	15.1	25.3	35.1	48.6
5								
10	6.5	9.1	11.1	15.6	21.6	36.1	50.0	69.2
20	7.9	10.9	13.2	18.4	25.4	42.5	58.8	81.3
50	10.5	14.3	17.1	23.4	32.2	53.9	74.5	102.9
100	13.3	17.9	21.2	28.5	39.4	65.8	90.8	125.4

The Lincoln Broadfield site shows no consistent pattern between the HIRDS and site-specific design rainfall estimates. The site-specific values are larger for the smaller ARI's (2.33 – 50-yrs, except 24-hours). The HIRDS values are larger for the 100-yr ARI event.

Table 6.26 HIRDS design rainfall table for 13 Mile Bush (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.4	6.6	8.5	12.8	18.4	32.8	47.3	68.1
5								
10	6.9	9.9	12.2	17.5	25.2	44.8	64.4	92.6
20	8.4	11.8	14.4	20.2	29.0	51.5	74.0	106.3
50	11.2	15.2	18.2	24.7	35.5	62.9	90.3	129.5
100	14.2	18.8	22.1	29.3	41.9	74.3	106.5	152.7

At 13 Mile Bush the HIRDS data are lower for the 10-min through to the 2-hour storm duration. The 6, 12 and 24-hr durations show no consistent pattern. The site-specific value is 17.7mm larger for the 100-yr, 24-hour duration storm.

Table 6.27 HIRDS design rainfall table for Nigger Hill (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.7	5.8	7.6	12.0	18.1	34.6	52.1	78.5
5								
10	5.7	8.6	10.9	16.4	24.6	47.0	70.6	106.1
20	6.9	10.2	12.8	18.9	18.4	54.0	81.1	121.7
50	9.2	13.2	16.2	23.2	34.8	66.1	99.1	148.5
100	11.7	16.3	19.8	27.6	41.3	78.2	117.2	175.4

At Nigger Hill, the HIRDS rainfall estimates are larger for all ARI's and all storm durations. The HIRDS 100yr, 24-hour storm duration is 32.4mm larger (23%) than that derived from the site-specific measurements.

Table 6.28 HIRDS design rainfall table for Ranger Stream (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	6.1	9.8	12.9	20.7	31.9	63.4	97.7	150.6
5								
10	9.6	14.6	18.7	28.4	43.3	84.7	129.2	197.1
20	11.9	17.6	22.1	32.8	49.8	96.5	146.6	222.6
50	16.0	22.9	28.2	40.4	60.9	116.7	176.1	265.6
100	20.6	28.5	34.6	48.0	72.0	136.8	205.2	307.7

The HIRDS estimates for Ranger Stream are greater than those derived by the site-specific rainfall measurements. They may be considered more conservative as they predict greater rainfalls. The HIRDS 100-ARI, 24-hour storm value is 55.2mm (22%) larger than the site-specific estimate.

Table 6.29 HIRDS design rainfall table for Ridgens Road (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.7	6.6	8.1	11.5	16.1	27.4	38.3	53.6
5								
10	7.4	10.1	21.1	16.5	23.0	38.6	53.6	74.5
20	9.2	12.3	14.6	19.5	27.0	45.2	62.6	86.6
50	12.5	16.3	19.1	24.9	34.3	57.0	78.4	108.0
100	16.2	20.7	23.9	30.6	41.9	69.2	94.9	130.1

As explained previously, it would appear that the site-specific data from Ridgens Road are biased by an extreme magnitude storm event. Therefore, design rainfall tables were developed that either included, or excluded, this particular event. When this event is included the site-specific values are all significantly greater than those from HIRDS as expected. When the extreme event is excluded, the HIRDS values tend to be larger. It is likely that this is because the HIRDS values actually include some of the effect of the extreme event, but in a 'diluted' form because of the averaging that takes place during data processing.

Table 6.30 HIRDS design rainfall table for Ryan's Bridge (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.8	5.6	7.0	10.3	14.7	26.0	37.3	53.4
5								
10	5.8	8.4	10.3	14.8	21.2	37.3	53.2	76.1
20	7.1	10.1	12.3	17.5	25.0	43.9	62.7	89.5
50	9.5	13.2	16.0	22.3	31.8	55.8	79.5	113.3
100	12.0	16.5	19.9	27.3	38.9	68.2	97.1	138.2

The HIRDS estimates are greater than the site-specific rainfall values for the 2-yr ARI for all storm durations at Ryan's Bridge. However, the site-specific data are greater for the 10-min, 10-50-yr ARI. The difference is greatest at the 24-hour, 100-yr ARI storm.

Table 6.31 HIRDS design rainfall table for Whitecliffs (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.0	6.1	7.8	12.0	16.9	29.2	41.2	58.2
5								
10	6.2	9.2	11.5	17.0	23.8	40.7	57.1	80.2
20	7.6	11.0	13.7	19.8	27.8	47.3	66.2	92.7
50	10.2	14.4	17.6	24.9	34.7	58.8	82.0	114.4
100	13.0	18.0	21.7	30.0	41.8	70.4	97.9	136.2

At Whitecliffs the site-specific estimates are greater for the 2.33 ARI, 10-min-12-hour storm durations, and all the 24-hour storm durations except the 2-yr ARI. At the 100-yr, 24-hour storm event the site-specific value is larger by 25.6mm (19%).

6.3 Climate change effects

In 2008 MfE produced *"Climate Change Effects and Impacts Assessment – A guidance manual for Local Government in New Zealand"*. The manual outlines different climate change scenarios for various regions throughout the country. It provides estimates of the expected increase in temperatures out to the 2040s and 2090s.

The various design rainfall tables for the Selwyn District (Table 6.1-6.16) have therefore been adjusted for predicted climate change to the 2040s and 2090s (Tables 6.32-6.63) using the methodology outlined in the MfE guidance manual. A predicted average increase in temperature of 0.9°C by the 2040s, and 2°C by the 2090s, was used to adjust the rainfall depth-duration tables. This approach provides some conservatism and resilience to the design rainfall tables. It also increases the sustainability, and reduces the risk, of works based on the design rainfalls.

Table 6.32 Arthurs Pass 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	7.6	13.5	18.0	30.0	51.7	111.8	167.7	234.6
5	10.4	16.7	22.0	35.6	61.0	132.1	199.1	278.6
10	13.0	19.4	25.1	39.9	67.9	147.6	223.9	313.4
20	15.4	21.9	28.0	43.8	73.9	161.7	247.3	346.0
50	18.8	25.2	31.8	48.7	81.0	178.6	276.3	385.8
100	21.3	27.7	34.5	52.1	85.8	189.9	296.2	412.9

Table 6.33 Arthurs Pass 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	8.2	14.5	19.3	32.1	55.1	118.0	176.2	245.3
5	11.3	18.0	23.6	38.3	65.2	140.5	211.1	294.4
10	14.0	20.9	27.1	42.9	73.0	158.0	239.0	334.0
20	16.7	23.6	30.3	47.3	79.7	174.0	266.0	371.7
50	20.3	27.3	34.5	52.7	87.7	193.3	298.9	417.5
100	23.1	29.9	37.4	56.4	92.8	205.4	320.5	446.8

Table 6.34 Bull Creek 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	2.9	4.8	6.3	10.0	16.4	35.7	55.0	83.5
5	4.5	7.1	9.0	13.6	21.3	46.2	68.6	104.2
10	5.7	8.7	10.8	16.0	24.6	53.5	78.3	120.5
20	6.8	10.1	12.4	18.0	27.2	59.7	87.0	135.7
50	8.0	11.7	14.3	20.3	30.1	67.0	97.0	154.2
100	8.9	12.8	15.5	21.8	32.1	71.7	103.7	166.9

Table 6.35 Bull Creek 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.1	5.2	6.7	10.7	17.4	37.7	57.8	87.3
5	4.9	7.6	9.6	14.6	22.8	49.1	72.8	110.1
10	6.1	9.4	11.6	17.2	26.4	57.3	83.6	128.4
20	7.3	10.9	13.4	19.4	29.4	64.3	93.5	145.7
50	8.7	12.6	15.4	21.9	32.6	72.5	105.0	166.8
100	9.6	13.8	16.8	23.5	34.7	77.6	112.2	180.6

Table 6.36 Carrington 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	9.5	15.5	21.0	36.6	62.1	135.6	202.8	292.8
5	11.5	18.3	24.6	41.1	70.3	154.8	230.9	334.9
10	12.9	20.7	27.7	43.7	75.5	168.6	250.8	367.1
20	14.4	22.8	30.5	45.9	79.5	180.7	268.4	396.6
50	16.2	25.7	34.3	48.0	83.8	194.8	288.9	432.0
100	17.6	27.9	37.0	49.3	86.3	203.8	301.8	455.6

Table 6.37 Carrington 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	10.3	16.7	22.5	39.1	66.1	143.1	213.1	306.1
5	12.4	19.7	26.5	44.1	75.2	164.6	244.9	353.9
10	13.9	22.3	29.8	47.1	81.1	180.5	267.7	391.2
20	15.5	24.7	32.9	49.5	85.7	194.5	288.7	426.1
50	17.5	27.8	37.1	52.0	90.7	210.8	312.6	467.5
100	19.0	30.2	40.0	53.4	93.4	220.5	326.5	493.0

Table 6.38 Cheeseman 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.5	7.6	10.1	15.2	23.4	45.7	65.4	82.4
5	5.9	9.7	12.7	18.0	27.5	54.5	78.9	99.5
10	7.3	11.9	15.2	20.4	30.8	61.8	89.7	113.7
20	9.1	14.2	18.0	22.8	34.0	68.9	100.1	127.6
50	11.9	18.0	22.1	25.9	38.1	78.0	113.3	145.3
100	14.6	21.3	25.7	28.4	41.0	84.7	122.6	157.9

Table 6.39 Cheeseman 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.9	8.2	10.9	16.2	25.0	48.2	68.7	86.1
5	6.4	10.5	13.7	19.3	29.4	58.0	83.7	105.1
10	7.9	12.8	16.4	21.9	33.1	66.1	95.7	121.2
20	9.9	15.4	19.4	24.6	36.6	74.2	107.6	137.1
50	12.9	19.5	23.9	28.1	41.2	84.4	122.6	157.2
100	15.8	23.1	27.8	30.7	44.3	91.6	132.7	170.9

Table 6.40 Christchurch Aero 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.7	7.4	9.1	12.7	17.2	29.1	40.9	53.8
5	6.6	10.4	12.5	16.9	23.4	38.1	53.7	70.2
10	8.3	12.7	15.2	20.3	29.0	46.8	65.1	83.8
20	9.8	15.1	17.9	23.5	34.5	56.6	77.3	97.0
50	11.7	18.1	21.3	27.8	41.6	71.6	95.4	114.0
100	13.2	20.4	23.8	30.9	47.0	84.6	108.3	126.3

Table 6.41 Christchurch Aero 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.1	7.9	9.7	13.6	18.3	30.7	43.0	56.3
5	7.2	11.2	13.4	18.2	25.1	40.5	56.9	74.1
10	8.9	13.8	16.4	21.8	31.1	50.1	69.5	89.3
20	10.6	16.3	19.3	25.4	37.2	61.0	83.1	104.2
50	12.6	19.6	23.1	30.0	45.0	77.5	103.2	123.3
100	14.3	22.0	25.8	33.4	50.8	91.5	117.2	136.6

Table 6.42 Coopers Knob 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.8	5.8	7.3	10.8	15.6	30.9	43.9	62.3
5	4.9	7.3	9.0	12.2	17.4	36.3	52.3	74.1
10	6.0	8.5	10.3	13.2	18.8	40.6	59.1	82.5
20	7.0	9.5	11.5	13.9	20.3	44.8	65.9	89.8
50	8.4	10.9	13.0	14.8	22.1	50.1	74.4	98.0
100	9.3	11.9	13.9	15.3	23.4	53.8	80.6	103.1

Table 6.43 Coopers Knob 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.1	6.2	7.9	11.6	16.6	32.6	46.1	65.2
5	5.3	7.8	9.6	13.1	18.6	38.6	55.5	78.3
10	6.5	9.1	11.1	14.2	20.2	43.5	63.1	87.9
20	7.5	10.3	12.4	15.0	21.9	48.2	70.8	96.4
50	9.0	11.8	14.0	16.0	23.9	54.2	80.5	106.0
100	10.1	12.9	15.1	16.6	25.3	58.2	87.2	111.6

Table 6.44 Grasmere 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	2.9	4.6	6.3	10.9	17.3	36.8	50.5	67.1
5	4.2	6.1	8.0	12.6	19.7	42.8	58.8	79.5
10	5.6	8.1	9.8	13.9	21.6	46.8	64.5	87.6
20	7.3	10.4	11.9	15.2	23.4	49.9	69.2	94.2
50	9.6	13.8	14.7	16.8	25.4	53.2	74.2	101.0
100	11.5	16.5	16.9	18.0	26.9	55.0	77.0	104.5

Table 6.45 Grasmere 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.1	5.0	6.7	11.7	18.4	38.8	53.0	70.2
5	4.5	6.6	8.6	13.5	21.1	45.6	62.4	84.0
10	6.0	8.8	10.6	14.9	23.2	50.1	68.8	93.3
20	7.9	11.2	12.8	16.4	25.2	53.7	74.4	101.2
50	10.4	15.0	15.9	18.2	27.5	57.5	80.3	109.3
100	12.4	17.9	18.3	19.5	29.1	59.5	83.3	113.1

Table 6.46 Highpeak Station 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.5	8.2	10.0	13.8	20.8	35.7	51.6	64.4
5	7.3	11.2	13.9	18.3	27.2	45.5	68.6	92.7
10	8.6	13.5	17.2	22.0	32.7	53.4	82.8	118.0
20	9.9	15.6	20.3	25.6	38.0	61.0	96.4	143.5
50	11.4	18.3	24.4	30.1	44.8	70.6	114.2	176.8
100	12.4	20.3	27.4	33.6	49.7	77.6	127.0	201.1

Table 6.47 Highpeak Station 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.9	8.9	10.8	14.7	22.1	37.7	54.3	67.3
5	7.9	12.1	14.9	19.6	29.1	48.4	72.8	97.9
10	9.3	14.6	18.5	23.6	35.1	57.1	88.4	125.8
20	10.7	16.9	22.0	27.6	41.0	65.7	103.7	154.2
50	12.3	19.8	26.4	32.6	48.5	76.4	123.5	191.3
100	13.5	21.9	29.7	36.3	53.8	84.0	137.5	217.6

Table 6.48 Lincoln Broadfield 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	6.5	8.5	10.0	12.8	17.1	29.1	37.2	44.2
5	8.5	11.3	12.7	17.1	22.5	38.2	49.6	58.5
10	9.6	13.4	14.4	20.3	26.6	45.2	59.8	70.9
20	10.6	15.0	15.7	23.0	30.4	51.5	69.8	83.1
50	11.7	17.0	17.7	26.4	35.2	59.3	82.3	98.6
100	12.4	18.3	18.9	28.6	38.4	64.5	91.3	109.9

Table 6.49 Lincoln Broadfield 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	7.1	9.2	10.8	13.7	18.2	30.7	39.1	46.3
5	9.2	12.2	13.7	18.4	24.0	40.6	52.6	61.8
10	10.4	14.5	15.6	21.8	28.6	48.4	63.8	75.6
20	11.5	16.2	17.0	24.8	32.8	55.4	75.1	89.2
50	12.6	18.4	19.1	28.5	38.0	64.1	89.1	106.7
100	13.5	19.8	20.4	31.0	41.5	69.8	98.8	118.9

Table 6.50 13 Mile Bush 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	6.0	9.5	11.6	15.3	22.4	37.1	49.6	66.5
5	8.8	13.7	16.3	20.5	27.4	45.1	63.9	90.6
10	11.4	17.6	20.6	25.5	31.4	51.8	76.3	112.2
20	13.9	21.3	24.9	30.4	35.4	58.0	88.7	133.8
50	17.4	26.3	30.6	37.0	40.4	65.9	104.7	162.1
100	19.9	30.0	34.8	41.8	44.2	71.5	116.2	182.7

Table 6.51 13 Mile Bush 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	6.5	10.3	12.5	16.3	23.8	39.2	52.1	69.5
5	9.5	14.8	17.6	22.0	29.3	48.0	67.7	95.7
10	12.3	19.0	22.2	27.4	33.7	55.4	81.5	119.6
20	15.1	23.0	26.9	32.8	38.1	62.5	95.3	143.8
50	18.8	28.4	33.1	40.0	43.7	71.3	113.3	175.4
100	21.6	32.5	37.7	45.2	47.8	77.4	125.7	197.7

Table 6.52 Nigger Hill 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	2.3	4.1	5.4	8.9	14.5	30.3	46.5	67.5
5	5.6	7.8	9.4	13.4	19.5	40.2	61.0	86.9
10	9.0	11.2	12.7	16.7	22.9	47.1	72.0	103.2
20	12.6	14.7	16.1	19.8	25.7	52.9	82.1	119.0
50	17.7	19.2	20.3	23.5	28.8	59.3	94.2	139.1
100	21.5	22.6	23.3	26.2	31.0	63.1	102.6	153.3

Table 6.53 Nigger Hill 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	2.4	4.4	5.8	9.5	15.4	32.0	48.9	70.6
5	6.0	8.4	10.1	14.4	20.9	42.7	64.7	91.9
10	9.7	12.1	13.7	18.0	24.6	50.4	76.8	110.0
20	13.7	15.9	17.3	21.3	27.8	56.9	88.2	127.9
50	19.1	20.8	21.9	25.4	31.2	64.1	102.0	150.6
100	23.3	24.5	25.2	28.3	33.5	68.3	111.0	165.9

Table 6.54 Ranger Stream 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.4	9.1	11.9	19.6	31.9	66.4	101.9	136.0
5	7.7	11.8	14.7	23.5	38.4	82.9	125.9	168.1
10	10.3	14.3	17.1	26.3	43.1	95.9	144.2	194.1
20	13.1	16.9	19.5	28.9	47.4	108.2	161.0	218.7
50	17.2	20.3	22.9	31.8	52.4	123.3	181.4	249.5
100	20.3	22.8	25.5	34.0	55.9	133.8	195.2	270.7

Table 6.55 Ranger Stream 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.8	9.8	12.8	21.0	33.9	70.1	107.1	142.2
5	8.4	12.7	15.8	25.2	41.1	88.2	133.6	177.6
10	11.1	15.5	18.4	28.4	46.3	102.7	153.9	206.8
20	14.2	18.3	21.0	31.2	51.1	116.4	173.2	235.0
50	18.6	21.9	24.8	34.5	56.7	133.4	196.3	269.9
100	21.9	24.7	27.6	36.8	60.4	144.8	211.2	292.9

Table 6.56 Ridgens Road 2040 projected design rainfalls (rainfall depths in mm). Note: Including all data.

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.6	4.9	7.2	9.9	15.1	27.4	40.5	52.8
5	7.7	10.3	13.5	16.3	21.8	34.8	48.4	66.1
10	13.5	17.2	20.9	23.8	28.4	41.4	54.3	76.5
20	20.7	25.5	29.2	32.1	35.3	48.0	59.6	86.2
50	31.8	37.6	40.8	44.0	44.4	56.7	65.8	98.3
100	41.1	47.3	50.1	51.3	53.3	63.0	69.9	106.4

Table 6.57 Ridgens Road 2090 projected design rainfalls (rainfall depths in mm). Note: Including all data.

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	3.9	5.3	7.8	10.5	16.1	29.0	42.5	55.2
5	8.4	11.1	14.6	17.5	23.4	37.0	51.3	69.8
10	14.6	18.6	22.6	25.6	30.5	44.3	58.0	81.5
20	22.4	27.6	31.6	34.6	38.0	51.7	64.1	92.7
50	34.5	40.7	44.2	47.6	48.0	61.4	71.2	106.4
100	44.4	51.2	54.2	55.6	57.7	68.2	75.6	115.2

Table 6.58 Ridgens Road 2040 projected design rainfalls (rainfall depths in mm). Note: Without the 15/11/04 storm event.

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.1	5.7	7.8	10.5	15.4	26.8	40.1	52.7
5	6.0	8.3	11.2	13.9	19.1	32.2	47.5	65.7
10	7.9	10.9	14.3	17.0	22.3	36.6	52.8	76.3
20	9.9	13.5	17.3	19.9	25.2	40.9	57.4	86.4
50	12.5	16.8	21.3	23.8	29.1	46.2	62.7	99.2
100	14.6	19.4	24.3	26.6	31.9	50.0	65.9	108.1

Table 6.59 Ridgens Road 2090 projected design rainfalls (rainfall depths in mm). Note: Without the 15/11/04 storm event.

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.4	6.1	8.4	11.2	16.4	28.3	42.1	55.1
5	6.5	9.0	12.1	15.0	20.4	34.2	50.3	69.5
10	8.6	11.8	15.4	18.3	23.9	39.2	56.4	81.3
20	10.7	14.6	18.7	21.5	27.2	44.0	61.8	92.8
50	13.6	18.2	23.1	25.8	31.4	50.0	67.9	107.3
100	15.8	21.0	26.3	28.8	34.6	54.1	71.3	116.9

Table 6.60 Ryans Bridge 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.0	5.6	6.9	9.4	13.5	24.8	34.1	42.7
5	5.6	7.6	9.2	12.3	18.0	31.3	43.7	53.7
10	7.1	9.5	11.2	15.4	22.8	37.8	52.5	63.3
20	8.6	11.5	13.3	18.7	27.8	44.3	61.5	72.9
50	10.7	14.0	16.0	23.4	34.7	53.1	73.4	85.2
100	12.4	16.0	18.0	27.0	40.0	59.6	82.3	94.1

Table 6.61 Ryans Bridge 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	4.3	6.0	7.4	10.1	14.4	26.2	35.8	44.6
5	6.0	8.2	9.9	13.2	19.3	33.3	46.3	56.7
10	7.7	10.3	12.1	16.5	24.5	40.4	56.0	67.4
20	9.3	12.4	14.3	20.2	30.0	47.6	66.1	78.4
50	11.6	15.2	17.3	25.3	37.6	57.4	79.5	92.2
100	13.5	17.3	19.5	29.2	43.3	64.5	89.1	101.8

Table 6.62 Whitecliffs 2040 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.3	6.8	8.6	12.9	20.3	36.5	48.2	58.1
5	7.0	9.4	12.1	16.9	25.3	42.4	59.4	79.1
10	8.6	11.9	15.2	20.5	29.4	46.4	68.7	99.8
20	10.3	14.2	18.3	24.1	33.2	49.6	77.7	121.6
50	12.6	17.4	22.5	28.7	37.8	53.4	89.4	151.3
100	14.3	19.7	25.6	32.2	41.1	55.6	97.8	173.4

Table 6.63 Whitecliffs 2090 projected design rainfalls (rainfall depths in mm).

	Duration							
ARI	**10-min**	**20-min**	**30-min**	**1-hour**	**2-hours**	**6-hours**	**12-hours**	**24-hours**
2	5.7	7.4	9.3	13.8	21.6	38.5	50.6	60.7
5	7.5	10.2	13.0	18.2	27.1	45.1	63.1	83.5
10	9.3	12.8	16.4	22.0	31.6	49.6	73.3	106.3
20	11.1	15.4	19.8	26.0	35.8	53.4	83.5	130.6
50	13.7	18.8	24.4	31.1	40.9	57.8	96.7	163.7
100	15.4	21.3	27.7	34.8	44.4	60.2	105.8	187.7

6.4 Summary

Based on the above analysis, it is suggested that the design rainfall table derived from data from the nearest rain gauge to each urban community be used in engineering design. In the case of the Ridgens Road, the design rainfalls estimated from the record excluding the extreme magnitude event of 15 November 2004 should be used. The use of the record including this event appears to produce unrealistically high design rainfalls.

For locations at greater distances from the rain gauges, the design rainfall tables can be adjusted using the scale factors provided. These scale factors relate the MAR at each rain gauge to the variation in MAR across each Thiessen polygon.

These design rainfall tables should then be adjusted for the potential effects of climate change. The magnitude of the adjustment should be based on the expected lifetime of the project under consideration. Projects with short lifetimes should use the 2040 tables. Projects with long lifetimes should use the 2090 tables.

In the lowest rainfall zone of the Selwyn District design rainfalls were calculated for four sites in reasonably close proximity. All these design rainfall tables give different estimates, particularly over the shorter durations. This is because of the relatively short record lengths, and the highly variable rainfall recorded at each site.

The conservative approach might be to use the design rainfall table with the largest estimates. However, if this table is affected by an extreme magnitude storm, then the values may be unrealistically high. While the use of such values would be conservative, they would also impose excessive cost by requiring extremely high levels of risk mitigation.

Although there would appear to be some questions regarding the consistency of the rainfall record from Christchurch Aero, this is the longest record analysed. It is likely therefore that the record includes a wider range of rainfall events, and more accurately approximates the actual long-term rainfall distribution. As a result, the design rainfalls based on the Christchurch Aero record are likely to be the most accurate in defining the long-term depth-duration-frequency pattern across the low rainfall zone.

Therefore, it is suggested that although the Christchurch Aero rain gauge lies outside Selwyn District, the design rainfalls derived from these data should be used for the lowest rainfall band (550-649mm) defined in Figure 5.1.

7 90th percentile 24-hour storm rainfall depths

90th percentile 24-hour storm rainfall depths were determined for each site in the Selwyn District. This was done by finding the 90th percentile of all rainfall amounts greater than 0mm i.e. days with no rainfall were excluded from the analysis. The 90th percentile design rainfalls calculated in this manner were then compared to those presented in the NIWA 90th Percentile Storm Rainfall Total Map of New Zealand published in the 2008 draft NZTA document '*Stormwater Treatment for Road Infrastructure'* (NZTA, 2008).

Table 7.1 The 90th percentile storm rainfall depths for the measured rainfall, NIWA 90th percentiles and the differences between them.

	Depths				
ARI - 24 hrs	Rainfall Stations (mm)	NIWA	Difference (mm)	Within NIWA band?	Length of Record (yrs)
Arthurs Pass	66.5	50-70	6.5	y	103
Bull Creek	26.0	27.5-30	-2.75	n	47
Carrington	84.5	50-70	24.5	n	20
Christchurch Aero	13.0	12.5-15	-0.75	y	54
Christchurch Gardens	14.0	12.5-15	0.25	y	136
Cheeseman	22.9	22.5-25	-0.85	y	19
Coopers Knob	15.5	15-17.5	-0.75	y	19
Grasmere	19.0	25-27.5	-7.25	n	21
Highpeak Station	27.5	22.5-25	3.75	n	56
Lincoln Broadfield	13.1	12.5-15	-0.65	y	37
13 Mile Bush	18.5	22.5-25	-5.25	n	21
Nigger Hill	20.3	22.5-25	-3.45	n	49
Ranger Stream	37.0	35-40	-0.5	y	31
Ridgens Road	15.5	15-17.5	-0.75	y	19
Ryans Bridge	15.0	12.5-15	1.25	y	13
Whitecliffs	18.5	20-22.5	-2.75	n	21

Table 7.1 lists the 90th percentile 24-hr rainfalls for the various rain gauges in the Selwyn District. The Carrington site had the greatest rainfall, and the Christchurch Aero site the least. Also shown in this table are the 90th percentile rainfall values taken from the NIWA map (Figure 7.1). When these two sets of rainfall depths are compared there are some differences (Table 7.1). In general the differences are small. However, at Carrington the calculated value from this study is 24.5mm larger than that from the NIWA map.

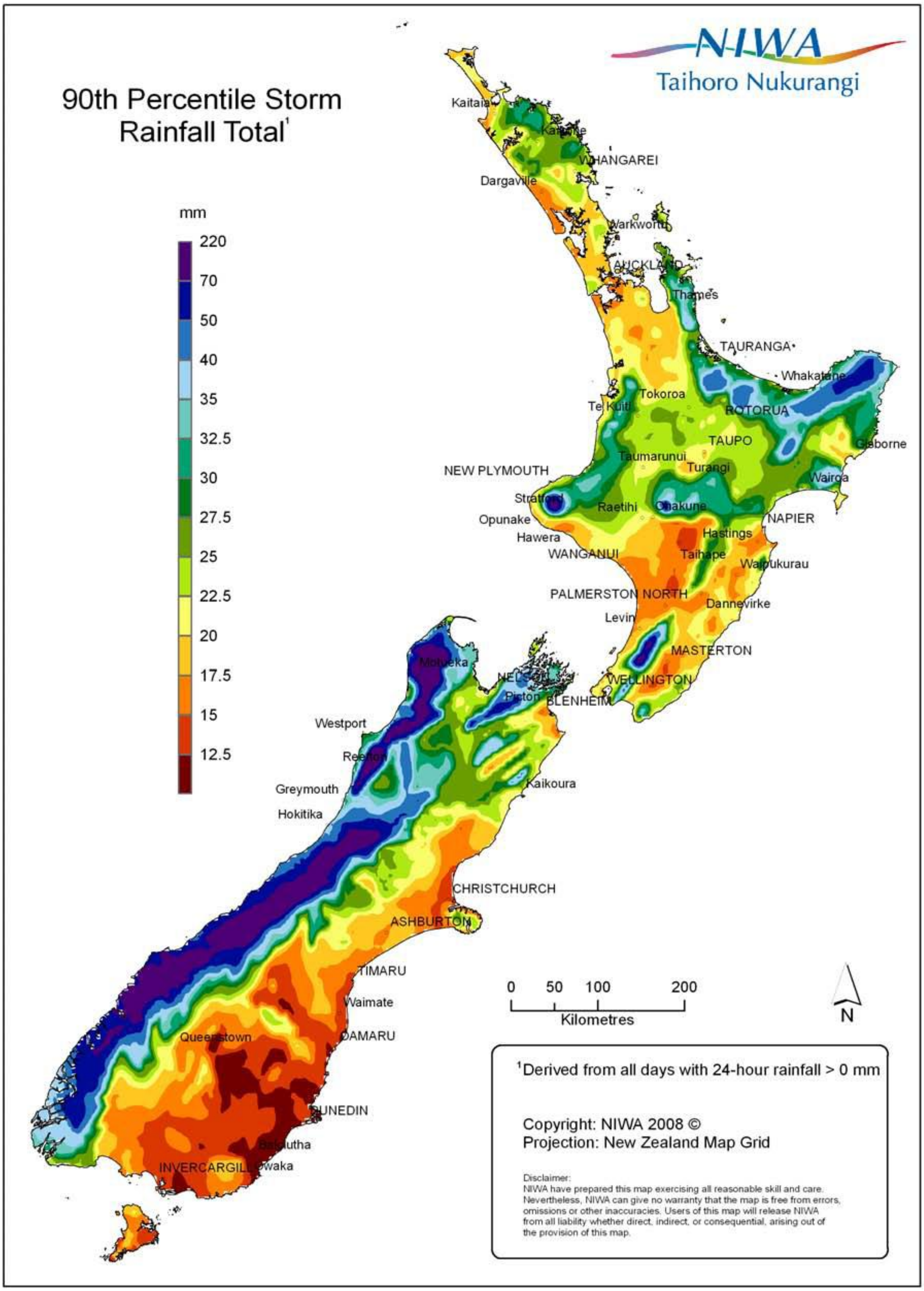

Figure 7.1 The NIWA 90th percentile storm rainfall map (NZTA, 2008).

8 Storm hyetographs

Details of specific storm events of various durations were obtained from each of the fourteen rainfall sites analysed. Typical storm hyetographs were then identified for each site (Figure 8.1-8.15). These typical hyetographs show the distribution of the total design rainfall over the duration of each storm event. As expected the more intense storm events occur over very short periods, usually less than 15-mins. Thus, the storm hyetographs shown are based on the shape of longer duration hyetographs.

It is suggested that for storm durations less than one hour the design rainfall should be applied as a 'block' over the duration in question. For example, if the 50-year ARI 30-min rainfall is 55mm then this should be applied evenly, essentially instantaneously, over 30 minutes.

For storm durations of 1-hour or longer the total rainfall can be apportioned on the basis of the typical hyetograph for each site. This means that a certain percentage of the rainfall is applied over various percentages of the total storm duration. With reference to Figure 8.1 relating to Arthur's Pass 1.2% of the total rainfall would be expected to fall within the first 10% of the storm duration; approximately 27% of the rainfall would fall in the 10% of time between the 50th and 60th percentile of the storm duration.

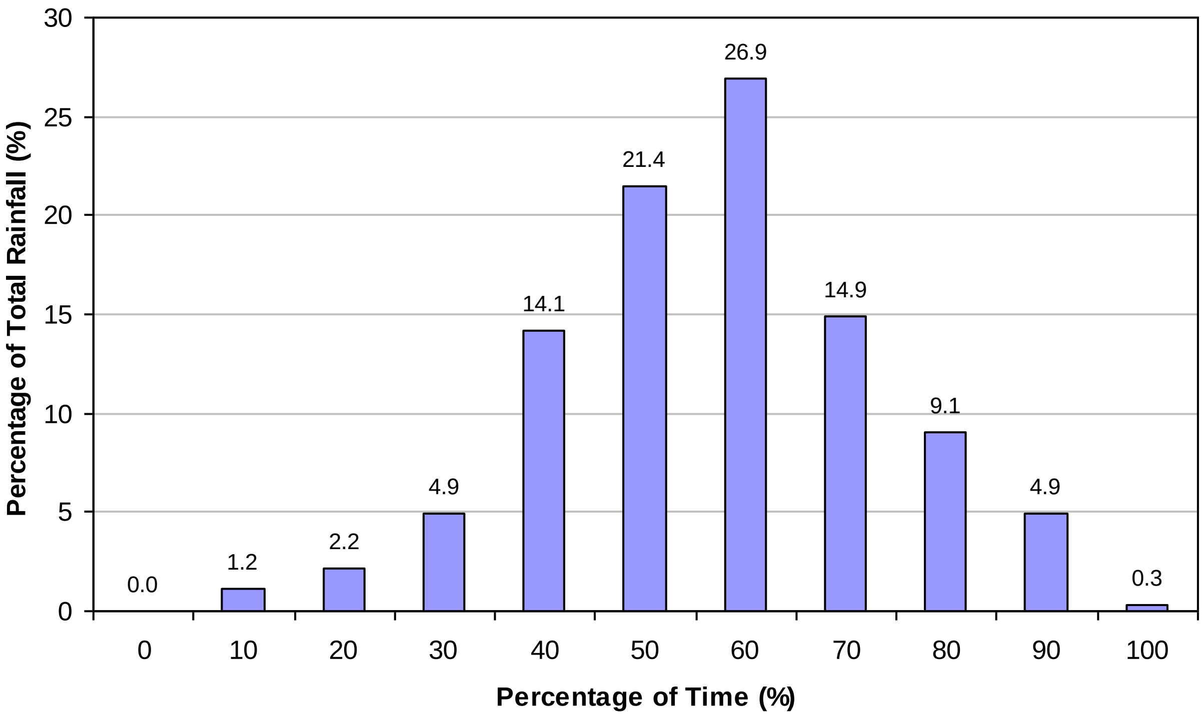

Figure 8.1 Arthur's Pass storm hyetograph.

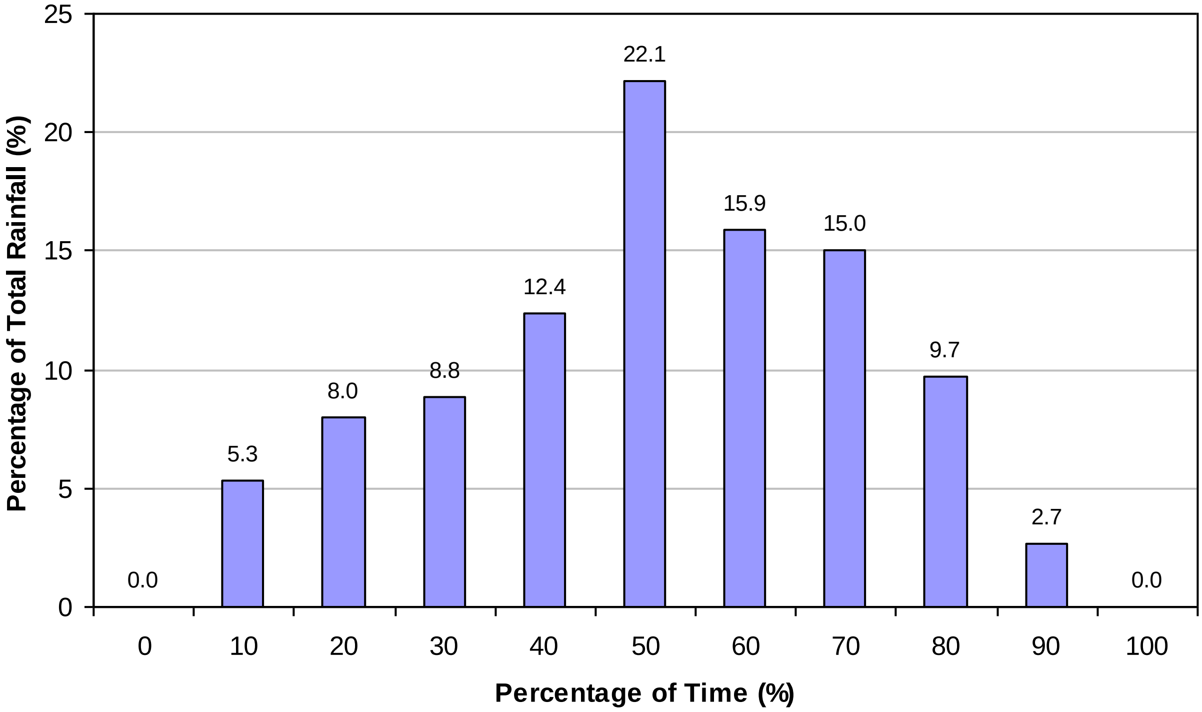

Figure 8.2 Bull Creek storm hyetograph.

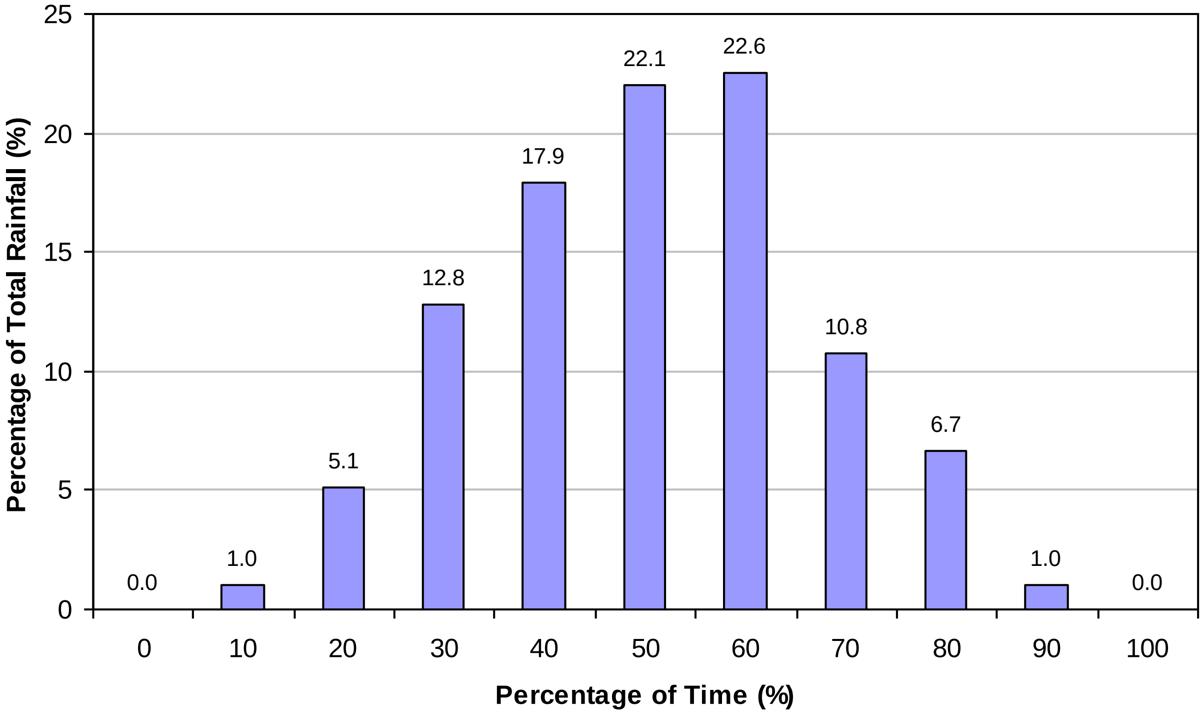

Figure 8.3 Carrington storm hyetograph.

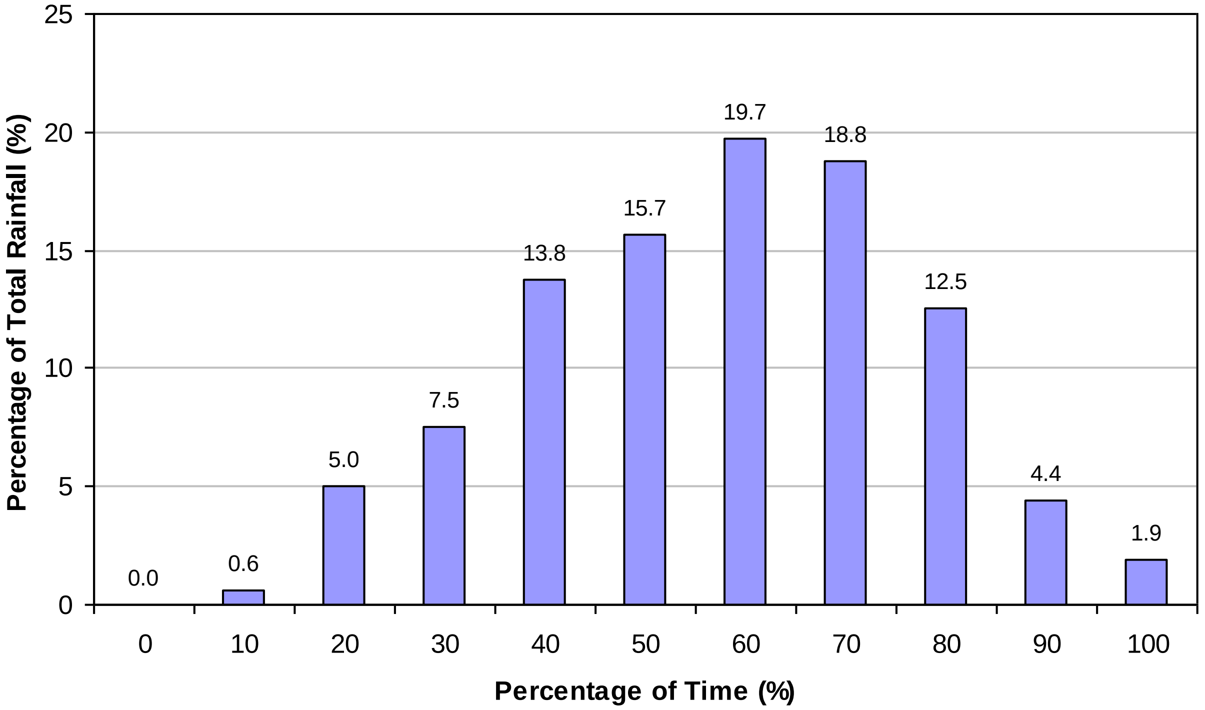

Figure 8.4 **Cheeseman storm hyetograph.**

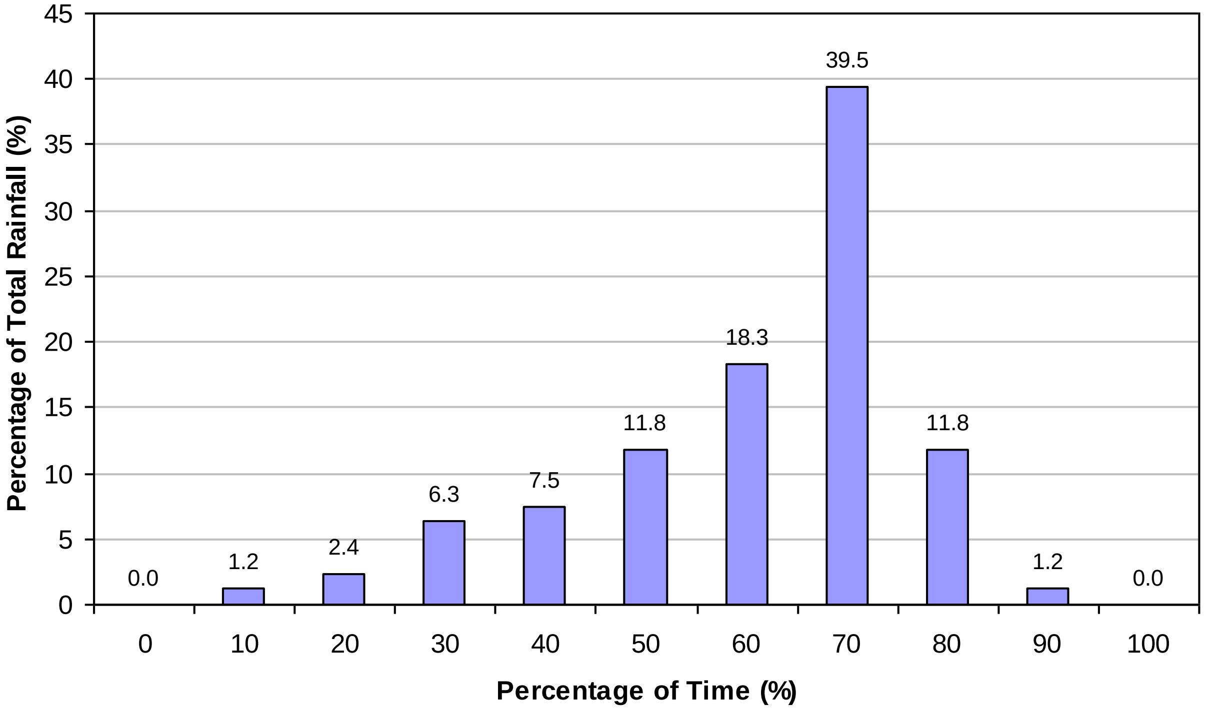

Figure 8.5 **Christchurch Aero storm hyetograph.**

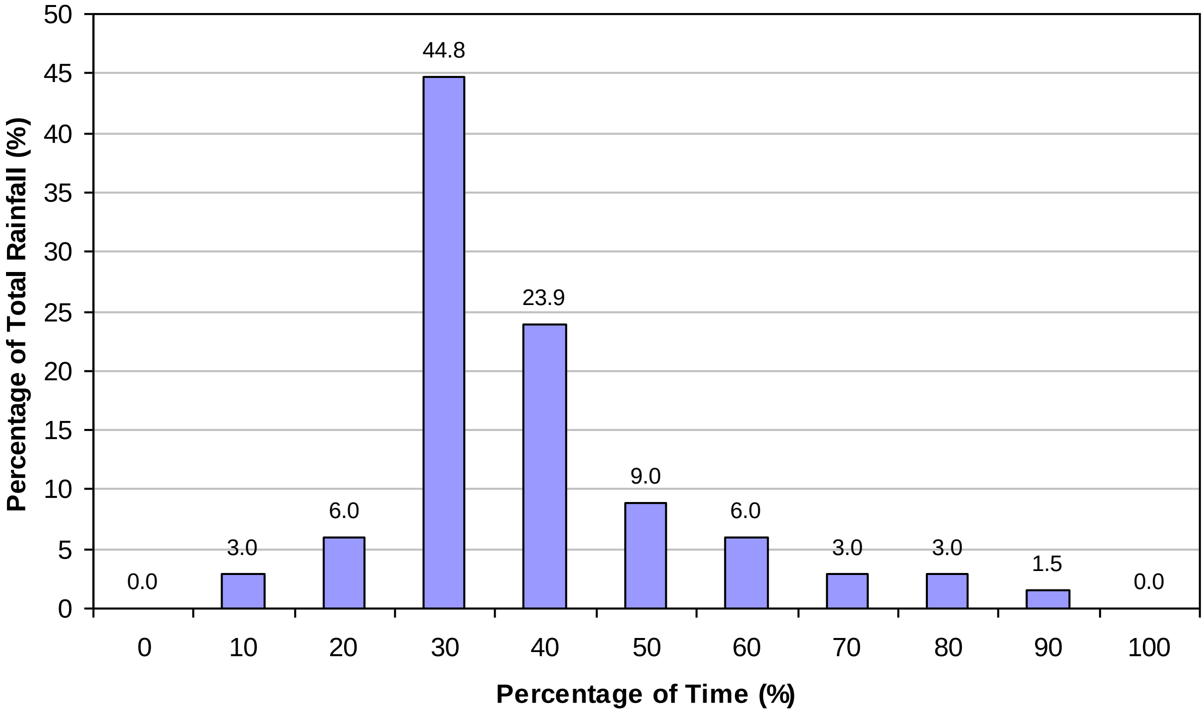

Figure 8.6 Coopers Knob storm hyetograph.

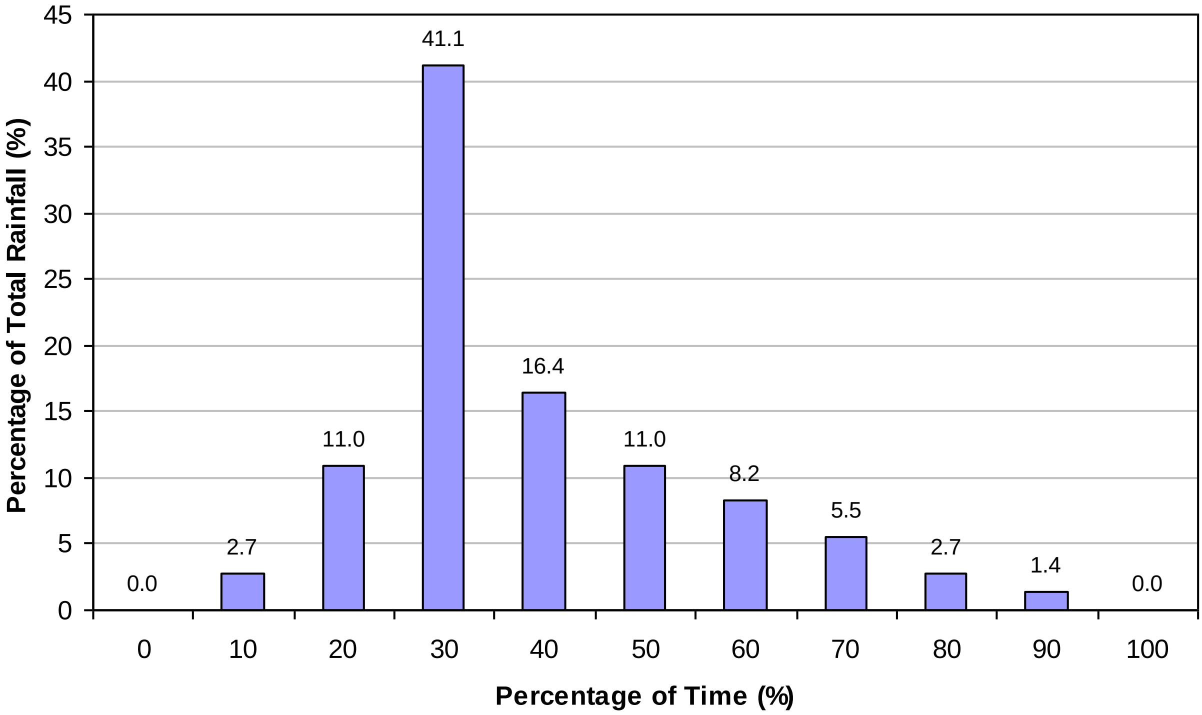

Figure 8.7 Grasmere storm hyetograph.

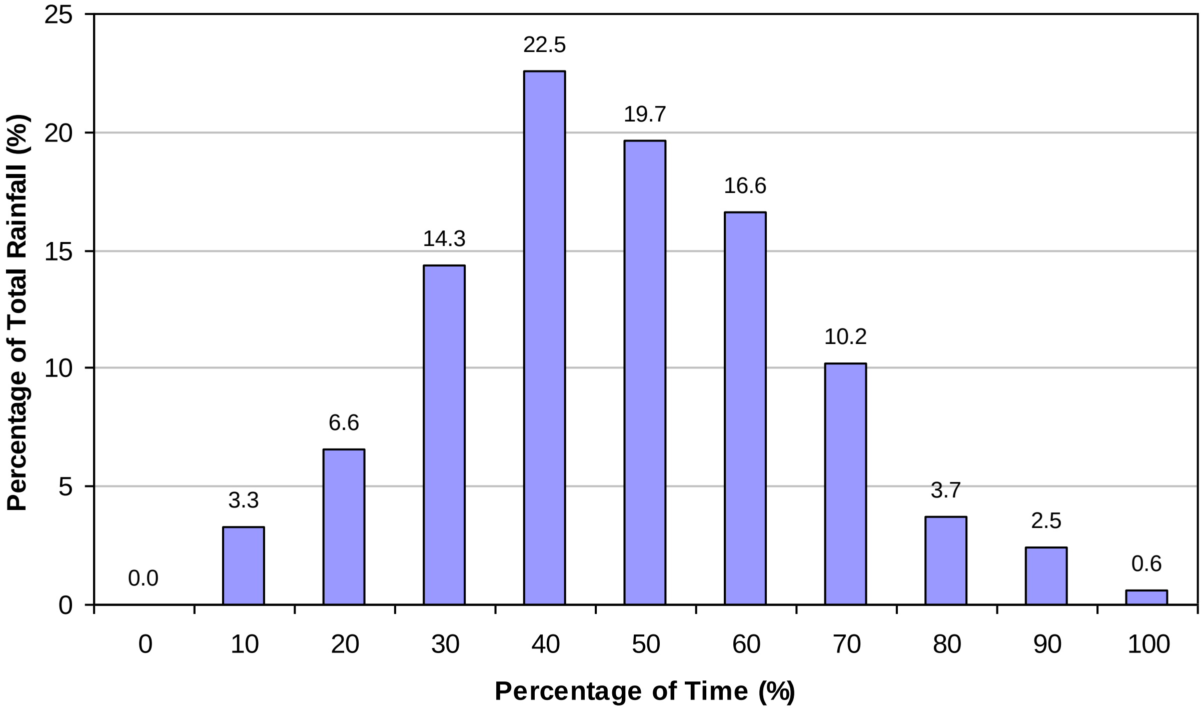

Figure 8.8 **Highpeak Station storm hyetograph.**

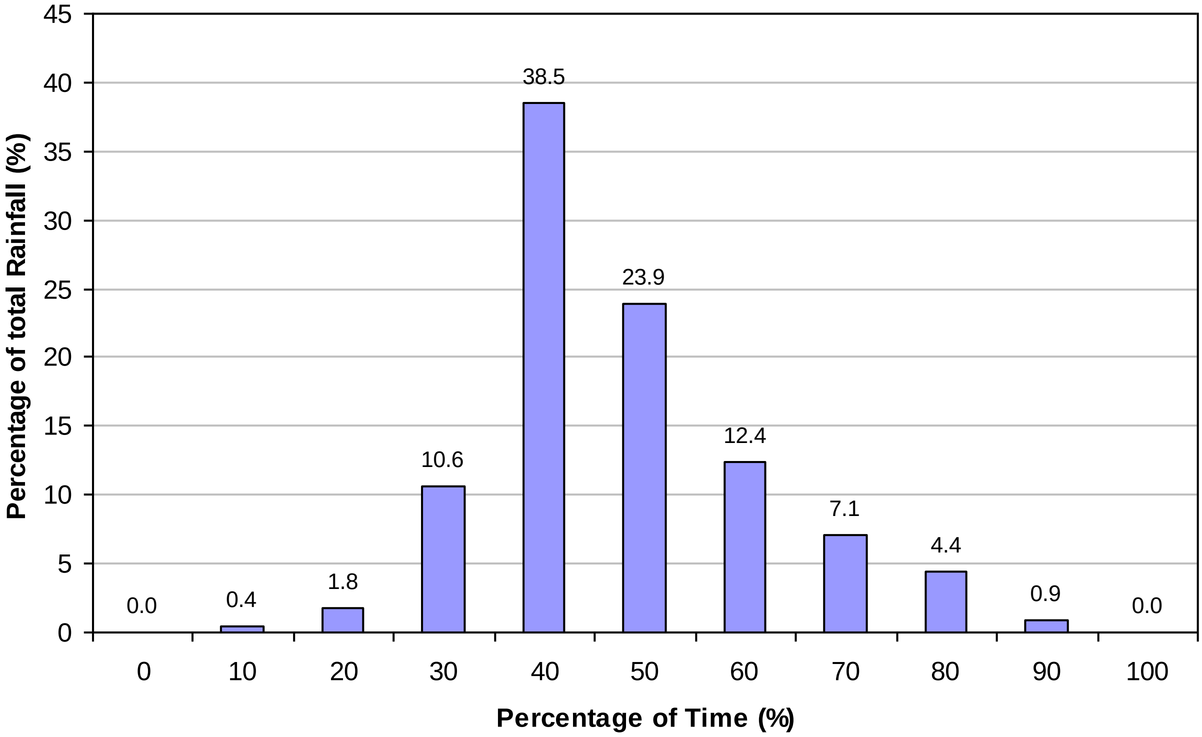

Figure 8.9 **Lincoln Broadfield storm hyetograph.**

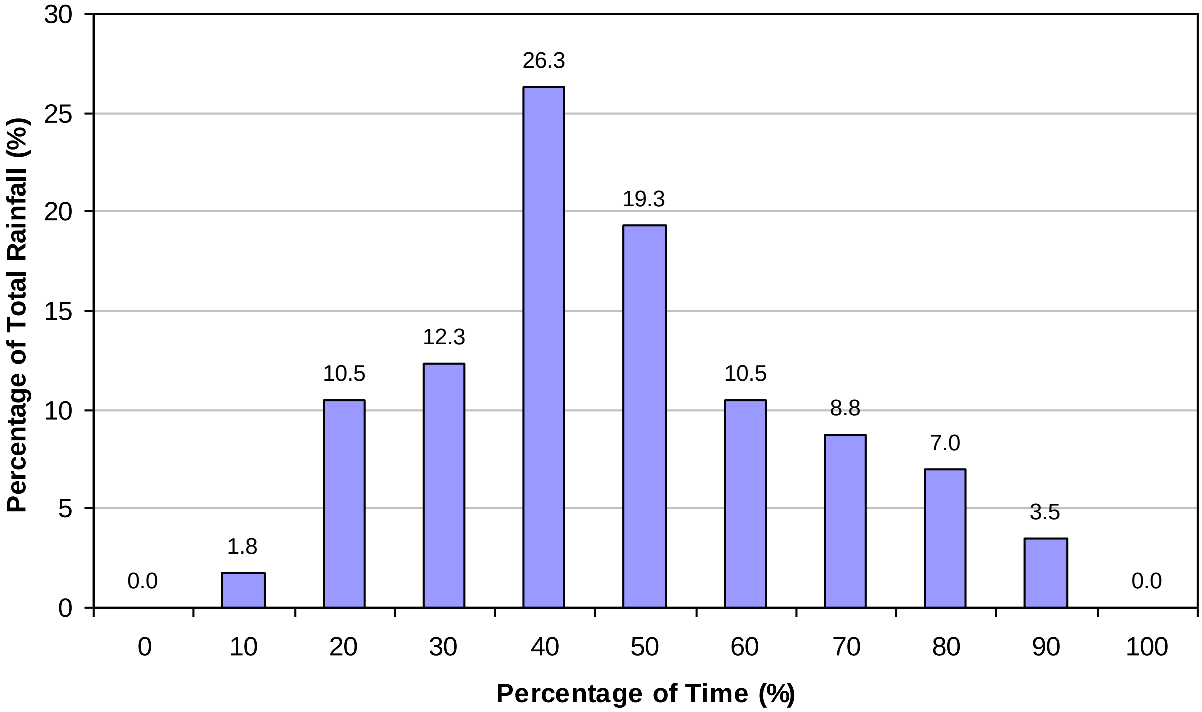

Figure 8.10 **13 Mile Bush storm hyetograph.**

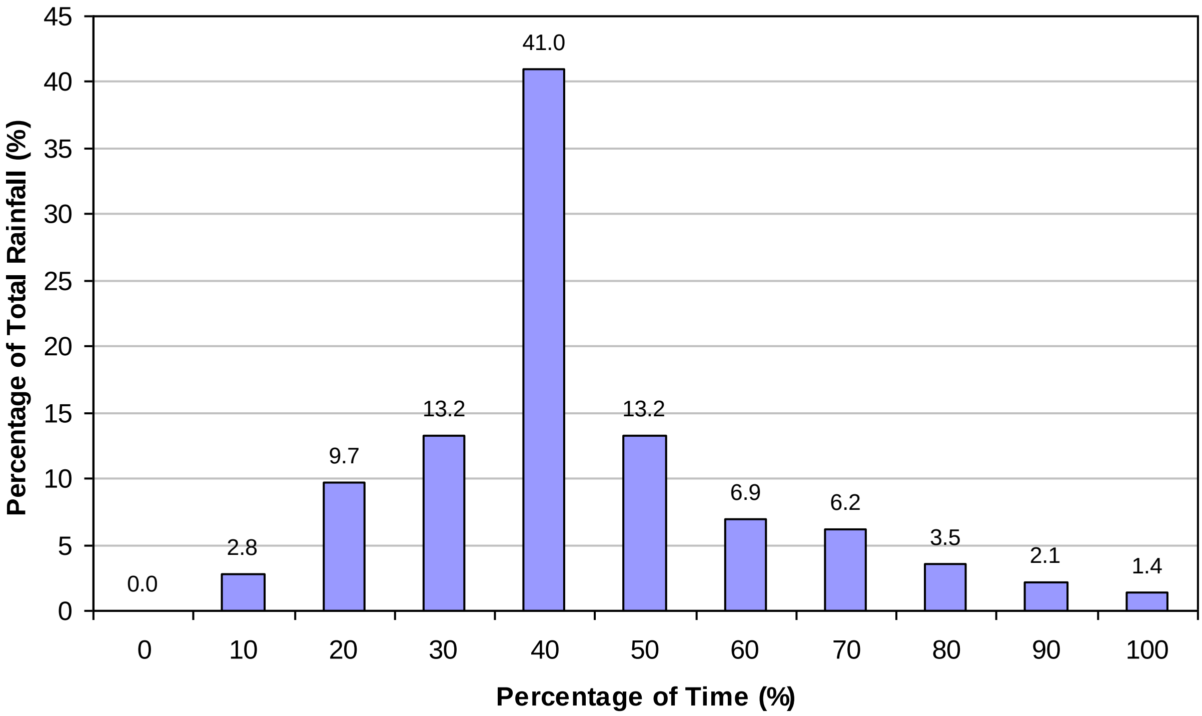

Figure 8.11 **Nigger Hill storm hyetograph.**

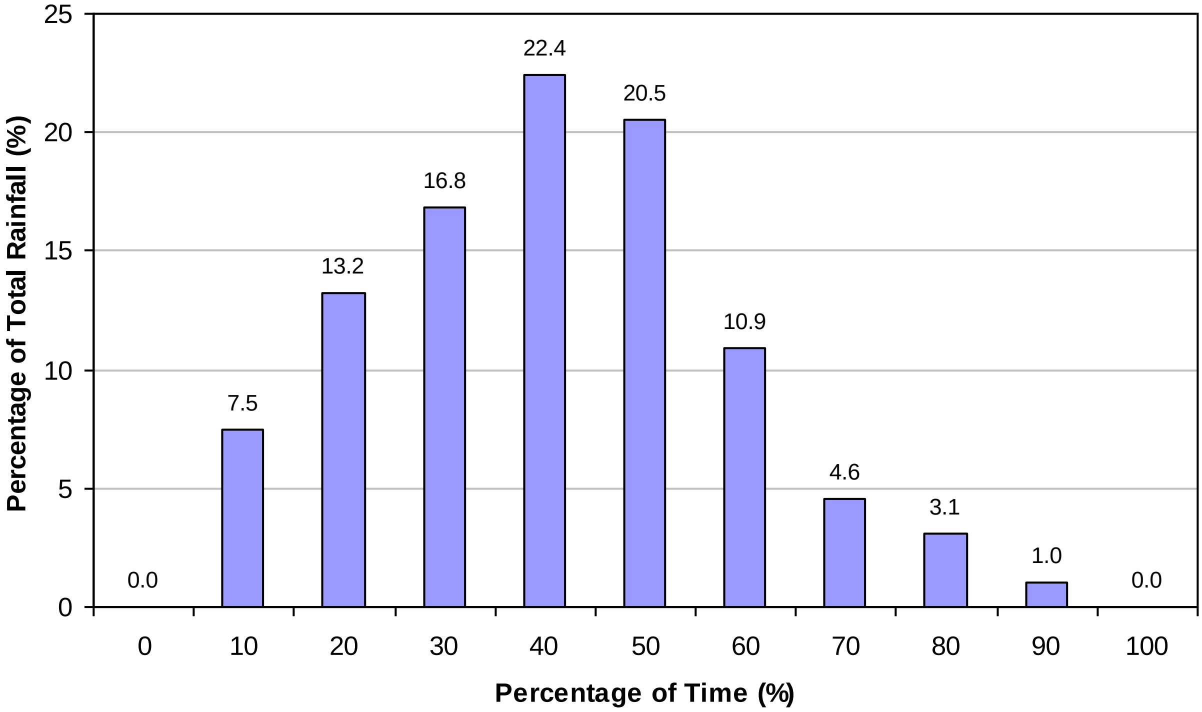

Figure 8.12 Ranger Stream storm hyetograph.

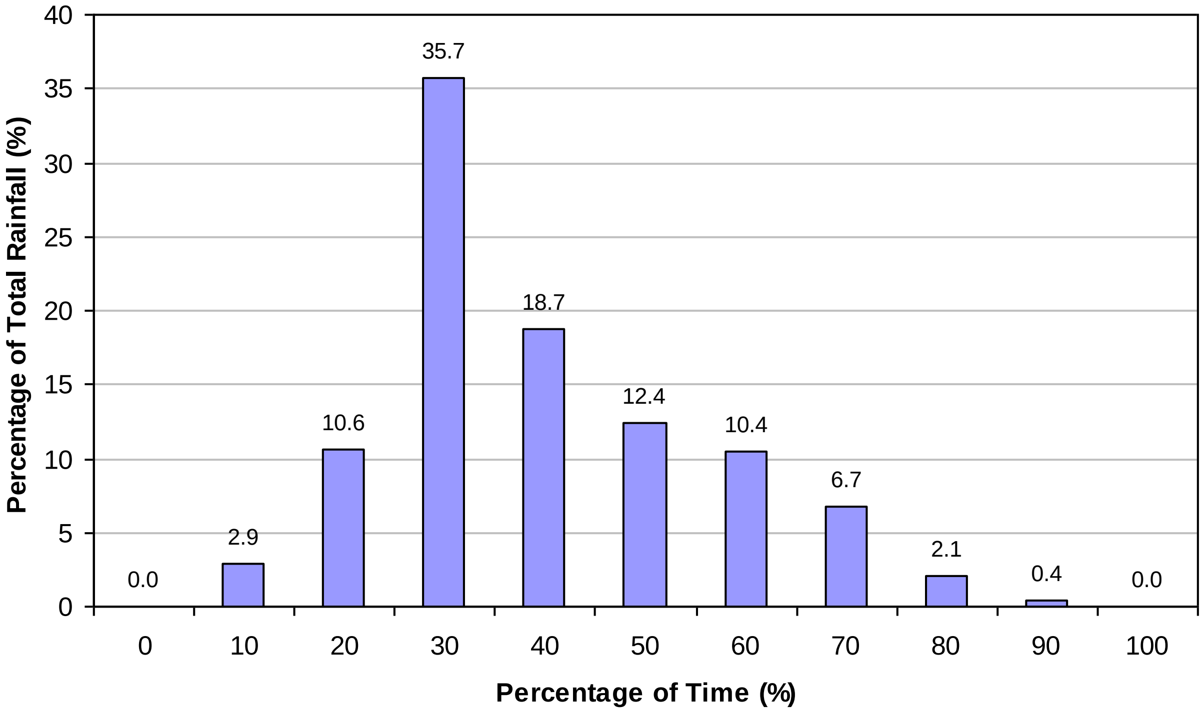

Figure 8.13 Ridgens Road storm hyetograph.

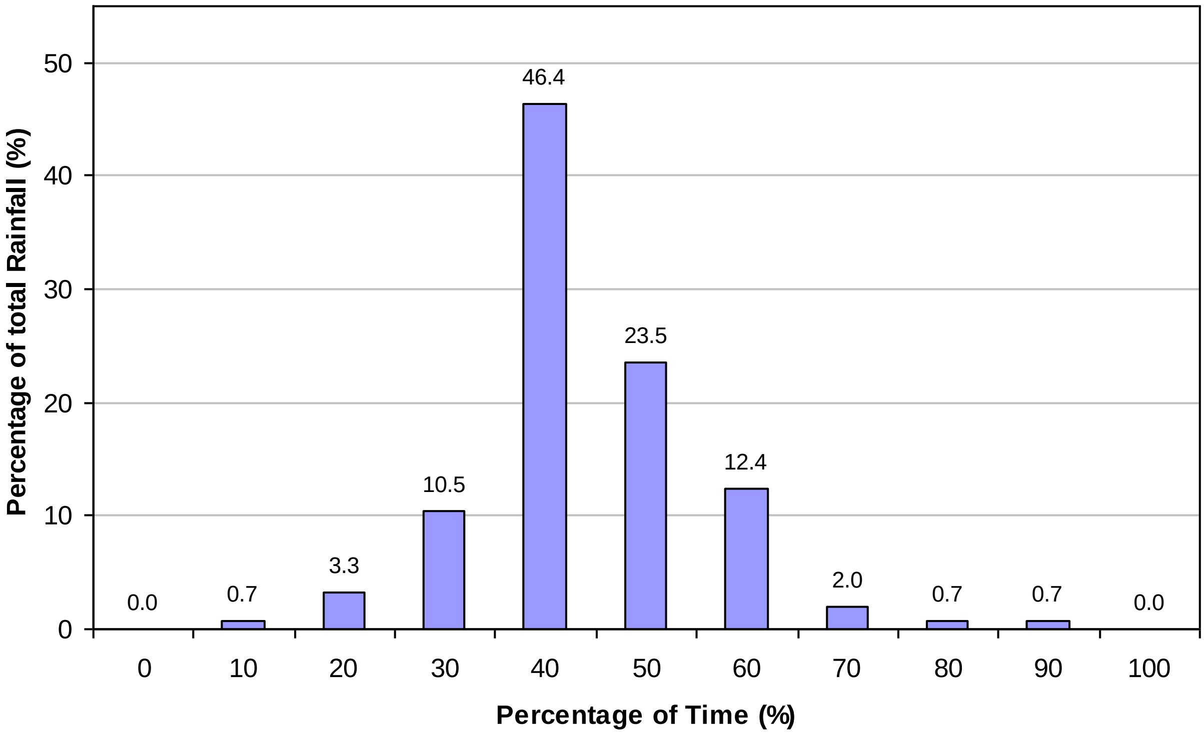

Figure 8.14 Ryan's Bridge storm hyetograph.

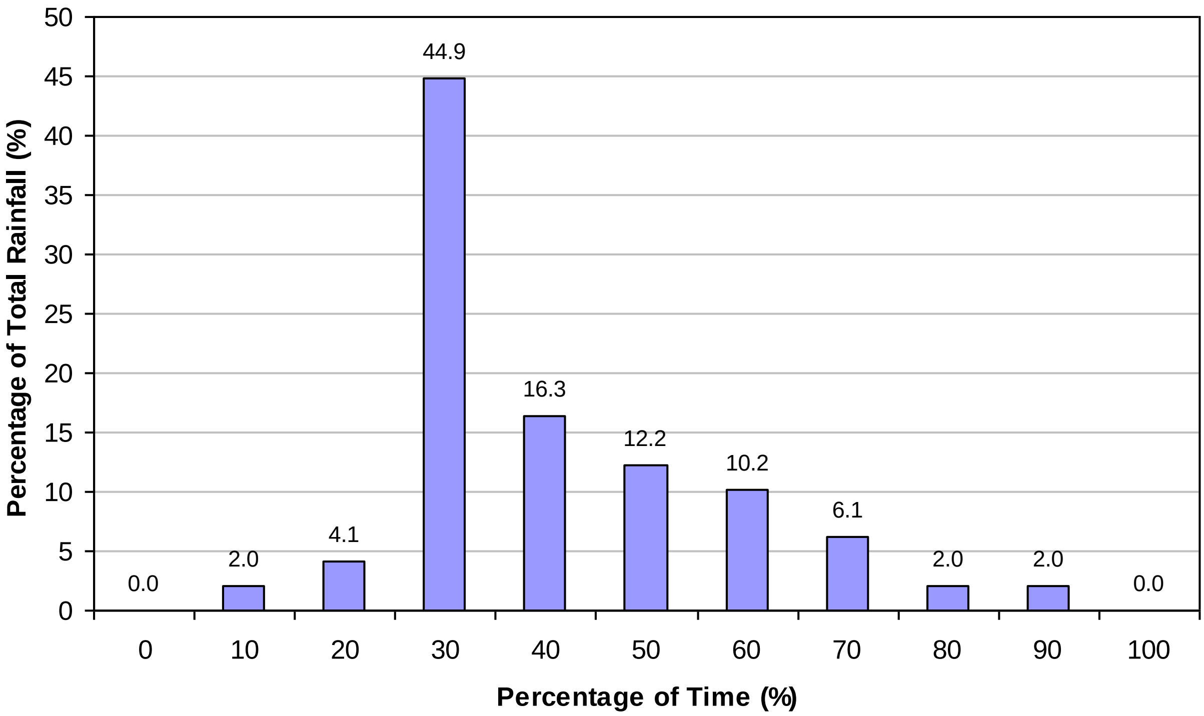

Figure 8.15 Whitecliffs storm hyetograph.

9 Conclusions

The spatial and temporal variability of rainfall across the Selwyn District has been determined. Using all available data, and kriging to interpolate between specific sites, the spatial variation in rainfall as defined by the MAR was quantified.

Design rainfall tables were developed using rainfall information from fourteen stations across the Selwyn District (Tables 4.1-4.14). The design rainfall table from the site nearest each urban community can now be used in engineering design. In the case of the Ridgens Road, the design rainfalls estimated from the record excluding the extreme magnitude event of 15 November 2004 should be used. The use of the record including this event appears to produce unrealistically high design rainfalls.

For locations at greater distances from the rain gauges, the design rainfall tables can be adjusted using the scale factors provided. These scale factors relate the MAR at each rain gauge to the variation in MAR across the appropriate Thiessen polygon.

These design rainfall tables should then be adjusted for the potential effects of climate change. The magnitude of the adjustment should be based on the expected lifetime of the project under consideration. Projects with short lifetimes should use the 2040 tables. Projects with long lifetimes should use the 2090 tables.

In the lowest rainfall zone of the Selwyn District design rainfalls were calculated for four sites in reasonably close proximity. All these design rainfall tables give different estimates, particularly over the shorter durations. This is because of the relatively short record lengths, and the highly variable rainfall recorded at each site.

The conservative approach might be to use the design rainfall table with the largest estimates. However, if this table is affected by an extreme magnitude storm, then the values may be unrealistically high. While the use of such values would be conservative their use would also impose excessive cost by requiring extremely high levels of risk mitigation.

Although there would appear to be some questions regarding the consistency of the rainfall record from Christchurch Aero, this is the longest record analysed. It is likely therefore that the record includes a wider range of rainfall events and more accurately approximates the actual long-term rainfall distribution. As a result, the design rainfalls based on the Christchurch Aero record are likely to be the most accurate in defining the long-term depth-duration-frequency pattern across the low rainfall zone.

Therefore, it is suggested that although the Christchurch Aero rain gauge lies outside Selwyn District the design rainfalls derived from these data should be used for the lowest rainfall band (550-649mm) shown in Figure 5.1.

In other rainfall bands where more than one set of design rainfalls have been developed it is suggested that the more extreme values should be used to ensure conservative design and to minimise any associated risk.

The design rainfall tables, in conjunction with climate change effects, typical storm hyetographs, rainfall spatial variability maps, and the impact of climatic cycles will aid in planning for infrastructure through to the 2090s.

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Appendix A
Frequency Analyses

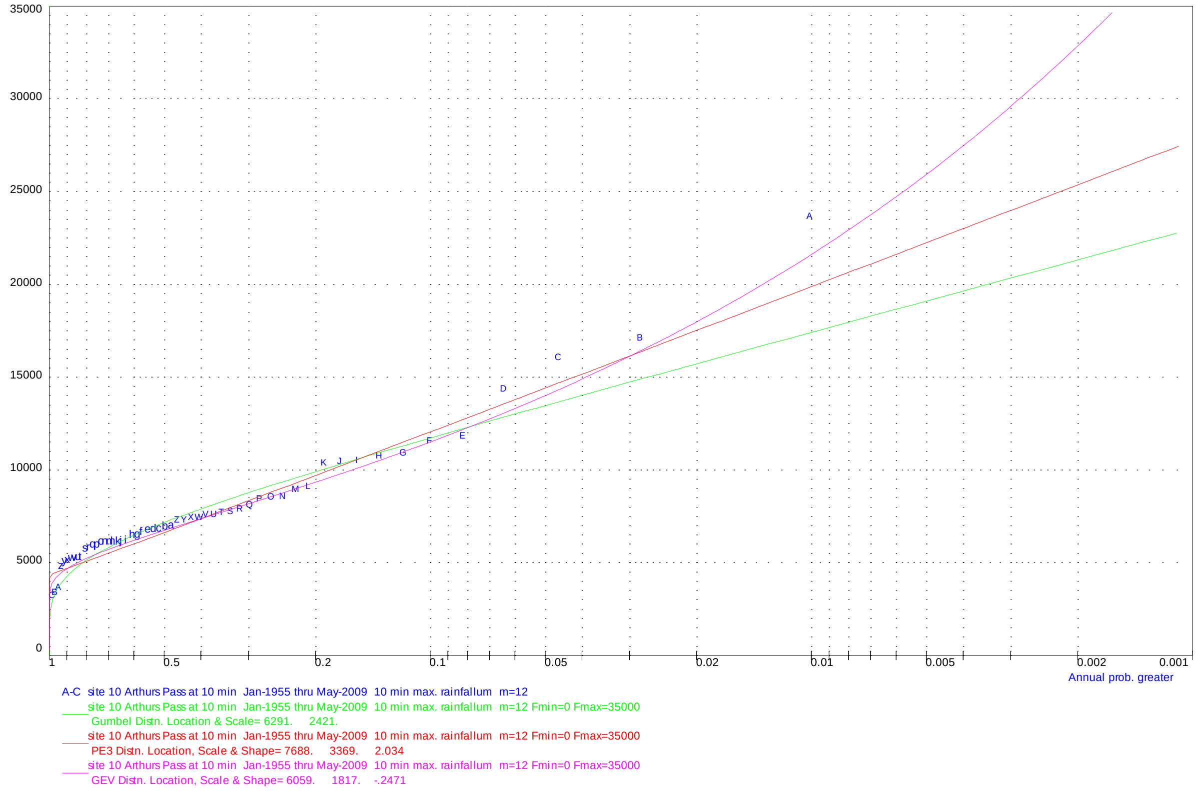


Figure A.1 Arthurs Pass 10-min rainfall frequency analysis.

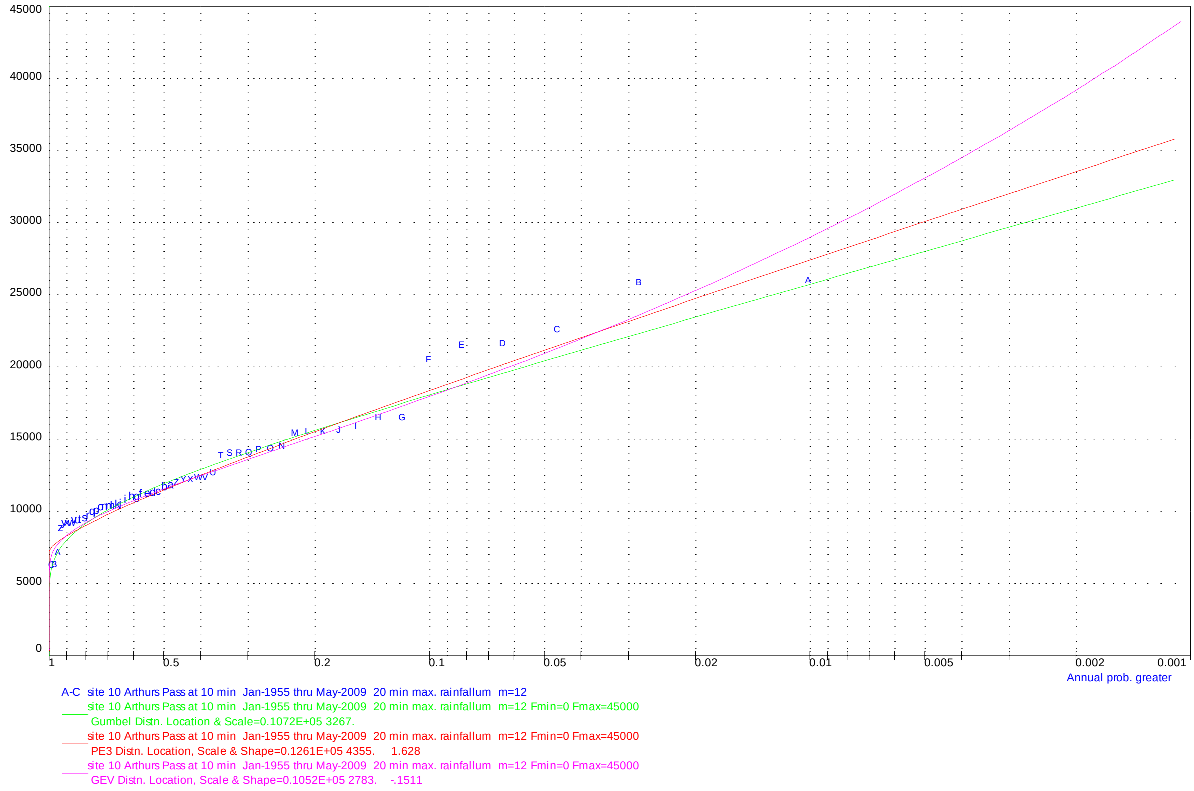


Figure A.2 Arthurs Pass 20-min rainfall frequency analysis.

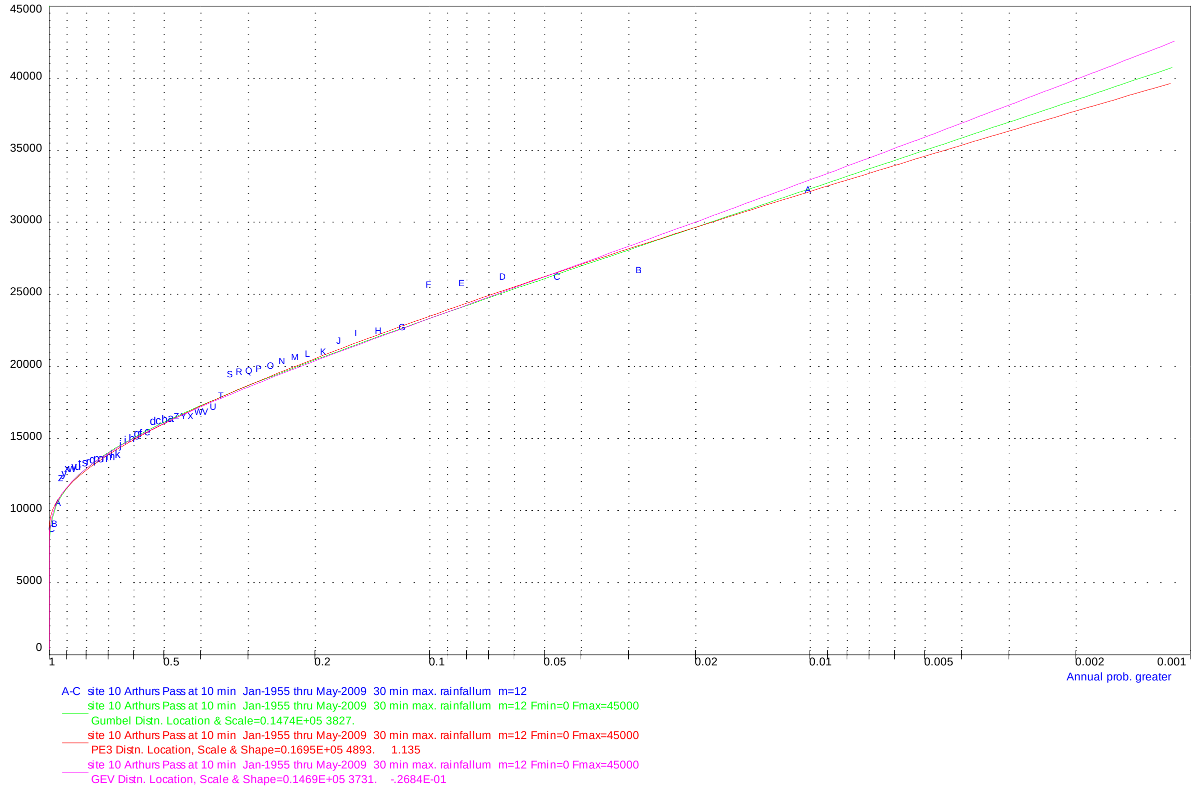


Figure A.3 Arthurs Pass 30-min rainfall frequency analysis.

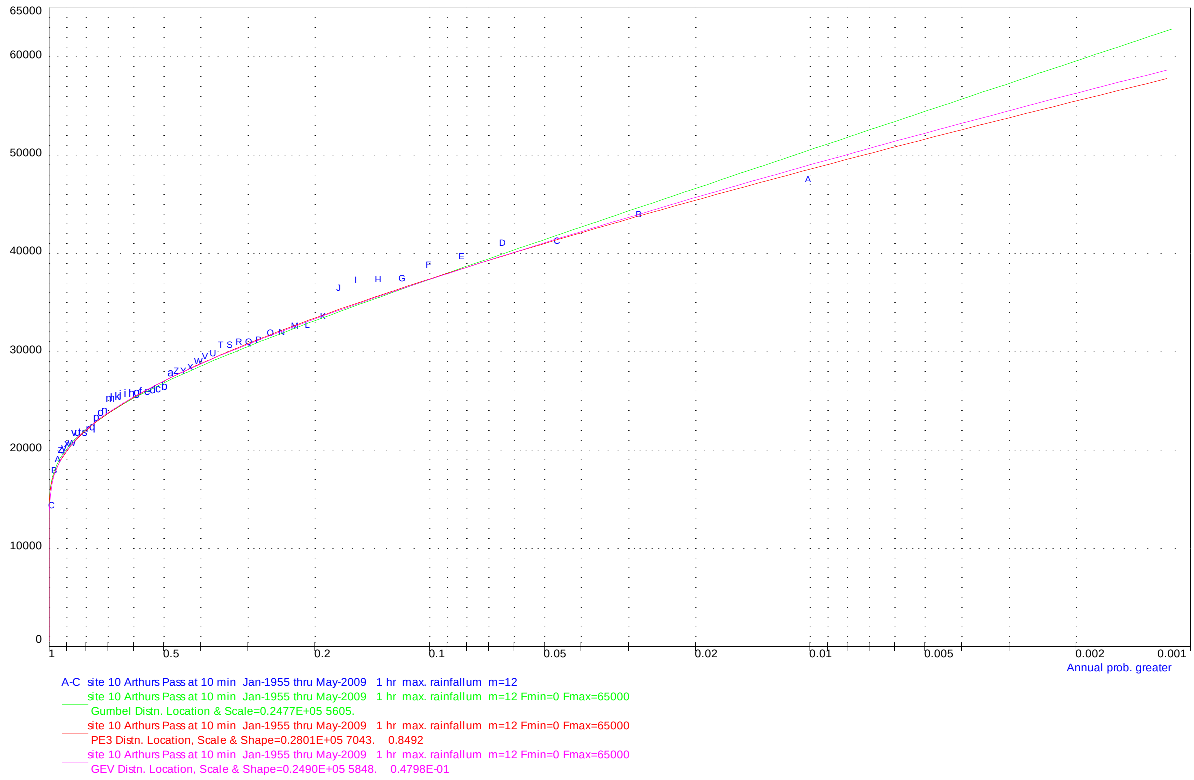


Figure A.4 Arthurs Pass 1-hour rainfall frequency analysis.

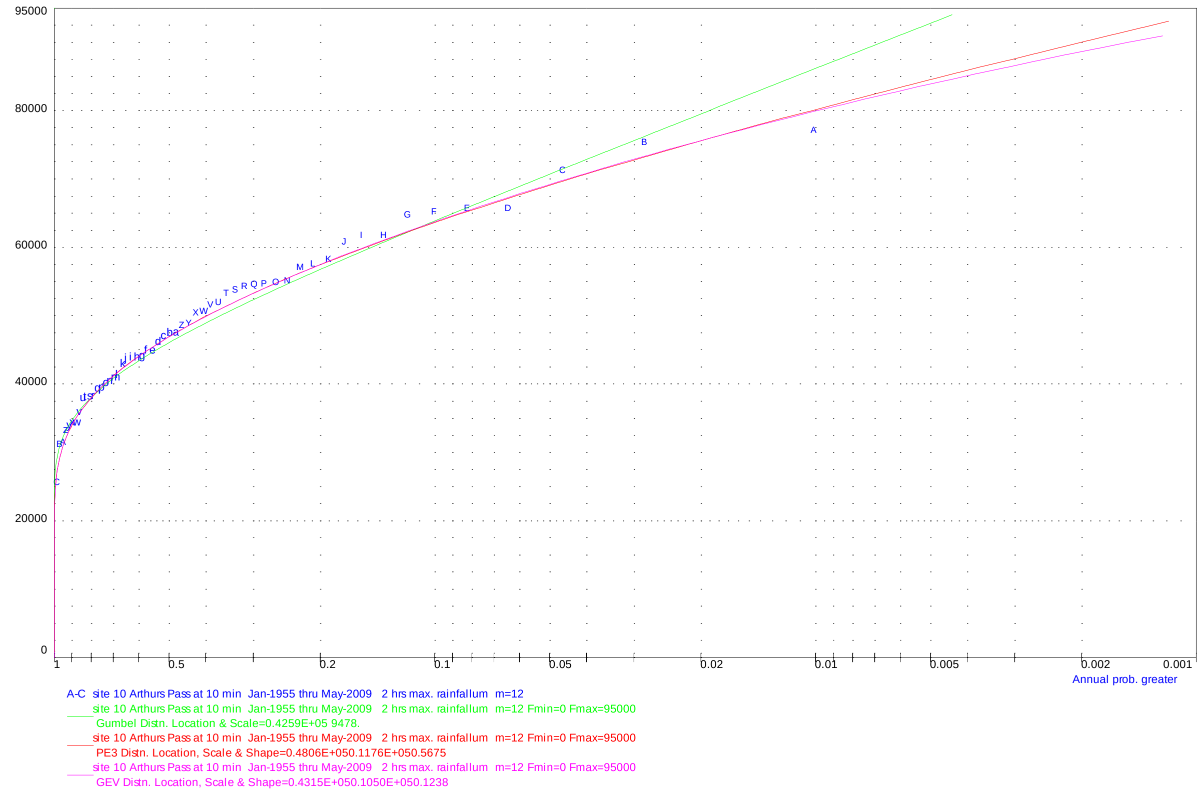


Figure A.5 Arthurs Pass 2-hour rainfall frequency analysis.

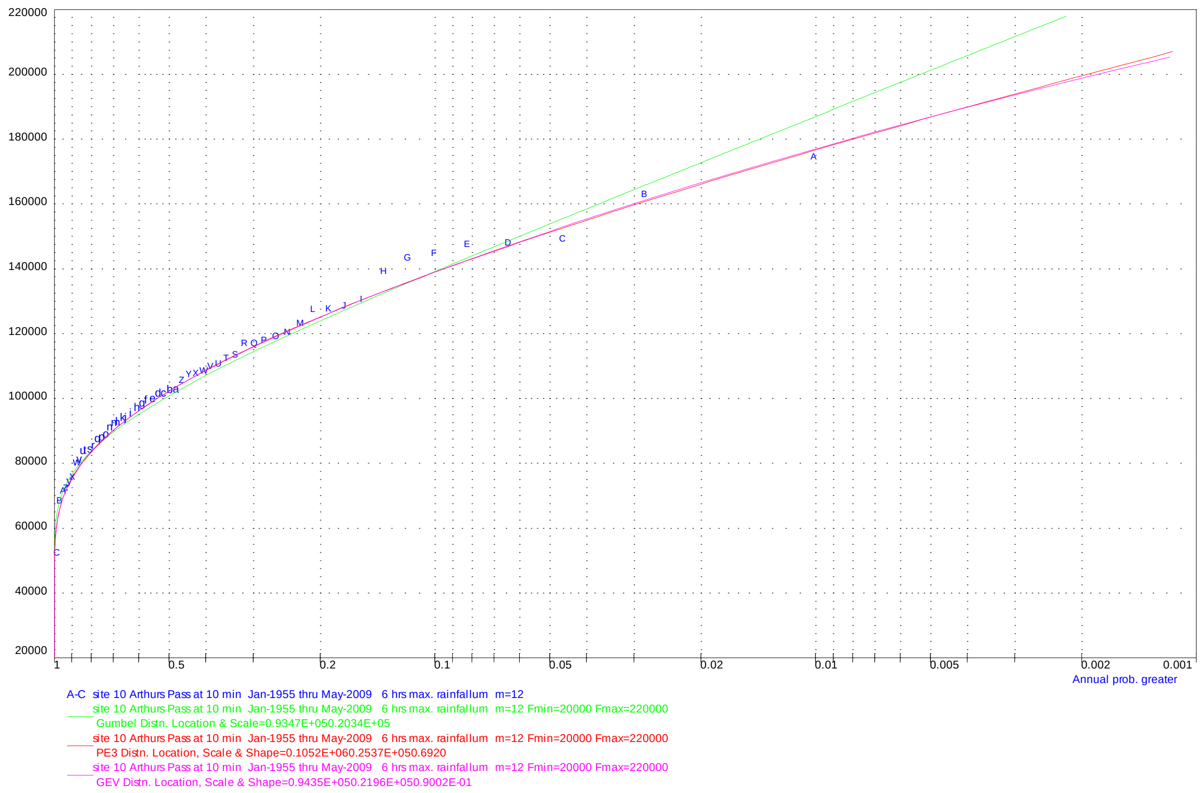


Figure A.6 Arthurs Pass 6-hour rainfall frequency analysis.

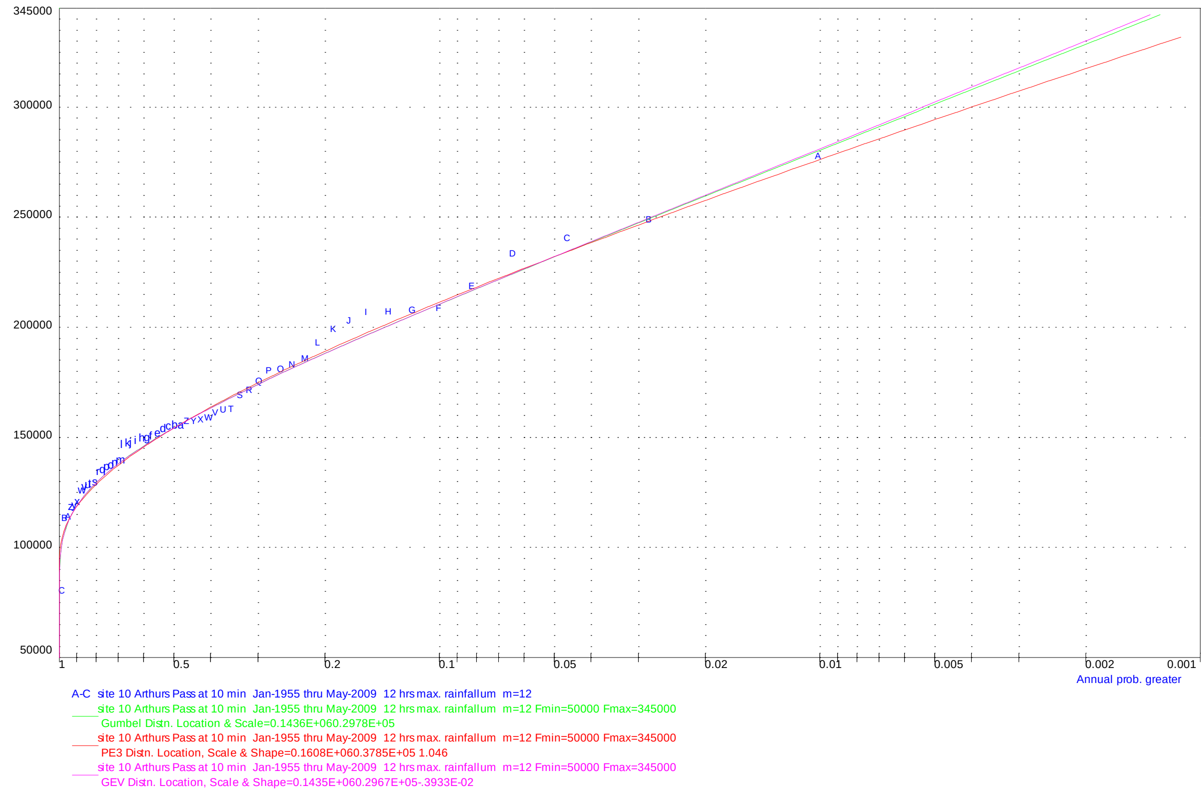


Figure A.7 Arthurs Pass 12-hour rainfall frequency analysis.

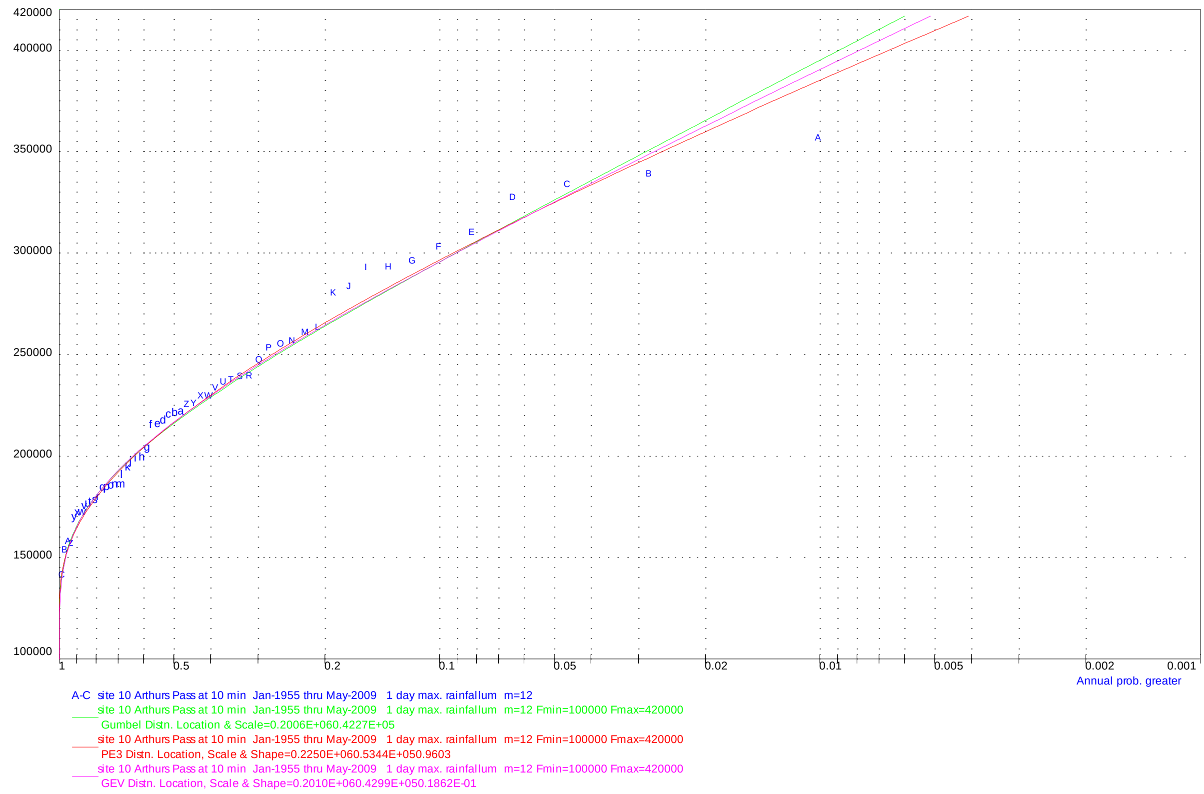


Figure A.8 Arthurs Pass 24-hour rainfall frequency analysis.

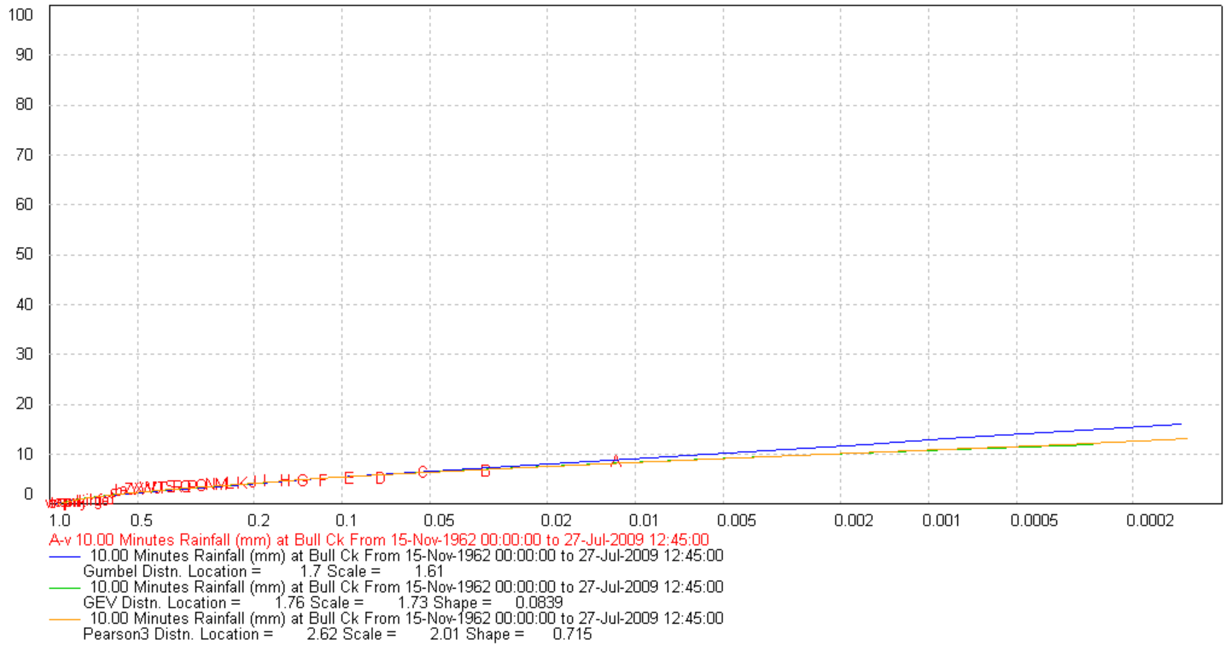


Figure A.9 Bull Creek 10-min rainfall frequency analysis.

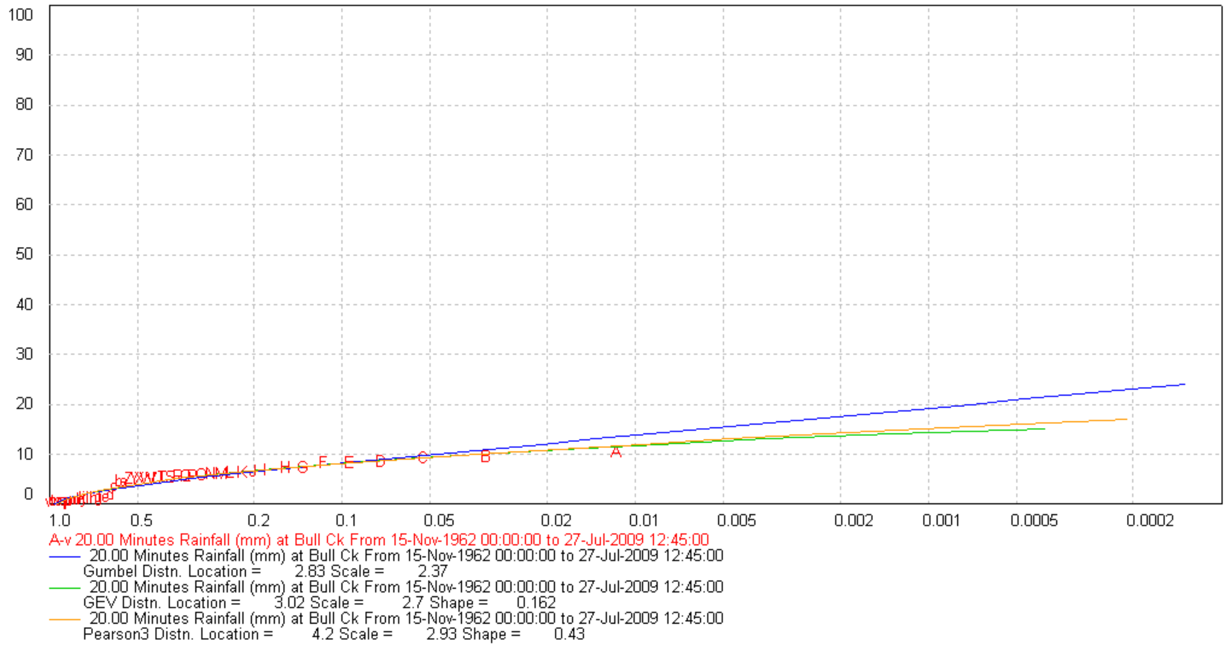


Figure A.10 Bull Creek 20-min rainfall frequency analysis.

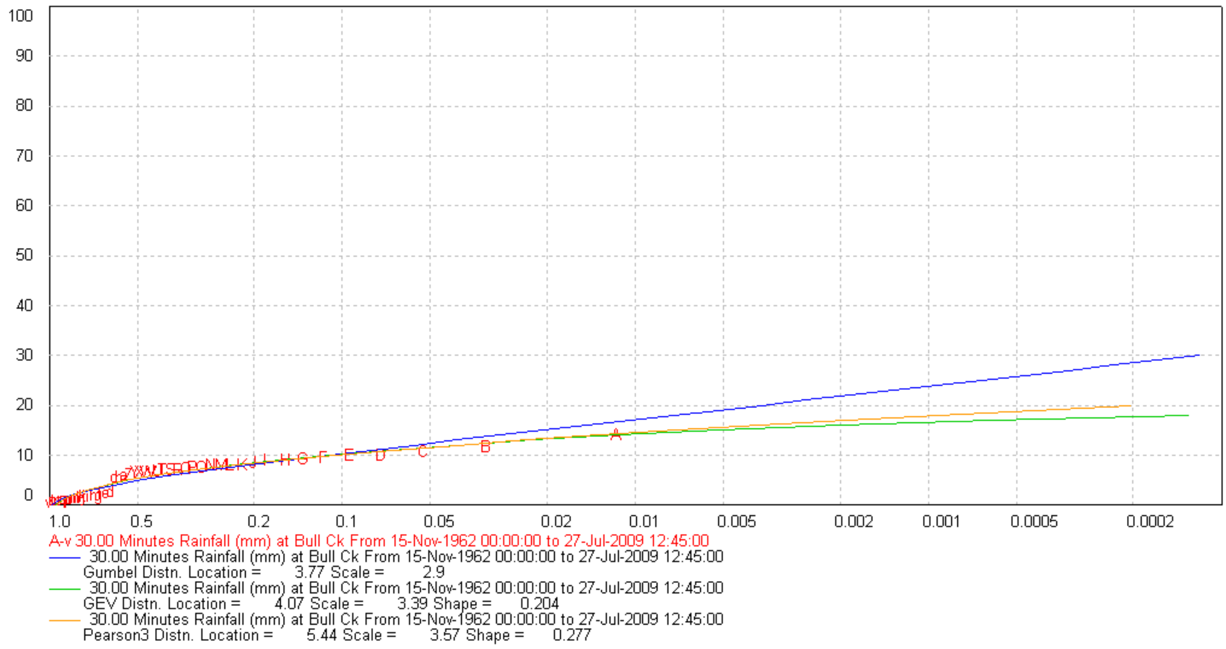


Figure A.11 Bull Creek 30-min rainfall frequency analysis.

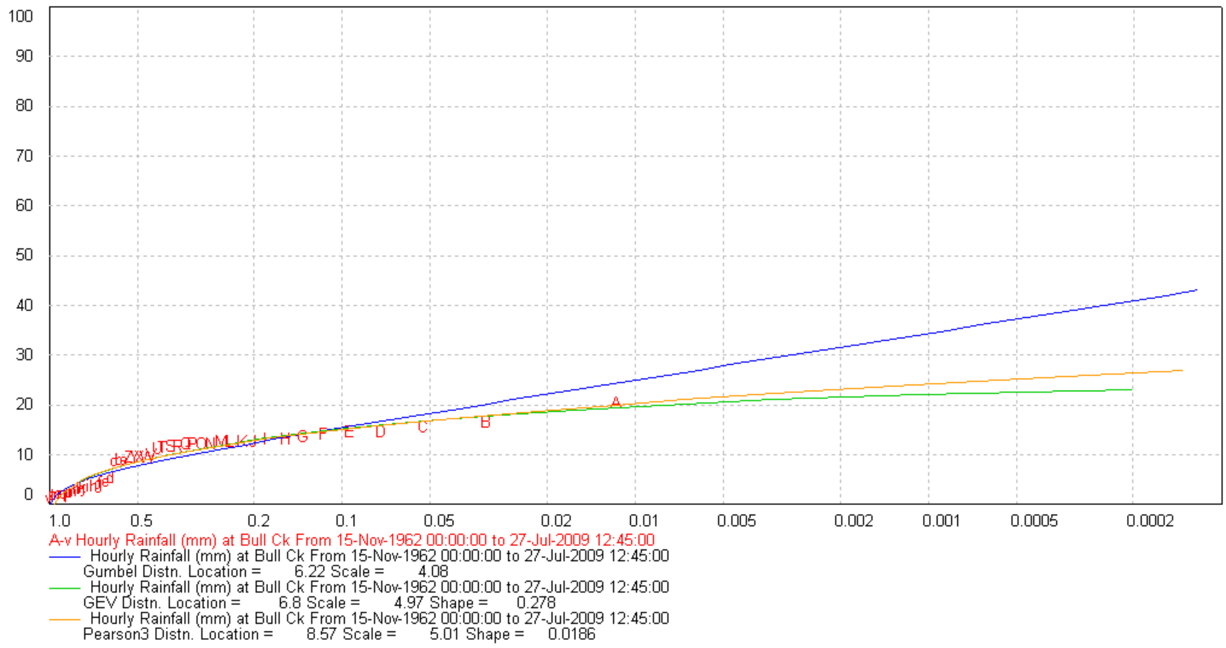


Figure A.12 Bull Creek 1-hour rainfall frequency analysis.

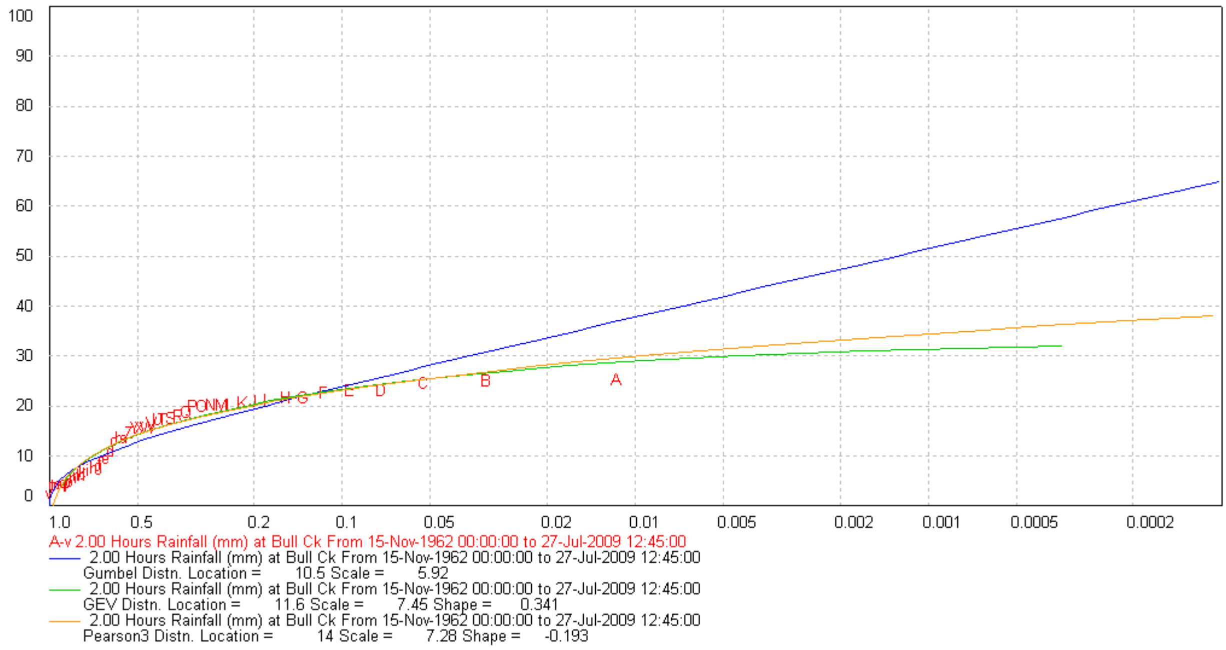


Figure A.13 Bull Creek 2-hour rainfall frequency analysis.

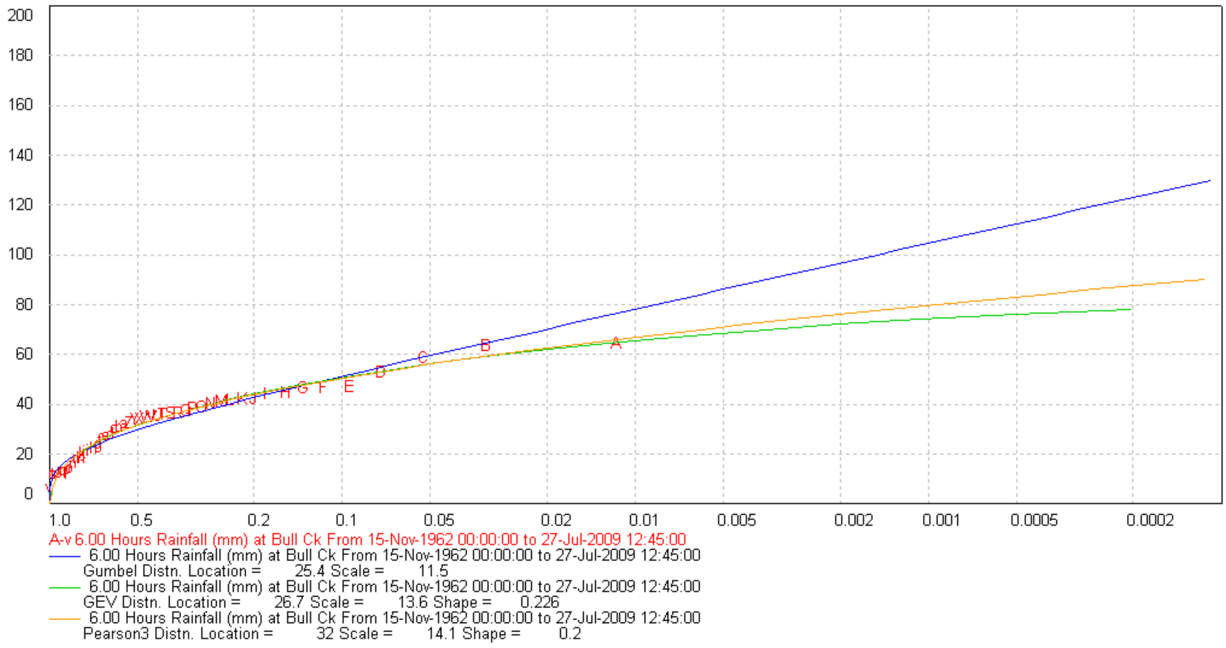


Figure A.14 Bull Creek 6-hour frequency analysis.

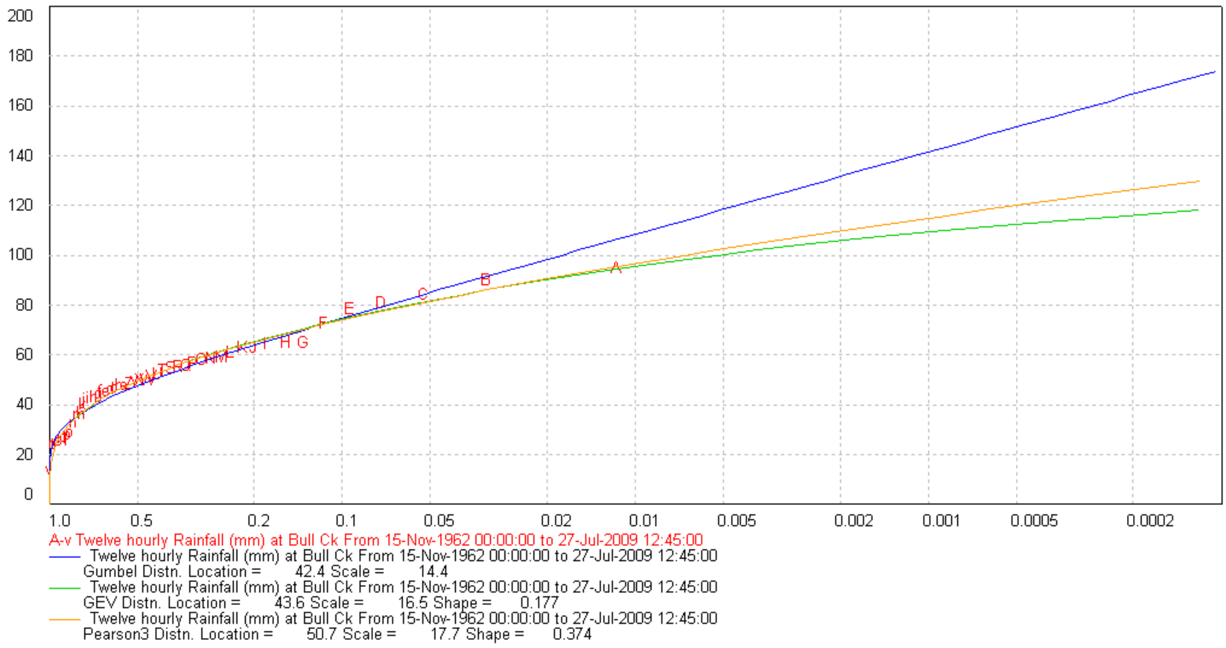


Figure A.15 Bull Creek 12-hour rainfall frequency analysis.

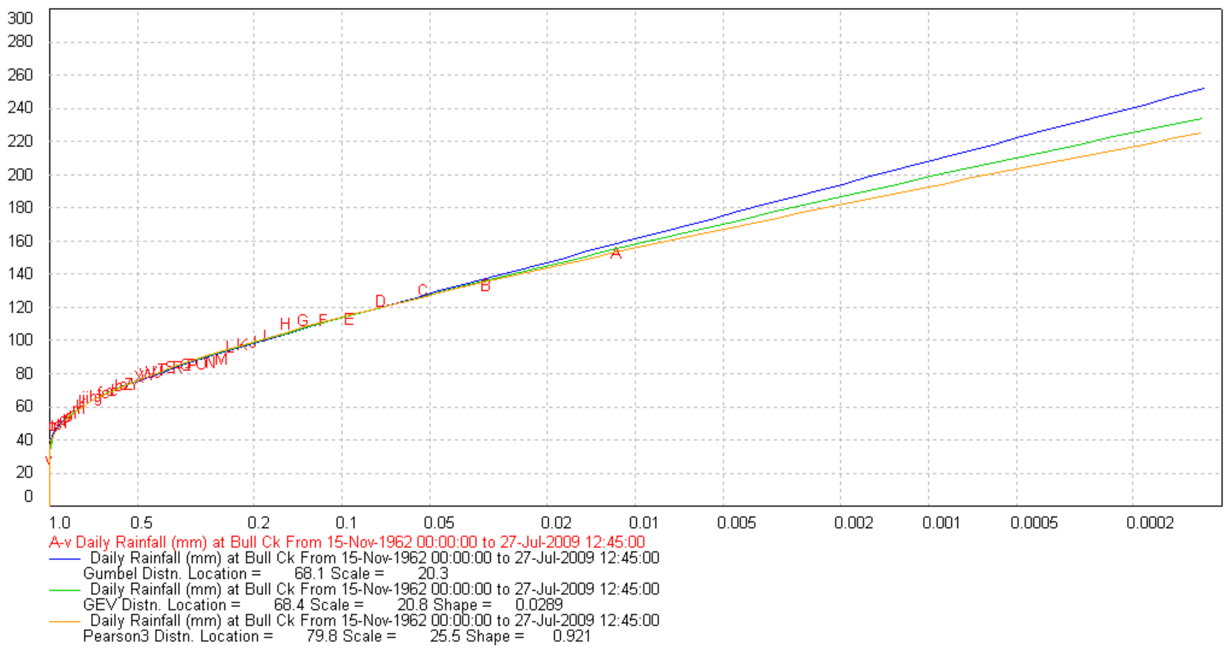


Figure A.16 Bull Creek 24-hour rainfall frequency analysis.

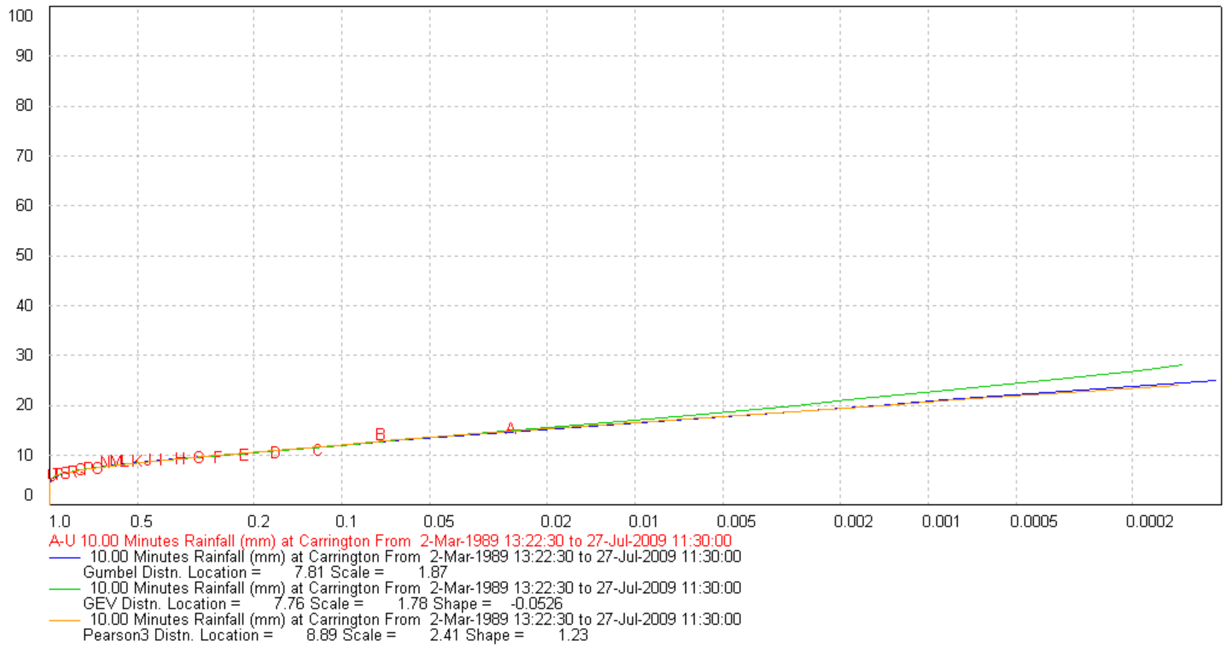


Figure A.17 Carrington 10-min rainfall frequency analysis.

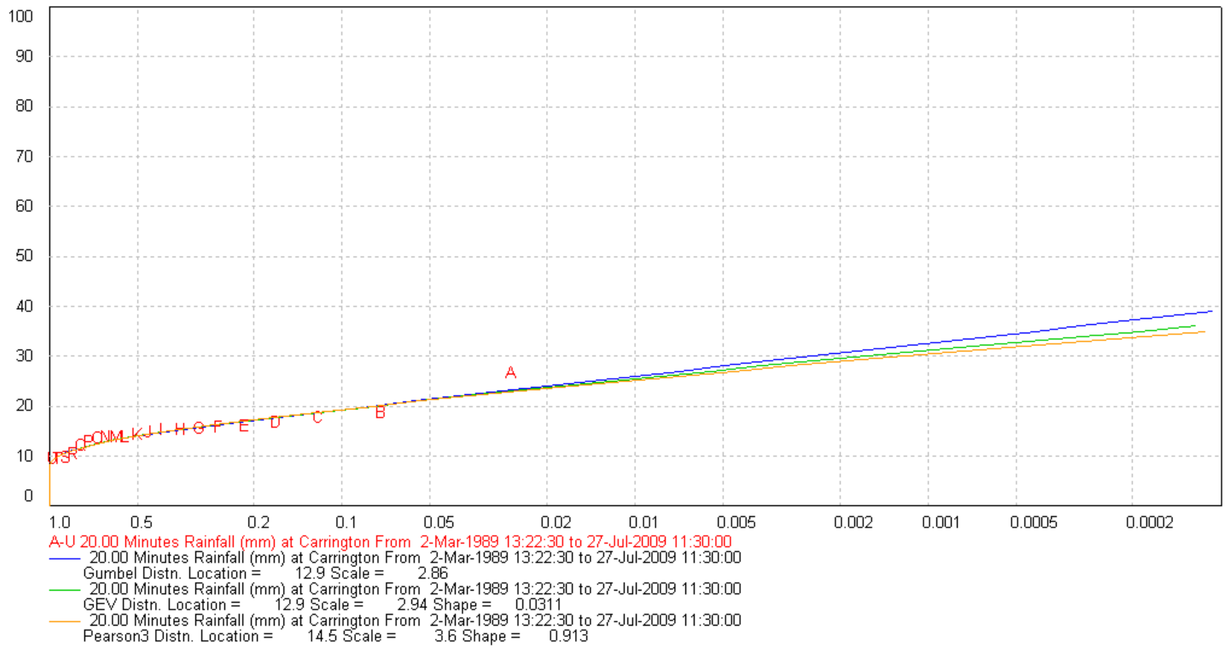


Figure A.18 Carrington 20-min rainfall frequency analysis.

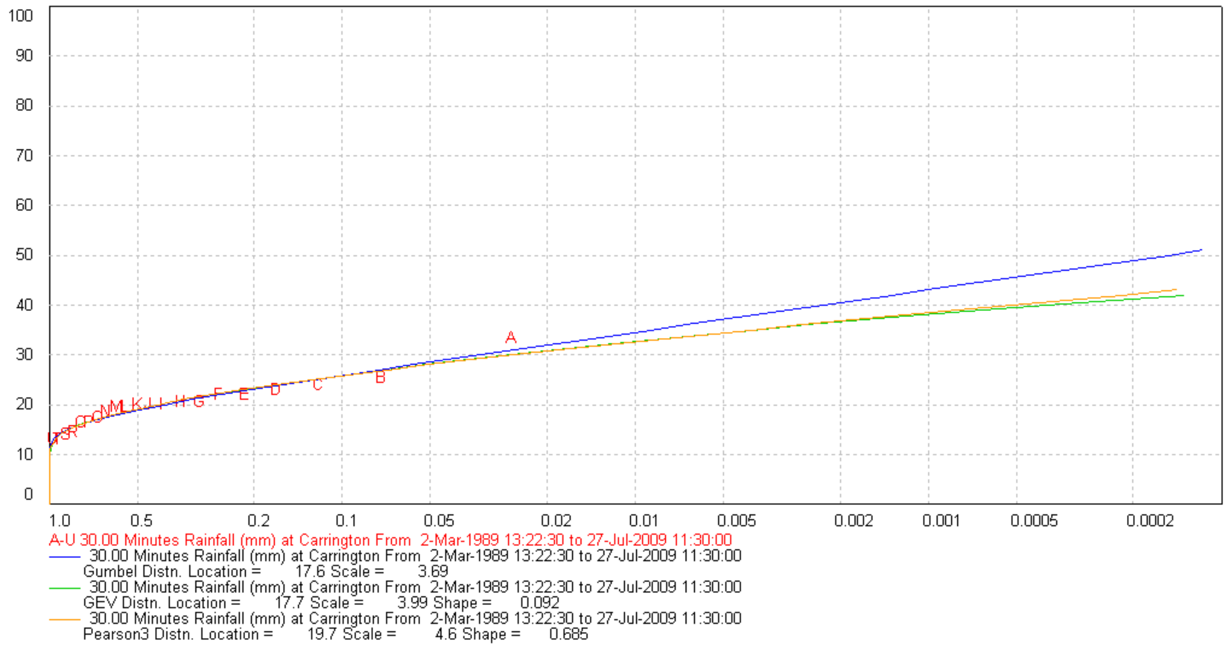


Figure A.19 Carrington 30-min rainfall frequency analysis.

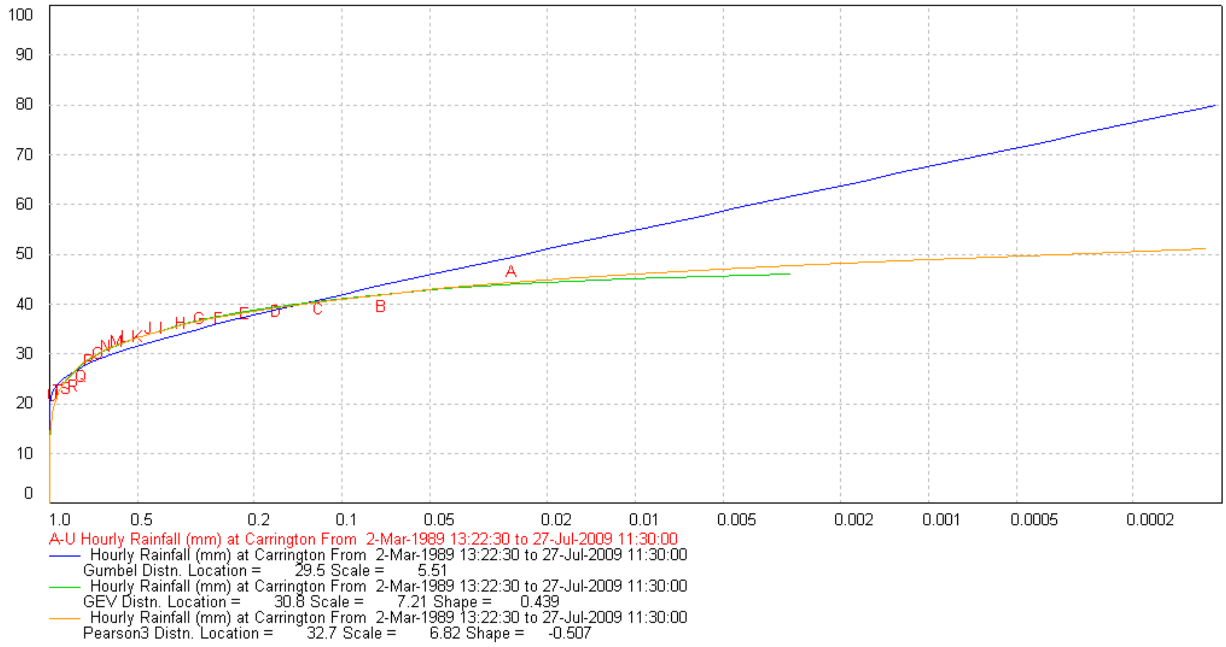


Figure A.20 Carrington 1-hour rainfall frequency analysis.

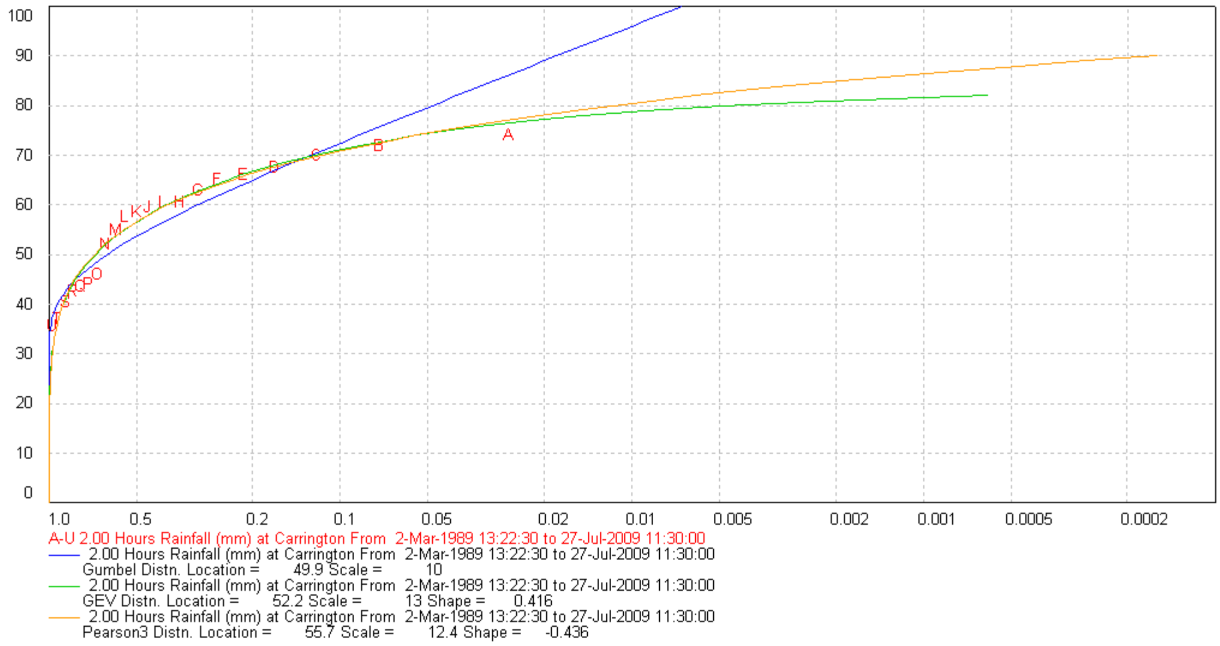


Figure A.21 Carrington 2-hour rainfall frequency analysis.

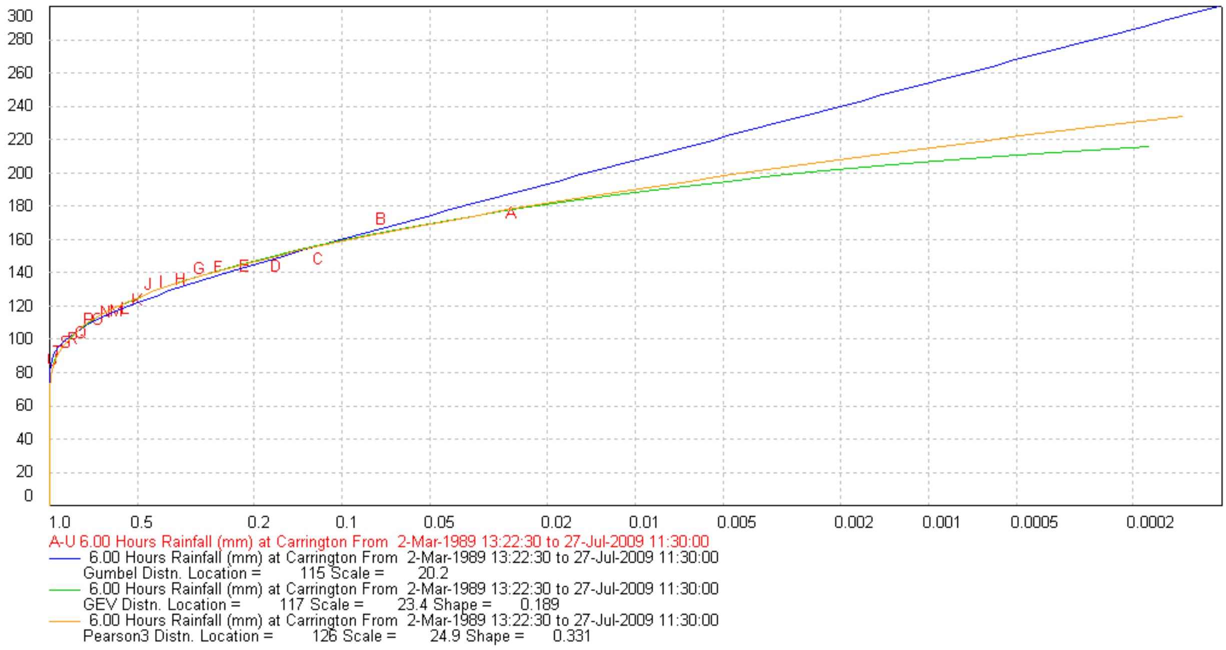


Figure A.22 Carrington 6-hour rainfall frequency analysis.

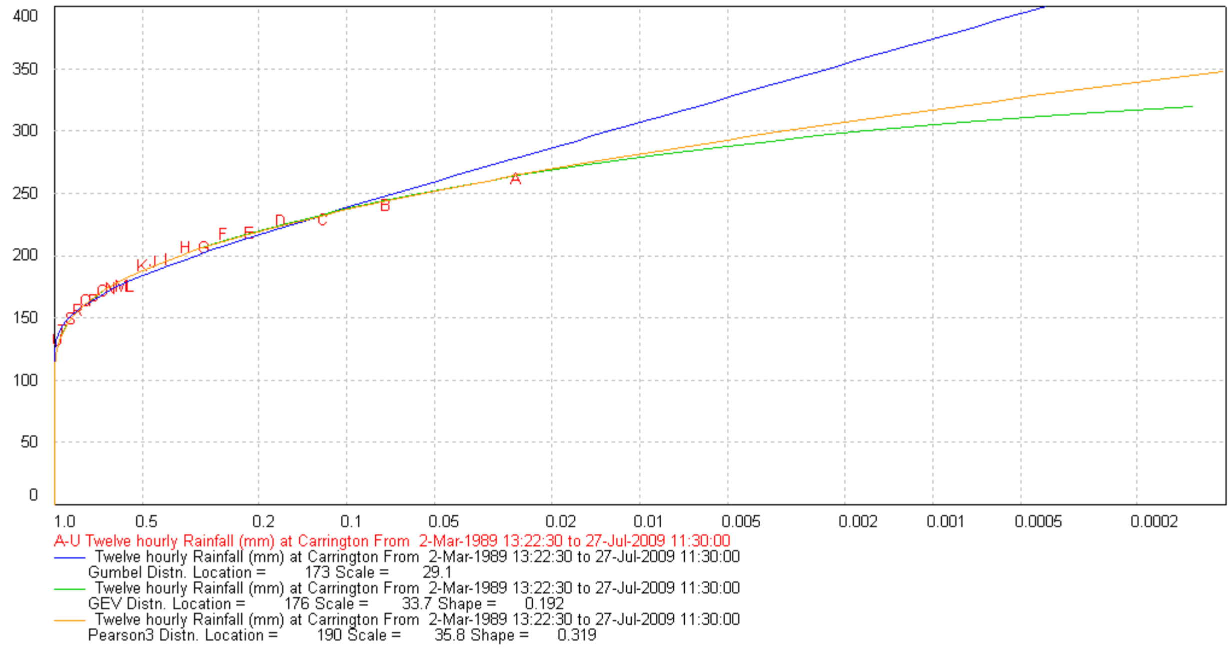


Figure A.23 Carrington 12-hour rainfall frequency analysis.

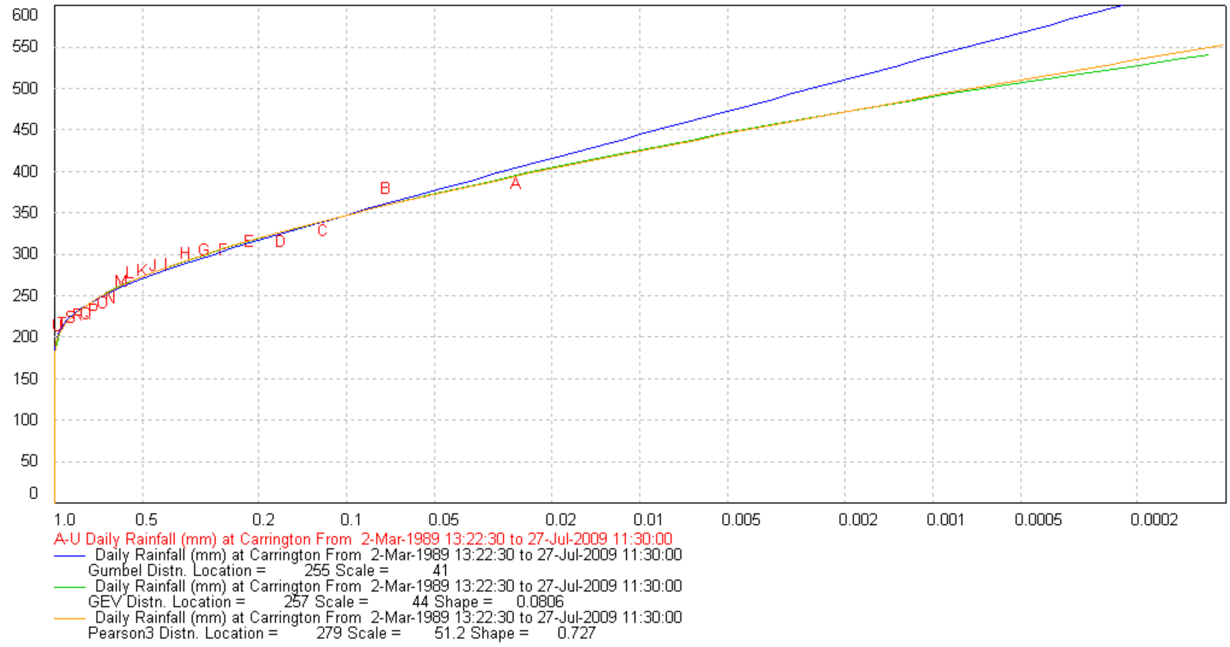


Figure A.24 Carrington 24-hour rainfall frequency analysis.

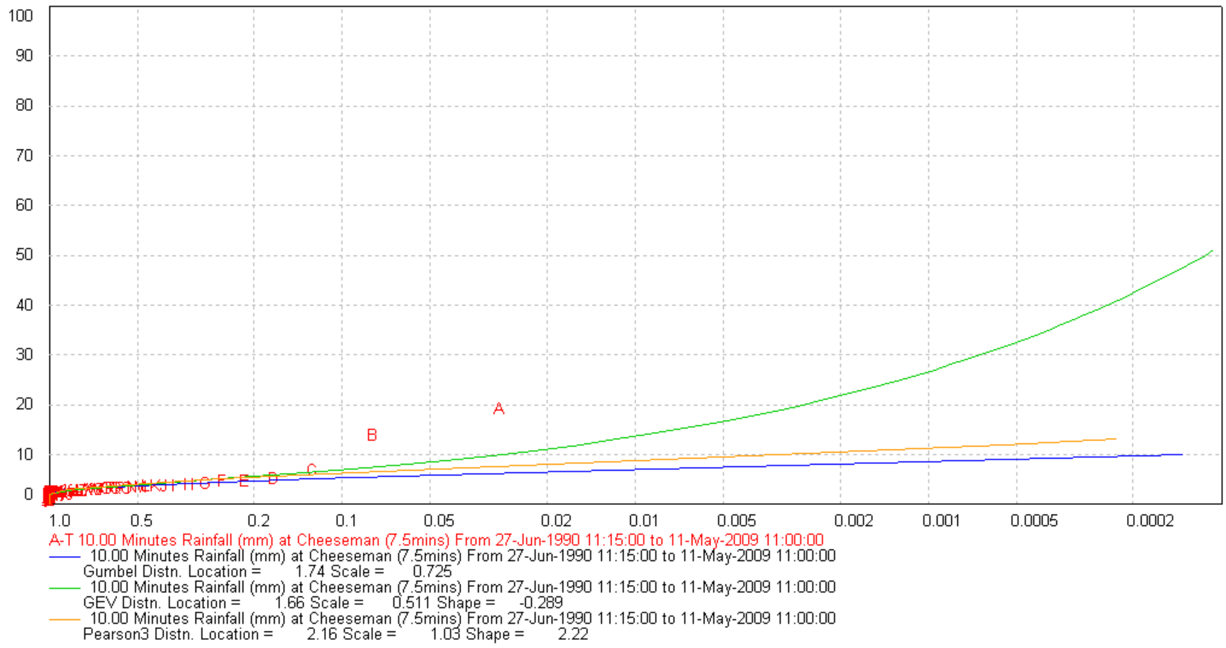


Figure A.25 Cheeseman 10-min rainfall frequency analysis (partition 1 month).

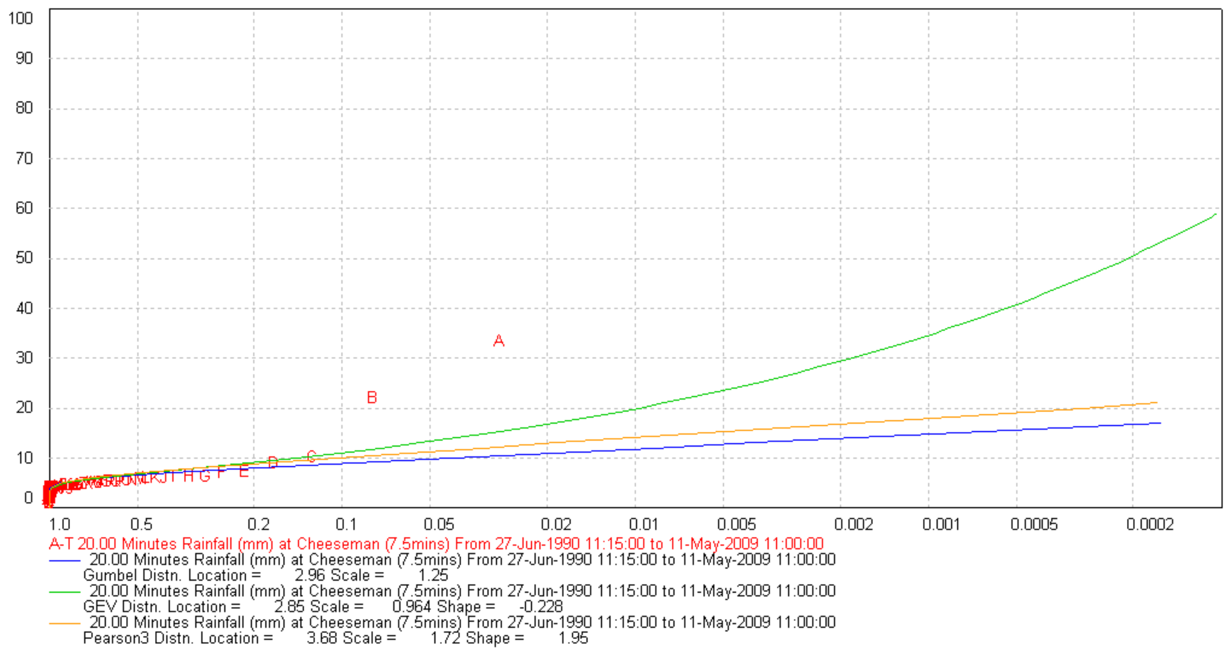


Figure A.26 Cheeseman 20-min rainfall frequency analysis (partition 1 month).

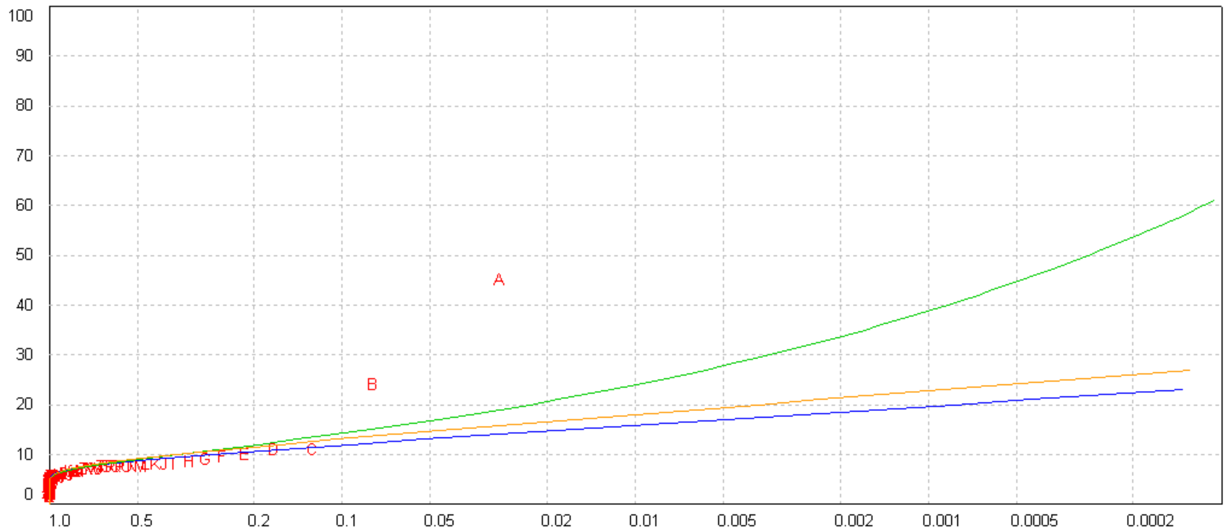


Figure A.27 Cheeseman 30-min rainfall frequency analysis (partition 1 month).

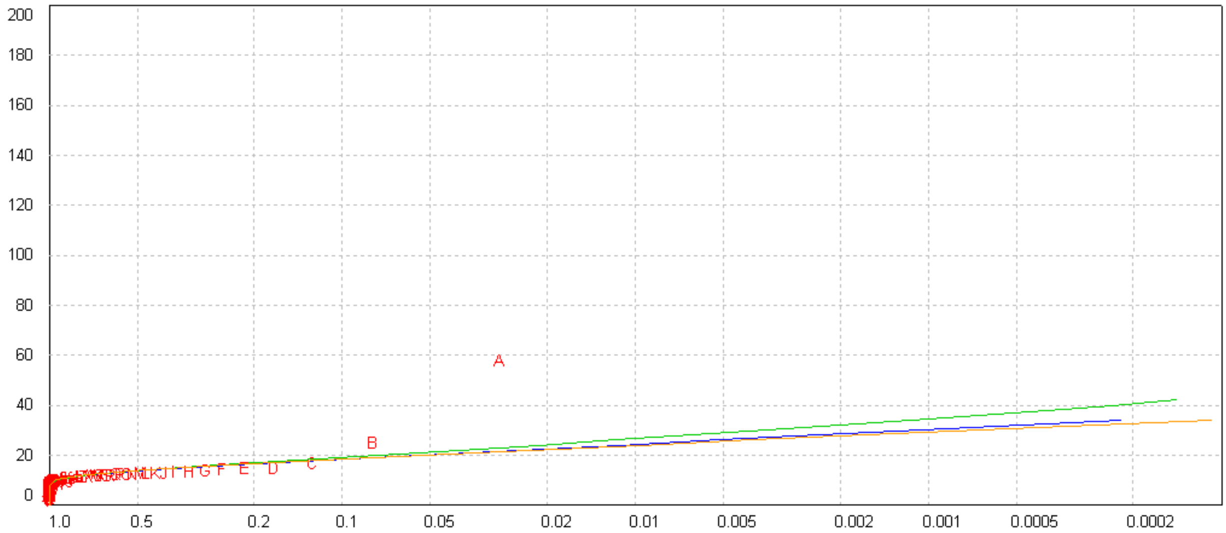


Figure A.28 Cheeseman 1-hour rainfall frequency analysis (partition 1 month).

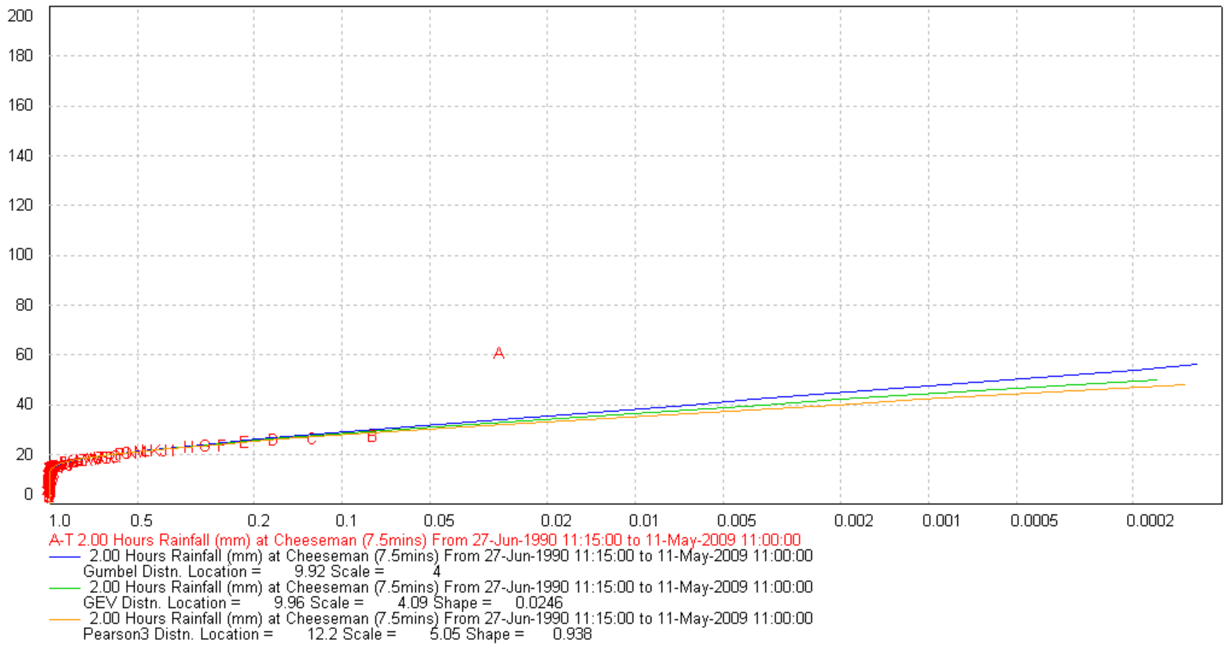


Figure A.29 Cheeseman 2-hour rainfall frequency analysis (partition 1 month).

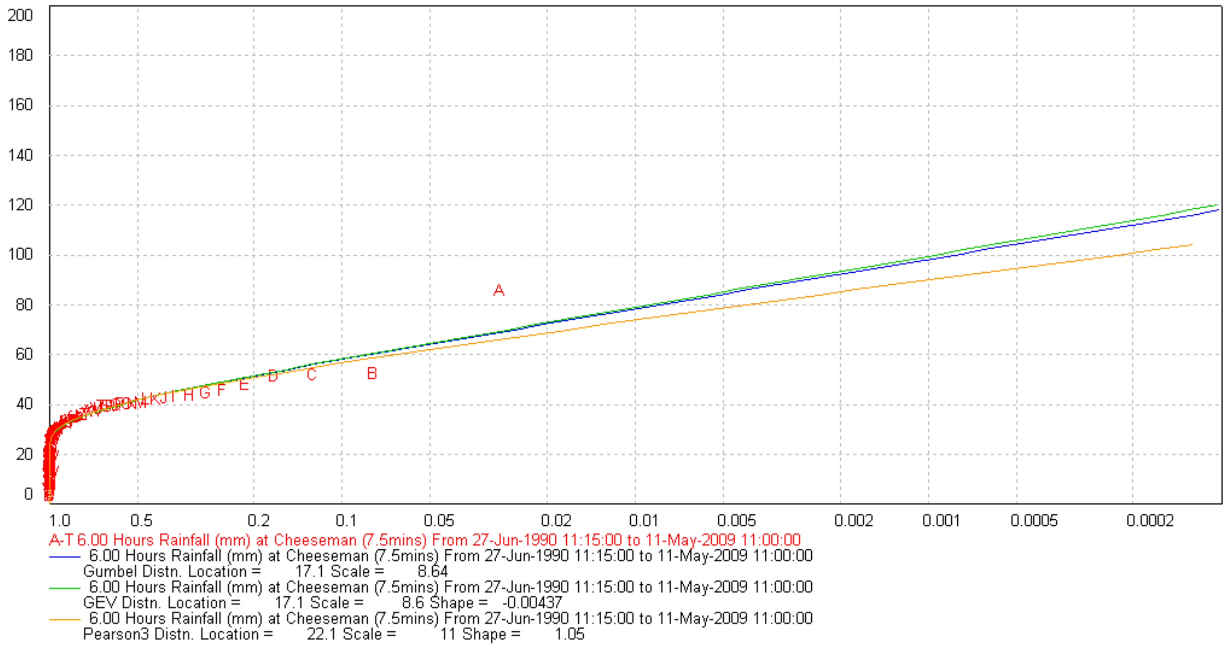


Figure A.30 Cheeseman 6-hour rainfall frequency analysis (partition 1 month).

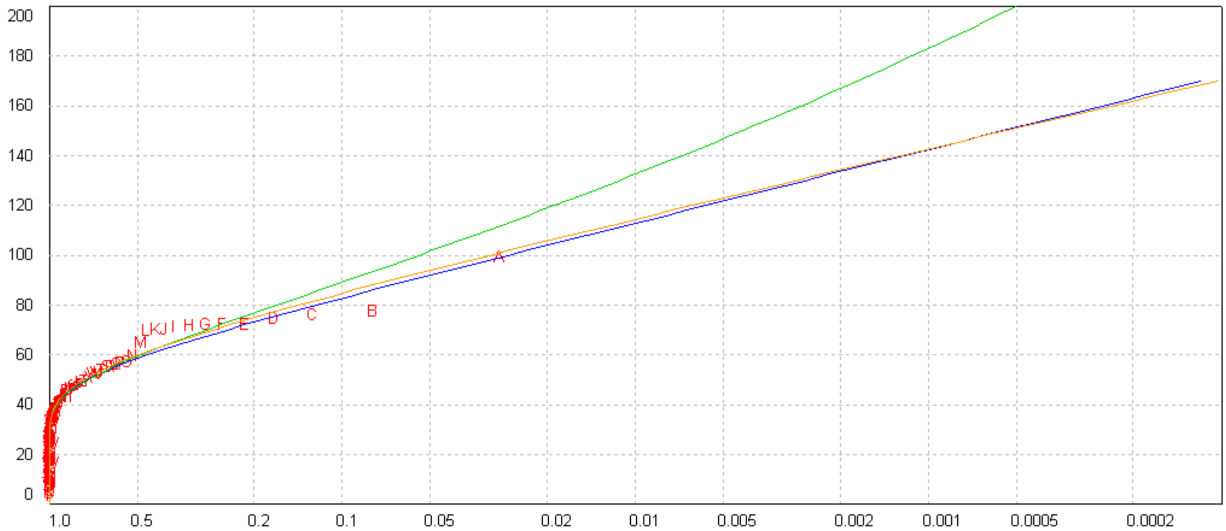


Figure A.31 Cheeseman 12-hour rainfall frequency analysis (partition 1 month).

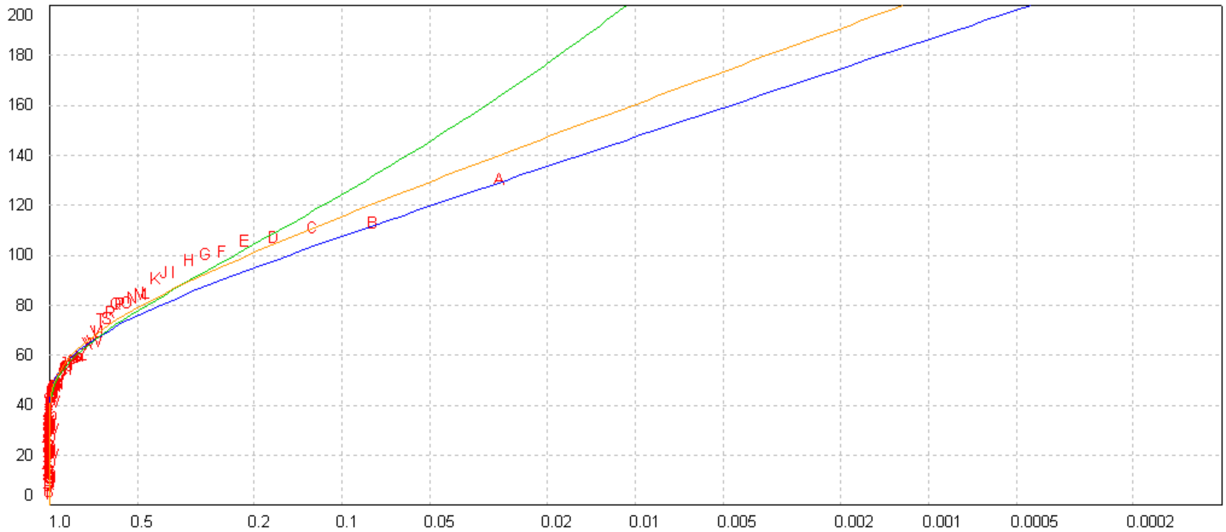


Figure A.32 Cheeseman 24-hour rainfall frequency analysis (partition 1 month).

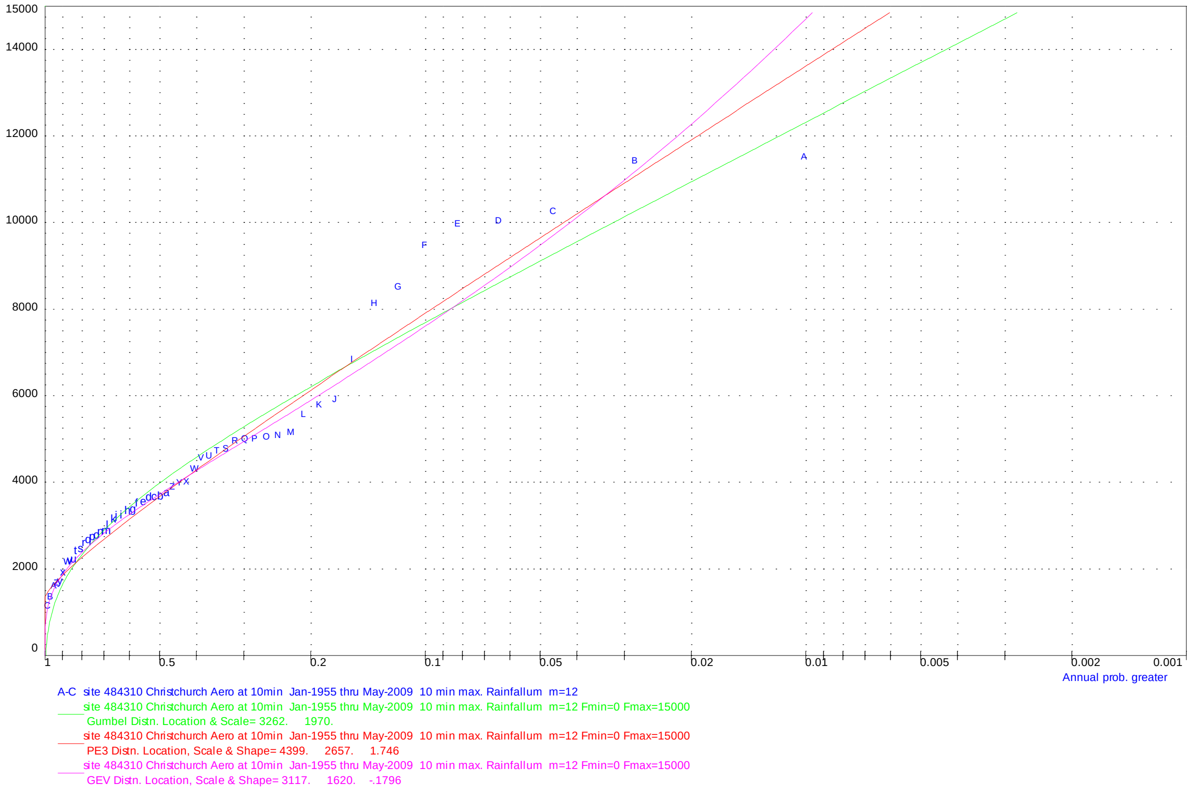


Figure A.33 Christchurch Aero 10-min rainfall frequency analysis.

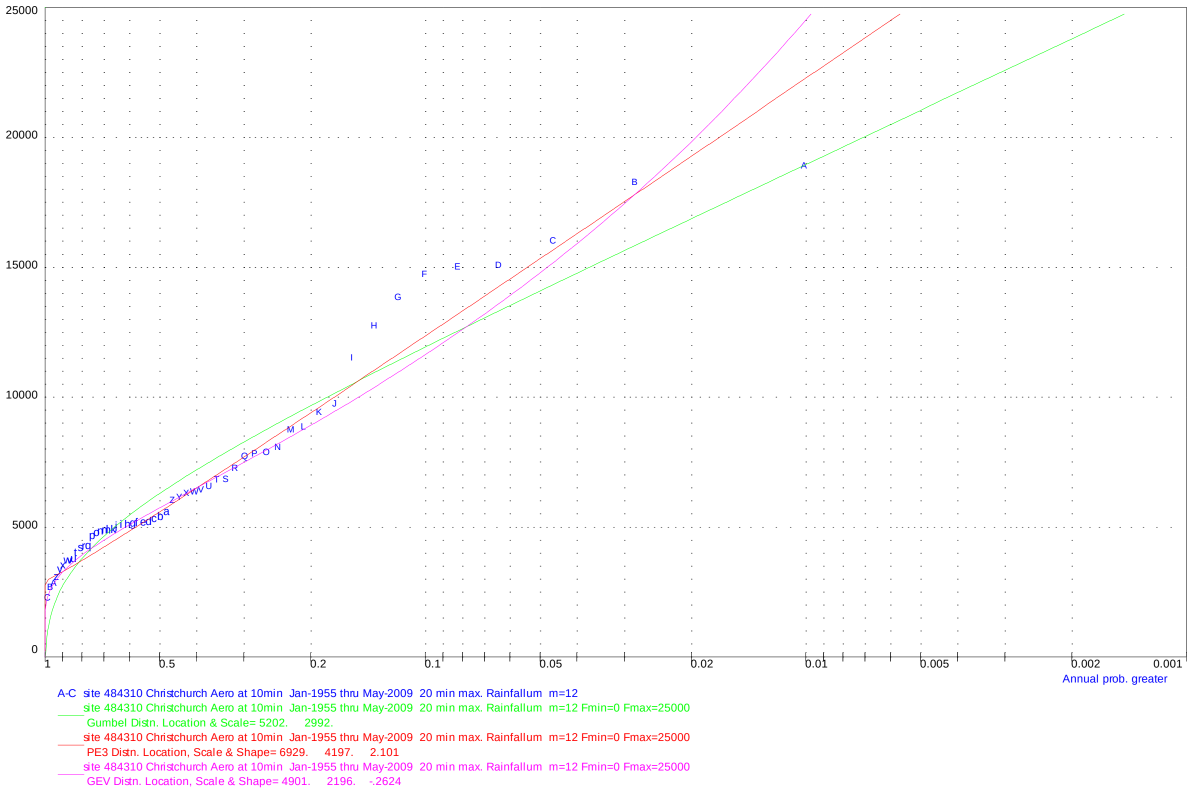


Figure A.34 Christchurch Aero 20-min rainfall frequency analysis.

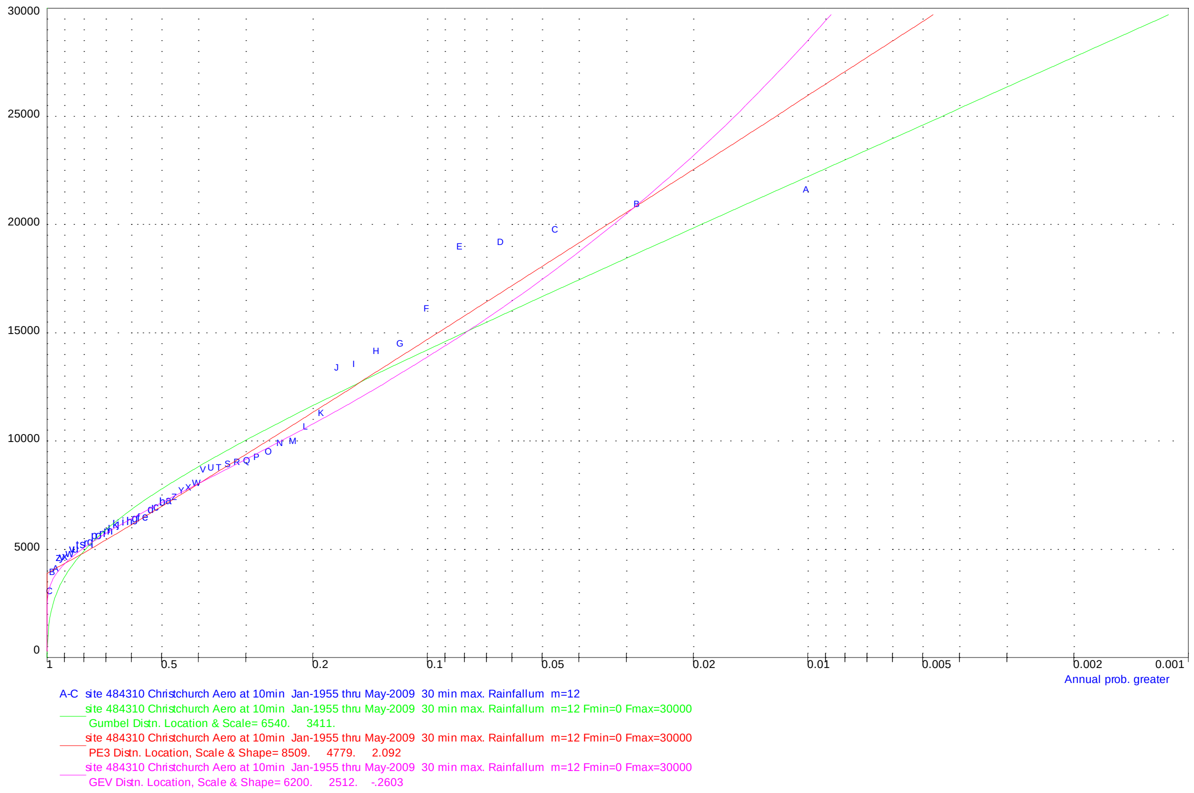


Figure A.35 Christchurch Aero 30-min rainfall frequency analysis.

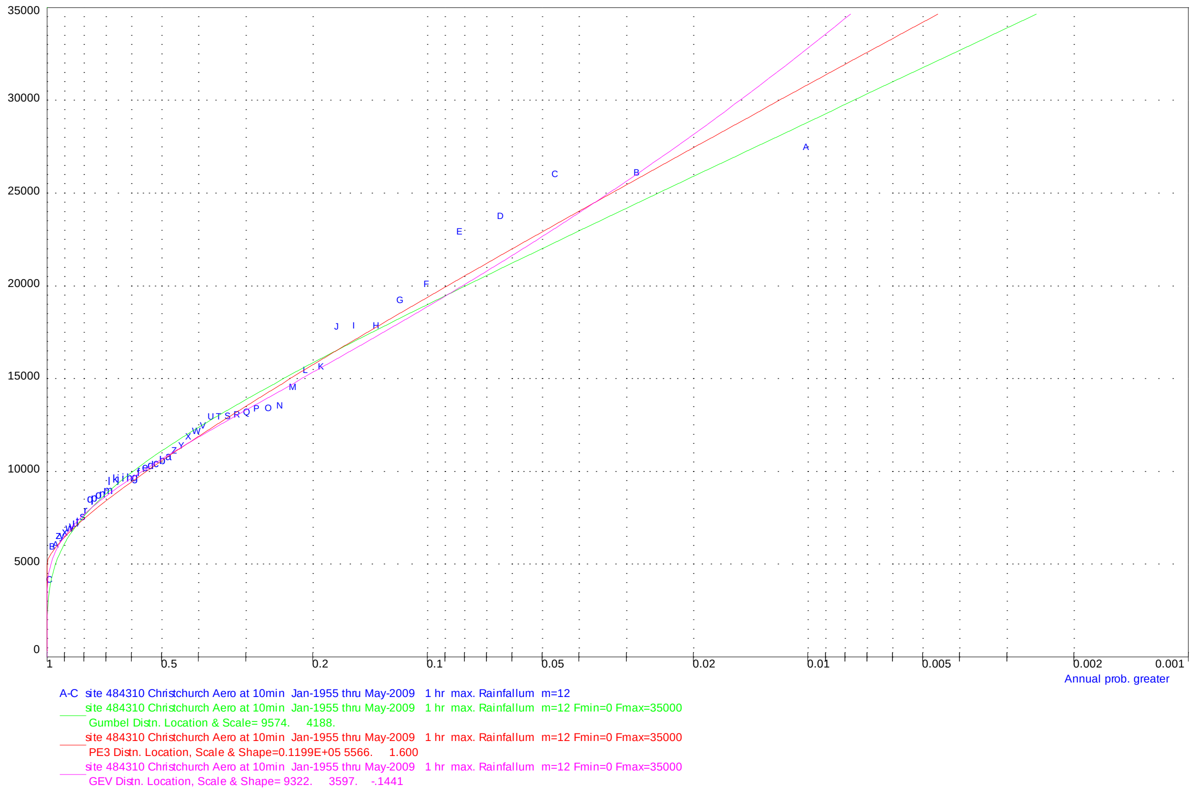


Figure A.36 Christchurch Aero 1-hour rainfall frequency analysis.

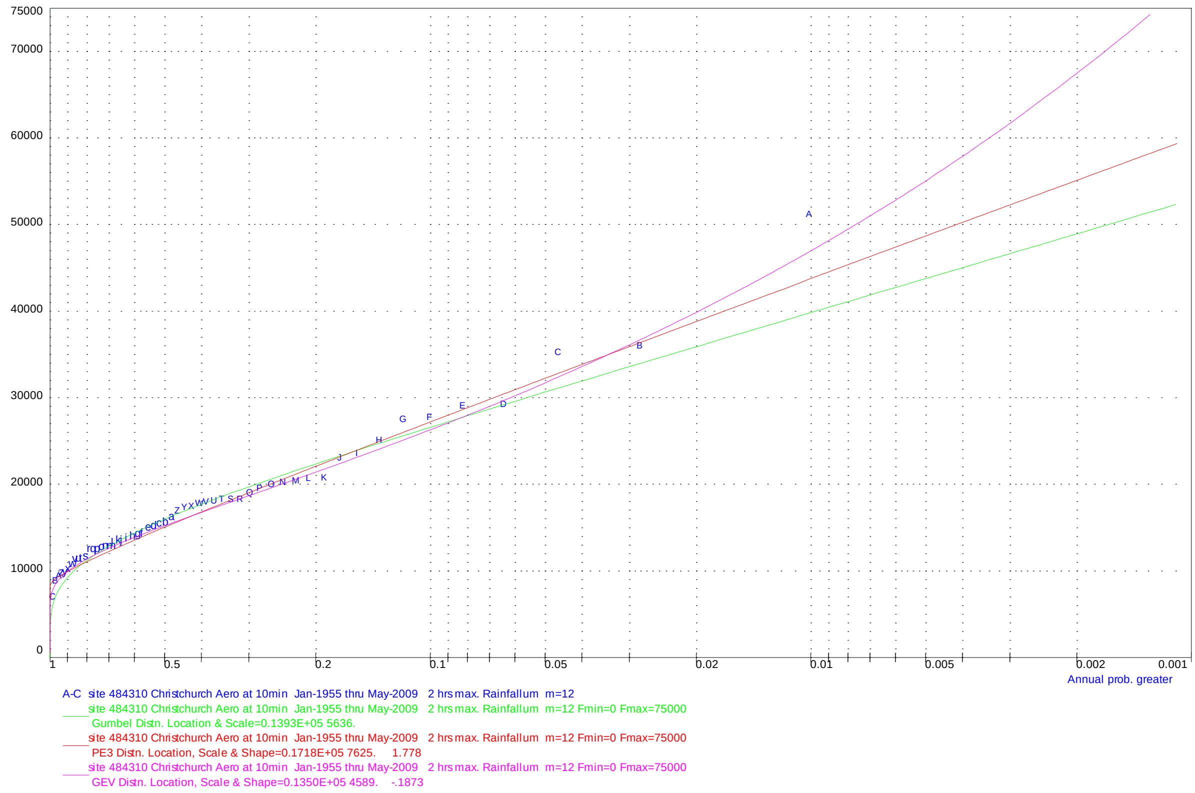


Figure A.37 Christchurch Aero 2-hour rainfall frequency analysis.

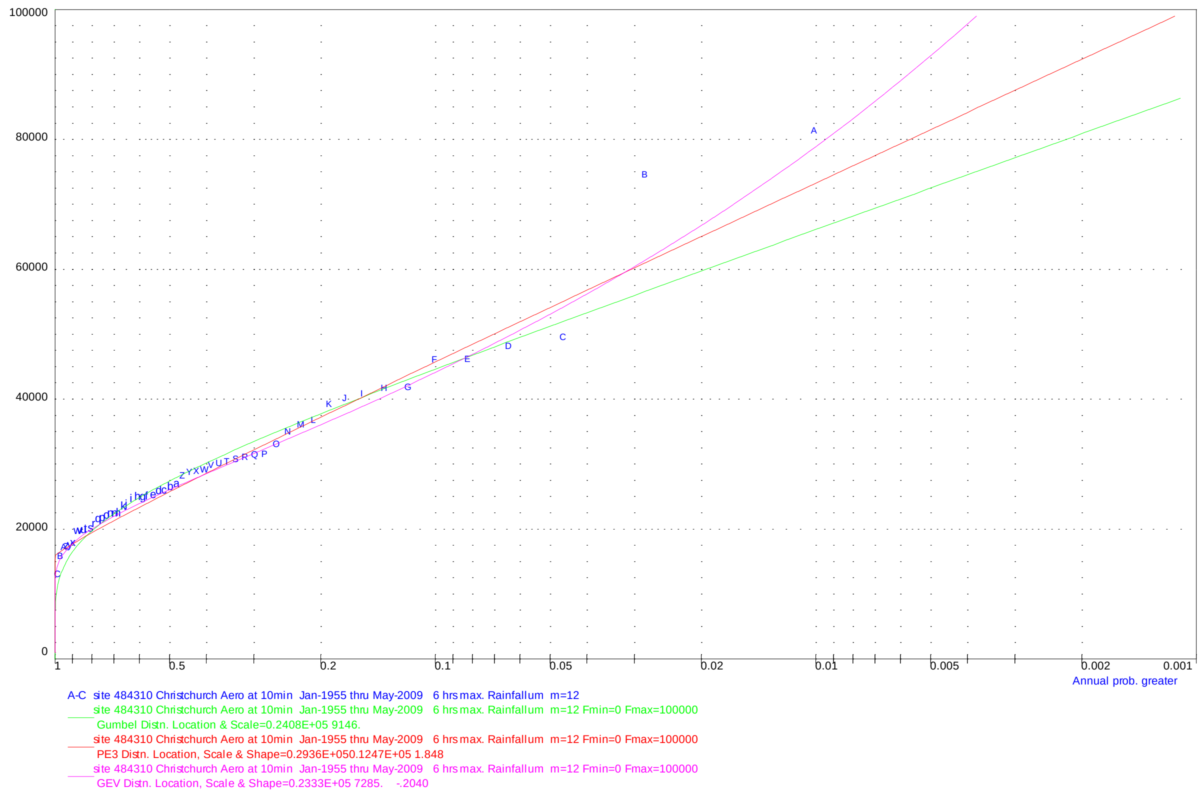
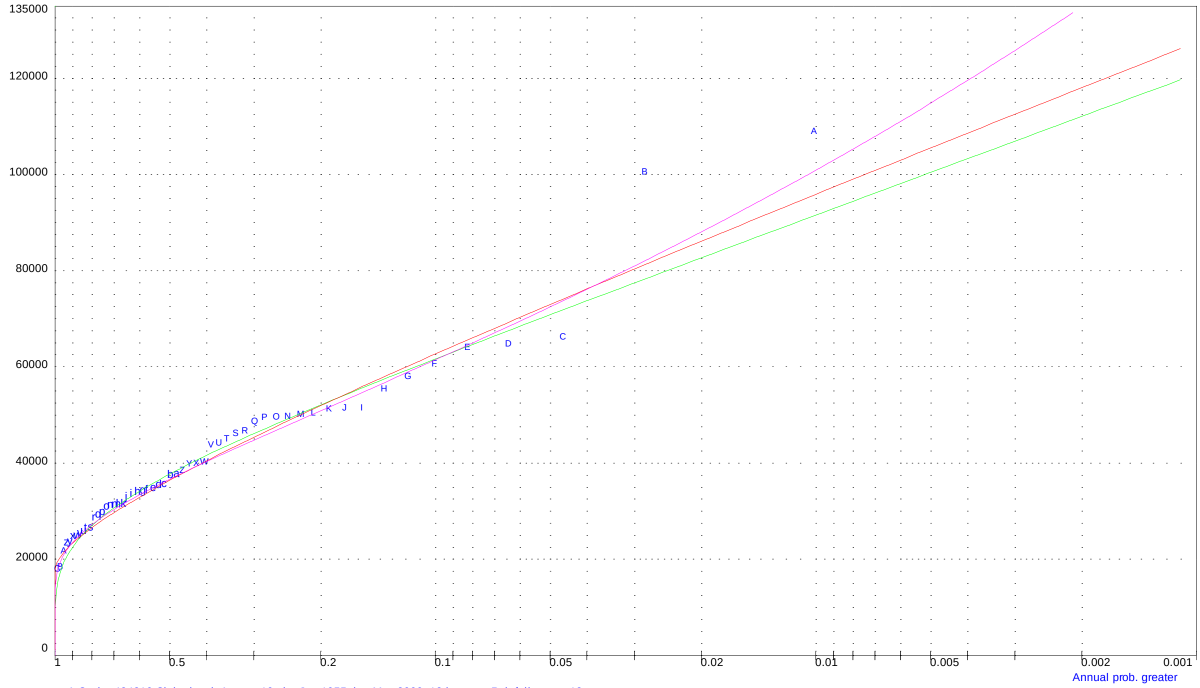


Figure A.38 Christchurch Aero 6-hour rainfall frequency analysis.



A-C site 484310 Christchurch Aero at 10min Jan-1955 thru May-2009 12 hrs max. Rainfallum m=12
site 484310 Christchurch Aero at 10min Jan-1955 thru May-2009 12 hrs max. Rainfallum m=12 Fmin=0 Fmax=135000
Gumbel Distn. Location & Scale=0.3308E+050.1272E+05
site 484310 Christchurch Aero at 10min Jan-1955 thru May-2009 12 hrs max. Rainfallum m=12 Fmin=0 Fmax=135000
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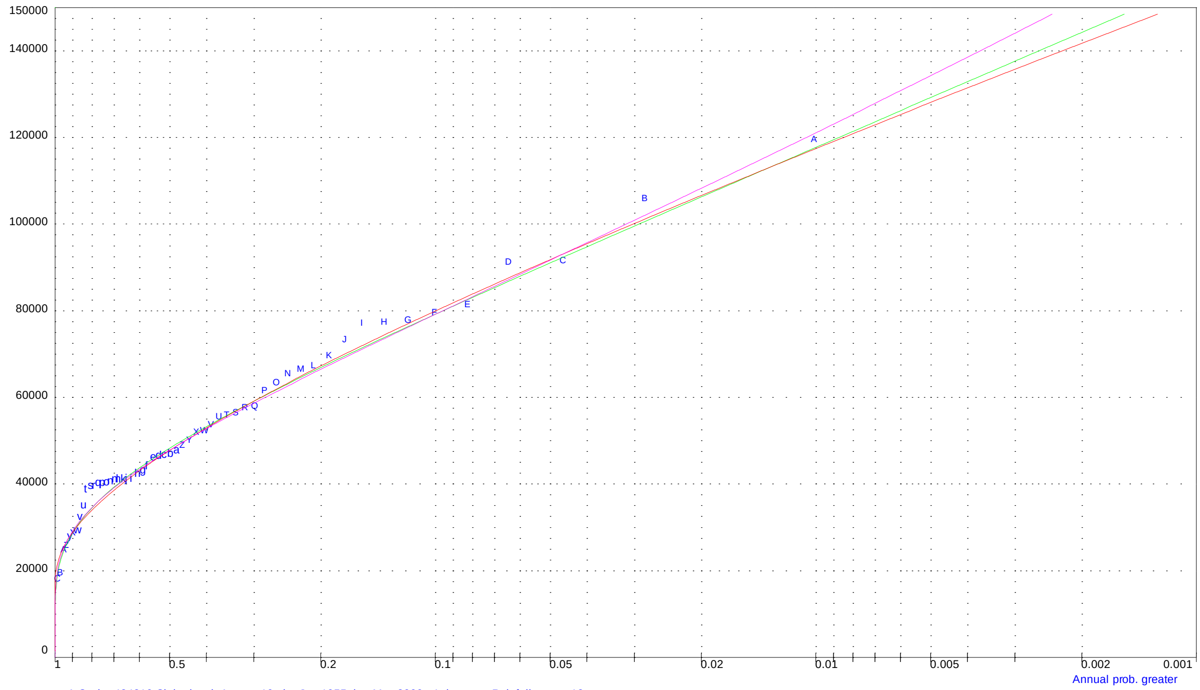
Figure A.39 Christchurch Aero 12-hour rainfall frequency analysis.



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site 484310 Christchurch Aero at 10min Jan-1955 thru May-2009 1 day max. Rainfallum m=12 Fmin=0 Fmax=150000
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Figure A.40 Christchurch Aero 24-hour rainfall frequency analysis.

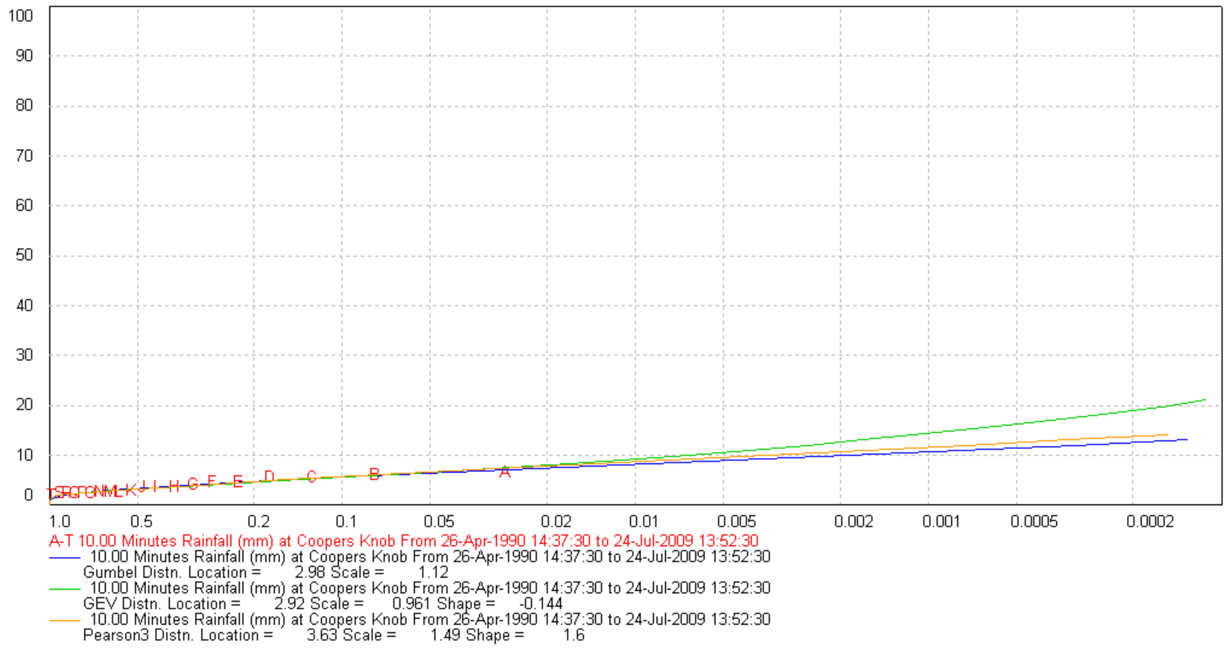

Figure A.41 Coopers Knob 10-min rainfall frequency analysis.

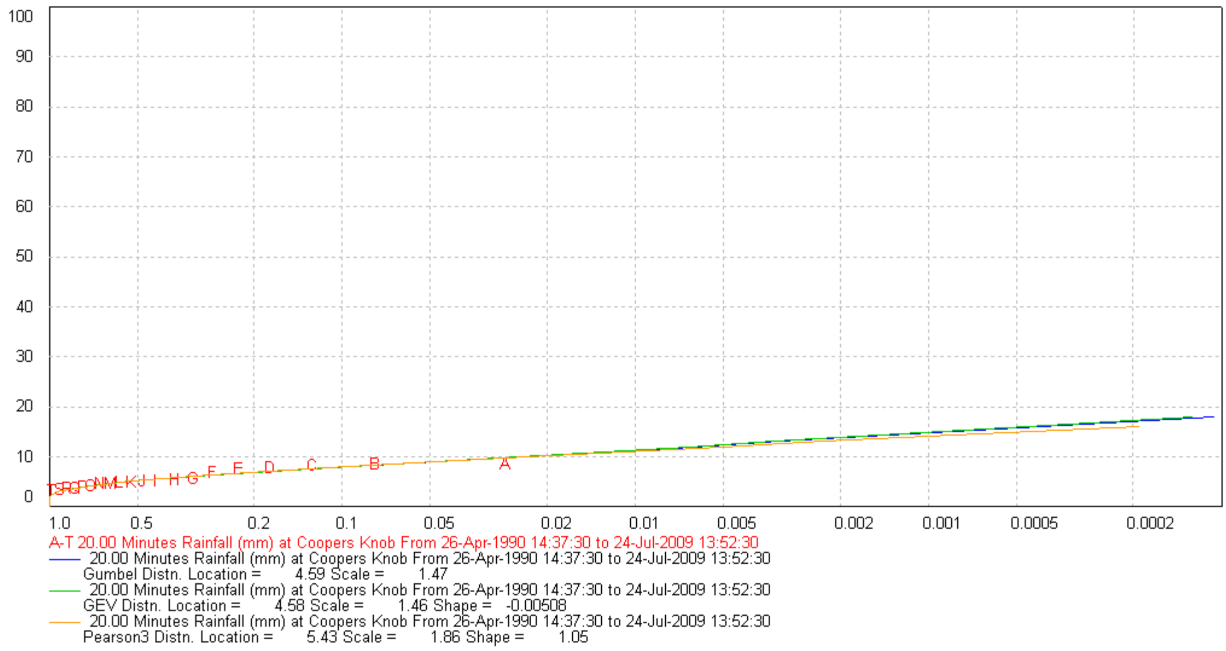

Figure A.42 Coopers Knob 20-min rainfall frequency analysis.

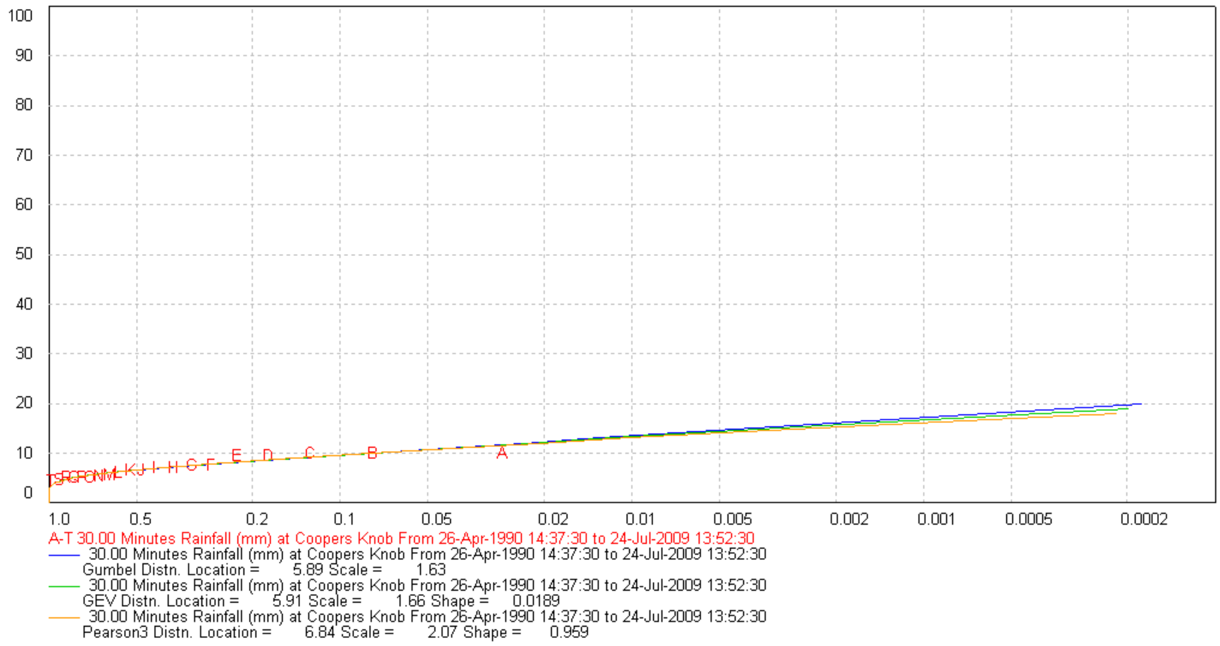

Figure A.43 Coopers Knob 30-min rainfall frequency analysis.

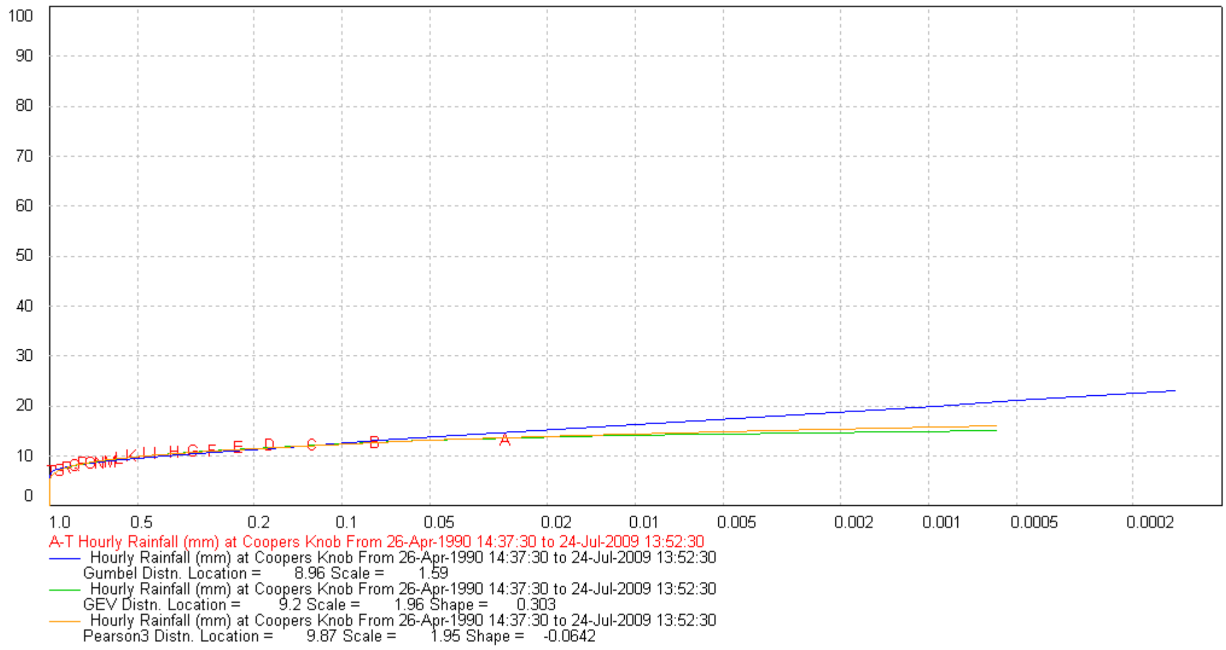

Figure A.44 Coopers Knob 1-hour rainfall frequency analysis.

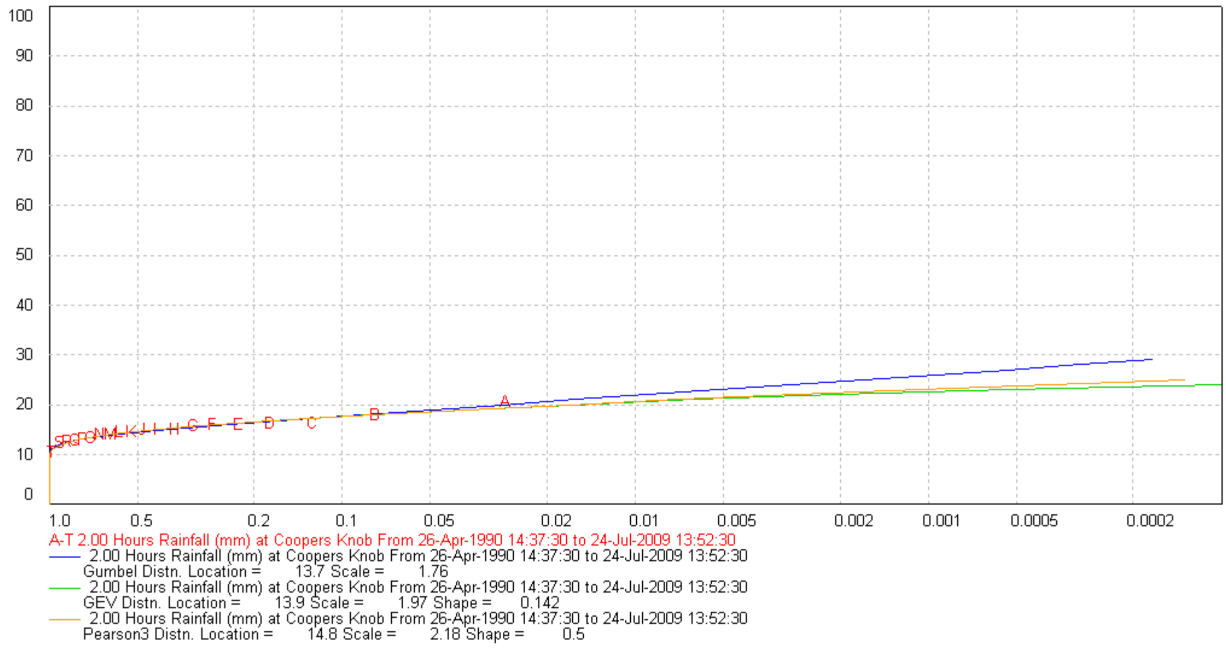

Figure A.45 Coopers Knob 2-hour rainfall frequency analysis.

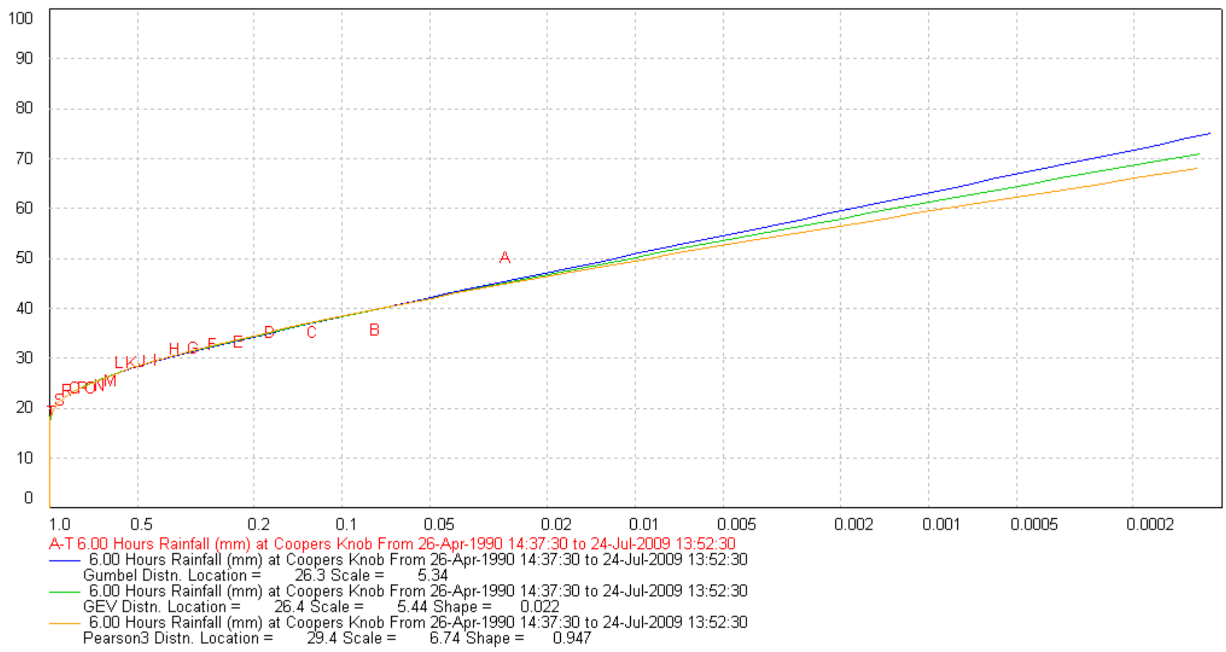

Figure A.46 Coopers Knob 6-hour rainfall frequency analysis.

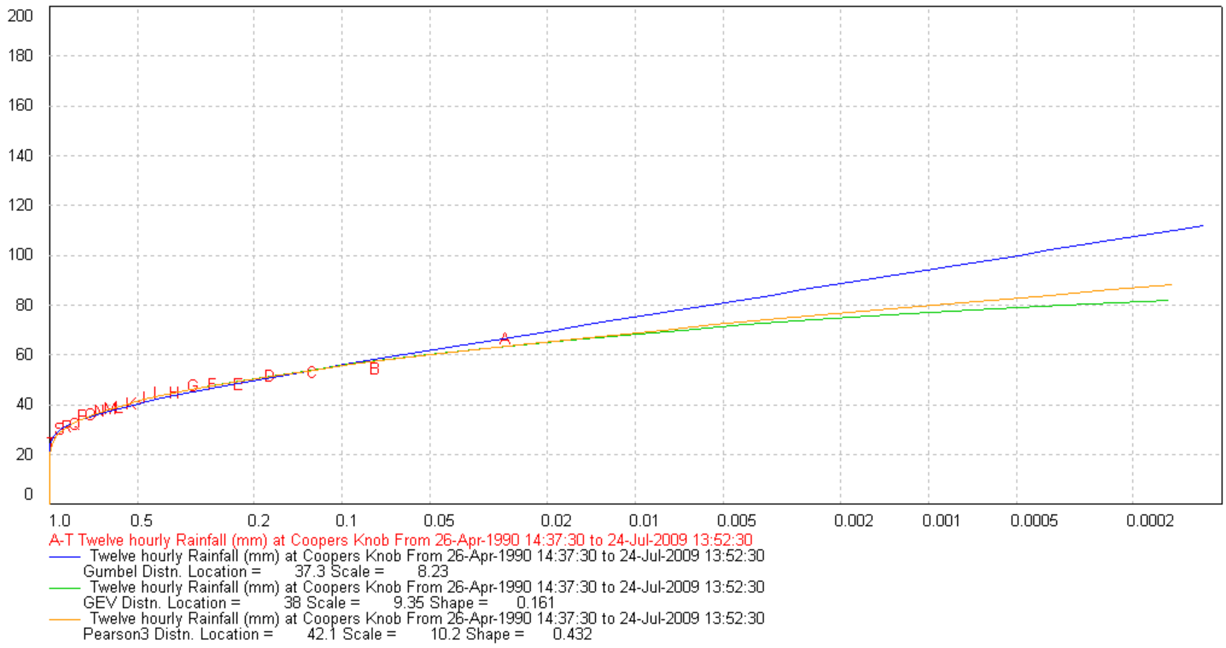

Figure A.47 Coopers Knob 12-hour rainfall frequency analysis.

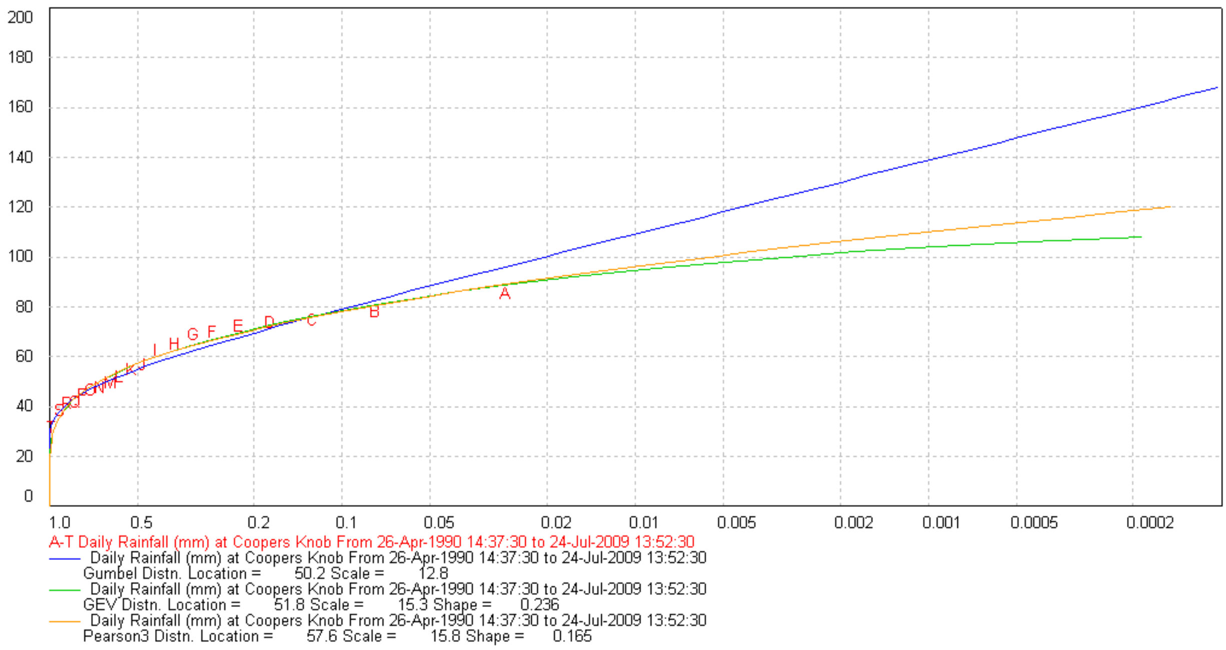

Figure A.48 Coopers Knob 24-hour rainfall frequency analysis.

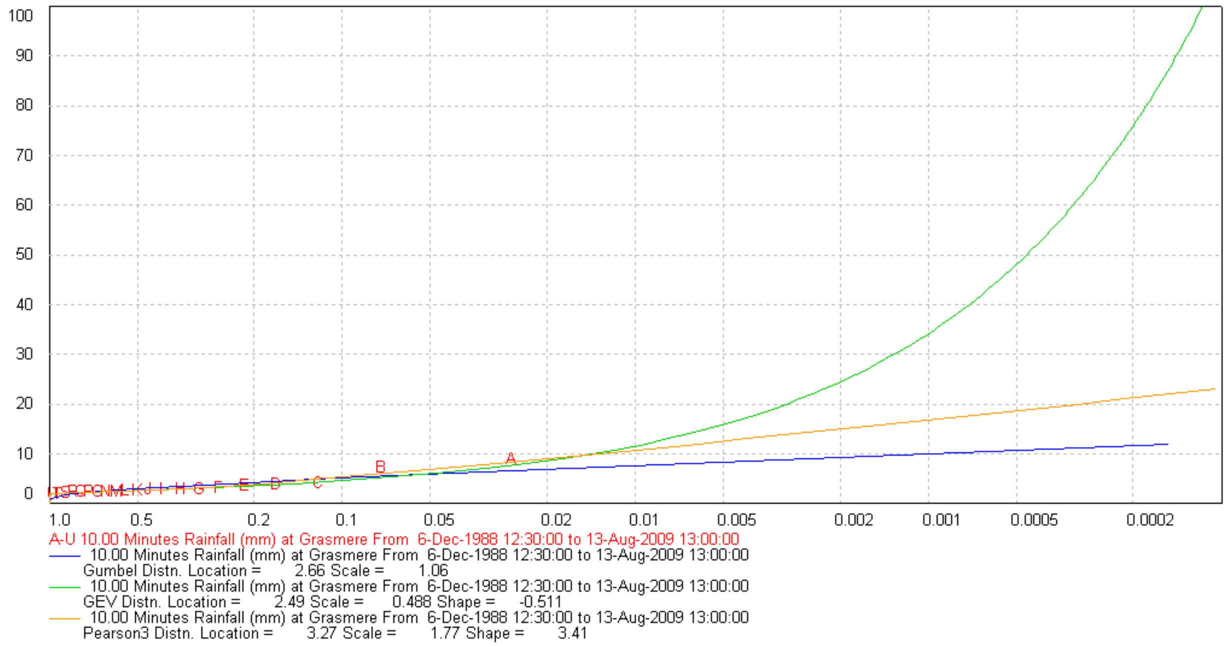

Figure A.49 Grasmere 10-min rainfall frequency analysis.

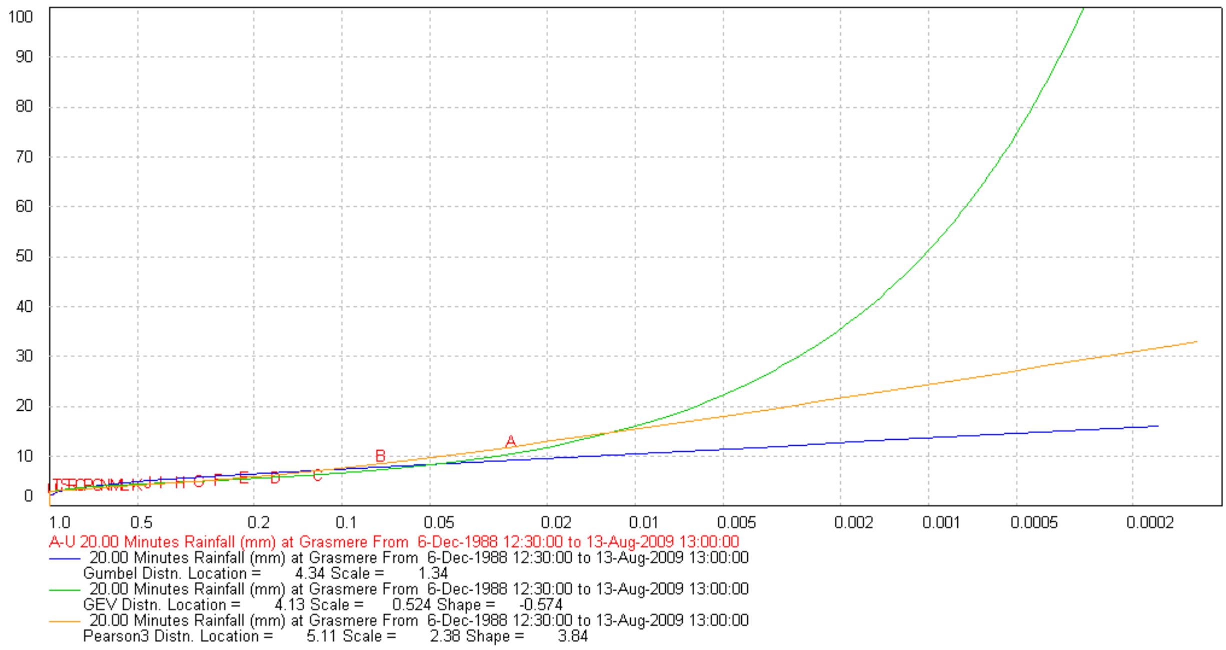

Figure A.50 Grasmere 20-min rainfall frequency analysis.

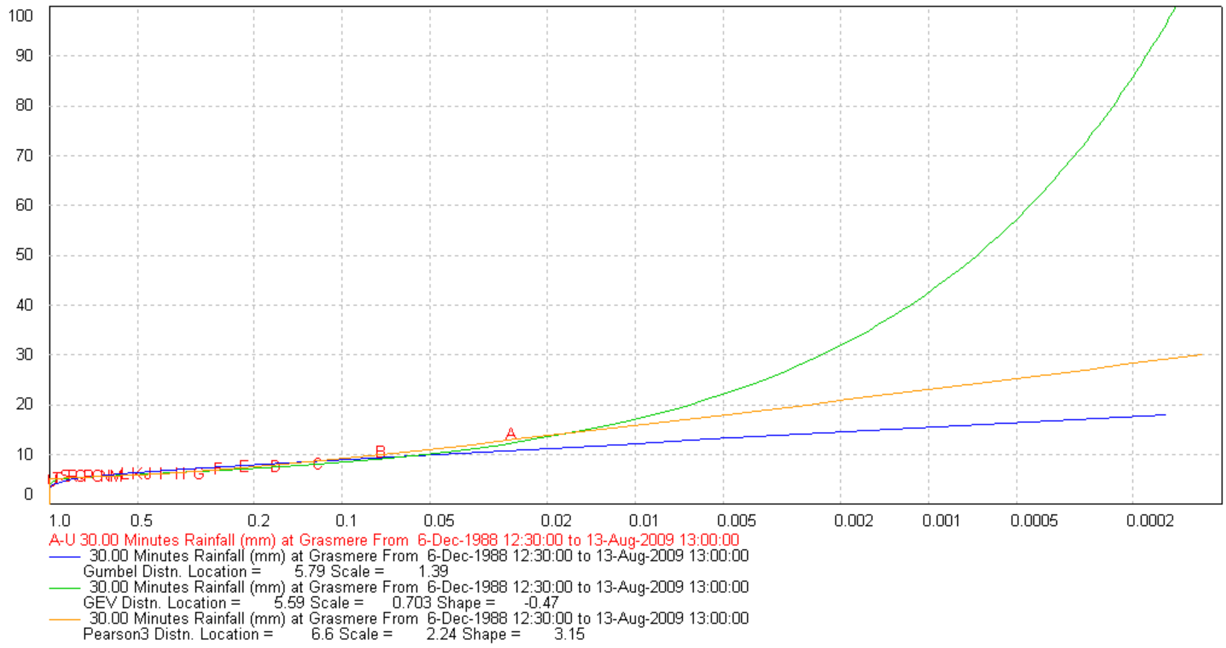

Figure A.51 Grasmere 30-min rainfall frequency analysis.

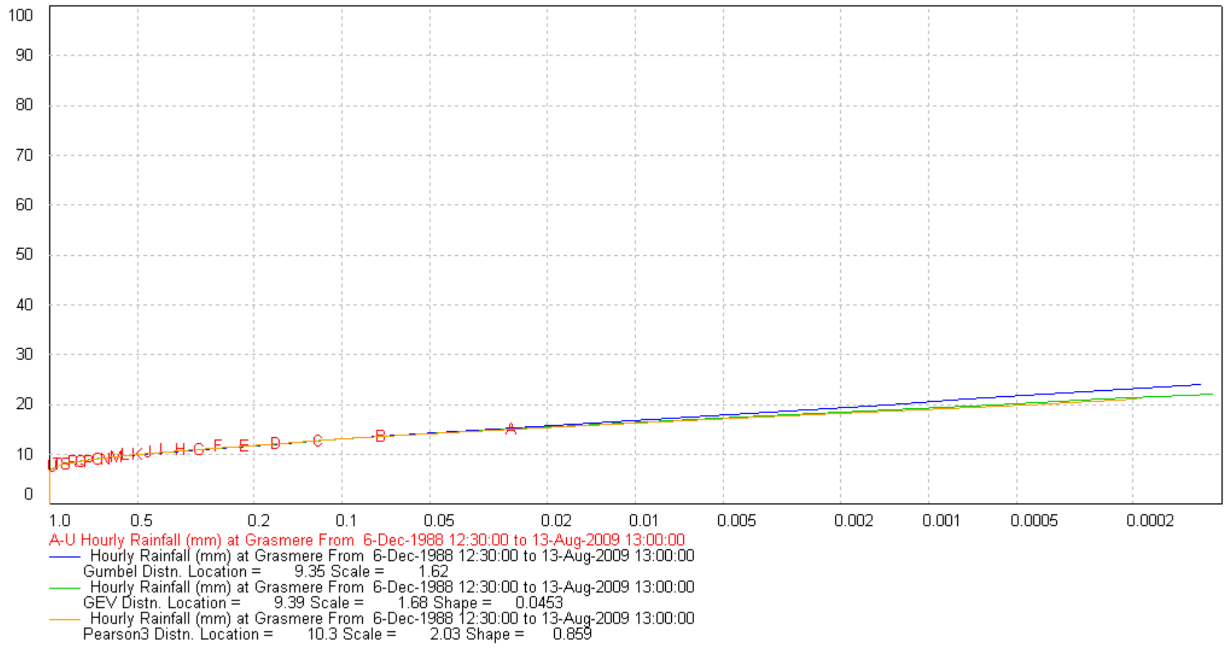

Figure A.52 Grasmere 1-hour rainfall frequency analysis.

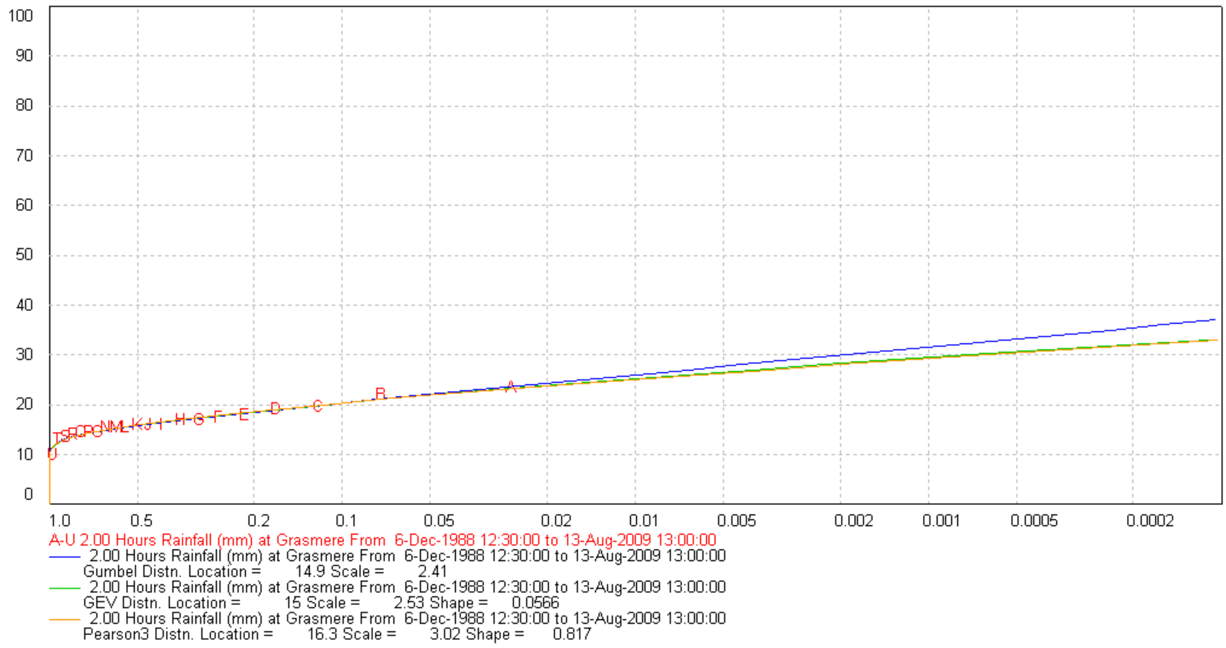

Figure A.53 Grasmere 2-hour rainfall frequency analysis.

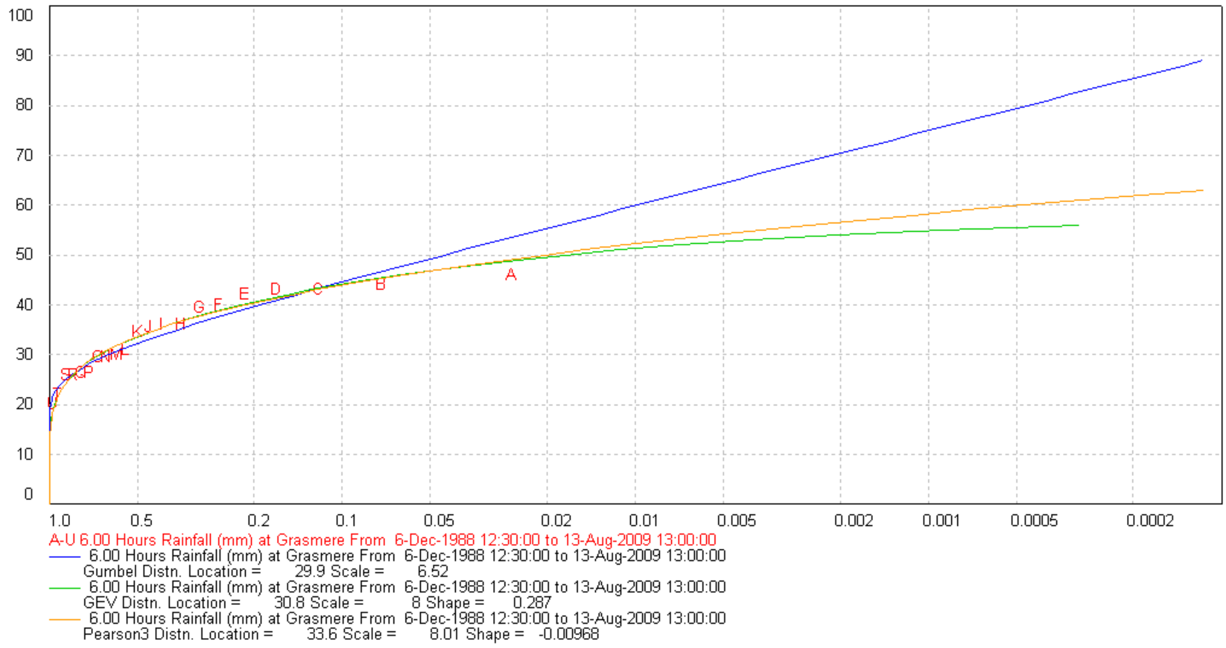

Figure A.54 Grasmere 6-hour rainfall frequency analysis.

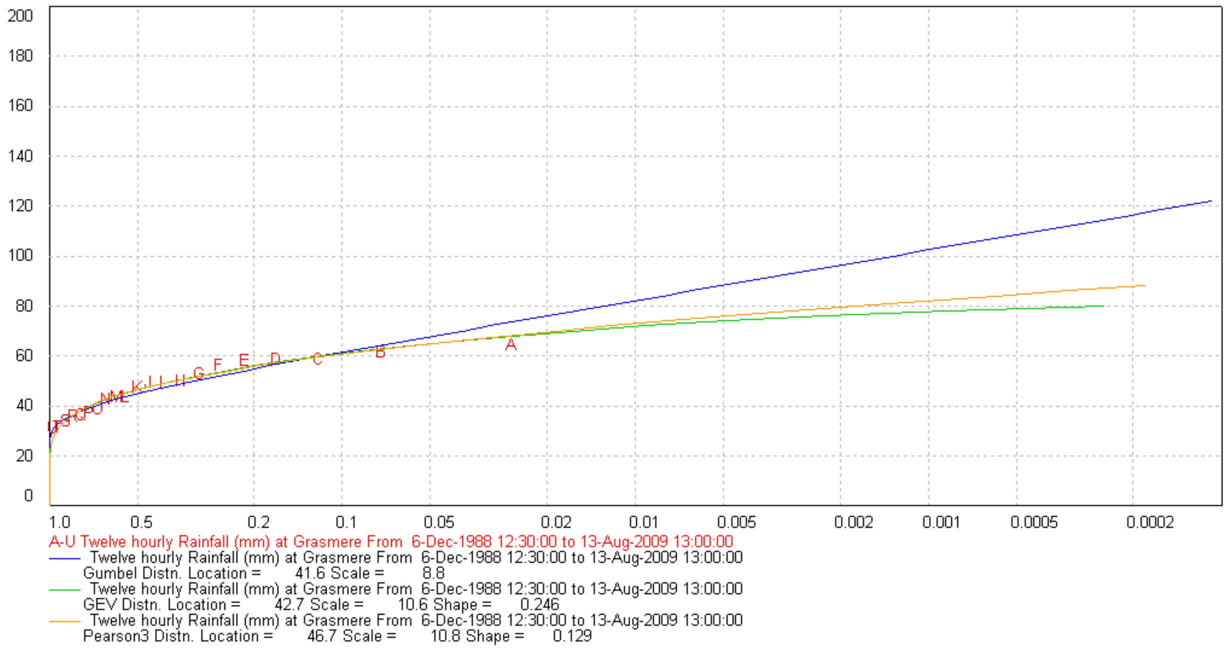

Figure A.55 Grasmere 12-hour rainfall frequency analysis.

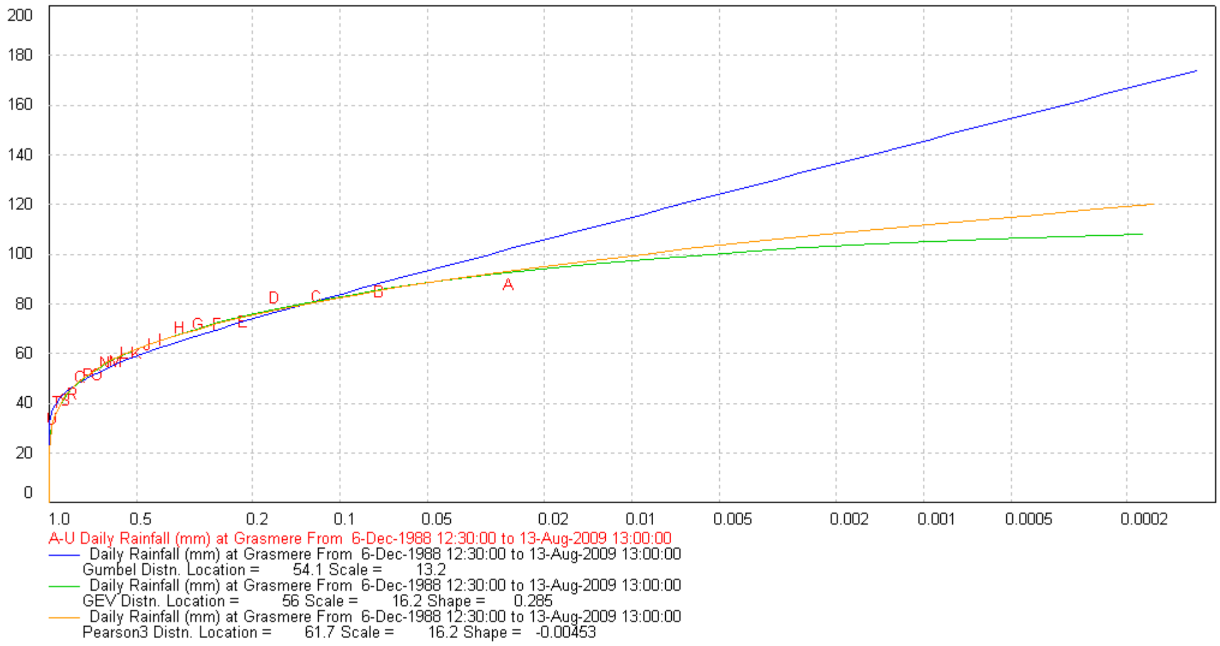

Figure A.56 Grasmere 24-hour rainfall frequency analysis.

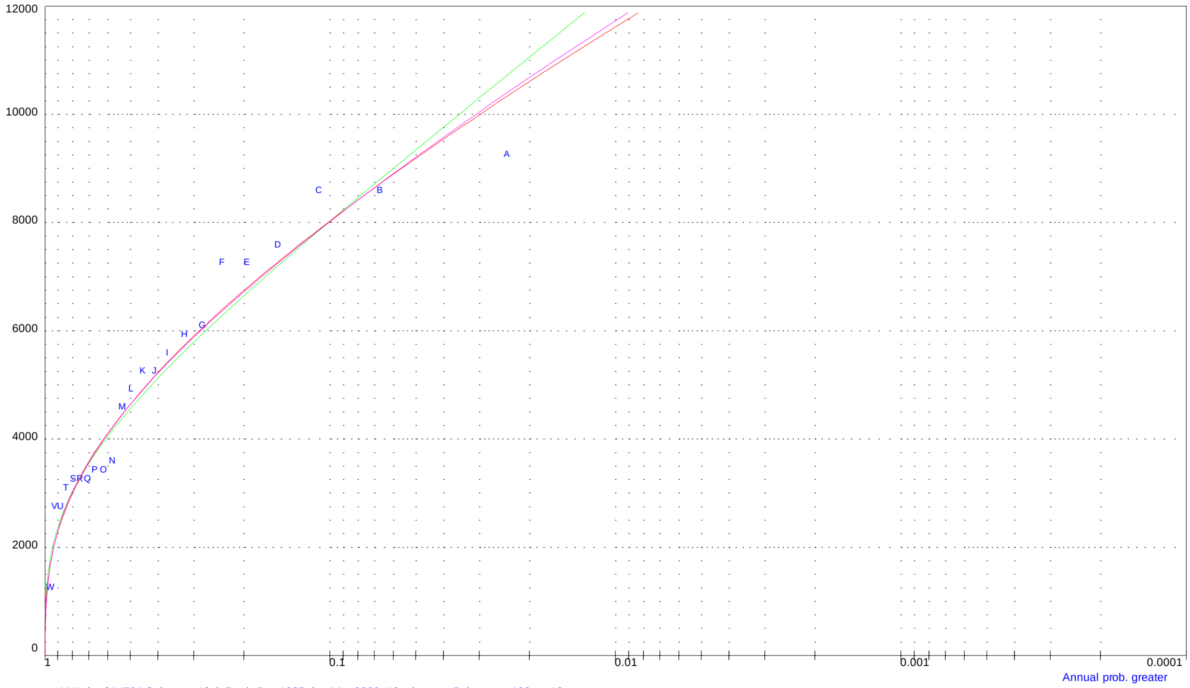

Figure A.57 High Peak 10-min rainfall frequency analysis.

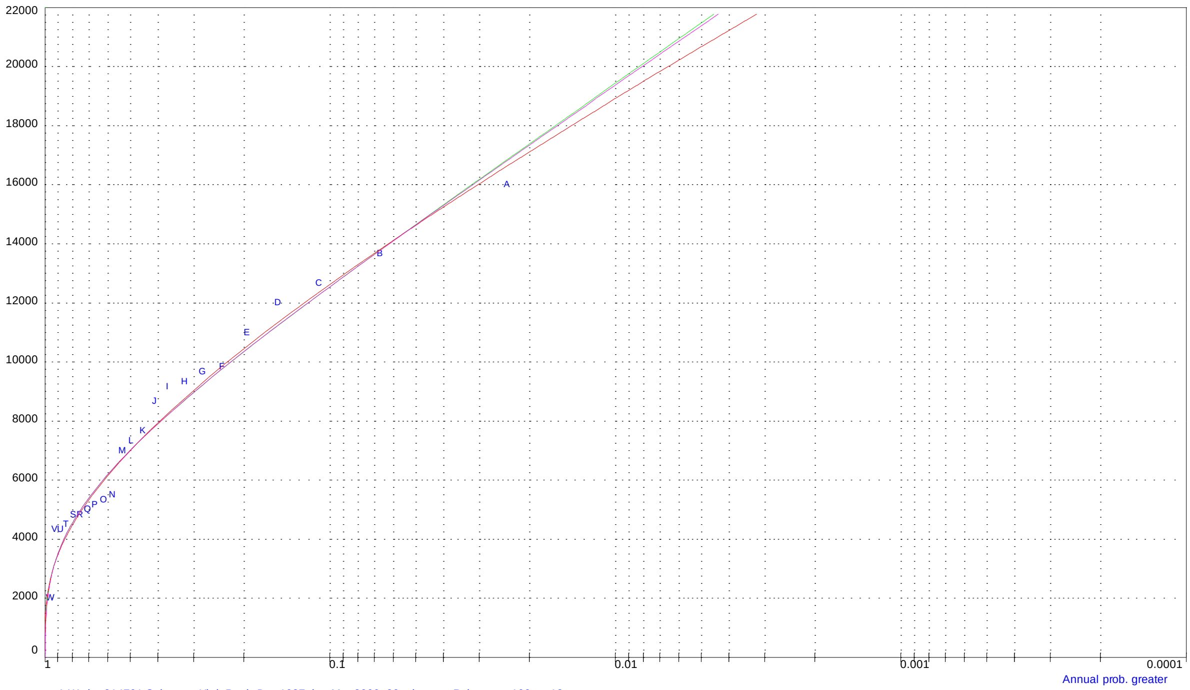

Figure A.58 High Peak 20-min rainfall frequency analysis.

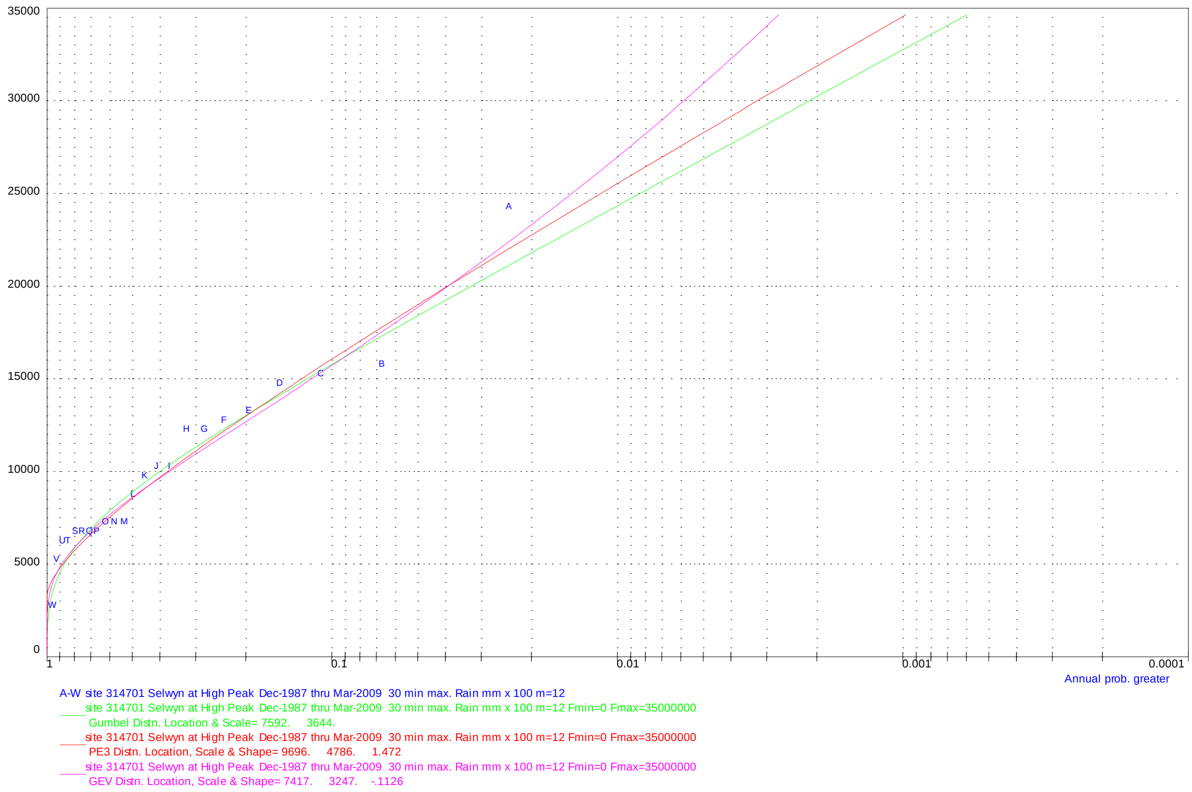

Figure A.59 High Peak 30-min rainfall frequency analysis.

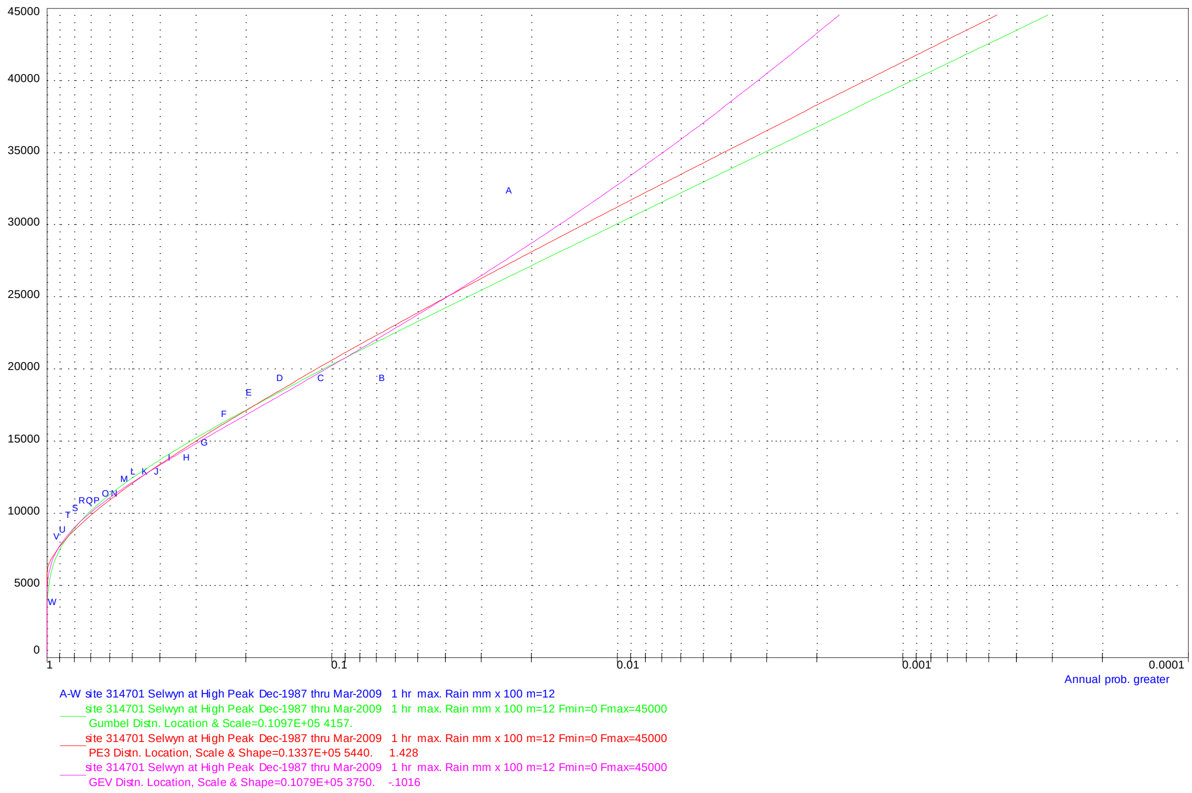

Figure A.60 High Peak 1-hour rainfall frequency analysis.

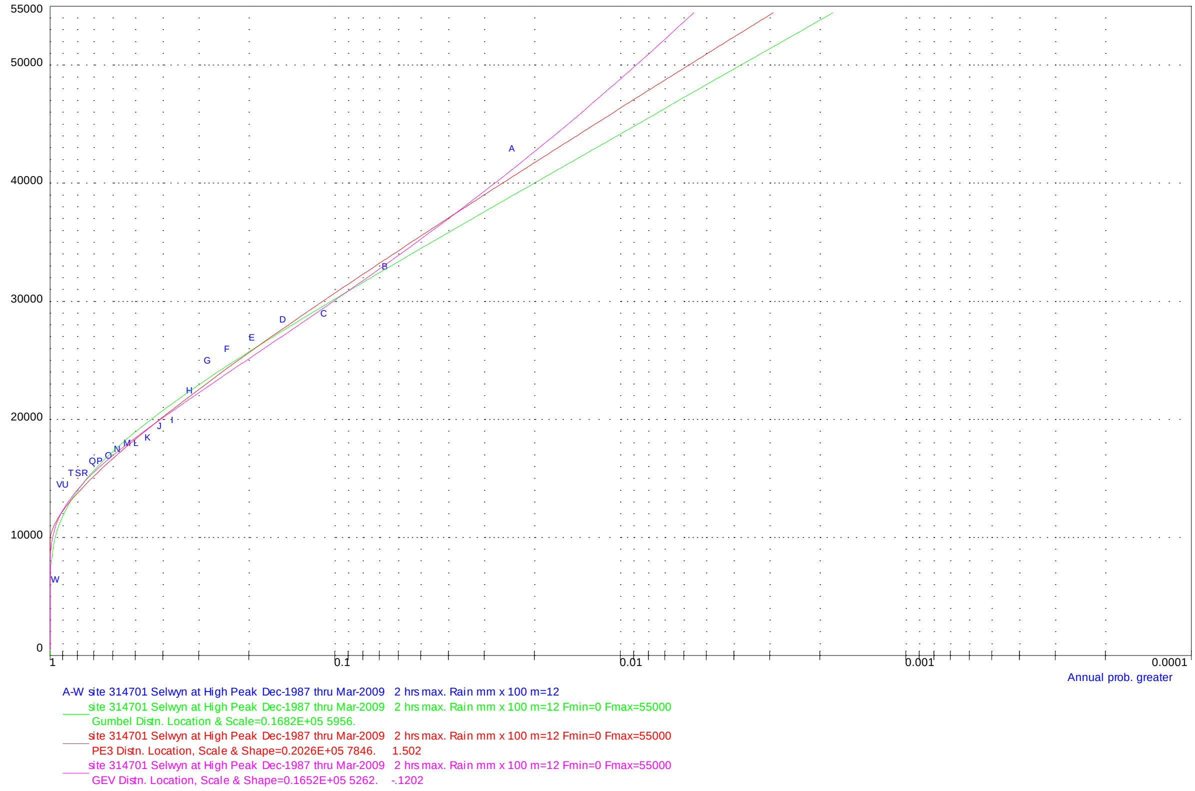

Figure A.61 High Peak 2-hour rainfall frequency analysis.

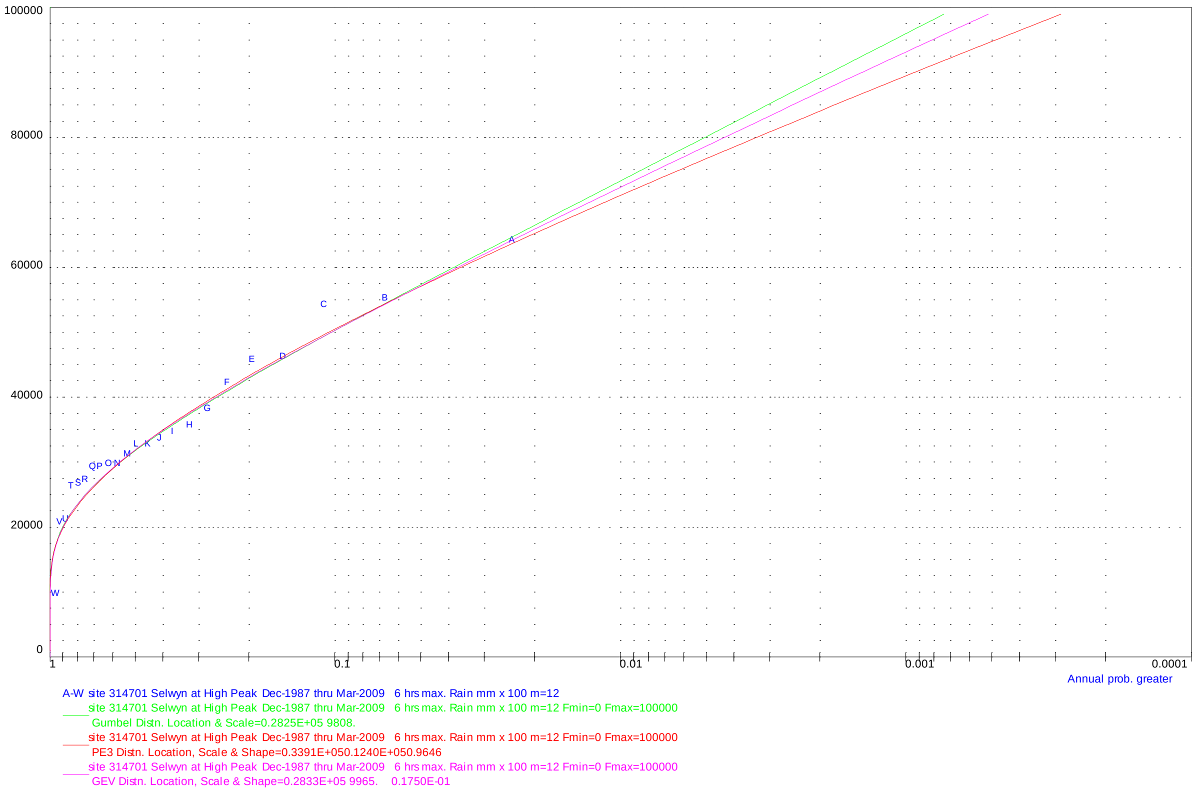

Figure A.62 High Peak 6-hour rainfall frequency analysis.

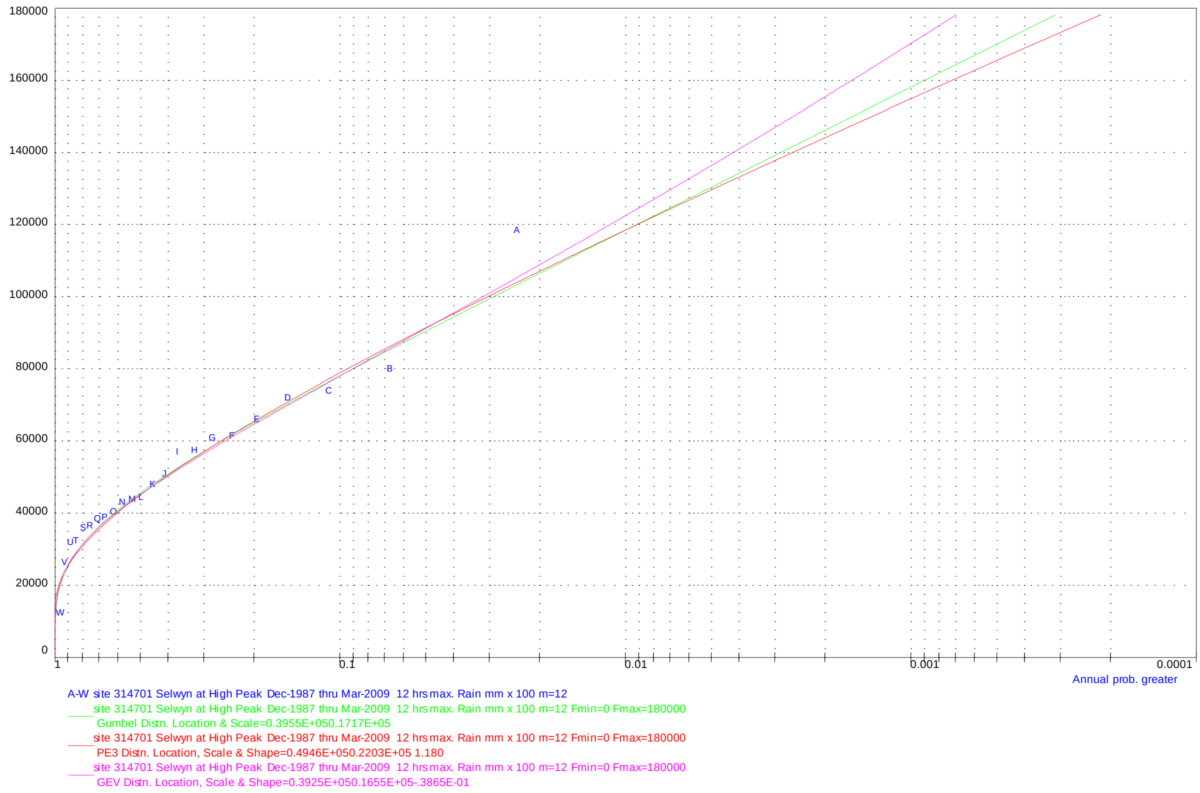

Figure A.63 High Peak 12-hour rainfall frequency analysis.

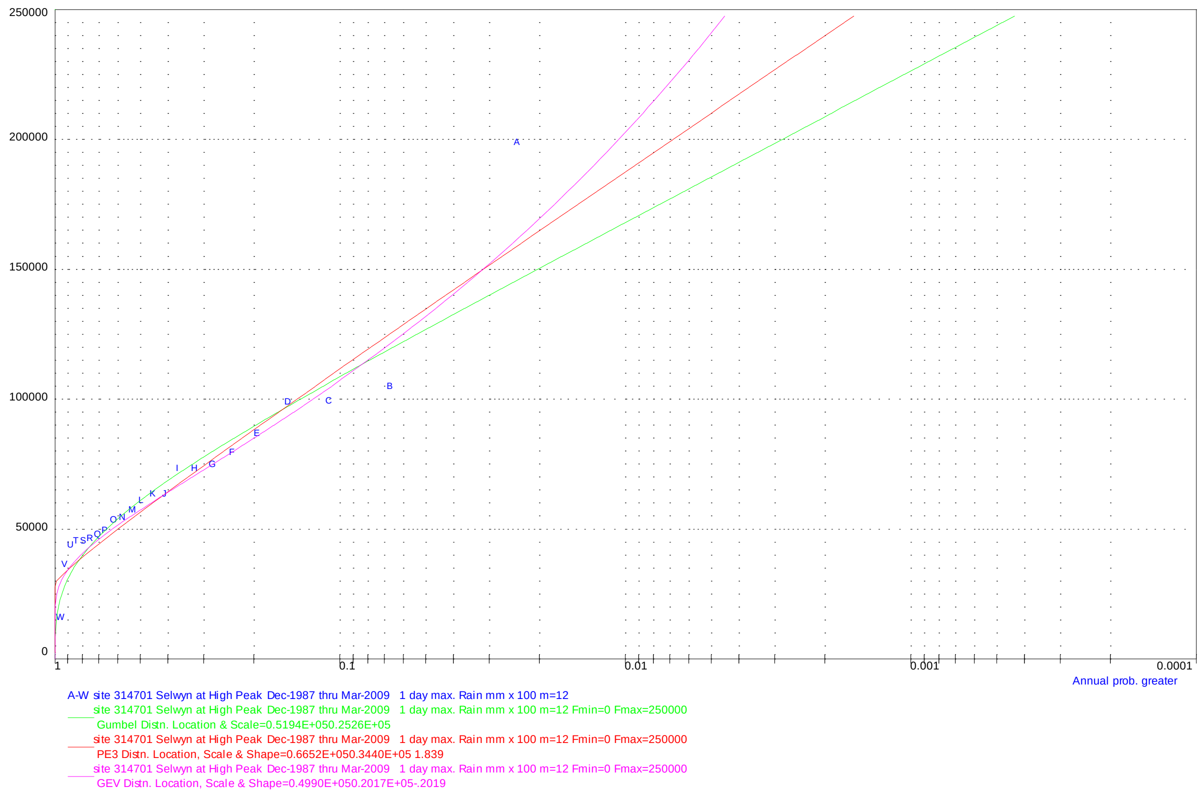

Figure A.64 High Peak 24-hour rainfall frequency analysis.

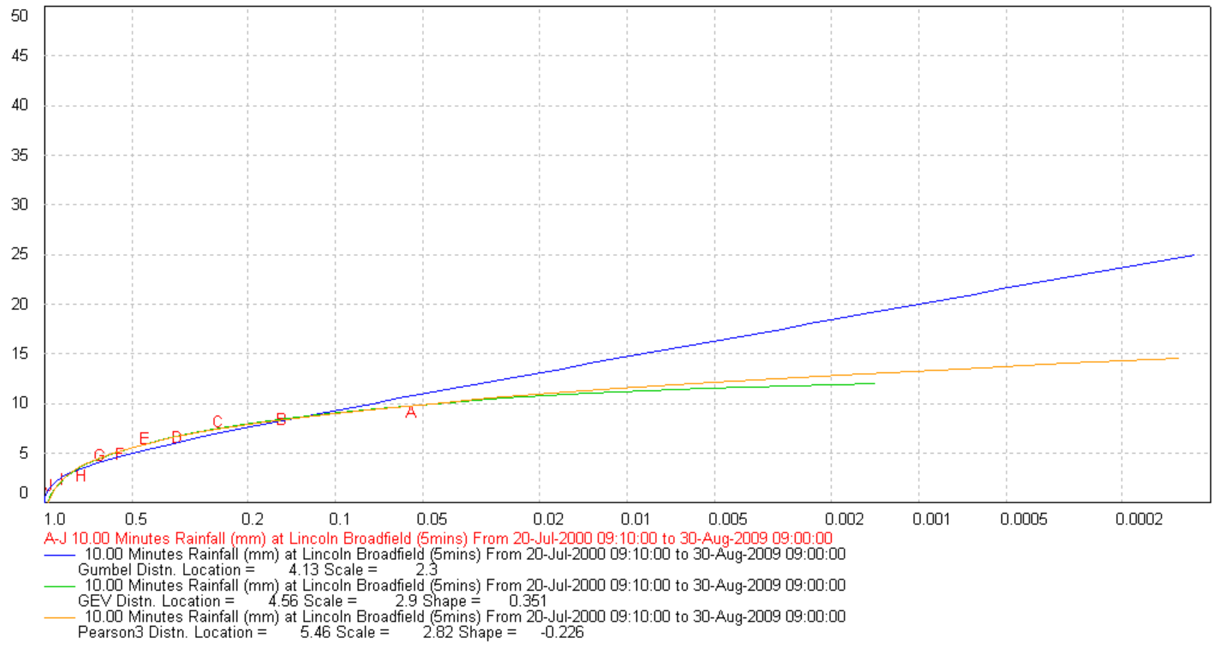

Figure A.65 Lincoln Broadfield 10-min rainfall frequency analysis.

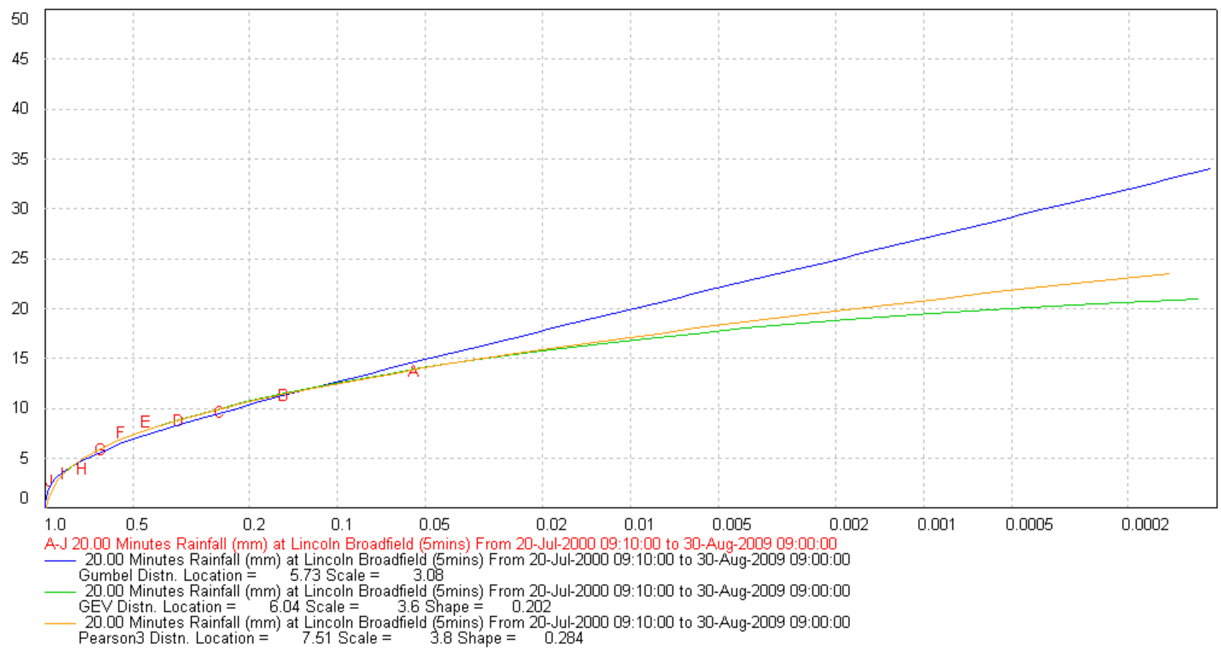

Figure A.66 Lincoln Broadfield 20-min rainfall frequency analysis.

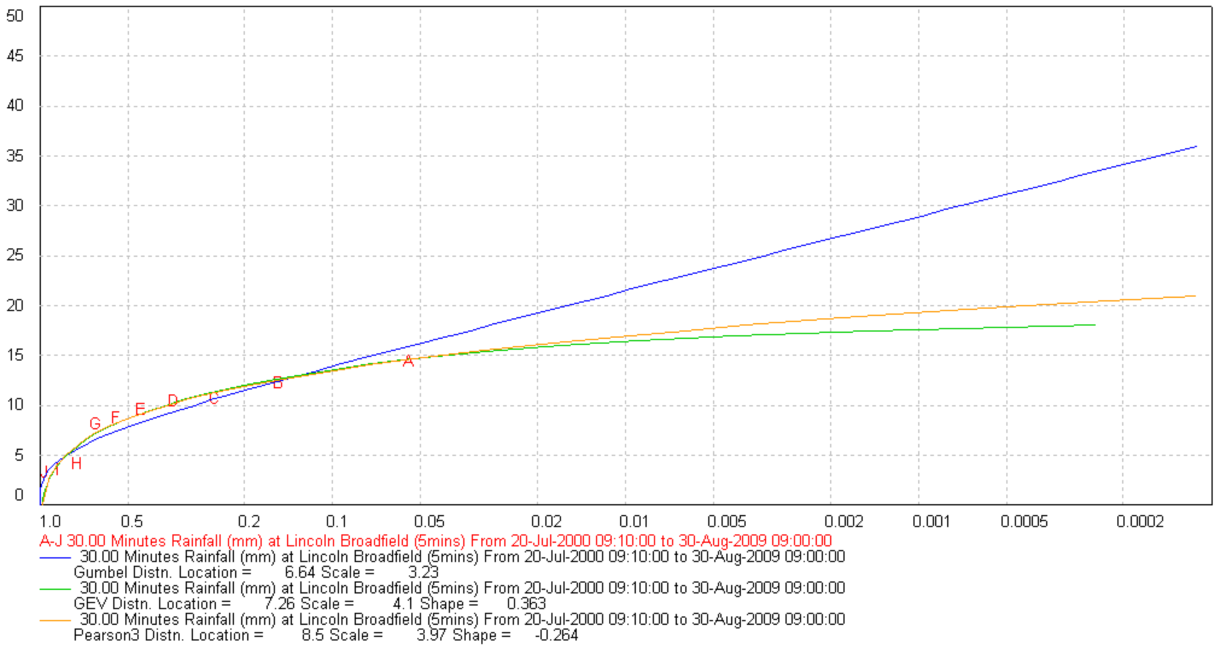

Figure A.67 Lincoln Broadfield 30-min rainfall frequency analysis.

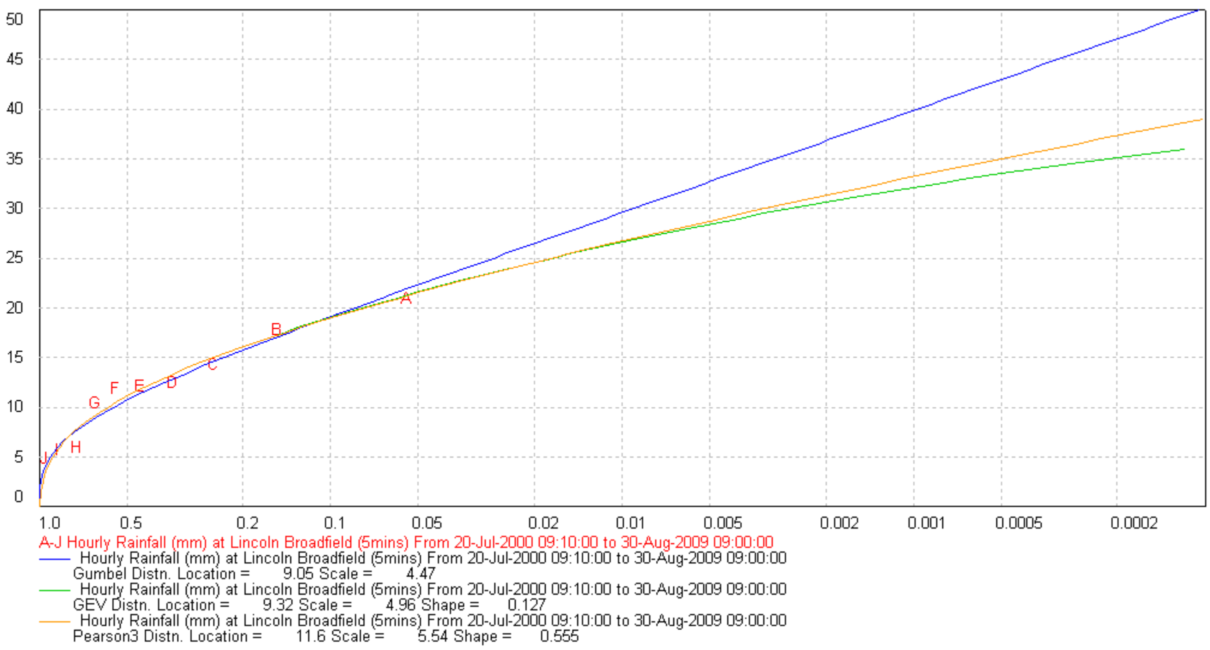

Figure A.68 Lincoln Broadfield 1-hour rainfall frequency analysis.

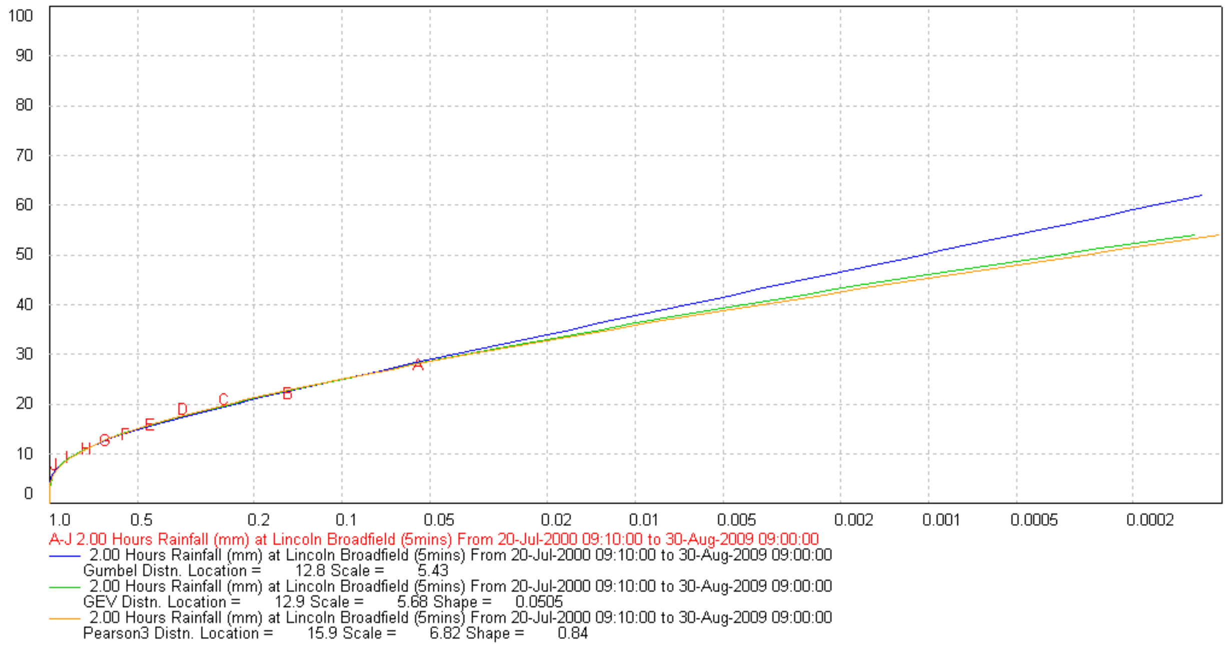

Figure A.69 Lincoln Broadfield 2-hour rainfall frequency analysis.

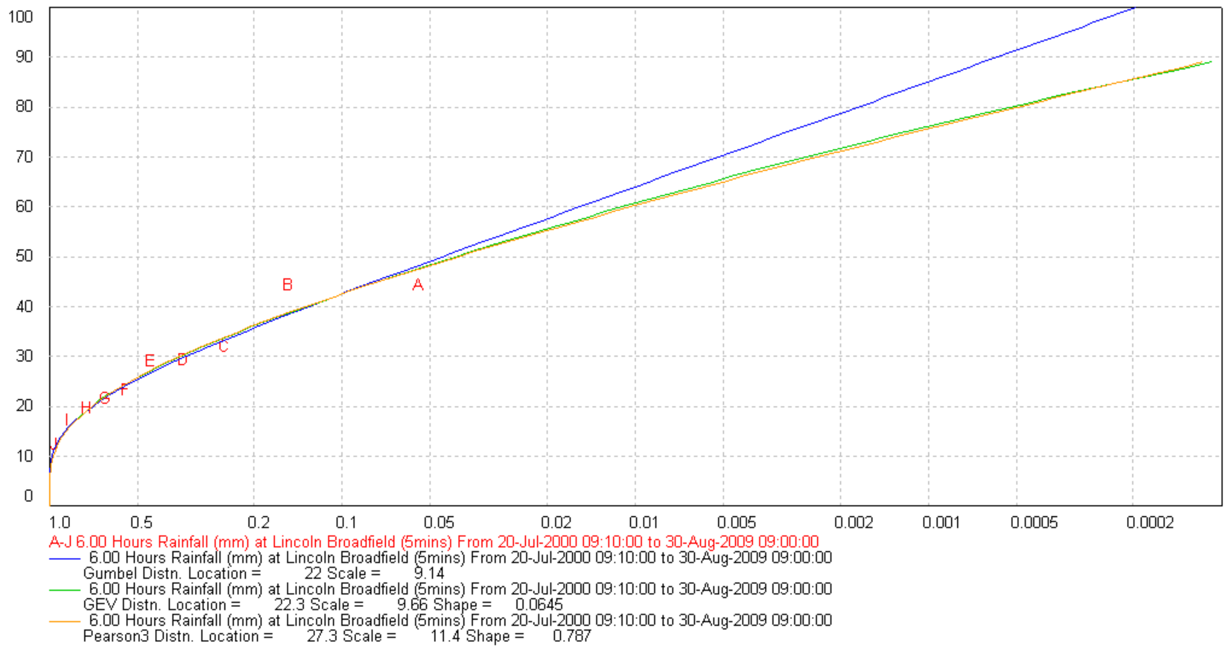

Figure A.70 Lincoln Broadfield 6-hour rainfall frequency analysis.

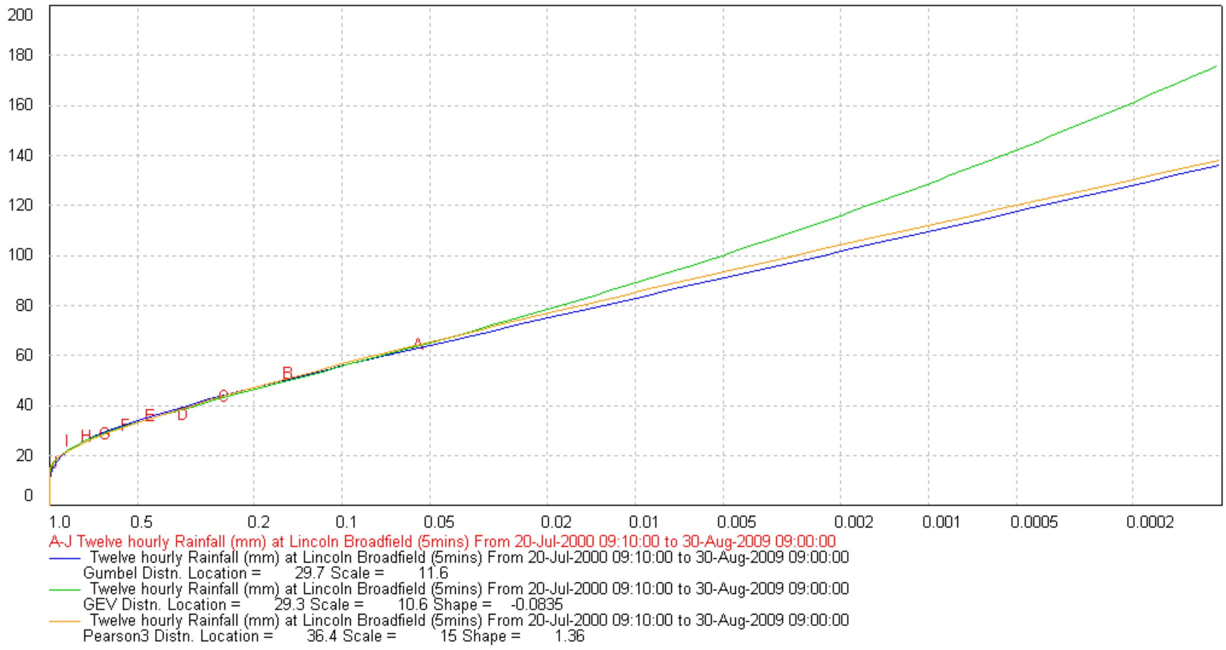

Figure A.71 Lincoln Broadfield 12-hour rainfall frequency analysis.

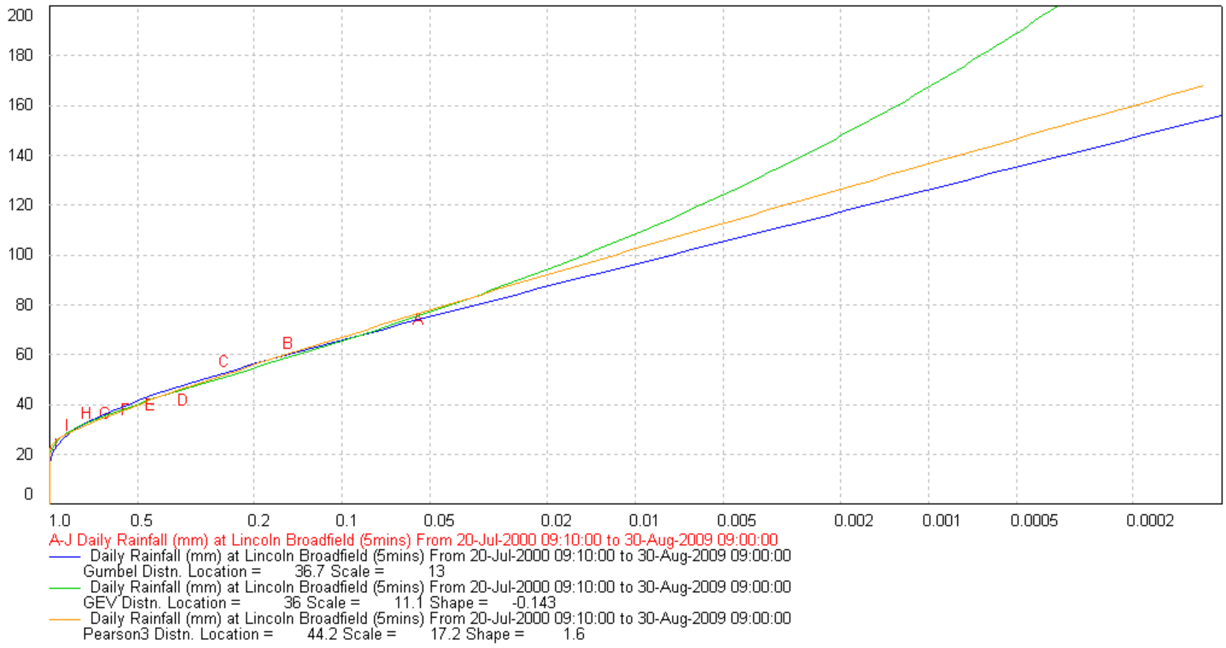

Figure A.72 Lincoln Broadfield 24-hour rainfall frequency analysis.

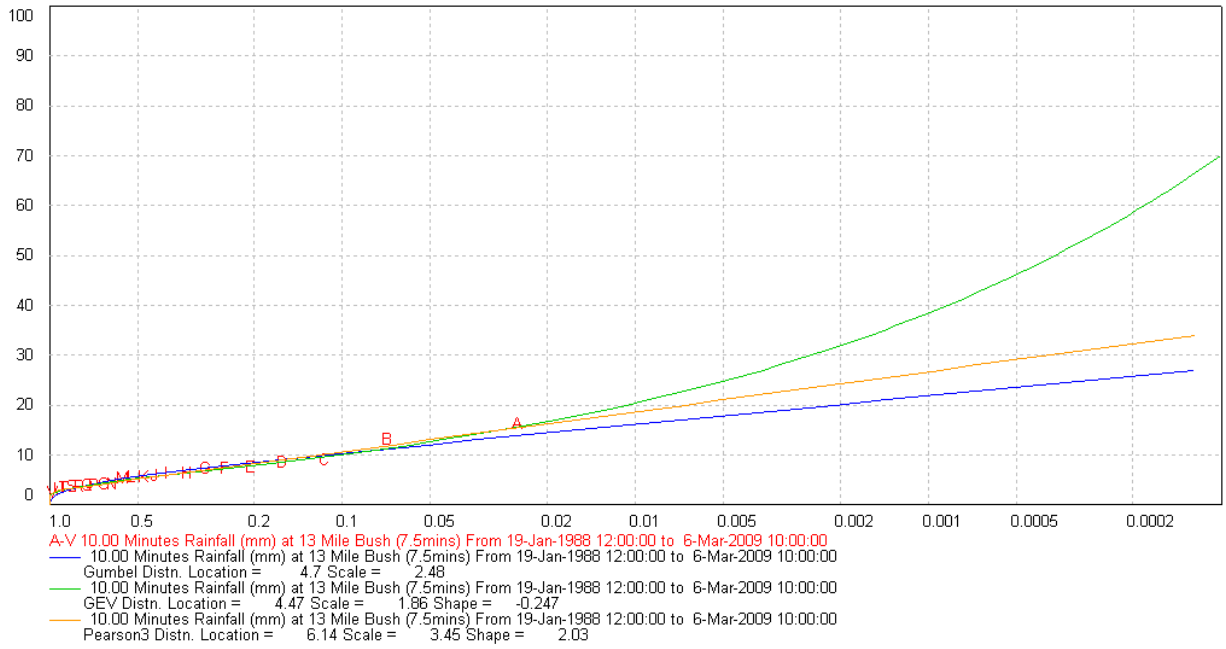

Figure A.73 13 Mile Bush 10-min rainfall frequency analysis.

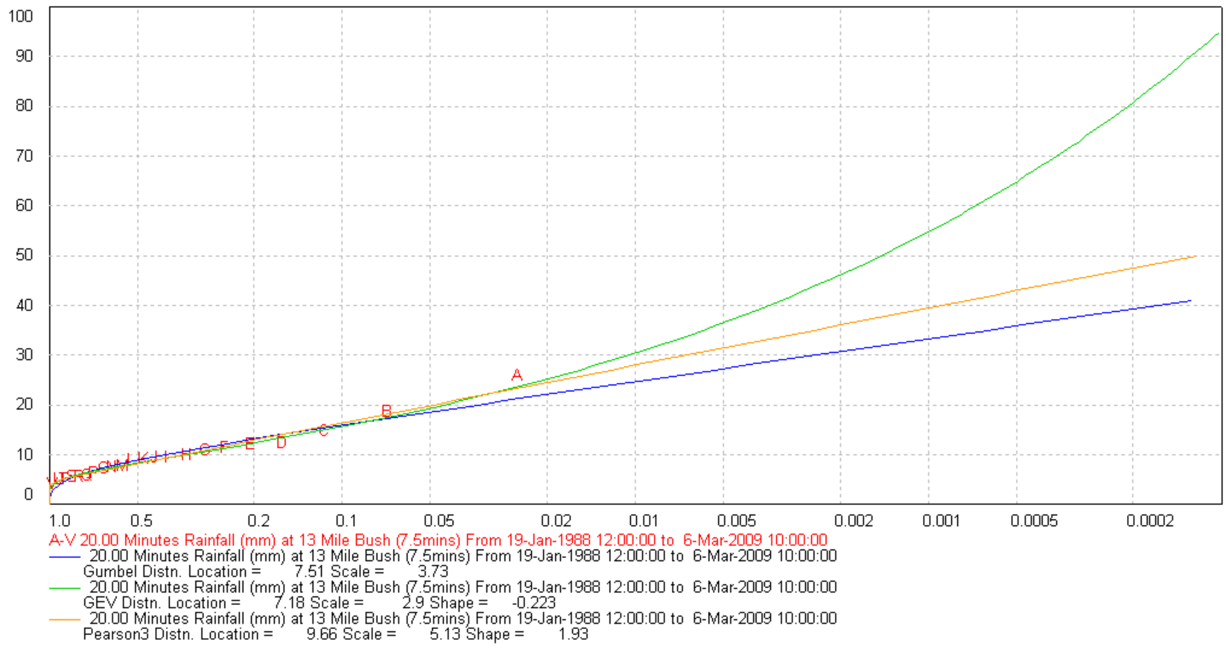

Figure A.74 13 Mile Bush 20-min rainfall frequency analysis.

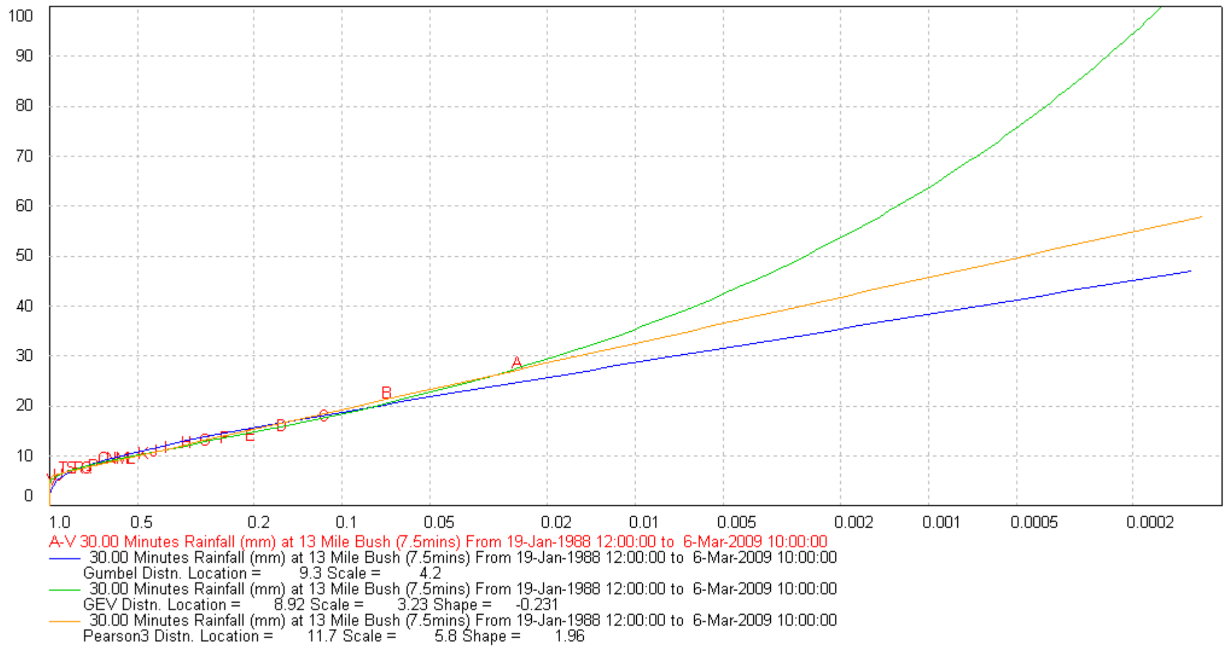

Figure A.75 13 Mile Bush 30-min rainfall frequency analysis.

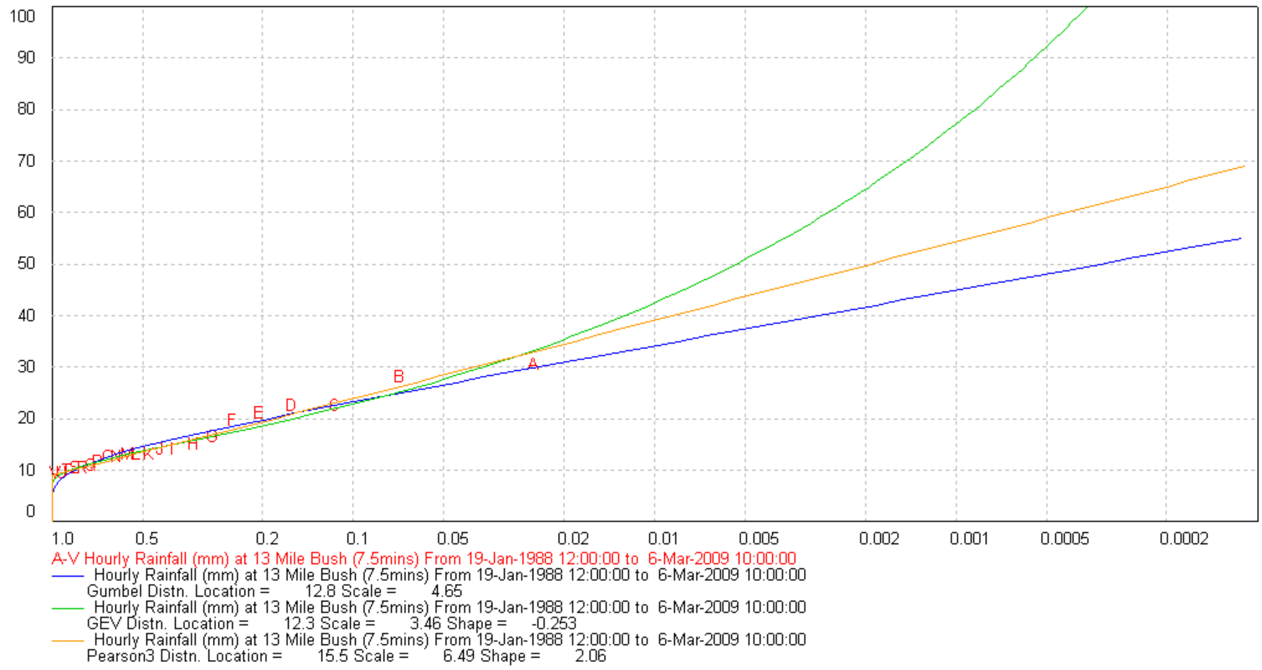

Figure A.76 13 Mile Bush 1-hour rainfall frequency analysis.

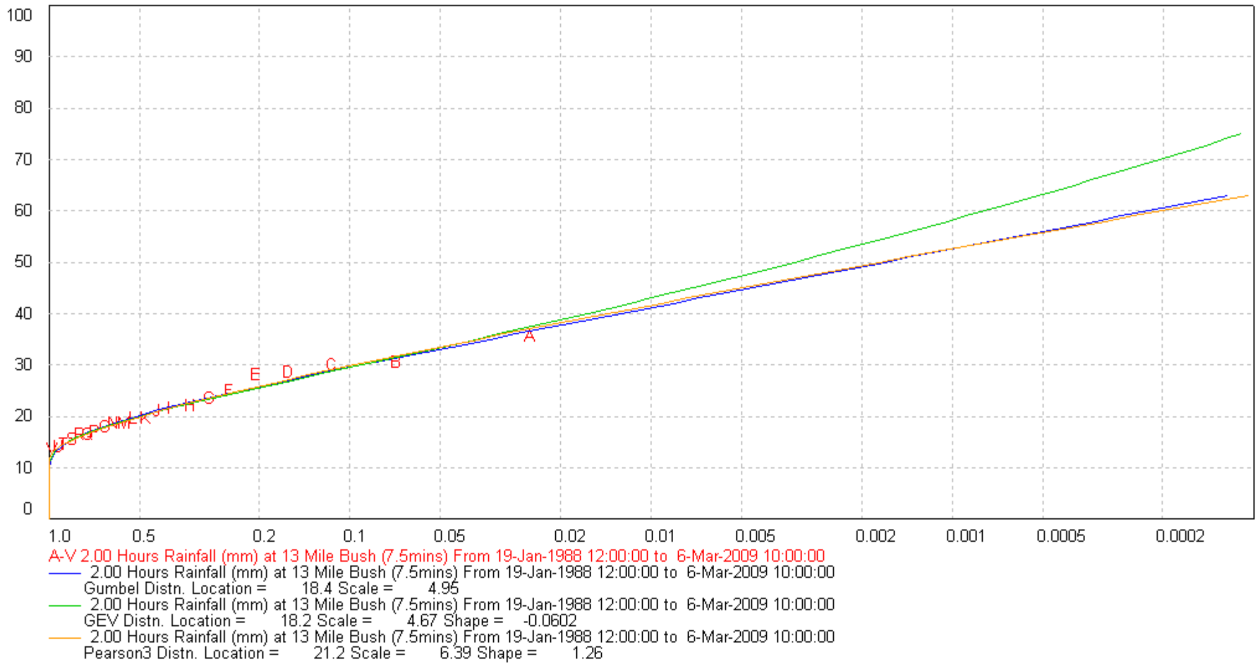

Figure A.77 13 Mile Bush 2-hour rainfall frequency analysis.

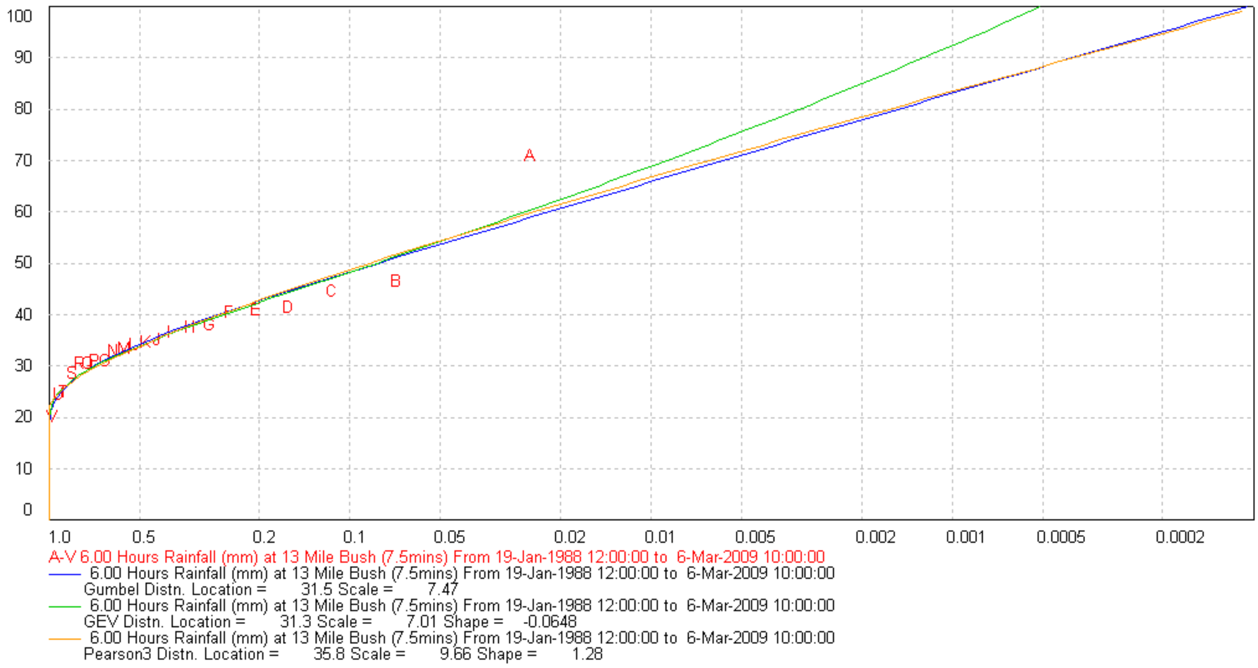

Figure A.78 13 Mile Bush 6-hour rainfall frequency analysis.

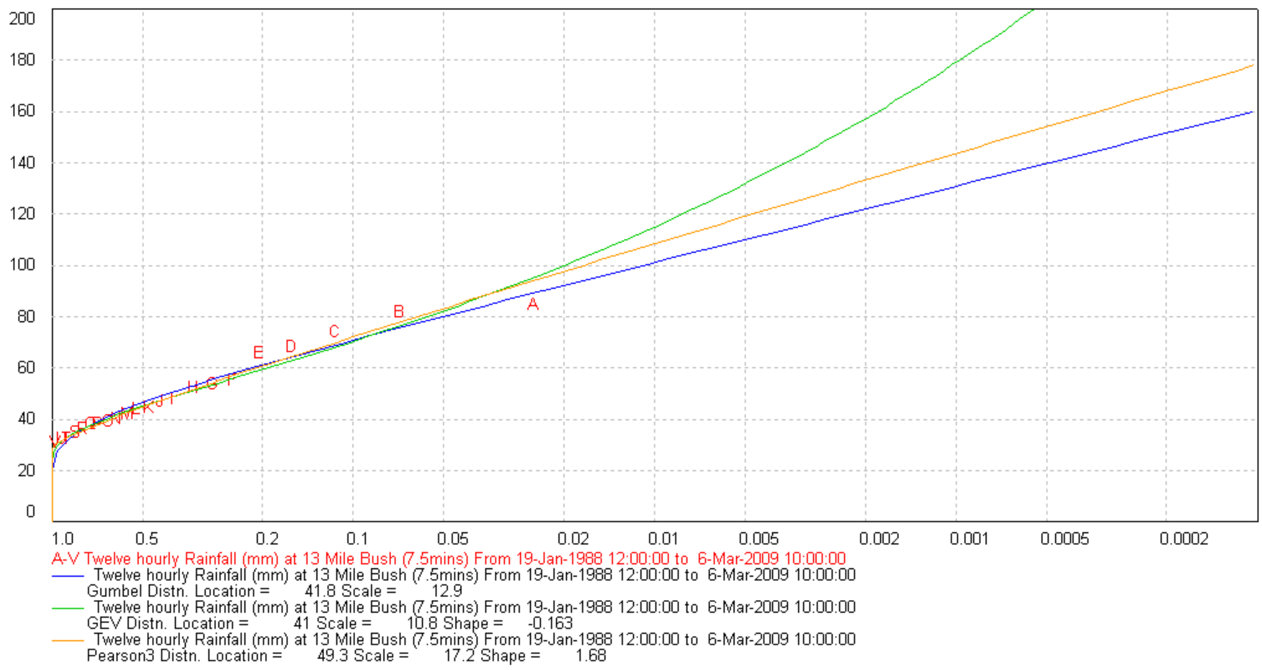

Figure A.79 13 Mile Bush 12-hour rainfall frequency analysis.

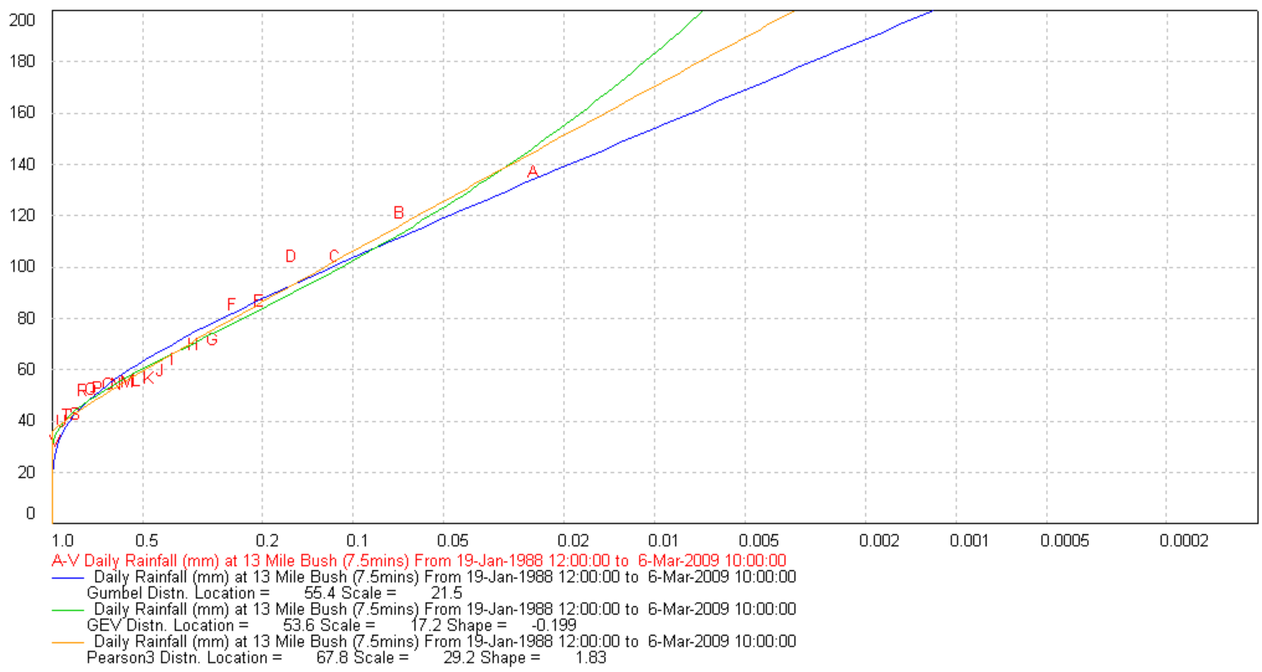

Figure A.80 13 Mile Bush 24-hour rainfall frequency analysis.

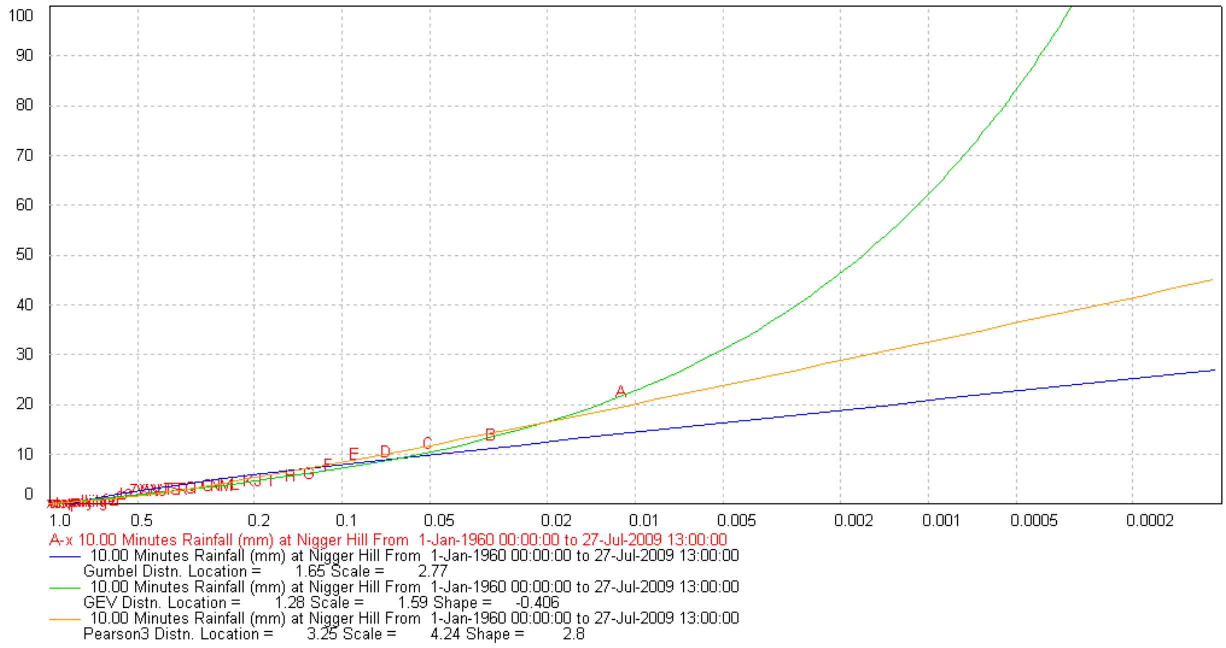

Figure A.81 Nigger Hill 10-min rainfall frequency analysis.

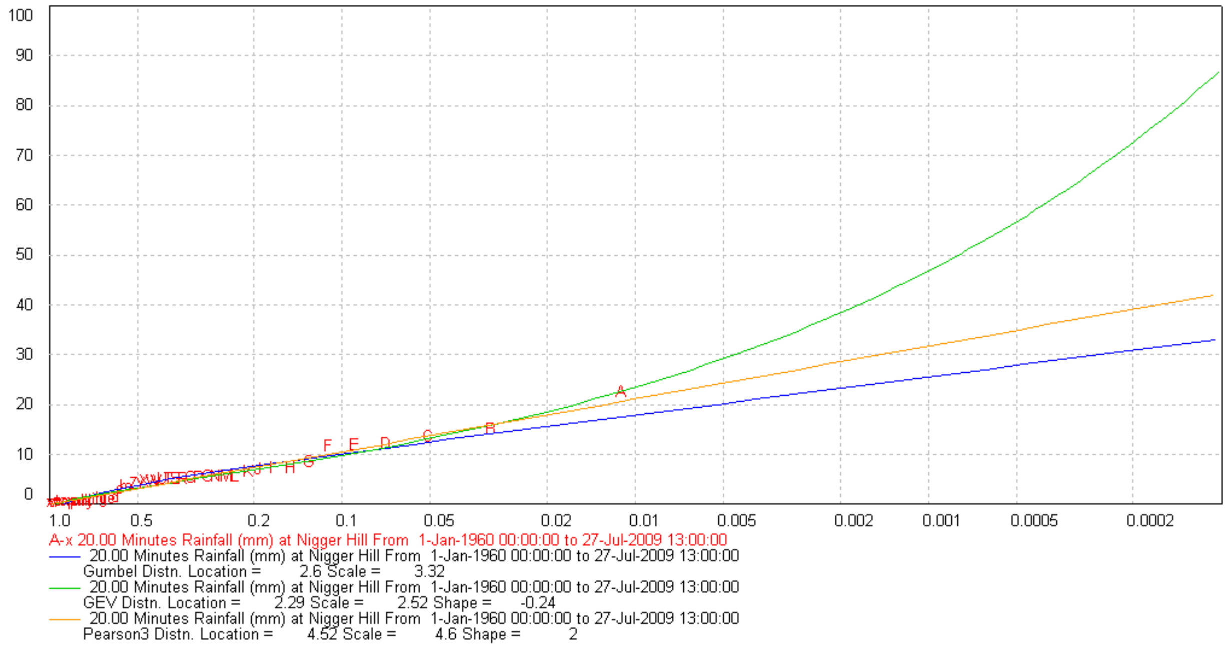

Figure A.82 Nigger Hill 20-min rainfall frequency analysis.

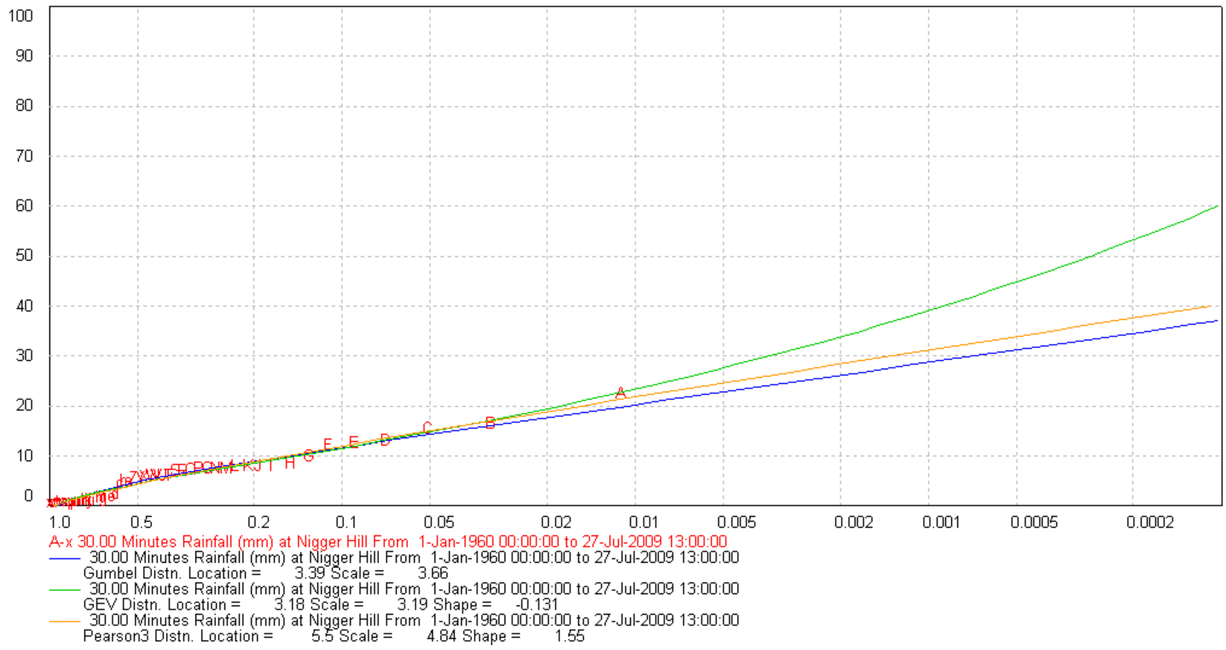

Figure A.83 Nigger Hill 30-min rainfall frequency analysis.

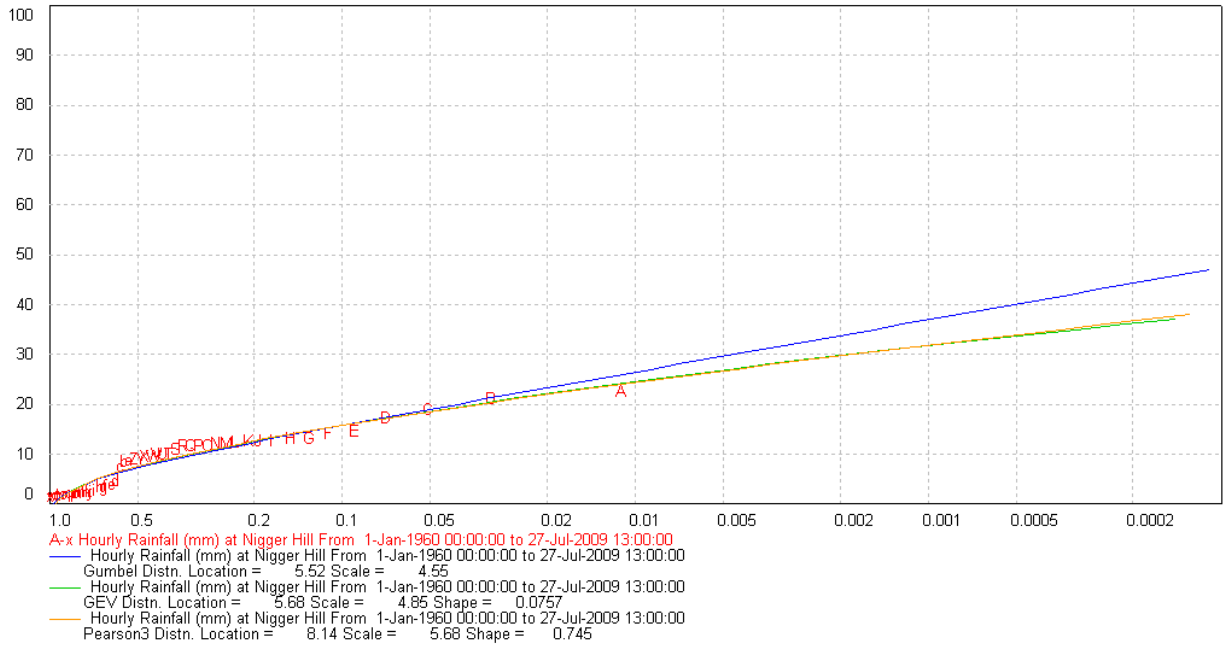

Figure A.84 Nigger Hill 1-hour rainfall frequency analysis.

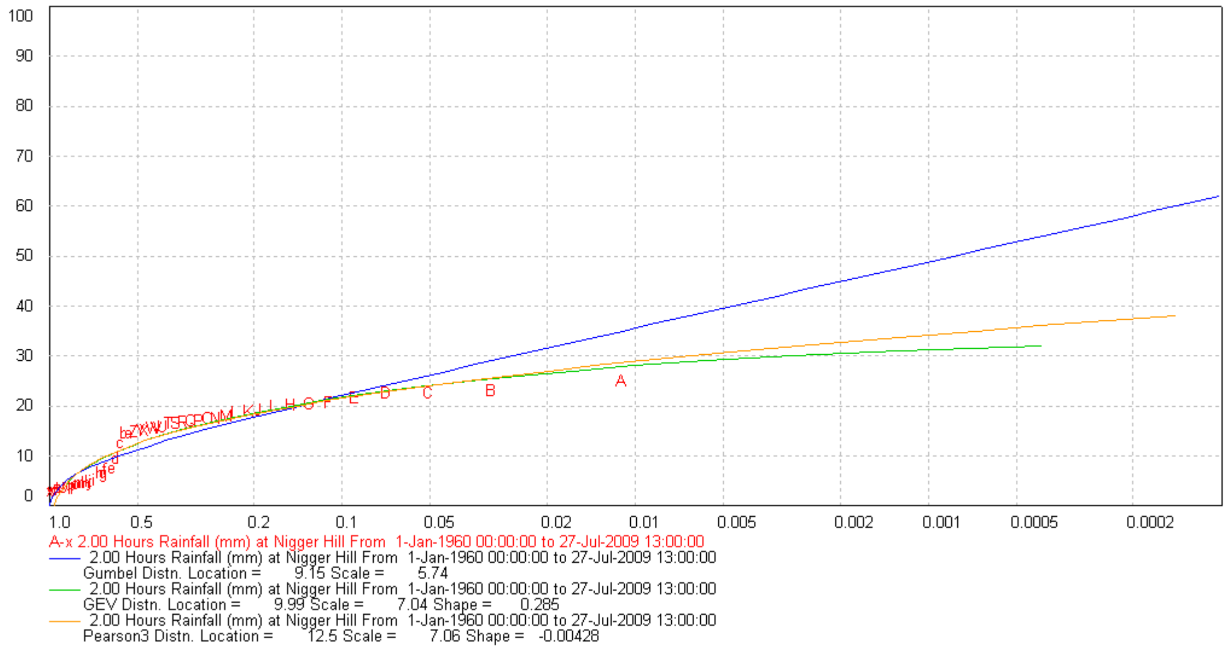

Figure A.85 Nigger Hill 2-hour rainfall frequency analysis.

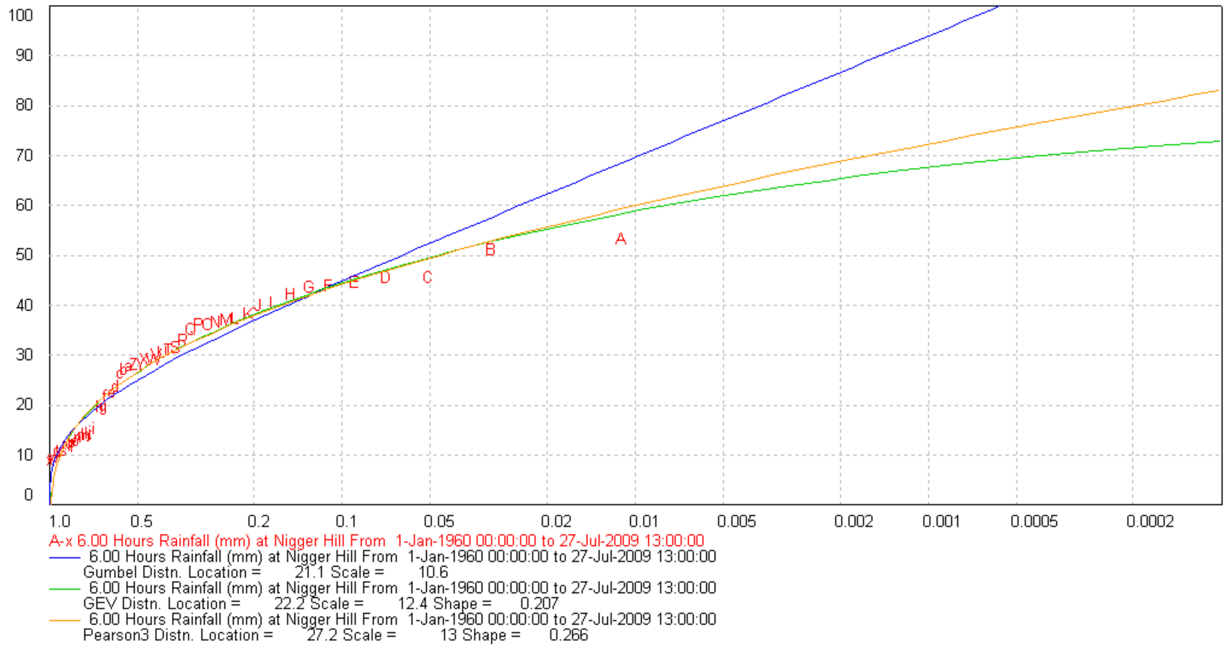

Figure A.86 Nigger Hill 6-hour rainfall frequency analysis.

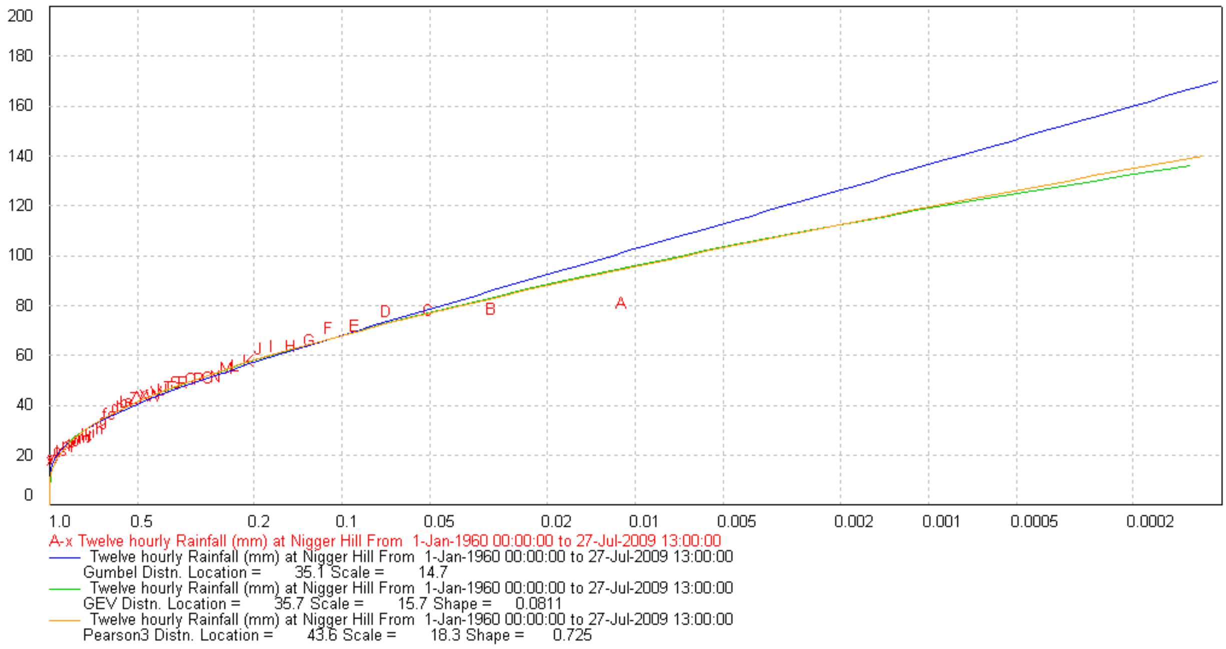

Figure A.87 Nigger Hill 12-hour rainfall frequency analysis.

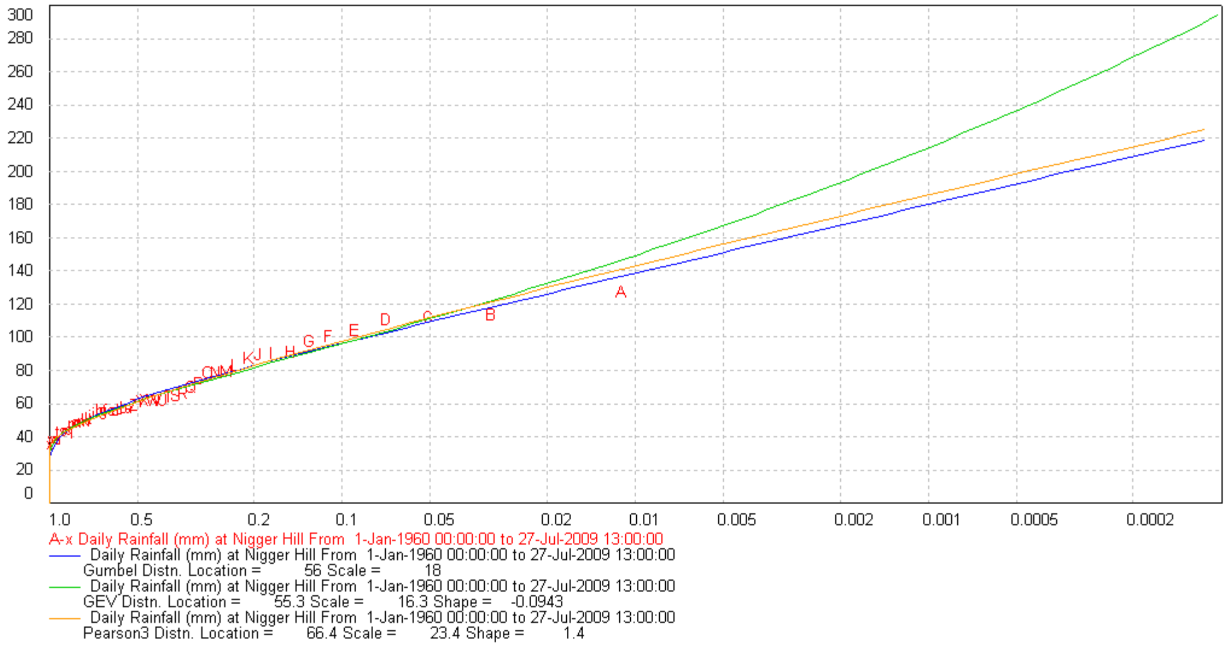

Figure A.88 Nigger Hill 24-hour rainfall frequency analysis.

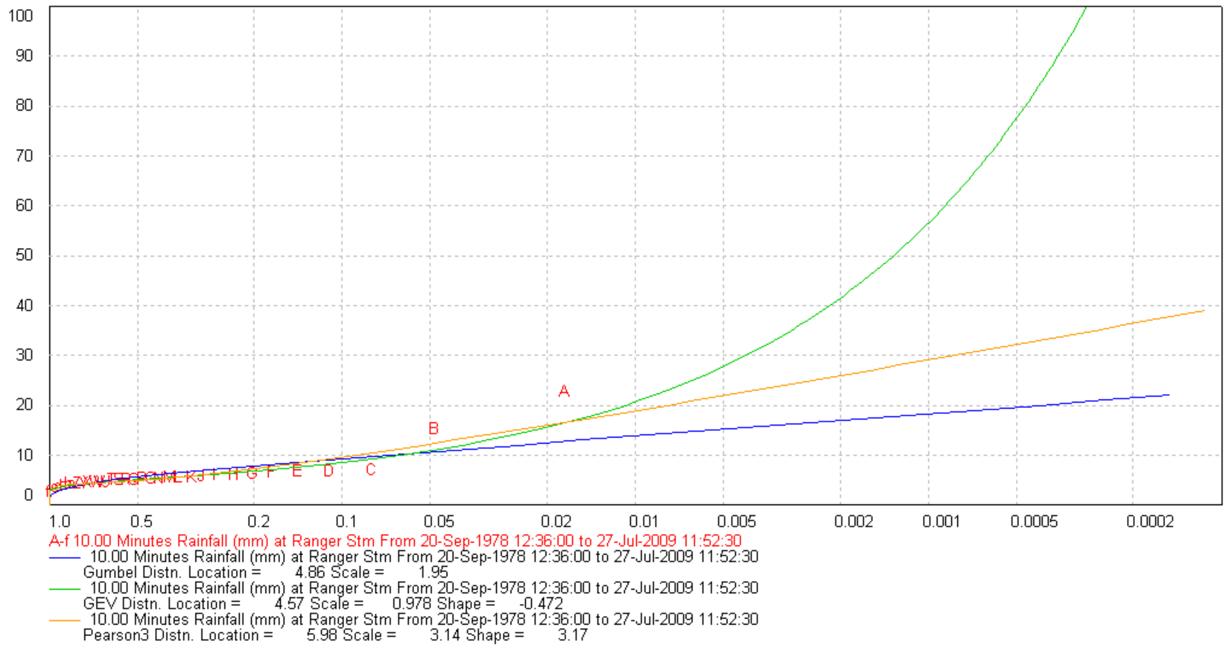

Figure A.89 Ranger Stream 10-min rainfall frequency analysis.

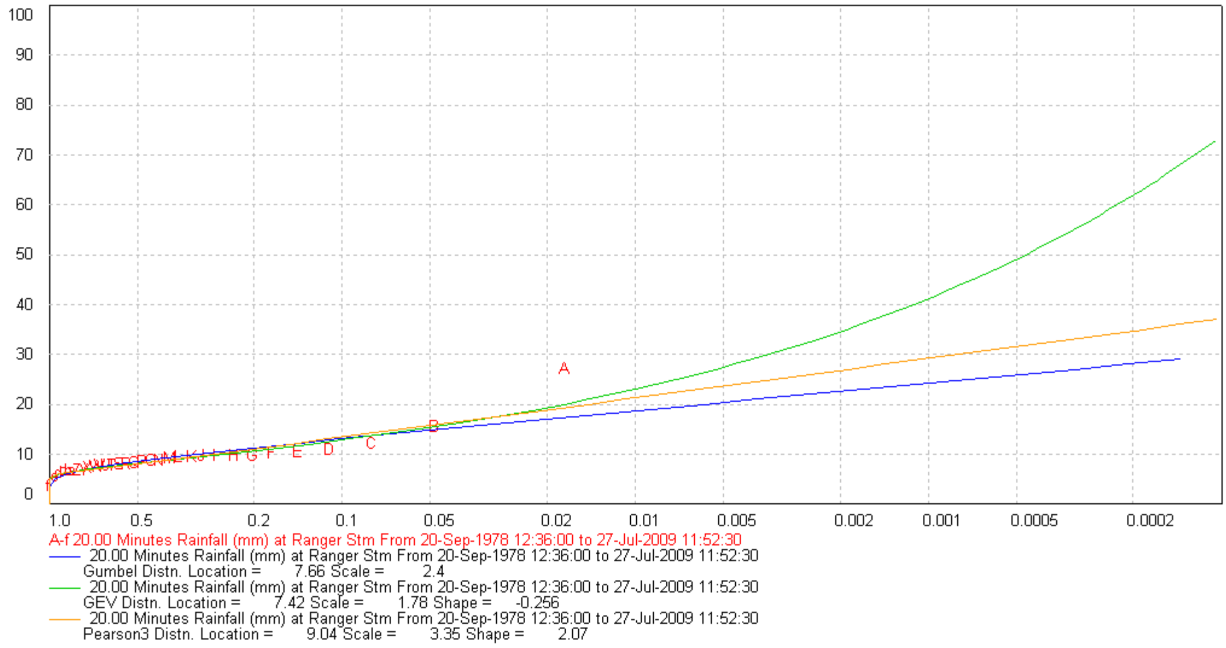

Figure A.90 Ranger Stream 20-min rainfall frequency analysis.

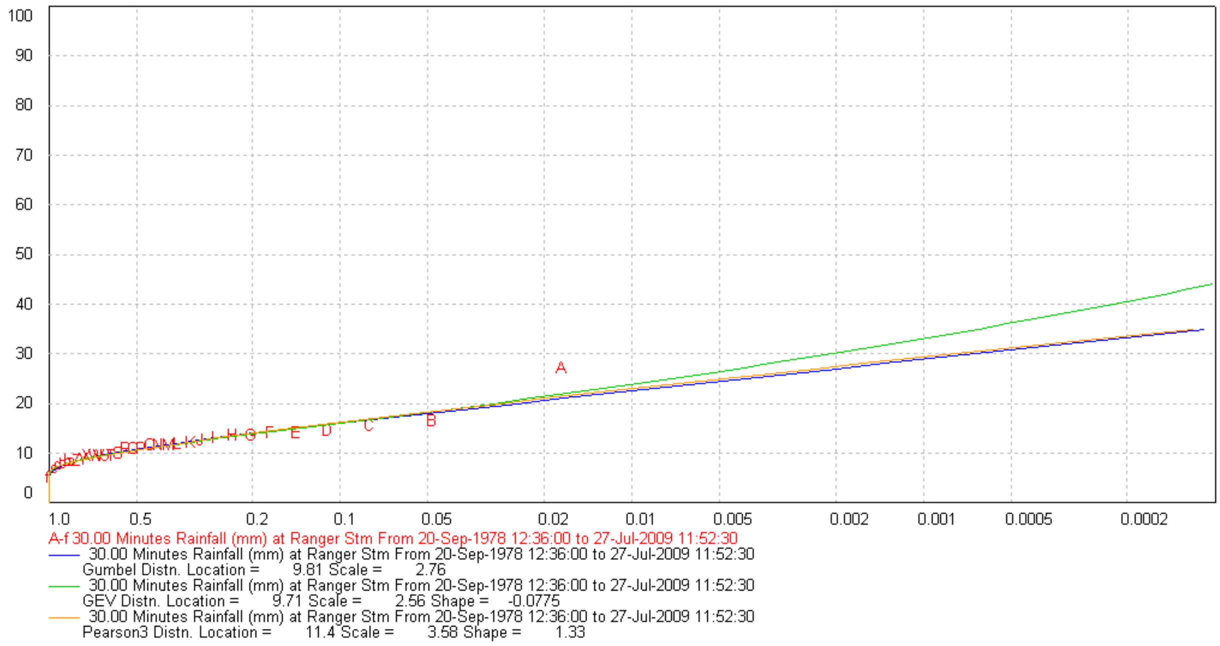

Figure A.91 Ranger Stream 30-min rainfall frequency analysis.

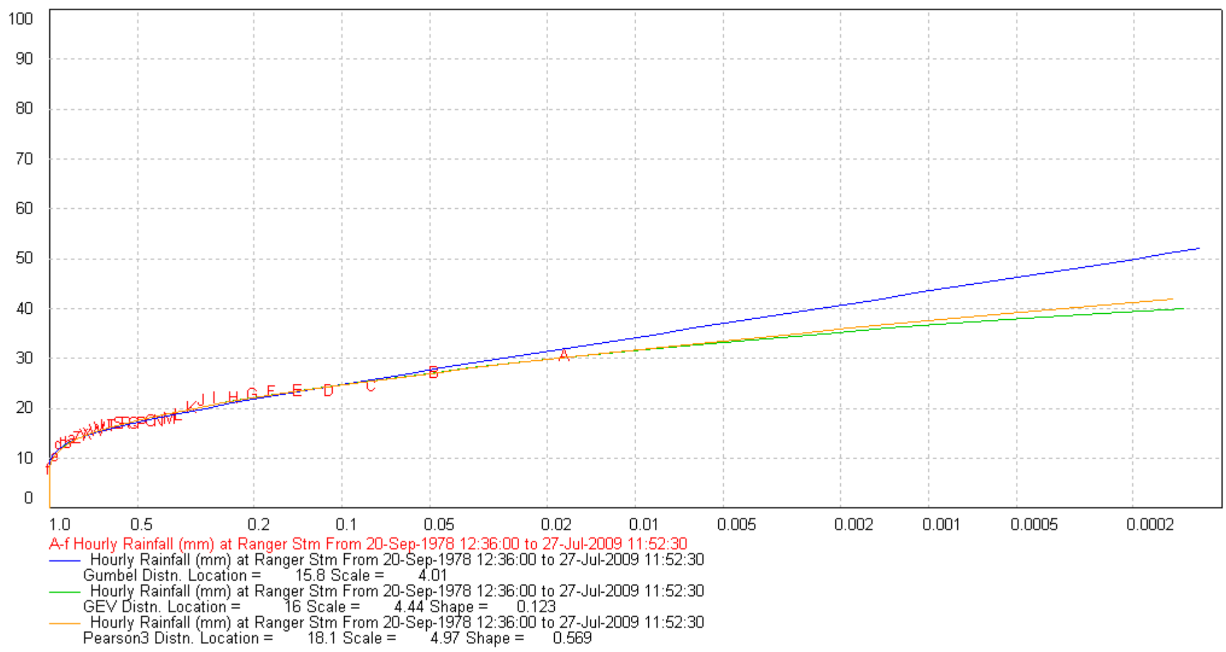

Figure A.92 Ranger Stream 1-hour rainfall frequency analysis.

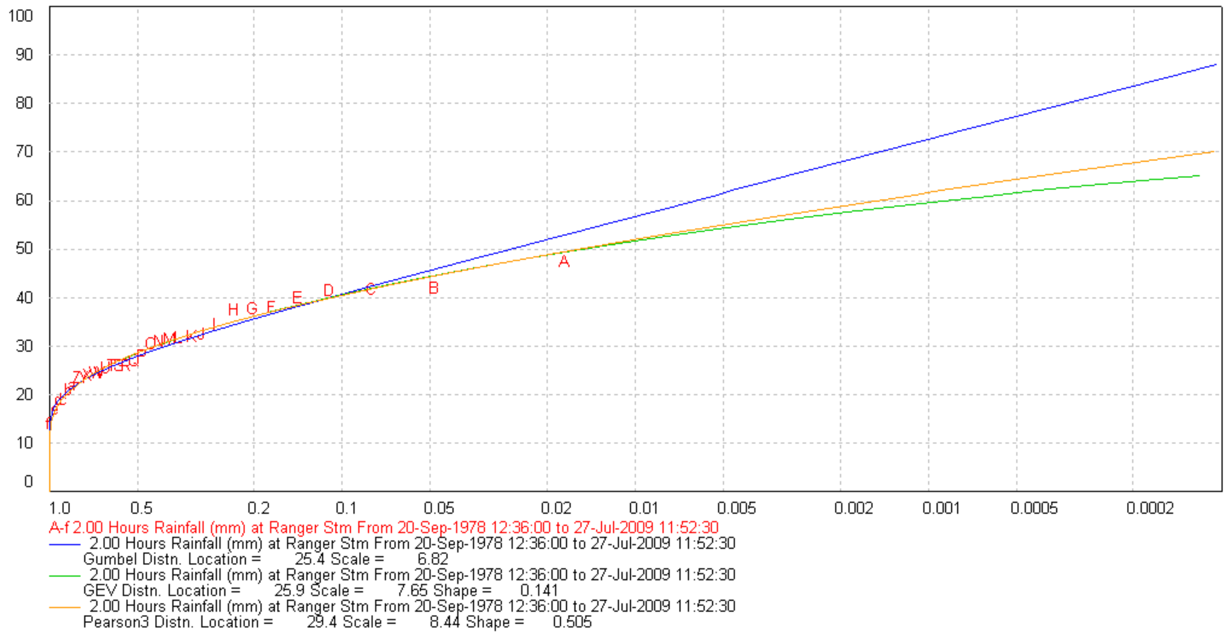

Figure A.93 **Ranger Stream 2-hour rainfall frequency analysis.**

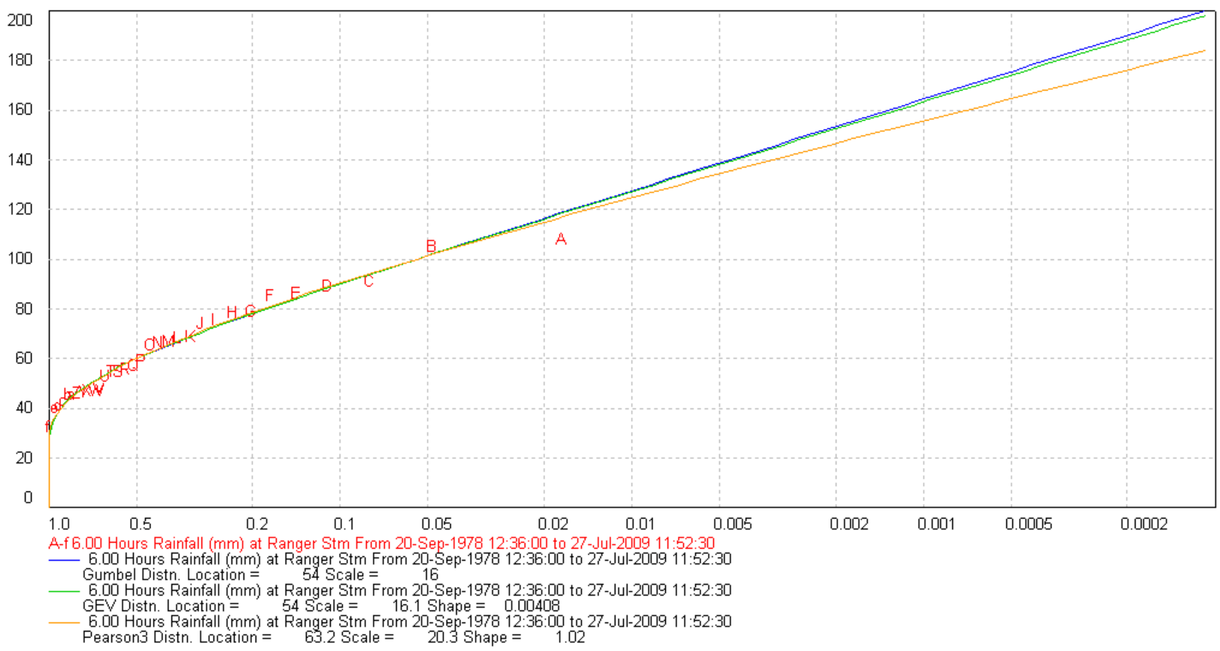

Figure A.94 **Ranger Stream 6-hour rainfall frequency analysis.**

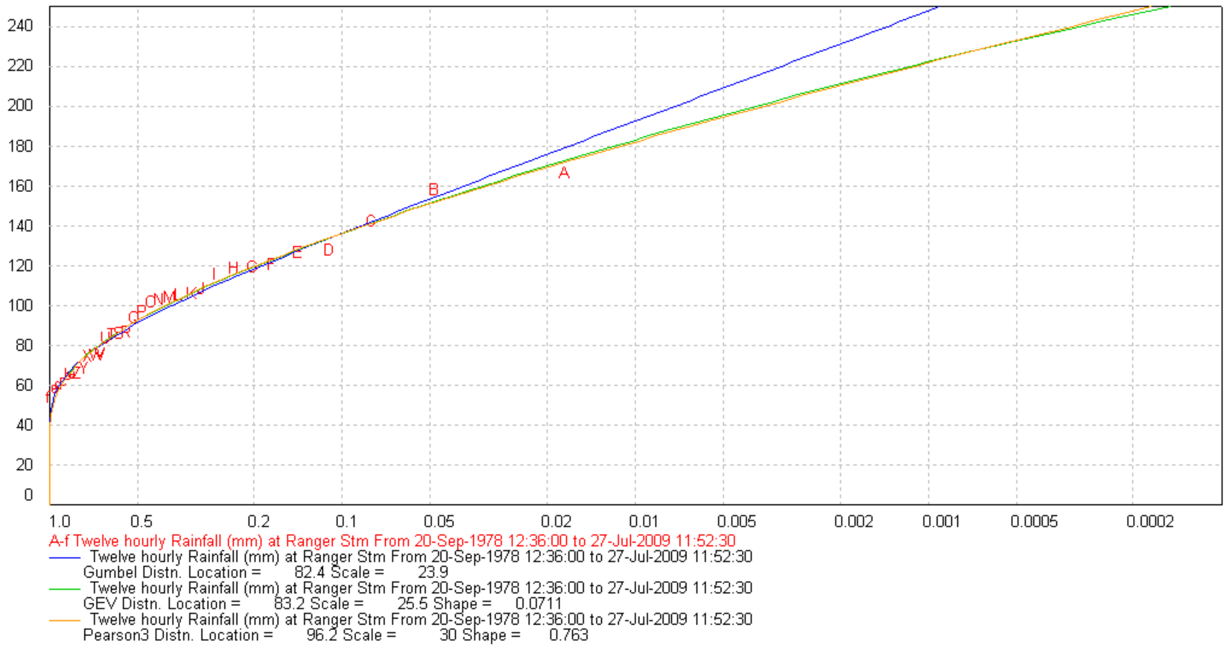

Figure A.95 Ranger Stream 12-hour rainfall frequency analysis.

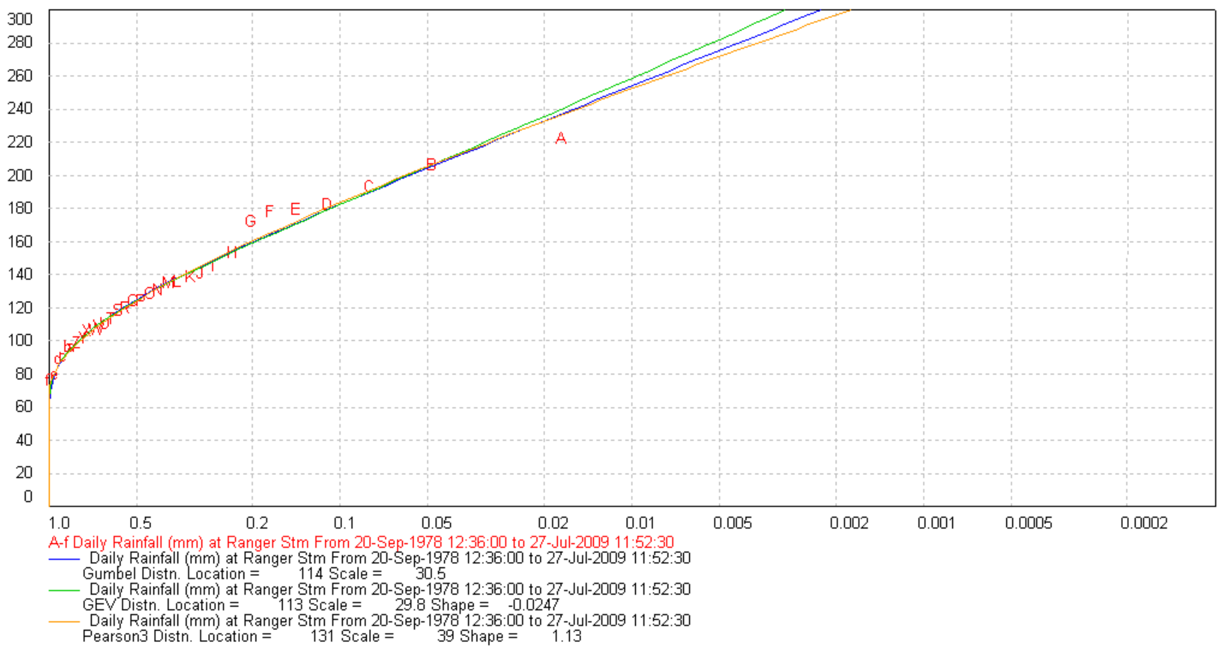

Figure A.96 Ranger Stream 24-hour rainfall frequency analysis.

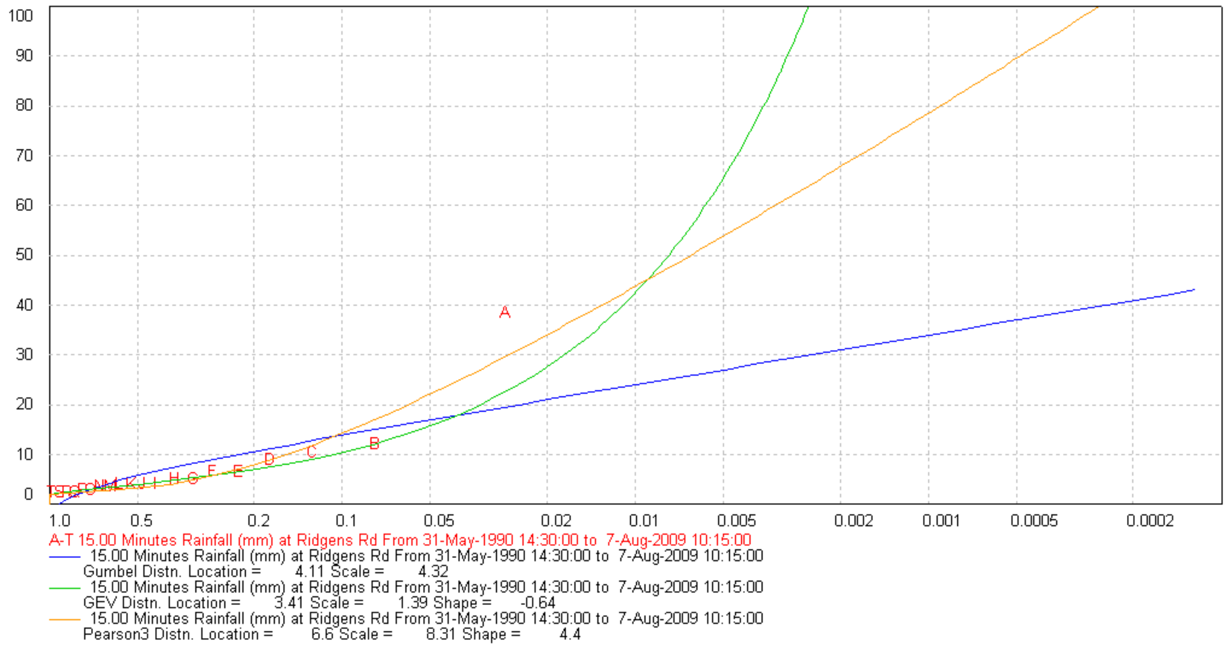

Figure A.97 Ridgens Road 15-min rainfall frequency analysis (Subsequently used define the 10-min design rainfall by interpolation).

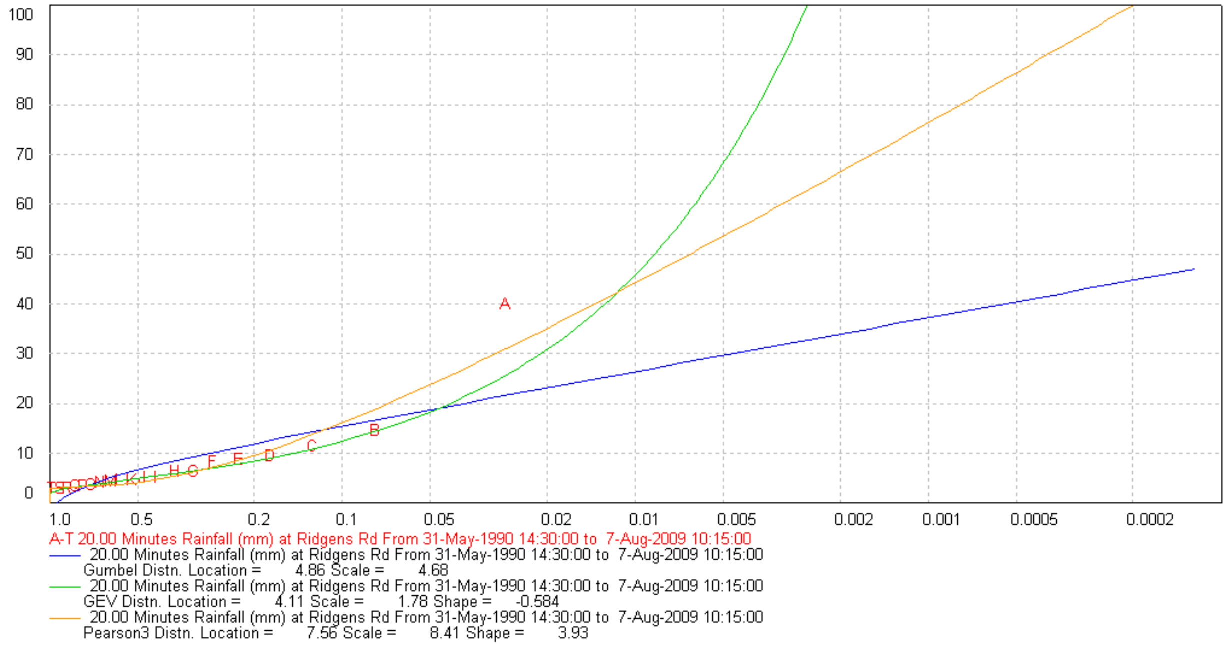

Figure A.98 Ridgens Road 20-min rainfall frequency analysis.

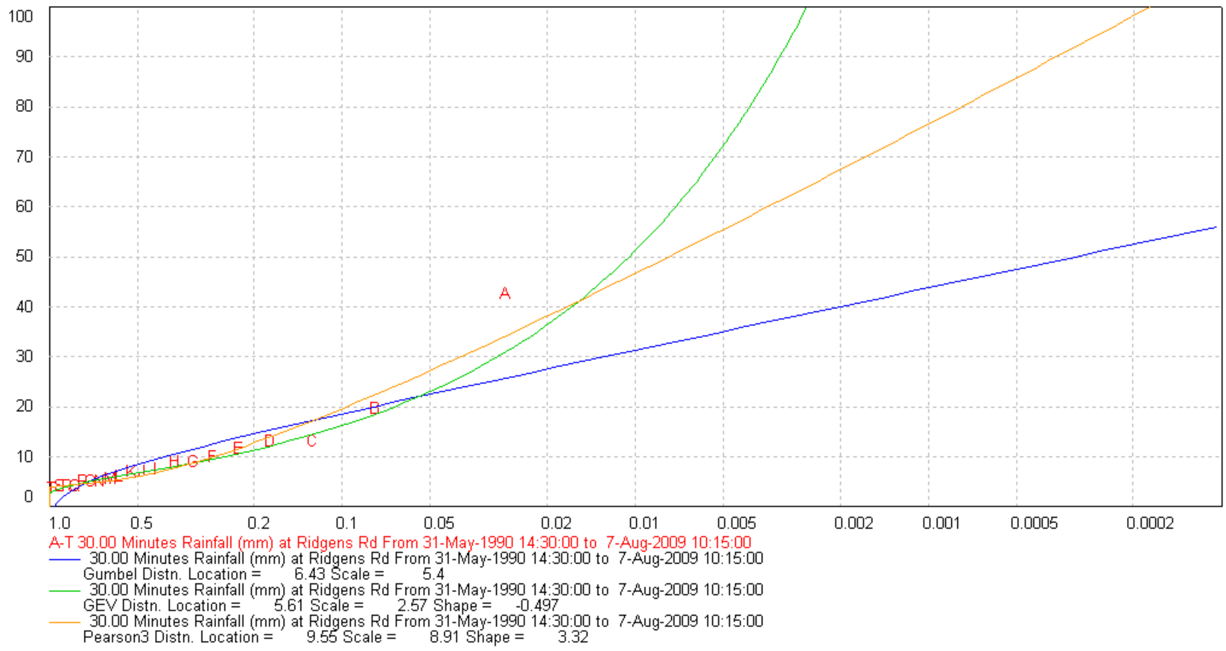

Figure A.99 Ridgens Road 30-min rainfall frequency analysis.

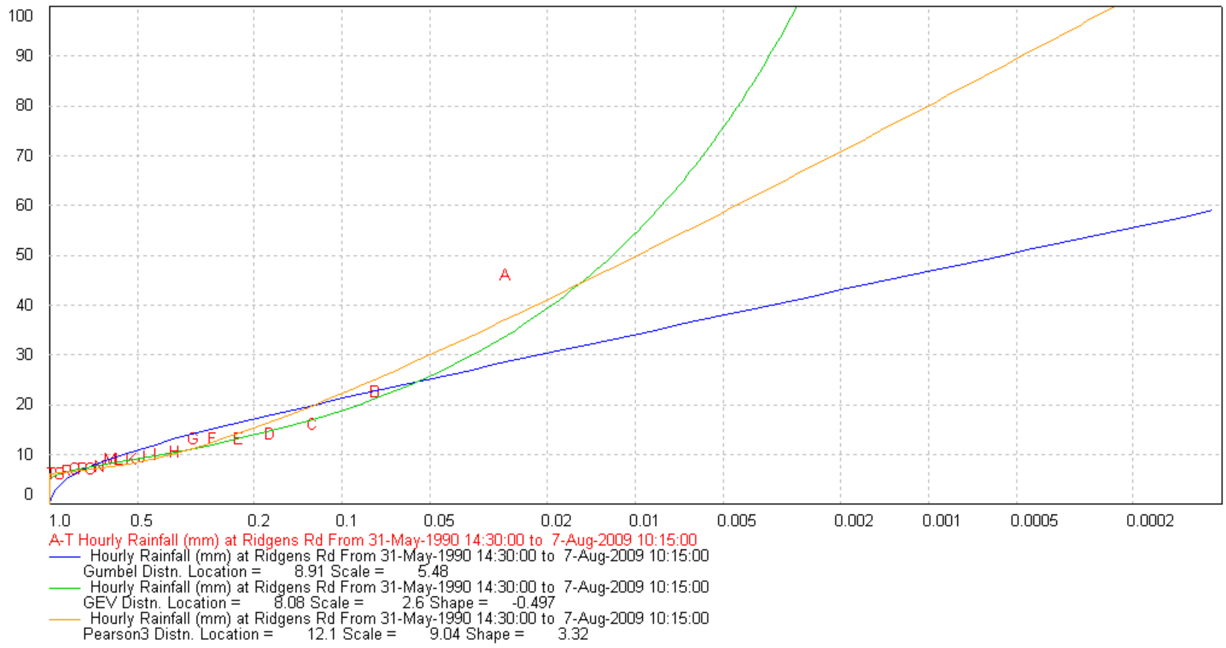

Figure A.100 Ridgens Road 1-hour rainfall frequency analysis.

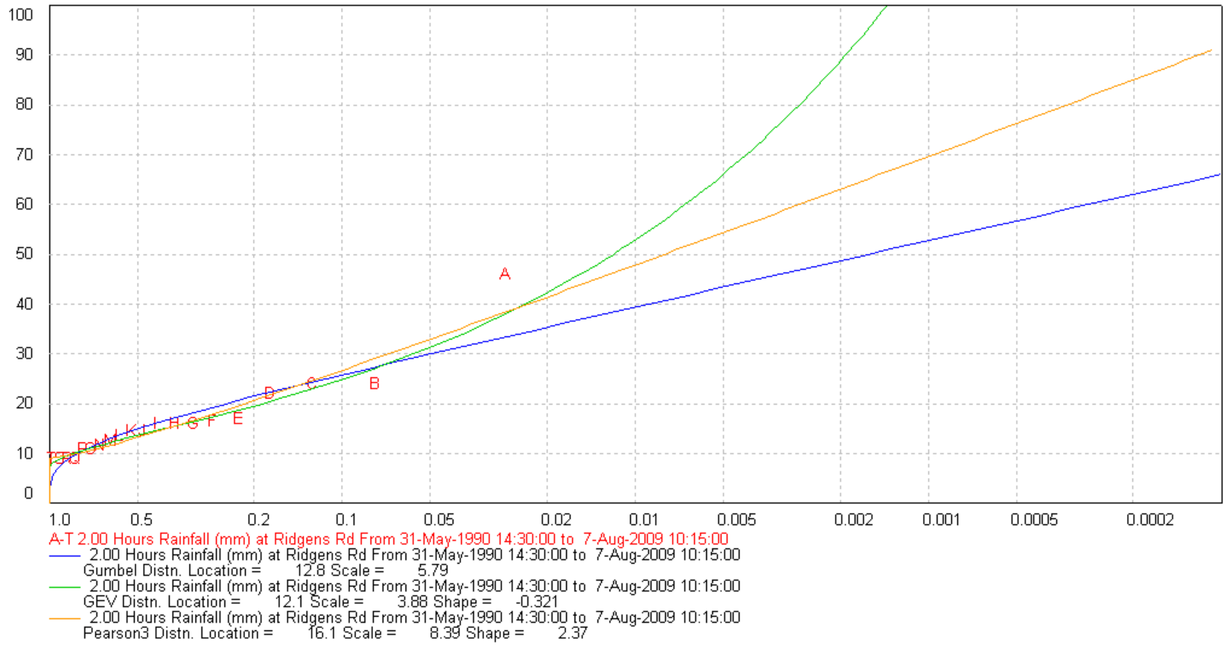

Figure A.101 Ridgens Road 2-hour rainfall frequency analysis.

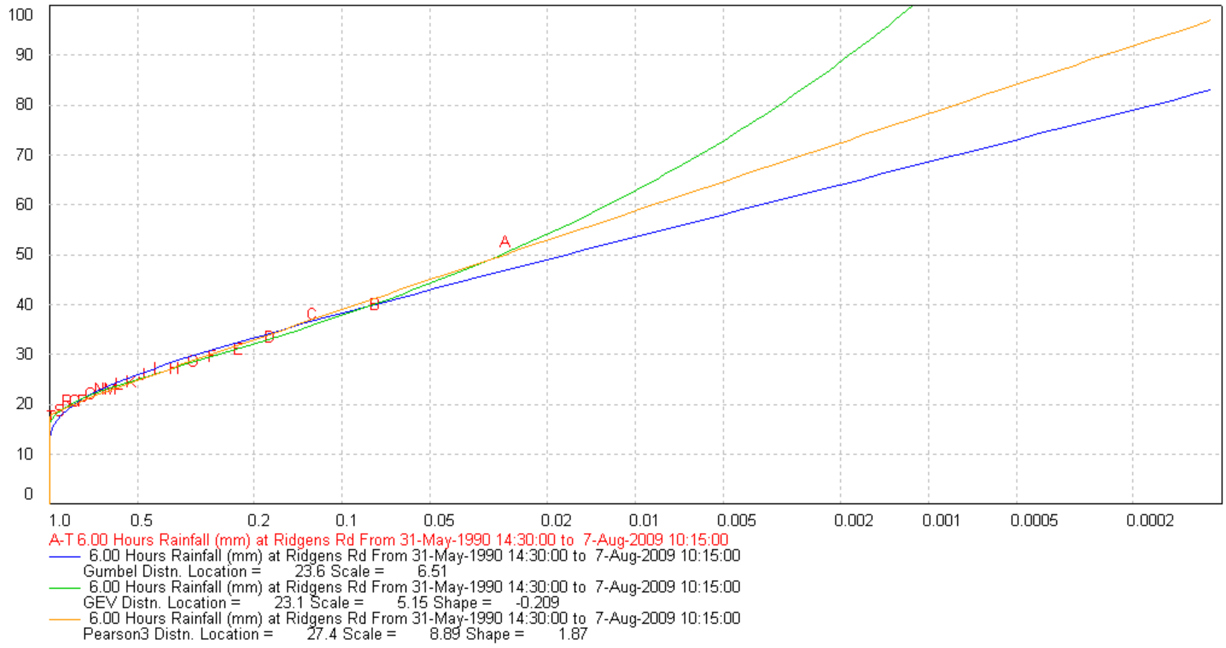

Figure A.102 Ridgens Road 6-hour rainfall frequency analysis.

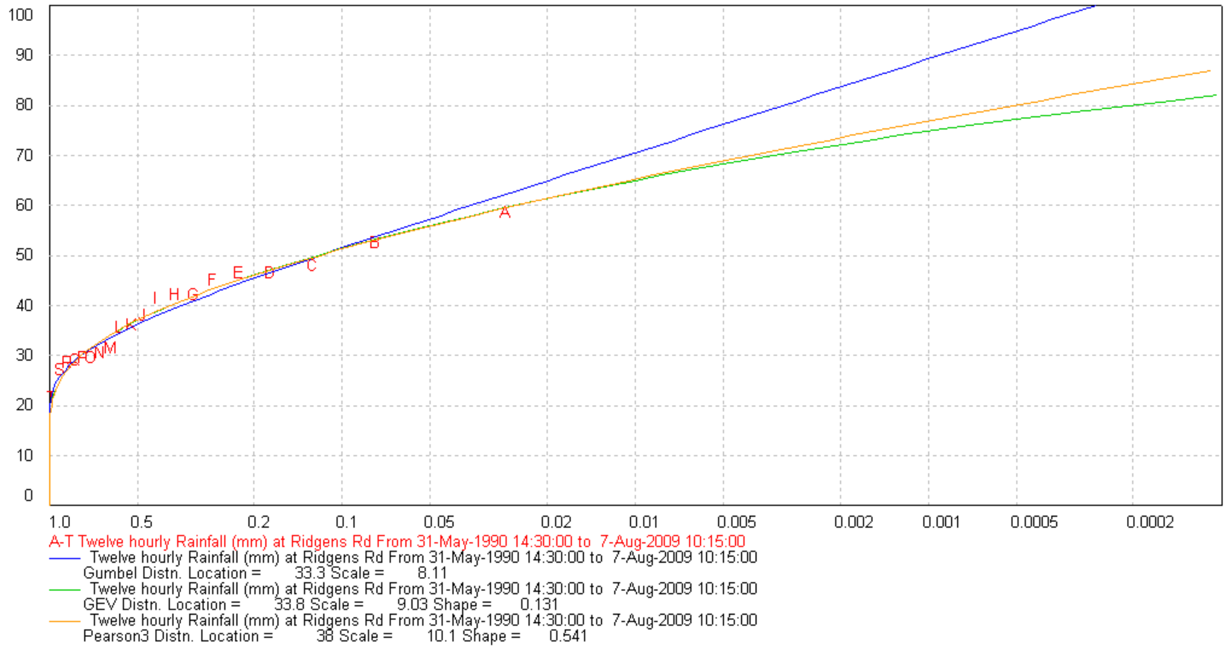

Figure A.103 Ridgens Road 12-hour rainfall frequency analysis.

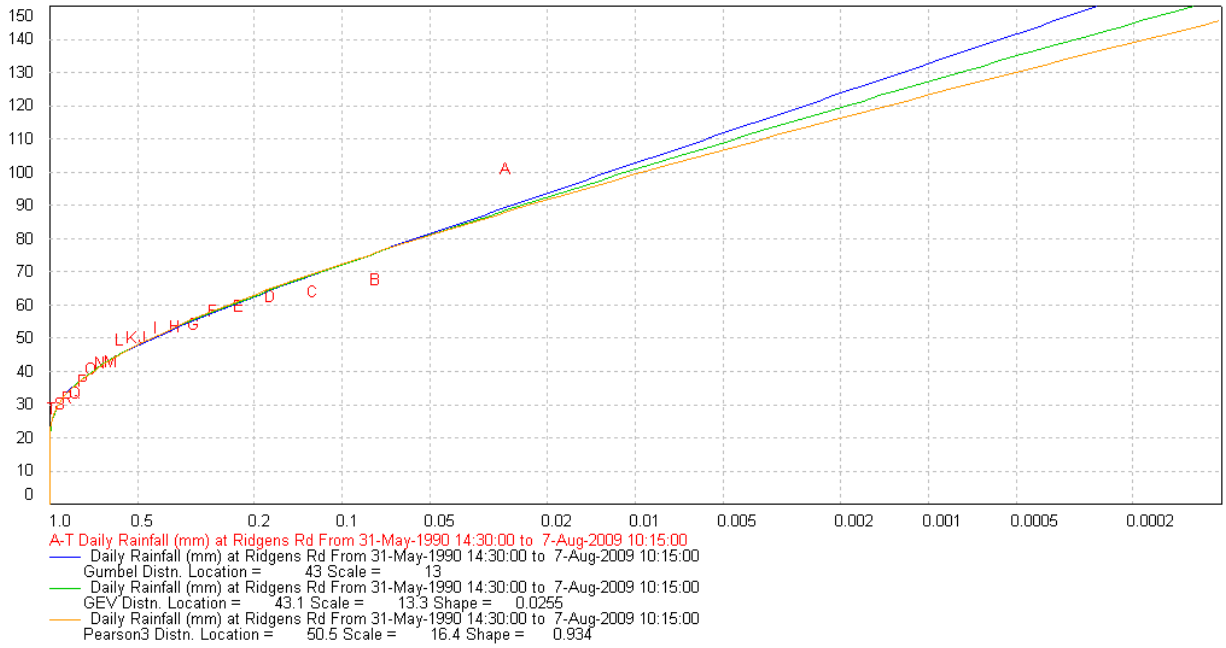

Figure A.104 Ridgens Road 24-hour rainfall frequency analysis.

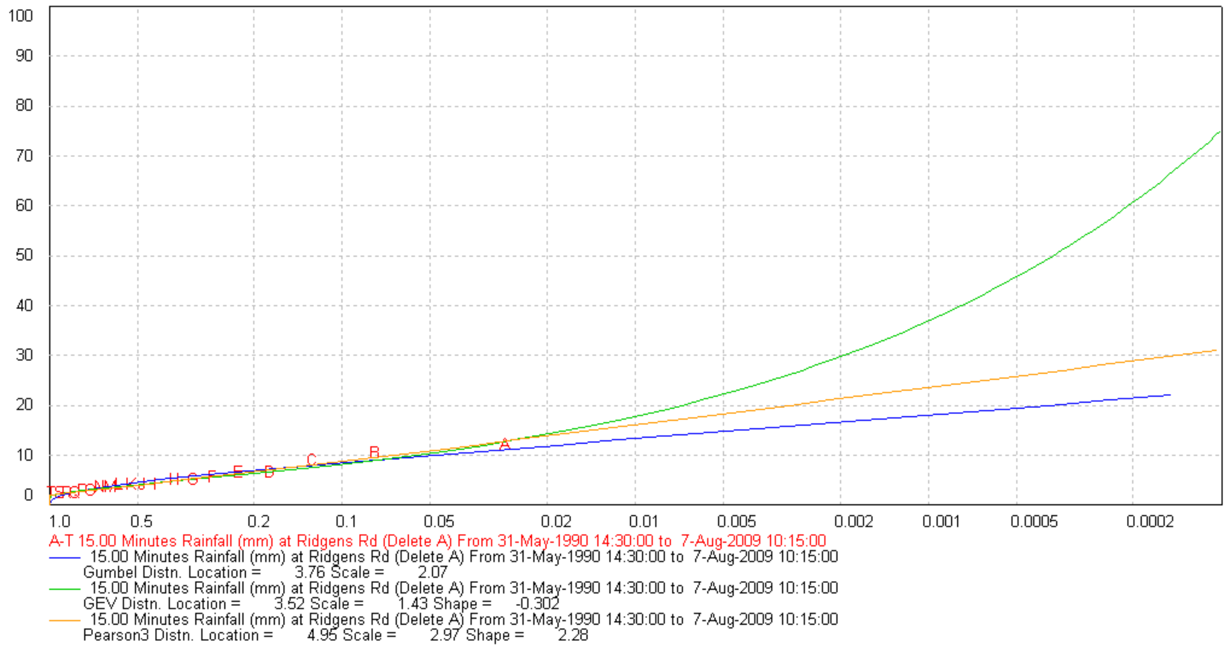

Figure A.105 Ridgens Road 15-min rainfall frequency analysis, without the 15/11/09 event (Subsequently used define the 10-min design rainfall by interpolation).

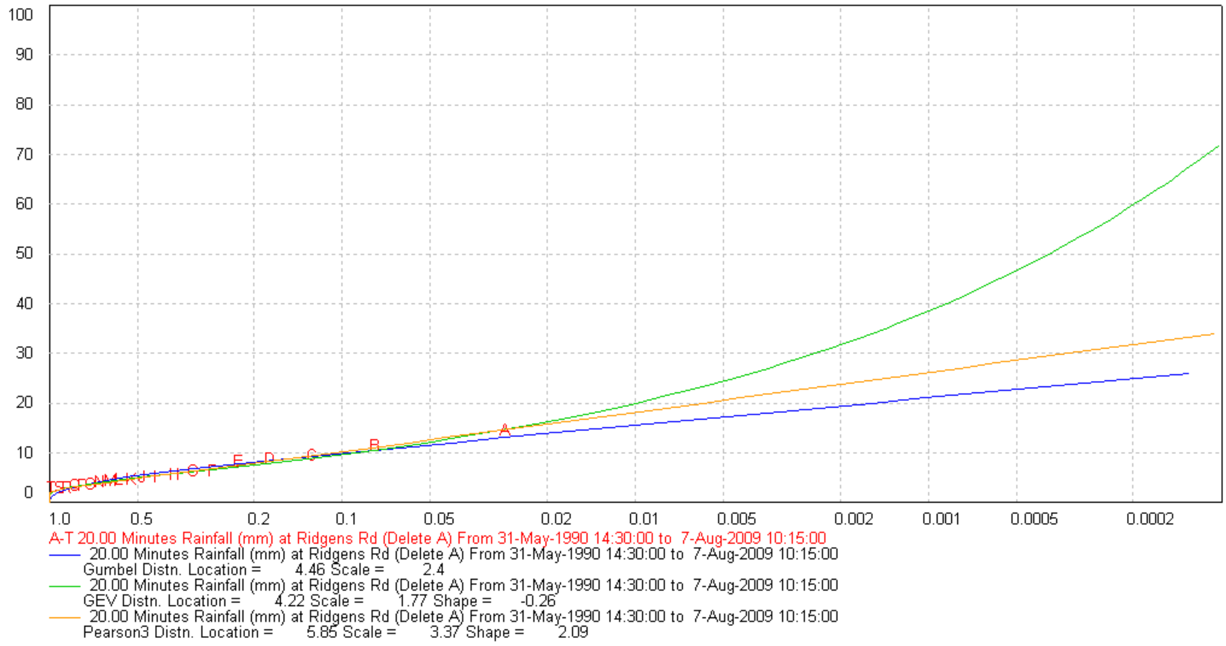

Figure A.106 Ridgens Road 20-min rainfall frequency analysis, without the 15/11/09 event.

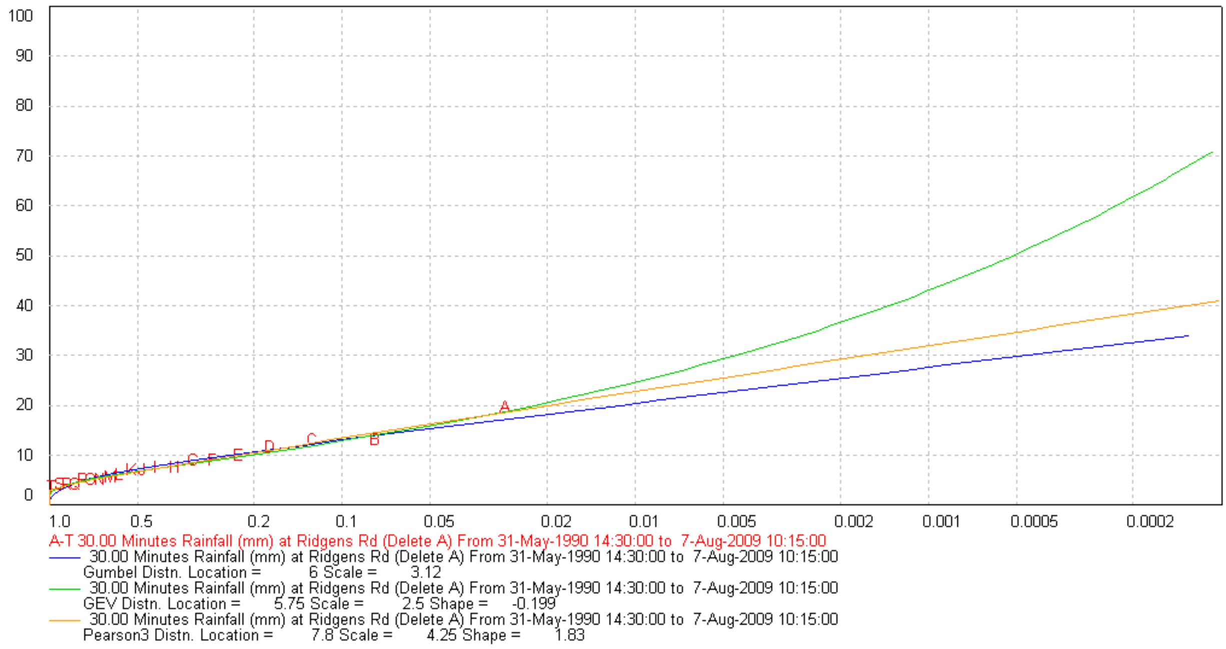

Figure A.107 Ridgens Road 30-min rainfall frequency analysis, without the 15/11/09 event.

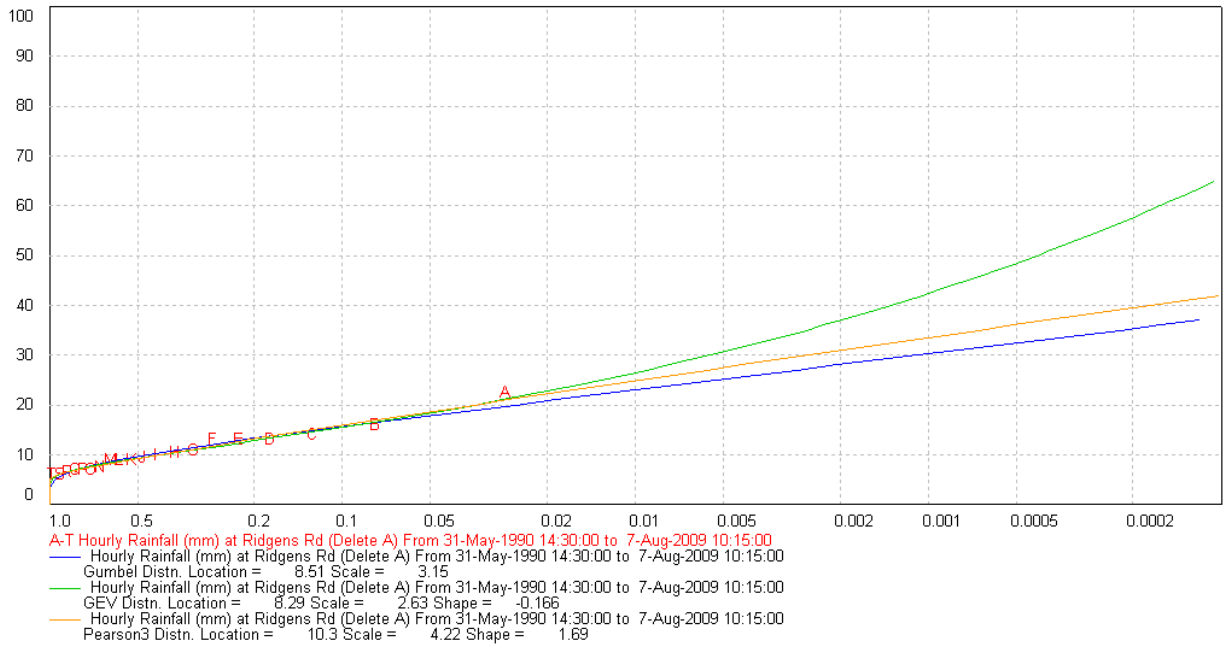

Figure A.108 Ridgens Road 1-hour rainfall frequency analysis, without the 15/11/09 event.

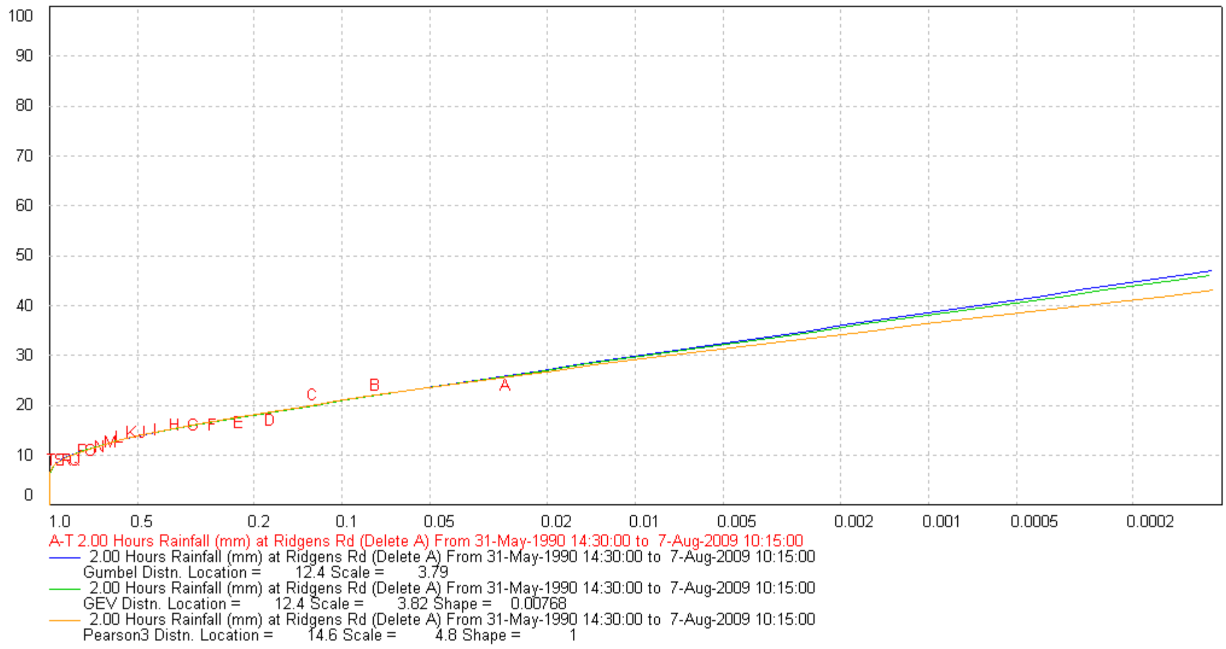

Figure A.109 Ridgens Road 2-hour rainfall frequency analysis, without the 15/11/09 event.

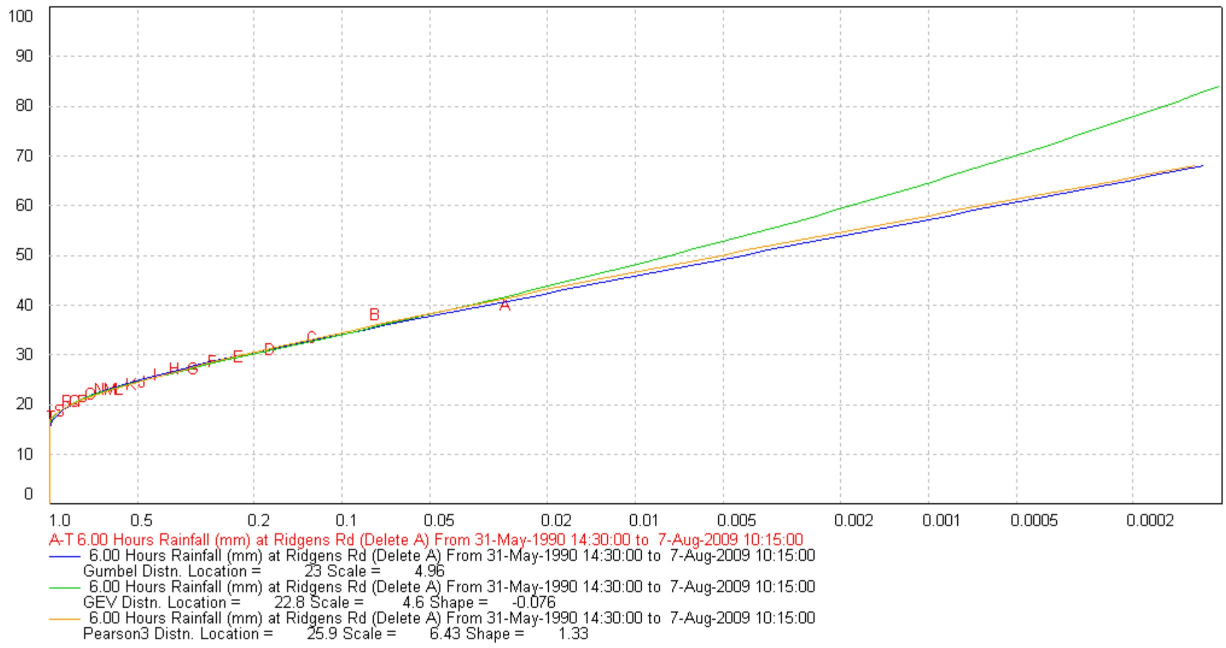

Figure A.110 Ridgens Road 6-hour rainfall frequency analysis, without the 15/11/09 event.

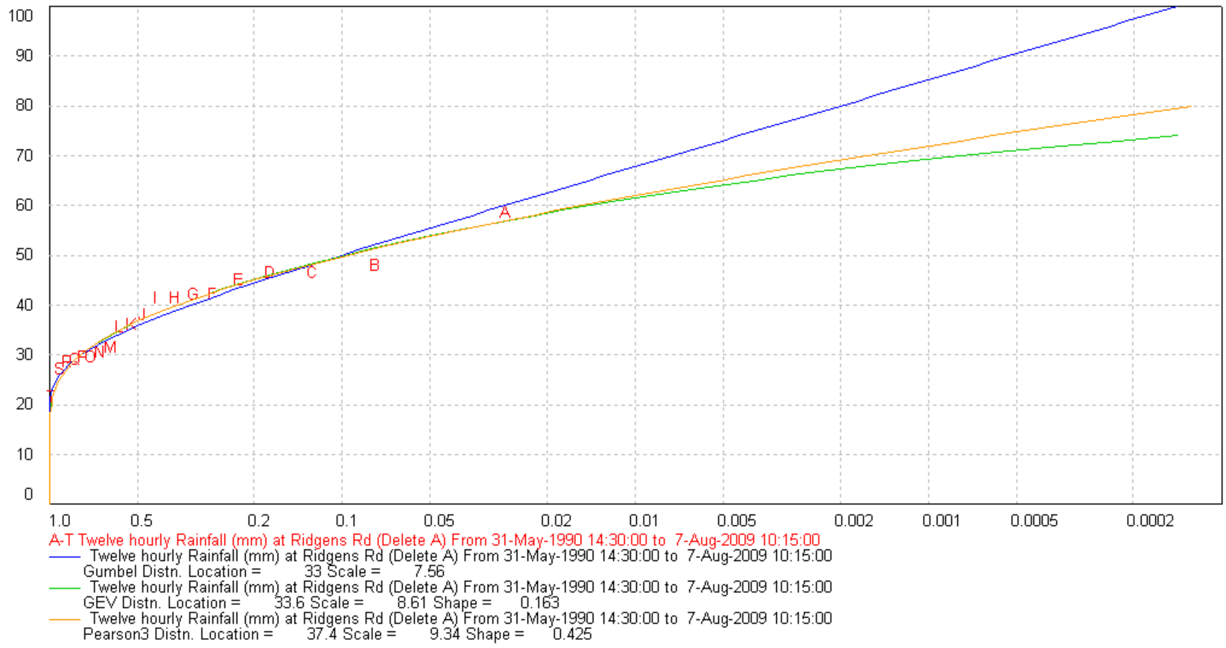

Figure A.111 Ridgens Road 12-hour rainfall frequency analysis, without the 15/11/09 event.

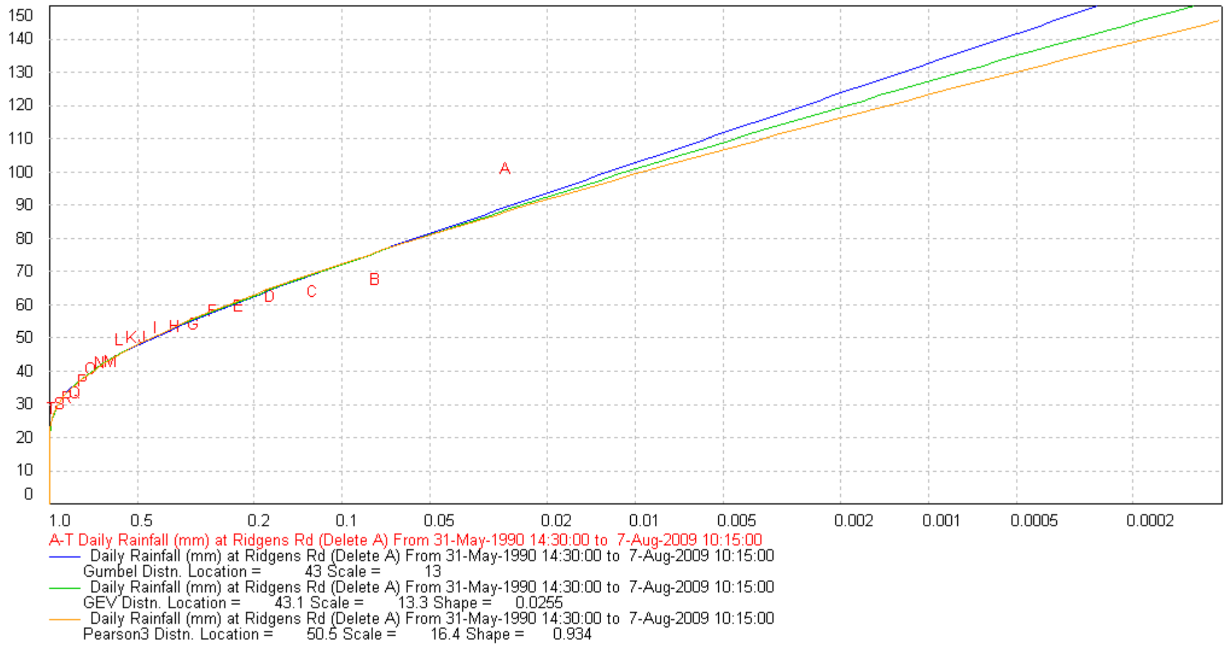

Figure A.112 Ridgens Road 24-hour rainfall frequency analysis, without the 15/11/09 event.

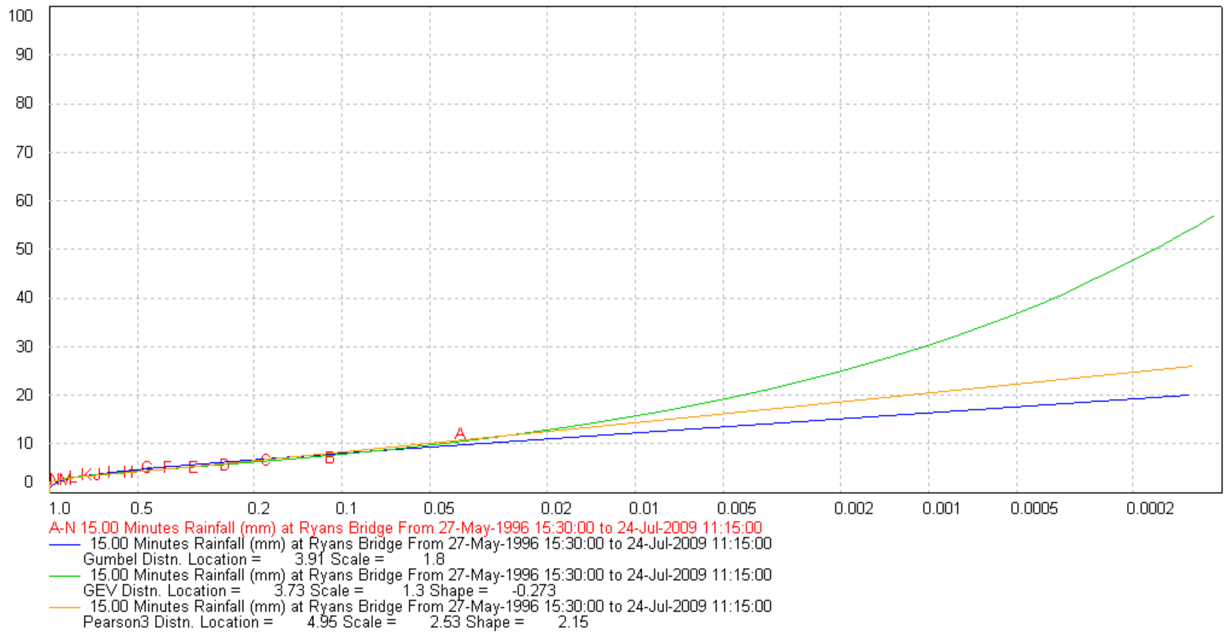

Figure A.113 Ryans Bridge 15-min rainfall frequency analysis.

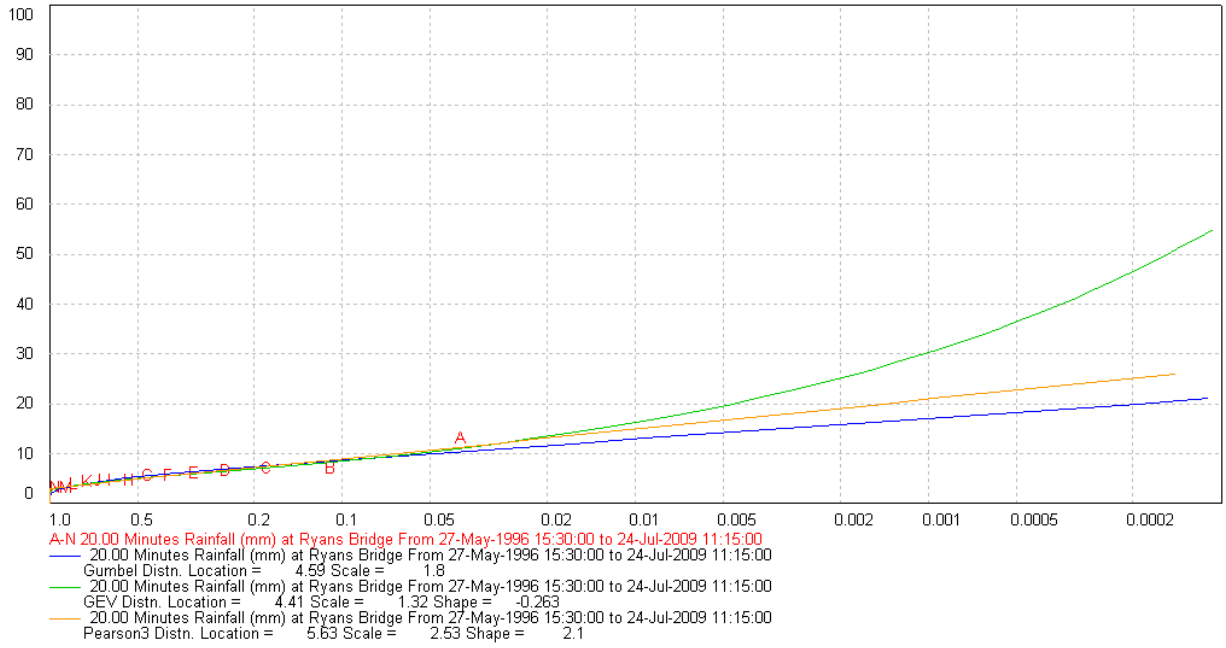

Figure A.114 Ryans Bridge 20-min rainfall frequency analysis.

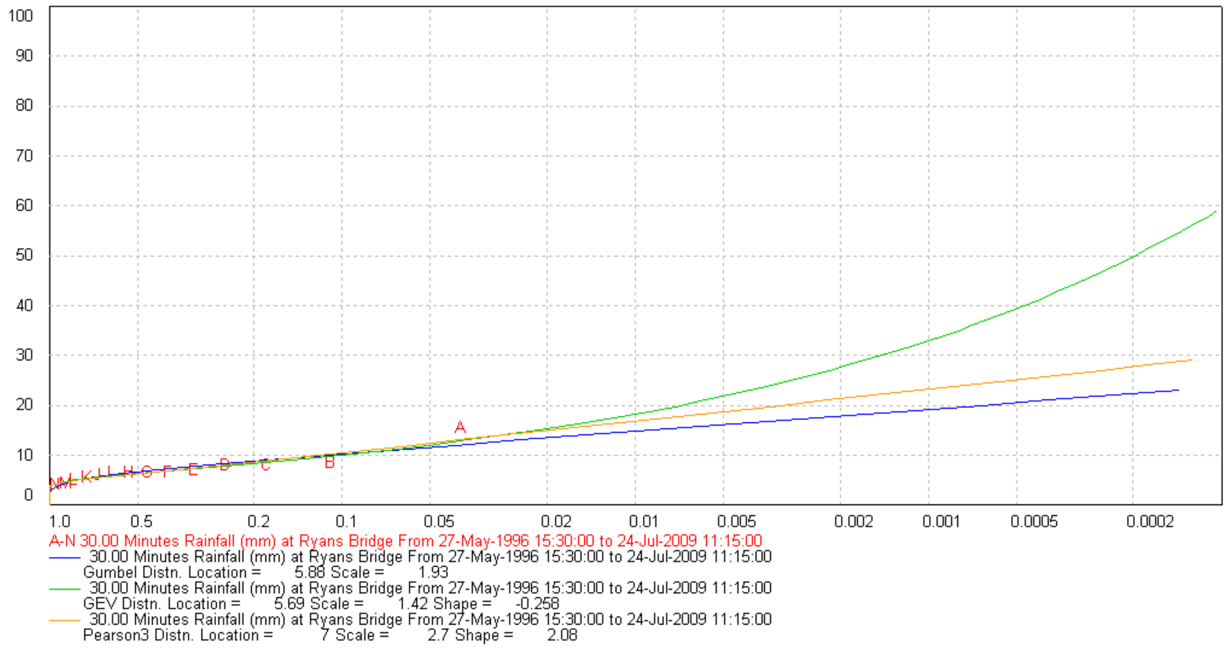

Figure A.115 Ryans Bridge 30-min rainfall frequency analysis.

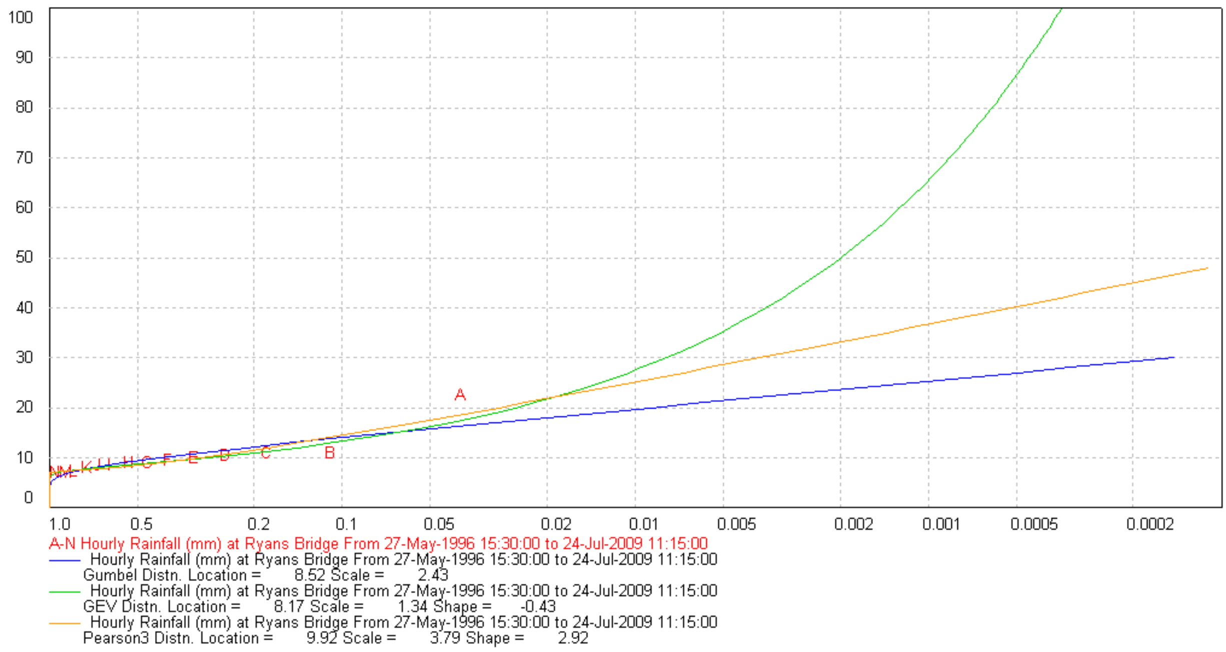

Figure A.116 Ryans Bridge 1-hour rainfall frequency analysis.

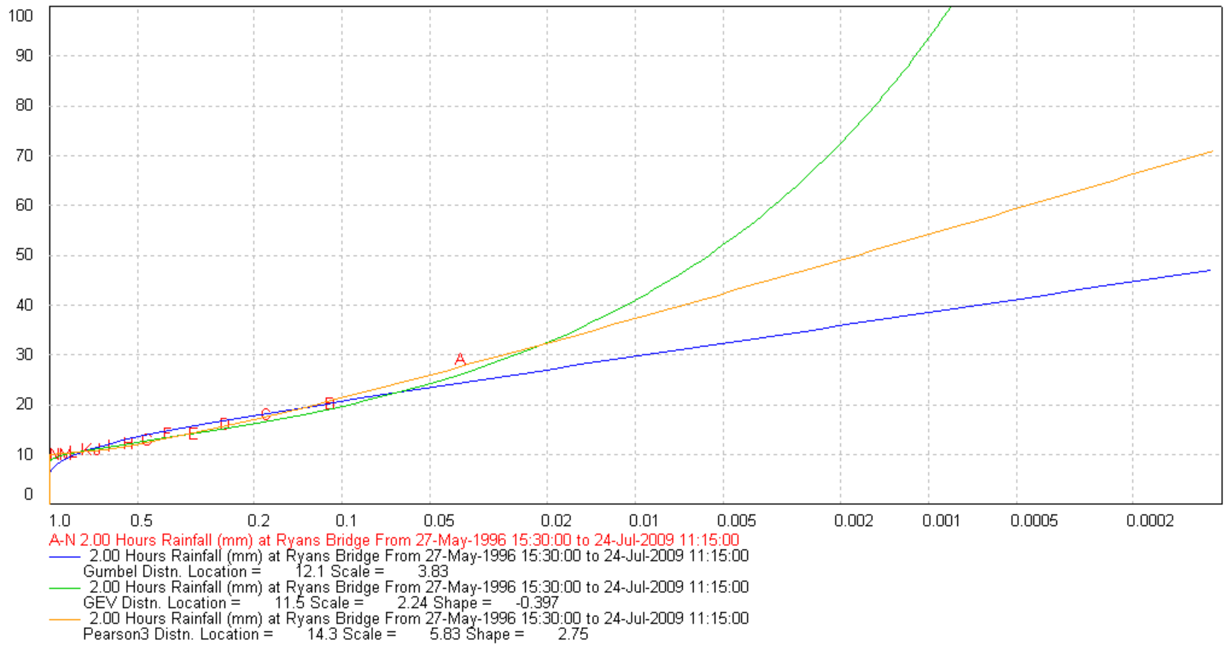

Figure A.117 Ryans Bridge 2-hour rainfall frequency analysis.

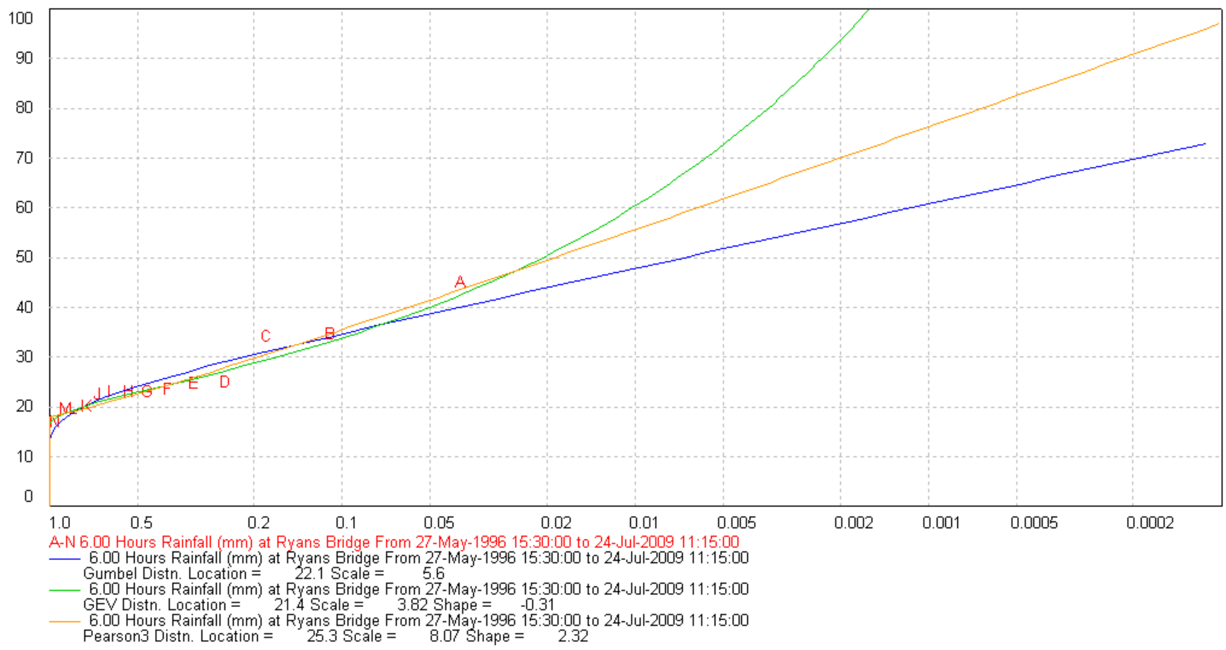

Figure A.118 Ryans Bridge 6-hour rainfall frequency analysis.

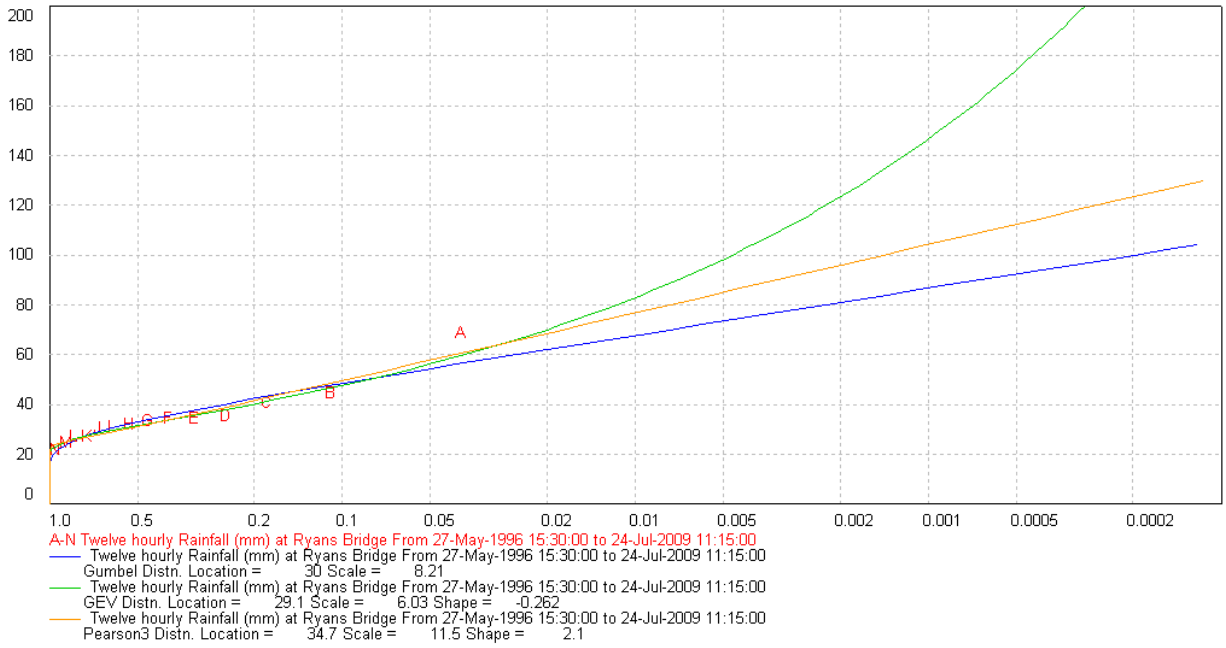

Figure A.119 Ryans Bridge 12-hour rainfall frequency analysis.

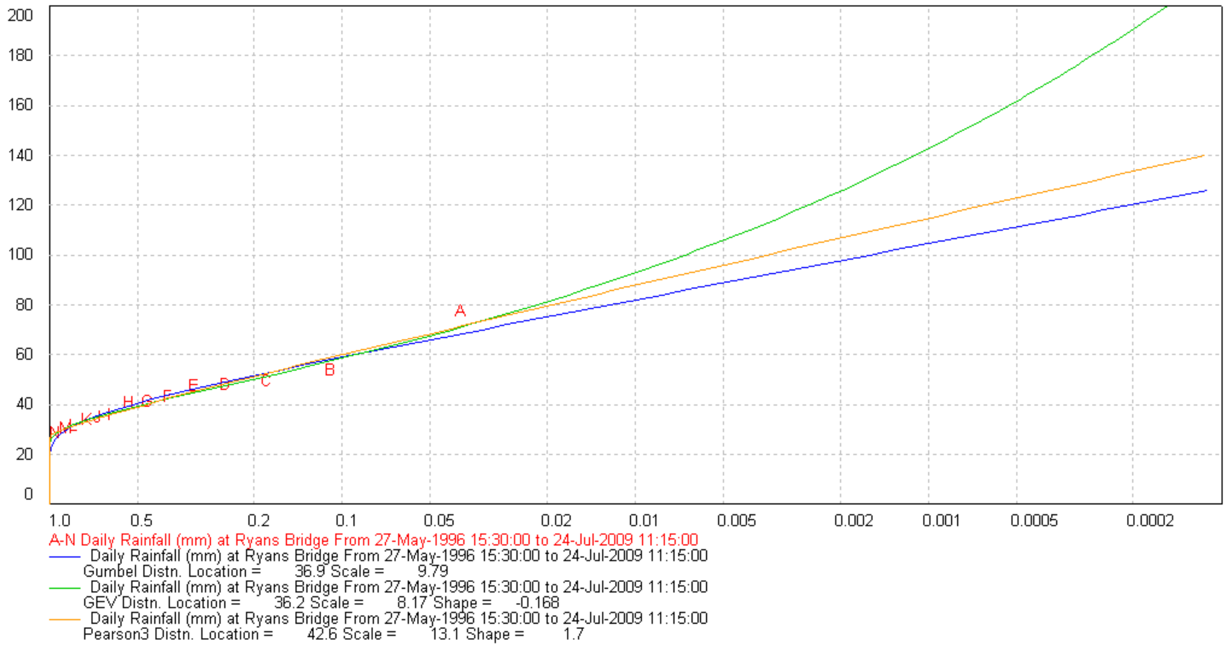

Figure A.120 Ryans Bridge 24-hour rainfall frequency analysis.

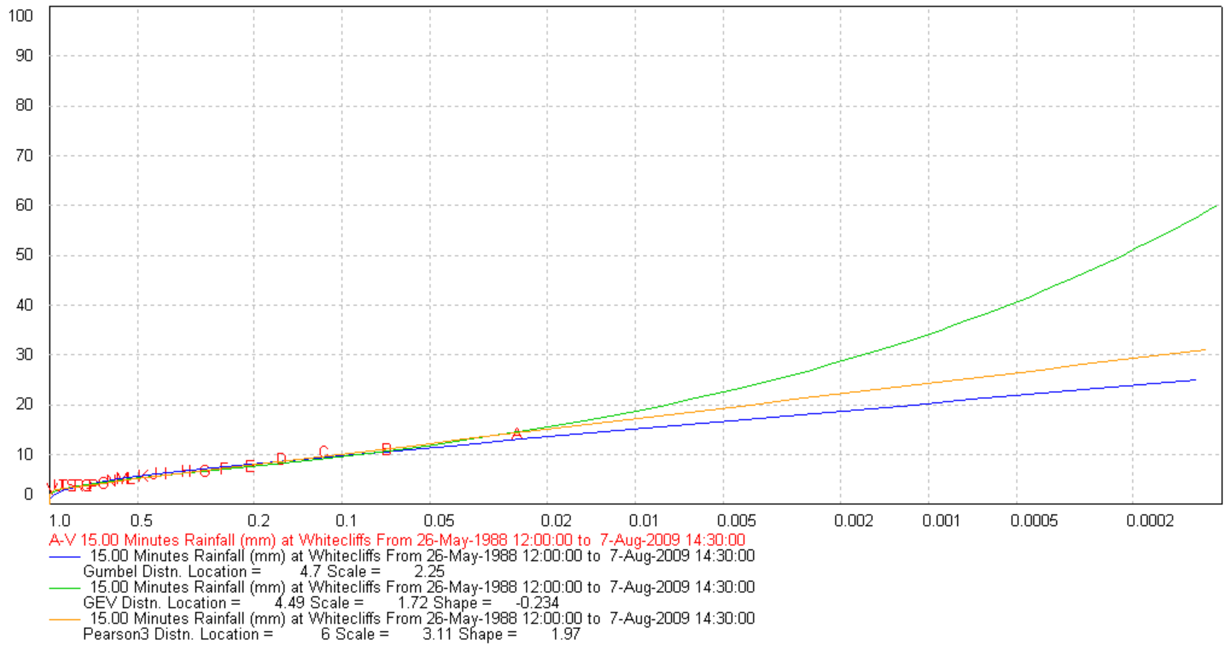

Figure A.121 Whitecliffs 15-min rainfall frequency analysis.

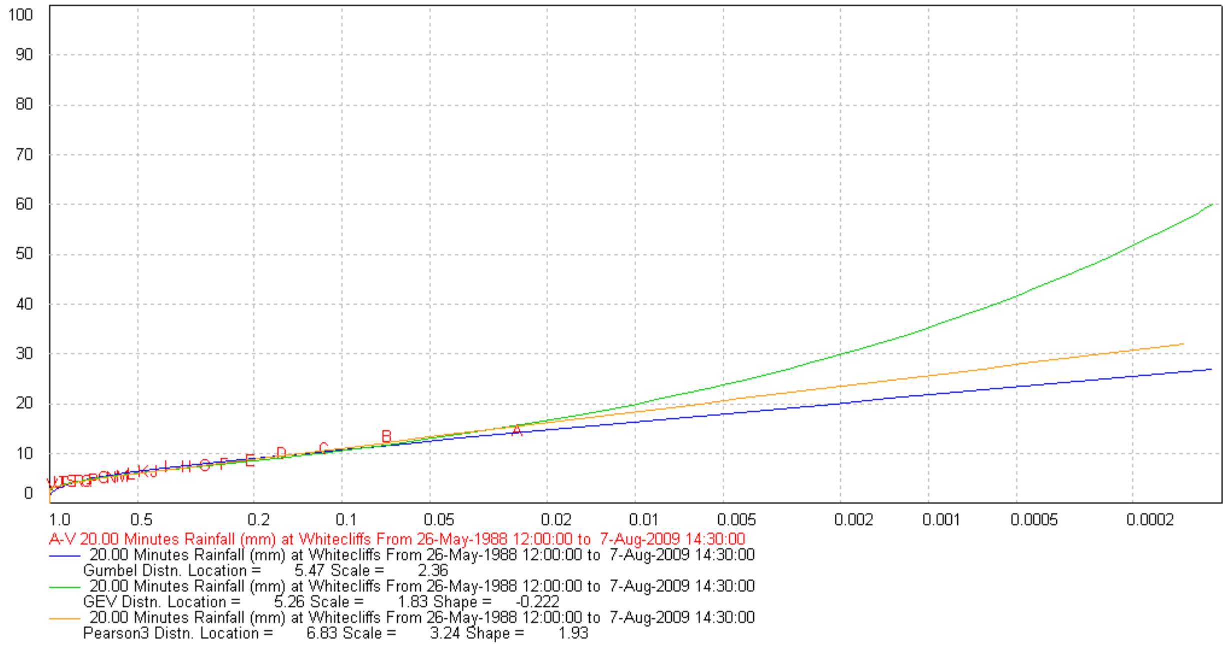

Figure A.122 Whitecliffs 20-min rainfall frequency analysis.

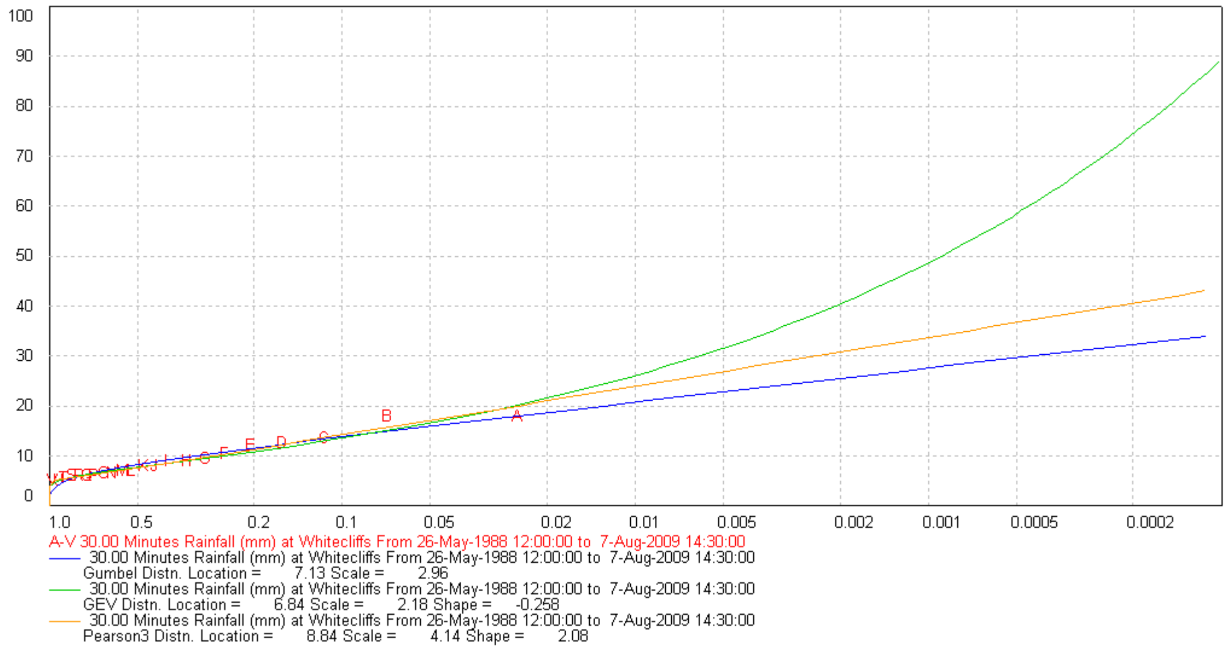

Figure A.123 Whitecliffs 30-mim rainfall frequency analysis.

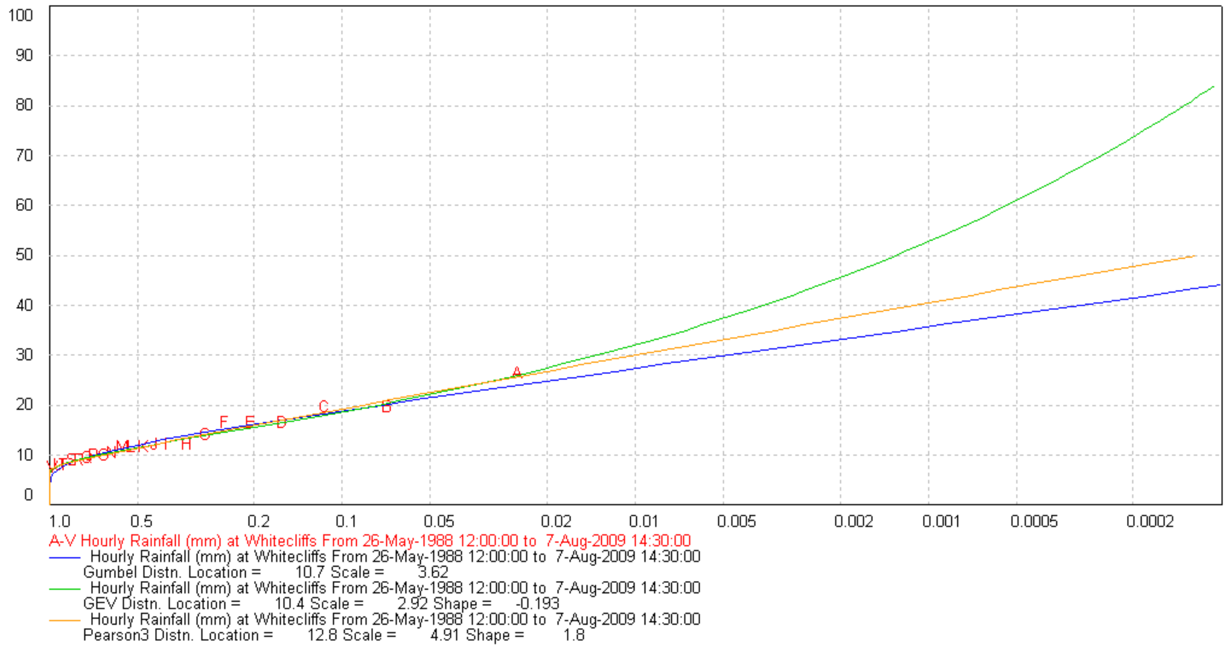

Figure A.124 Whitrecliffs 1-hour rainfall frequency analysis.

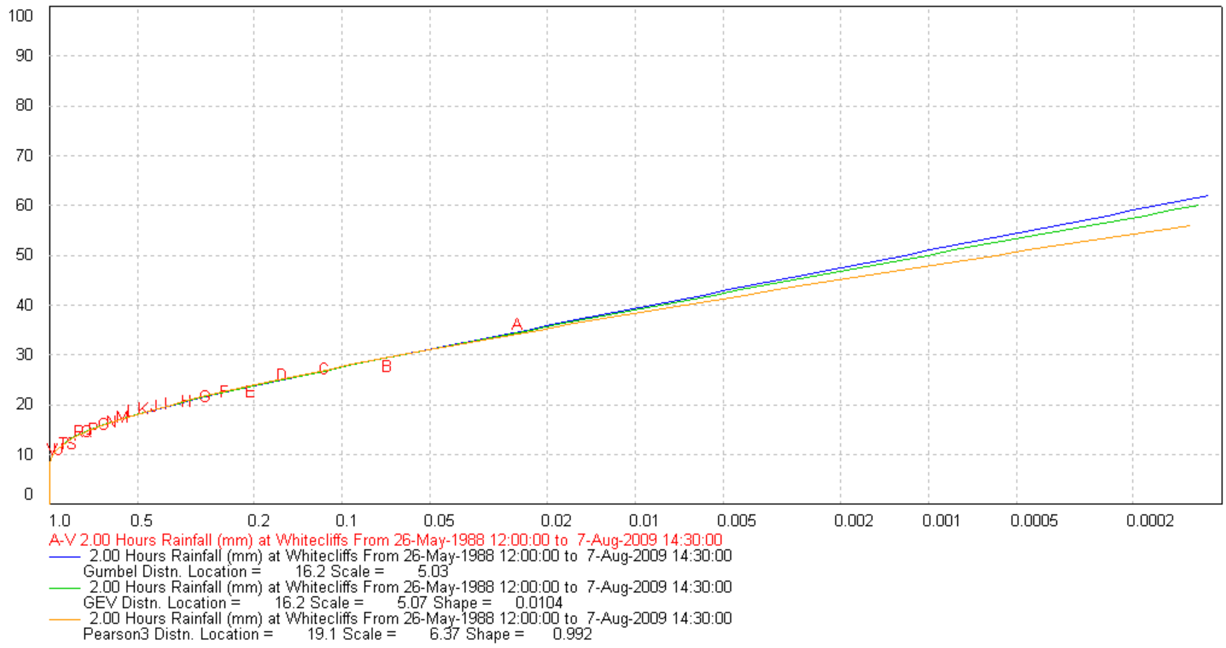

Figure A.125 Whitecliffs 2-hour rainfall frequency analysis

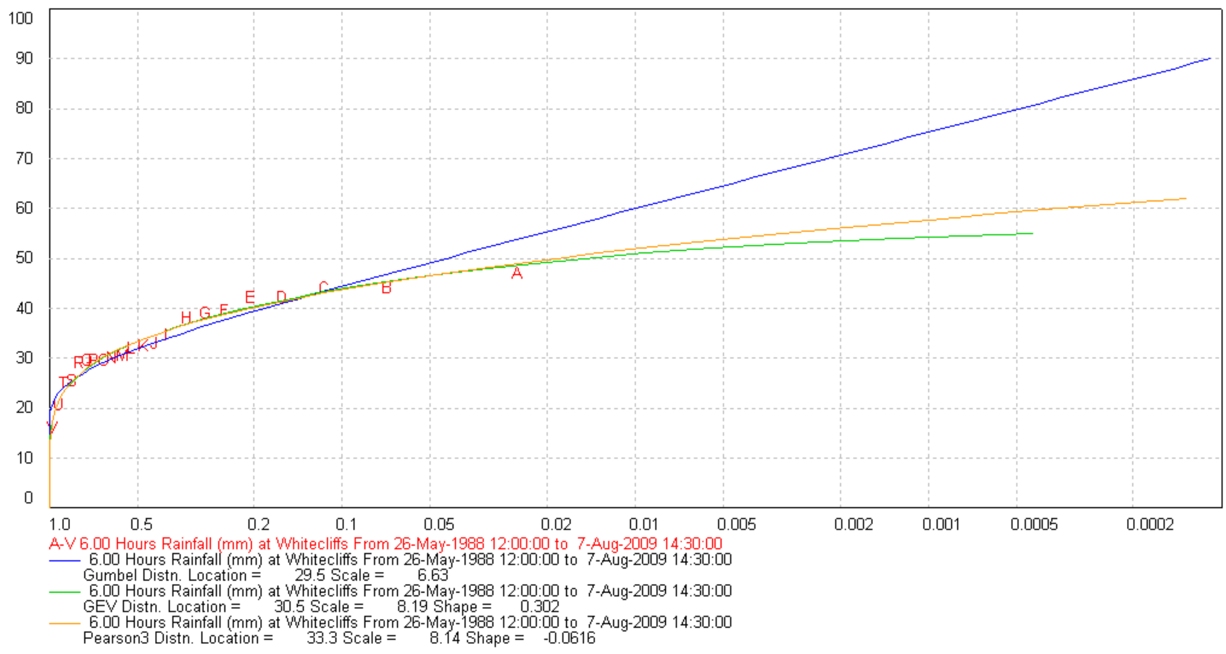

Figure A.126 Whitecliffs 6-hour rainfall frequency analysis.

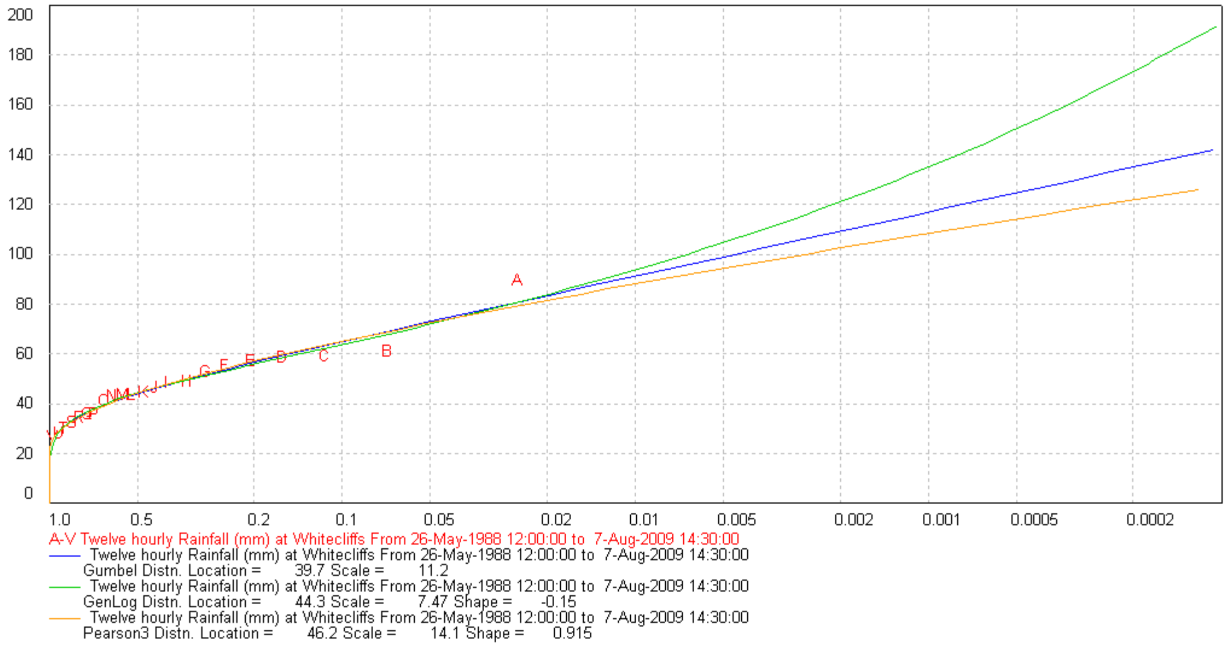

Figure A.127 Whitecliffs 12-hour rainfall frequency analysis.

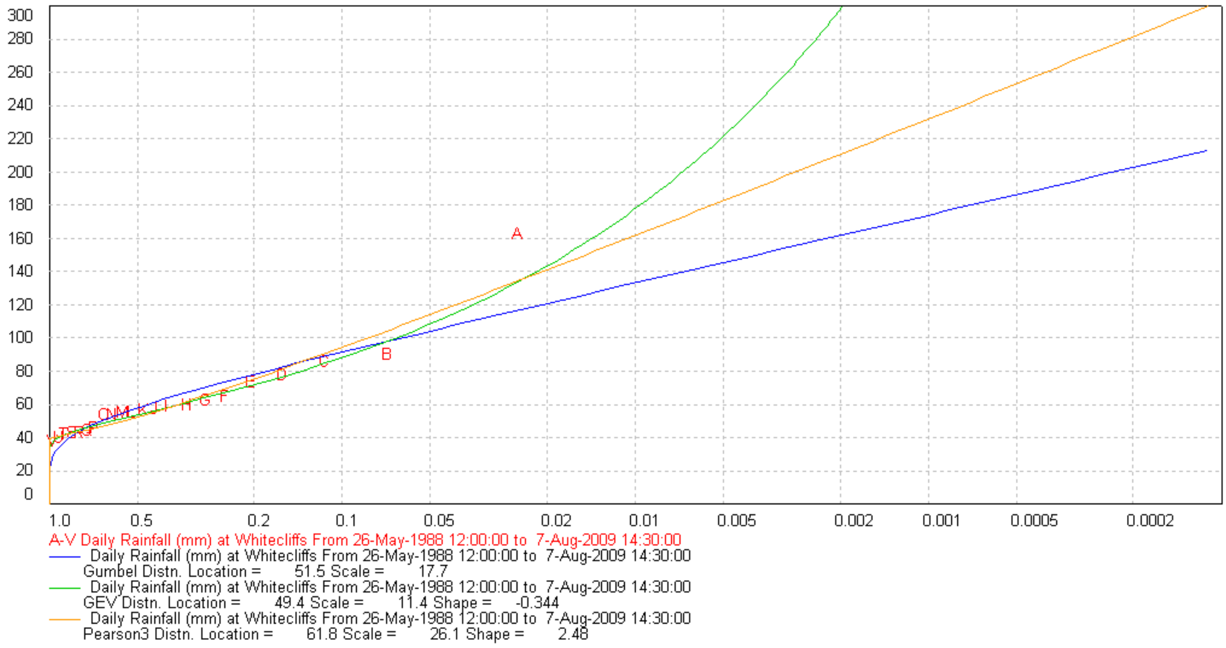

Figure A.128 Whitecliffs 24-hour rainfall frequency analysis.

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