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DISCUSSION

Dam safety: an evaluation of some procedures for design flood estimation

Discussion by D. W. Reed & E. J. Stewart
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CONTEXT

Cluckie (1990) states that "when a site has about 40 or 50 years of record it is unlikely to contribute significantly to the improvement of a regionally based statistical estimate by the availability of more data". In the present paper, the authors conclude that "databases with more than 300 station-years can be considered in a quite good condition in terms of quantity of information and that, consequently, the addition of more records may not materially affect the outcome of any future analysis". Coupled with the encouragement given to downweight or exclude "outliers", there would seem to be an inference that there is sometimes an overabundance of information for flood frequency estimation. While this may be true in lesser contexts, the conclusion seems misplaced in a paper which discusses dam safety procedures.

The authors' use of a pooling system based on distance from the subject site has similarities with that put forward for rainfall frequency estimation by Reed & Stewart (1989) but does not make any explicit allowance for inter-dependence in the gauged annual maxima. Both Schaefer (1990) and Buishand (1990) appear to accept Hosking & Wallis's conclusion that inter-site dependence adds uncertainty but no bias to regional flood estimates (Hosking & Wallis, 1988).

The example which follows demonstrates that the GEV–PWM regional procedure can be highly sensitive to the occurrence of a widespread extreme event. In these circumstances it appears advisable for a regional flood frequency analysis to exploit all the available information, and to make some allowance for inter-site dependence. This finding does not sit comfortably with the conclusions of Cluckie & Pessoa (1990) and Hosking & Wallis (1988).

EXAMPLE

A network of 18 sites centred on the Brecon Beacons was selected as a basis for flood estimation in central South Wales. The network spans about 2500 km^2 and is a rather more compact region for flood analysis than that studied by Cluckie & Pessoa (1990). Record start and end dates of 1961 and 1984 were imposed so that systematic comparisons could be made with a parallel analysis of maximum rainfall. To ensure that the pooled data were

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reasonably standardized, stations were included in the regional analysis only when the index flood (the mean annual flood, $\bar{Q}$) was based on at least ten annual maxima.

The calendar was initially "turned back" to 1970, when four stations satisfied this criterion. A regional flood growth curve was derived by the GEV–PWM regionalization algorithm presented by Hosking *et al.* (1985), i.e. with biassed estimators and weighting according to record length. Quantile estimates for a typical station were also noted.

The calendar was then advanced year by year, and the analysis repeated using available data to 1971, 1972, etc.. The solid line in Fig. 1 indicates that the regional GEV shifts from near EV1 (in the period 1970–1978) to strongly EV2 (in 1979–1984). Figure 2 shows the resultant effect on 10 and 100-year quantile estimates for a typical station, the Ebbw at Rhiwderyn. The slight dip in estimates in 1976 is spurious, being caused by inappropriate use of Hosking *et al.*'s GEV–PWM solution in a case when the k parameter is almost zero. More significantly, it is seen that the occurrence of a widespread extreme event in December 1979 has a very marked effect on the 100-year quantile estimates.

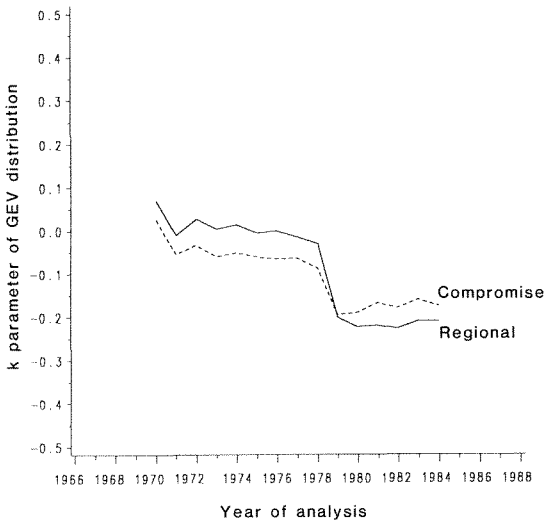

Fig. 1 *GEV k parameter for flood peaks.*

Checks revealed that the December 1979 event was unusual only in terms of its size. Date information confirmed that annual maximum events often occur simultaneously (i.e. on or about the same day) at many stations in the network.

A measure of spatial interdependence in the annual maxima is illustrated in Fig. 3. It is based on the concept of an equivalent number of independent stations (Reed & Dales, 1988; Dales & Reed, 1989). The degree of dependence, d, ranges from 0 (no dependence) to 1 (complete dependence) according to:

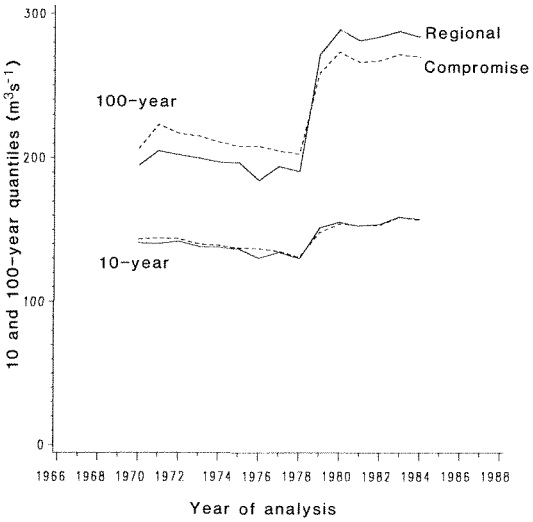

Fig. 2 Flood quantiles, Ebbw at Rhiwderyn.

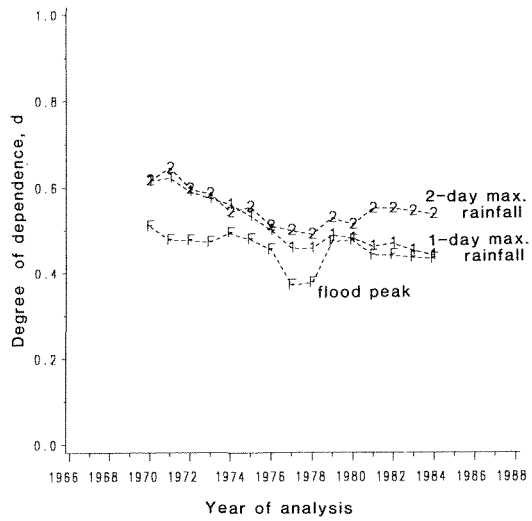

Fig. 3 Degree of dependence, by GEV.

$$d = 1 - \ln N_e / \ln N$$

where N_e is the equivalent number of independent sites in the N-gauge network. It is seen from Fig. 3 that the degree of dependence in the flood maxima is slightly less than that in 1- or 2-day maximum rainfall derived for a network of 18 daily raingauges chosen to span the same region. There is some year-to-year variation in the degree of dependence in the pooled annual maxima but the occurrence of the December 1979 event has only a moderate impact on d.

The broken lines in Figs 1 and 2 correspond to a compromise analysis

which gives equal weight to the GEV–PWM regional growth curve and one based on a translation (by $\ln N_e$ units) of the network maximum growth curve. The latter is the outcome of a GEV–PWM fit to the annual maximum series comprising the largest standardized events seen in the network (Dales & Reed, 1989). Although the compromise analysis is still sensitive to the December 1979 widespread extreme event, the effect is less severe than in the standard regional analysis.

SUMMARY

It is concluded that the GEV–PWM regional analysis can be very sensitive to the occurrence of a widespread extreme event. This is thought to be an inherent weakness in pooled analysis methods which take no explicit account of spatial dependence, and is unlikely to be peculiar to the GEV–PWM procedure.

The authors' suggestion that estimates of the regional growth curve tend to become comparatively stable once 300 or 400 station-years of data are available is therefore unduly optimistic.

While there is little doubt that regional procedures such as that based on the GEV–PWM have greatly improved the consistency of design flood estimates, some fundamental questions remain. Should regions be fixed or flexible? On what criteria should stations be included? And how are the effects of inter-site dependence to be treated?

REFERENCES

Buishand, T. A. (1990) Extreme value estimation by combining data from several sites. Hydrology Session, XV General Assembly, European Geophysical Society, Copenhagen, April 1990 (also published in *Hydrol. Sci. J.* (1991) **36**(4), 345-365).

Cluckie, I. D. (1990) Extreme flood assessment. *Weather* **45**(4), 126-132.

Cluckie, I. D. & Pessoa, M. L. (1990) Dam safety: an evaluation of some procedures for design flood estimation. *Hydrol. Sci. J.* **35**(5), 547-569.

Dales, M. Y. & Reed, D. W. (1989) Regional flood and storm hazard assessment. Institute of Hydrology Report no. 102, Institute of Hydrology, Wallingford, Oxfordshire, OX10 8BB, UK.

Hosking, J. R. M. & Wallis, J. R. (1988) The effect of intersite dependence on regional flood frequency analysis. *Wat. Resour. Res.* **24**(4), 588-600.

Hosking, J. R. M., Wallis, J. R. & Wood, E. F. (1985) Estimation of the generalized extreme value distribution by the method of probability weighted moments. *Technometrics* **27**, 251-261.

Reed, D. W. & Dales, M. Y. (1988) Regional rainfall risk: a study of spatial dependence. IAHR International Symposium on Stochastic Hydraulics, Birmingham, August 1988.

Reed, D. W. & Stewart, E. J. (1989) Focus on rainfall growth estimation. Proc. 2nd National Hydrology Symposium, Sheffield, September 1989, 3.57-3.65.

Schaefer, M. G. (1990) Regional analyses of precipitation annual maxima in Washington State. *Wat. Resour. Res.* **26**(1), 119-131.

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The contribution of Reed & Stewart (1991) to the debate concerning extreme flood estimation is welcomed. They were concerned about the apparent readiness in Cluckie & Pessoa (1990) to "downweight or exclude outliers" and also the comment "that (regional) databases with more than 300 station-years can be considered in quite good condition in terms of quantity of information and that the addition of more records may not materially affect the outcome of any future analysis".

The question of outliers is a vexed one and not more so than in the case of extreme flood estimation. Reed & Stewart (1991) should not confuse an inability to suggest the definitive answer to this question with the current approach adopted! The difficulty of dealing with outliers that may have been produced by generating processes fundamentally different from those supposed in the assumptions inherent in applying almost all of the current probabilistic models of extreme flood behaviour guarantees that a definitive approach does not exist at this time. The Authors' detailed comments on the problem of outliers have been interpreted as "an apparent readiness" to exclude data rather than a cautious approach to dealing with unusual (and often relatively unexplained) events.

The issue of when is a regional annual maximum flood database sufficiently large so as to provide relatively robust estimates of extreme floods was addressed in Cluckie & Pessoa (1990) by suggesting, for the GEV–PWM and the method adopted by the Authors for "pooling" the regional data, that 300 station-years provided a useful guide as to the necessary minimum amount of data required. This was not a rigid comment but rather a natural finding that large data sets tend to be less affected by the arrival of new information. This has also been noted by Hosking & Wallis (1988) and by Cluckie (1990).

Reed & Stewart (1991) have analysed the December 1979 flood which caused severe flooding thoughout southeast Wales and nearby regions. The widespread nature of this flood increased the inter-site dependence and hence the likely additional certainty that this may introduce to the GEV–PWM procedure. The sensitivity of regional statistical procedures in general to this problem is undisputed. However, what must also be acknowledged is the lack of good sense in applying any single-site statistical procedure to extreme flood estimation and the absolute necessity of employing regional methods even with the problems that remain.

There is indeed little doubt that regional procedures such as those based upon the GEV–PWM have greatly improved the overall consistency of design flood estimation. There remain a great many unresolved issues concerning the particular regionalization procedure adopted, inter-site dependence, stationarity of the climate, stationarity of the flood generating process (or processes!), total "risk" based design which considers the joint

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occurrence of hydrological, hydraulic, structural, etc. failure events and indeed the evolution of modern safety standards for dam safety purposes in general.

What Reed & Stewart (1991) failed to pass comment on was the approach adopted by the Authors which utilized weather radar data to obtain PMP–PMF based estimates of extreme floods through the analysis of individual storms (such as the December 1979 widespread frontal event) to avoid some of the previous problems alluded to above but undoubtedly to discover a new range of difficulties which will require future attention.

REFERENCES

Cluckie, I. D. (1990) Extreme flood assessment. *Weather* **45**(4), 126-132.

Cluckie, I. D. & Pessoa, M. L. (1990) Dam safety: an evaluation of some procedures for design flood estimation. *Hydrol. Sci. J.* **35**(5), 547-569.

Hosking, J. R. M. & Wallis, J. R. (1988) The effect of intersite dependence on regional flood frequency analysis. *Wat. Resour. Res.* **24**(4), 588-600.

Reed, D. W. & Stewart, E. J. (1991) Discussion of dam safety: an evaluation of some procedures for design flood estimation. *Hydrol. Sci. J.* **36**(5), 487-490.