Institute of Hydrology

Natural Environment Research Council

STATISTICAL FLOOD FREQUENCY ESTIMATION

Progress report to MAFF, 31 March 1994

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Projects to 31 March 1994:

FD0409	Review of statistical flood estimation procedures
FD0411	Multiple floods in a wet season

Projects from 1 April 1994:

FD0409	Statistical flood frequency estimation
FD0416	Catchment characterization for flood estimation

Context

April 1st sees the start of research directly linked to production of the Flood Estimation Handbook. This note summarizes recent progress on the above projects, and reports the base from which research on the Handbook begins formally.

Multiple floods in a wet season project

Progress on the multiple floods project was delayed by maternity leave. Rather than pursuing the original research plan, which would have required a time extension beyond 31 March 1994, the research has been refocused onto elements directly relevant to the Flood Estimation Handbook. Bayliss (1994) presents a more specific outcome from the multiple floods project.

Flood frequency generalization for the Flood Estimation Handbook

Flood peak data

Previous MAFF-funded work has constructed a unique set of flood peak information: the UK peaks-over-threshold (POT) flood dataset (Bayliss & Jones, 1993). It is a vast resource, comprising peak magnitudes and dates for more than 77000 flood events. Abstraction of POT data is relatively time-consuming. In terms of the period of record for which POT data are held, the dataset is already between four and 11 years out of date. At 18.4 years, the mean period of record held is, however, already substantial, and wholesale extension of the POT data series is not planned.

Collection of annual maximum data is a little more straightforward. Monthly instantaneous maxima from primary gauging stations are routinely reported to the National Water Archive at IH. With good cooperation from the National Rivers Authority, it will be possible to update annual maximum records efficiently. We will, however, wish to ensure that adequate quality control checks are applied. A black spot may be in detecting, and dealing with, those flood peak data which derive from the use of a new or varied stage-discharge rating.

The plan is sympathetic to the above factors and seeks to combine annual maximum and POT flood data to best effect. The existing POT dataset will be exploited to specific ends. To promote consistency, analyses will be standardized where possible to utilize an average of four peaks per year on each catchment.

Investigation of non-stationarity

Previous research on peaks-over-threshold analysis methods (Naden, 1993) included some exploration of the stationarity of UK flood series (see also Naden & Bayliss, 1993). A test was used to identify possible break-points in the frequency or magnitude of threshold exceedances. Subsequent investigation identified rating or data inconsistencies in a number of cases.

It is relevant to check more explicitly for systematic trend in the frequency or magnitude of exceedances, and software has recently been written to this end. Where significant trends are found, the next step will be to seek explanations. Other software is being used to construct corresponding series of POT rainfall data. If tests reveal no explanatory trend in extreme rainfalls, catchments showing flood peak trends will be subject to more detailed scrutiny to discern particular land-use factors that may be implicated. This is an open-ended area of study and will be carried out in parallel with other tasks, as resources permit.

Construction of regions for pooling flood data

The principal use of POT data envisaged for the Flood Estimation Handbook is in the construction of catchment groupings for the pooling of flood peak data; this task, or its outcome, is sometimes referred to as a *regionalization*. The classification of gauged catchments into groups sharing a common flood regime, and the development of procedures to allocate ungauged sites to appropriate groups, are tasks of the utmost importance. The pooling of flood data according to arbitrary or subjective boundaries is no longer acceptable, either scientifically or pragmatically. Researchers elsewhere appear to be using statistics (e.g. L-moment ratios) of the annual maximum flood series in their search for more meaningful groupings of catchments. However, their strategy is self-fulfilling, leading to groups which are apparently homogeneous, yet may be sharply different from adjacent groups. Typically, the annual maximum flood data are used to:

- determine the index flood (and its relationship with catchment characteristics),
- select regional groupings,
- verify regional groupings,
- construct flood growth curves (required to obtain consistent estimates of rare events).

This fourfold exploitation over-plunders the annual maximum data. The approach bases too many judgements on too few data.

No other country has POT flood data for such a large and dense network of gauging stations as the UK one. The availability of these data allows a new and radical approach to constructing regions for pooling flood peak data.

Basing flood regionalization on date information

The hypothesis is made that date information provides a fingerprint of flood regime. Because the information is generally accurate, and is readily available for more than 77000 flood events, additional use of dates is strongly attractive. In constructing and interpreting indices based on date information, it must be borne in mind that similarity in the temporal pattern of flood incidence, though a reasonably *necessary* condition for similarity of flood regime, may not be a *sufficient* one. It is therefore important that catchment groupings are checked for similarity of physical characteristics. Such checks are naturally made as part of the task of developing rules for allocating ungauged catchments to flood regions.

Indices of flood regime based on date information

Indices are being derived from date information to represent three separate aspects of flood regime: seasonality, regularity and "correspondence with rainfall".

Seasonality

Bayliss & Jones (1993) summarize flood seasonality using directional statistics (pp. 18-28 of Mardia, 1972). Flood dates are represented as unit masses on a circle of unit radius, the polar angle defining the calendar day of the flood occurrence. A "mean POT flood day" and a "standard deviation about mean POT day" are defined by reference to the centroid of the unit masses.

While it is necessary to use at least two indices to represent the seasonal distribution of flood occurrences on any catchment, the requirement in classification studies is only to index *dissimilarity* between objects (i.e. catchments). For this, a single number is needed that summarizes the degree of difference between two samples of directional data. A simple choice is the inter-centroid distance (Fig. 1). A more sophisticated approach is to use a uniform-scores test to evaluate the significance level at which the hypothesis that two samples of directional data are identical is rejected (pp. 196-201 of Mardia). The significance level then provides the required measure of seasonal dissimilarity, d_s.

Regularity

The second index derives from work on the "multiple floods in a wet season" project. Because of the standardization of the POT series to yield an average of four peaks per year, the mean recurrence interval between floods provides no useful distinguishing information, being about 91 days on all catchments. The standard deviation of flood recurrence interval is, however,

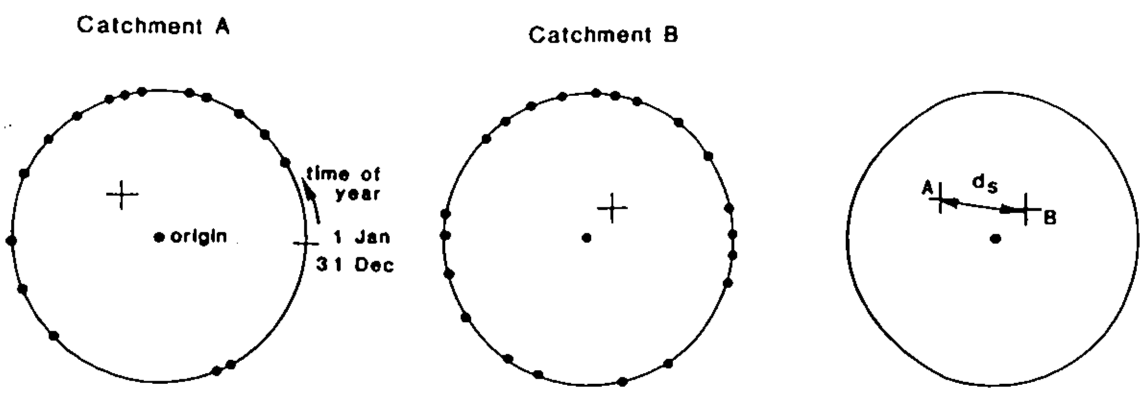


Fig. 1 A measure of seasonal dissimilarity in flood occurrence (catchments A and B)

informative; small values indicate catchments where flood occurrence is relatively regular, while large values correspond to those where floods occur irregularly (e.g. long gaps followed by a run of events). Because it is not generally possible to achieve a POT series with an average of *exactly* four peaks per year, and because of leap year effects, there are minor variations in the mean recurrence interval about the theoretical value of 91.3 days. Consequently, the coefficient of variation of recurrence intervals, CVRI, (i.e. standard deviation divided by mean) is adopted as the index of flood irregularity; if required, 1/CVRI can act as an index of regularity. As an example, Fig. 2 presents POT flood series for contrasting catchments: the "regular" Ystwyth (CVRI = 1.01) and the "irregular" Glen (CVRI = 2.07). A more detailed interpretation of this new index is presented by Bayliss (1994).

It is envisaged that the absolute difference in values of CVRI will provide a suitable measure of inter-catchment dissimilarity in flood regularity, i.e. $d_r = | CVRI_A - CVRI_B |$.

Correspondence with rainfall

The final index derives from work on "triggers" to flood and landslide occurrence, undertaken for DOE (Reed, 1992) and CEC (Naden et al., 1993) respectively. The idea is to index the degree of seasonal correspondence between occurrences of heavy rainfall and occurrences of floods. The seasonal distribution of POT flood peaks is compared to that of an equivalent series of POT 1-day rainfalls, i.e. concurrent and local. [The rainfall magnitudes are used to determine the ranking of 1-day maxima; thereafter only date information is used. With daily rainfall data alone, it is impractical to tailor independence rules closely to the response characteristics of a particular catchment. Thus the simple rule is adopted that rainfall peaks must be at least two days apart (i.e. a clear day apart) to be classed as independent. The effect of this is not thought to be serious, but could be neutralized by applying the same simple rule to the POT flood data, i.e. requiring adjacent peaks to be a clear day apart for them to be classed as independent. If used, this procedural modification will only be applied for the purpose of deriving the correspondence index.] One choice for the index is the inter-centroid distance defined by directional statistics, i.e. as per Fig. 1 but with catchment A denoting rainfalls and catchment B denoting floods. Another is the uniform-scores test significance level, referred to earlier.

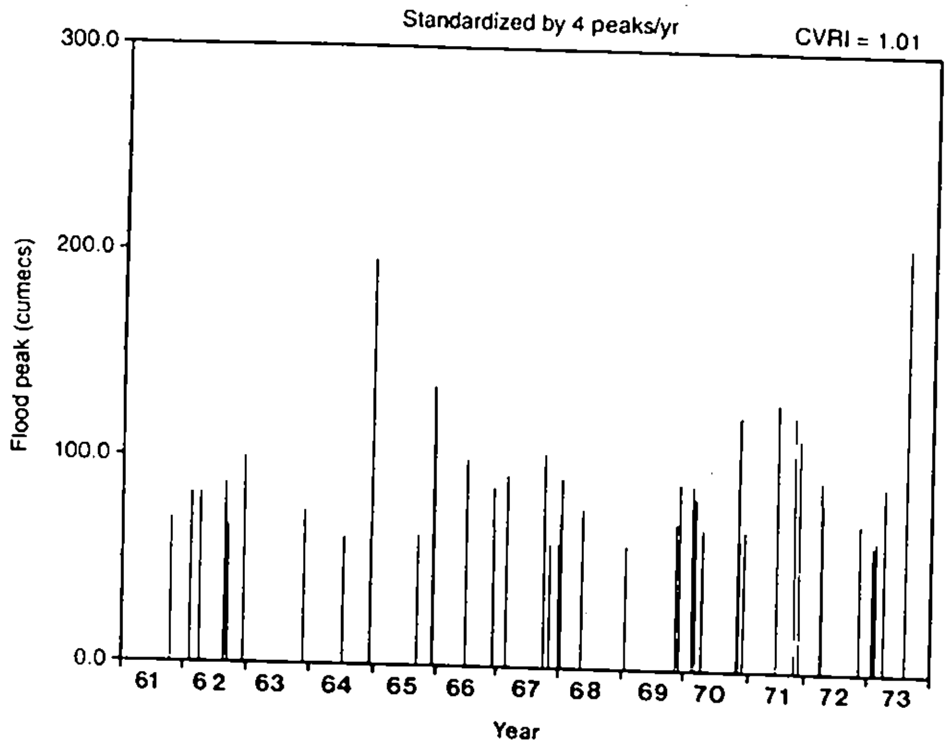
In the classification of catchments according to flood regime, the requirement is to index inter-catchment *differences* in the degree of correspondence between maximum rainfallls and flood peaks. A mechanism for doing this has been devised but is not readily illustrated.

Progress

Initial work is appraising indices of seasonality, regularity and "correspondence with rainfall" to ensure that each is well defined for the sample sizes typically available, and that each fulfils a useful role in distinguishing flood regime. It is apparent from Fig. 3 that there is little association between the index of regularity, CVRI, and "mean POT flood day" or "standard deviation about mean POT day". This suggests that the assessment of regularity is providing additional distinguishing information, thus vindicating part of the original thinking behind the multiple floods project.

FIG. 2

63001 Ystwyth @ Pont Llolwyn



31002 - Glen @ Kates Bridge

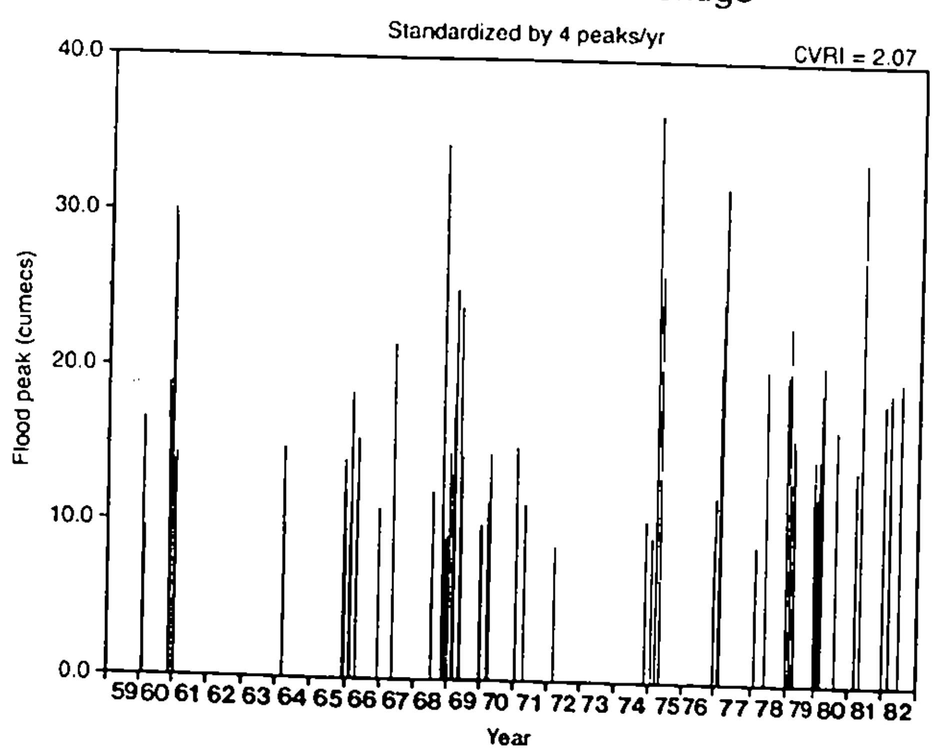
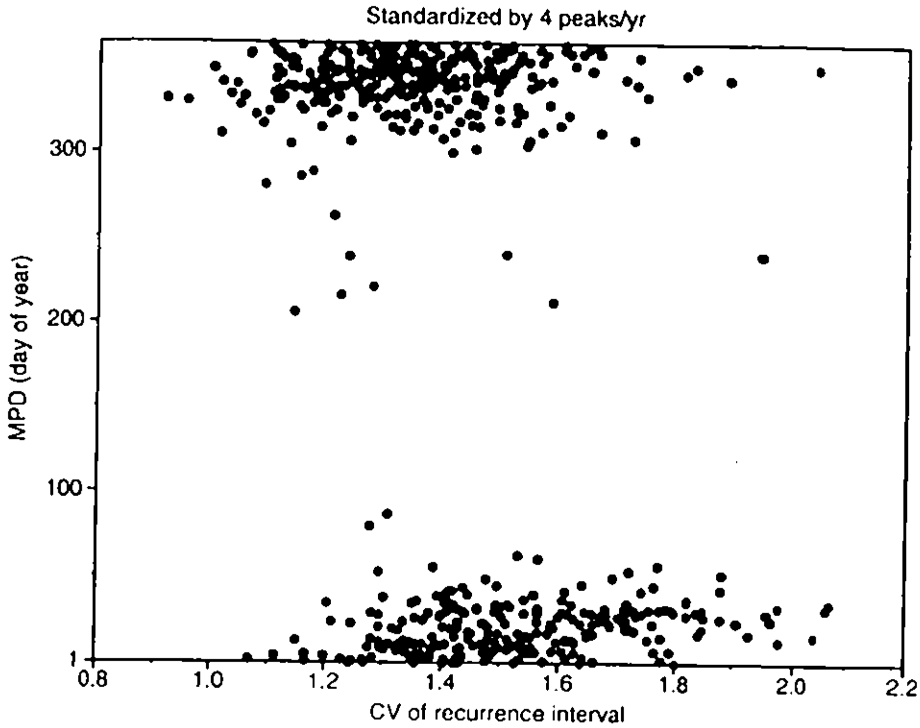
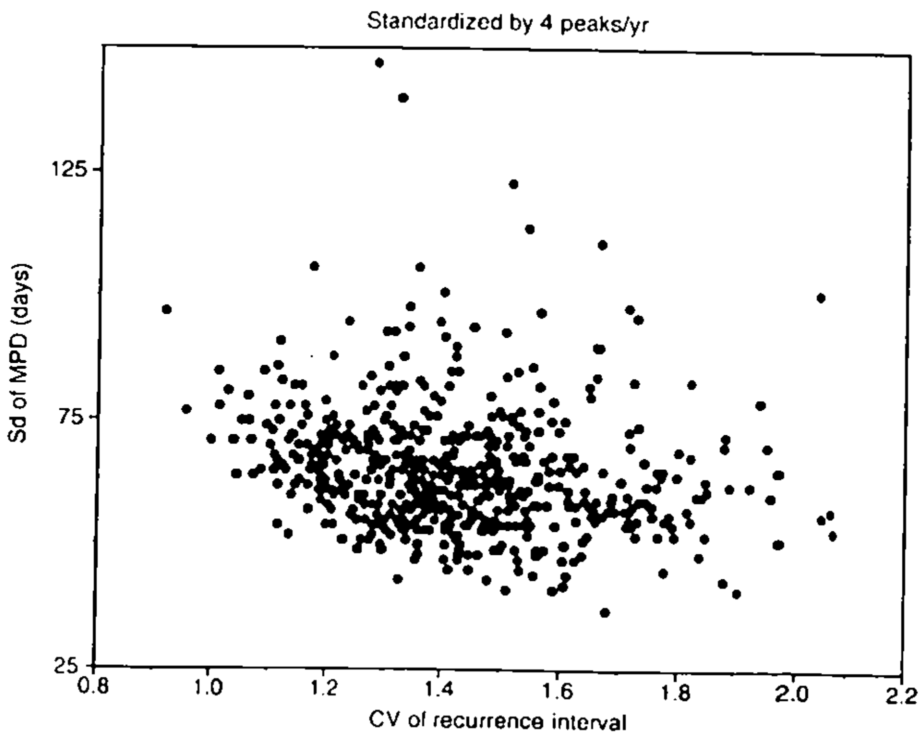


FIG. 3



Standardized by 4 peaks/yr
MPD (day of year)
300
200
100
1
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
CV of recurrence interval



Standardized by 4 peaks/yr
Sd of MPD (days)
125
75
25
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
CV of recurrence interval

Formation of regions

Catchments exhibiting a similar flood regime will be grouped together by cluster analysis, using a dissimilarity measure based on the above indices. To date, work has been geared to gaining familiarity with classification methods (e.g. Gordon, 1981). Some trials have been carried out using clustering algorithms available in the SAS computer package. Tests will be applied to explore the sensitivity of the classification to the choice of threshold exceedance rate, normally four peaks per year.

Interpretation and validation of regions

Regional groupings will be verified in two ways. Firstly, the distribution of annual maximum floods will be represented by L-moment ratios (Cunnane, 1989; Hosking, 1990), and the homogeneity of groupings assessed (e.g. by the methods of Hosking & Wallis, 1991). Secondly, the groupings will be inspected for physical conformity, to determine whether different catchment types have been inadvertently grouped together, and to identify distinguishing characteristics of each group. Particular attention will be paid to groups that are unsustainably small, to determine in what way their flood regime is significantly different and with which other groups they might be amalgamated for growth curve derivation or index flood formulation. It is expected that the treatment of urbanized catchments will require particular care.

Some iteration with the previous step will be necessary, the choices of dissimilarity measure and classification method being reviewed to overcome weaknesses in the initial regionalization, and to avoid prejudice in the groupings adopted.

Choice of index flood

A literature search will be undertaken for explicit studies of the choice of index flood. The default will be to continue to use the mean annual flood as the index variable in the generalization of flood frequency.

Derivation of flood growth curves

After standardizing by dividing by the index flood, annual maxima will be pooled and a flood growth curve fitted by the method of regionally weighted probability-weighted moments. Use of a type of modified station-year method (see Reed & Stewart, 1989) may be considered as a possible alternative.

Index flood formulation

A major task is derivation of formulae to allow estimation of the index flood from catchment characteristics. Much will depend on the outcome of the first phase of work on project FD0416, in which the feasibility of joint derivation, of an index flood equation and improved digital mapping of stream networks, is to be explored. This work will commence shortly.

Treatment of special catchment factors

All gauged catchments will be included in the classification of flood regime. However, it is recognized that special features - such as urbanization and flood plains - may not be sufficiently widespread in the datasets to allow their action to be adequately represented in index flood formulae derived by (e.g.) multiple regression analysis. It is likely that a hybrid approach will be used in which index flood formulae are derived for "normal" catchments, and explicit adjustment factors subsequently developed for one or more special factors.

Urbanization has a dramatic effect on the seasonality, regularity and "correspondence with rainfall" of flood occurrence, and it is believed that the regionalization approach outlined above will successfully distinguish these catchments. The identification and treatment of major flood plain effects will, however, be problematic. A key difficulty is that, by nature, flood plain effects are threshold-sensitive.

References

Bayliss A.C. (1994) On the variability of flood occurrence. Report to MAFF, Institute of Hydrology, Wallingford (in preparation).

Bayliss A.C. & Jones R.C. (1993) Peaks-over-threshold flood database: summary statistics and seasonality. Report No. 121, Institute of Hydrology, Wallingford, 61pp.

Cunnane C. (1989) Statistical distributions for flood frequency analysis. Operational Hydrology Rep. No. 33, WMO, Geneva, Publ. No. 718, 118pp.

Gordon A.D. (1981) Classification. Chapman & Hall, London, 193pp.

Hosking J.R.M. (1990) L-moments: analysis and estimation of distributions using linear combinations of order statistics. J. Roy. Statist. Soc., Series B, 52, 1, 105-124.

Hosking J.R.M. & Wallis J.R. (1991) Some statistics useful in regional frequency analysis. Research Report RC-17096, IBM, New York.

Mardia K.V. (1972) Statistics of directional data. Academic Press, London, 357pp.

Naden P.S. (1993) Methods and techniques in peaks-over-threshold flood analysis. Report to MAFF (draft, June 1993).

Naden P.S. & Bayliss A.C. (1993) Flood estimation: peak-over-threshold techniques. Proc. MAFF Conf. of River and Coastal Engineers, Loughborough, July 1993, 9.1.1-9.1.18 and 9.4.1-9.4.3.

Naden P.S., Calver A.F., Reed D.W. & Reynard N.S. (1993) Rainfall-induced landslides: a hydrological perspective. Report to CEC, EPOCH Contract No. 0029, Institute of Hydrology, Wallingford, 63pp.

Reed D.W. (1992) Triggers to severe floods: extreme rainfall and antecedent wetness. In: water resources and reservoir engineering (eds. Parr N.M., Charles J.A. & Walker S.), Thomas Telford Ltd., london, 219-228.

Reed D.W. and Stewart E.J. (1989) Focus on rainfall growth estimation. Proc. 2nd Nat. Hydrol. Symp., Sheffield, Sept. 1989: 3.57-3.65.