Design rainfalls for urban drainage: the Flood Estimation Handbook

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Abstract

The Flood Estimation Handbook (FEH) will provide a new set of design rainfall depths for all locations in the UK. This paper describes the significance of the FEH for urban drainage studies, summarising the FEH rainfall analysis and comparing it with the design rainfalls currently used for design storms in urban drainage, which are taken from the Flood Studies Report of 1975. Some implications for design flows in UK urban drainage studies are outlined.

Flood Estimation Handbook

Engineers and hydrologists will soon have a new set of procedures for estimating design floods and rainfall depths. The Flood Estimation Handbook (FEH) which has been developed by the Institute of Hydrology is due for publication in Spring 1999. The FEH comprises new methods of statistical flood and rainfall frequency estimation, as well as presenting a restatement of the Flood Studies Report rainfall-runoff method, and introducing a new set of digital catchment characteristics.

The five volumes of the FEH will be accompanied by a suite of software and digital maps of rainfall statistics and catchment characteristics based on drainage path geometry, soil type, urbanisation and the presence of lakes.

The FEH is designed primarily for river flood estimation, but it will have an impact on the design and analysis of urban drainage systems. Currently, all design events for sewer design and assessment based on the Wallingford Procedure (DOE/NWC, 1981) use the rainfall statistics of the Flood Studies Report (NERC, 1975). The FEH is intended to replace this, and Volume 2 presents a new procedure for rainfall frequency estimation.

FEH rainfall analysis

This section is a brief summary of the work involved in producing the FEH rainfall frequency results. The following section describes how the results will be presented to users.

Figure 1 summarises the analysis. The phrases on the left of the figure differentiate the underlying method, followed during the research, from the work done by a user. Following standard practice in frequency estimation, the analysis is divided into two stages:

(i) the estimation of an *index variable* at each site, which is used to *standardise* the data;

(ii) the derivation of *growth curves*, which relate rainfalls of different return periods to the index variable.

The key concepts of the FEH analysis are:

- it is based on annual maximum rainfall data, for rainfall durations between 1 hour and 8 days. Records from 6106 daily gauges and 375 rainfall recorders are used;
- the *index variable* is the median of annual maximum rainfalls at a site, RMED;
- rainfall *growth curves* are derived using the new FORGEX method;
- results for different durations are combined into a model linking rainfall depth, duration and frequency (a DDF model);
- the model is calibrated at each 1-km grid point covering the UK.

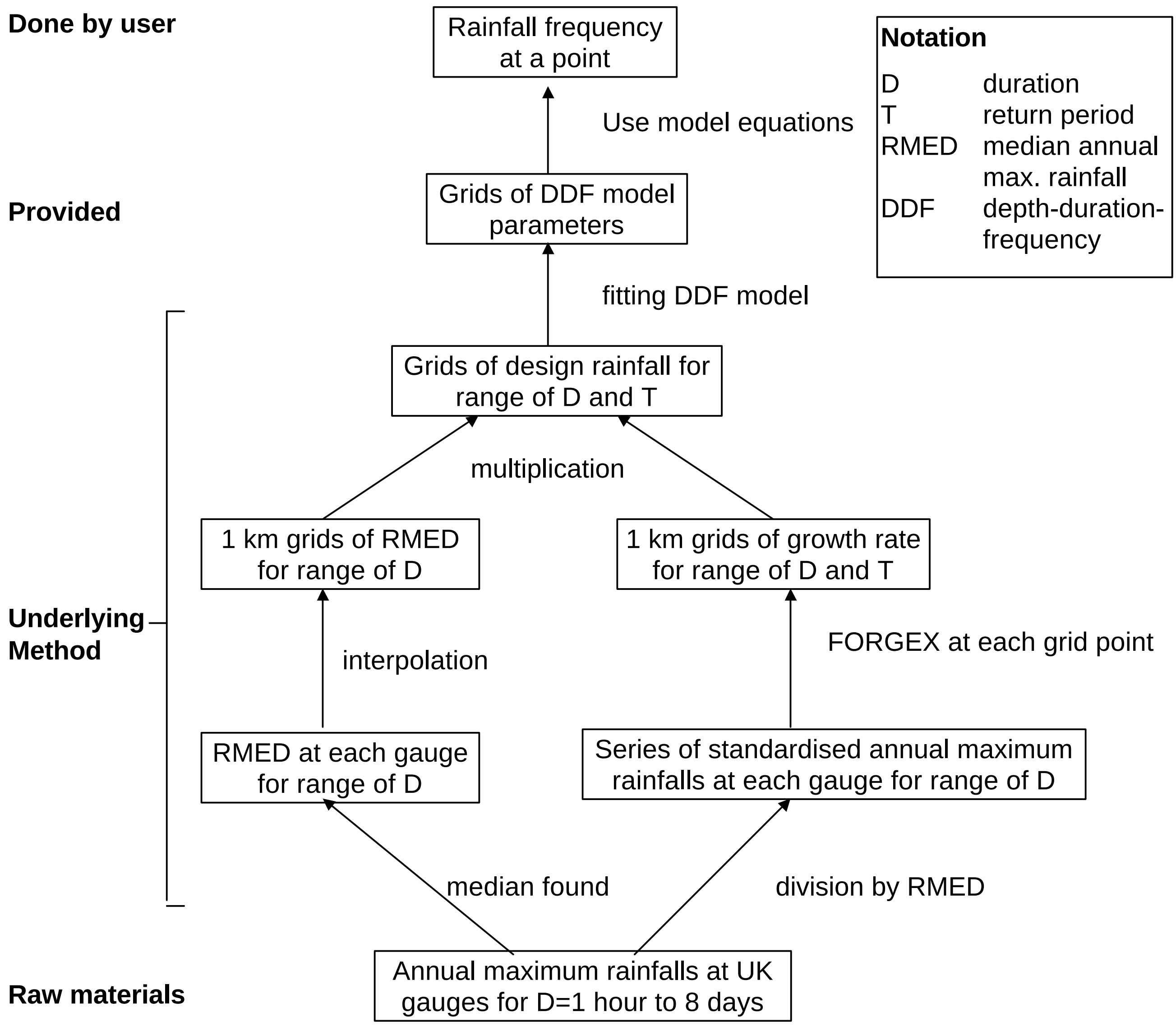

Figure 1 Summary of the FEH rainfall frequency analysis

The index variable, RMED, was interpolated between raingauge sites using topographic information, as described by Faulkner and Prudhomme (1998). The FORGEX method derives growth curves for any site from rainfall data over a group of gauges focused on the site of interest. The method uses local data where possible, expanding the size of the group for longer return periods. It accounts for spatial dependence in rainfall extremes, by forming “network maxima”, as described by Reed *et al.* (1999). Details of the analysis are also given in Volume 2 of the FEH.

Presentation of FEH rainfall results: the DDF model

Users of the FEH will be provided with the equations for the DDF model, which enable the estimation of a design rainfall depth of a given duration and return period for any location in the UK. Alternatively, the model can assess the rarity of an observed rainfall depth, accumulated over a given duration.

Figure 2 is an example of a DDF diagram for central Blackpool. Rainfall is plotted on a logarithmic scale against duration, with a line for each of several return periods. The lines are defined by six parameters, which control the slope and position of the lines, and their variation with return period. The increase of rainfall with duration is represented by three concatenated line segments, with breaks in slope at durations of 12 and 48 hours.

The model is fitted to design rainfalls aggregated over various durations from 1 hour to 8 days, and for various return periods up to 1000 years. Some extrapolation to shorter durations, as on Figure 2, is reasonable, but such answers should be treated with less confidence. This range of durations is suitable for river flood estimation, but for urban drainage design, rainfall durations as short as 15 minutes are important. It is proposed to extend the FEH rainfall frequency analysis to shorter durations, so that the results can be incorporated into urban drainage manuals and software.

The DDF model as described is designed to provide rainfall estimates for return periods longer than 1 year. For shorter return periods, often required in analysing urban pollution events, the annual maximum scale is inappropriate, as it only allows for one extreme rainfall event per year, and the peak-over-threshold (POT) scale must be used instead. Extrapolated rainfall frequency estimates can be provided for a POT return period, T_{POT}, by converting it into an annual maximum return period, T_{AM}, using Langbein's formula (IH, 1977):

$$\frac{1}{T_{AM}} = 1 - \exp\left(1 - \frac{1}{T_{POT}}\right).$$

This formula ensures that $T_{AM}>1$. It is possible that an extension of the FEH analysis could include abstracting POT rainfall data, to strengthen the basis of rainfall estimates for urban pollution management. However, for short durations, long records of tabulated annual maximum rainfall data are more plentiful than continuous computerised records from which POT data could be abstracted.

The FEH will be accompanied by a CD-ROM which includes 1-km grids over the UK of the six parameters of the DDF model. Software for design rainfall calculations will be provided. Additionally, catchment-average parameters will be available for every topographic catchment in the UK which drains an area of 0.5 km^2 or more. For smaller catchments, the point parameters will suffice. These enable the estimation of design rainfall for a typical point in a catchment. The catchment-average parameters are derived using the Institute of Hydrology digital terrain model.

Comparison of FEH and FSR rainfall results

The Wallingford Procedure embodies the rainfall depths and areal reduction factors (ARFs) of the Flood Studies Report (FSR), although it allows for alternatives to the FSR temporal profiles. The Flood Estimation Handbook research programme has provided a new procedure for estimating rainfall frequency, but it has not included work on ARFs or rainfall profiles.

The FEH rainfall frequency analysis can be compared with the FSR as follows:

- The FEH is based on more data (7400 station-years for 1-hour rainfall, compared with 2300 for the FSR);
- FEH growth curves are derived with more advanced methods which focus on the site of interest, and account for spatial dependence in extreme rainfall;
- FEH results are more detailed, following local data and topography, whereas FSR results have been criticised for being over-general, masking important local and regional variations (Bootman and Willis, 1981; Dales and Reed, 1989);

- FEH results are provided in digital format, with automatic calculation of design rainfalls;
- FEH short-duration design rainfalls are higher in most areas at long return periods, but similar or lower in most areas for shorter return periods.

Over most of lowland Britain, FEH design rainfalls, for a duration of 1 hour and a return period of 5 years, are 10-20% smaller than the corresponding FSR results. The difference exceeds 30% in parts of eastern Scotland. However, the new FEH results are greater than the FSR results in parts of south-east and east England, over 20% greater in Berkshire, and also higher in upland areas.

For longer return periods, the picture is different. The FEH growth factors are significantly higher in most locations than the FSR ones, and so FEH design rainfalls, for a duration of 1 hour and a return period of 100 years, are 10-30% greater in most locations. The difference increases to over 40% in parts of south-east England (Berkshire and Essex), Cambridgeshire, Lincolnshire, and most upland areas. There are a few areas where the new results are slightly smaller at long return periods: eastern Scotland and parts of the Welsh borders and Cumbria.

Implications for urban drainage studies

Although the FEH rainfall analysis has still to be extended to sub-hourly durations, the results for a rainfall duration of 1 hour suggest that short-duration design rainfalls will change for many areas of the country. In most areas, the change acts in the direction of decreasing design rainfalls for short return periods and increasing them for long return periods. However, there are locations where design rainfall for all return periods increase, and these include urbanised areas such as the western Home Counties, parts of the East Midlands and some of the towns of the Lancashire Pennines.

If other factors remain constant, design flows for urban drainage will increase in these areas. They are likely to decrease for urban areas in the West Midlands and north-east England.

For drainage schemes which must meet higher standards of service, the required design rainfalls for longer return periods will increase in most areas, and by a greater amount in the urban areas of Berkshire, Essex, the East Midlands and Lancashire.

Further research needs

To allow urban drainage studies to benefit from this research, the FEH rainfall analysis should be extended to shorter durations, and the results incorporated into HydroWorks and other standard software. In addition, the results could be used to modify the stochastic rainfall generator which was developed by Cowpertwait *et al*. (1991) and is used in STORMPAC to generate synthetic rainfall data for urban pollution management. This would allow better consistency between methods based on the rainfall generator and design storm methods, as well as incorporating into the rainfall generator rainfall variations due to the surrounding topography.

Acknowledgements

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References

Bootman, A.P. and Willis, A. (1981) Discussion of Folland *et al.* (1981), Proc. *Flood Studies Report - five years on* (1980), Thomas Telford, pp. 62-63.

Cowpertwait, P.S.P, Metcalfe, A.V., O'Connell, P.E., Mawdsley, J.A. and Threlfall, J.L.

(1991) Stochastic generation of rainfall time series. Foundation for Water Research, report no. FR0217.

Dales, M.Y. and Reed, D.W. (1989) Regional flood and storm hazard assessment. *Report No. 102*, Institute of Hydrology, Wallingford.

Department of Environment / National Water Council (1981) Design and analysis of urban storm drainage - The Wallingford Procedure. STC Report No. 28, NWC.

Faulkner, D.S. and Prudhomme, C. (1998) Mapping an index of extreme rainfall across the UK. *Hydrol. and Earth System Sci.* **2**, 183-194.

Institute of Hydrology (1977) The estimation of low return period floods. *Flood Studies Supplementary Report No. 2*, IH, Wallingford.

Natural Environment Research Council (1975) Flood Studies Report. 5 volumes. NERC, London.

Reed, D.W., Faulkner, D.S. and Stewart, E.J. (1999) The FORGEX method of rainfall growth estimation II: Description. *Hydrol. and Earth System Sci.,* accepted.

DISCUSSION

Question John Blanksby Sheffield Hallam University

The UK profiles seem to give an enormous over prediction of intensity in short duration storms. Could you comment on other european models.

Answer

I agree the design profiles do give very high intensity in short duration storms. The shorter the duration the higher the peak gets. Profiles were not included in the current research because research is moving much more towards continuous simulation. I am not able to comment on other European models.

Question David Fortune Wallingford Software

Will the next version of the manual be available on CD?

Answer

Not the text but the results and methods will be.

Question John Turner Leeds City Council

Are values for seasonal variations in rainfall that were available in the flood studies report still applicable.

Answer

The new study has not looked at seasonal effects., although it does include a review of other studies on seasonality.

Question Ian Noble Montgomery Watson

Looking up and down the country at the variation from the established practice (40% in SE England) and bearing in mind that a 10% increase in depth doubles the return period. Have you looked at the implication on existing flood frequency prediction?

Answer

It is significant and is confirmed what is observed say in overflow spills.

Question George Heywood Tynemarch

There seems to be an urgent need to extend this to shorter duration storms, is the data available?

Answer

Yes the data is available and hopefully the work could be done quickly , but it all depends on funding.