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Comparison of a regional method for estimating design floods with two rainfall-based methods

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Abstract

Design floods estimated using frequency analyses of between 14 and 23 years of flood records for six catchments are compared with estimates of design floods made using methods that assume no flood records are available for the catchments. One method is a regional flood frequency estimation scheme that uses mapped data to provide estimates of flood statistics. The others are empirical methods that transform estimates of storm rainfall of given frequency over a catchment into an estimate of peak runoff with the same frequency. Estimates of the mean annual flood and the 1-in-100 annual exceedence probability flood derived from the three methods are compared with estimates from the recorded flood data. The regional method estimates are consistently closer to the estimates from the flood records than are estimates based on rainfall-runoff methods.

Introduction

To estimate design flood magnitudes for streams or rivers for which little or no data are available, engineers use methods for flood estimation that require no "at-site" data. In the past, the Rational method and the "TM61" method have been used in New Zealand. These methods transform estimates of catchment storm rainfall with stated exceedence probability to estimates of peak runoff with the same exceedence probability. The methods are described in the "Culvert Manual" (Ministry of Works and Development (MWD), 1978). There are few assessments of their performance in New Zealand: they came into use in the 1950s when little systematic streamflow data were available to calibrate or verify the performance of hydrological models, but estimates of the frequencies of extreme rainfall were available. The methods continue to be used to provide design flood estimates for rural catchments, although the main use of the Rational method is for urban drainages, where the areas involved are typically measured in hectares rather than square kilometres. To reflect their dependence on rainfall data, they are termed "rainfall-runoff" methods.

With the advent of a comprehensive national hydrological data archive, a regional method for estimating flood flows has been extensively researched (e.g. Pearson and McKerchar, 1989). The regional method is based on observed flood data and does not require estimates of catchment storm rainfall. This method also is not well verified, primarily because most of the available data were used in calibrating the method. An elaboration of this method, intended for catchments with drainage areas of less than 100 km^2, is described in Pearson (1991b).

In the last decade, flood data have continued to accumulate in the archive, and in this paper we use records for six catchments to compare estimates of design flood derived from flood records with four "no-data" estimates. The work was part of a broader study of the adequacy of current methods for bridge waterway design (Macky and McKerchar, 1997).

Method

Six catchments with between 14 and 23 years of records that had not been used in developing the Regional method described in Pearson and McKerchar (1989) were selected. Their median catchment area is 122 km^2 and areas range from 1.24 km^2 to 351 km^2. Figure 1 shows the location of the six catchments and Table 1 lists relevant catchment details.

Water levels and flows were recorded by standard stream gauging methods; the errors for floods flows estimated from rating curves typically have standard errors of estimate of five to ten percent.

Two flood parameters are used, the mean annual flood, and the 1-in-100 annual exceedence probability (AEP) flood. The mean annual flood is the arithmetic mean of the peak flow in each year of record: the 1-in-100 AEP estimates are obtained from frequency analysis of the annual maxima using the Extreme Value type 1 (EV1 or Gumbel) distribution fitted using the method of probability-weighted moments (McKerchar and Pearson, 1989). These are termed "flood record" estimates. To confirm that the two-parameter EV1 distribution was appropriate, the three-parameter General Extreme Value (GEV) distribution was also fitted, and the third parameter, which specifies shape of the distribution, tested to see if it should be regarded as significant. The EV1 estimates were compared with "no-data" estimates from the Regional, TM61, and the Rational methods.

Details of the TM61 method and the Rational method taken from MWD (1978) are summarised in the Appendix. Both methods require estimates of a rainfall intensity for the catchments for a duration equal to the "time of concentration". The "time of concentration" is estimated from empirical

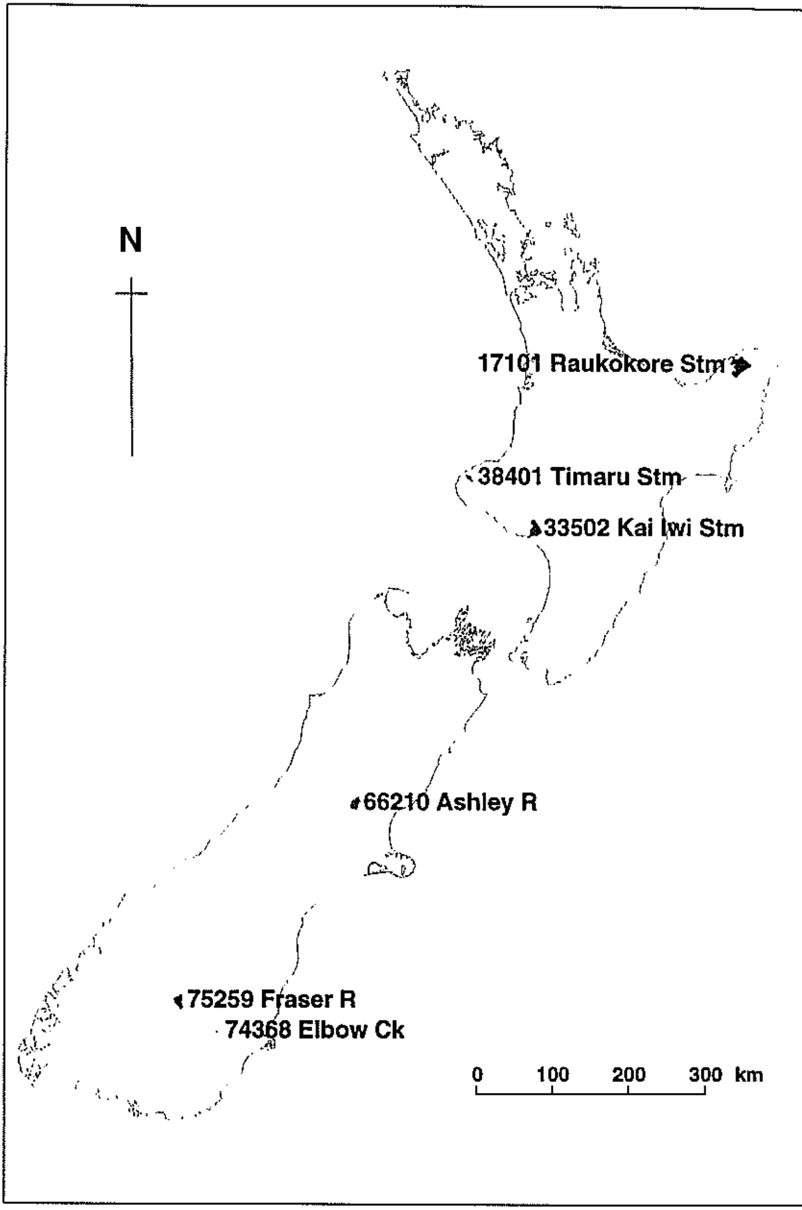

Figure 1 – Location of catchments used to check design flood estimates. The station numbers and some details of the record are in Walter (2000).

Table 1: Details of catchments

Station number (Walter, 2000)	Stream	Length record	Estimates based on flood records		Description of catchments				Rational method runoff coefficient		Catchment rainfall time of concentration	
			(Mean annual)	(1-in-100 AEP)	Catchment area	Length main channel	Channel slope[1]	Time of concentration[2]	A	B	(Mean annual)	(1-in-100 AEP)
		(years)	m3/s)	(m3/s)	(km2)	(km)	(m/m)	(h)			(mm/h)	(mm/h)
17101	Raukokore	15	787	1630	351	49.3	0.0067	12	0.5	0.45	10.1	21.3
33502	Kai Iwi	18	24	51	192	50.1	0.0048	15	0.45	0.50	5.5	11.6
38401	Timaru	14	63	140	27	14.9	0.042	3	0.7	0.40	26.8	56.5
66210	Ashley	18	78	178	121	18.5	0.030	4	0.7[3]	0.40	13.2	27.9
74368	Elbow	16	1.3	6.6	1.24	1.44	0.055	0.5	0.5[3]	0.40	20.1	46.0
75259	Fraser	23	33	86	122	22.7	0.027	5	0.7	0.40	4.3	9.0

Note 1: Channel slope estimated using modified Taylor-Schwarz method (MWD, 1978).

Note 2: Time of concentration is mean of estimates from Ramser-Kirpich and Bransby-Willams formulae (MWD, 1978).

Note 3: Add 0.05 for 1-in-100 AEP.

formulae (MWD, 1978) that use channel length and slope determined from maps. Rainfall intensity is determined from a set of maps in Tomlinson (1980) that are now encapsulated in a computer program named "HIRDS" (Thompson, 1995). (The "Culvert Manual" advises that the Rational method should be used for catchments with areas of up to 25 km^2, but this advice was waived in this study, as it often is in design studies.)

The flood magnitudes given by both methods depend on coefficients that must be estimated from information about the soils and cover of the catchment in question. For the Rational method, the Culvert Manual uses tables of coefficients published in Turner (1960). Estimates made using these coefficients will be termed "Rational A".

An alternative set of Rational method runoff coefficients printed in NZIE (1980) is reproduced in the NZ Building Industry Document E1 (1992). These coefficients are widely used by territorial local authorities (P.L. Blackwood, pers. comm.). Estimates made using these coefficients will be termed "Rational B".

Results

The flood record estimates, channel lengths and slopes, time of concentration and rainfall intensities for the six selected catchments are presented in Table 1. In the analysis of the flood record data, significance tests for the shape parameter for the GEV distribution indicated that none was significant at the one percent level, and only one (Elbow Creek) was significant at the five percent level. The EV1 results are used. Except for Elbow Creek, the standard errors of the mean annual flood estimates range from 8 to 11 percent and the standard errors for the 1/100 AEP floods range from 13 to 15 percent. For Elbow Creek, the standard error of the mean annual flood estimate was 27 percent, and the standard error for the 1/100 AEP flood was also of this order.

The "flood record" estimates of mean annual and 1/100 AEP flood peak and the four alternative "no-data" estimates are illustrated in Figure 2.

Percentage differences between the "flood record" estimates of the mean annual and the 1/100 AEP flood and the "no-data" estimates are summarised in Tables 2 and 3. The median values of the differences are estimates of the bias of each method.

Discussion

The four "no-data" methods vary in performance, but for the sample of six catchments examined, the Regional method provides flood estimates that are consistently more reliable than those of the TM61 and Rational A methods (Fig.2). The Regional method shows the greatest percentage errors for the

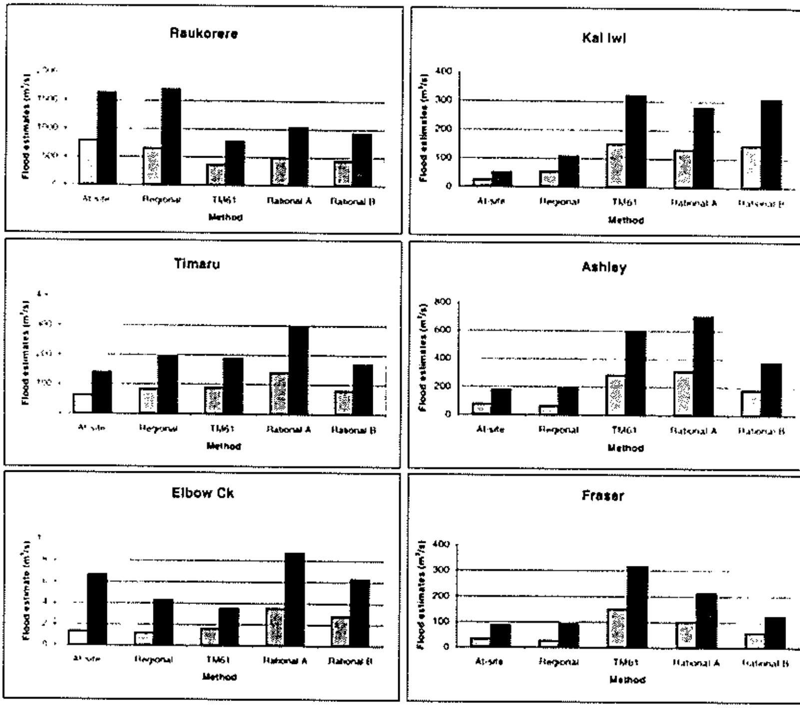

Figure 2 – Comparison of "flood record" and "no-data" estimates of mean annual flood and 1-in-100 AEP floods for six catchments. The mean annual flood estimates are light shaded; the 1-in-100 AEP estimates are dark shaded.

Kai Iwi Stream, however the errors of the rainfall-runoff methods are much greater for this catchment (Fig.2).

Table 3 shows that the median of the percentage difference of the Regional 1-in-100 AEP flood estimate from the flood record estimates is only five percent and the range of the differences is from –36 percent to 113 percent. In contrast, the rainfall-runoff method estimates are biased, generally yielding overestimates of the mean annual (Table 2) and 1-in-100 AEP floods (Table 3). Also, their estimates vary widely, with values ranging from one half to four or five times the estimates based on flood records.

The key difference between the Regional method and the other "no-data" methods is that the TM61 and Rational methods require rainfall intensity estimates. In many parts of the country where the network of raingauges is sparse, the uncertainties in the storm rainfall estimates are substantial. In addition, the methods require estimates of a number of factors to characterise the catchment. In contrast, the Regional method is based directly on recorded

Table 2: Summary of percentage differences between the estimates based on flood records and "no-data" estimates of mean annual flood.

Method	Percentage differences from estimates based on flood records		
	Minimum	Median	Maximum
Regional	-22	-14	122
TM61	-53	154	530
Rational A	-37	183	447
Rational B	-44	92	509

Table 3: Summary of percentage differences between the estimates based on flood records and "no-data" estimates of 1/100 AEP flood peak.

Method	Percentage differences from estimates based on flood records		
	Minimum	Median	Maximum
Regional	-36	5	113
TM61	-52	135	536
Rational A	-36	130	452
Rational B	-43	31	514

flood data, does not require an estimate of rainfall or catchment factors, and has a lower bias. Both the rainfall intensity estimates and the regional flood estimates are derived using the EV1 distribution; hence systematic error arising from the use of different distributions to derive the two sets of estimates should not arise.

While the focus of this work is on the comparison of results of alternative flood estimation methods, it is important to acknowledge that there is some subjectivity in applying the rainfall-runoff methods. The main sources of subjectivity stem from the choice of estimates of the time of concentration, and the runoff coefficient for the Rational method.

The runoff coefficients are a key parameter for the rainfall-based methods. For the Rational method, the Rational B coefficients provide results with less bias than the Rational A coefficients, but the results are still highly variable. The sample of six catchments distributed over the country is too small to draw conclusions about the regional applicability of the coefficients.

For the flood record analyses, the significance tests of the shape parameter for the GEV distribution demonstrate that in five of the six cases, the EV1 analysis is appropriate, and in one case (Elbow Creek) it is marginal. Elbow Creek presented a dilemma. The flood record includes a flood that is 6.47 m^3/s, nearly five times the mean annual flood. This single value is the reason for the exceptionally high standard error of estimate of the mean annual flood (27 percent) and for the marginal fit of the EV1 distribution. This high level of variability in annual flood peaks is typical of eastern regions of the country (McKerchar and Pearson, 1989). Further discussion on the selection of distributions is in Pearson (1991a).

The "flood record" estimates, which are our best estimates of the flood percentiles, are subject to sampling error and model error. Sampling error occurs because we have used relatively short samples of data (between 14 and 23 years length) to estimate the flood percentiles and we would expect differing results from other samples of similar length. Sampling errors for the 1-in-100 AEP estimates are of typically of the order of 10-15 percent, but they are greater for Elbow Creek. Uncertainty in the choice of the distribution is a source of model error. We anticipate that this is low because previous work (McKerchar and Pearson, 1989) has demonstrated that the EV1 distribution fits many maximum flood series in New Zealand.

Conclusions

The key difference between the Regional method and the rainfall-runoff methods is that the former is derived from recorded flood data, whereas the latter require estimates of storm rainfall intensities. Six catchments distributed around New Zealand is a very limited basis for drawing conclusions. The results for this limited sample suggest that:

- design flood estimates generated by the rainfall-runoff methods can vary widely from estimates from flood records, and overall tend to be too large;
- the Regional method (McKerchar and Pearson, 1989) yields design flood estimates that tend to be closer to the estimates from flood record estimates than either the TM61 or the Rational method estimates, and should be preferred for engineering design purposes.

Acknowledgment

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Appendix: Detail on rainfall-runoff flood estimation methods from the "Culvert Manual" (MWD, 1978).

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Technical Memorandum 61 method (TM61)

The TM61 formula is:

$$Q_p = 0.0139\ CRSA^{3/4}$$

where:

Q_p = estimate of the peak design discharge (m^3/s);

C = a coefficient dependent on the physiography of the catchment;
R = a rainfall factor dependent on the design storm;
S = a catchment shape factor;
A = catchment area (km^2).

Guidelines are provided for estimating these factors. The coefficient C is determined as a function of two factors, which respectively are intended to account for the effects of infiltration, ground surface and cover characteristics, and slope of the channels. The storm duration used to determine the rainfall factor R is taken as the time of concentration, and three empirical formulae and a nomogram are provided to estimate this quantity. The formulae require estimates of the length and slope of the main channel. The shape factor S is a function of the dimensionless quantity (A / L_d^2), where A is catchment area, and L_d is the direct (straight line) distance from the furthest point of the catchment to the catchment outlet.

The Rational method

The Rational method formula is:

$$Q_p = CIA / 3.6$$

where:

Q_p = estimate of the peak design discharge (m^3/s);

C is a runoff coefficient;
I is rainfall intensity (mm/hr) for a duration equal to the time of concentration for the catchment;
A is catchment area (km^2).

As noted in the paper, alternative sets of runoff coefficients are available, and we use two. The design storm duration is estimated using the same empirical formulae as for the TM61 method.

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