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NOTE

Estimating return periods of outliers: the Southland flood of 1984

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Abstract

A short at-site record of annual maximum rainfall depths of given duration or annual maximum flood peaks can be readily combined with other information to predict return periods of extreme outliers occurring in such samples using a Bayesian inference approach. Sources of additional information used herein include predictive results from regional and national analyses.

The approach is illustrated by a case study of the Southland storm of January 1984. For this event, the return period of the 24-hour duration rainfall depth at Invercargill airport is assessed to be 840 years with an error range of about 700 to 1000 years and the flood peak in the Waihopai River to be 1900 years with an error range of about 900 to 4000 years. These results are consistent with the estimate made in 1984 of 1000-year return periods for both outliers.

Keywords

rainfall depth outlier; flood peak outlier; Bayesian MCMC flood analysis; flood estimation; statistical hydrology

Introduction

In January 1984, a very severe storm generated extreme rainfalls and severe floods over a wide area of Southland, New Zealand. The synoptic situation that gave rise to the storm was typical of those producing heavy rainfalls in New Zealand but in this instance the air mass was particularly humid and deep (Hill and Quayle, 1984). Much of the damage to property occurred in the northern suburban area of Invercargill as a result of extensive flooding by the Waihopai River. At the time, storm damage costs were exceeded only by those of the 1931 Napier earthquake.

Riddell (1984) estimated return periods of some 1000 years for both the flood peak in the Waihopai River and the 24-hour rainfall at the nearby Invercargill Airport. Both the flood record and the rainfall depth provide excellent examples of the occurrence of an extreme outlier in a small sample: in 1984 the record lengths were 26 years for the Waihopai River and 43 years for the Airport. Using a binomial model, the probability of at least one 1000-year event occurring in 26 years is 2.6% and in 43 years is 4.2%. However, with, say, 100 independent raingauges each with 50 years of record, one would expect to find five events having 1000-year return periods and the probability of finding at least one is 99%. Consequently, the general problem of assigning return periods to outliers in small samples is not an uncommon one in hydrology and it is of considerable importance for engineering design, planning and regulation.

Here, we employ a Bayesian inference approach (Viglione *et al.*, 2013; Parkes and Demeritt, 2016) to combine site data updated since 1984 with information from national and regional predictive models to estimate outlier return period and approximate return period standard error. (Historic, paleohydrologic, predictions from hydrologic and hydraulic models and other types of suitable information were not available.) Additional information is incorporated in an effort to sharpen predictions and reduce the magnitude of standard errors. The aim is to illustrate an approach to estimating return periods of extreme outliers using, as a case study, the Southland storm of 1984.

Analysis

In estimating outlier return periods for the 1984 Southland storm, we treat the rainfall depth and flood peak magnitude separately but the method of analysis is the same.

Rainfall depth

The problem is to estimate the return period, T, of the 24-hour rainfall depth of 134 mm recorded at Invercargill Airport on 26-27 January 1984. Firstly, we specify available relevant information and then combine various estimates to predict values of P/P_m for T = 100, 500 and 1000 years, where P is 24-hour rainfall depth and P_m is the mean of the annual maximum values of P. Note that for the 1984 storm $P/P_m = 3.32$ (with P_m = 40.4 mm) which is an extreme value but not an extraordinary one compared, for example, with the 1923 event recorded at Keinton Combe in North Canterbury (New Zealand Meteorological Service (NZMS) Station No. H23611) where $P/P_m = 4.79$. We then plot site values and predict values of P/P_m as a function of T, and from this relationship estimate T for the 1984 storm value of 3.32.

Information sources

Systematic record

A continuous record of daily (9 am to 9 am) rainfall depths is available at Invercargill Airport (NZMS Station I68433) for the period 1941-2016. These data were fitted using an Extreme Value Type 2 (EV2) distribution (Stedinger *et al.*, 1993) giving the predicted values of P/P_m for T = 100, 500 and 1000 years along with estimated standard errors (Table 1).

Regional analysis

Values of P/P_m from long-term records available from raingauges at Awarua Plains (I68531), Centre Island Light (I67481), Winton (I68133) and Gore (I68192) were

Table 1 – Predictions of dimensionless 24-hour rainfall depths, P/P_m (P_m = 40.2 mm), and standard errors for 100, 500 and 1000-year return periods at Invercargill Airport using various information sources and combination of information.

Information source	Return period (years)		
	100	**500**	**1000**
Systematic site record	2.24 ±0.11	3.04 ±0.18	3.46 ±0.24
Regional frequency curve	2.28 ±0.14	3.05 ±0.20	3.44 ±0.24
HIRDS	2.52 ±0.11	–	–
National predictor (Griffiths *et al.*, 2014)	2.44 ±0.17	3.25 ±0.26	3.64 ±0.36
Combination of information	2.37 ±0.06	3.09 ±0.12	3.49 ±0.15

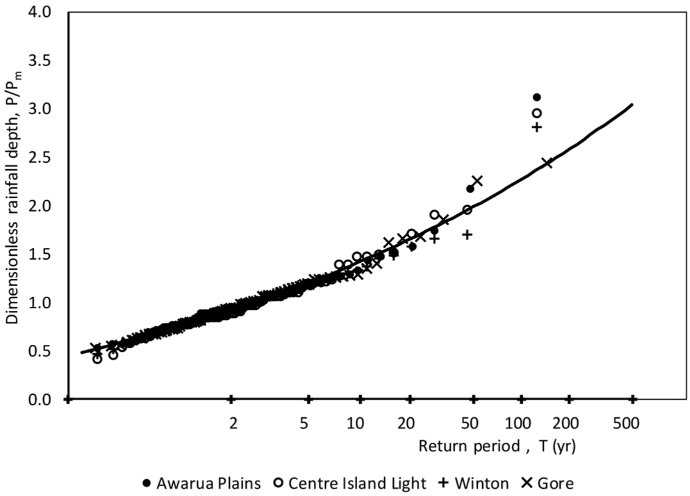

Figure 1 – Dimensionless annual maximum 24-hour rainfall depth-frequency relation for the Southland Region.

plotted as a function of T and fitted using median values of the EV2 parameters for the individual series to yield the required values of P/P_m (Table 1, Fig. 1).

National analyses

The High Intensity Rainfall Design System (HIRDS, version 3) (see Thompson, 2002 for version 2), which at any location predicts point rainfall depth for a specified duration and return period up to 100 years, was employed to predict P/P_m for T = 100 (Table 1). Similarly, P/P_m values for T = 100, 500 and 1000 years were determined using predicted values of P/P_m in Griffiths *et al.* (2014) for a 24-hour duration and the specified return periods (Table 1).

Combination of information

The Bayesian method of Kuczera (1983) was used to combine the various values of P/P_m for the three values of T (Table 1). The relevant equations employed sequentially are given in McKerchar and Pearson (1989, Equations 5.8 to 5.10) to yield the Combination values in Table 1. These three values and the site data are plotted in Figure 2 and fitted with a second order polynomial. For the 1984 rainfall of P/P_m = 3.32, the predicted

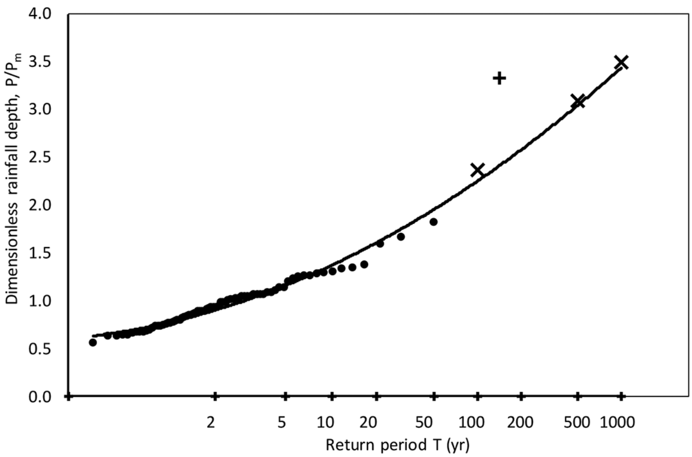

Figure 2 – Dimensionless annual maximum 24-hour rainfall depth versus return period at Invercargill Airport (1941-2016), P_m = 40.4 mm (• measured data; × Combination values (Table 1); + 1984 outlier).

value of T from Figure 1 is 820 years. The factorial standard error associated with this prediction is difficult to estimate. However, assuming there is no error in the site data, but including the standard errors in the Combination numbers (Table 1), a range of fits to the data in Figure 2 suggests that we may be 90% or perhaps more certain that the predicted value of T lies between about 700 and 1000 years.

Flood peak magnitude

The flood peak of 27 January 1984 at the Waihopai Above Scour hydrological recording station (Site No. 78504; Walter, 2000) was not gauged: water overflowed the berms and floating timber obstructed a bridge opening downstream, which affected the hydraulic control for the site. An attempt to calculate the peak magnitude using a slope-area method was unsuccessful (Hydrology Centre, 1988). Consequently, the peak discharge needs to be estimated by indirect means. Two methods are given in Hydrology Centre (1988): firstly, a rainfall-runoff model was developed which performed well and predicted a range of 140 to 200 m^3/s for the peak discharge. Assuming a 90% level of confidence for this range we adopt a value of 170 ±36 m^3/s. Secondly, a regional analysis involving data from 12 sites coupled with the assumption that the 1984 flood peak was the largest since 1891 yielded a predicted value of 166 ±30 m^3/s. Evidence in support of these results is provided by a plot of annual maximum flood peak discharges at Waihopai Above Scour versus 24-hour annual maximum rainfall depths at Invercargill Airport. A second order polynomial fitted to these data yielded a predicted value for the 1984 peak of 172 ±40 m^3/s. The closeness of this estimate to those of Hydrology Centre (1988) is, however, largely fortuitous as the fitted polynomial explains only 56% of the variance and the largest recorded annual maximum at the site is 85 m^3/s.

From the above we assign a value of 170 ±30 m^3/s for the 1984 flood peak at Waihopai Above Scour. Next, as with the rainfall analysis, available relevant flood information is specified and then combined to estimate T for the 1984 flood peak.

Information sources

Systematic record

A continuous record of annual maxima is available at Waihopai Above Scour for the period 1959-2014. A standard error of ±5% was assigned to annual maxima below 50 m^3/s and ±10% to maxima above 50 m^3/s and these data, together with the estimated value for the 1984 peak, were modelled using a Bayesian Monte Carlo Markov Chain (MCMC) inference approach. Details of the MCMC algorithm employed can be found in Renard *et al.* (2006). The results, along with their estimated standard errors, are listed in Table 2 for T = 100, 500 and 1000 years in terms of Q/Q_m, where Q is the annual maximum peak discharge and Q_m is the mean annual flood.

Regional analyses

Griffiths *et al.* (2011) extended earlier work by McKerchar and Pearson (1989) on flood frequency in the Southland Region. Peak value estimates and associated standard errors for T = 100, 500 and 1000 years are readily obtained from their analyses assuming no site data are available. Also, values of Q/Q_m from long-term records at 16 regional sites are displayed in Figure 3.These data were fitted to the median values for the EV2 parameters for the individual series and predicted peak values for T = 100, 500 and 1000 years were obtained (Table 2).

National analysis

Griffiths and McKerchar (2016) developed flood frequency prediction relations for New Zealand in terms of mean basin elevation and average number of flood peaks exceeding half the mean annual flood. From this analysis

Table 2 – Prediction of dimensionless flood peak discharges, Q/Q_m (Q_m = 43 m^3/s), and standard errors for 100, 500 and 1000-year return periods at Waihopai Above Scour using various information sources and combination of information

Information source	Return period (years)		
	100	500	1000
Systematic site record	2.58 ±0.47	3.42 ±0.81	3.84 ±1.23
Regional frequency curve	2.65 ±0.47	3.46 ±0.81	3.84 ±1.16
Regional predictor (Griffiths *et al.*, 2011)	2.51 ±0.42	3.09 ±0.58	3.33 ±0.67
National predictor (Griffiths *et al.*, 2016)	2.60 ±0.47	3.60 ±0.93	-
Combination of information	2.58 ±0.23	3.33 ±0.38	3.53 ±0.53

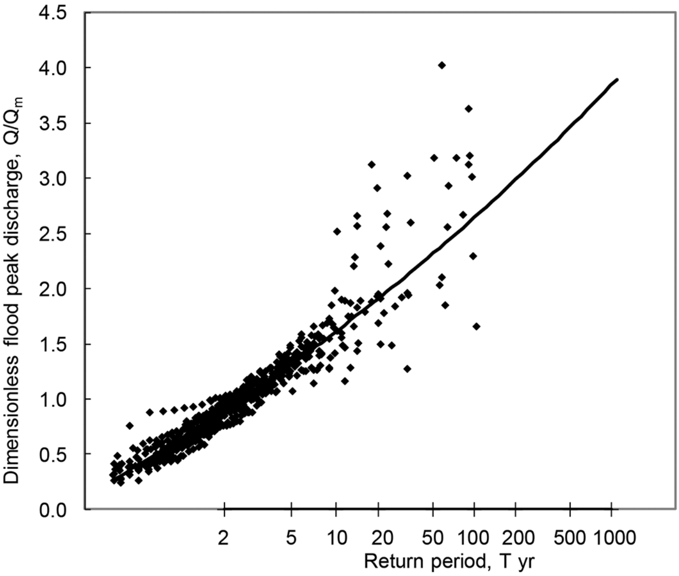

Figure 3 – Dimensionless annual maximum flood peak discharge-frequency relation for Southern Region using data from 16 sites.

predicted values of flood peaks for T = 100 and 500 years were determined (Table 2).

Combination of information

The Bayesian method of Kuczera (1983) was again used to combine the various estimates of Q/Q_m for the three values of T (Table 2). The Combination values and the site data are plotted in Figure 4 and fitted with a second order polynomial. For the 1984 flood peak of Q/Q_m = 3.95, the predicted value of T is 1900 years. The factorial standard error associated with this prediction is difficult to estimate. The annual maxima, the Combination values and the 1984 peak value all have errors. A range of fits to the data suggests that we may be 90% or perhaps more certain that the predicted value of T lies between about 900 and 4000 years.

It is sometimes assumed that for large floods the return period of the critical duration of rainfall and that of the resulting flood peak are the same. However, the degree of correspondence may vary widely depending on antecedent catchment conditions and the relationship between actual catchment rainfall and that measured by raingauge(s).

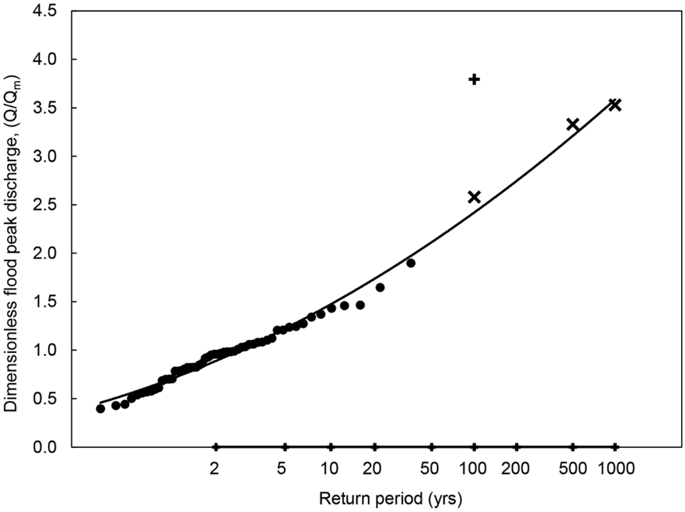

Figure 4 – Dimensionless annual maximum flood peak discharge versus return period at Waihopai Above Scour (1959-2014), Q_m = 43 m^3/s (• measured data; × Combination values (Table 2); + 1984 outlier).

Conclusions

Combination of a systematic record of annual maxima with other information to predict the return period of an outlier may be readily achieved using a Bayesian inference approach.

For the Southland storm of 1984, using subsequent records and additional information from regional and national predictive studies, the return period of the 24-hour rainfall depth at Invercargill Airport is assessed to be 840 years with an approximate standard error range at the 90% confidence level of 700 to 1000 years. The return period for the flood peak at Waihopai Above Scour is assessed to be 1900 years with an error range of about 900 to 4000 years.

It is noteworthy that, given the record lengths and analytical techniques then available, the estimates in Riddell (1984) of 1000-year return periods for both rainfall depth and flood peak magnitude are consistent with our results.

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