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Review of flood frequency in the Canterbury region

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Report prepared for Environment Canterbury by
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NIWA

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Executive summary

Flood frequency relations are derived for the Canterbury Region from a database of 1664 stationary and serially independent, annual maximum, flood peaks recorded at 54 sites during the period 1930 to 2010. At each site flood frequency relations are modelled by the Generalised Extreme Value Distribution. Contour maps are presented showing the spatial variation of a mean annual flood factor and a flood frequency factor. These maps may be used to estimate a design flood of given return period in ungauged basins or those with a short record. The results of this review are similar to, and improve upon, those of McKerchar and Pearson (1989). To improve the precision of estimates much more information is needed about rainfall intensities together with an individual catchment approach rather than one based on a non-homogenous flood region. No evidence of the influence of the Interdecadal Pacific Oscillation and the El Niño Southern Oscillation on climate variability was found in the longer flood records; nor was any trend due to human influences detected. Some guidelines are given, however, for dealing with the potential impact of human induced climate change.

1 Introduction

Environment Canterbury (Canterbury Regional Council) requested that a review be undertaken of flood frequency in the Canterbury Region. The purpose of the review is to update part of a previous national study by McKerchar and Pearson (1989) by including flood peak records collected in the Region since that earlier work, as well as incorporating records now available from additional stream gauges.

The methodology used herein for estimating the magnitude and frequency of flood peaks from measurements made under a particular climatic regime is similar to that of McKerchar and Pearson (1989).

Our analysis involves seven steps. First, annual maximum, instantaneous, flood peak records are gathered from the various hydrological recording stations, and some of the longer records are examined for evidence of climate variability and change. Second, mean annual flood is computed at each station. Third, the spatial variation across the Region of a function of mean annual flood and catchment area is defined by contours. Fourth, the relationship between flood peak magnitude and frequency is determined at all stations. Fifth, the spatial variation across the Region of the ratio of the 100-year return period flood to the mean annual flood is defined by contours. Sixth, based on information obtained in the third and fifth steps, formulae are given for estimating flood peak magnitude for a specified return period together with standard errors for natural basins in the Region. Seventh, advice is offered for dealing with potential future climate change.

The aim of the review is to provide design flood frequency estimates for use in the Canterbury Region applicable to the climatic regime and catchment conditions for the period 1930 to 2010.

2 Data

Flood peak data for this study came from hydrological recording stations or sites operated by Environment Canterbury and the National Institute of Water and Atmospheric Research Ltd (NIWA) (Walter, 2000). Details about these sites and their upstream basins and records are given in Table 2-1 and Figure 2-1.

Some 54 sites were selected for analysis: sites with annual peaks affected by one or more of wetlands, lakes, groundwater supply, glaciers and problematic high stage ratings were omitted.

Water stage time series for all remaining sites were checked for errors. Stage discharge rating curves were also checked to see that curves were consistent with one another and their definition was reasonably supported by gaugings.

A minimum record length of six years was imposed for estimating mean annual flood.

Table 2-1: Details of sites, records, catchment area, mean annual flood and flood frequency factor.

Site	River	Site name	Record length yrs	Area, A km^2	Mean annual flood, Q_m m^3/s	Mean annual flood factor $Q_m/A^{0.866}$	GEV distribution type	100 yr flood, Q_{100} m^3/s	Flood frequency factor, $q_{100} = Q_{100}/Q_m$
62103	Acheron	Clarence	50	973	331	0.9	1	834	2.5
62104	Ribble	Airstrip	9	20	14.6	1.1	1	50.1	3.4
62105	Clarence	Jollies	51	440	192	1.0	1	482	2.5
63501	Rosy Morn	Weir	33	1.69	2.22	1.4	2	11.4	5.1
64602	Waiau	Marble Pt/Leslie Hills	48	1980	986	1.4	1	1828	1.9
64606	Waiau	Malings Pass	45	74.6	87.4	2.1	1	178	2.0
64608	Hope	Glynn Wye	27	696	573	2.0	1	982	1.7
64610	Stanton	Cheddar Valley	43	41.9	35.0	1.4	1	117	3.3
65101	Hurunui	SH1 Br.	36	2518	769	0.9	1	2055	2.7
65104	Hurunui	Mandamus	54	1060	523	1.3	1	1224	2.3
65109	Hurunui Sth Br.	Esk Head	25	305	218	1.5	1	535	2.5
65901	Waipara	White Gorge	23	370	118	0.7	1	429	3.6
65904	Waipara	Teviotdale	11	716	209	0.7	1	859	4.1
66204	Ashley	Gorge	39	472	311	1.5	1	987	3.2
66210	Ashley	Lees Valley	22	121	72.7	1.1	1	177	2.4
66213	Okuku	Fox Ck	15	222	159	1.5	1	446	2.8
66214	Ashley	Rangiora Traffic Br	20	1169	718	1.6	1	2505	3.5
66401	Waimakariri	Old Highway Bge	81	3210	1481	1.4	2	4155	2.8
66405	Camp Stm	Craigieburn	40	0.9	0.577	0.6	2	2.39	4.1
66602	Avon	Gloucester St Br	26	38	17.8	0.8	3	29.3	1.6
66604	Hoon Hay	Hoon Hay Weir	15	3.26	1.44	0.5	1	5.81	4.0
66612	Heathcote	Buxton	20	63.9	16.3	0.4	1	34.0	2.1
67001	Opara (Okains)	Friesian Stud Farm	13	21	21	1.5	1	67.0	3.2
67601	Reynolds	Brankins Br	8	3.21	6.8	2.5	1	23.3	3.4
67702	Kaituna	Kaituna Valley Rd	25	39.5	34.9	1.4	1	113	3.2
68001	Selwyn	Whitecliffs	46	164	76.9	0.9	2	367	4.8
68002	Selwyn	Coes Ford	27	762	141	0.5	2	956	6.8

Site	River	Site name	Record length yrs	Area, A km^2	Mean annual flood, Q_m m^3/s	Mean annual flood factor $Q_m/A^{0.866}$	GEV distribution type	100 yr flood, Q_{100} m^3/s	Flood frequency factor, $q_{100} = Q_{100}/Q_m$
68526	Rakaia	Fighting Hill/Gorge	53	2560	2517	2.8	1	5768	2.3
68529	Dry Acheron	Water Race	11	6.19	2.76	0.6	1	7.33	2.7
68801	Ashburton	SHBr	15	1579	293	0.5	1	1087	3.7
68806	Sth Ashburton	Mt Somers	44	539	100	0.4	1	290	2.9
68810	North Ashburton	Old Weir	29	276	148	1.1	1	408	2.8
68819	Taylors Stm	SH72	6	38.3	45.0	1.9			
68822	Bowyers Stm	SH72	6	42.9	48.5	1.9			
69302	Rangitata	Klondyke	32	1461	1156	2.1	2	4228	3.7
69505	Orari	Gorge/Silverton	46	522	195	0.9	2	1148	5.9
69602	Temuka	Manse Br	28	575	241	1.0	2	1440	6.0
69614	Opuha	Skipton	32	458	214	1.1	2	863	4.0
69618	Opihi	Rockwood	46	406	154	0.8	2	944	6.1
69621	Rocky Gully	Rockburn	45	23	14.6	1.0	2	103	7.1
69633	Kakahu	Mitchell's Weir No 9	19	2.75	2.19	0.9	1	6.65	3.0
69634	Kakahu	Turnbulls Weir No 10	19	4.55	4.75	1.3	1	20.1	4.2
69635	Tengawai	Picnic Grounds	29	489	199	0.9	2	1548	7.8
69649	Waihi	DOC Reserve	20	40	45.5	1.9	1	150	3.3
70105	Pareora	Huts	29	424	245	1.3	2	1510	6.2
70902	Waihao	McCulloughs Br	28	488	161	0.8	2	1682	10.4
71103	Hakataramea	Above MHBr	47	899	165	0.5	2	1231	7.5
71106	Maerewhenua	Kellys Gully	40	187	133	1.4	1	428	3.2
71116	Ahuriri	Sth Diadem	47	557	240	1.0	1	615	2.6
71121	Twizel	SHB	7	250	67.4	0.6			
71129	Forks	Balmoral	48	98	22.6	0.4	2	74.5	3.3
71135	Jollie	Mt Cook Stn	46	139	74.1	1.0	2	243	3.3
71170	Awamoko	Georgetown	16	117	42.3	0.7	1	202	4.8
71178	Otekaieke	Weir/Gorge/Stockbridge	24	78.7	44	1.0	1	168	3.8

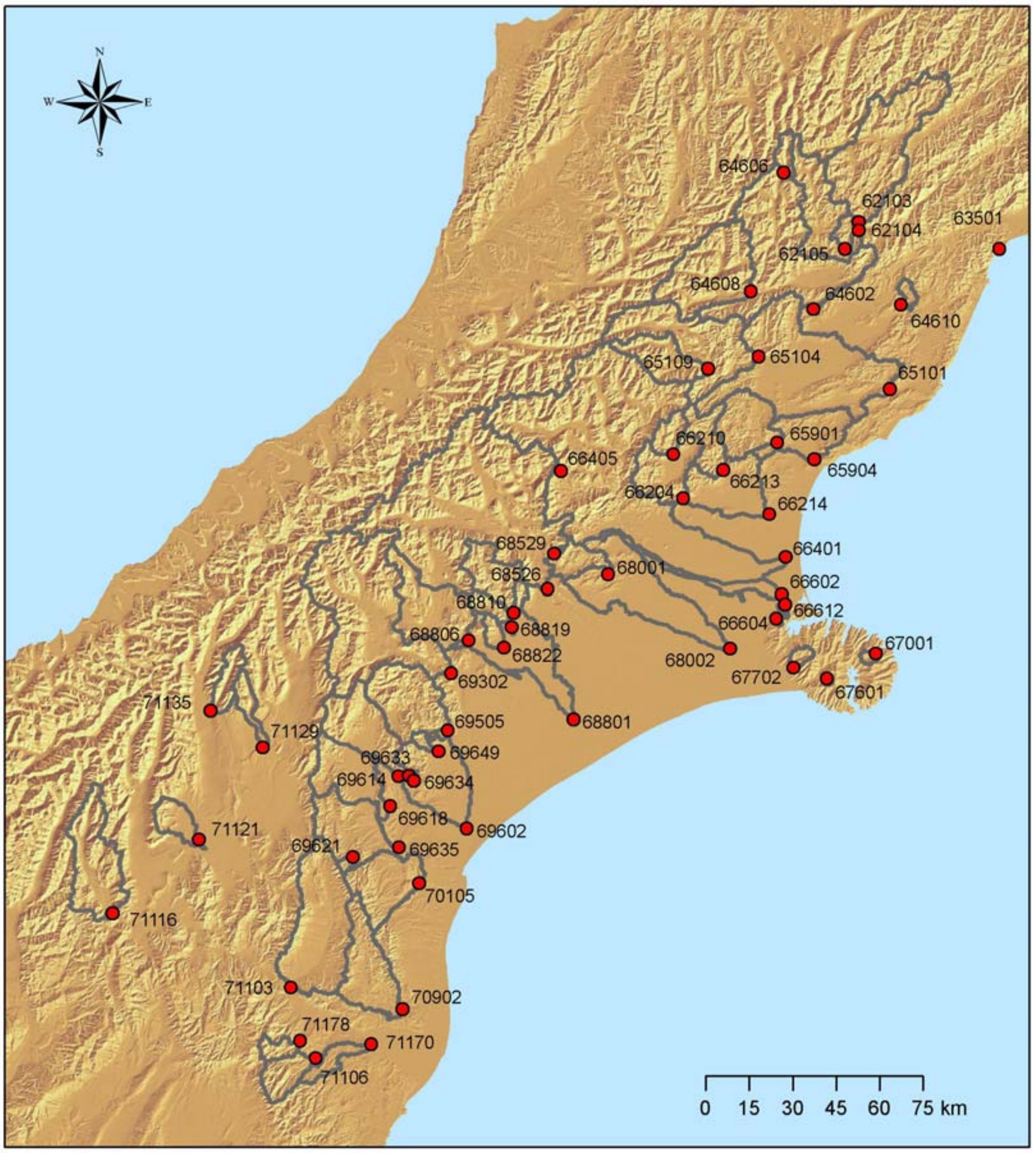

Figure 2-1: Location of sites identified by site number (Table 2-1).

The time series of annual maximum instantaneous flood peaks for four of the sites having longer records – Acheron at Clarence (50 yr), Waimakariri at Old Highway Bridge (81 yr), Hakataramea above MHBr (47 yr) and Ahuriri at South Diadem (47 yr) (Table 2.1) - were examined for evidence of climate variability and change as reflected in the record as trend, periodicity, persistence or shifts. Test statistics computed using the three records included the Spearman rank order correlation coefficient and, for a split sample, the Mann-Whitney test for location difference and the Wald-Wolfowitz runs test for any difference. No pattern in trend, periodicity, persistence or shift was detected in any of the time series.

However, the Ahuriri data do display some clustering of higher values in the interval 1978-1999. This pattern is consistent with the finding of higher rainfalls and higher flows in southerly catchments draining from the Main Divide to the Southern Alps over this period by

McKerchar and Henderson (2003). They attributed this behaviour to a phase of the Interdecadel Pacific Ocillation that favours El Niño conditions.

3 Mean annual floods

A common approach to estimating mean annual flood, Q_m, is to employ regression equations of the form

$$Q_m = aA^b B^c C^d \ldots \quad (1)$$

In which A is catchment area and $B, C\ldots$ are climatic and physiographic variables. Here we use the data in Table 2.1 to derive the expression

$$Q_m = 1.03\, A^{0.866} \quad (2)$$

with a correlation coefficient, r, of 0.931 and a standard error (of the logarithms of the data), SE, of 0.210.

We note, also, that in theory the exponent for A in Equation 2 should be 0.750 (Griffiths and McKerchar 2008).

From Equation 2 we define a mean annual flood factor

$$Q_{mf} = Q_m / A^{0.866} \quad (3)$$

and present contours of Q_{mf} values (plotted at the centroids of the catchments within the Region except for catchments draining from the Main Divide where we used the centroid of the rainfall distribution) in Figure 3-1. By comparing Equations 1 and 3 it can be seen that Q_{mf} is an unknown function of various climatic and physiographic variables such as evapotranspiration and catchment slope and cover. Along a contour this unknown function is assumed to be constant and its spatial variation is defined by the pattern of contours in Figure 3-1 which is similar to (although more detailed), as might be expected, the pattern of contours of $Q_m / A^{0.866}$ obtained by McKerchar and Pearson (1989). To assess the fit of the contours to the data, average values for each catchment estimated from Figure 3-1 were compared with at-site values. The statistic E, defined by

$$E = 100\left[Q_m\ (map) - Q_m\ (site)\right] / Q_m\ (site) \quad (4)$$

was calculated for all sites and has a mean value or bias of +2% and a root mean square value, (RMS), of ± 16%.

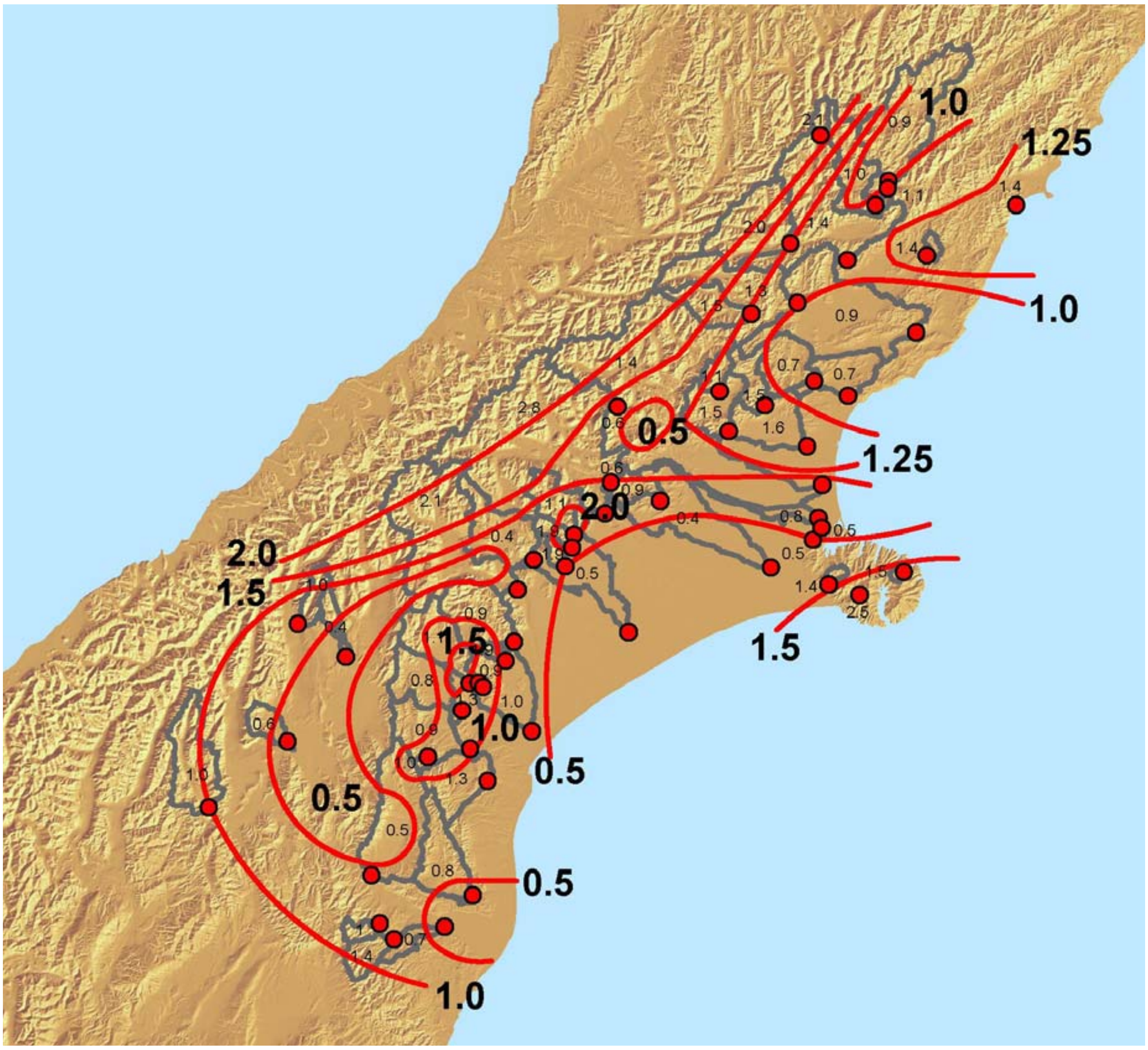

Figure 3-1: Mean annual flood factor Q_{mf}.

4 Flood frequency analysis

4.1 At site analysis

Following McKerchar and Pearson (1989) the Generalised Extreme Value Distribution (GEV) was fitted to the flood peak data for each site using the method of probability weighted moments. A minimum record length of 8 years was imposed for acceptance of an Extreme Value Type 1 (EV1) and 20 years for EV2 and EV3 fits. Using the hypothesis tests of Phien (1987) it was found from the value of the GEV *k* that of the 51 fits, 33 displayed EV1 behaviour, 17 EV2 and one EV3 (Table 2-1).

The EV2 fits largely occurred in a cluster in eastern South Canterbury (Table 2-1) as found by McKerchar and Pearson (1989) and Pearson (1991). The former authors postulated that this behaviour was due to the infrequency of large rainfall events in the area.

Although we accept the value of the 100 yr flood peak, Q_{100} (Table 2-1) estimated by the GEV analysis, whether it be from an EV1, EV2 or EV3 best fit, for the purpose of prediction at river locations with little or no data we follow McKerchar and Pearson (1989) for the present and adopt the EV1 distribution. The reasons are that the EV1 model predominates in the Canterbury Region, it has lower standard errors associated with parameter estimation from shorter records (10 to 20 years) and being 2 parameter, unlike EV2 and EV3 which are 3 parameter distributions, the spatial variation of parameters is much easier to accommodate.

A consequence of this decision is that where a predictive EV1 distribution is fitted at a site with data displaying EV2 tendencies, larger return period floods (say 100 year and larger) will be underestimated. The reverse will occur with the EV3 case. However, the EV2 derived Q_{100} values are used in regional contouring so biases in the estimates at unmonitored sites will be less than if the EV1 distribution had been used in the at-site analysis. We are confident that these biases (which are unlikely to exceed ± 10%) are less than the usual degree of uncertainty in measuring flood peaks.

The EV1 distribution has a cumulative distribution function *F(Q)* defined by

$$F(Q) = 1-(1/T) = \exp\left\{-\exp\left[-(Q-u)/\alpha\right]\right\} \qquad (5)$$

in which *Q* is the instantaneous annual maximum flood peak discharge, *T* is return period and *u* and α are location and scale parameters, respectively. Also, if

$$y = -\ln\left\{-\ln\left[1-(1/T)\right]\right\} \qquad (6)$$

where *y* is the Gumbel reduced variate then from Equations 5 and 6 we may write

$$Q = u + \alpha y \qquad (7)$$

As regards errors the standard error of the estimate for the *T* year event, *SE(Q),* is the square root of the variance, where the variance is (Phien 1987)

$$\mathrm{var}(Q) = (\alpha^2/n)\begin{bmatrix}(1.1128n-0.9066)-(0.4574n-1.1722)\,y \\ +(0.8046n-0.1855)\,y^2\end{bmatrix}/(n-1) \qquad (8)$$

in which *n* is the number of years of record.

4.2 Contours

The dimensionless flood peak discharge for a return period of 100 years, q_{100}, is defined as

$$q_{100} = Q_{100}/Q_m \qquad (9)$$

In Figure 4-1 we present contours of equal values of q_{100} (Table 2-1) drawn as appropriate through the centroids of the relevant catchments within the Region. Low q_{100} values occur in the west where the rainfall is higher and more frequent, and high q_{100} values occur in the east where the rainfall is low and infrequent. The contour pattern in Figure 4-1 is similar to (but more detailed than) that obtained by McKerchar and Pearson (1989). Moreover by fitting the EV2 distribution when required the q_{100} contours in Figure 4-1 are higher than those presented by McKerchar and Pearson (1989) particularly in South Canterbury.

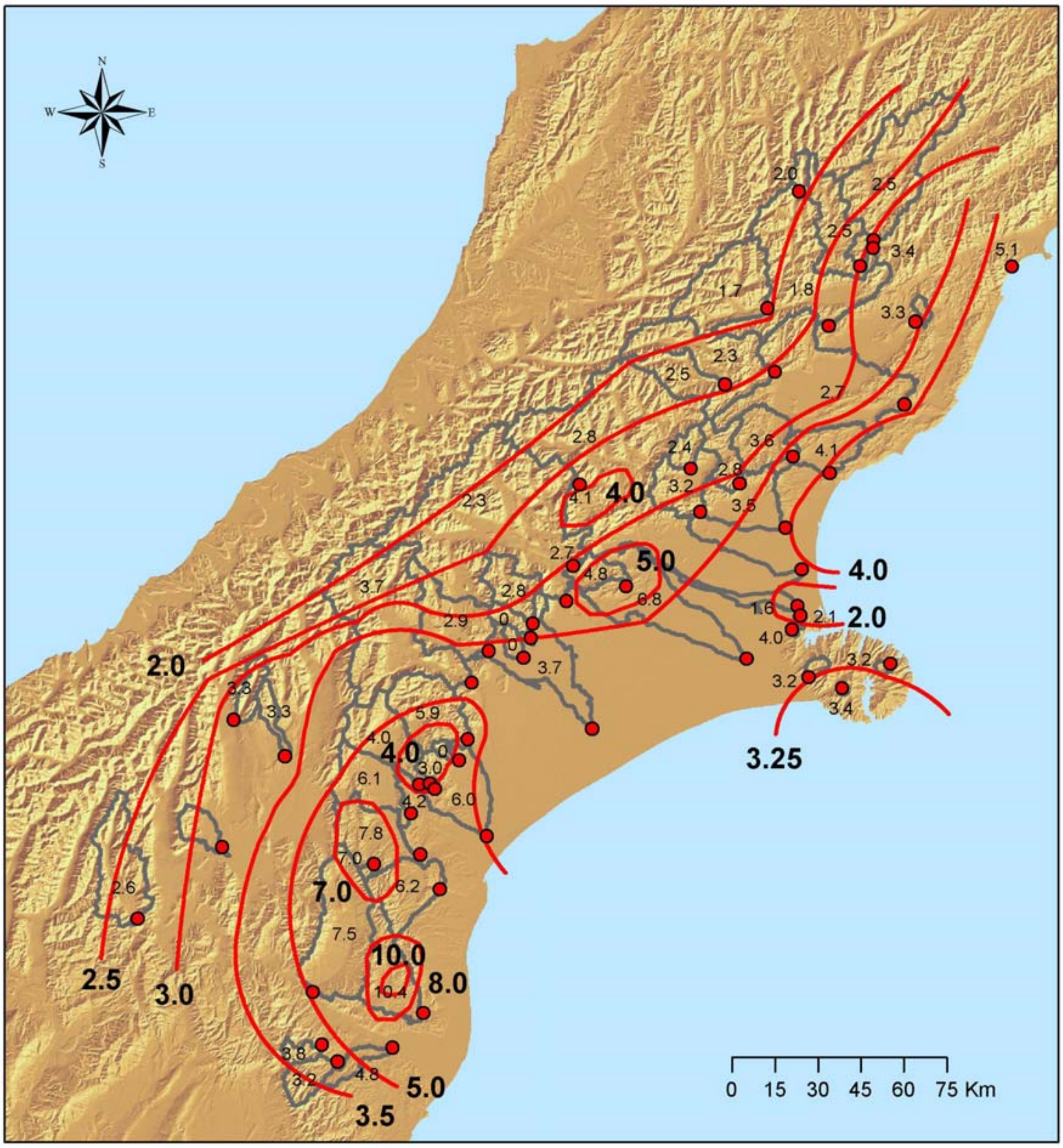

Figure 4-1: Map of $q_{100} = Q_{100}/Q_m$.

To assess the fit of the contours to the q_{100} site results, q_{100} values for each catchment estimated from Figure 4-1 were compared with at-site values. The statistic, E_1, defined by

$$E_1 = 100\left[q_{100}(map) - q_{100}(site)\right] / \ q_{100}(site) \qquad (10)$$

was calculated for all sites and has a mean value or bias of 1% and a RMS of ± 21%.

5 Application

5.1 Estimation of Q_{100} and its prediction error

Provided Q_{100} and q_{100} are independent the variance of Q_{100} may be expressed approximately as (Kendall and Stuart 1977)

$$\mathrm{var}(Q_{100}) \approx q^2{}_{100}\,\mathrm{var}(Q_m) + Q^2{}_m\,\mathrm{var}(q_{100}) \tag{11}$$

When Q_{100} and q_{100} are estimated from Figures 3-1 and 4-1 respectively the prediction standard errors (RMSE values) are 16% and 21% as calculated in Sections 3 and 4. Substitution of these values in Equation 11 yields

$$\mathrm{var}(Q_{100}) \approx q^2{}_{100}\,(0.16\,Q_m)^2 + Q^2{}_m (0.21\,q_{100})^2 \approx (0.264\,Q_m\,q_{100})^2 \tag{12}$$

Thus the prediction standard error of the estimate for Q_{100} is ±26.4%.

It is of interest to note here that Equation 12 can rewritten as

$$\mathrm{var}(Q_{100}) \approx (0.264\,Q_{100})^2 \tag{13}$$

McKerchar and Pearson (1989) obtained

$$\mathrm{var}\ (Q_{100}) = (0.281\ Q_{100})^2 \tag{14}$$

From Equations 13 and 14 it follows that our value of var(Q_{100}) is 94% of that of McKerchar and Pearson (1989).

5.2 Return periods other than 100 years

Using Equation 7 we may write (repeating Equation 7 for completeness)

$$Q = u + \alpha y \tag{15}$$

$$Q_{100} = u + \alpha\, y_{100} \tag{16}$$

$$Q_m = u + \alpha\, y_m \tag{17}$$

in which y_{100} and y_m are Gumbel reduced variates for the 100 year and mean annual flood respectively.

Elimination of u and α from Equations 15, 16 and 17 yields

$$Q/Q_m = x + (1\text{-}x)\ q_{100} \tag{18}$$

where

$$x = (y_{100} - y) / (y_{100} - y_m) = 1.1435 - 0.2486\ y$$

where y_{100} = 4.600 and y_m = 0.5772 from Equation (6) with T = 100 and T = 2.328 respectively.

From Equations 11 and 18 the prediction variance for Q is

$$var(Q) = x^2\ var\ (Q_m) + (1\text{-}x)^2\ var\ (Q_{100}) \quad (19)$$

and when Q_m is estimated from Figure 3-1 this becomes

$$var(Q) = x^2\ (0.16Q_m)^2 + (1\text{-}x)^2\ (0.264\ Q_m\, q_{100})^2 \quad (20)$$

Hence the prediction standard error of the estimate for Q is from Equations 18 and 20

$$SE\ (Q)/Q = \left[(0.160\,x)^2 + (1-x)^2\,(0.264\,q_{100})^2\right]^{0.5} / \left[x + (1-x)\,q_{100}\right] \quad (21)$$

In Table 5-1, Q/Q_m and $SE(Q)/Q$ are evaluated from Equations 18 and 21 respectively for the range of contours on the flood frequency map (Figure 4-1).

Table 5-1: Evaluation of Q/Q_m and SE(Q)/Q for specified q_{100} and T.

			q100:	1.5	2	2.5	3	4	5	6	7	8	9	10
T	y	x												
Q/Q_m														
5	1.4999	0.7706		1.11	1.23	1.34	1.46	1.69	1.92	2.15	2.38	2.61	2.84	3.06
10	2.2504	0.5841		1.21	1.42	1.62	1.83	2.25	2.66	3.08	3.50	3.91	4.33	4.74
20	2.9702	0.4051		1.30	1.59	1.89	2.19	2.78	3.38	3.97	4.57	5.16	5.76	6.35
50	3.9019	0.1735		1.41	1.83	2.24	2.65	3.48	4.31	5.13	5.96	6.79	7.61	8.44
100	4.6001	-0.0001		1.50	2.00	2.50	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
200	5.2958	-0.1730		1.59	2.17	2.76	3.35	4.52	5.69	6.87	8.04	9.21	10.38	11.56
500	6.2136	-0.4012		1.70	2.40	3.10	3.80	5.20	6.60	8.01	9.41	10.81	12.21	13.61
SE (Q)/Q														
5	1.4999	0.7706		0.14	0.14	0.15	0.15	0.16	0.17	0.18	0.19	0.19	0.20	0.20
10	2.2504	0.5841		0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.22	0.23	0.23	0.23
20	2.9702	0.4051		0.19	0.20	0.21	0.22	0.23	0.23	0.24	0.24	0.24	0.25	0.25
50	3.9019	0.1735		0.23	0.24	0.24	0.25	0.25	0.25	0.26	0.26	0.26	0.26	0.26
100	4.6001	-0.0001		0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
200	5.2958	-0.1730		0.29	0.29	0.28	0.28	0.27	0.27	0.27	0.27	0.27	0.27	0.27
500	6.2136	-0.4012		0.33	0.31	0.30	0.29	0.28	0.28	0.28	0.28	0.27	0.27	0.27

5.3 Strategy for flood frequency estimation

The strategy we recommend for flood frequency estimation is pooling of contour map information (Figures 3-1 and 4-1) with any available at-site data. Depending on the length of site record (n years) we suggest three different approaches as follows:

(a) No at-site data (n=0).

In this case Q_{mf} is read from the contour map (Figure 3-1) and multiplied by $A^{0.866}$ (in km^2), as in Equation 3, to give the Q_m map estimate in m^3/s. The variance of this estimate is $(0.16\ Q_m)^2$ and its standard error is 16%. Next, the flood frequency factor q_{100} is read from the contour map (Figure 4-1). Then Q_m and q_{100} are substituted into

Equation 18 to give an estimate *Q(map)*. Its variance is given by Equation 20 and its standard error by Equation 21.

(b) Less than 10 years of at-site data

Here, there are not enough data to perform an at-site flood frequency analysis. The contour map Q_m and q_{100} estimates are first obtained in (a) above. Then Q_m is calculated from the at-site data, that is the usual sample mean.

The variance of $Q_m(site)$ for n ≤ 5 is given by Phien (1987)

$$\mathrm{var}\left[Q_m\,(site)\right] = 0.1017\left[Q_m\,(map)\right]^2\left[q_{100}\,(map) - 1\right]^2 / \,n \tag{22}$$

For $n \geq 5$, following Phien (1987)

$$\mathrm{var}\left[Q_m\,(site)\right] = \sum_{j=1}^{n}\left[Q_j - Q_m\,(site)\right]^2 / \,n(n-1)$$

The two Q_m estimates are then pooled (Kuczera 1983) using the general formula (here with $Q = Q_m$)

$$Q\ (pool) = sQ(map) + (1\text{-}s)\ Q\ (site) \tag{23}$$

where

$$s = \mathrm{var}\,Q\,(site) / \left[\mathrm{var}\,Q\,(site) + \mathrm{var}\,Q\,(map)\right] \tag{24}$$

The prediction variance for the pooled estimate is

$$\mathrm{var}\left[Q\,(pool)\right] = s\,\mathrm{var}\left[Q\,(map)\right] \tag{25}$$

Q_m *(pool)* is used with q_{100} *(map)* in Equation 18 to give *Q*, and its variance is given by Equation 19.

(c) 10 or more years of at-site data (n ≥ 10)

In this case there are enough data to carry out an at-site flood frequency analysis. Again, the contour map *Q* and its variance is obtained as in (a) above. The site *Q* estimate and its variance are obtained from an EV1 analysis of the available annual maxima as described in 4.1 above. The two *Q* estimates are then pooled using Equations 23 and 24. The design flood peak is *Q (pool)*; its variance is given by Equation 25.

5.4 Example

To show how the strategy of 5.3 may be applied we consider, for the purposes of illustration only, the site Stanton at Cheddar Valley (Site No. 64610, Table 2.1). The three scenarios of interest to estimate 50 year return period (*T* = 50) floods are: (a) no data, (b) first 5 years of record (1968-1972) and (c) full record of 43 years (1968 to 2010).

(a) No data

Relevant data include:

Symbol	Source	Estimate
A	Walter (2000)	41.9 km^2
Q_{mf}	Figure 3-1	1.25
q_{100}	Figure 4-1	3.5
x_{50}	Equations 6, 18	0.1735
Q_{50}/Q_m	Table 5-1 or Equations 6, 18	3.07
$SE\ (Q_{50}/Q_m)$	Table 5-1 or Equation 21	0.25

From these data we find

$Q_m\ (map)$ = $1.25 \times (41.9)^{0.866}$ (Equation 3)

= 31.8 m^3/s

$var\,[Q_m\ (map)] = (0.16 \times 31.8)^2 = 25.9$

$Q_{50}\ (map) = 31.8 \times 3.07 = 97.6$ m^3/s

The standard error is ± 25% so

$var\,[Q_{50}\ (map)] = (0.25 \times 97.6)^2 = 596$

(b) Five years of record (1970-1974)

From the first five years of record, $Q_m\ (site)$ = 17.8 m^3/s reflecting a quiet period in the record. Since $n \le 5$ the variance of $Q_m\ (site)$ is estimated using Equation 22.

$var\,[Q_m\ (site)]$ = $0.1017 \times 31.8^2\ (3.5 - 1)^2/5$

= 129

and so

$$SE\left[Q_m\,(site)\right]/\,Q_m\,(site) = \sqrt{129}\,/17.8 = \pm\,64\%$$

This estimate is combined with the map estimate $Q_m\ (map)$ from (a) to get a pooled estimate of Q_m, using Equations 25 and 26. First from Equation 24

$s = 129\ /\ (129 + 25.9) = 0.833$

Then with Equation 23

$Q_m\ (pool) = (0.833 \times 31.8) + (0.171 \times 17.8) = 29.5$ m^3/s

and from Equation 25

$var\,[Q_m\ (pool)] = 0.833 \times 25.9 = 21.6$

and

$$SE\left[Q_m\,(pool)\right]Q_m\,(pool)=\sqrt{21.6}\,/\,29.5=\pm 15.7\%$$

Finally

Q_{50} = Q_m *(pool)* (Q_{50} / Q_m) = 29.5 x 3.07 = 90.6 m^3/s

To estimate the *var* (Q_{50}) we first require *var* (Q_{100}).

From Equation 11

var (Q_{100})	=	(3.5^2 x 21.6) + 29.5^2 (0.21 x $3.5)^2$
	=	735

then from Equation 19

var (Q_{50})	=	0.1735^2 x 21.6 + 0.8265^2 x 735
	=	503

and

$$SE\,(Q_{50})\,/\,Q_{50}=\sqrt{503}\,/\,90.6=\pm\,24.8\%$$

(c) Full record (1970-2008)

Here the map estimate Q_{50} *(map)* from (a) is combined with the Q_{50} *(site)* value obtained from frequency analysis of the n = 43 years of record. From this record Q_m *(site)* = 35 m^3/s, *var* [Q_m*(site)*] = 15.9 and *SE* [Q_m*(site)*]/Q_m*(site)*] = 11.4%

With the reduced variate y_{50} = 3.9 (Equation 6) and values of u = 23.2 and α = 20.5 from an EV1 analysis of the site data, Equation 7 gives

Q_{50} = 23.2 + 20.5 x 3.9 = 103 m^3/s

From Equation 8

$$\mathrm{var}\,(Q_{50})=(20.5^2\,/\,43)\left[498.22\right]/\,42=116$$

and *SE* [Q_{50} *(site)*] / Q_{50} = ± 10.5%

Combining the variances from the map and site estimates with Equation 24 and Equation 25 yields

s = 116 / (116 + 596) = 0.163

var [Q_{50} *(pool)*] = 0.163 x 596 = 97

Hence from Equation 23

Q_{50} *(pool)* = 0.163 x 98 + 0.837 x 103 = 102 m^3/s

and *SE* [Q_{50} *(pool)*] / Q_{50} = ± 9.7%

A summary of results is given in Table 5-2. This shows that with no data the Q_{50} *(map)* estimate is 97.6 m^3/s ± 25%, with 5 years of data Q_{50} *(pool)* is 90.3 m^3/s ± 24.7% and with 43 years of data Q_{50} *(pool)* is 102 ± 9.7%. The large reduction in standard error that occurs with the last estimate is to be expected with a long site record.

Table 5-2: Summary of Stanton at Cheddar Valley results (all flood peak values in m^3/s and standard errors as %).

Scenario	Q_m (map)	Q_m (site)	Q_m (pool)	Q_{50} (map)	Q_{50} (site)	Q_{50} (pool)
n=0	31.8 ± 16%	-	-	97.6 ± 25%	-	-
n=5	31.8 ± 16%	17.8 ± 64%	29.5 ± 15.7%	97.6 ± 25%	-	90.3 ± 24.7%
n=43	31.8 ± 16%	35 ± 11.4%	-	97.6 ± 25%	103 ± 10.5%	102 ± 9.7%

6 Climate variability and change

As discussed in Section 2 the long term records at four sites – Acheron at Clarence, Waimakariri at Old Highway Bridge, Hakataramea above MHBr and Ahuriri at South Diadem - can each be assumed to be stationary and composed of independent values. We also checked these records closely for any visual evidence of trends as well as the influence of the Interdecadal Pacific Oscillation and El Niño Southern Oscillation. From this we infer that although the flood regime has been quite variable since records began its behaviour has not changed significantly. We were unable to detect any influence of climate change induced by humans. When this occurs it will be superimposed on the natural variability. To provide guidance for assessing the impacts of these effects, the Ministry for the Environment has produced a manual (MfE 2008) based in part on the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC 2007).

Projections of global climate for the coming century vary depending upon which greenhouse gas emission scenario (from potentially low emissions, e.g. the B2 SRES scenario, to potentially high emissions, e.g. the AIFI SRES scenario) is used in the climate model run. A low emission scenario will result in less temperature change compared with a high emission scenario. The specifications of Global Climate Models (GCMs) being run at institutions around the world also varies slightly and thus the projections of global climate change for the same emission scenario vary depending upon the GCM being used. As a result, global climate projections are always presented as a range of likely changes rather than a single value (see Figure 2.1 and Tables 2.2 to 2.5 in MfE (2008)). Generally speaking for Canterbury we can expect more westerlies and the potential for more frequent floods with an increase in the size of the largest flood peaks, at least in the alpine rivers.

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

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

7 Conclusions and recommendations

- Statistical analysis indicates that the time series of annual maximum flood peaks at sites throughout the Canterbury Region are stationary and serially independent.
- The Generalised Extreme Value Distribution may be used to model annual maximum flood peak – return period relations.
- Statistical analysis of long term records of annual maximum flood peaks revealed no evidence of either trend, periodicity, persistence or shifts in the time series or the influence of the Interdecadal Pacific Oscillation and El Niňo Southern Oscillation.
- The results of this review generally confirm those of earlier work by McKerchar and Pearson (1989), but are more detailed as might be expected with more sites and longer records than previously and are higher in South Canterbury. It is clear from our analysis that the flood region examined is by no means homogeneous and the contouring method used is probably at the limit of its applicability. To further improve the explanation of variance generally, we believe much more information is needed about rainfall intensities, so that flood frequency can be predicted on a catchment by catchment basis (using, for example, rainfall-runoff modelling) as opposed to a collection of basins exhibiting non-homogenous behaviour.
- To allow for the potential effect of human induced climate change on future flood peak magnitudes, it is recommended that the Ministry for the Environment guidelines be followed and that possible impacts of a range of projections be evaluated. Selection of design flood magnitudes will involve consideration and balancing of the risks and costs of projected impacts.
- It is recommended that the data and relationships presented in this report be used in design in the Canterbury Region. This is because the analysis is based on all flood peak records available to date and is specific to the Region. It is important in design to take account of the size of the standard errors of the various flood peak estimates.

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