SEASONAL FLOOD PROBABILITY FOR SOUTH CANTERBURY NEW ZEALAND RIVERS

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SUMMARY

It is common practice to estimate flood probabilities on an annual basis. If flood magnitude probabilities vary within a year, such results could be misleading. These differences need not necessarily arise from obvious flood process differences, such as snowmelt versus rainfall. And they might be operationally important: when expected damage varies within years (e.g. for cropped land); or when the particular time period of interest for flooding to occur is less than a year (e.g. a dam or bridge project construction site).
For the first time in New Zealand, a preliminary examination has been made of seasonal flood probabilities for four rivers in a region previously characterised by annual data best fitted by an annual maxima/EV2 approach. A peak-over-threshold/Generalised Pareto parametric approach was most promising for the seasonal data, and suggested within-year probability variation for some rivers.

Keywords: floods, flood estimation, seasonal floods, partial duration, Pareto

1 INTRODUCTION

In NZ, regional flood estimation techniques for operational purposes have been refined in a series of quasi-official publications, leading to the most recent, published in 1989. (Beable, McKerchar, 1982, McKerchar, Pearson, 1989). For most of New Zealand, the parametric approach used in these techniques to estimate annual flood probabilities led to Extreme Value Type 1 (EV1 or Gumbel) as the preferred probability distribution for extrapolating observed flood event data from rated river discharge sites to smaller annual exceedance probabilities than the data range. A quite small minority of gauging sites in particular regions provided data not well fitted by EV1, but apparently better fitted by EV2 distributions. One such area was South Canterbury, on the East Coast of South Island (Figure 2-1).
It is most common to estimate flood magnitude probabilities with the 'conditioning event' being the passage of one year (calendar year or hydrological year). Useful statistical techniques derived from extreme value theory do not proscribe the choice in this way; the conditioning event could also be the passage of one summer, one spring, or one January, for example. In principle, a month or a week could be the conditioning event, but the likelihood of threshold and independence difficulties, and non-occurrence of "floods", becomes greater as the chosen time period becomes shorter.
An underlying problem with many parametric approaches to flood magnitude probability estimation is too few data points to provide confidence in parameter estimates. The problem is neither better nor worse when a season, rather than a year, is the conditioning event. Gauged data periods for New Zealand rivers are short in comparison to some in Europe. There are now periods greater than 30 years available at some sites, sufficient to conduct preliminary analyses of the kind described in this paper.
Hydrological and catchment management reasons for considering seasonal flood magnitude probabilities include:

- Expected flood damage variation during a year e.g. land in agricultural or horticultural crops. This can affect benefit:cost analyses and priorities for flood control works.
- Vulnerability to flood damage during part only of a year e.g. a dam or bridge construction site. This can affect the choice of construction start time and duration.
- Flood probability variation within years complicates the results of annual maxima analyses.

If any of these reasons exist for a site or area, and there is some *a priori* reason to believe that within-year flood magnitude probability variation might be occurring, a seasonal analysis could be useful. The first two reasons were present for the study location, and the third was suspected.

2 LOCATION

Canterbury is one of the six regional government areas of South Island, New Zealand. South Canterbury is East of the main NE-SW mountain divide (the Southern Alps), and between approximately latitudes 44° S and 45° S (Figure 2-1). There were seven rivers studied, indicated by name in Figure 2-2, in which the dot symbols are approximately at the location of the discharge recording sites. Only data from the four rivers having the longest periods of record are presented here.
Some information about the rivers and their catchments is given in Table 2-1. Hydrographic information is summarised in Table 2-2 (in which dates are given as yymmdd). For this study, the two Orari River records from closely adjacent sites, with 69505 replacing 69506, were combined using changeover date 821231.

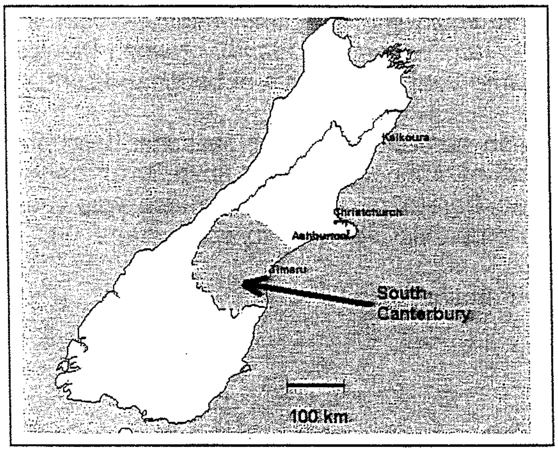

Figure 2-1: South Island, New Zealand, with Canterbury region boundary marked, and South Canterbury shown shaded.

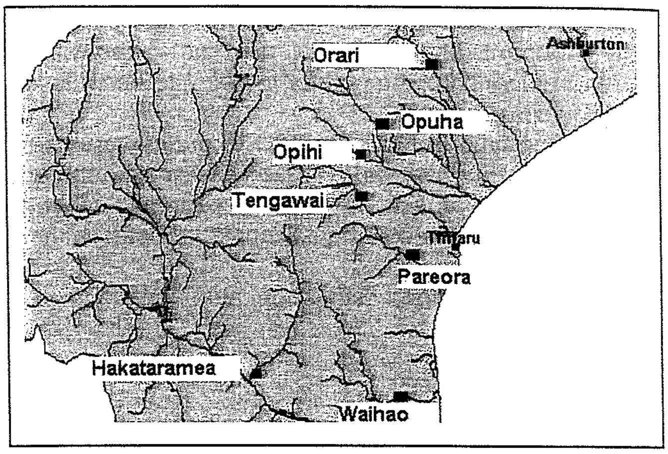

Figure 2-2: Approximate gauging site locations for seven rivers in South Canterbury.

Table 2-1: Catchment and flow data for four rivers; total length of record used 33 years 1966-98.

River	Catchment km^2	Mean Flow m^3/s	Mean Ann. Flood m^3/s
Hakataramea	896	6.1	191
Opihi	406	5.5	165
Opuha	458	9.7	204
Orari	520	10.6	215

Table 2-2: Hydrographic data for four rivers.

River	Site #	Levels Start	Levels End	First Rating	Last Rating	Gap Days
Hakataramea	71103	631231	990118	631126	981204	74
Opihi	69618	630701	990125	640511	970912	384
Opuha	69614	620301	990115	640801	980116	268
Orari	69506	650812	830613	640504		-
Orari	69505	820908	990107		981014	55

The climate in South Canterbury is temperate, with mean annual rainfall about 600 mm at Timaru (Figure 2-1), and much higher along the western mountain boundary. It is about 4000 mm at The Hermitage tourist hotel at Mt Cook, and up to about 8000 mm at high elevations in the mountains. Yellow-brown and yellow-grey earths and rendzina soils on plains areas (Cutler, 1968) overlie moderately indurated greywacke (quartzite), non-foliated schist and tertiary rocks (Mutch, 1963).

3 ANNUAL ANALYSES

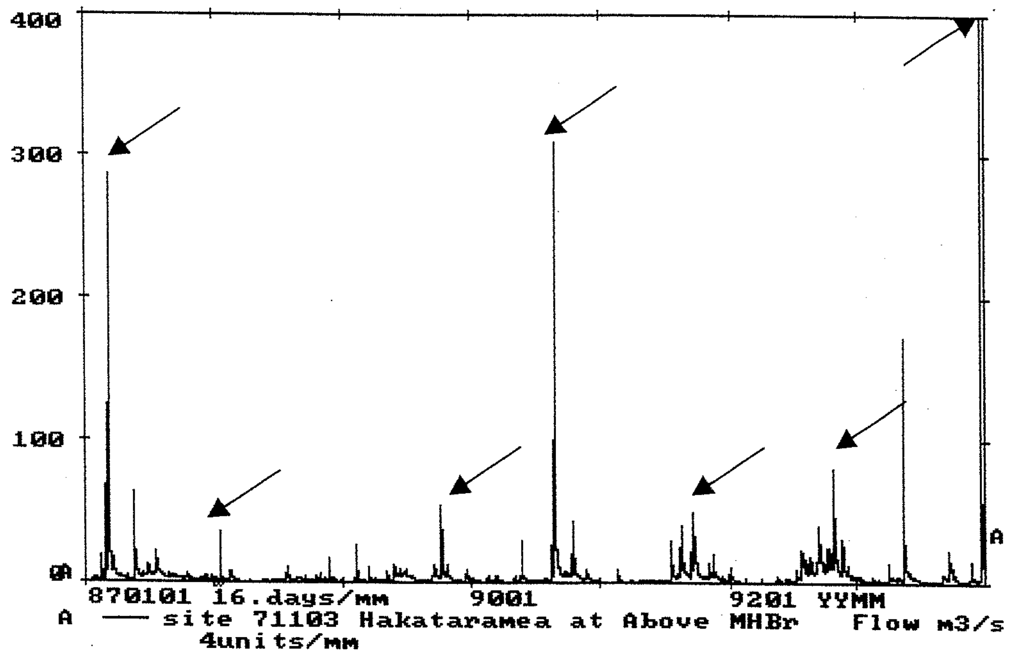

Figure 3-1: Discharge hydrograph 1987 to 1993, Hakataramea River, annual maxima arrowed.

Figure 3-1 shows part (7 years) of a record of discharge, converted from recorded stage heights using current meter ratings, for the Hakataramea River. Annual maximum flows are indicated by the arrows. Provided that a multi-peaked flood does not occur through a year change, in which case the last maximum in one year might not be independent of the first maximum in the next year, there is no particular difficulty in identifying the series of annual maxima.

An appropriate probability distribution for maxima of flood events is the General Extreme Value (GEV). The well-known and often used EV1, or Gumbel, distribution is the special case of GEV when the shape parameter, κ, is zero (Stedinger et al., 1993).

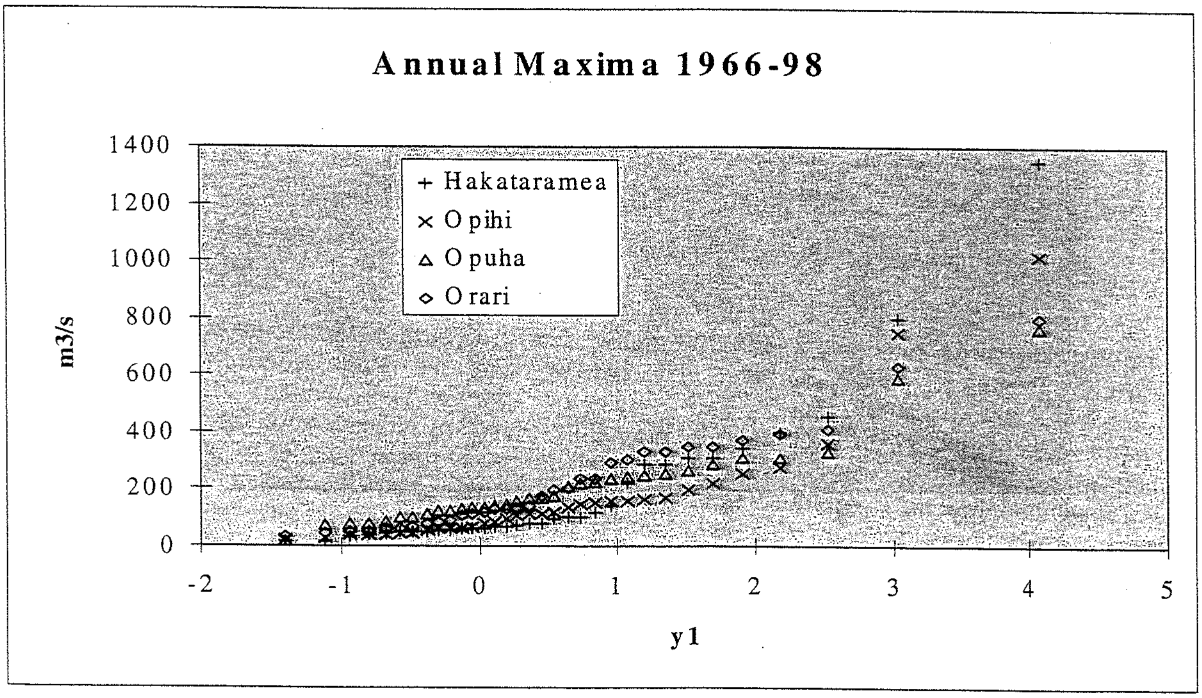

Figure 3-2: Annual maxima 1966-1988 for four rivers, against EV1 reduced variate, y_1.

Figure 3-1 also indicates that in this (complete duration series) approach, some floods of greater magnitude than those included are left out because they occur in a year containing a flood of higher magnitude (e.g. May 1987, May 1993).
The annual maxima for four rivers 1966-1998 are plotted in Figure 3-2 against the EV1 reduced variate, y_1. The Gringorten (1963) plotting position formula relating rank to probability has been used. y_1 is

(1) $$y_1 = \frac{x-u}{\alpha}$$

and the cumulative probability distribution, F_1, of x is

(2) $$F_1(x) = e^{-e^{-\left(\frac{x-u}{\alpha}\right)}}$$

in which:

x flood discharge magnitude
u location parameter
α scale parameter

As cumulative probability is the complement of exceedance,

(3) $$y_1 = -\ln(-\ln(1 - AEP))$$

where AEP is the annual exceedance probability $p(x \geq x_{reference})$. Values for u and α were obtained in this study using linear moments (Hosking, 1988; 1990) to fit equation (2) to the data.
From equations (1) and (3), flood magnitude data conforming to equation (2) would plot linearly against y_1, which is a measure of probability. The data in Figure 3-2 clearly do not plot linearly.

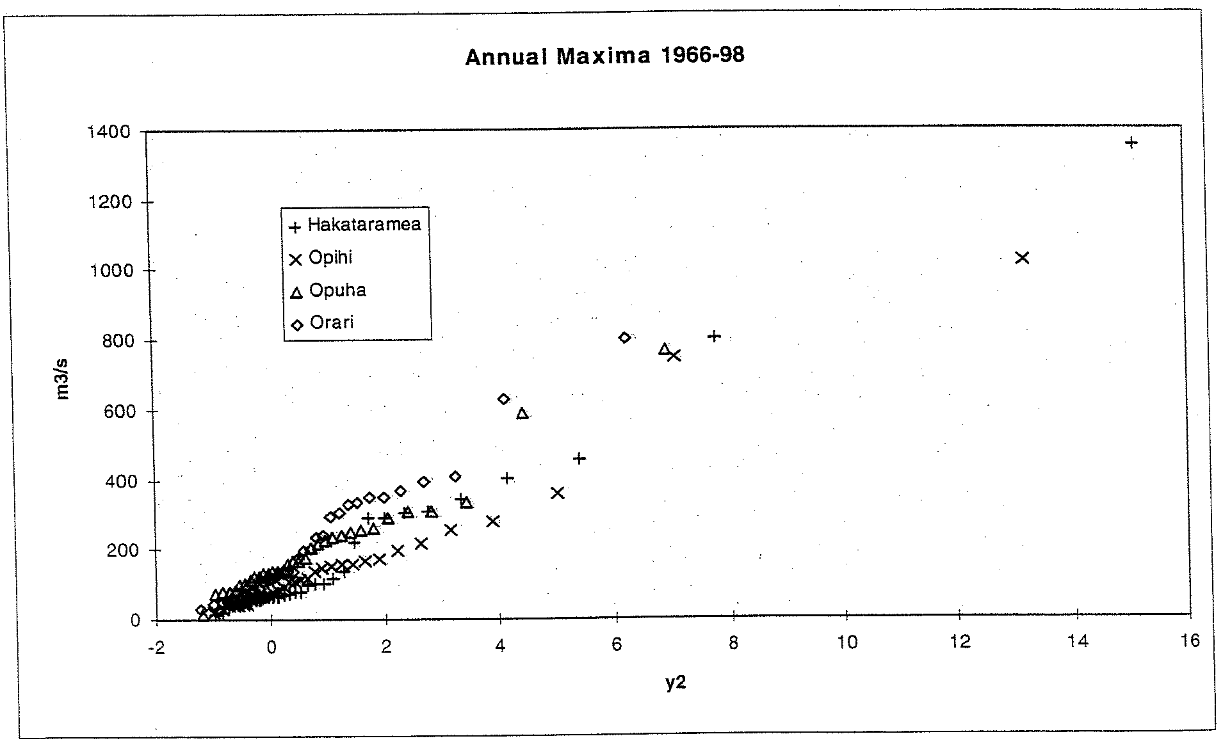

Figure 3-3: Annual maxima 1966-1988 for four rivers, against EV2 reduced variate, y_2.

In Figure 3-3 the same flood magnitude data are shown plotted against the EV2 reduced variate, y_2. y_2 has the same linear relationship with x, but the cumulative probability distribution is

(4) $$F_2(x) = e^{-\left[1-\frac{\kappa(x-u)}{\alpha}\right]^{\frac{1}{\kappa}}} \qquad \kappa < 0$$

and the relationship with AEP is

(5) $$y_2 = \frac{1}{\kappa}\left\{1-\left[-\ln(1-AEP)\right]^{\kappa}\right\}$$

The additional parameter introduced is

κ shape parameter

Flood magnitudes conforming to equation (4) would plot linearly against y_2, which is a measure of probability. The fit shown in Figure 3-3 (also shown by the three rivers of shorter total period of record in Figure 2-2) is why this region has been previously said to be "EV2" rather than the "EV1" regions typical of most of New Zealand (McKerchar, Pearson, 1989). But clearly the linearity is far from perfect.
A censored partial duration series, of independent flood magnitudes greater than a specified threshold, is an alternative to the complete duration series formed from one flood magnitude maximum for each conditioning event, such as a year.

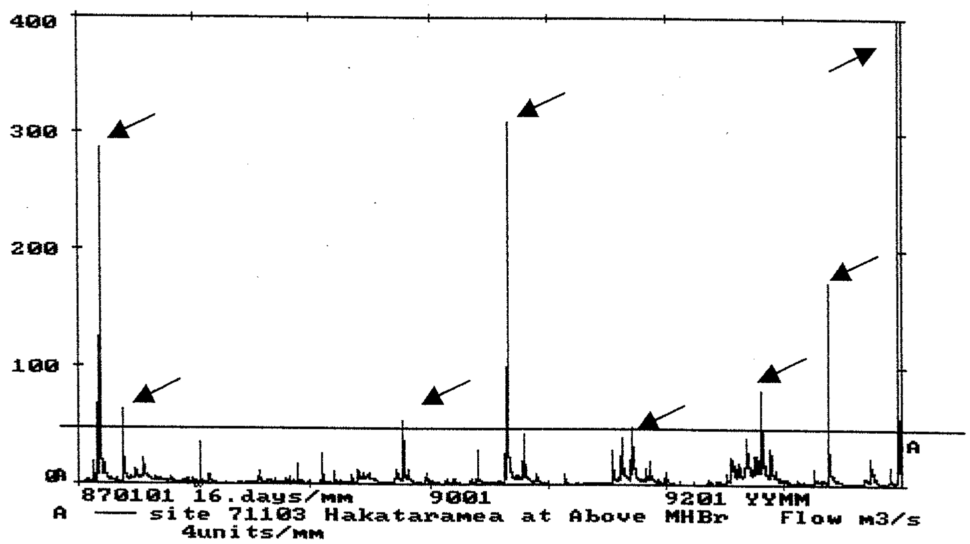

Figure 3-4: Discharge hydrograph 1987 to 1993, Hakataramea River, independent peaks > 50 m^3/s arrowed.

Figure 3-4 shows the same period of record as Figure 3-1, but the magnitudes indicated by arrows are all "independent" peaks greater than a "threshold" of 50 m^3/s. These can be used to form a whole-record peak-over-threshold (POT) series.
The multiple flood peaks visible in March 1987 and August 1990 do not arise from independent "events", but it is not a trivial matter to decide on "independence" in general. The eight peaks indicated here exceed a threshold discharge equal to mean discharge plus three standard deviations (rounded to nearest 5 m^3/s). This gives a similar number of flood events to the complete duration series (seven in Figure 3-1), but again, it is not a trivial matter to decide on a threshold value in general.
Lang et al. (1999) have reviewed POT modelling practice and offered guidelines, based on accumulated international experience, for setting independence criteria and selecting threshold values in circumstances like these.
An appropriate probability distribution for independent POT flood events is the Generalised Pareto (GPa). A special case of GPa when the shape parameter, δ, is zero is the 2-parameter exponential distribution (Stedinger et al., 1993).

The POT magnitudes for 1966-1998 for the same four rivers as in Figure 3-2 are plotted in Figure 3-5 against the GPa reduced variate, y_p. Again, the Gringorten (1963) plotting position formula relating rank to probability has been used. y_p is

(6) $$y_p = \frac{x - v}{\beta}$$

and the cumulative probability distribution, F_p, of x is

(7) $$F_p(x) = 1 - \left[1 - \delta\frac{x - v}{\beta}\right]^{\frac{1}{\delta}}$$

in which:

x flood discharge magnitude
v location parameter
β scale parameter
δ shape parameter

As cumulative probability is the complement of exceedance,

(8) $$y_p = \frac{1}{\delta}\left[1 - (AEP)^{\delta}\right]$$

where AEP is the annual exceedance probability $p(x \geq x_{reference})$. As for GEV, linear moments (Hosking, 1988,1990) were used to evaluate v, β and δ.

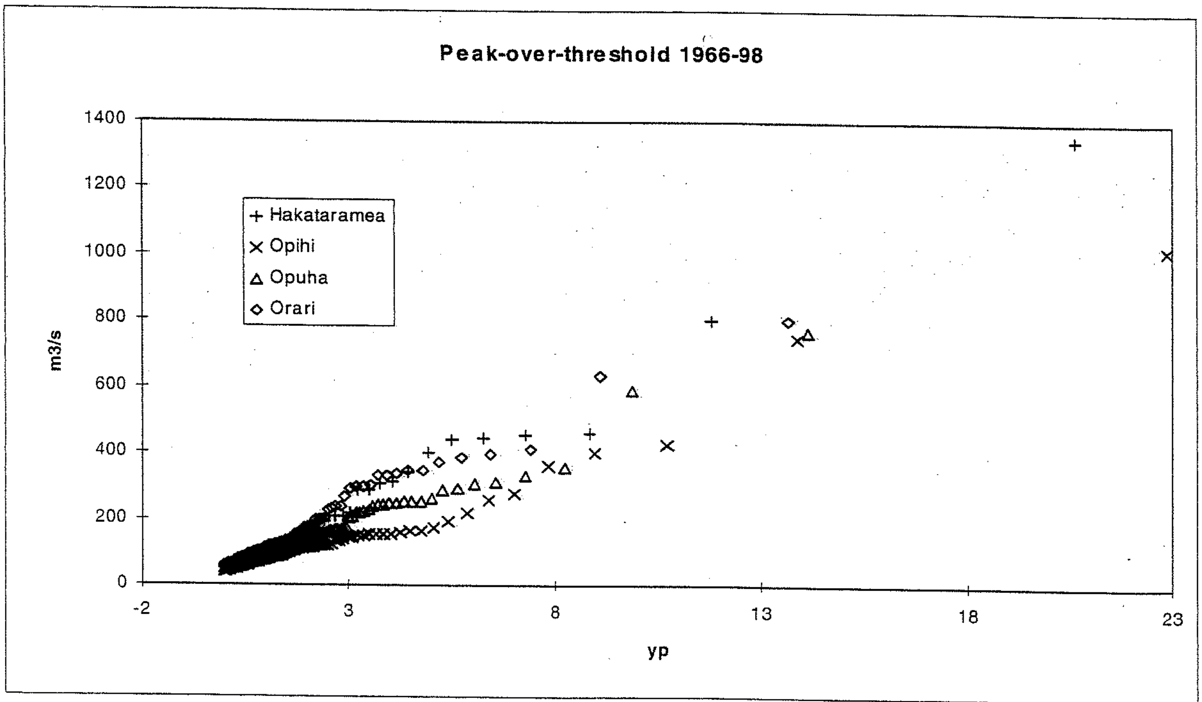

Figure 3-5: Annual peaks-over-threshold 1966-1988 for four rivers, against GPa reduced variate, y_p.

From equations (6) and (8), flood magnitude data conforming to equation (7) would plot linearly against y_p, which is a measure of probability. Comparing Figures 3-2 and 3-5 does not immediately suggest superiority of either approach in terms of conformity of the data to a linear model.

4 SEASONAL ANALYSES

A previous investigation of Hakataramea River data (Painter, Larsen, 1995) suggested that flood magnitude probabilities varying within years could be affecting interpretation of annual probabilities. That preliminary study investigated weather pattern effects on flood magnitude probability, but without clear relationships being established. Instead, mixtures of distributions were apparent, with seasonality of probabilities suspected.

South Canterbury rivers are short and steep (Figure 2-2), rising in mountain and foothill areas, and flowing in predominantly rural floodplains to the Pacific Ocean. Most have some degree of river control imposed by stopbanks (levees) to prevent flooding of highways, towns and agricultural land for livestock and cropping. The flooding which does occur (Connell et al., 2001) thus has different costs depending on the state of the agricultural land at the time of flooding. In 1997, a dam under construction on the Opuha River to provide irrigation water supply and hydro-electricity failed when a flood exceeded the capacity of the diversion works in place at the time. The flood probability determination was controversial, and the legal and financial implications were important (Anon, 2001).

The three hydrological and catchment management reasons for considering seasonal flood magnitude probabilities listed in the Introduction therefore have applied in South Canterbury.

For seasonal, compared to annual, analyses, the same two approaches could be taken: selecting seasonal maxima for a complete duration series, or selecting peaks over a threshold for a partial duration series. Some of the difficulties with each approach described for annual analyses are exacerbated with the reduced length of record which follows from extracting seasonal data from a total record. In addition, there is now the problem of deciding what are "seasons" in order to most appropriately select the "conditioning event". Ideally, the most relevant seasons would be "flood behaviour" seasons. But in the present context, for the study region climate, geology and land use, this flood behaviour seasonality is unknown, and whether it exists is unknown.

The simplest rational approach is to adopt the conventional (austral) seasons: December-February (DJF) summer; March-May (MAM) autumn; June-August (JJA) winter; September-November (SON) spring. Once databases and algorithms are appropriately established, varying the season boundaries only implies extra computational effort.

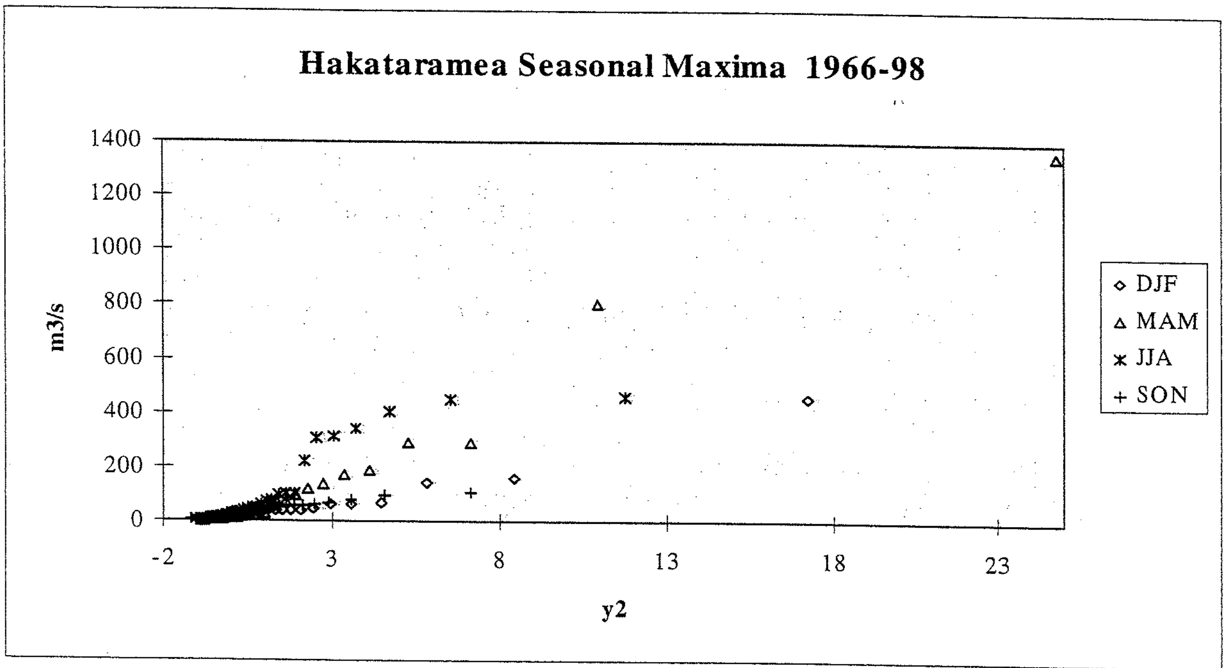

Figure 4-1: Seasonal maxima 1966-1988 for the Hakataramea River, against EV2 reduced variate, y_2.

Seasonal maxima selection, and seasonal peak-over-threshold selection are as in Figures 3-1 and 3-4, respectively, but in each case the time axis is discontinuous, comprising the sequence of 3 months from each year in the total record appropriate to the chosen season.

Comparing the results from all seasons for each river indicates whether or not flood probability variation within years is occurring. Comparing the results from all rivers for each season indicates (as for annual analyses) whether or not regional analysis is likely to be useful.

Figure 4-1 shows the seasonal maxima for the Hakataramea River, plotted against the EV2 variate, y_2. The implication from Figure 4-1 is that spring and summer plot with similar flood probability, and that this differs from each of autumn and winter. It is also noticeable that there is a magnitude gap from about 100-200 m^3/s in the winter (JJA) data. Summer and winter maxima plot differently for the Opihi and Orari Rivers, as for the Hakataramea River, but autumn and spring behaviour is not consistent for all four rivers. Seasonal data are not clearly different for the Opuha River.
Figure 4-2 shows seasonal peak-over-threshold data for the Hakataramea River, plotted against the GPa variate, y_p. The implication from Figure 4-2 is that autumn and summer plot with similar flood probability, and that this differs from each of spring and winter. Both approaches suggest that summer and winter are different, but are not consistent about autumn and spring. Only summer plots differently for the Opihi River, only autumn for the Orari River. In contrast to the seasonal maxima data, the peak-over-threshold data for the Opuha River show summer and autumn data together, but different from each of spring and winter.

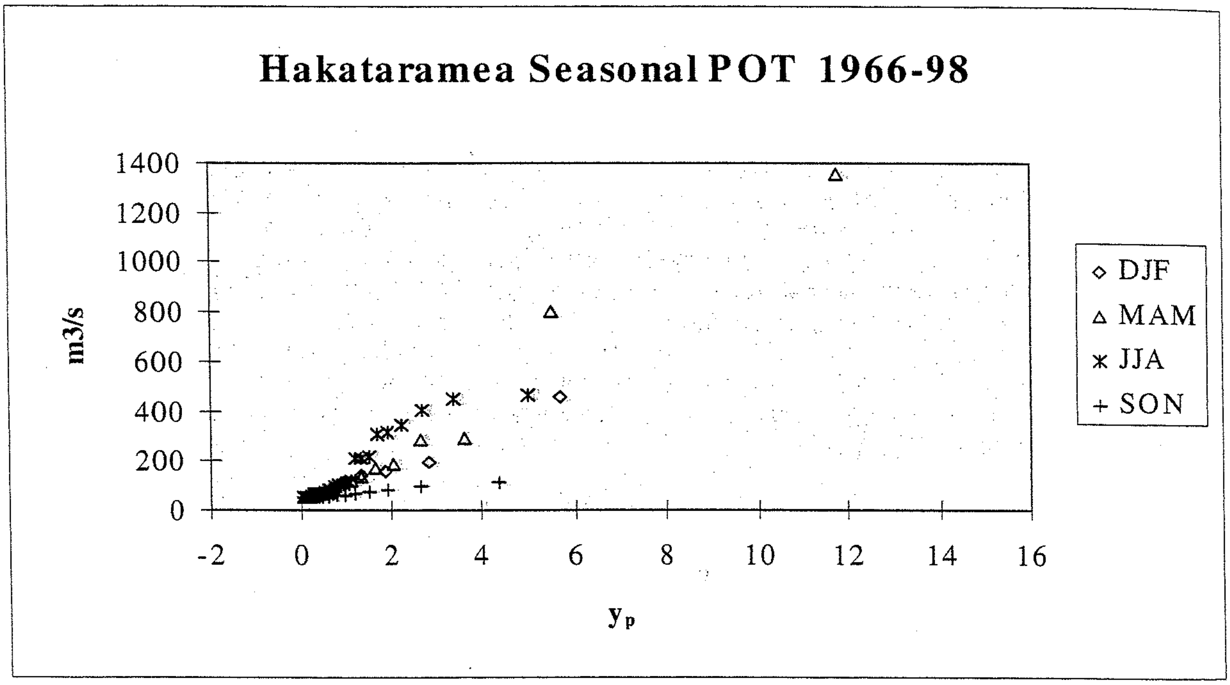

Figure 4-2: Seasonal peaks-over-threshold 1966-1988 for Hakataramea River, against GPa reduced variate, y_p.

Figure 5-1 summarises the seasonal peak-over-threshold results, for the four rivers, by season.

5 DISCUSSION & CONCLUSIONS

The relative advantages of using annual maxima to derive a complete duration series, or peaks over a threshold to derive a partial duration series, have been well discussed in the literature in the context of annual exceedance probabilities of floods (Madsen et al., 1997). The occurrence of floods in mixtures of distributions, due to differing rainfall or catchment processes, has also been reported and discussed (Arnell, Gabriele, 1988). Seasonal occurrence of floods is well understood in many climatic contexts, from monsoonal to arid (Meigh et al., 1997) and when spring snowmelt contrasts with rainfall events in other seasons (Stoddart, Watt, 1970). This study draws on all three of these contexts, but applies the understanding to seasonal probabilities of flood magnitudes in a climatic and geological setting where the reasons for within-year variation in probability, if any, are not obvious.
The preliminary results for seasonal flood magnitude probabilities reported here for four rivers in South Canterbury, New Zealand, indicate the likelihood that probabilities do differ in some seasons from others, and therefore differ from the usual annual probabilities. Seasonal maxima complete duration series and GEV fitting by linear moments, leads to "EV2" values for the shape parameter, κ. The requirement that the maxima be chosen from among an "asymptotically large" number of "floods" in the conditioning event (Leadbetter et al., 1983) is not well met, and this approach is not preferred.

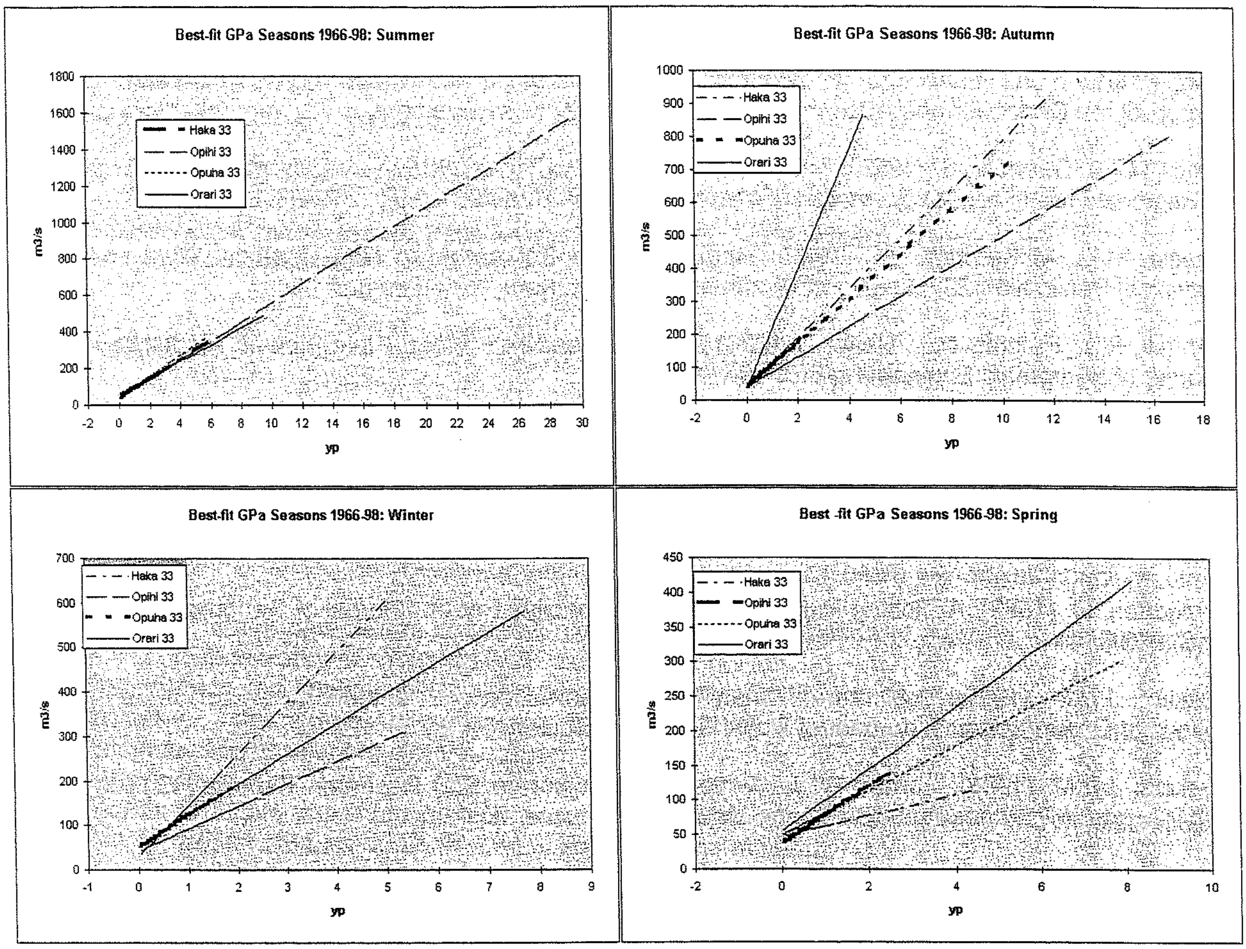

Figure 5-1: Best-fit GPa to seasonal POT series for four rivers 1966-1998.

An approach using partial duration series of independent peaks over a threshold, and GPa fitting by linear moments, is preferable, providing appropriate choices of criteria for independence and threshold values are made. Such an approach used here showed seasonal differences in flood magnitude probabilities which differed in some river/season cases from the AMS/GEV approach.

The present results were obtained using the following relatively simple criteria:

- Event peaks independent if separated by three days or more
- Threshold discharge equal to mean plus three standard deviations
- Mean arrival rate equivalent to at least 1.6 events per year

A recent review (Lang et al., 1999) has provided "coherent practice-oriented guidelines" which will allow refinement of the methodology for a closer examination of the data for these four rivers, and the three others also shown in Figure 2-2, which now each have 19 years of data available. Another recent paper (Martins, Stedinger, 2001) has provided means of restricting the shape parameter, δ, of the GPa distribution, to a "statistically physically reasonable range". Two of the 16 fitted values of δ in this study (4 rivers, 4 seasons) were "absurd" (Opihi Spring +0.270, Opuha Winter +0.453, Figure 5-1). There are many traps and difficulties in working with small samples of flood data from unknown parent distributions (Cunnane, 1985). Some of these are made worse by choosing to examine seasonal data. But doing so shows promise both for explaining some hitherto mysterious behaviour, and for providing operationally significant information.

6 ACKNOWLEDGEMENTS

Rob Connell and Tony Boyle of Environment Canterbury, New Zealand, arranged data provision and financial support for the work on which this paper is based. George Griffiths of Environment Canterbury approved its conference presentation. Charles Pearson of the National Institute for Water and Atmospheric Research (NIWA) provided technical advice.

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