British Hydrological Society

BHS National Meeting

UK flood hydrology 40 years after the Flood Studies Report

Tuesday 22 November 2016

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ABSTRACTS

How innovative were the Flood Studies?

Max Beran (ex Institute of Hydrology Floods Team member)

40 years ago design flood estimation was dominated by the Lloyd Davies, Bilham and Bransby Williams formulae, not a high bar to surpass technically. However, flood estimation procedures more solidly founded on data and evidence were being applied in some consulting offices, academic institutions and the more alert water management agencies. So I raise the bar in answering the question in the title to identify the more "scientific" novelties found in the Flood Studies Report (FSR). See Chapter 3.2 of Rodda and Robinson (2015) for expanded material on the following summaries.

Flood frequency analysis of peak discharge: well established as a research tool but less so in engineering practice where basic issues such as data type – peak over threshold or annual maxima, distribution choice, and parameter fitting were discussed as matters for subjective judgment, and error of estimate of the T-year flood hardly at all. The FSR laid out statistical fundamentals and derived sampling distributions of quantiles and order statistics for candidate distributions and parameter estimators. These led to pooled region Q:T curves, a practical expression for error of estimate, and unbiased plotting positions to allow historic floods to extend the Q:T relationship to high return periods.

Other statistical novelties pioneered in the FSR for flood frequency analysis were (a) data extension using neighbouring flood and rain data to reduce the variance of the mean annual flood estimate from short records; (b) statistics of volume floods as the ratio of D-hour maxima to the instantaneous peak; and (c) modelling flood peaks as a stochastic process within a continuous hydrograph via the shot noise model.

Flood hydrograph prediction in the FSR took the form of a rainfall losses model convoluted with a unit hydrograph, again well known in the literature but little used in UK. Digital data acquisition techniques were developed at IH and the Met Office to yield 1500 high flow events from 138 catchments. Academic effort was concentrated on temporal aspects – i.e. unit hydrograph shape – treating the effective rainfall hyetograph as given. This was reversed in the FSR where it was apparent from the data that storm loss – raw minus effective rainfall – was much the larger source of estimation error. Variations from storm to storm on the same catchment required a new catchment wetness index combining depth of storm rainfall and pre-storm soil moisture deficit as well as antecedent precipitation, the classical measure. This led to the concept of a standard percentage runoff (SPR), which was calculated for each study catchment. SPR's variation from catchment to catchment was found to be best predicted from a specially developed soil winter rainfall acceptance potential mapped nationally by the UK Soil Survey. As for the unit hydrograph, sufficient reproduction of the output hydrograph from the effective hyetograph required only a simple near-triangular shape with dimensions wholly dependent on time to peak Tp. An equally simple relationship was found between lag and Tp providing a practical route for hydrograph prediction from perhaps a single season and a simply instrumented basin.

T-year flood peak from rainfall runoff method: classically what was computed by a rainfall-runoff model amounted to a flood following a T-year rainstorm, hence a peak discharge of indeterminate return period. A key innovation of the FSR was the identification of a set of inputs to the losses unit hydrograph model that homed in on the T-year flood peak. This was achieved by a two-stage process involving firstly a simulation of the probability density function (pdf) of model output flood peaks by sampling across the pdf's of model inputs. The second stage was to inspect pathways through the simulation to identify a stable set of model inputs that would on average provide a result close to that achieved from the full pdf.

Application to ungauged catchments: of both the flood frequency and rainfall runoff approach was based on regression on catchment physiographic characteristics of relevant indices such as mean annual flood, time to peak and standard percentage runoff. Both the statistical analysis and the catchment characterisation involved novel techniques. As regards the latter, the FSR set encompassed not just area and rainfall as was customary, but topography, stream network and land use plus the soil variable already referred to. A new climate variable was also created by combining soil moisture deficit and a short term rainfall statistic – both from Met Office work. All of course were map-based variables in those pre-digital days though some early applications of terrain analysis were trialled through links with NERC's Experimental Cartography Unit. Principal Components Analysis and Ridge Regression were employed to select among alternative indices and create subsets tailored to particular catchments and flood indices. ANOVA enabled the objective creation of regions that differed from each other by regression multiplier or by regression coefficient. Previous studies either did not form such subsets or did so visually based on a subjective post-hoc impression of residuals. A surprising finding was the dominance of stream slope in predicting unit hydrograph time to peak rather than the expected catchment size indexed by area or main stream length.

<u>Reservoir safety, spillway design and freeboard determination</u> were the applications of greatest interest to the Institution of Civil Engineers (ICE). The FSR preserved ICE's "maximum of experience" approach but borrowed from US and Australian practice to exploit the rainfall runoff model to maximise the rainfall input and route this through an adjusted catchment condition – enhanced wetness, snowmelt, speeded up response – as opposed to a flood peak envelope as embedded in the then current ICE recommendations.

Reference

Rodda, J.C. and Robinson, M. 2015. Progress in modern hydrology. Wiley Blackwell. 384p

Hydrological modelling aspects of a 1980s statutory safety inspection of earth-embankment dam spillways: Unit Hydrographs then and now

Ian Littlewood (IGL Environment)

The talk has two main parts, linked by the application of Unit Hydrograph (UH) theory and how it has improved over the 40+ years since publication of the Flood Studies Report (FSR), in 1975. Part 1 summarises an early-1980s statutory safety inspection of a cascade of earth-embankment dam spillways, using the (then) still fairly new FSR methods (e.g. the well-known triangular UH within the FSR rainfall–streamflow model). Part 2 builds upon collaborative CEH/Australian National University (ANU) research in the late 1980s that lead to introduction of the IHACRES rainfall–streamflow modelling methodology, in 1990. IHACRES extends the application of long-established UH theory (1932) – from (a) analysis of event-based direct flow hydrographs (FSR, the Flood Estimation Handbook (1999) and Revitalisation of the FSR/FEH Rainfall Runoff Method (2005)) to (b) analysis of long time series of (total) streamflow, i.e. continuous flow simulation. Key features of FSR/FEH and IHACRES rainfall–streamflow modelling are compared qualitatively. Issues concerning the regionalisation of FSR/FEH and IHACRES UHs, to assist with estimating hydrographs at ungauged sites, are discussed.

Flood seasonality and the assessment of seasonal flood risk

David Archer (JBA Consulting and Visiting Fellow, Newcastle University)

Estimates of seasonal flood risks are often required for engineering design and construction in and adjacent to rivers and for the determination of risks to crops grown on the floodplain. The requirement is usually for events of low return period.

The seasonality of flooding was discussed in FSR. However, no attempt was made to provide a practical means of estimation. Seasonality was further investigated in FEH and subsequent revisions but mainly as a means of improving the estimation of annual floods or flood hydrographs rather than assessing risks in specified seasons or months.

In this presentation, a flexible method of seasonal risk assessment based on POT data from northeast England (Archer, 1981) will be revisited and extended. Using all the Northumbrian gauged data then available this analysis identified spatial variations in flood seasonality and the effects of changing return period. A method of specifying the risk of occurrence of a flood of specified magnitude in any month or combination of months for events down to 0.25 QBAR will be presented.

Peak flow reconstruction and POT data: Two ways to improve flood frequency analysis

Alistair Cargill (SEPA)/Andrew Black (University of Dundee)

Whilst fully supporting the methods of the FSR and FEH, this presentation will explore two ways in which flood estimation could be improved in future. Neither approach is new per se, but they have maybe been overlooked in terms of their true potential.

Floods are real events that are all too often thought about only on purely theoretical terms. The benefit of today's computing power and technology allows analysts to undertake assessments (both hydrological and/or hydraulic) siting behind a desk. Does such an approach lead to a true understanding of the values they are deriving? Flood estimation should always involve good quality hydrometric data where possible. The need to maintain such records is vital and cannot be underestimated. This presentation makes the case for another form of observed flood information that is central to improving estimates going forward. Undertaking post-flood survey (especially on ungauged catchments) following notable floods, provides both an improved understanding of flood processes locally but can contribute towards the creation of a flood event repository nationally. Such a database has great potential to provide a most useful context in which to place flood estimates derived via standard methods as part of a desktop study.

Despite the relative success and merits of both the Flood Studies Report (FSR) and Flood Estimation Handbook (FEH) approaches, they are both arguably limited in their application by an over-reliance on annual maximum data when undertaking statistical flood frequency analysis. Despite the fact methods and rules for Peaks Over Threshold (POT) data extraction were set out in the FSR (1975), the use of such partial duration series has been very limited within the UK standard methods to date. This is despite the existence of the Generalised Pareto Distribution as an apparent 'choice' within the list of probability distribution functions available within WINFAP-FEH software.

Examples from past research will be used to illustrate the potential benefits of POT data for flood frequency analysis. Post-flood survey work undertaken by SEPA in recent years will be used to illustrate (allied with the use of flood envelope curves) how such an approach may instil greater confidence in flood estimates generally.

The Peak Flow Data Story; from FSR to NRFA and onward

Catherine Sefton and Harry Dixon (Centre for Ecology & Hydrology)

The peak flow dataset initiated by the Flood Studies Report (FSR) has seen significant developments in network size, data quality and technology over the last 40 years, resulting in the current service hosted by the National River Flow Archive (NRFA). Annual maxima and peaks over threshold data are now available on the NRFA website at nearly 1000 stations across the UK, and managed under a collaborative project between CEH and the Measuring Authorities. The project aims to deliver regular data updates, period of record validation and improvements in metadata and national consistency. Anticipated technological developments include software tools to improve user access to the data. Looking further ahead, the potential provision of local, historical and palaeoflood data is being explored with a view to improving their incorporation into Flood Estimation Handbook (FEH) techniques. Existing systems, most notably the Chronology of British Hydrological Events, and emerging apps and websites offer the means for collation of some such datatypes. However, the distribution and often unstructured format of the data will make searches and processing time consuming and lack full integration with hydrometric records. This presentation will review options for developing a data system which allows instrumental and pre-instrumental data to be used in a combined approach to flood estimation.

From flow duration curves to flood flows: estimating QMED from flow regime descriptors

Andy Young (Wallingford HydroSolutions)

Guidance for the practical application of flood estimation methods stresses the value of using available local data to evaluate, adapt and hopefully improve the at site estimate of flood risk. This is particularly challenging in the ungauged catchment and the practitioner commonly looks towards flood peak data from suitable donor catchments to achieve this.

The UK has a relatively dense gauging station network – currently comprising around 1500 primary flow-measurement stations and augmented by a substantial number of secondary and temporary monitoring sites. The NRFA[1] Peak Flows dataset is an exceptional resource of high quality flood series. Within this dataset there are 838 catchments judged as being of suitable hydrometric quality for the estimation of the FEH index flow, the median annual flood (QMED), and 797 that meet the minimum record length criterion for estimating QMED directly from the AMAX series. Thus flow data from only about 50% of the primary UK network, and a smaller fraction of the total network can be used to directly constrain uncertainty in the estimation of QMED within the current FEH estimation methods.

This paper explores the relationships between QMED and the flow duration curve statistics commonly used to summarise gauged records for within bank, non-flood flows. The development of a linking equation for estimating QMED from these flows is presented. The paper explores the sensitivity of the relationships to the magnitude of catchment water use and return and considers the length of record required to reliably estimate flow duration curve statistics. It is argued that a linking equation of this nature offers the potential for significantly increasing the set of gauged catchments that can be used as at-site local data to inform the estimation of QMED in practice.

[1] National River Flows Archive (http://nrfa.ceh.ac.uk/)

An Innovative Application of FEH Method in Quality Peak Flow Estimation for Flood Risk Management

Aminul Chowdhury (WSP Parsons Brinckerhoff)

A core component for quantifying flood risk is flood hydrology. This is also the most error prone dataset and can therefore have the biggest uncertainties associated with it. It is therefore prudent to direct most effort into improving this data to ensure resulting flood risk management decisions are sound.

Practitioners carrying out hydrological studies are faced with multiple techniques, variables and decisions and it is almost inevitable that different estimates will be produced by different hydrologists and sometimes by the same hydrologists. Repeatability is inevitably difficult.

It is of great interest to clients to have good sound and believable estimates and preferably one estimate in order to base multiple decisions. Having made best use of available data provides the best defence when faced with a challenge and additionally being able to demonstrate the logic of flood flow propagation in a catchment is also a powerful tool.

Quality of data required is also a consideration when determining flood flows and ensuring the resulting estimates fit the need. This risk based approach can be easily focussed by rating the risk in each settlement in a catchment perhaps by numbers of properties in the floodplain and applying a suitable level of rigour to the determining the estimates for that community.

Where a high confidence in data is required there needs to be good locally gauged flow data and reliable rating curves. And this requirement can be reconciled with what is available to identify where the quality needs to be improved and where there maybe complete gaps in our understanding. The additional spin off from this exercise can assist in building a programme of gauging station improvements and focus on improving ratings for the future. This paper develops this need further and describes how FEH method had been applied successfully in one area in the Environment Agency. The paper also highlights some areas where improvements could be made in light of the current flood estimation techniques.

Continuous Simulation: A viable alternative to FEH for design flow estimation in permeable catchments?

Paul Wass (JBA Consulting)

Chalk fed rivers pose particular challenges for flood estimation. Their high permeability makes them especially sensitive to catchment wetness and rainfall variations at a seasonal scale. Many years can pass in some catchments without a flow that is considered a flood; there may even be years when a river dries up completely. Several such rivers drain the chalk-dominated areas of Hampshire.

This talk evaluates an alternative to the FSR and FEH as a method of flood flow estimation for permeable river basins: Continuous Simulation (CS). CS combines a synthetic rainfall series with a rainfall runoff model to produce a long flow time series. Design flows are calculated directly from plotting positions of simulated AMAX flows. CS has previously proved a powerful method for evaluating flood risk where there is interaction of multiple variables, such as inflow and controlled storage or tributaries with contrasting responses. Previous studies have applied the technique to the Medway and Don catchments.

Applying CS successfully to rivers draining the Hampshire chalk demands a realistic model of the catchment and synthetic rainfall and evaporation inputs with the right depth, duration and frequency. Our chosen rainfall runoff model (the Probability Distributed Moisture model) worked well in most cases, but one catchment appeared to feedback high groundwater levels into soil wetness: something PDM cannot replicate directly. Further work on PDM to develop that link might improve its performance in such situations.

Synthetic rainfall matched FEH depths and frequencies closely to 12 days' duration. However, chalk catchments are influenced by consecutive years' rainfall: far beyond anything available from FEH statistics. This makes synthetic inter-seasonal rainfall durations and frequencies difficult to check. We therefore suspect that the simulated rainfall series was responsible for the flatter-than-observed flood growth curves generated by the CS. Further work to look at the expected frequency of rainfall depths at long (seasonal) durations would help solve this problem.

Lastly, the skills and software needed to apply CS are not commonplace. The shortage of know-how and tools to apply it are significant barriers to its wider adoption.

Current Challenges in Flood Estimation: An Environment Agency Perspective

Mike Vaughan, Environment Agency

The Environment Agency applies flood estimation techniques for a wide range of purposes, including flood risk mapping, scheme design, emergency planning and post-event reviews. It also reviews others' flood estimates, as well as funding research into improving flood estimation techniques through the Joint Programme with Defra.

Current proposals for research to be funded through the joint programme have made the case for improvements to the FEH rainfall-runoff methodology. These include the use of a variable unit hydrograph time to peak and the explicit calibration of flood event volumes. They have also proposed extending the maximum rainfall duration in the FEH DDF model beyond the current eight days, to allow its use with permeable catchments, large river basins and low-lying areas. But are these the most important areas on which to focus limited funding? And are they too incremental, or should we be looking for a step-change in flood estimation?

The presentation will summarise the current research proposals, and seek to stimulate discussion on the direction of future developments in flood estimation.