Institute of Hydrology

Natural Environment Research Council


Natural
Environment
Research
Council

PROJECT FD0415

CONSOLIDATION OF FSR RAINFALL-RUNOFF METHOD

PROGRESS REPORT 1994/95

H. A. HOUGHTON-CARR

Institute of Hydrology
Maclean Building
Crowmarsh Gifford
Wallingford
Oxon
OX10 8BB

Tel: 01 491 838800
Fax: 01 491 692424
Telex: 849365 HYDROL G

March 1995

Executive summary

A comprehensive technical rewrite of the FSR rainfall-runoff method, scheduled for publication in Spring 1997, will form volume 4 of the Flood Estimation Handbook. In the two years prior to the rewrite, it is necessary to sustain the method and to disseminate results of ongoing research to the user community.

The UK Flood Event Archive, the database behind the FSR rainfall-runoff method, contains details of 4537 flood events from 312 catchments throughout the UK. Data collection and analysis are no longer part of the programme of strategic research funded by MAFF, and the archive is now maintained as part of the National River Flow Archive at the Institute of Hydrology. In the past year, data from the archive have been provided for 12 specific requests from users of the FSR rainfall-runoff method.

The small catchment flood estimation project examined the response to rainfall of small catchments. Results showed that the existing FSSR16 unit hydrograph time-to-peak estimation equation performed reasonably well on small rural catchments, but tended to overestimate response times for small part-urban catchments. A new equation was derived for estimation of the unit hydrograph time-to-peak which can be applied to catchments of any size. The project is described in Institute of Hydrology Report 124 (Marshall & Bayliss, 1994).

The Hydrology Of Soil Types (HOST) project provided a replacement for the 5-class Winter Rainfall Acceptance Potential (WRAP) classification of soils, used to estimate standard percentage runoff. The new scheme has 29 classes, based on 11 response models, and is generally a more useful, accurate and meaningful classification. Applications of the classification have been developed which lead to improved estimates of standard percentage runoff, and also of parameters used in low flow estimation procedures. The project is described in a report to MAFF (Boorman *et al.*, 1994), and in Institute of Hydrology Report 126 (Boorman *et al.*, 1995).

Research related to the FSR rainfall-runoff method, which is being carried out by other organisations, is also reviewed.

Contents

1 Introduction

The FSR rainfall-runoff method provides one of the principal methods of estimating flood magnitudes of given probability or frequency of occurrence used in the UK. However, despite, or rather because of, a multitude of related publications, users find application of the method somewhat difficult. Up-to-date dedicated software e.g. Micro-FSR (Institute of Hydrology, 1991) facilitates application, but at the same time fails to cover the theory behind the methodology, which is essential for a full understanding of results.

The principal objective of this project is to prepare a comprehensive technical rewrite of the FSR rainfall-runoff method for publication in Spring 1997. This rewrite is planned to form volume 4 of the Flood Estimation Handbook (Reed, 1994), and will include all relevant aspects of the basic methodology, supplementary research and recommendations, and specialist guidance issued to users of the method. This information exists, but is presently widely scattered in supplementary reports, conference papers, training notes and case studies. The technical content of the rewrite may be influenced by suggestions made by the Flood Estimation Handbook Advisory Group. The secondary objectives of the project, in the two years prior to the rewrite, are to sustain the method and to disseminate results of ongoing research to the user community.

This first progress report summarises the achievements of the project in the past financial year. The report is divided into seven sections, plus references. Section 2 considers the background to the project in more detail, and is followed by three sections describing related work within the Institute of Hydrology: the first is devoted to the UK Flood Event Archive, the database behind the FSR rainfall-runoff method, and contains details of the number of events held on the archive; the others consider the final outputs from two recently completed research projects which have resulted in further modifications to the FSR rainfall-runoff method. These are followed by a review of work by other organisations, which may affect the FSR rainfall-runoff method. Section 7 summarises the progress of the project, and outlines the proposed work in the next financial year.

2 Background

The Flood Studies Report (FSR), published by the Natural Environment Research Council in 1975, presents a number of complementary techniques for use in the UK for estimating flood magnitudes of given probability or frequency of occurrence i.e. return period. The simplest approach is the statistical method, whereby an index flood is scaled up to the required return period using a regional growth curve. However, this method estimates only peak flow, which may suffice for the design of culverts and bridges, but which is inadequate for the design of flood storage or reservoir spillways where the entire flow hydrograph is required for routing. In these latter circumstances, use of the more complex rainfall-runoff method is generally required.

The FSR rainfall-runoff method presents the 3-parameter unit hydrograph and losses model of the catchment, with a design rainfall input and a design flood output. The three model parameters are:

- the unit hydrograph time-to-peak, which determines how quickly the catchment responds to the effective rainfall input,

- the percentage runoff, which is the ratio of effective to total rainfall i.e. the proportion of the total rainfall input which becomes response runoff in the river,

- the baseflow, or average non-separated flow, which represents the flow in the river prior to the event.

The three model parameters are related, via multiple regression equations, to physical and climatic characteristics of the catchment, enabling flood estimates to be made at ungauged sites, though such estimates might be improved using observed data from or local to the site of interest. The multiple regression equations were calculated using a database of model parameter values, derived from observed runoff and rainfall data, and physical and climatic characteristics. This database is known as the UK Flood Event Archive.

Since 1975, there have been many developments in flood hydrology, and although the basic philosophy of flood estimation using FSR techniques is unchanged, there have been notable enhancements which are directly relevant to use of the methods. Between 1977 and 1988, the Institute of Hydrology published a series of 18 Flood Studies Supplementary Reports (FSSRs). For the FSR rainfall-runoff method, the most important report is FSSR16 (1985) which presented revised model parameter estimation equations, though FSSR5 (1979) which considered flood estimation on catchments subject to urbanisation, and FSSR13 (1983) which rationalised suggestions for the use of local data in flood estimation, are also of consequence.

In 1989, version 1 of a microcomputer-based implementation of the methods contained in the FSR and FSSRs, known as Micro-FSR, was released by the Institute of Hydrology. Version 2 of the software (Institute of Hydrology, 1991), released in 1992, additionally includes the recommendations from the ICE guide to floods and reservoir safety (Institution of Civil Engineers, 1989) and the CIRIA/Butterworths update of TN100 for the design of flood storage reservoirs (Hall, Hockin & Ellis, 1993).

The FSSR series is now closed and specific recommendations arising from current research within the Institute of Hydrology are published in the Institute of Hydrology Report series, and in relevant journals and conference proceedings. In the current financial year, the estimation equation for the unit hydrograph time-to-peak was revised still further (Institute of Hydrology Report 124; Marshall & Bayliss, 1994), as has part of the estimation equation for the percentage runoff (Institute of Hydrology Report 126; Boorman *et al.*, 1995). Other research related to the FSR rainfall-runoff method is carried out and published by other organisations, most notably the Met. Office who, together with Salford University, have completed a review of Probable Maximum Precipitations and Probable Maximum Floods (Austin *et al.*, 1995). These and other advances are considered in more detail in sections 4 to 6. The coming financial year looks forward to publication of the third edition of the ICE guide, and release of Micro-FSR version 3.

Volume 4 of the Flood Estimation Handbook aims to address the problems caused to users by this bewildering assortment of information and methodologies, by preparing a comprehensive technical rewrite of the method. All information about the method will be brought together, providing greater clarity and ease of use, and doing away with the need for users to be aware of, and refer to, many documents. The technical rewrite is scheduled for publication in Spring 1997.

3 UK Flood Event Archive

The UK Flood Event Archive is the database which supports the FSR rainfall-runoff method, and now forms part of the National River Flow Archive (NRFA) at the Institute of Hydrology. The UK Flood Event Archive currently contains 4537 events from 312 catchments throughout the UK. A flood event is essentially defined as a rise and subsequent fall in the river level, together with the causative catchment rainfall. The majority of events are fairly simple short duration rainfall-runoff events. The collection and analysis of flood event data are no longer part of the programme of strategic research funded by MAFF but, in the past year, analyses have been completed on 39 events from the Frome at Ebley Mill catchment in Stroud as part of a commissioned research project for the National Rivers Authority.

Once entered on the archive, events may be used for many different projects. Results from analyses are also stored on the archive and it is easy to access these data in any number of ways and select them according to many different criteria. Members of the NRFA maintain the UK Flood Event Archive and service specific requests for data from users of the FSR rainfall-runoff method. In the past year data have been provided for 12 such requests, mainly from consultants and also a few in-house queries.

4 Flood estimation for small catchments

Accurate estimation of the FSR rainfall-runoff model parameters on small lowland catchments is particularly difficult. Most of the small catchments with good quality data in the archive are rural, steep and impermeable in high rainfall regions, whereas these lowland catchments tend to be part-urban on permeable soils in low rainfall regions. The small catchment flood estimation project carried out by the Institute of Hydrology aimed to examine the response to rainfall of small catchments, and to derive improved model parameter estimation equations where possible.

The study region was central southern England, and 15 small catchments, chosen to compensate for the deficiencies in the original data set, were instrumented. Data were collected and analysed from at least five flood events for each site. Additional flood event data were provided from 12 essentially rural small catchments in England and Wales (ADAS Soil and Water Research Centre), and from 46 small catchments held on the UK Flood Event Archive. Results showed that the existing FSSR16 unit hydrograph time-to-peak estimation equation performed reasonably well on small rural catchments, but tended to overestimate response times for small part-urban catchments. A new equation was derived for estimation of the unit hydrograph time-to-peak which can be applied to catchments of any size. New equations were also derived for the relationship between time-to-peak and catchment lag on small catchments, and for estimation of the mean annual flood on small catchments.

The project was completed in 1994. The project is described in Institute of Hydrology Report 124 (Marshall & Bayliss, 1994), and the results and new equations are being disseminated to users.

5 Hydrology Of Soil Types: a hydrologically-based classification of the soils of the United Kingdom

The percentage runoff parameter of the unit hydrograph and losses model is composed of standard and dynamic parts; the former represents the normal capacity of the catchment to generate runoff, and the latter represents the variation in runoff dependent on the wetness of the catchment prior to the storm, and on the storm magnitude. There may also be an urban adjustment. In FSSR16, the standard percentage runoff is estimated from the 5-class Winter Rainfall Acceptance Potential (WRAP) map, developed for the FSR. The percentage runoff is the most important parameter of the unit hydrograph and losses model, yet the most poorly estimated. The Hydrology Of Soil Types (HOST) project aimed to replace the WRAP classification with a more useful, accurate and meaningful classification. The HOST project was a collaborative venture between the Institute of Hydrology, Soil Survey and Land Research Centre, Macaulay Land Use Research Institute and Department of Agriculture Northern Ireland.

The new hydrologically-based classification of soils in the UK uses existing data sets that describe both the soils and their substrate, and the hydrological response of catchments, and is based on conceptual models of the processes that occur in soils and substrate. The resulting scheme has 29 classes, based on 11 response models. Soils are assigned to classes on the basis of their physical properties and with reference to the hydrogeology of the substrate. Applications of the classification have been developed which lead to improved estimates of parameters required in flood and low flow estimation procedures, in particular the standard percentage runoff.

The project was completed in 1994. A product of the HOST project is a computer data set, on a 1 km grid, that covers the whole of the UK, though access to the classification is also provided by the 1:250,000 soil maps produced during the 1980s. The project is described in a report to MAFF (Boorman *et al.*, 1994), and in Institute of Hydrology Report 126 (Boorman *et al.*, 1995), and the results and new equations are being disseminated to users.

6 Review of related work by other organisations

6.1 PROBABLE MAXIMUM PRECIPITATION AND PROBABLE MAXIMUM FLOOD RESEARCH (MET. OFFICE AND SALFORD UNIVERSITY)

Design floods for major reservoirs in the UK are often based on the Probable Maximum Flood (PMF) arising from the Probable Maximum Precipitation (PMP), with critical storm duration for the catchment being considered. The FSR rainfall-runoff method provides the methods of estimating PMP and PMF which are the currently accepted standards. However, the analysis upon which the FSR approach is based was carried out using data from raingauges to estimate storm rainfall. Since the late 1970s data from weather radars have become increasingly available. DOE commissioned the Met. Office and Salford University to update the estimation of PMP, and to examine the impact on PMF by utilising radar-derived rainfall data and the current rainfall archive.

The work, which involved using radar data for convective storms used with numerical models of storm systems and reservoir catchment models to estimate PMPs and PMFs for three test catchments, was completed in 1994 (Austin *et al.*, 1995). The results showed that PMP values derived for three different catchment areas are remarkably similar to the FSR values for storm durations less than 11 hours. However, increased PMP estimates relative to the FSR values were found for durations in excess of 12 hours, which in turn produced PMF peaks slightly smaller than those from the FSR. The report recommends further work to understand these differences. In addition, the methods need to be generalised for application country-wide before they can be incorporated in the FSR rainfall-runoff method.

6.2 SNOWMELT RESEARCH (MET. OFFICE)

The melting of lying snow has the potential to produce large amounts of runoff especially when accompanied by rainfall, and it is on record that several major flood events in the UK had a snowmelt component to them e.g. the Tay floods of 1990 and 1993. The FSR discusses the contribution of snowmelt to floods, and presents a country-wide estimate of the 24-hour melt rate of 100-year return period of 42 mm which could continue for two to three days. This value is used in the FSR rainfall-runoff method when deriving seasonal PMPs. However, doubts concerning this extreme melt rate have been expressed, most notably by Archer (1981) who suggested the FSR value underestimated melting in northern England and Scotland. Further to a review by Reed & Field (1992), DOE commissioned the Met. Office to estimate rare snowmelt rates in the UK.

The work, which involved calculating hourly snowmelt rates and annual maximum snowmelt totals for various durations at 25 stations which were further analysed to give snowmelts for specific durations and return periods, was completed in 1994 (Hough & Hollis, 1995). The 24-hour melt of 5-year return period at a site was related to altitude alone, to altitude and northing, to temperature alone, and to temperature and windspeed, in separate multiple regression equations. This methodology enables calculation of the 5-year snowmelt at any point in the UK. However, this snowmelt rate needs to be scaled up to the 100-year return period before it can be incorporated in the FSR rainfall-runoff method.

6.3 LINKAGE OF FLOOD FREQUENCY CURVE WITH PROBABLE MAXIMUM FLOOD ESTIMATE (DR. M. J. LOWING)

The FSR makes recommendations as to when each of the approaches it presents for deriving a flood frequency curve should be favoured, but treats methods of combining the separate curves less well. Similarly, although the question of associating a return period with the PMF has often been debated, there is no standard technique for plotting the PMF at a particular point on the same plot as the flood frequency curve. DOE commissioned Dr. M. J. Lowing, via Salford University, to develop a systematic way of producing a composite flood frequency curve defined up to the level of the PMF.

The work was completed in 1994 (Lowing, 1994). The results give an interpolation technique which will work to generate a curve between any segment of a growth curve i.e. a flood frequency curve, and any upper limit constraint i.e. a PMF. In addition, a method of weighted averages is formulated to allow the estimation of flood hydrographs corresponding to intermediate points on the flood frequency curve. The resulting methodology is generally applicable, and can be incorporated in the FSR rainfall-runoff method.

7 Summary

The principal objective of this project is to prepare a comprehensive technical rewrite of the FSR rainfall-runoff method for publication in Spring 1997. The FSR rainfall-runoff method provides one of the principal methods of estimating flood magnitudes of given return period used in the UK. This rewrite will form volume 4 of the Flood Estimation Handbook, and will include all relevant aspects of the basic methodology, supplementary research and recommendations, and specialist guidance issued to users of the method.

The secondary objectives of the project, in the two years prior to the rewrite, are to sustain the method and to disseminate results of ongoing research to the user community. This entails maintenance of the UK Flood Event Archive, the database behind the FSR rainfall-runoff method, and servicing of specific requests for flood event data from users of the method. The archive contains details of 4537 flood events from 312 catchments throughout the UK and, in the past year, 12 data requests have been fulfilled. Results from two recently completed research projects are being disseminated to users. Firstly, the small catchment flood estimation project developed an improved estimation equation for unit hydrograph time-to-peak (Institute of Hydrology Report 124; Marshall & Bayliss, 1994), replacing that of FSSR16. Secondly, the Hydrology Of Soil Types (HOST) project provided a new soil classification from which improved estimates of standard percentage runoff can be derived (Institute of Hydrology Report 126; Boorman *et al.*, 1995).

Related work by other organisations which may affect the FSR rainfall-runoff method has been reviewed. Work by the Met. Office and Salford University has updated the methodology for estimating PMPs and PMFs, but the methods need to be generalised for application country-wide before they can be incorporated in the FSR rainfall-runoff method. Similarly other work by the Met. Office has provided a new way of estimating snowmelt rates, but these rates need to be scaled up from 5-year return period to 100-year return period before they can be incorporated in the FSR rainfall-runoff method. Dr. M. J. Lowing has developed a generally applicable and systematic way of producing a composite flood frequency curve defined up to the level of the PMF, which can be incorporated in the FSR rainfall-runoff method.

The objectives for the next year will be to continue sustenance of the method and maintenance of the archive. Further developments in related research, both at the Institute of Hydrology and at other organisations, will continue to be reviewed, in particular the publication of the third edition of the ICE guide to floods and reservoir safety expected early in 1996. A draft contents list for volume 4 of the Flood Estimation Handbook will be drawn up.

8 References

Archer, D.R. 1981. Severe snowmelt runoff in north-east England and its implications. *Proc. Instn. Civ. Engrs, Part 2*, 71, 1047-1060.

Austin, B.N., Cluckie, I.D., Collier, C.G. & Hardaker, P.J. 1995. *Radar-based estimation of Probable Maximum Precipitation and Flood.* METSTAR Consultants / Salford University report to DOE.

Boorman, D.B., Gannon, B., Gustard, A., Hollis, J.M. & Lilly, A. 1994. Hydrological aspects of the HOST classification of soils. *Institute of Hydrology Report to MAFF.*

Boorman, D.B., Hollis, J.M. & Lilly, A. 1995. Hydrology Of Soil Types: a hydrologically-based classification of the soils of the United Kingdom. *Institute of Hydrology Report 126.*

Hall, M.J., Hockin, D.L. & Ellis, J.B. 1993. *The Design of Flood Storage Reservoirs.* Construction Industry Research and Information Association (CIRIA) RP393. CIRIA / Butterworths, London.

Hough, M.N. & Hollis, D. 1995. *Rare snowmelt estimation in the United Kingdom.* METSTAR Consultants report to DOE.

Institute of Hydrology. 1979. Design flood estimation in catchments subject to urbanisation. *Flood Studies Supplementary Report No. 5.*

Institute of Hydrology. 1983. Some suggestions for the use of local data in flood estimation. *Flood Studies Supplementary Report No. 13.*

Institute of Hydrology. 1985. The FSR rainfall-runoff model parameter estimation equations updated. *Flood Studies Supplementary Report No. 16.*

Institute of Hydrology (IH). 1991. *Micro-FSR v2.0 Operation Manual.* IH, Wallingford.

Institution of Civil Engineers (ICE). 1989. *Floods and Reservoir Safety: an engineering guide.* ICE, London.

Lowing, M.J. 1994. *Linkage of flood frequency curve with maximum flood estimate.* Report to DOE.

Marshall, D.C.W. & Bayliss, A.C. 1994. Flood estimation for small catchments. *Institute of Hydrology Report.124.*

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

Reed, D.W. 1994. Plans for the Flood Estimation Handbook. *Proc. MAFF Conference of River and Coastal Engineers, July 1994, Loughborough, UK,* 8.3.1 - 8.3.8.

Reed, D.W. & Field, E.K. 1992. Reservoir flood estimation: another look. *Institute of Hydrology Report 114.*