Journal of Hydrology (NZ) 40(2): 105-127, 2001

Two-component extreme value distribution applied to Canterbury annual maximum flood peaks

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Abstract

To make use of data from the largest floods in the Canterbury region of New Zealand, which are often outliers in standard EV1 and EV2 distributions, the Two-Component Extreme Value (TCEV) distribution was applied to annual maxima flood series data. Historic and anecdotal data were used to increase at-site sample sizes and improve the reliability of corresponding plotting positions for each site. Regional TCEV / L-moments analysis was also used. The results showed tendencies toward two-component distributions within the Canterbury region. Most East Coast rivers showed a marked tendency toward a TCEV distribution that was greatest in the southern rivers. The flood frequency characteristics of Main Divide rivers altered with distance of the upper catchment boundary from the West Coast. The tendency toward a two-component distribution is related to two dominant storm directions, and is affected by topography, orographic rainfall, rain shadows and catchment alignment to storm directions.

Key Words: Annual Maxima, Extreme Value Distribution, Two-Component, L-moments, Flood Frequency, Homogeneity, Historical Data, Canterbury.

Introduction

Annual maxima flood series may contain a very large event, often termed an "outlier", which does not fit the distribution being applied to the flood series. For this reason, outliers are sometimes dropped from analyses. However we do this at our peril! The main objective in flood frequency analysis is to estimate the size and probability of very large floods. Outliers are the very events we need to investigate (particularly their measurement errors and data quality, although this is not the main focus of this paper). As they do not appear to fit in with the annual maxima series being analysed, the outliers may be part of another distribution and not part of the statistical distribution of the remainder of the flood series. Examining data with the Two-Component Extreme Value (TCEV) distribution (Rossi *et al.*, 1984) can indicate whether a second distribution is present.

Parts of the Canterbury region of New Zealand have been shown to have flood and storm rainfall frequency distributions that tend away from the Extreme Value Type I, EV1, or Gumbel distribution (McKerchar and Pearson, 1989, 1990; Pearson, 1991a; Griffiths and Pearson, 1993; Madsen *et al*,. 1997; Pearson and Henderson, 1998). These studies show that the Extreme Value Type II (EV2) distribution of the Generalised Extreme value (GEV) distribution is a better descriptor than the EV1 for Canterbury annual hydrological extrema. An attractive alternative to the EV2 distribution (which has an increasing upward curvature on a Gumbel plot) is the two-EV1-line approach offered by the TCEV distribution.

This paper uses the TCEV distribution to improve our knowledge of the flood frequencies of rivers in the Canterbury region. We carried out TCEV analyses of at-site (single) flood records, using historical and anecdotal information. The analysis uses L-moments (Hosking, 1990; Pearson, 1991a) to test the homogeneity of Canterbury flood frequency regions (groups of stations) and the suitability of the TCEV distribution to represent these regions.

Theory and methods

The TCEV distribution was developed by Rossi *et al.* (1984) and applied to Italian and UK annual maximum flood series. Statistical properties of the distribution were presented by Rossi *et al.* and expanded upon in a follow-up commentary by Beran *et al.* (1986). The TCEV was first applied in New Zealand in a study of Southland floods (Thompson, 1988).

The TCEV distribution is the distribution of the maxima of two independent Extreme Value Type I (Gumbel) distributions. The underlying theory assumes that there are two flood-producing processes, each a Poisson process in time with exponential distribution magnitudes. One of the processes represents the more frequent and smaller flood events ("basic" flood series), and the other represents the less frequent but larger events (i.e. the "outlier" series) (e.g. Rossi *et al.*, 1984; van Montfort, 1996).

The TCEV cumulative distribution function $F(x)$ is given by,

$$F(x) = \exp \{ - \lambda_1 \exp (-x / \theta_1) - \lambda_2 \exp (-x / \theta_2) \} \qquad (1)$$

where $F(x)$ is the probability of the annual maxima being less than x, θ_1 and θ_2 are the means of the underlying basic and outlier series respectively, and λ_1 and λ_2 are their respective Poisson rates of occurrence. Clearly we have $\theta_2 > \theta_1$, and $\lambda_1 > \lambda_2$. Parameters θ_1, θ_2, λ_1 and λ_2 need to be estimated when fitting the TCEV distribution to flood data. When plotted on Gumbel probability paper, the TCEV distribution appears as two EV1 lines, with a curved transition between the shallower basic series EV1 line and the steeper outlier series line (Fig. 1).

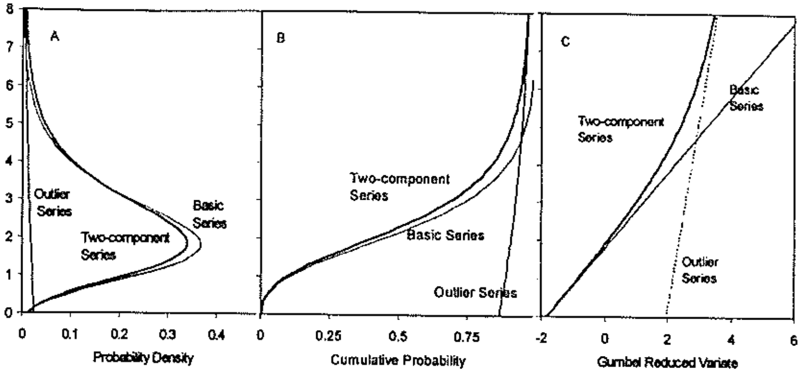


Figure 1 – (A) TCEV probability density function distribution with individual component Gumbel probability densities (parameters θ_1=1, θ_2=5, λ_1=1, λ_2=0.1). (B) Cumulative distribution function (*F*(*x*))of Figure 1A distributions. (C) Gumbel probability plot of Figure 1A distributions. [Compare with Pearson 1992, Figure 6.4.]

The TCEV distribution can be fitted to annual maximum flood series using a number of methods, such as methods of moments, maximum likelihood, probability-weighted moments, and least squares. In this paper we fit the TCEV distribution function (*F*(*x*), Equation 1) to individual flood series (*x*) using least squares. However, analysis of a single-site flood series using the TCEV distribution requires extreme care because it has four parameters (compared with two parameters for the EV1 distribution and three parameters for the EV2 distribution). To compensate for this, historical data, anecdotal evidence and flood series from other nearby river locations with a similar climatic record and topography were used to extend the annual series used and provide a longer return-period plotting position for flood peaks.

A better use of a four-parameter distribution is in regional flood studies. To assess the appropriateness (in a regional sense) of using the TCEV distribution and the homogeneity of flood frequency of regional groupings of catchments, we estimate L-moment ratios of annual maximum flood series (Hosking, 1990; Hosking and Wallis, 1993; Pearson, 1991a, 1991b; Pearson and Davies, 1997; Vogel and Fennessey, 1993, Vogel *et al.*, 1993). Unbiased estimators of L-moments were used (Hosking, 1990). Of particular interest are the L-moment ratios L-skewness and L-kurtosis. Sample values of these

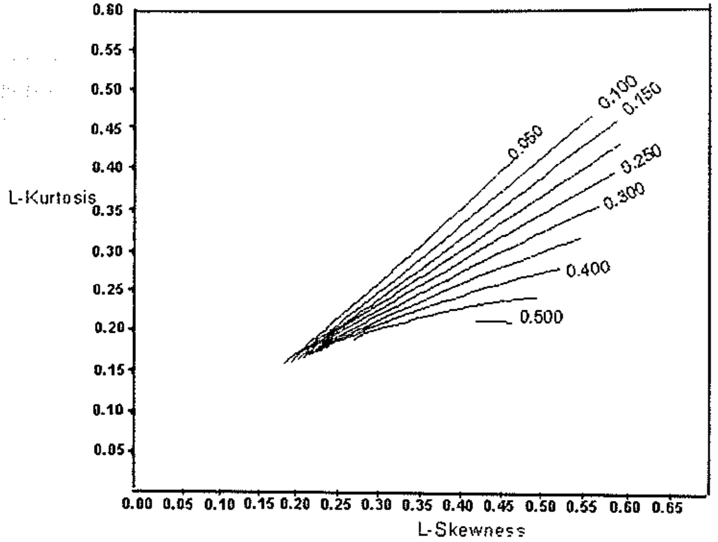


Figure 2 – L-moment ratio plot (L-kurtosis versus L-skewness) for the TCEV distribution for various probabilities (p) of an annual maximum flood valuecoming from the outlier series.

ratios are plotted against theoretical values of different extreme value distributions. The proximity and clustering of the sample values allows the most likely regional parent distribution and clusters of similar catchments to be identified (Hosking and Wallis, 1993; Pearson, 1991a; Vogel and Fennessey, 1993; Vogel *et al.*, 1993). Figure 2 shows the population values of L-skewness and L-kurtosis for the TCEV distribution, for probabilities (p) of an annual maximum value from a TCEV distribution being from the outlier series. The probability p is a function of the TCEV parameters θ_1, θ_2, λ_1 and λ_2, given by Beran *et al.* (1986). A plot similar to Figure 2 was presented by Gabriele and Arnell (1991). Hosking and Wallis (1993) tests are used to test flood frequency homogeneity of catchment groupings using L-moment ratios, including L-CV.

The use of the TCEV distribution may also be viewed as a censoring technique that determines a threshold above which the upper maxima fit an EV1 distribution. The reliability of the predicted frequency on the upper limb depends on how many maxima are on it, and at some sites there are only a few. Therefore historical data have been used to improve the number of points on the upper limb, with anecdotal evidence being sought to improve the reliability of the plotting positions of these points, and regional methods have been employed.

Data

Annual maximum flood data from 31 Environment Canterbury streamflow recording sites were used in this study. Twelve records are from catchments that drain from the Main Divide of the South Island, and 19 are from catchments that drain from ranges east of the Main Divide, with 9 in North Canterbury and 10 in South Canterbury (Fig. 3). The stations have between 10 and 50 years of continuous record, with an average of 24 years. During the periods of continuous recording some rivers had the largest floods in living memory. In this case the length of record used to determine Gringorten (1963) plotting positions for the analysis was increased to reflect this.

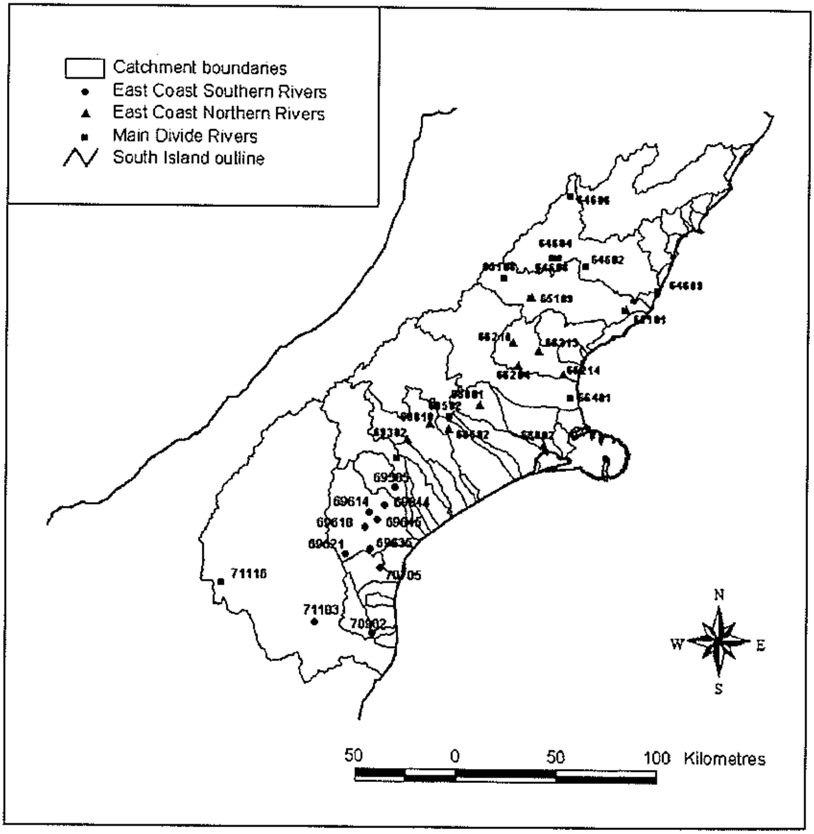


Figure 3 – Location map of Canterbury rivers and water-level recording stations used in this study.

In addition to annual maxima from continuous records, many of the rivers have longer records of less reliable historical data. These data are not as reliable as the annual maxima data that have flow gaugings as a basis for their stage-discharge rating curve relationships, even though many have continuous high flow ratings that are based on slope-area calculations (the same method used to estimate many of the historical flood discharges). Again in this case the length of the historical record was increased.

In some cases a large event was recorded, but no other large floods were recorded for the next 20 years. In this case the length of time since the date of the large flood was used to determine the plotting position for the analysis, with a lesser length of time adopted for the more recent historical flood series.

The largest flood in many Canterbury rivers in the 19th century occurred in 1868. In South Canterbury, the 1986 flood has been called the largest flood in living memory. The beginning of the 20th century could be regarded as living memory, therefore the 1986 flood was considered to be the largest flood in the 20th century.

However it is not known if the 1986 flood is the largest flood for both centuries. If it were the largest flood in 200 years, its Gringorten plotting position return period would be 362 years; if it were the second largest flood the plotting position would reduce to 128 years. If it were assumed that the 1986 flood was the largest flood in the 20th century, it would have a Gringorten plotting position of 178 years. This is a compromise between the 362-year plotting position and 128-year plotting position and reflects our state of knowledge and the uncertainties in estimating the return period of very large events. Therefore the 178-year plotting position was adopted for the 1986 flood.

The 1994 flood was also a very large event on many rivers and was considered to be the second largest flood in the last half of the 20th century: the 1986 flood was the largest flood, but there may have been a flood in the first half of the century that was as large or larger than the 1994 event (e.g. the 1932 flood on the Pareora River). The Hakataramea, Waihao, Pareora, Tengawai and Opihi rivers flood series were treated in this manner.

In summary, the annual maxima data series and their plotting positions were improved with historic and anecdotal evidence, and analysed using the TCEV distribution. The L-moment analysis used the annual series data only.

Results

Figure 4 shows the results of fitting the TCEV distribution to data for four rivers. The EV1 and EV2 curves are also plotted for comparision. One river drains a Main Divide catchment (Waimakariri River, Griffiths *et al.* 1989),

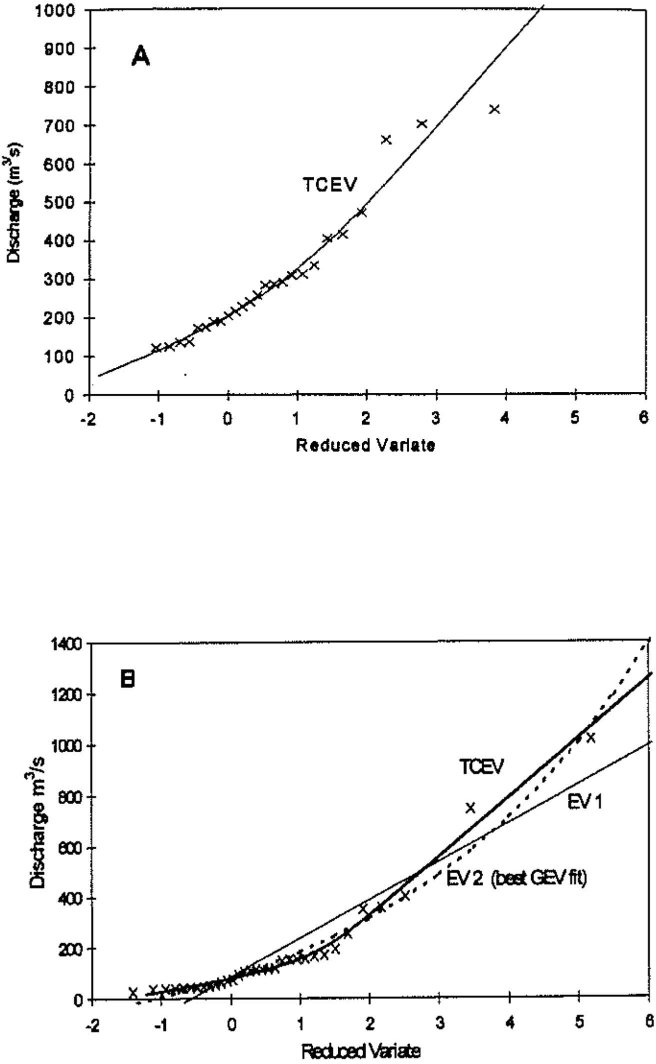
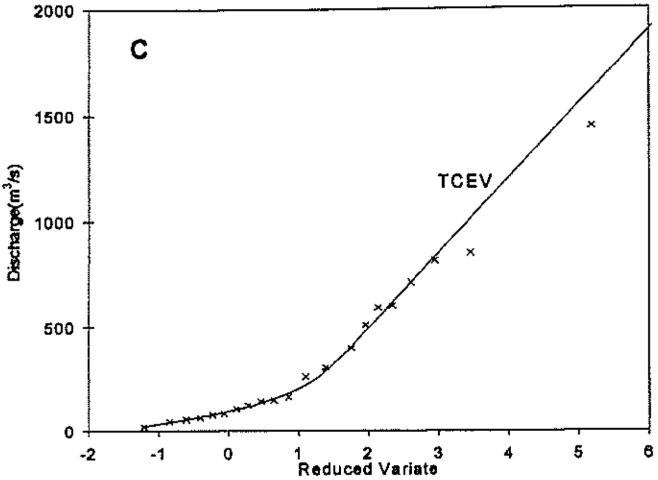


Figure 4 – TCEV distributions (solid lines) fitted to four Canterbury rivers: A) Ashley River at Gorge (annual series since 1973; B) Opihi at Rockwood (annual series since 1964).



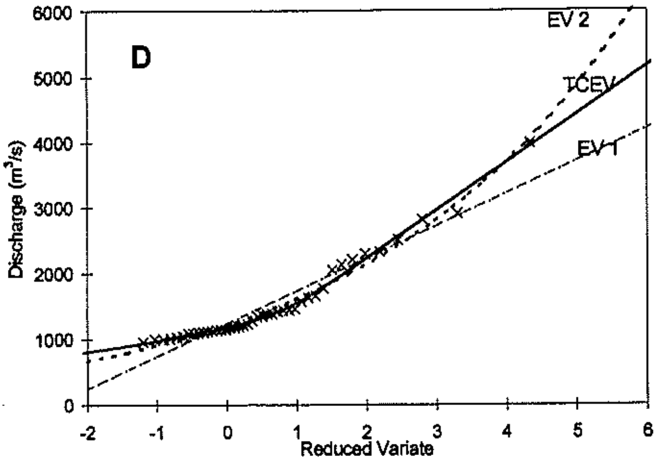


Figure 4 – TCEV distributions (solid lines) fitted to four Canterbury rivers: C) Tengawai River at Cave (historical data since 1951 and annual series since 1982); D) Waimakariri River at Old Highway Bridge (annual series since 1957). EV1 and EV2 distribution fits (broken lines) are shown for the Opihi and Waimakariri data.

two are from South Canterbury (Opihi and Tengawai Rivers), and one is from North Canterbury (Ashley River). The South Canterbury data show a marked tendency towards a TCEV distribution, whereas the Main Divide and North Canterbury examples show a small tendency towards a TCEV distribution.

From individual analyses of all of the rivers, sites were grouped as East Coast or Main Divide rivers, as floods in each of these areas are produced by different weather conditions. East Coast rivers flood primarily from easterly rain whereas Main Divide rivers flood from westerly rain spilling over the Main Divide. East Coast rivers were divided further, as many southern rivers have had very large floods (the largest in living memory in some cases) in their flood series, while the northern rivers have not. Figures 5a, and 5b show the results for the southern and northern East Coast rivers, while Figure 5c shows the results for the Main Divide rivers. A trend toward a TCEV distribution is most evident in the southern East Coast rivers.

Figures 6a and 6b show TCEV distributions fitted to normalised data for all northern and southern East Coast rivers, and for Main Divide rivers. The data were normalised using the mean annual flood. The graphs show the variation in two-component behaviour within the Canterbury Region. The TCEV distribution would be satisfactory for estimating flood frequencies for the southern East Coast rivers. For the Main Divide rivers the EV1 distribution would be satisfactory.

Figure 7 presents L-moment analyses of the annual maximum flood data. The L-moment ratio plots confirm the findings of the Gumbel probability plots (Figs. 4-6). These plots show that, for the southern East Coast rivers, on average one in four of their annual maximum flood peaks are from the outlier distribution rather than from the basic distribution (Fig. 7d).

Discussion

The graphs in Figures 5 and 6 show that, as well as a tendency toward a two-component distribution in Canterbury annual maximum flood series, there is also a wide range in the ratios of large floods to mean annual flood. North Canterbury ratios (dotted lines, Fig. 6a) are smaller than those for South Canterbury (full lines, Fig. 6a). The South Canterbury rivers have had two very large floods, one in 1986 and one in 1994, whereas the North Canterbury rivers have not. Whether this is a distinct flood frequency difference or whether North Canterbury has simply not had similar very large events through chance alone is open to question. If it is chance alone, this will be answered through continued long-term monitoring.

To further analyse these differences, we must consider the characteristics of the storms that produce floods in Canterbury. Storms causing the large

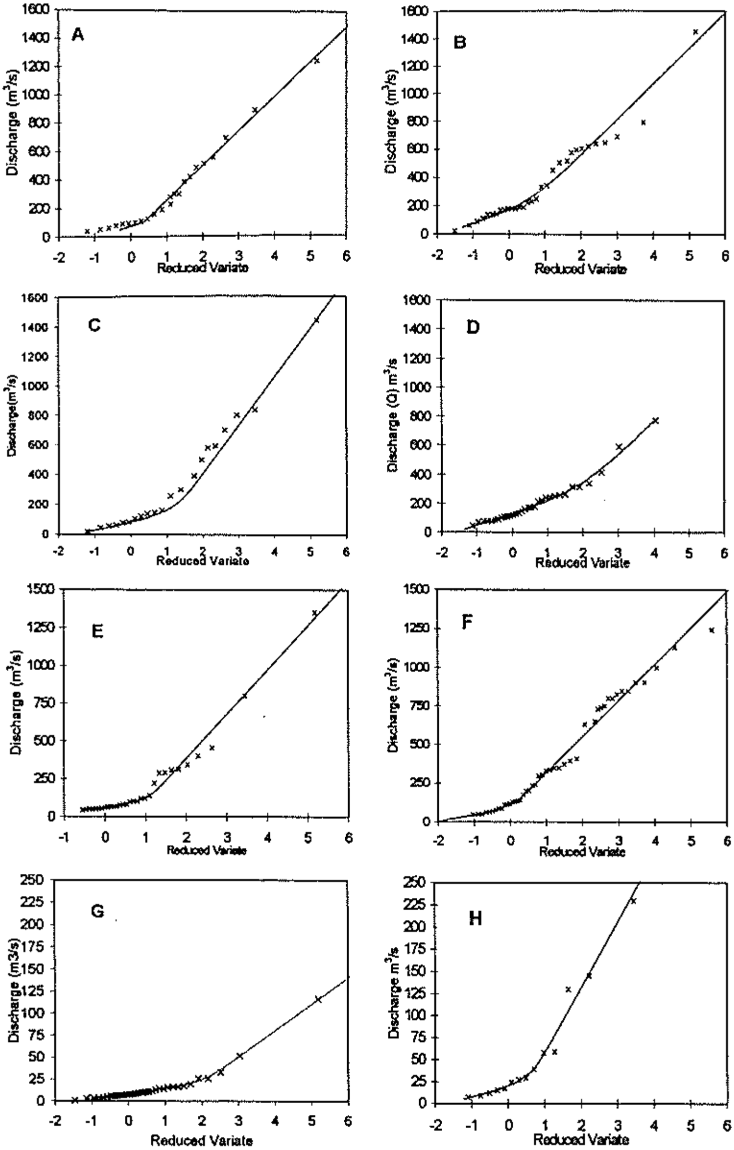


Figure 5(a) – Individual TCEV distributions and series data for southern East Coast rivers: A) Waihao River, B) Pareora River, C) Tengawai River, D) Opuha River, E) Hakataramea River, F) Orari River, G) Rocky Gully Stream, and H) Kakaku River.

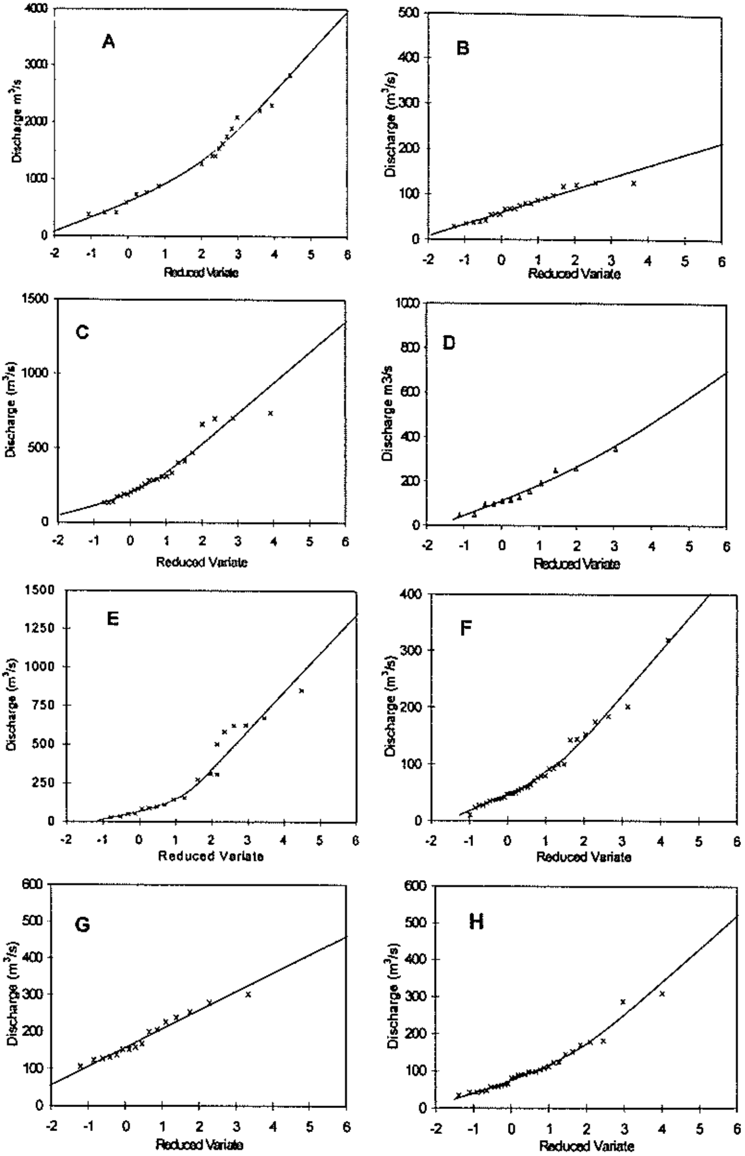


Figure 5(b) – Individual TCEV distributions and series data for northern East Coast rivers: A) Ashley River at Traffic Bridge, B) Ashley River at Lees Valley, C) Ashley River at Gorge, D) Okuku River, E) Selwyn River at Coes Ford, F) Selwyn River at Whitecliffs, G) North Ashburton River, and H) South Ashburton River.

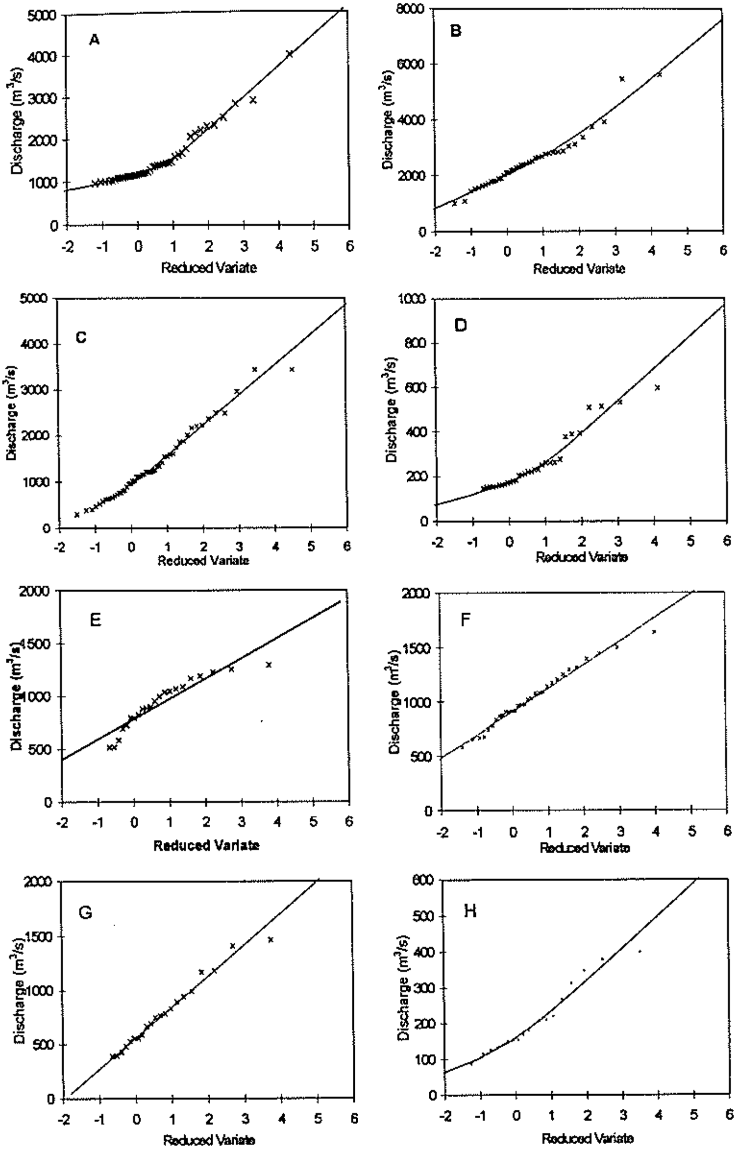


Figure 5(c) – Individual TCEV distributions and series data for Main Divide rivers: A) Waimakariri River, B) Rakaia River, C) Rangitata River, D) Ahuriri River, E) Waiau River at mouth, F) Waiau River at Marble Point, G) Hurunui River at SH1, and H) Hurunui River at Esk Head.

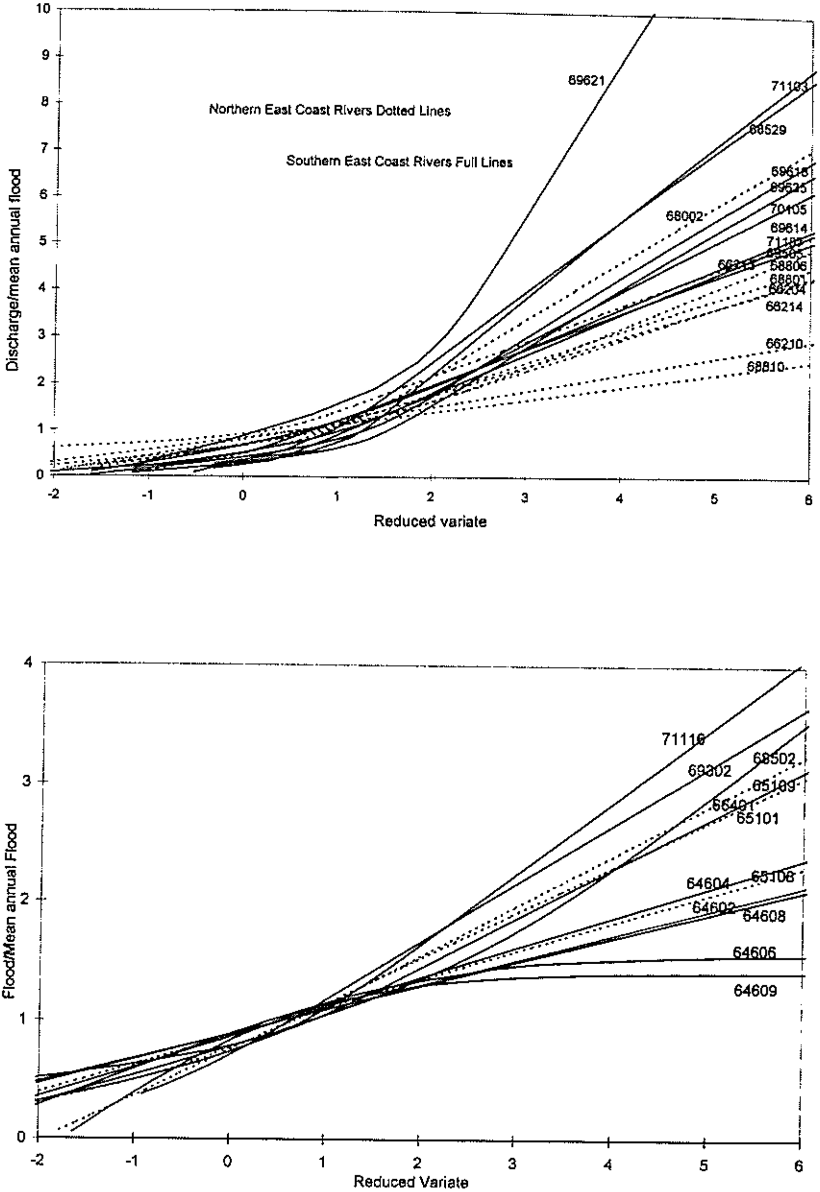


Figure 6 – Regional TCEV distributions for a) East Coast rivers and b) Main Divide Canterbury rivers.

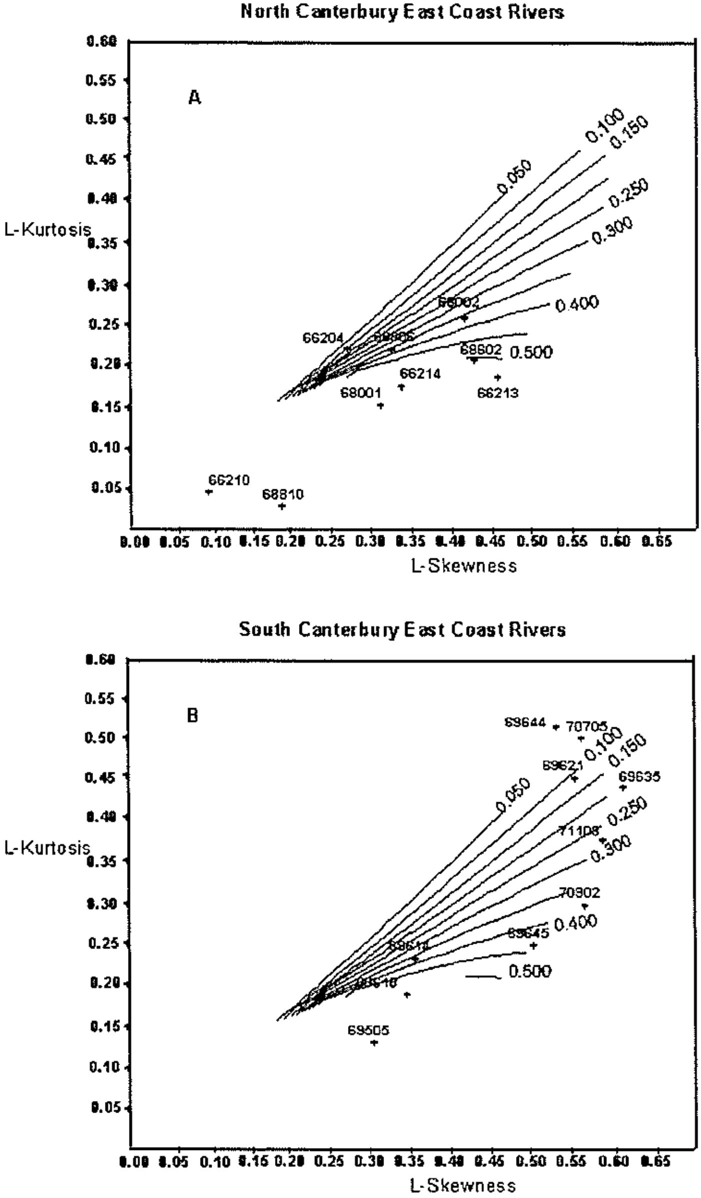
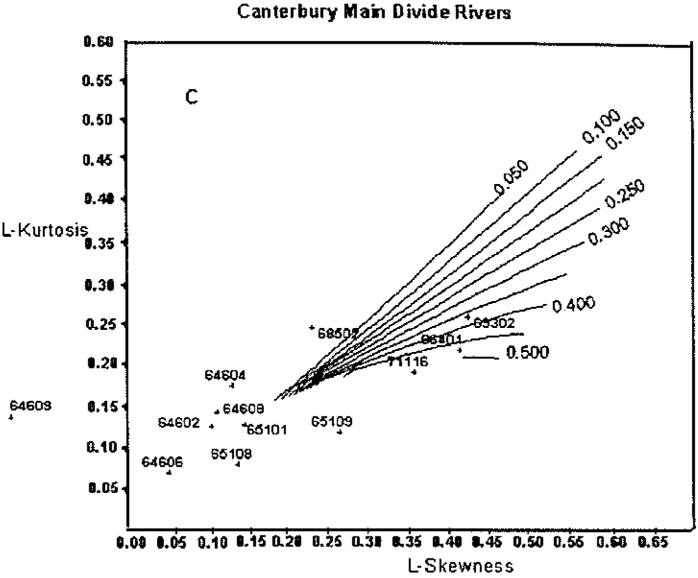


Figure 7 – L-moment ratio plots for a) North Canterbury East Coast rivers; b) South Canterbury East Coast rivers; c) Canterbury Main Divide rivers; and d) record-length weighted means for each sub-region (Main Divide weighted mean is at [0.20, 0.16]).


Canterbury Main Divide Rivers
C
L-Kurtosis
L-Skewness
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
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0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
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0.50
0.55
0.60
0.65
0.050
0.100
0.150
0.250
0.300
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68502
69302
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71116
64604
64603
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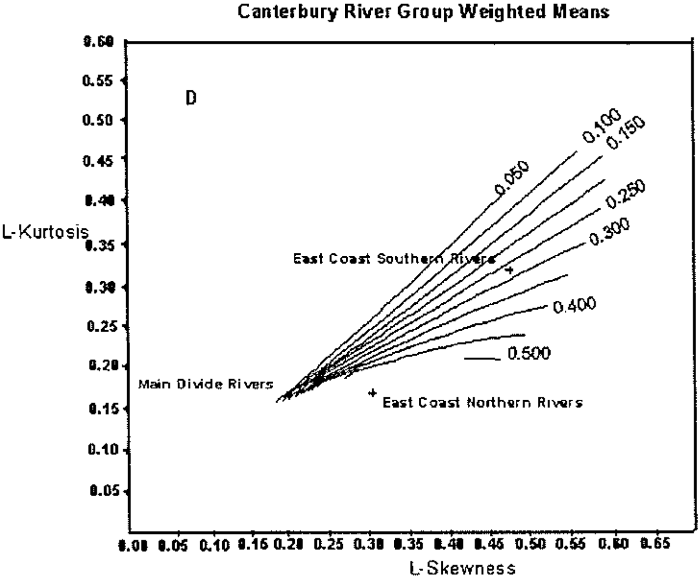
65109
65108
64606


Canterbury River Group Weighted Means
D
L-Kurtosis
L-Skewness
0.60
0.55
0.50
0.45
0.40
0.35
0.30
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0.55
0.60
0.65
0.050
0.100
0.150
0.250
0.300
0.400
0.500
East Coast Southern Rivers
Main Divide Rivers
East Coast Northern Rivers

floods in the East Coast rivers in Canterbury tend to have a northeasterly component. They arise from depressions that are centred about central New Zealand and force warm moist air into Canterbury. This warm, moist air carries most potential rainfall into the Canterbury Region. It is this type of storm that is thought to be the cause of the tendency toward a two-component flood distribution for the East Coast rivers. Easterly and southerly storms may occur more frequently, but they do not have the same moisture-producing properties. Northeasterly storms may occur more rarely, but they bring more moisture and rain into the area.

Figure 8 shows, for these East Coast rivers, the alignment of the axes of divides at the upstream ends of the catchments. The North Canterbury rivers flow southeast from a range of hills (AB) that lie normal to southeasterly winds, but South Canterbury rivers flow northeast from a range of hills (BC) that lie normal to northeasterly winds. For northeasterly storms the orographic effect will be greater in South Canterbury, and for southeasterly storms it will be greater in North Canterbury. As air masses coming from the southerly direction are cooler, they contains less moisture, and so the floods in North Canterbury from southeasterly storms are smaller than the floods in South Canterbury caused by northeasterly storms.

The North Branch of the Ashburton River and the Ashley River at Lees Valley show no tendency toward a TCEV distribution, and they have low ratios of 100-year to mean annual flood (Fig. 5). Their specific mean annual floods (~0.6 $m^3 s^{-1} km^{-2}$, Table 1) lie between the higher values of Main Divide rivers and the lower values of mid and south Canterbury rivers. Their lack of very large recorded floods (in comparison with their mean annual flood) may be due to orographic shading from storms from the east. The shading is caused by Mt Hutt on the North Branch Ashburton River and the Okuku Range on the Ashley River. Extremely large easterly storms may overcome this shading effect (e.g. the 1951 event when easterly rain extended well inland into the Ashburton catchment) and these rivers could well exhibit tendencies toward TCEV distributions. The Hakataramea River and South Branch Ashburton River (both inland from the east coast and well protected) have longer records: both exhibit low specific mean annual floods (~0.2 $m^3 s^{-1} km^{-2}$, Table 1) and tendencies toward TCEV distributions, particularly the Hakataramea, which had its highest peak recorded during the 1986 event. The largest floods for these catchments are caused by storms with an easterly component. The South Ashburton also receives westerly spillover, but its flat, swampy upper catchment acts as a retention basin during flood peaks. Isohyets of easterly rainfall for the 1951 flood on the Ashburton River show high rainfall in the South Branch Ashburton River catchment. The two components of the South Ashburton appear to be lower, more frequent westerly floods (basic series) and higher, less frequent easterly floods (outlier series).

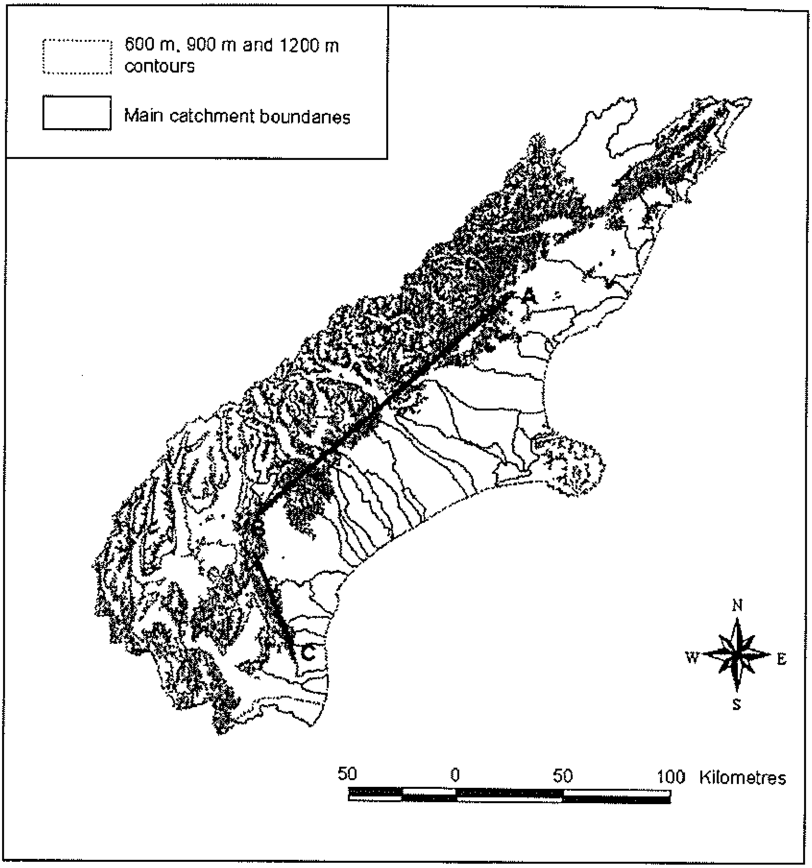

Figure 8 – Approximate divide axes for Canterbury East Coast rivers.

For the Main Divide rivers, floods occur from westerly rainfall spilling over the Divide. Despite this dominant process, tendencies toward TCEV distributions are evident in some high country records.

Table 2 gives the results of L-moment homogeneity / heterogeneity tests (Hosking and Wallis, 1993). The group of Main Divide rivers is not homogeneous: this is evident in the spread of the data shown in Figure 6b. The main cause of the heterogeneity is the variability of the flood frequency of the Waiau River and its tributaries. If these rivers and the Hurunui River are removed, the group is homogeneous (Table 2). An important factor for homogeniety in this group is the distance of a catchment's western-most

Table 1 – Canterbury water level recorder sites used in this study.

Site Number	River & Station Name	Area (km^2)	Mean Annual Flood m^3/s	Specific Discharge for mean annual flood $m^3/s/km^2$
64606	Waiau at Mailings Pass	74.6	93	1.247
64604	Waiau at Glen Hope	714	278	0.389
64602	Waiau at Marble Point	1980	1019	0.515
64608	Hope at Glynn Wye (Waiau trib.)	696	555	0.797
64609	Waiau at Mouth	3297	930	0.282
65109	Hurunui at Esk Head	182	310	1.703
65108	Hurunui at No 2 Hut Bridge	305	207	0.679
65101	Hurunui at SH1	2518	705	0.280
66401	Waimakariri at Old Highway Bridge	3210	1520	0.474
68502	Rakaia at Gorge	2640	2454	0.930
69302	Rangitata at Gorge	1641	1331	0.811
71116	Ahuriri at South Diadem	557	239	0.429
66204	Ashley at Gorge	472	305	0.646
66210	Ashley at Lees Valley	121	74	0.612
66213	Okuku at Fox Creek	222	128	0.577
66214	Ashley at Rangiora Traffic Bridge	1169	923	0.790
68001	Selwyn at Whitecliffs	164	74	0.451
68002	Selwyn at Coes Ford	762	139	0.182
68602	Dry Creek at RDR Siphon	55	10.6	0.193
68810	North Ashburton at Weir	276	185	0.670
68806	South Ashburton at Mt Somers	539	106	0.197
69505	Orari at Gorge	522	215	0.412
69644	Te Moana at Glentohi	77.8	60	0.771
69645	Kakahu at Mulvihills	43.7	57	1.304
69614	Opuha at Skipton	458	203	0.443
69618	Opihi at Rockwood	406	173	0.426
69635	Tengawai at Cave (picnic grounds)	489	262	0.536
69621	Rocky Gully at Rockburn	22.4	15.4	0.688
70105	Pareora at Mt Horrible	424	274	0.646
71187	Waihao at Mt Culloughs Bridge	488	285	0.584
71103	Hakataramea above MH Bridge	899	177	0.197

Table 2 – Results of Hosking and Wallis (1993) L moment ratio homogeneity tests. The test statistics V_i indicate homogeneity of catchment groupings / sub-regions when they are less than 2. V_1 is based on L-CV alone; V_2 on L-CV and L-skewness; and V_3 on L-skewness and L-kurtosis.

Canterbury Sub-Region	V1 (L-CV)	V2 (L-CV & (L-skewness)	Vs (L-skewness & L-kurtosis)
Main Divide rivers	4.19*	3.81*	2.19*
Main Divide rivers (without Waiau River)	1.13	1.19	0.32
East Coast rivers	4.45*	2.12*	.21
Southern East Coast rivers	0.25	0.37	0.24
Northern East Coast rivers	6.41*	1.13	-0.93
Northern East Coast rivers without Dry Creek	2.81*	0.01	-0.80
Northern East Coast rivers (without Dry Creek, Lees Valley and North and South Ashburton)	0.84	-0.93	-1.68

* Indicates region flood frequency heterogeneity

point to the West Coast coastline. The Waiau River's divide is furtherest from the west coast whereas the divides of the Rangitata, Rakaia and Waimakariri rivers are closer.

Of the East Coast rivers, the southern rivers show a very strong tendency toward a TCEV distribution, and this is reflected in Figure 6a. Removal of Rocky Gully Stream, the only small catchment in this group, improves the homogeneity results for this sub-region (Table 2). The rivers in this area have a similar topography.

However the northern rivers do not show such a strong tendency. These rivers have a more marked difference in topography. If Dry Creek (a smaller catchment) is removed the homogeneity is improved (Table 2), and if the inland catchments (Lees Valley and the North and South Ashburton Rivers) are also removed, the area becomes homogeneous.

A preliminary analysis of weather patterns for the top five flood events for the East Coast rivers (Table 3) shows the predominant wind directions. Southeasterly winds/storms relate to a depression east of the North Island, whereas northeasterly winds/storms correspond to troughs west of the North Island. The results in Table 3 confirm that the South Canterbury rivers have more extreme floods from northeastly storms than North Canterbury rivers, which have more floods from southeastly storms.

The results suggest that topography has a strong influence on the flood frequency homogeneity of groups of rivers. This means that the Canterbury Region could be divided into several sub-regions. These are based on the catchment divide alignment and position relative to other topographical features and storm characteristics. This topic requires further research before this hypothesis could be conclusively proven.

Table 3 – Predominant wind directions of storms causing the largest recorded East Coast River floods (Soil Conservation and River Control Council, 1957; New Zealand Meteorological Service Synoptic charts; The Christchurch Press; South Canterbury Catchment Board, 1989)

Site Number	River & Station Name	Date (floods in order of largest flood peak)	Predominant storm/wind direction
66204	Ashley at Gorge	19 August 2000	SE/NE on land
		13 March 1986	NE
		23 December 1993	SE
		12 March 1987	SE
		19 March 1994	SE
66213	Okuku at Fox Creek	23 December 1993	SE
		19 August 2000	SE
		19 March 1994	SE
68002	Selwyn at Coes Ford	17-18 April 1951	E/NE
		19 August 2000	SE/NE on land
		14 July 1963	E
		18 July 1961	E/NE
		21-22 February 1945	E
68810	North Ashburton at Weir	19 March 1994	SE
		23 December 1993	SE
		13 October 1990	
		13 March 1986	NE
		13 September 1988	NW
68806	South Ashburton at Mt Somers	11 August 1986	NE
		20 April 1978	SE /NE on land
		17 September 1970	
		6 May 1979	NW followed by SE
		19 March 1994	SE
69505	Orari at Gorge	13 March 1986	NE
		28 January 1975	NE
		20 April 1978	SE /NE on land
		19 March 1994	SE
		16 May 1972	NE

Site Number	River & Station Name	Date (floods in order of largest flood peak)	Predominant storm/wind direction
69614	Opuha at Skipton	19 March 1994	SE/NE on land
		21 February 1945	NE
		13 March 1986	SE
		18 July 1961	E/NE
		17-18 April 1951	E
69618	Opihi at Rockwood	13 March 1986	NE
		19 March 1994	SE
		21 February 1945	E
		17-18 April 1951	E/NE
		18 July 1961	E/NE
69635	Tengawai at Cave (picnic grounds)	13 March 1986	NE
		18 July 1961	E/NE
		19 March 1994	E
		17-18 April 1951	E/NE
		30 January 1965	E/NE
69621	Rocky Gully at Rockburn	13 March 1986	NE
		16 May 1972	NE
		24 August 1990	
		23 December 1993	SE
		19 March 1994	SE
70105	Pareora at Mt Horrible	13 March 1986	NE
		20-21 February 1932	E
		16 May 1972	NE
		21 February 1945	E
		18 July 1961	E/NE
71187	Waihao at Mt Culloughs Bridge	13 March 1986	SE /NE on land
		19 March 1994	SE
		18 July 1961	E/NE
		24 August 1990	
		23 December 1993	SE
71103	Hakataramea above MH Bridge	13 March 1986	NE
		19 March 1994	SE
		23 December 1993	SE
		26 August 1978	SE
		6 June 1980	NE

Conclusions

An analysis of annual maximum flood series from Canterbury showed that the TCEV distribution fits many of these series. This also applies to series that were extended using historical data and anecdotal evidence. The South Canterbury East Coast rivers (Fig. 5a) have a marked tendency toward a two-component distribution, while the North Canterbury East Coast rivers (Fig. 5b) have a lesser two-component tendency. It is hypothesised that the difference in tendencies toward a two-component distribution between the north and south East Coast rivers is real and due to orographic effects and the alignment of their upper catchment boundary. Two different storm directions are postulated as the reason for the applicability of the TCEV distribution to flood series from the Canterbury East Coast rivers.

For Main Divide rivers (Fig. 5c) the predominant storm direction is from the west. This was strong enough to be the only process evident in the flood series, and hence the EV1 distribution continues to be the preferred option for these (and West Coast) rivers. Some weak evidence of a two-component distribution was detected in some flood maxima series from this region, but no explanation is offered at this stage.

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Manuscript received: 18 April 2001; accepted for publication: 26 June 2001