

**Meteorological scenarios for
the Western Bay of Plenty**

**AK00108 (final version)
22 December 2000**

Meteorological scenarios for the Western Bay of Plenty

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Prepared for

Western Bay of Plenty Engineering Lifelines Project

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NIWA Client Report AK00108 (final version)

22 December 2000

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Executive Summary

- Only daily rainfall data in the Western Bay of Plenty were analysed in this report. Although flooding events do occur at shorter time scales (e.g. the 9 hour event which occurred on 9 April 2000), the majority of long-term rainfall data are recorded daily. Only the Tauranga Airport and Te Puke automatic weather stations record high frequency rainfall data (hourly) at present in the Western Bay of Plenty as part of the National Climate Database Network, managed by NIWA. These stations have only recorded high frequency data since 1990 and 1994, respectively.
- Major flooding in the Western Bay of Plenty typically occurs with depressions from the north, associated with strong, moist, north-easterly winds, and active frontal systems. Violent thunderstorm activity is a major cause of extreme (and often localised) rainfall in the Bay of Plenty. These thunderstorms are either embedded in fronts, or are caused by strong daytime heating/atmospheric instability.
- Three flooding events in the Western Bay of Plenty were analysed from the historical rainfall record, in order to serve as a benchmark for sections 4 and 5. Analysis of the flood event on the 20th April, 1923, estimated daily rainfall return periods of approximately 1-in-240 years at Tauranga Airport (although much less elsewhere).
- The return period estimates for the extreme event on 17 April 1948 were exceptional, with the 34 mm of rainfall observed at Tauranga Airport over 10 minutes being a New Zealand record. The estimated return periods for the extended flood event of 19-22 March 1979 ranged between 121 and 217 years in the Western Bay of Plenty region.
- In order to estimate the 1-in-150-year and 1-in-475-year daily rainfall, sites with more than 30 year's worth of data were analysed. It was imperative to use the longest (high quality) data records to achieve a 'representative' long-term rainfall distribution – so that decadal climate shifts such as the Interdecadal Pacific Oscillation (IPO) do not skew results.
- The IPO is a particular issue in the Bay of Plenty, in that the most recent phase of the IPO (1977 – 1998) has resulted in stronger south-westerly winds, with lower rainfall, and fewer floods, in the Bay of Plenty. It is notable that the most severe storm rainfall occurred in the Tauranga record prior to 1979 (eg 1948, 1951, 1961, 1978, 1979), in the north-easterly phase of the IPO, and also after 2000 (April 2000).
- Gumbel or extreme value type 1 distribution analyses were performed, augmented by enhancement factors after Tomlinson (1980). Estimates in the Western Bay of Plenty ranged between daily rainfalls of 157mm and 500mm for the 150 year return period, and between 180mm and 572mm for the 475 year return period.
- It is important to note that there is significant level of uncertainty associated with these ARI estimates, as each step of the methodology (see section 4.4) has uncertainty associated with it. Users of these ARI estimates should consider this when applying the results of the analysis.
- The ARI rainfall contours, for both 150 years and 475 years, broadly follow the elevation contours, which is physically realistic for daily rainfall data. However, as mentioned previously, shorter duration (eg. <3 hours), localised rainfalls caused by convective processes are less likely to be affected by elevation alone. It is possible that preferred regions for short duration, convective rainfall do exist

within the Western Bay of Plenty, caused by topography which is subject to differential heating, or low level wind convergence, etc.

- It is recommended that all available high frequency rainfall data held by the Council or other independent sources is utilised in a future analysis of extreme high frequency rainfall events, in order to quantify the magnitude and frequency of these, and to assess whether favoured localities within the Western Bay of Plenty do exist. NIWA may be able to digitise further pluviograph (rainfall gauge) traces from Tauranga Airport, in order to analyse short-duration rain rates.
- The strongest winds in western Bay of Plenty are typically from the west-southwest, and are usually associated with the passage of active fronts. Although high winds are relatively infrequent in many lowland areas, they are a common occurrence in exposed areas in the Kaimai Range. Strong winds also occur, although less frequently at low levels, from the north through east sector, being associated with deep depressions centred to the north or northwest of the region.
- Tornadoes, although very localised and generally much smaller than those occurring in the USA, do occur occasionally in the Western Bay the Plenty. They typically have a small damage path, of around 10 to 30 metres wide and one to five kilometres long. Tornadoes are rare events in New Zealand. They are typically observed by chance, and are poorly observed (no details, and often not notified). Data are sparse in formal databases, such as The National Climate Database, managed by NIWA.
- To evaluate the 1-in-150-year and 1-in-475-year wind gust, estimates at eight representative sites in the Western Bay of Plenty were produced analytically. The estimated 1-in-150-year gust speed for a height of 10 metres above ground level ranged between 46 m/s and 61 m/s at the eight selected sites, and between 49 m/s and 66 m/s for the 1-in-475-year estimate.
- The extreme gust isopleths in Figures 7 and 8 were subjectively developed, and broadly follow the elevation contours. This is a physically realistic result when interpolating between discrete points, in the absence of other information. Some sites, like the top of Mauao, are exceptional (with contour detail lacking in the broad scale figures). Figures 7 and 8 have the most value if used in the appropriate way – namely to identify probable broad scale spatial patterns of extreme wind gusts in the Western Bay of Plenty, based on estimates at discrete sites calculated with current best-practice methodologies.
- In the methodologies used to produce both the rainfall and wind gust return period estimates, it was assumed that there is no change in climate over the duration of time comparable to the return period (such as might occur due to global warming). Users of the information produced in this report need to acknowledge this underlying assumption.
- It is recommended that regional climate change scenarios for the Bay of Plenty be derived once the Third Assessment Report from the IPCC (Intergovernmental Panel on Climate Change) is released in 2001. Guidance on regional changes in extreme rainfalls and ARIs under a changing climate are necessary for longer term planning.
- The estimates for both the 1-in-150-year and 1-in-475-year daily rainfall and wind gusts are discrete (calculated at a point). Spatial interpolation allows isopleths to be drawn around the point estimates in the maps, for visual interpretation. There are obvious limitations to discrete estimates being spatially analysed, given the inherent uncertainties in the original estimation process. Users of this information also need to acknowledge this limitation, particularly if these results are inserted into a GIS system.

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1. Introduction

The Western Bay of Plenty Engineering Lifelines Project requested information about meteorological hazards in the Western Bay of Plenty region – specifically heavy rainfall and high winds – which might impact on ‘lifeline’ infrastructure.

This report was produced to meet two aims - the first was to analyse selected historical ‘lifeline’ events (e.g extreme events in the Western Bay of Plenty data record), and estimate average recurrence intervals (ARI)¹, which would illustrate both the magnitude of the event, and how frequently these types of events might occur. These case studies serve as a benchmark to the estimates produced in the latter part of the report.

The second aim was to provide point estimates of the 1-in-150-year and 1-in-475-year daily rainfall and 3 second gust speed in the Western Bay of Plenty, and spatially map these using standard interpolation techniques. (The periods were chosen to be consistent with other hazard information).

The results from the 1-in-150-year and 1-in-475-year analyses would also be provided in electronic format, so that the WBOP Engineering Lifelines Project might incorporate these into a Geographic Information System, for future analysis.

2. Recurrence Interval Estimation

The first meteorological observation in the Western Bay of Plenty started in 1898. However, the majority of climate records in the Western Bay of Plenty are less than 50 years in length (see Appendix 1 for data record details).

Therefore, average recurrence intervals (ARI), and the estimates for the 1-in-150-year and 1-in-475-year events, are obtained by analytical modelling, or by estimation from extreme value distributions e.g extrapolating from available data, but going well beyond the observed data period. Estimates obtained in this way have obvious uncertainty associated with them.

The estimates for the 1-in-150-year and 1-in-475-year events are discrete (calculated at a point). Interpolation allows isopleths to be drawn around the point estimates in the spatial maps, for visual interpretation of the results. There are obvious limitations to discrete estimates being spatially analysed, given the inherent uncertainties in the original estimation process.

3. Daily data

It is important to note that daily rainfall data are analysed in this report. While it is acknowledged that flooding events do occur in the Western Bay of Plenty on time scales shorter than 24 hours (e.g. the 9 hour event which occurred on 9 April 2000), the majority of long-term, widespread rainfall data are recorded daily.

¹ Commonly referred to as ‘return periods’

Only the Tauranga Airport and Te Puke automatic weather stations record high frequency rainfall data (hourly) at present in the Western Bay of Plenty as part of the National Climate Database Network, managed by NIWA. These stations have recorded high frequency data since 1990 and 1994, respectively.

This lack of long-term, high frequency rainfall data accessible by NIWA inhibits any high frequency analysis to estimate large ARI values, e.g the 1-in-150-year and 1-in-475-year events. It is recommended that all available high frequency rainfall data held by the Council or other independent sources is utilised in a future analysis of extreme high frequency rainfall events, in order to quantify the magnitude and frequency of these.

4. Extreme Rainfalls

4.1 Floods in the Western Bay of Plenty: Introduction

The earliest documented record of a severe flood in the Western Bay of Plenty dates back to 1920. A detailed study (by the Soil Conservation and Rivers Control Council) was made in 1957, noting 25 floods of various severity in the district in the 34-year period from 1920 to 1953, 80 percent of which occurred during the first six months of the year. Flood descriptions taken from that study, and analysis of other more recent events, shows that there have been at least four major flood producing rainfall events since 1920, three of which are described in this report.

Major flooding in the Western Bay of Plenty is frequently associated with depressions that originate in the north Tasman Sea or subtropics and then pass over the northern half of the North Island. When they are centred northwest of the Western Bay of Plenty they may bring strong, moist north or northeasterly air flow over the region. As these air masses ascend the inland high country, they typically dump heavy rain, particularly at higher elevations, enhancing river flows into the plains. Rainfall can be prolonged especially if the frontal systems associated with the depression are slow moving, or particularly extreme if frontal systems contain embedded thunderstorms within them.

There are also occasions when heavy rainfall can occur in very localised area - associated with afternoon thunderstorm build-ups, due to strong daytime heating, or from thunderstorms that are part of a frontal passage. Situations like this would typically occur between October and April. They can result in localised high intensity rainfall – often in the space of 20 minutes to an hour with local surface flooding, causing occasional wash-outs and temporary power failures. Violent thunderstorms have produced torrential rainfall totalling 34 mm in 10 minutes (a New Zealand record), and 95 mm in one hour, in Tauranga.

4.2 Three severe floods in the Western Bay of Plenty

As a background to understanding the types and magnitudes of rainfall events that can cause serious flooding in the Western Bay of Plenty, brief descriptions of three of the most severe floods since 1920 are listed. These include the events of 20 April 1923, 17 April 1948 (which was very notable due to phenomenally intense rainfall, most of which occurred within 6 hours), and the more prolonged 19-22 March 1979 event.

All rainfall data listed in this section are 9am to 9am daily rainfall totals, as clearly stated in tables.

The nominal regional average rainfall, and percentage of stations recording rainfall totalling at least 100 mm, are listed in corresponding tables, and peak rainfalls at individual localities have also been itemised. The regional average rainfall is the average of all available Western Bay of Plenty rainfall stations (the stations are always listed in each table) for each event. This figure is useful at times in determining the relative ranking or severity of storms from a regional perspective.

The notes given help to characterise the flood events in the Western Bay of Plenty and point to some of the locations that were the most vulnerable. In all cases, rainfall of at least 200 mm was recorded in the most affected localities, and this amount sometimes fell in less than 24 hours. In most cases, rivers overflowed, and flood-waters entered urban areas, or covered large areas of rural land. Landslips, damage to bridges, road or rail links, and stock losses were a consequence of these events. Some of the information provided below was extracted from press reporting at the time of the events and therefore may not be completely accurate in describing the floods.

Flood 1: 20 April 1923

High rainfall and widespread flooding occurred throughout the region, amongst easterly gales and vivid electrical storms. Extremely high rainfall, totalling 239 mm, was recorded at Tauranga in the 24 hours to 9.00 am on the 21st. Water invaded several businesses on the Strand. Wash-outs damaged the railway line and roads were blocked.

Table 1: Daily rainfall (mm) for selected locations from 19 through 20 April 1923.

Totals are for 24 hours from 9.00 am on the date listed.

Number	Site Location	19 April	20 April	19-20 April Total
B75381	Waihi	91	186	277
B75891	Kaimai School	25	233	258
B76621	Tauranga Airport	11	239	250
	Percent of stations in western Bay with rainfall of at least 100 mm	Nil	100%	
	Regional average rainfall (mm)	42	219	261

% of stations in WBOP with rainfall > 100mm refers to % of available recording stations (listed) with rainfall > 100mm.

Table 2: The highest 1, 2 and 3-day rainfalls recorded during April 20, 1923 and their estimated return periods.

Site	Duration	Amount (mm)	Average return period (yrs)
Waihi	1-day	186	4
“ “	2-days	277	8
Kaimai School	1-day	233	15
“ “	2-days	258	8
Tauranga Airport	1-day	239	241
“ “	2-days	250	71

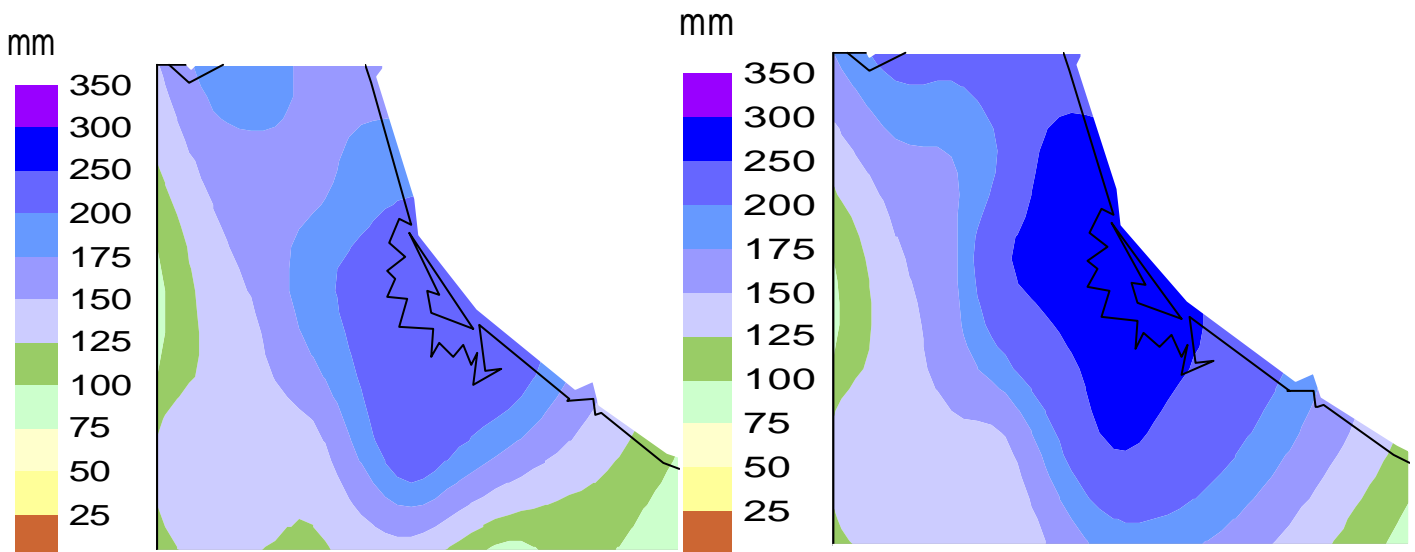


Figure 1: Total rainfall during (a) 20 April 1923, and (b) 19-20 April 1923

Flood 2: 17 April 1948

Violent thunderstorms, embedded in an active frontal system, moved eastward across the Western Bay of Plenty during the evening, producing rainfall of phenomenal intensity over a period of a few hours. The result was extensive flooding throughout Tauranga business areas, where water flowed 0.3 to 0.5 metres feet deep in some of the main streets.

Table 3: Daily rainfall (mm) for selected locations on 17 April 1948.

Totals are for 24 hours from 9.00 am on the date listed.

Number	Site Location	17 April
B75591	Katikati	99
B75891	Kaimai School	73
B76621	Tauranga Airport	228
B76711	Otumoetai	149
B76951	Rotoehu Forest	148
Percent of stations in western Bay with rainfall of at least 100 mm		60%
Regional average rainfall (mm)		139

% of stations in WBOP with rainfall > 100mm refers to % of available recording stations (listed) with rainfall > 100mm.

Table 4: The highest 5-min to 1-day rainfalls recorded during April 17, 1948 & ARI

Site	Duration	Amount (mm)	Average return period (yrs)
Katikati	1-day	99	< 2
Kaimai School	1-day	73	<2
Tauranga Airport	5-minute	17	100
“ “	10-minute	34 ^{New Zealand record}	1000*
“ “	20-minute	51	600*
“ “	30-minute	68	>1000*
“ “	1-hour	95	600*
“ “	2-hours	146	>1000*
“ “	6-hours	212	>1000*
“ “	12-hours	221	750*
“ “	24-hours	230	300
Otumoetai	1-day	149	11
Rotoehu Forest	1-day	148	5

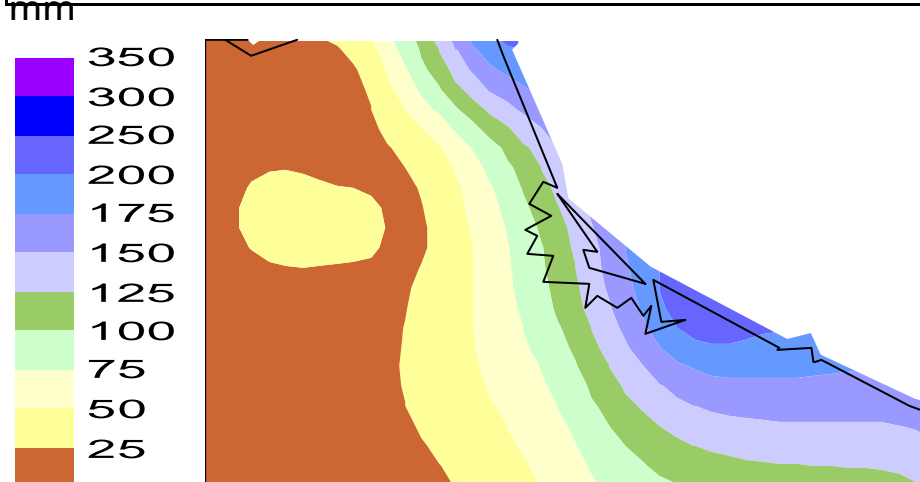


Figure 2: Total rainfall during the storm of 17 April, 1948

**It is not appropriate to use a level of precision such as “600 years” given the errors of extrapolating so far beyond the data sample period. It is better to think of these ARIs as very large eg > 500 years, and ignore the ‘precision’ of an ARI estimate of 600 years, for example.*

Flood 3: 19-22 March 1979

This flood was preceded by two earlier high rainfall events. The first occurred during 9-10 April, followed by another on 15 April; after which soil moisture levels were at full capacity (saturated). Landslips and flooding resulted throughout the region after further high rainfall on the 19th. At Te Puke 203 mm were recorded in 24 hours that day, and at Tauranga Airport 178 mm in the same period, both record one-day totals for March. Although rainfall was most intense on the 19th, moderate to heavy falls continued for some days after. Significant delays in harvesting occurred due to the rainfall.

Table 5: Daily rainfall (mm) for selected locations during the events preceding the 19-22 March 1979 floods.

Totals are for 24 hours from 9 00 am on the date listed.

Number	Site Location	9 March	10 March	15 March
B75581	Wharawhara Water Station	132	11	102
B75591	Katikati	10	20	41
B75681	Shaftesbury	69	8	31
B75691	Katikati Lockington	93	14	82
B75782	Te Ariki Falls	114	33	54
B76602	Te Puna	-	-	62
B76611	Tauranga	43	15	52
B76621	Tauranga Airport	50	22	49
B76701	Whakamarama	152	33	89
B76702	Lower Kaimai, River Lodge	118	22	68
B76716	Hairini	45	19	49
B76717	Oropi Water Treatment Plant	55	56	34
B76741	Maketu	68	22	59
B76802	McLaren Falls	142	33	72
B76832	Te Puke	68	35	59
B76833	Te Puke 2	81	37	63
B76835	Te Puke	83	35	62
B76841	Pongakawa	65	29	70
B76842	Maniatutu	83	55	68
B76861	Pikowai	64	44	58
B76921	Te Ranga	137	47	63
B76951	Rotoehu Forest	47	38	44
	Percent of stations in western Bay with rainfall of at least 100 mm	29%	Nil	Nil
	Regional average rainfall (mm)	82	30	61

Data in Italics are estimated

% of stations in WBOP with rainfall > 100mm refers to % of available recording stations (listed) with rainfall > 100mm.

Table 6: Daily rainfall (mm) for selected locations during 18-22 March 1979.

Totals are for 24 hours from 9.00 am on the date listed.

Number	Site Location	18 March	19 March	20 March	21 March	22 March	18-22 March Total
B75581	Wharawhara Water Station	45	82	81	59	57	324
B75591	Katikati	39	39	41	2	11	132
B75681	Shaftesbury	24	74	73	52	37	259
B75691	Katikati Lockington	18	78	72	40	60	268
B75782	Te Arika Falls	30	88	91	32	78	320
B76602	Te Puna	-	-	45	38	21	-
B76611	Tauranga	24	195	75	34	14	343
B76621	Tauranga Airport	17	178	84	34	16	329
B76701	Whakamarama	9	116	74	65	35	298
B76702	Lower Kaimai, River Lodge	19	66	65	39	22	211
B76716	Hairini	8	<i>118</i>	84	34	9	253
B76717	Oropi Water Treatment Plant	2	55	91	36	18	201
B76741	Maketu	17	103	48	13	23	204
B76802	McLaren Falls	36	41	59	39	20	195
B76832	Te Puke	12	238	84	42	91	466
B76833	Te Puke 2	14	293	83	46	111	548
B76835	Te Puke	22	302	83	46	106	559
B76841	Pongakawa	25	212	55	11	12	223
B76842	Maniatutu	16	132	61	10	17	236
B76861	Pikowai	41	91	61	4	25	223
B76921	Te Ranga	20	147	98	51	73	389
B76951	Rotoehu Forest	13	97	64	9	28	211
	Percent of stations in western Bay with rainfall of at least 100 mm	50%	Nil	Nil	Nil	9%	
	Regional average rainfall (mm)	22	127	71	33	40	295

Data in Italics are estimated.

% of stations in WBOP with rainfall > 100mm refers to % of available recording stations (listed) with rainfall > 100mm.

Table 7: The highest 1 day to 5-day rainfalls recorded during March 18-22, 1979 and their estimated return periods, for selected stations.

Site	1-day Duration, Amount (mm) & Average return period (yrs)	2-day Duration, Amount (mm) & Average return period (yrs)	3-day Duration, Amount (mm) & Average return period (yrs)	4-day Duration, Amount (mm) & Average return period (yrs)	5-day Duration, Amount (mm) & Average return period (yrs)
Tauranga	195 mm, 121 yrs	270 mm, 81 yrs	304 mm, 99 yrs	328 mm, 113 yrs	343 mm, 81 yrs
Tauranga Airport	178 mm, 30 yrs	262 mm, 100 yrs	296 mm, 141 yrs	313 mm, 156 yrs	329 mm, 175 yrs
Hairini	118 mm, 9 yrs	202 mm, 3 yrs	236 mm, 36 yrs	245 mm, 10 yrs	253 mm, 14 yrs
Maketu	103 mm, 4 yrs	151 mm, 4 yrs	168 mm, 4 yrs	181 mm, 5 yrs	204 mm, 11 yrs
Te Puke	238 mm, 261 yrs	321 mm, 144 yrs	363 mm, 127 yrs	454 mm, 271 yrs	466 mm, 195 yrs

Te Puke 2	293 mm, 117 yrs	376 mm, 119 yrs	422 mm, 115 yrs	533 mm, 222 yrs	548 mm, 154 yrs
Te Puke	309 mm, 219 yrs	384 mm, 217 yrs	431 mm, 142 yrs	537 mm, 287 yrs	559 mm, 306 yrs
Pongakawa	212 mm, 36 yrs	267 mm, 26 yrs	292 mm, 20 yrs	303 mm, 15 yrs	223 mm, 15 yrs
Te Ranga	147 mm, 3 yrs	245 mm, 6 yrs	296 mm, 9 yrs	369 mm, 15 yrs	389 mm, 15 yrs
Rotoehu Forest	97 mm, 2 yrs	161 mm, 3 yrs	174 mm, 3 yrs	198 mm, 4 yrs	211 mm, 4 yrs

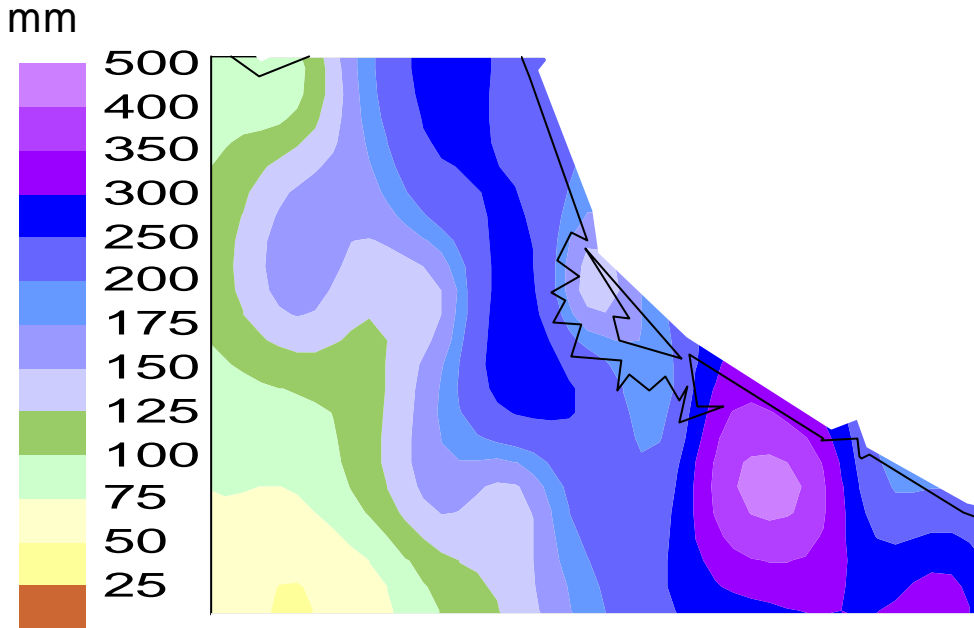


Figure 3: Total rainfall during the rainfall event of 18-22 March, 1979

Note: It is possible that the pattern of lower rainfall over the north-west of Matakana Island in Figure 3 is an artefact of the plotting technique, but it is difficult to determine this. No rainfall data were available from Matakana Island itself to insert into the figure. The interpolation technique used here is based on a contouring method devised by Tomlinson and Thompson, which incorporates topographical effects. It is a procedure that is often used, and is well verified in New Zealand.

4.3 Risk estimates for extreme rainfall events

In order to estimate storm rainfalls which could be expected at certain return periods in different parts of the Western Bay of Plenty, analyses of such storm rainfalls from sites with a data record greater than 30 years was undertaken. It is imperative to use the longest (high quality) data records to achieve a 'representative' long-term rainfall distribution – so that decadal climate shifts such as the Interdecadal Pacific Oscillation (IPO) do not skew results.

The IPO is a particular issue in the Bay of Plenty, in that the most recent phase of the IPO (1977 – 1998) has resulted in stronger south-westerly winds, with lower rainfall, and fewer floods, in the Bay of Plenty. It is notable that the most severe storm rainfall occurred in the Tauranga record prior to 1979 (eg 1948, 1951, 1961, 1978, 1979), in the north-easterly phase of the IPO, and also after 2000 (April 2000). For further information about the IPO, reference Salinger and Mullan, 1999.

For the purposes of this report, the required return periods are 150 years and 475 years, which is consistent with the risk levels determined for severe earthquakes.

A common method of analysing extreme rainfalls at a given location is to fit an extreme value statistical distribution to a series of annual maximum rainfalls (daily 9am to 9am totals in this case). In this study we

have adopted the familiar Gumbel or extreme value type 1 distribution (Gumbel, 1958). The Gumbel distribution has historically been the most widely used when estimating extreme rainfall in New Zealand.

However, Environment B.O.P. has clearly shown that for most of the Bay of Plenty river flows that an extreme value type 2 distribution (EV2) is warranted (pers. comm Peter Blackwood). The reasons for EV2 are both meteorological and related to soil type.

There have been several studies (e.g. Beable and McKerchar, 1980) which have also concluded that an EV2 distribution is appropriate for parts of the Bay of Plenty. Other recent studies (OPUS) have used the Log Pearson Type III for Tauranga and Western Bay of Plenty rainfalls. This was curved in the EV2 direction and is essentially almost a proxy for EV2 – the EV2 distribution was less preferred because of a more extreme curvature. However, an EV2 distribution is rare in nature, with no upper limit, and should be applied with considerable caution (pers. comm Peter Blackwood).

Therefore, in the absence of strong information to use an alternative distribution across the majority of stations to be analysed, a Gumbel distribution was used here for the extreme rainfall analysis. The fitting method of L Moments was adopted here.

It is acknowledged that the Gumbel distribution fit is sub-optimal for Katikati and Whakamarama in particular (see Appendix 2), understating the ARI estimates. This trend is evident to a much lesser degree in the Maketu 2 day Gumbel plot, Otumoetai, Te Puke, and Maniatutu.

It is important to note that there is significant level of uncertainty associated with the ARI estimates produced in this report, as each step of the methodology (see section 4.4) has uncertainty associated with it. Users of these ARI estimates should consider this when applying the results of the analysis.

4.4 1-in-150 year and 1-in-475 year daily (24hr) rainfall calculations

1. Gumbel analyses of one and two day 9am to 9am rainfalls at a number of Western Bay of Plenty locations are located in Appendix 2. They provide estimates of rainfall depths for return periods (ARIs) of up to 1000 years.
2. Rainfall depths for the daily (9am to 9am) rainfall 150 year and 475 year estimated return periods were determined by a linear interpolation between the 100 year and 1000 year estimates (see Appendix 2). In doing so it has been assumed that there is no change in climate over the duration of time comparable to the return period (such as might occur due to global warming).
3. An analysis of the Gumbel distribution of 9 am to 9 am rainfalls at 13 locations throughout the region (including stations at Waihi Beach, Katikati, Tauranga, and Te Puke) showed that, on average, the estimated 150 year return period depths were 106 % of the estimated 100 year depths (ranging between 104 % and 106 %). Similarly, the 475 year estimated return period depths were 121 % (ranging between 118 % and 123 %) of the estimated 100 year depths.

For users of ARI estimates, eg Council, Lifelines, Engineers, etc. it is important to produce *24 hour* daily rainfall ARI estimates. Tomlinson (1980) noted the empirical relationship which shows maximum 24-hour rainfall depths are empirically ~ 14 % higher than 9 am – 9 am maxima.

It was necessary to convert 9 am to 9 am daily rainfall ARI estimates to 24 hour daily rainfall ARI estimates. It was also essential that 24 hour ARI estimates were interpolated between the 13 locations across the Western Bay of Plenty, so that high-resolution spatial information could be produced (for example, Figures 4 and 5). An interpolation method which incorporated relevant topographical information was desirable (eg as devised by Tomlinson and Thompson).

Therefore, the following method was employed: A high-resolution data set, comprising of 100 year ARI estimates for 24 hour daily rainfall, based on depth estimates by Tomlinson (1980), was augmented by the enhancement factors given in 3, to produce 150 year and 475 year ARI estimates at a high resolution. The 13 calibration station data ARI estimates from 2 were included in this data set, after multiplication by 1.14.

Contour maps of estimated 24-hour rainfall depths for 150 and 475 year return periods are given in Figure 4 and 5.

The ARI rainfall contours, for both 150 years and 475 years, broadly follow the elevation contours, as would be expected with daily rainfall data. However, as mentioned previously, shorter duration (eg. <3 hours), localised rainfalls caused by convective processes are less likely to be affected by elevation alone.

It is possible that preferred regions for short duration, convective rainfall do exist within the Western Bay of Plenty, caused by topography which is subject to differential heating, or low level wind convergence, etc. Further analysis, as outlined in section 3, is needed using a dense network of high frequency (hourly or less) rainfall data to assess any favoured localities.

4.5 Storm duration ratios

Estimates of rainfall depths for other storm durations may be obtained by employing relevant depth-duration coefficients, given in Table 8. The base intensity is the 24-hour fall (with a ratio of 1.00 on the table). For example, a 1-in-150 year ARI 12 hour rainfall near Tauranga could expect to be approximately 77 percent of the 1-in-150-year ARI 24 hour fall in that vicinity.

It should be noted that these ratios are averages compiled from empirical data from stations all across New Zealand (Tomlinson, 1980). Note that the scatter in the empirical data would be expected to be large, given the fact that rainfall records were used from all over New Zealand, from many different climatic regions around the country. These ratios may not be fully appropriate for the climate of the Bay of Plenty, in particular with respect to the exceedingly “peaky” short-duration rainfall events observed in the region.

Analysis of local, high frequency, rainfall records may reveal empirical results more applicable to the Bay of Plenty.

Table 8: Depth-duration ratios based on the 24-hour storm rainfall, for durations of 6 hours to 72 hours (after Tomlinson, 1980)

Duration (h)	6	12	24	48	72
Ratio (150 yr)	0.55	0.77	1.00	1.24	1.38

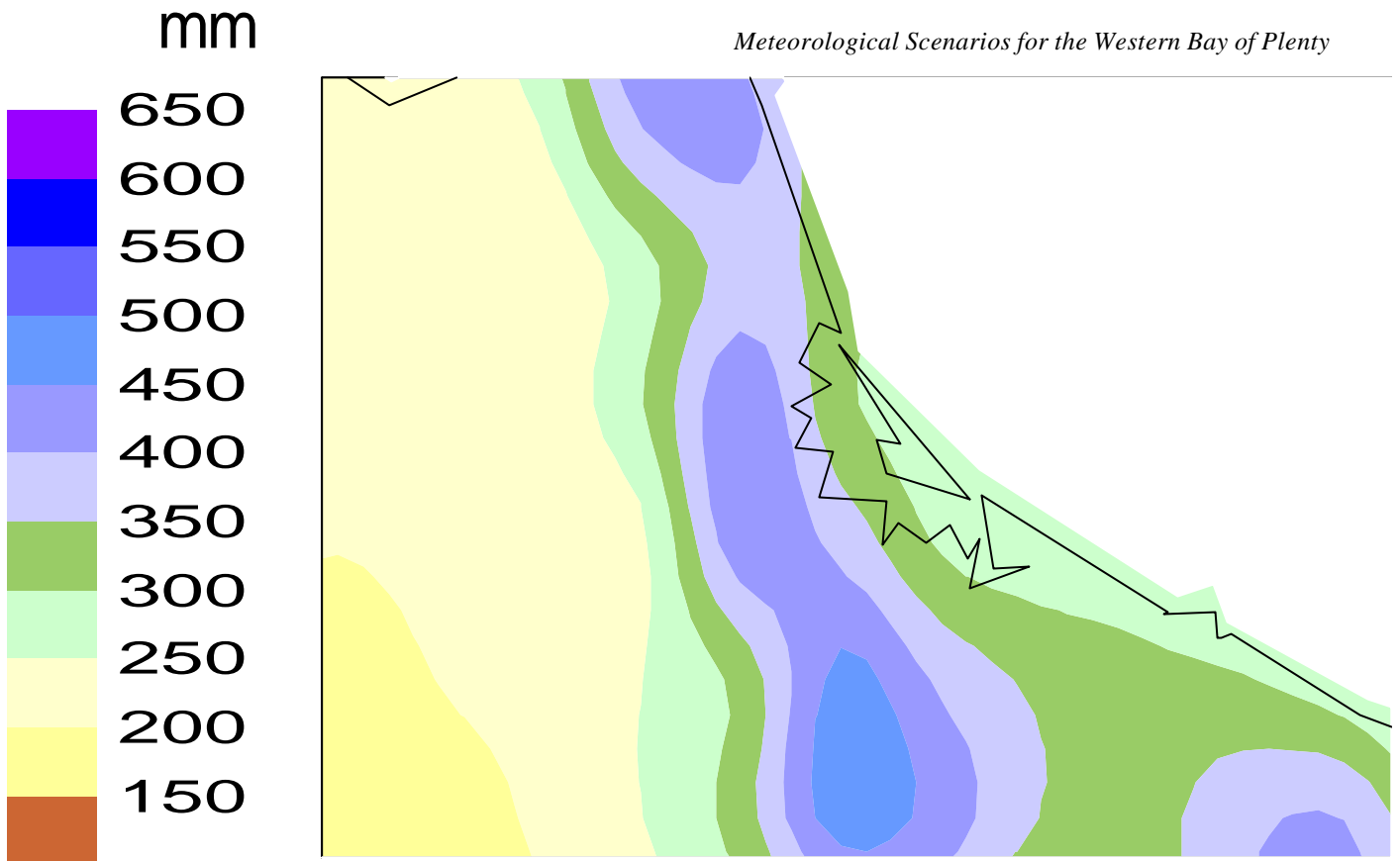


Figure 4: Spatial distribution of high intensity 24-hour rainfall (mm), that is expected to be equalled or exceeded at average intervals of 150 years. (Based on Tomlinson, 1980)

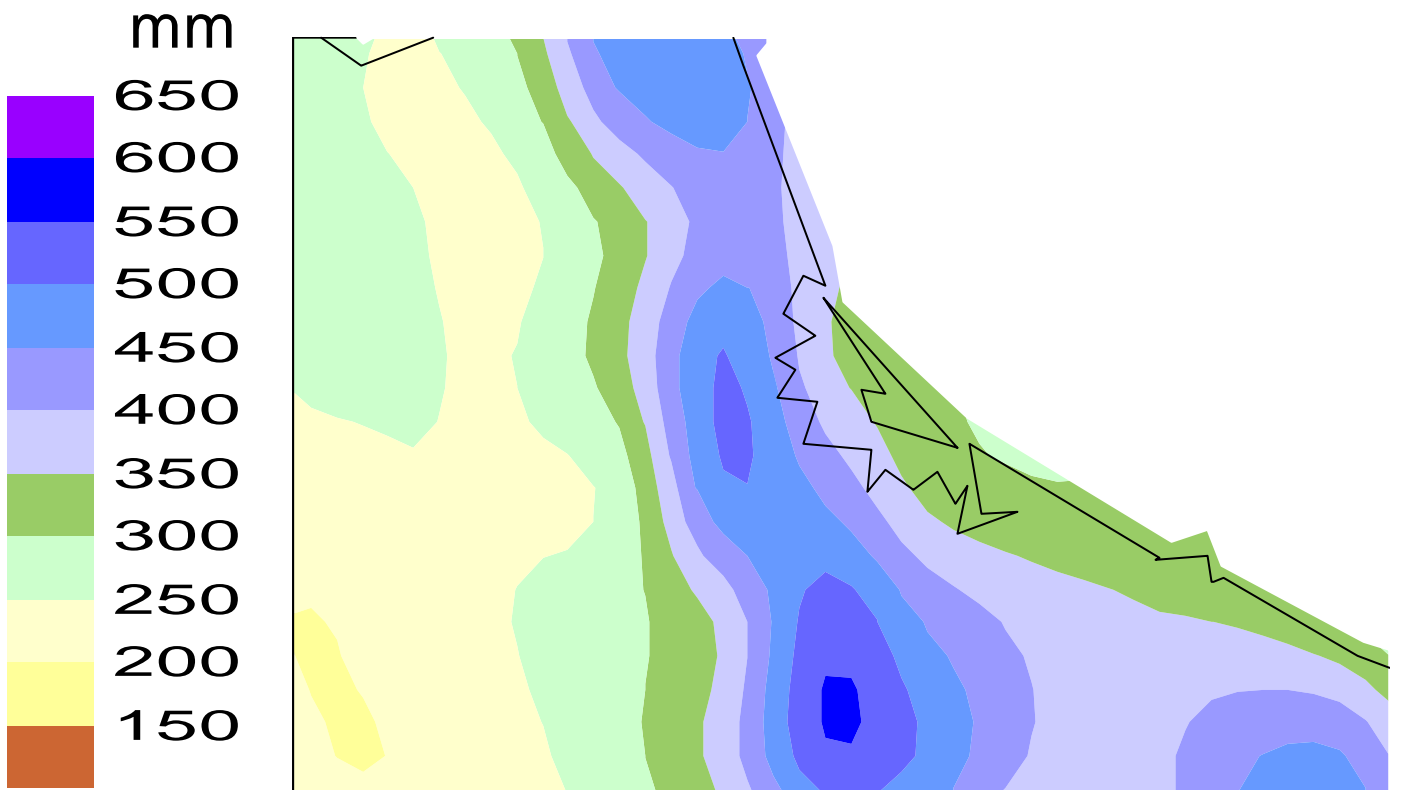


Figure 5: Spatial distribution of high intensity 24-hour rainfall (mm), that is expected to be equalled or exceeded at average intervals of 475 years. (Based on Tomlinson, 1980)

5 Extreme winds in the Western Bay of Plenty

5.1 Wind Storms – an introduction

The strongest winds in western Bay of Plenty are typically from the west-southwest sector (between 230° and 270°), and are usually associated with active frontal passages. Although high winds are relatively infrequent in many lowland areas, they are a common occurrence in exposed areas in the Kaimai Range. Strong winds also occur, although less frequently at low levels, from the north through east sector, being associated with deep depressions centred to the north or northwest of the region.

Tornadoes, although very localised and generally much smaller than those occurring in the USA, do occur in the Western Bay the Plenty. A rather significant event was that of 31 March 1984, when a tornado struck the Tauranga suburb of Otumoetai damaging 40 homes. Roofs were torn off, windows smashed and trees uprooted. Another was that of 14 May 1971, which left a 1 kilometre track of damage. A few tornadoes, although not all damaging, are sighted in the region on average in most years. Those that do result in damage typically have a damage path 10 to 30 metres wide and one to five kilometres long.

(Note that tornadoes are rare events in New Zealand. They are typically observed by chance, and are poorly observed (no details, and often not notified). The climate database at NIWA Wellington holds very little tornado information. Analysis of such incomplete and poor quality data would be strongly advised against).

5.2 Maximum recorded wind gusts in the Bay of Plenty

There have been two long term, high frequency, wind data records in the Western Bay of Plenty - at the Tauranga Airport, and at nearby Mt. Te Aroha. The Port of Tauranga has made lower frequency 'casual' wind observations since 1964, but gust information is almost always lacking. The frequency of the Port of Tauranga record was initially daily, but gradually increased to predominantly 6 hourly in recent years.

Extreme maximum wind gusts (i.e. maximum wind speeds with a nominal duration of three seconds) recorded at the available wind stations in the region are listed in Table 9. Although Mt. Te Aroha is just outside the region, its data have been included in the table as an example of high wind speeds that are likely to be experienced in well-exposed hill country sites in the Western Bay of Plenty.

Table 9 shows that at Mt. Te Aroha (an exposed hill top location), the maximum gust recorded is more than 1.7 times the maximum gust recorded at Tauranga Airport (a coastal, lowland site). It should be noted that the data record periods are different, but the Tauranga Airport record does fully overlap the Mt. Te Aroha record.

Table 10 indicates the observed frequencies of wind gusts near gale force (59 km/h or 16 m/s) and storm force (93 km/h or 26 m/s) at the two stations. The frequency of strong winds would typically be expected to be higher over exposed summits and hilltop locations, than in the coastal and plains areas.

Table 9: Extreme maximum wind gusts recorded at selected western Bay of Plenty sites. {Extreme gusts are the maximum recorded wind speeds with a nominal duration of three seconds}.

Station	Period	Max. gust (km/h) & (m/s)	ARI (years)	Date
Tauranga Airport (4 metres)	1942-1999	126 km/h from 230° (35 m/s)	44 years	2 Oct 1987
Mt. Te Aroha (951 metres)	1978-1986	222* km/h from 090° (62 m/s)	38 years	19 Jul 1978

* Power failed and a higher speed may have occurred.

Table 10: Mean annual wind gust frequencies at selected western Bay of Plenty sites. {Extreme gusts are the maximum recorded wind speeds with a nominal duration of three seconds}.

Station	Period	Days per year with gusts > 59 km/h (>16 m/s)	Days per year with gusts > 93 km/h (> 26 m/s)
Tauranga Airport (4 metres)	1959-1989	35	1
Tauranga Airport AWS (4 metres)	1990-1999	29	0
Mt. Te Aroha (951 metres)	1979-1986	148	37

The data in Table 10 above show that on average there are about 30 days per year in coastal localities where wind gusts exceed 59 km/h (16 m/s). Such gust speeds would be sufficient to cause dust storms and damage to light structures such as tents. It would be difficult, for example, for cars to tow caravans. There are much fewer cases of storm force wind gusts (93 km/h or 26 m/s). Gusts of this nature are strong enough to uproot trees and cause structural damage to buildings. The data indicate that high gusts are more frequent with increase in altitude, particularly in well-exposed hill top areas.

5.3 Calculation of the 1-in-150-year and 1-in-475-year wind gust estimates

This report aims to characterise the extreme winds in the Bay of Plenty by selecting sites in particular terrains and quantifying the wind extremes expected there. This is done via the methods described in the Code of Practice and Commentary of New Zealand Standard 4203 (1992). Additional details are contained in the Australian Standard AS 1170.2 (1989).

It should be noted that climate change may gradually influence the extreme wind climate in New Zealand, and it is not taken into account in the design methodologies. The main risk for the Bay of Plenty is considered to be a possible increased incidence of tropical cyclones (although no firm statements were made in the IPCC Summary for Policymakers (1995)). However, the Third Assessment Report will be available from the IPCC in 2001, and the latest global climate change summaries need to be assessed, when available, to re-evaluate this risk.

Firstly, eight sites in the Western Bay of Plenty were chosen (subjectively) as calibration sites, covering a range of locations typical of the Western Bay of Plenty. ARI estimates were calculated at these discrete sites. Contours have been subjectively inserted between the discrete ARI estimates, with graphical depiction in Figure 7 and 8.

There are reservations about the adequacy of graphically contouring the site-specific ARI estimates shown in Table 12 and Table 13. Figures 7 and 8 show ARI (150 and 475 years, respectively) maximum 3-second wind gust speed (regardless of wind direction) contoured in a broad fashion suitable to show spatial patterns in the wider Western Bay of Plenty. Figures 7 and 8 have value if used in the appropriate way – namely to identify probable broad scale spatial patterns of extreme wind gusts in the Western Bay of Plenty, based on estimates at discrete sites calculated with current best-practice methodologies.

5.31 Sites chosen

The sites are marked on the map below (Figure 6). They have been selected to represent a range of hill shape, elevation and coastal situations. The map does not show the contours in the detail used to evaluate the speeds.

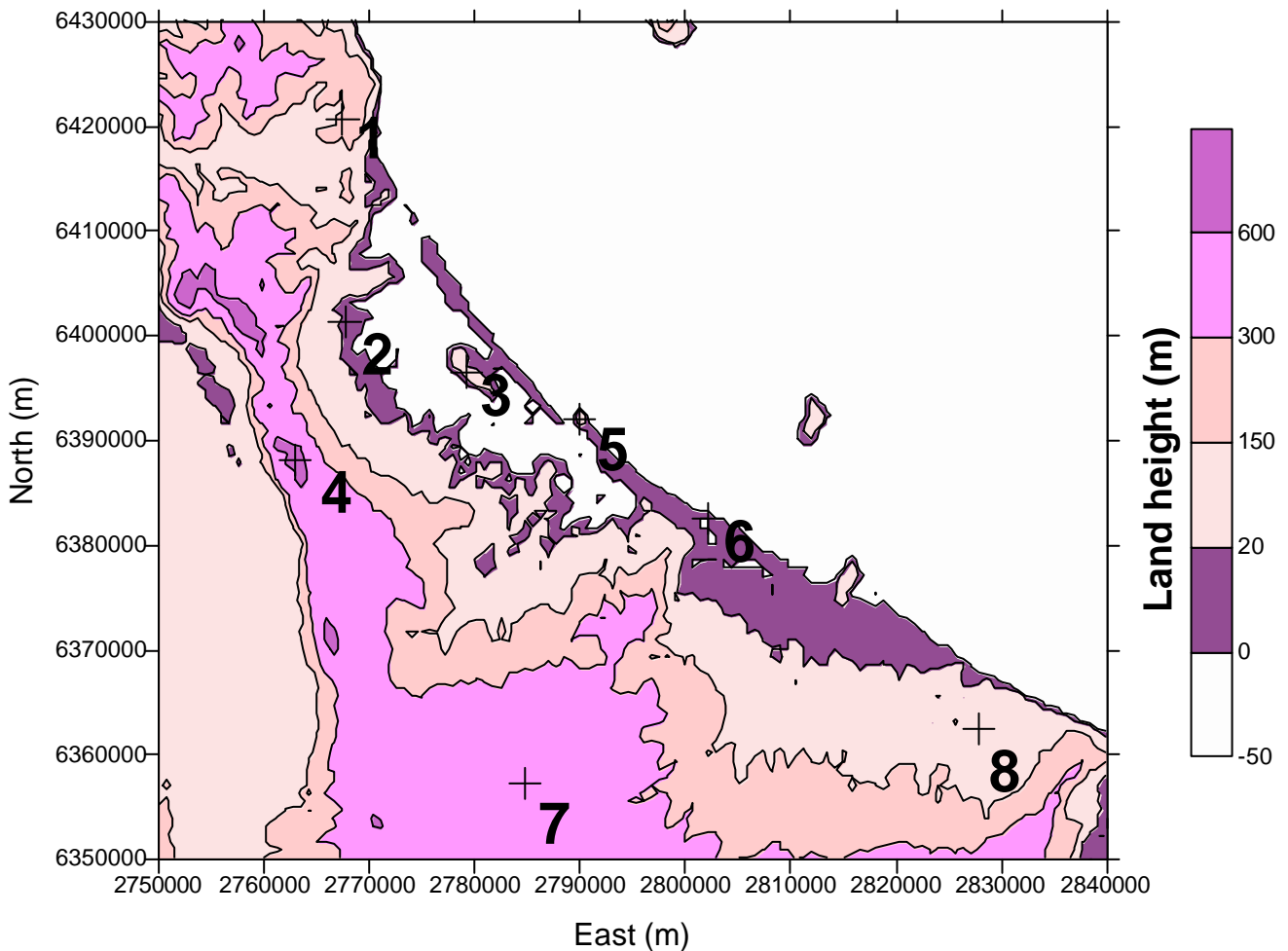


Figure 6: Location map showing positions of points used for determining site winds. The sites corresponding to the numbers are named and positions given in Section 5.32.

5.32 Site locations

The site names, locations and elevations of the chosen sites are shown in Table 11.

Table 11: Selected locations, chosen to be representative for the various topographical features of the Western Bay of Plenty.

No.	Name	Height (m)	Map	East (m)	North (m)	Lat deg	S min	sec	Long Deg	E min	sec
1	Matangia	320	T13	683	195	37	24	6.49	175	55	8.11
2	Katikati	59	T13	669	16	37	33	47	175	54	11.4
3	Matakana No 2	72	U14	799	959	37	36	51.9	176	4	51.9
4	Pukepenga	841	T14	630	878	37	41	14.6	175	51	33.2
5	Mauao	252	U14	902	920	37	38	58.4	176	11	49.5
6	Papamoa Beach	5	U14	20	833	37	43	40.5	176	19	47.8
7	Puwhenua	619	U15	842	593	37	56	38.9	176	7	46.2
8	Matamanu	230	V15	285	627	37	54	48.6	176	37	42.2

5.33 Site descriptions

1. Matangia

The site is on top of a hill 6 kilometres east of Waihi. It is part of a more extensive system of hills separating the Bay of Plenty from the inland plain. Hill slopes are steep near the summit.

2. Katikati

The site is on a small hill just west of Katikati.

3. Matakana No 2

The site is on a gently-sloping hill on Matakana Island.

4. Pukepenga

The site is on the main ridge of the Kaimai range. It is regarded as representative of the ridge which is one of the windiest places in the Bay of Plenty area.

5. Mauao

This steep-sided isolated hill is also a windy site that is exceptional for its location. One or two comparable sites can be picked off the map. Schematic contours are drawn around them.

6. Papamoa Beach

This site is on a low dune and is regarded as having winds typical of coastal plain sites.

7. Puwhenua

This hill in the volcanic plateau is regarded as having winds typical of the tops of the irregularities of the land surface.

8. Matamanu

The hills near the coast are characterised by the winds at this site.

5.34 Basic wind speeds

The basic wind speeds adopted for the calculations are regional values for these parts of the North Island. The sites 1 - 4 lie in one region and sites 5 - 8 in another. The regions and data are given in the table below. They are for a height of 10 metres, over open, flat land.

	N	NE	E	SE	S	SW	W	NW
Basic regional speed (m/s) at 10 m above ground (Sites 1-4)	44	44	45	43	43	46	46	42
(Sites 5-8)	44	42	42	42	42	43	44	44

5.35 Derivation of site speeds

The basic wind speeds are multiplied by a factor (M(z,cat multiplier) allowing for the surface roughness (friction characteristic) and the height above ground. The product is the derived basic wind speed.

The degrees to which the local hill features affect the winds at the site have been estimated and topography multipliers calculated using a computer programme based on AS1170. The values of the hillshape multiplier and other parts of the multiplier (elevation and channelling) are given in the tables below. They are multiplied by the derived basic wind speed to obtain the site wind speed. The data are tabulated for each site below.

1. Matangia

Derived basic speed (V x M(z,cat) m/s)								
10 m	42	42	43	41	41	44	44	40
20 m	46	46	47	45	45	48	48	44
30 m	48	48	49	47	47	50	50	46
Hill-shape multipliers at the specified heights								
10 m	1.42	1.34	1.39	1.39	1.39	1.34	1.42	1.43
20 m	1.39	1.31	1.34	1.34	1.34	1.31	1.39	1.41
30 m	1.35	1.28	1.29	1.29	1.29	1.28	1.35	1.38
Other landform multipliers at the heights								
10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Site speeds at heights above ground level (m/s)								
475-year return period								
10 m	56	53	56	54	54	55	59	54
20 m	61	57	60	57	57	60	63	59
30 m	62	59	60	58	58	61	65	61
150-year return period								
10 m	52	49	52	50	50	51	54	50
20 m	56	53	55	53	53	55	58	54

30 m

57

55

56

54

54

57

60

56

2. Katikati

Derived basic speed ($V \times M(z,cat)$ m/s)

10 m	42	42	43	41	41	44	44	40
20 m	46	46	47	45	45	48	48	44
30 m	48	48	49	47	47	50	50	46

Hill-shape multipliers at the specified heights

10 m	1.28	1.18	1.19	1.18	1.29	1.18	1.21	1.18
20 m	1.25	1.17	1.15	1.17	1.27	1.17	1.20	1.17
30 m	1.22	1.16	1.12	1.16	1.25	1.16	1.18	1.16

Other landform multipliers at the heights

10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Site speeds at heights above ground level (m/s)

475-year return period

10 m	51	47	48	46	50	49	50	45
20 m	55	51	51	50	54	53	54	49
30 m	56	53	53	52	56	56	56	51

150-year return period

10 m	47	43	45	42	47	45	47	41
20 m	51	47	48	46	50	49	50	45
30 m	52	49	49	48	52	52	52	47

3. Matakana No 2

Derived basic speed ($V \times M(z,cat)$ m/s)

10 m	44	44	45	43	43	46	46	42
20 m	47	47	48	46	46	49	49	45
30 m	49	49	50	48	48	52	52	47

Hill-shape multipliers at the specified heights

10 m	1.16	1.15	1.14	1.16	1.17	1.14	1.13	1.17
20 m	1.16	1.15	1.14	1.15	1.16	1.14	1.13	1.16
30 m	1.15	1.14	1.14	1.14	1.16	1.13	1.12	1.16

Other landform multipliers at the heights

10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Site speeds at heights above ground level (m/s)

475-year return period

10 m	48	48	48	47	47	49	49	46
20 m	52	51	52	51	51	53	53	50
30 m	54	53	54	52	53	55	55	52

150-year return period

10 m	45	44	45	43	44	46	45	43
20 m	48	48	48	47	47	49	49	46
30 m	50	50	50	48	49	51	51	48

4. Pukepunga

Derived basic speed ($V \times M(z,cat)$ m/s)

10 m	40	40	41	39	39	41	41	38
20 m	44	44	45	43	43	46	46	42
30 m	46	46	47	45	45	48	48	44

Hill-shape multipliers at the specified heights

10 m	1.37	1.43	1.50	1.36	1.43	1.43	1.49	1.43
20 m	1.38	1.45	1.52	1.37	1.45	1.45	1.50	1.45
30 m	1.38	1.46	1.52	1.37	1.45	1.46	1.51	1.45

Other landform multipliers at the heights

10 m	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
20 m	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
30 m	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13

Site speeds at heights above ground level (m/s)

475-year return period

10 m	58	61	65	56	59	64	66	58
20 m	65	68	73	63	66	71	74	65
30 m	69	72	77	66	70	75	78	69

150-year return period

10 m	54	56	60	52	55	59	61	54
20 m	60	63	68	58	62	66	68	60
30 m	64	67	72	62	65	70	72	64

5. Mauao

Derived basic speed ($V \times M(z,cat)$ m/s)

10 m	42	40	40	40	40	41	42	42
20 m	46	44	44	44	44	45	46	46
30 m	48	46	46	46	46	47	48	48

Hill-shape multipliers at the specified heights

10 m	1.45	1.46	1.46	1.46	1.44	1.45	1.45	1.45
20 m	1.45	1.47	1.46	1.46	1.43	1.45	1.45	1.45
30 m	1.44	1.46	1.46	1.46	1.42	1.44	1.44	1.44

Other landform multipliers at the heights

10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Site speeds at heights above ground level (m/s)

475-year return period

10 m	57	55	55	55	55	56	57	57
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20 m	63	61	61	61	60	62	63	63
30 m	66	64	64	64	62	64	66	66
150-year return period								
10 m	53	51	51	51	51	52	53	53
20 m	59	57	56	56	55	57	58	58
30 m	61	59	59	59	57	60	61	61

6. Papamoa Beach

Derived basic speed ($V \times M(z, cat)$ m/s)

10 m	44	42	42	42	42	43	44	44
20 m	48	46	45	45	45	46	47	47
30 m	50	48	48	48	48	49	50	50

Hill-shape multipliers at the specified heights

10 m	1.15	1.21	1.15	1.00	1.15	1.21	1.15	1.00
20 m	1.13	1.18	1.12	1.00	1.12	1.17	1.12	1.00
30 m	1.10	1.14	1.10	1.00	1.10	1.14	1.10	1.00

Other landform multipliers at the heights

10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Site speeds at heights above ground level (m/s)

475-year return period

10 m	48	48	45	40	45	49	48	42
20 m	52	51	48	43	48	51	51	45
30 m	53	52	50	45	50	53	52	48

150-year return period

10 m	44	44	42	37	42	45	44	38
20 m	48	48	45	40	45	48	47	42
30 m	49	48	46	42	46	49	48	44

7. Puwhenua

Derived basic speed ($V \times M(z, cat)$ m/s)

10 m	40	38	38	38	38	39	40	40
20 m	44	42	42	42	42	43	44	44
30 m	46	44	44	44	44	45	46	46

Hill-shape multipliers at the specified heights

10 m	1.36	1.41	1.38	1.36	1.36	1.42	1.38	1.41
20 m	1.33	1.40	1.39	1.36	1.36	1.42	1.38	1.42
30 m	1.29	1.39	1.38	1.34	1.34	1.40	1.36	1.41

Other landform multipliers at the heights

10 m	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
20 m	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
30 m	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09

Site speeds at heights above ground level (m/s)								
475-year return period								
10 m	56	55	54	54	54	57	57	58
20 m	60	61	60	59	59	63	63	64
30 m	62	63	63	61	61	65	65	67
150-year return period								
10 m	52	51	50	50	50	53	52	54
20 m	56	56	56	55	55	58	58	60
30 m	57	58	58	57	57	61	60	63

8. Matamānu

Derived basic speed ($V \times M(z, cat)$) m/s)								
10 m	40	38	38	38	38	39	40	40
20 m	44	42	42	42	42	43	44	44
30 m	46	44	44	44	44	45	46	46

Hill-shape multipliers at the specified heights								
10 m	1.27	1.38	1.35	1.45	1.27	1.39	1.35	1.44
20 m	1.28	1.39	1.35	1.46	1.28	1.40	1.36	1.44
30 m	1.28	1.38	1.34	1.46	1.28	1.39	1.35	1.42

Other landform multipliers at the heights								
10 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
30 m	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Site speeds at heights above ground level (m/s)								
475-year return period								
10 m	48	50	48	52	46	51	51	54
20 m	53	55	54	58	51	57	56	60
30 m	56	57	56	61	53	60	59	62
150-year return period								
10 m	44	46	45	48	42	47	47	50
20 m	49	51	50	54	47	53	52	55
30 m	52	53	52	56	49	55	55	58

5.36 Summary of site wind speeds

The site wind speed estimates at 10 m above local ground level for a 3-second gust speed at the 150-year return period are in Table 12 below. They are the highest of the directional speeds. The values are correct for the local ground roughness and for 10 m above local ground level. Other heights are available above in the tables.

	Matangia	Katikati	Matakana	Pukepenga
Site speed (m/s)	54	47	46	61
	Mauao	Papamoa Beach	Puwhenua	Matamanu
Site speed (m/s)	53	45	54	50

Table 12: Estimates of the 10 metre (agl) 3-second gust speed (m/s) for an ARI of 150 years.

Similarly, the site wind speed estimates at 10 m above local ground level for a 3-second gust speed at the 475-year return period are shown in Table 13.

	Matangia	Katikati	Matakana	Pukepenga
Site speed (m/s)	59	51	49	66
	Mauao	Papamoa Beach	Puwhenua	Matamanu
Site speed (m/s)	57	49	58	54

Table 13: Estimates of the 10 metre (agl) 3-second gust speed (m/s) for an ARI of 475 years.

The site ARI estimates have been used to (subjectively) plot isopleths (wind gust speed contours) to delineate land areas with similar characteristics i.e. areas with several similar hill heights and shapes, areas of flat land, or long ridge systems. Because sites with high speeds are generally on hilltops, the many sites below hilltop level will have wind speeds below the map value.

Figure 7 represents estimated wind gusts speeds at a 150-year return period, and Figure 8 shows estimated 475-year return period wind gust speeds.

Figures 7 and 8 have value if used in the appropriate way – namely to identify probable broad scale spatial patterns of extreme wind gusts in the Western Bay of Plenty, based on estimates at discrete sites calculated with current best-practice methodologies.

Note that the sites chosen generally have speeds at the upper end of the range for the area in which they are located. Some sites, like the top of Mauao, are exceptional. The broad detail of Figures 7 and 8 is insufficient to resolve the many contours around Mauao, and it is therefore duly noted that Mauao site gust speeds are approximately 10 m/s greater than the contours detailed in the Figures.

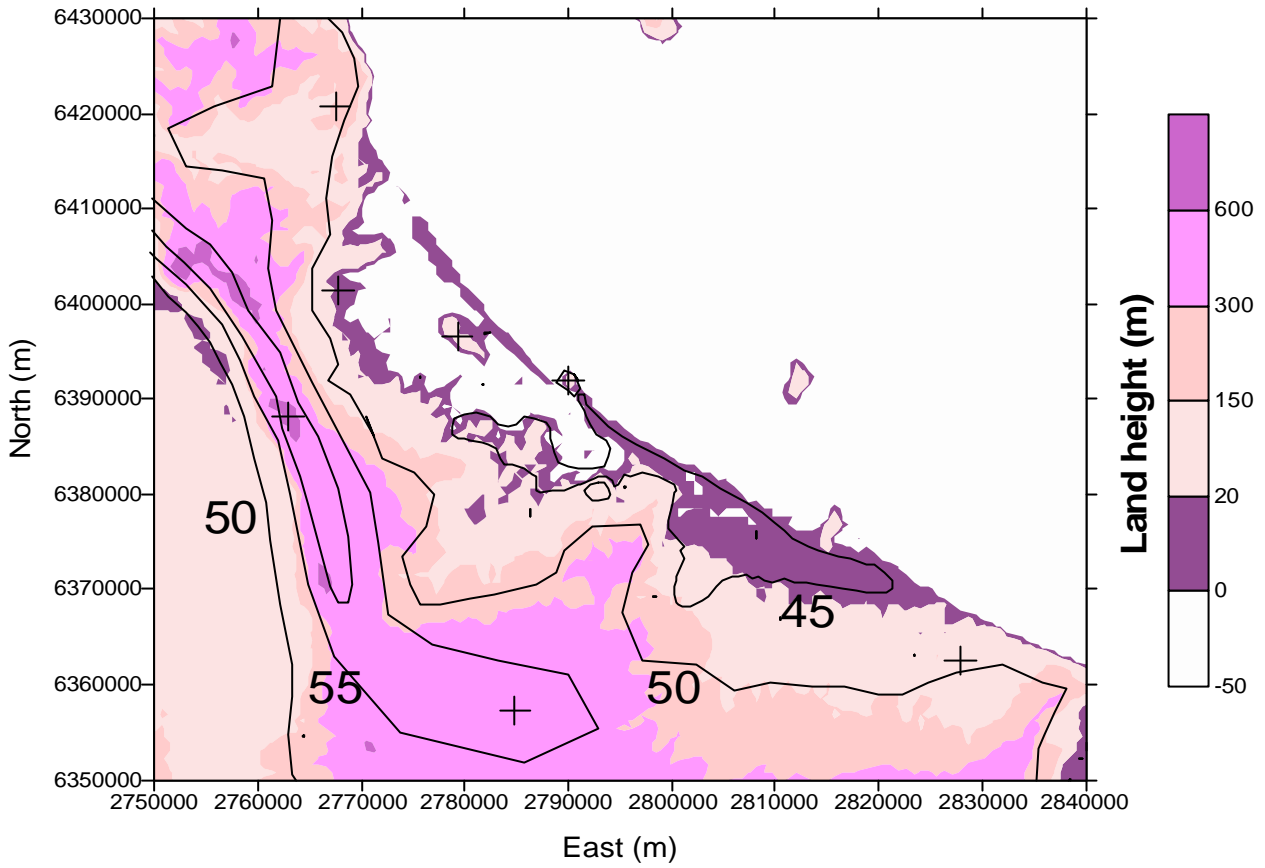


Figure 7: Distribution of maximum wind speeds (m/s) at a 150 -year return period.

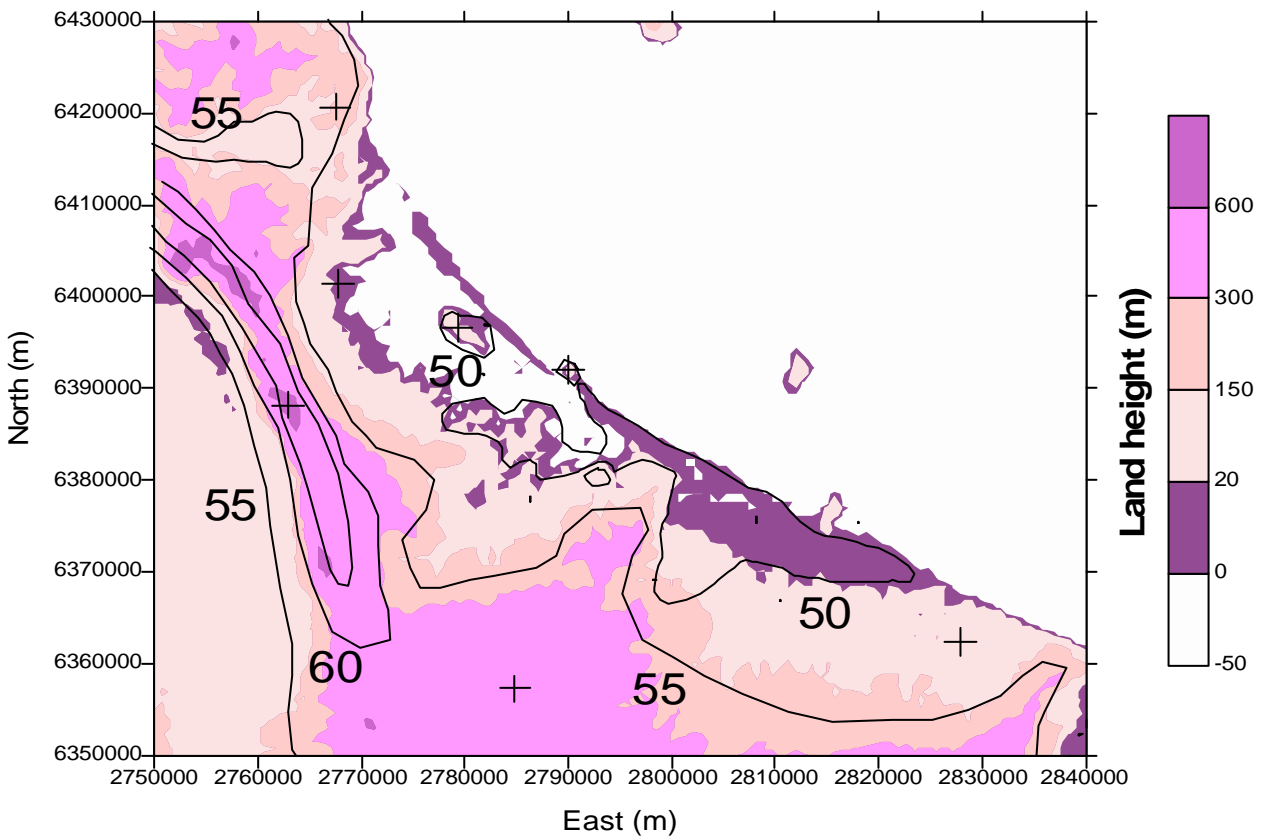


Figure 8: Distribution of maximum wind speeds (m/s) at a 475 -year return period.

Conclusions

Only daily rainfall data in the Western Bay of Plenty were analysed in this report. Although flooding events do occur at shorter time scales (e.g. the 9 hour event which occurred on 9 April 2000), the majority of long-term rainfall data are recorded daily. Only the Tauranga Airport and Te Puke automatic weather stations record high frequency rainfall data (hourly) at present in the Western Bay of Plenty as part of the National Climate Database Network, managed by NIWA. These stations have only recorded high frequency data since 1990 and 1994, respectively.

Major flooding in the Western Bay of Plenty typically occurs with depressions from the north, associated with strong, moist, north-easterly winds, and active frontal systems. Violent thunderstorm activity is a major cause of extreme (and often localised) rainfall in the Bay of Plenty. These thunderstorms are either embedded in fronts, or are caused by strong daytime heating/atmospheric instability.

Analysis of the flood event on the 20th April, 1923, estimated daily rainfall return periods of approximately 1-in-240 years at Tauranga Airport (although much less elsewhere). The return period estimates for the extreme event on 17 April 1948 were exceptional (eg >> 500 years) at Tauranga Airport, with record short duration rainfalls (the 34 mm of rainfall observed at Tauranga Airport over 10 minutes is a New Zealand record). The estimated return periods for the extended flood event of 19-22 March 1979 ranged between 121 and 217 years in the Western Bay of Plenty region.

In order to estimate the 1-in-150-year and 1-in-475-year daily rainfall in the Western Bay of Plenty, sites with more than 30 year's worth of data were analysed. It was imperative to use the longest (high quality) data records to achieve a 'representative' long-term rainfall distribution – so that decadal climate shifts such as the Interdecadal Pacific Oscillation (IPO) do not skew results. The IPO is a particular issue in the Bay of Plenty, in that the most recent phase of the IPO (1977 – 1998) has resulted in stronger south-westerly winds, with lower rainfall, and fewer floods, in the Bay of Plenty. It is notable that the most severe storm rainfall occurred in the Tauranga record prior to 1979 (eg 1948, 1951, 1961, 1978, 1979), in the north-easterly phase of the IPO, and also after 2000 (April 2000).

Gumbel or extreme value distribution analyses were performed, augmented by enhancement factors after Tomlinson (1980). Estimates in the Western Bay of Plenty ranged between daily rainfalls of 157mm and 500mm for the 150 year return period, and between 180mm and 572mm for the 475 year return period. It is important to note that there is significant level of uncertainty associated with these ARI estimates, as each step of the methodology (see section 4.4) has uncertainty associated with it. Users of these ARI estimates should consider this when applying the results of the analysis.

The ARI rainfall contours, for both 150 years and 475 years, broadly follow the elevation contours, which is physically realistic for daily rainfall data. However, as mentioned previously, shorter duration (eg. <3 hours), localised rainfalls caused by convective processes are less likely to be affected by elevation alone. It is possible that preferred regions for short duration, convective rainfall do exist within the Western Bay of Plenty, caused by topography which is subject to differential heating, or low level wind convergence, etc.

It is recommended that all available high frequency rainfall data held by the Council or other independent sources is utilised in a future analysis of extreme high frequency rainfall events, in order to quantify the

magnitude and frequency of these, and to assess whether favoured localities within the Western Bay of Plenty do exist. NIWA may be able to digitise further pluviograph (rainfall gauge) traces from Tauranga Airport, in order to analyse short-duration rain rates.

The strongest winds in western Bay of Plenty are typically from the west-southwest, and are usually associated with the passage of active fronts. Although high winds are relatively infrequent in many lowland areas, they are a common occurrence in exposed areas in the Kaimai Range. Strong winds also occur, although less frequently at low levels, from the north through east sector, being associated with deep depressions centred to the north or northwest of the region.

Tornadoes, although very localised and generally much smaller than those occurring in the USA, do occur occasionally in the Western Bay the Plenty. They typically have a small damage path, of around 10 to 30 metres wide and one to five kilometres long. Tornadoes are rare events in New Zealand. They are typically observed by chance, and are poorly observed (no details, and often not notified). Data are sparse in formal databases, such as The National Climate Database, managed by NIWA.

To evaluate the 1-in-150-year and 1-in-475-year wind gust, estimates at eight representative sites in the Western Bay of Plenty were produced analytically. The estimated 1-in-150-year gust speed for a height of 10 metres above ground level ranged between 46 m/s and 61 m/s at the eight selected sites, and between 49 m/s and 66 m/s for the 1-in-475-year estimate.

The extreme gust isopleths in Figures 7 and 8 were subjectively developed, and broadly follow the elevation contours. This is a physically realistic result when interpolating between discrete points, in the absence of other information. Some sites, like the top of Mauao, are exceptional (with contour detail lacking in the broad scale figures). Figures 7 and 8 have the most value if used in the appropriate way – namely to identify probable broad scale spatial patterns of extreme wind gusts in the Western Bay of Plenty, based on estimates at discrete sites calculated with current best-practice methodologies.

In the methodologies used to produce both the rainfall and wind gust return period estimates, it was assumed that there is no change in climate over the duration of time comparable to the return period (such as might occur due to global warming). Users of the information produced in this report need to acknowledge this underlying assumption.

It is recommended that regional climate change scenarios for the Bay of Plenty be derived once the Third Assessment Report from the IPCC (Intergovernmental Panel on Climate Change) is released in 2001. Guidance on regional changes in extreme rainfalls and ARIs under a changing climate are necessary for longer term planning.

The estimates for both the 1-in-150-year and 1-in-475-year daily rainfall and wind gusts are discrete (calculated at a point). Spatial interpolation allows isopleths to be drawn around the point estimates in the maps, for visual interpretation. There are obvious limitations to discrete estimates being spatially analysed, given the inherent uncertainties in the original estimation process. Users of this information also need to acknowledge this limitation, particularly if these results are inserted into a GIS system.

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APPENDIX 1 – Rainfall stations in the Western Bay of Plenty & vicinity

STATION NUMBER	NAME	LAT	LONG	Height (metres)	FIRST DATA	LAST DATA	GRID_REF
B75381	WAIHI	37.38	175.85	91	02-OCT-1898	01-Jan-90	T13618194
B75491	WAIHI BEACH	37.41	175.93	8	02-Oct-55	01-Sep-00	U13704167
B75572	MT TE AROHA TV STN	37.53	175.75	951	02-Jan-67	01-Jul-89	T13525038
B75581	WHARAWHARA WATER STN	37.56	175.86	122	02-Nov-69	01-Sep-00	T14634994
B75591	KATIKATI	37.55	175.95	6	02-Mar-33	01-Dec-79	U13708018
B75681	SHAFTESBURY	37.61	175.8	55	02-Dec-51	01-Aug-00	T14573947
B75691	KATIKATI LOCKINGTON	37.61	175.9	107	02-Jan-73	01-Jan-81	T14671935
B75782	TE ARIKI FALLS	37.75	175.88	253	02-Mar-68	01-Jan-97	T14641796
B75891	KAIMAI SCHOOL	37.83	175.96	376	02-May-22	01-Mar-49	U15707698
B76602	TE PUNA	37.66	176.06	27	02-Jun-66	01-Dec-87	U14800873
B76611	TAURANGA	37.68	176.16	2	02-Jan-70	01-Feb-94	U14894870
B76621	TAURANGA AERO	37.66	176.2	4	02-Jan-10	01-Feb-96	U14924873
B76701	WHAKAMARAMA	37.73	176	256	02-Jan-50	01-Sep-00	U14748812
B76702	LR KAIMAI,RIVER LODG	37.78	176.05	46	02-Jan-75	01-Jun-82	
B76711	OTUMOETAI	37.7	176.1	30	02-Jul-47	01-Jan-73	
B76712	TAURANGA	37.7	176.15	30	02-Feb-47	01-Jun-70	
B76716	HAIRINI	37.73	176.15	30	02-Oct-69	01-Jul-83	U14888805
B76717	OROPI WATER TREATMENT	37.76	176.13	65	02-Aug-72	01-Sep-00	U14865769
B76741	MAKETU	37.78	176.45	100	02-Jan-50	01-May-85	V14150740
B76802	MCLAREN FALLS	37.8	176.03	122	02-Oct-67	01-Nov-95	U14778734
B76832	TE PUKE	37.8	176.31	61	02-Aug-58	01-Jul-89	U14022729
B76833	TE PUKE NO 2	37.83	176.31	122	02-Mar-65	01-Jun-90	U15023699
B76835	TE PUKE	37.81	176.31	91	02-Jan-73	01-Sep-89	U14026706
B76841	PONGAKAWA	37.81	176.48	5	02-Jan-67	01-Oct-81	V15170694
B76842	MANIATUTU	37.85	176.45	64	02-Apr-62	01-Sep-00	V15142667
B76861	PIKOWAI	37.86	176.65	63	02-Jan-68	01-Mar-00	V15319640
B76921	TE RANGA	37.9	176.26	335	02-Oct-49	01-May-00	U15979616
B76951	ROTOEHU FOREST	37.9	176.51	72	02-Jan-38	01-Jul-88	V15186607

APPENDIX 2 – Gumbel Distributions

1-day (9 am - 9 am) annual extreme rainfalls and their return periods are shown below, including Gumbel distributions of 1-day and 2-day maximum observed annual rainfalls, indicating theoretical maximum falls with return periods of up to 1000 years. These estimates were used as part of the methodology to produce Figure 4 and Figure 5.

Tauranga Airport B76621

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

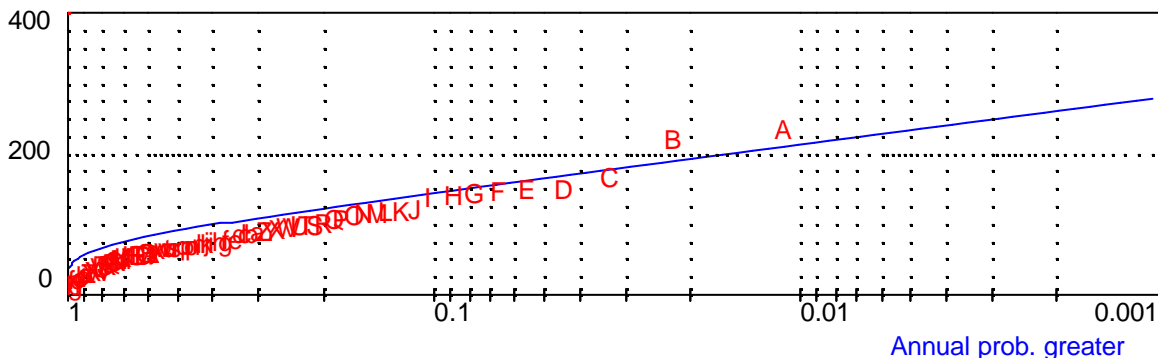
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			280	0.001	1000
			258	0.002	475
20-Apr-1923	239	A	239	0.004	241
17-Apr-1948	228	B	228	0.006	164
			226	0.007	150
			213	0.010	100
			193	0.020	50
19-Mar-1979	178	C	178	0.033	30
			166	0.050	20
Mean Annual 97 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at Tauranga Airport. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176621 B76621 Tauranga Air 1001 thru 9602 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distr. Location & Scale= 79.80 29.04

A-h site 1176621 B76621 Tauranga Air 1001 thru 9602 rain mm m=12

Tauranga Airport B76621

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

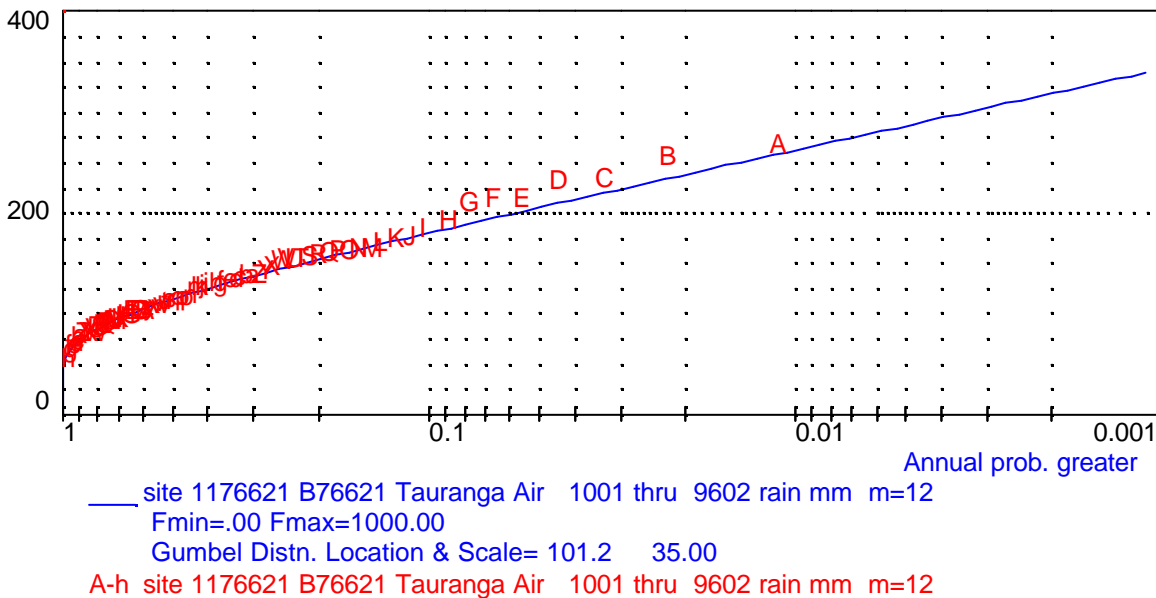
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			343	0.001	1000
			317	0.002	475
			278	0.007	150
19-Mar-1979	262	A	262	0.010	100
19-Apr-1923	250	B	250	0.014	71
			237	0.020	50
17-Apr-1948	230	C	230	0.025	40
7-Jul-1951	226	D	226	0.028	36
3-Dec-1962	210	E	210	0.044	23
9-Oct-1916	209	F	209	0.045	22
5-Jun-1920	206	G	206	0.049	20
Mean annual 121					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Tauranga. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Oropi B76717

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

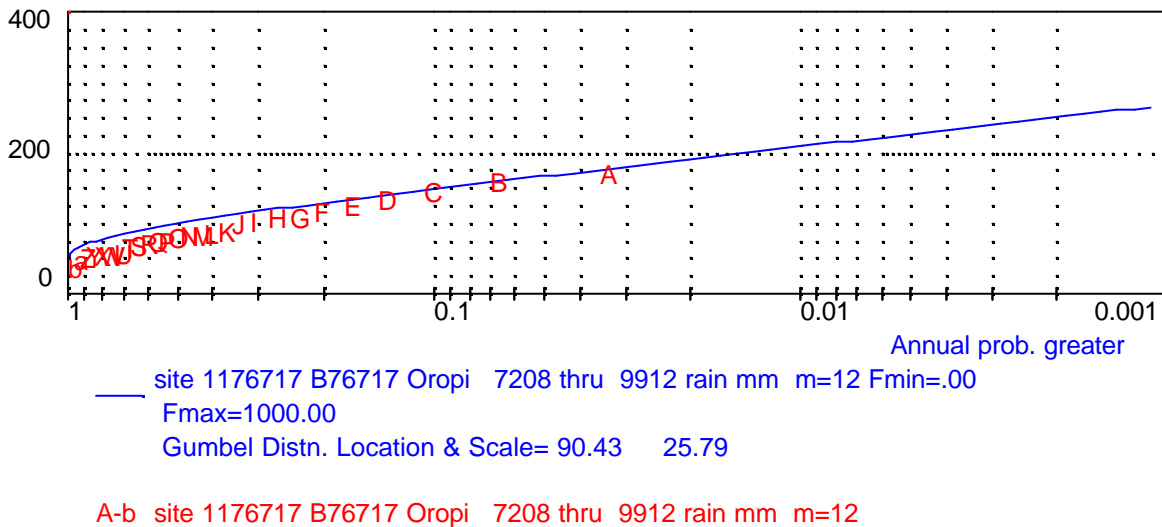
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			269	0.001	1000
			253	0.002	475
			213	0.007	150
			209	0.010	100
			191	0.020	50
22-May-1977	181	A	181	0.029	34
7-Dec-1983	170	B	170	0.046	22
			167	0.050	20
Mean Annual 90 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at Oropi. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Oropi B76717

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

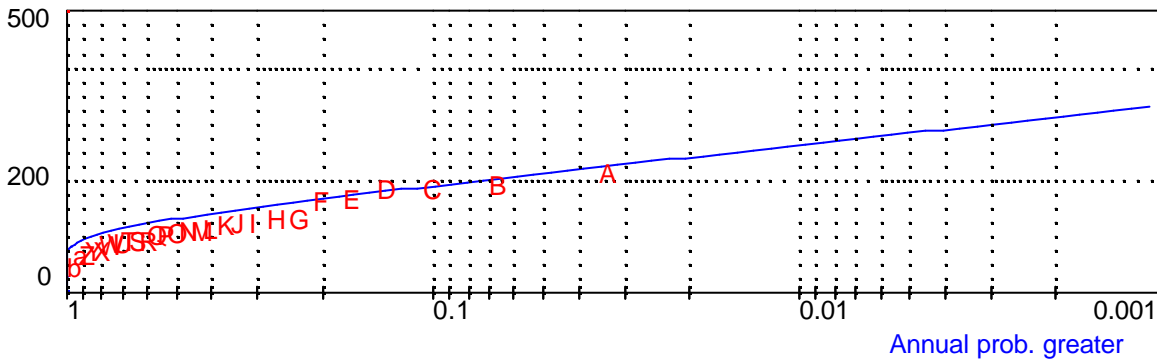
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			333	0.001	1000
			317	0.002	475
			278	0.007	150
			262	0.010	100
			241	0.020	50
20-Mar-1987	227	A	227	0.031	32
			212	0.050	20
Mean maximum	Annual 120				

Figure below: Gumbel distribution of 2-day rainfalls at Oropi. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176717 B76717 Oropi 7208 thru 9912 rain mm m=12 Fmin=.00
 Fmax=1000.00
 Gumbel Distn. Location & Scale= 120.2 30.84

A-b site 1176717 B76717 Oropi 7208 thru 9912 rain mm m=12

Waihi Beach B75491

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

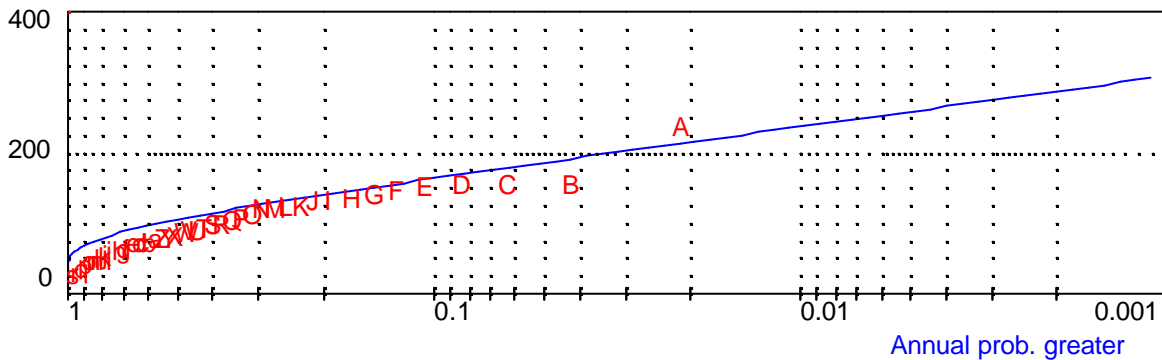
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			310	0.001	1000
			287	0.002	475
			251	0.007	150
21-Dec-1973	242	A	242	0.009	117
			237	0.010	100
			216	0.020	50
			187	0.050	20
Mean annual 94 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at Waihi Beach. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1175491 B75491 Waihi Beach 5510 thru 9912 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 93.74 31.26

A-s site 1175491 B75491 Waihi Beach 5510 thru 9912 rain mm m=12

Waihi Beach B75491

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

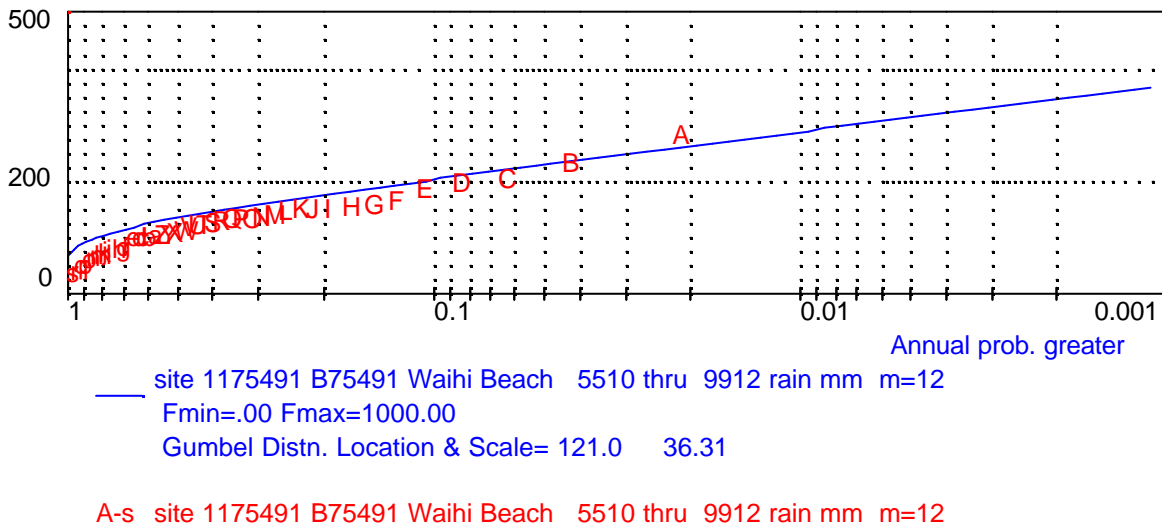
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceeded only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			372	0.001	1000
			348	0.002	475
			305	0.007	150
20-Mar-1987	289	A	289	0.010	104
			288	0.010	100
			263	0.020	50
20-Dec-1973	246	B	246	0.032	32
			229	0.050	20
Mean annual 121					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Waihi Beach. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Katikati B75591

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

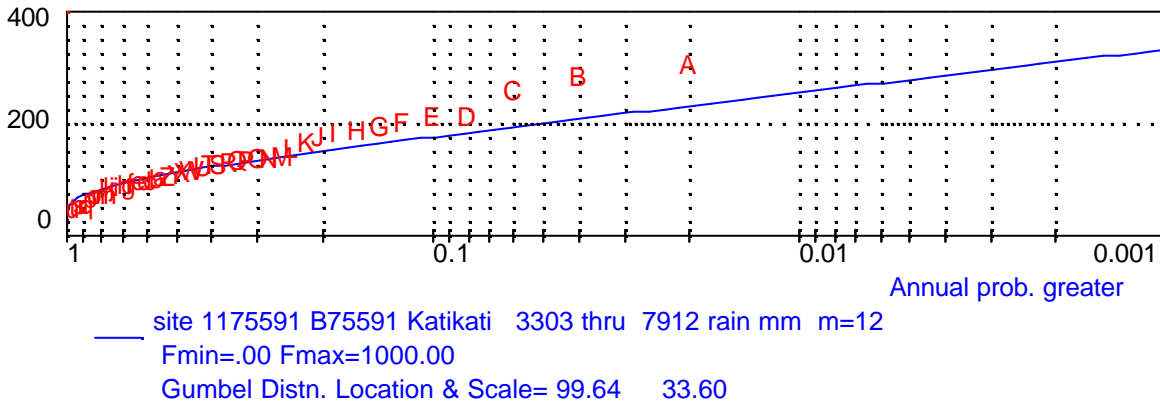
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			332	0.001	1000
			307	0.002	475
			269	0.007	150
			254	0.010	100
28-Feb-1928	247	A	247	0.013	80
14-Dec-1940	231	B	231	0.020	51
			231	0.020	50
1-Feb-1936	214	C	214	0.032	31
			199	0.050	20
Mean annual 100 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at Katikati. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



A-u site 1175591 B75591 Katikati 3303 thru 7912 rain mm m=12

Katikati B75591

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

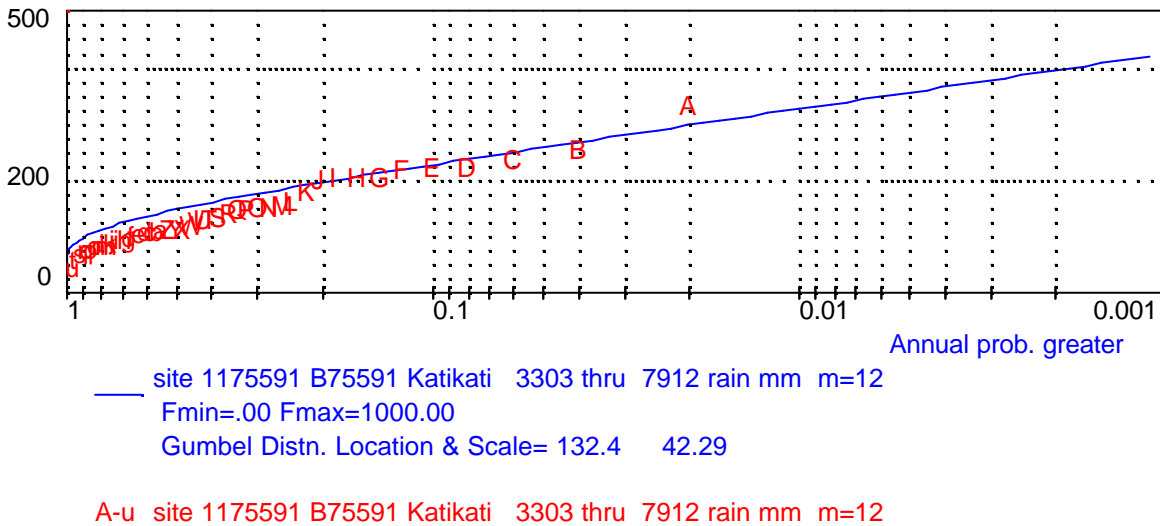
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			425	0.001	1000
			396	0.002	475
			346	0.007	150
24-Jun-1946	334	A	334	0.009	117
			327	0.010	100
			297	0.020	50
13-Dec-1940	266	B	266	0.042	24
			258	0.050	20
Mean annual 132					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Katikati. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Whakamarama B76701

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

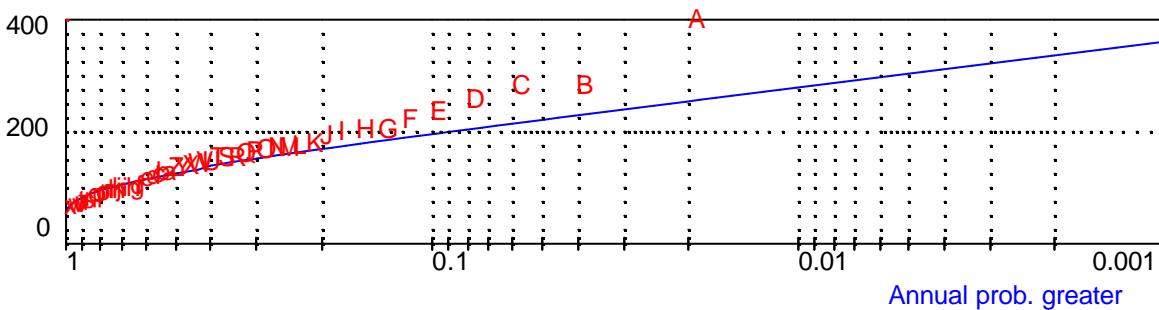
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
13-Jun-1961	316	A	360	0.001	1000
			336	0.002	475
			316	0.003	288
			295	0.007	150
			278	0.010	100
31-May-1962	232	B	253	0.020	50
			232	0.036	28
15-May-1972	231	C	231	0.036	28
			219	0.050	20
Mean annual 113 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at Whakamarama. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176701 B76701 Whakamarama 5001 thru 9912 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 113.2 35.77

A-x site 1176701 B76701 Whakamarama 5001 thru 9912 rain mm m=12

Whakamarama B76701

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

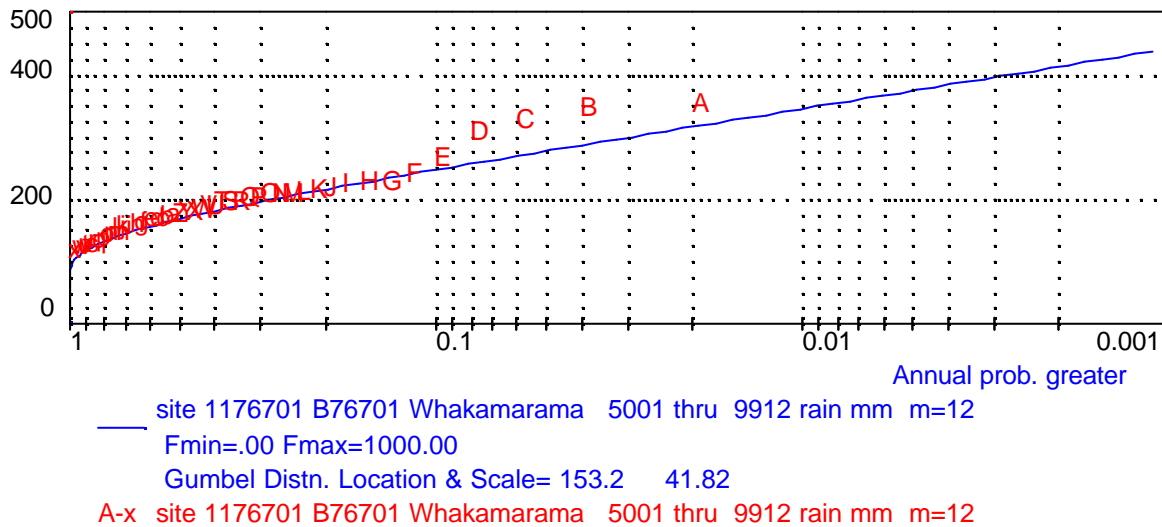
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			442	0.001	1000
			417	0.002	475
			366	0.007	150
			345	0.010	100
6-Dec-1983	343	A	343	0.011	94
13-Jun-1961	334	B	334	0.013	75
30-May-1962	316	C	316	0.020	50
8-Mar-1972	295	D	295	0.033	30
			277	0.050	20
Mean annual 153 maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Whakamarama. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Kaimai School B75891

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

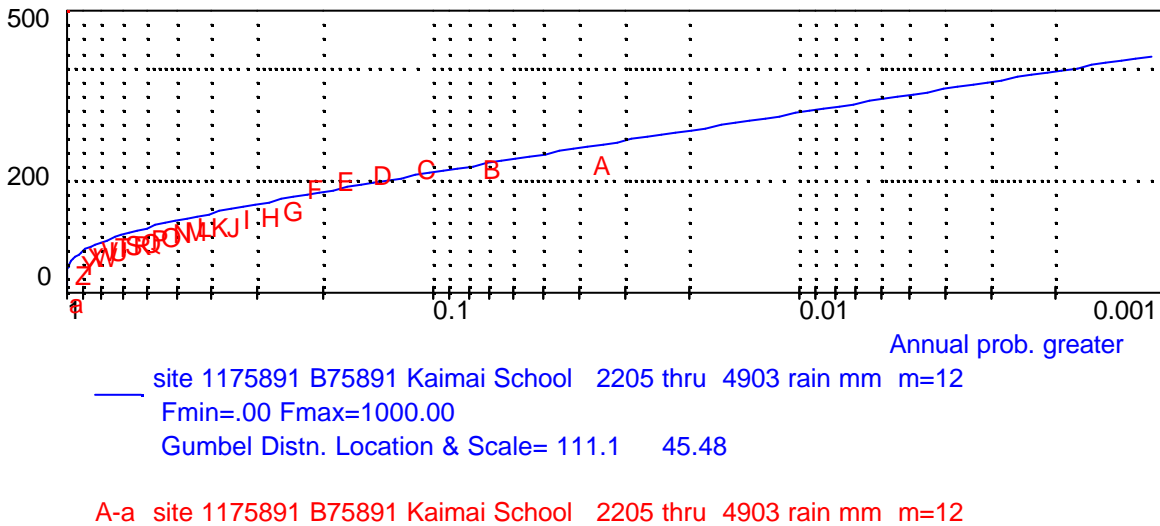
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			425	0.001	1000
			387	0.002	475
			339	0.007	150
20-Apr-1923			320	0.010	100
			288	0.020	50
			246	0.050	20
4-Feb-1938	238	A	238	0.060	17
Mean Annual maximum	137				

Figure below: Gumbel distribution of 1-day rainfalls at Kaimai School. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Kaimai School B75891

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

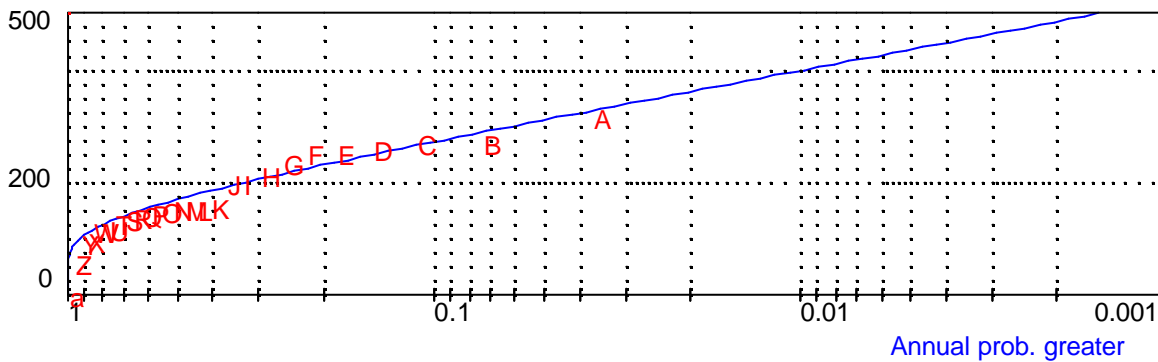
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			523	0.001	1000
			482	0.002	475
			423	0.007	150
			399	0.010	100
			361	0.020	50
27-Dec-1928	315	A	315	0.046	22
			310	0.050	20
Mean annual 181					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Kaimai School. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1175891 B75891 Kaimai School 2205 thru 4903 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distr. Location & Scale= 149.8 54.07

A-a site 1175891 B75891 Kaimai School 2205 thru 4903 rain mm m=12

McLaren Falls B76802

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

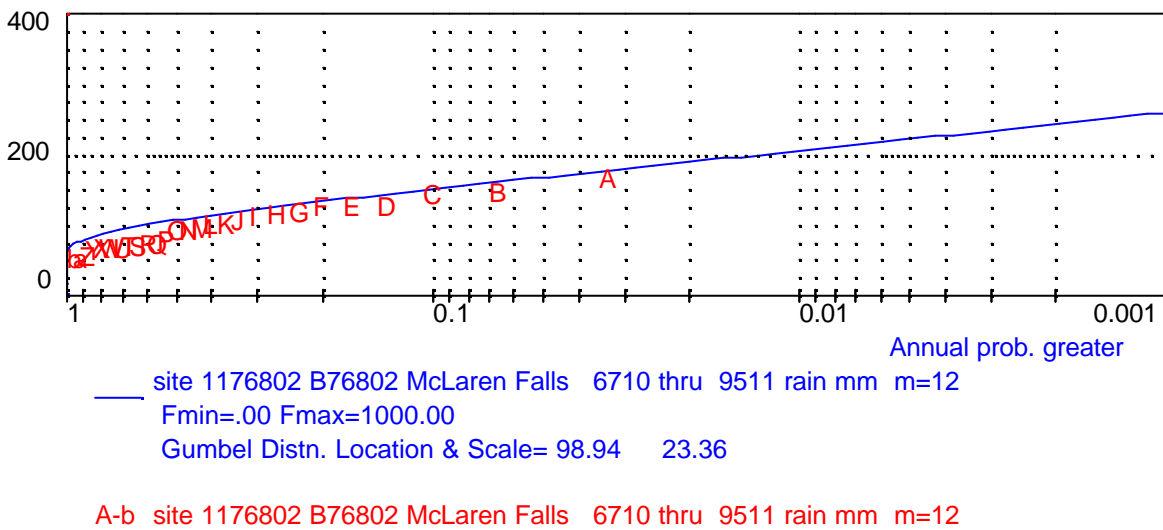
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			260	0.001	1000
			249	0.002	475
			218	0.007	150
			206	0.010	100
			190	0.020	50
13-Aug-1970	179	A	179	0.032	31
			168	0.050	20
Mean annual 99 maximum					

Figure below: Gumbel distribution of 1-day rainfalls at McLaren Falls. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



McLaren Falls B76802

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

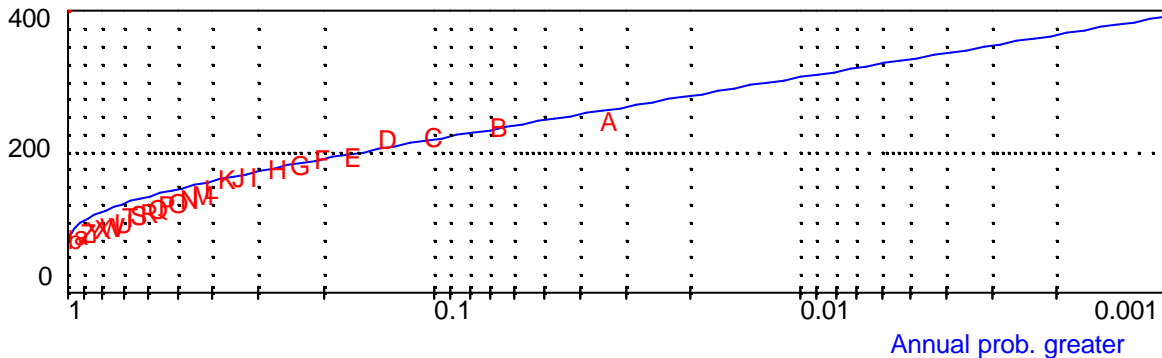
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			393	0.001	1000
			370	0.002	475
			324	0.007	150
			306	0.010	100
			280	0.020	50
20-Mar-1987	247	A	247	0.048	21
			245	0.050	20
Mean annual 134 maximum					

Figure below: Gumbel distribution of 2-day rainfalls at McLaren Falls Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176802 B76802 McLaren Falls 6710 thru 9511 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distr. Location & Scale= 133.7 37.53

A-b site 1176802 B76802 McLaren Falls 6710 thru 9511 rain mm m=12

Maketu B76741

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

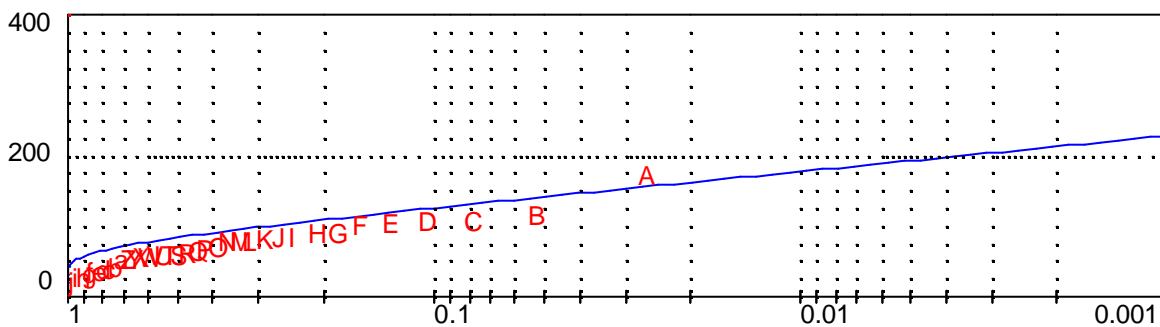
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
17-Apr-1974	184	A	229	0.001	1000
			214	0.002	475
			188	0.007	150
			184	0.008	133
			177	0.010	100
			162	0.020	50
			142	0.050	20
Mean Annual maximum			76		

Figure below: Gumbel distribution of 1-day rainfalls at Maketu. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Annual prob. greater
 — site 1176741 B76741 Maketu 5001 thru 8505 rain mm m=12 Fmin=.00
 Fmax=1000.00
 Gumbel Distr. Location & Scale= 75.88 22.17

A-j site 1176741 B76741 Maketu 5001 thru 8505 rain mm m=12

Maketu B76741

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

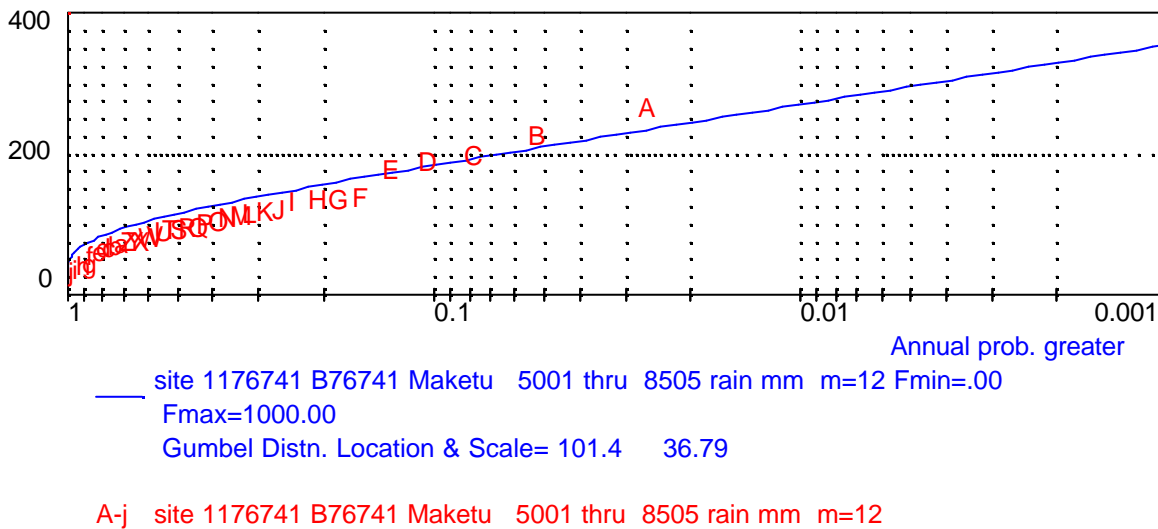
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			356	0.001	1000
			328	0.002	475
			287	0.007	150
			271	0.010	100
17-Apr-1974	268	A	268	0.011	93
			245	0.020	50
2-Dec-1962	232	B	232	0.028	36
			211	0.050	20
Mean Annual maximum	101				

Figure below: Gumbel distribution of 2-day rainfalls at Maketu. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Rotoehu Forest B76951

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

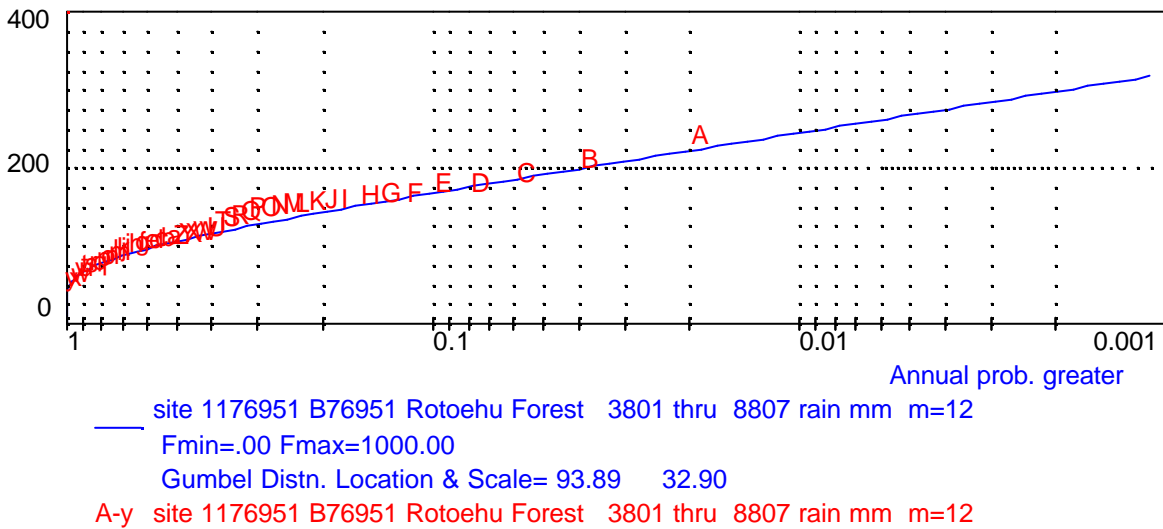
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			321	0.001	1000
			296	0.002	475
			260	0.007	150
			245	0.010	100
22-Feb-1944	232	A	232	0.015	67
			222	0.020	50
17-Apr-1974	201	B	201	0.038	26
			192	0.050	20
Mean Annual maximum	113				

Figure below: Gumbel distribution of 1-day rainfalls at Rotoehu Forest. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Rotoehu Forest B76951

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

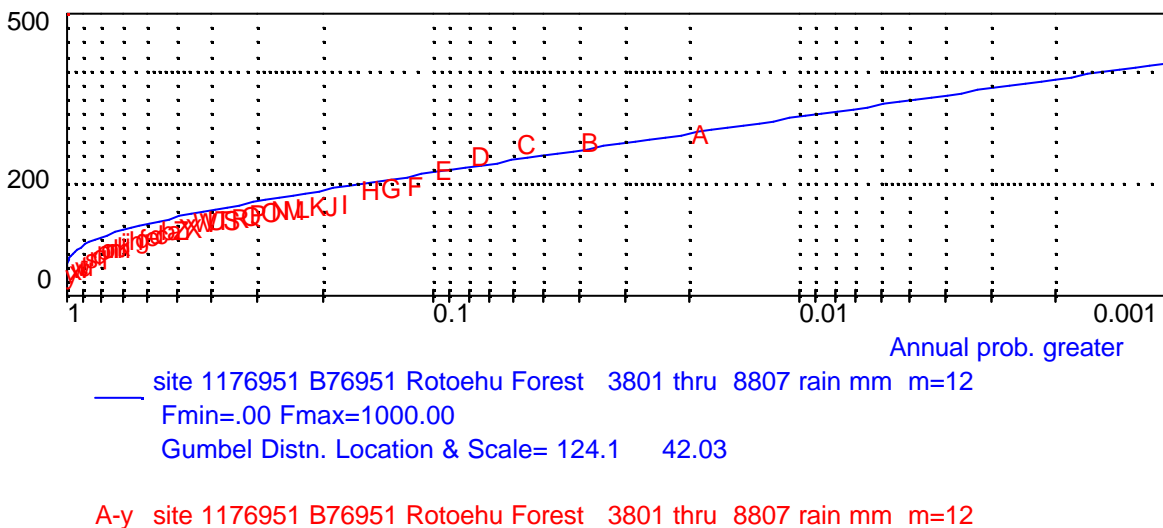
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			414	0.001	1000
			384	0.002	475
			336	0.007	150
			317	0.010	100
21-Feb-1944	294	A	294	0.017	57
			288	0.020	50
4-Jul-1951	281	B	281	0.024	42
17-Apr-1974	278	C	278	0.025	40
18-Dec-1962	258	D	258	0.040	25
			249	0.050	20
Mean annual 148 maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Rotoehu Forest. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Otumoetai B76711

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

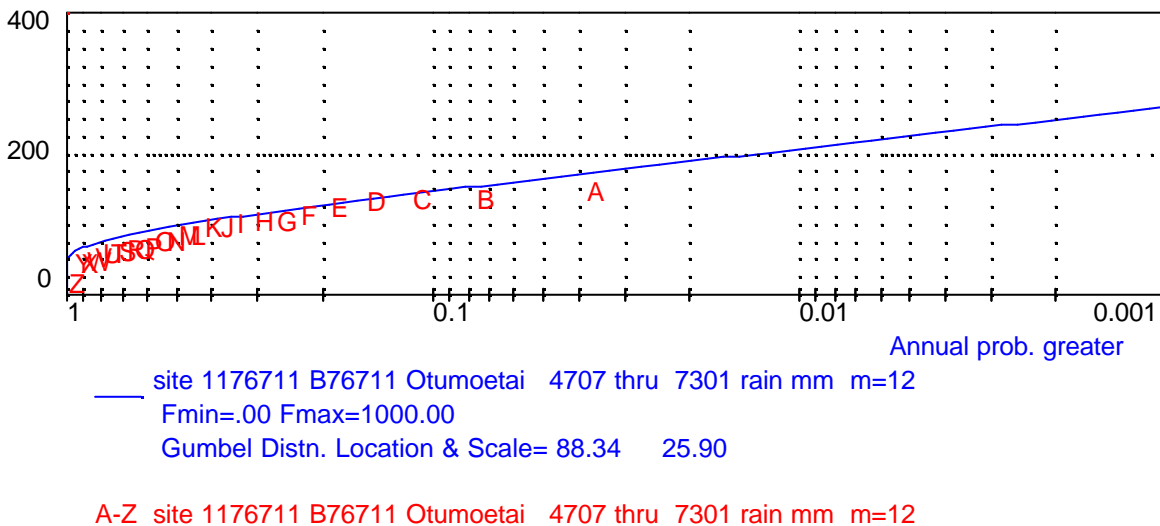
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			267	0.001	1000
			252	0.002	475
			220	0.007	150
			208	0.010	100
			189	0.020	50
			165	0.050	20
3-Dec-1962	161	A	161	0.059	17
Mean Annual maximum	103				

Figure below: Gumbel distribution of 1-day rainfalls at Otumoetai. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Otumoetai B76711

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

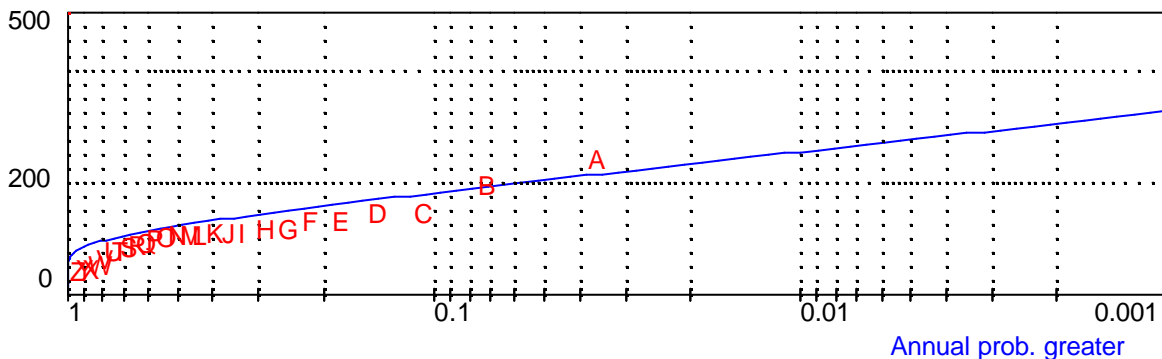
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			326	0.001	1000
			307	0.002	475
			269	0.007	150
			254	0.010	100
4-Jul-1951	250	A	250	0.011	88
			232	0.020	50
3-Dec-1962	211	B	211	0.039	25
			203	0.050	20
Mean annual 111					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Otumoetai. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176711 B76711 Otumoetai 4707 thru 7301 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 110.8 31.09

A-Z site 1176711 B76711 Otumoetai 4707 thru 7301 rain mm m=12

Te Puke B76832

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

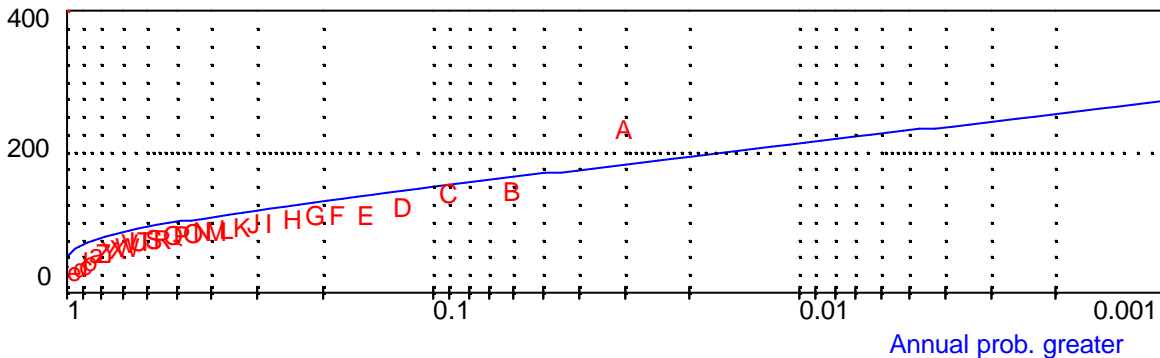
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
19-Mar-1979	238	A	273	0.001	1000
			257	0.002	475
			238	0.004	261
			225	0.007	150
			212	0.010	100
			194	0.020	50
			169	0.050	20
Mean Annual maximum			106		

Figure below: Gumbel distribution of 1-day rainfalls at Te Puke. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176832 B76832 Te Puke 5808 thru 8907 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 90.43 26.44

A-e site 1176832 B76832 Te Puke 5808 thru 8907 rain mm m=12

Te Puke B76832

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

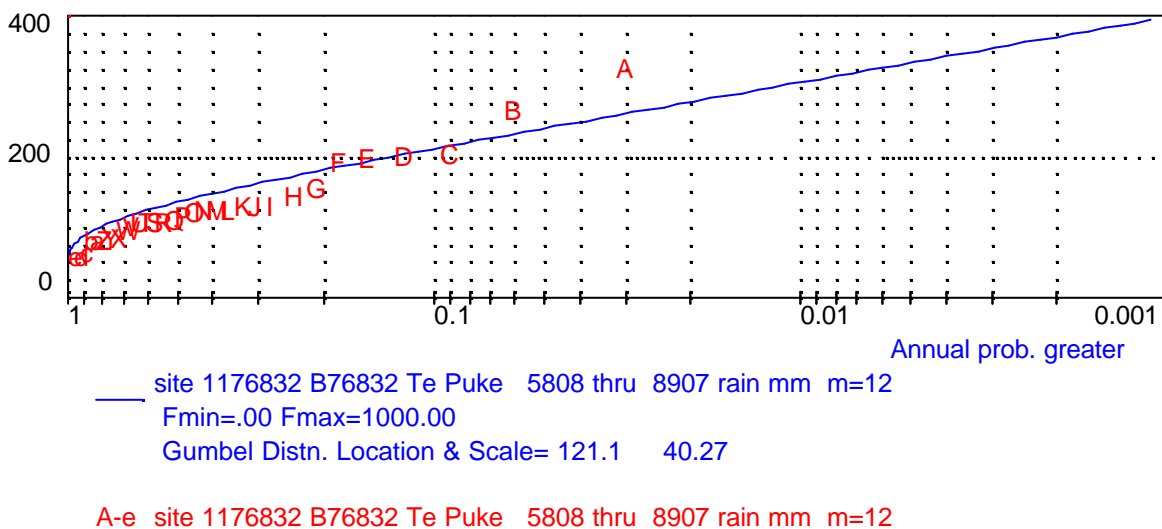
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			399	0.001	1000
			370	0.002	475
			324	0.007	150
19-Mar-1979	321	A	321	0.007	144
			306	0.010	100
			278	0.020	50
8-Mar-1972	268	B	268	0.026	39
			240	0.050	20
Mean annual maximum			144		

Figure below: Gumbel distribution of 2-day rainfalls at Te Puke. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Maniatutu B76842

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

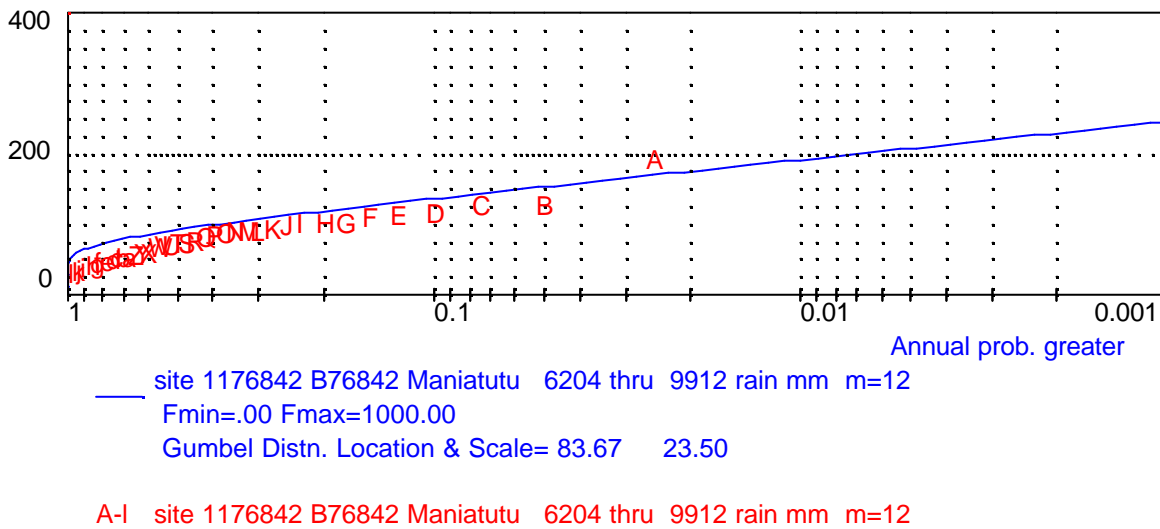
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
17-Apr-1974	200	A	246	0.001	1000
			232	0.002	475
			205	0.007	150
			200	0.007	142
			192	0.010	100
			175	0.020	50
			153	0.050	20
Mean	Annual 84				
	maximum				

Figure below: Gumbel distribution of 1-day rainfalls at Maniatutu. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Maniatutu B76842

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

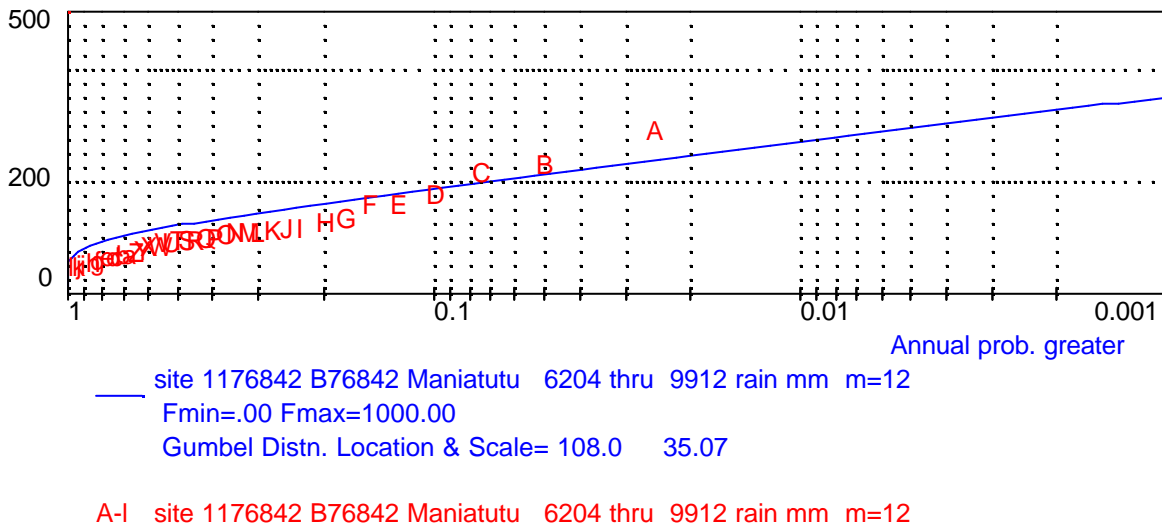
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
17-Apr-1974	297	A	350	0.001	1000
			325	0.002	475
			297	0.005	216
			285	0.007	150
			269	0.010	100
2-Dec-1962	240	B	241	0.020	50
			240	0.023	44
8-Mar-1972	229	C	229	0.032	32
			212	0.050	20
Mean annual 108 maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Maniatutu. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



Te Ranga B76921

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 1-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

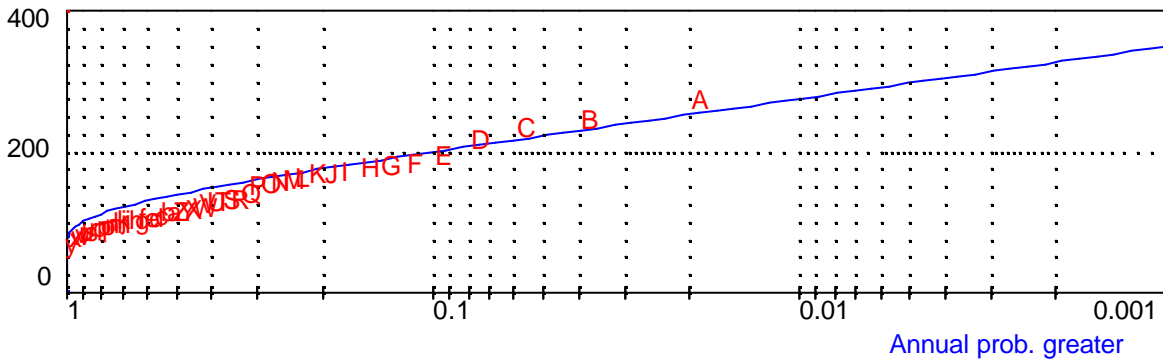
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 1-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 1-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			350	0.001	1000
			334	0.002	475
			293	0.007	150
			276	0.010	100
31-May-1962	275	A	275	0.010	98
			253	0.020	50
2-May-1999	250	B	250	0.022	45
13-Aug-1970	241	C	241	0.029	34
4-Jul-1951	224	D	224	0.049	20
Mean Annual maximum	128				

Figure below: Gumbel distribution of 1-day rainfalls at Te Ranga. Each letter represents the maximum 1-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176921 B76921 Te Ranga 4910 thru 9912 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 127.7 32.19

A-y site 1176921 B76921 Te Ranga 4910 thru 9912 rain mm m=12

Te Ranga B76921

Columns shown in the table are:

Date: In the form of yymmdd (year, month, day)

Observed rain: Highest 2-day (9.00 am to 9.00 am) falls from the climate record

Rain identification: The letters shown in the plotted position on the graphs below.

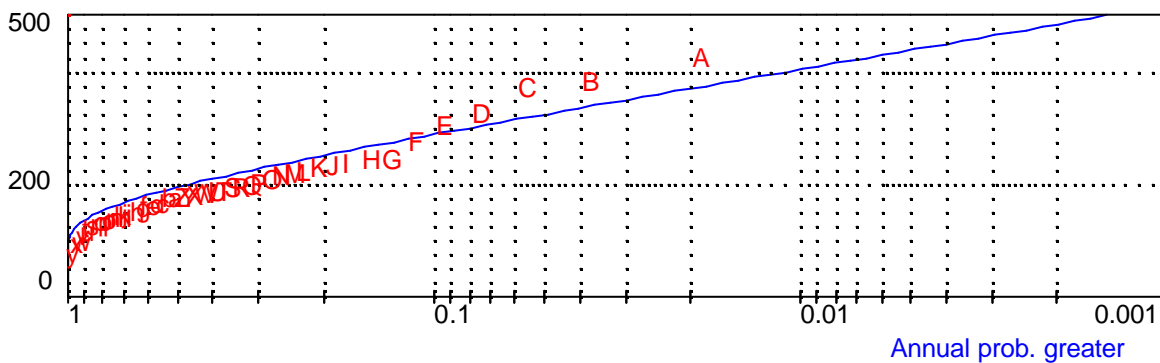
Plotted total: If no rain identification letter is shown (col 3) then this is the estimated 2-day fall which would be equalled or exceed only once in the number of years shown in the last column.

Probability: The probability (chance) of a rainfall of the respective amount occurring in any one year.

Return period: The estimated average return period for 2-day rainfalls.

Date	Observed rain	Rain identification	Plotted total	Probability (1/y)	Return period (yrs)
			519	0.001	1000
			490	0.002	475
			429	0.007	150
4-Jul-1951	419	A	419	0.007	134
			405	0.010	100
1-May-1999	379	B	379	0.017	60
30-May-1962	371	C	371	0.020	51
			370	0.020	50
4-Nov-1999	328	D	328	0.047	21
			324	0.050	20
Mean annual 177					
maximum					

Figure below: Gumbel distribution of 2-day rainfalls at Te Ranga. Each letter represents the maximum 2-day fall in each year respectively. The axes show depth of rain in millimetres (vertical) and annual probability (horizontal).



— site 1176921 B76921 Te Ranga 4910 thru 9912 rain mm m=12
 Fmin=.00 Fmax=1000.00
 Gumbel Distn. Location & Scale= 176.7 49.54

A-y site 1176921 B76921 Te Ranga 4910 thru 9912 rain mm m=12

APPENDIX 3 – Report Specification

INTRODUCTION

The Western Bay of Plenty Engineering Lifelines Project is interested in a review of meteorological hazards in the Western Bay of Plenty region – specifically heavy rainfall and high winds – which might impact on ‘lifeline’ infrastructure. There is a need for spatial analyses of these variables across the Western Bay of Plenty district, and also for estimates of the 1- in - 150 year and 1- in - 475 year events.

This proposal has been revised after discussion with s 7(2)(a) - Privacy Project coordinator.

REPORT FOCUS

In this report, there will be two main areas of analysis:

The first is to take the maximum recorded wind and broad-scale rainfall from the archived climate data record for WBOP, analyse these, and to determine from this record how often such events are likely to occur. This average frequency of recurrence, (or average return period), is a useful indication of how often resources that are designed to cope with such events might be needed.

A second focus for the Lifelines Project is the spatial estimation of average return periods of 150 and 475 years (these periods chosen to be consistent with other hazard information). Because meteorological observations have usually not been recorded for this length of time, estimates of the severity of meteorological events for these return periods need to be obtained by analytical modelling or estimation from extreme value distributions, extrapolating from available data. Estimates obtained in this way have uncertainty associated with them, because such extreme events may have never been actually measured in the data record. The estimates will be iterated over many sites in the Western Bay of Plenty district, and an interpolated spatial map provided.

REPORT CONTENT

1. Executive Summary
2. High winds analysis

2.1

The wind record in the WBOP district is generally scarce, with most data available at the Port of Tauranga or the Tauranga aerodrome.

At all available wind stations within the WBOP district, the maximum 3 recorded wind gust speeds will be tabled, along with a brief commentary about the meteorological situations which typically cause the strongest winds.

An assessment of the recorded frequency of maximum wind gust speeds at these wind stations will also be undertaken.

2.2

Eight sites across the WBOP district will be chosen due to their theoretical (differing) wind environment. These sites will be clearly located and identified. A process whereby the basic regional wind speeds are estimated, the derived winds speeds are calculated, and local topography multipliers are computed, will be undertaken.

A summary of the estimated 1 in 150 year and 1 in 475 year return period wind gust speeds will be presented for these 8 sites in both tabular and graphical (spatial*) form (eg jpeg inserted into the word document). Please note that these estimates will be based on the current engineering guidelines. No account for global climate change, etc, is made in these methodologies.

***CAVEAT**

Note that the estimates for the eight sites within the WBOP district are *discrete* estimates, calculated at a point source. Dr ^{s 7(2)(a) - Privacy} NIWA Wellington, would provide a jpeg image in the report document, which draws isopleths around the wind gust speeds as estimated, for visual interpretation of the results only. He has strong reservations about offering a GIS version of these results, and wishes to underline the obvious limitations of discrete estimates being spatially analysed and interpolated to the 'nth degree' within a GIS system, given the inherent uncertainties in the original estimation process.

NIWA would, however, provide an electronic text file, which contains site latitude, longitude, estimation parameters, etc, for insertion into a GIS system by the WBOP Engineering Lifelines group if they so wish, but would request that the caveat noted above be included in any GIS use of the estimates.

3. Heavy rainfall

3.1

An assessment of 3 recorded severe rain/floods in the WBOP district will be undertaken, which will briefly outline the antecedent meteorological situation, table the recorded daily rainfall at rainfall gauges across the district, including their estimated return periods, and spatially** map the 24 hour (daily) rainfall pattern in the WBOP by way of jpeg image inserted into the report document.

Note that brief commentary about the use of daily data, as opposed to other frequency data, will be included in the report.

3.2

By using Gumbel Extreme Value Distribution theory, an estimated distribution of daily rainfall extremes for each key rainfall gauge across the WBOP district will be calculated. This enables estimates of the 1-in-

150 year and 1-in-475 year rainfall events at each site to be produced. Two jpeg maps will be supplied, which spatially interpolate the 1-in-150 year, and 1-in-475 year, daily rainfall estimates across the district, between rainfall gauges.

Please note that this method uses historical data to calculate extreme rainfall distributions, and therefore extreme estimates, and no account for global climate change has been incorporated into these methodologies.

**NIWA would again provide 2 electronic text files, which contain gauge latitude, longitude, rainfall and estimation parameters, for insertion into a GIS system by the WBOP Engineering Lifelines group if they so wish, but would request that the caveat noted on the previous page be included in any GIS use of the estimates.

4. Conclusions, caveats
5. References