DEVELOPING FEH METHODS – A NEW MODEL OF RAINFALL FREQUENCY

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Abstract:
This paper describes recent Joint Environment Agency/Defra-funded research to develop a new model of rainfall depth-duration frequency (DDF) for the UK to replace the current, widely-used Flood Estimation Handbook (FEH) model. The new model is based on the analysis of annual maxima derived from a large number of daily and hourly raingauges throughout the UK, and the results are applicable to rainfall durations from 1 hour to 8 days and for return periods from 2 to over 10,000 years. Differences with the FEH results are generally modest for return periods less than 200 years. However, estimated rainfalls for longer return periods tend to be lower than those derived from the FEH except in Scotland, where estimates for the shortest durations have increased. A follow-on project starting in the near future will incorporate the new DDF model into a revised software utility to replace that currently available on the FEH CD-ROM 3.

1 BACKGROUND

Recent research under the Joint Environment Agency/Defra Flood and Coastal Risk Management R&D Programme has developed a new model of rainfall depth-duration frequency (DDF) applicable to the whole of the UK. The project was led by CEH and involved researchers from the Met Office and the Universities of Salford and Sheffield. The model has been developed for rainfall durations from 1 hour to 8 days, and was commissioned in response to concerns expressed by reservoir engineers about the apparently high estimates produced by the Flood Estimation Handbook (FEH) rainfall model (Institute of Hydrology, 1999) when it was applied to return periods in excess of its recommended upper limit of 1,000 years. One particular aspect of the FEH model that was considered to be in need of revisiting was the form of the extrapolation used to provide rainfall inputs to reservoir flood safety assessments.

The new DDF model has been designed to provide rainfall estimates for return periods ranging from 2 to over 10,000 years, and it is proposed that it should eventually replace the FEH rainfall model for hydrological design studies using rainfall-runoff techniques and for assessing the rarity of particular rainfall events in the UK.

2 DATA

During the first stage of the project, an extensive archive of daily and hourly raingauge data was compiled from data supplied by the Met Office, the Environment Agency and SEPA. Met Éireann also made continuous daily rainfall records available for 30 gauges in the Republic of Ireland, located near the border with Northern Ireland. From the continuous hourly and daily records, annual maxima were abstracted for 11 key rainfall durations ranging from 1 hour to 8 days. The final dataset consisted of annual maxima for over 6,500 daily raingauges (a slight increase in the number used in the FEH), and for 969 hourly gauges (more than twice the number used in the FEH). The daily annual maximum dataset provides very good coverage of the UK, while the hourly dataset is less dense and lacks information in some areas such as south-west England, often where digital records are, as yet, too short to allow the analysis of extremes. In addition, upland areas are not particularly well represented in the hourly dataset, reflecting a general lack of raingauges in such locations.

Another source of information available to the project was a database detailing 63 extreme storm events experienced in the UK between 1880 and 2006. These events tend not to be well represented in the systematic dataset because they often include observations involving non-standard measuring equipment and qualitative information. However, the data were used in the testing and validation of the final model to provide independent checks and comparisons.

3 STATISTICAL MODELLING

The new DDF model was developed after an extensive statistical analysis of the annual maximum dataset. The basic approach taken mirrored that used in the FEH rainfall analysis, which adopted a two-stage index-flood methodology, and the project introduced a number of key revisions. Firstly, the simple standardisation used in the FEH, whereby annual maxima at each raingauge are divided by the at-site median value of the appropriate duration (RMED), was replaced by a revised standardisation designed to remove more of the location-dependent variation in the distribution of rainfall before combining data from networks of raingauges. The second stage used in the FEH was the application of the Focused Rainfall Growth Extension (FORGEX) methodology (Stewart *et al.*, 1998). The project has made a number of changes to FORGEX, most notably by using a new model of the spatial dependence in rainfall extremes that allows dependence to reduce gradually as return period increases. Also the FORGEX algorithm has been improved to give a better fit to the data points (network maxima) and to ensure more gradual variation between locations.

Rainfall frequency curves were produced by the revised methodology for durations from 1 hour to 8 days at 71 test sites chosen on the basis of their proximity to long, reliable annual maximum records and/or major reservoirs. A new DDF model was then fitted to the results. The new model is more flexible than the FEH model, and is better able to represent the output from the revised FORGEX methodology across the full range of durations and return periods. Unlike the FEH, the new model does not increase exponentially (on the Gumbel return period scale) if extrapolated beyond the range of return periods represented in the observed data.

Further work is needed to generalise the model so that it can be applied at any location in the UK. In particular, improved maps of RMED will be required for the full range of durations as the new dataset has provided observations in previously sparsely gauged areas such as the Lake District. This will be carried out during the second phase of the project.

4 EXAMPLE RESULTS

The results of applying the new DDF model at the 71 test sites across the UK have been compared with rainfall estimates derived from the FEH model and its predecessor, the Flood Studies Report (FSR) model (NERC, 1975), for a range of durations and for return periods from 100 to 10,000 years. For the shorter durations (less than 6 hours), the new estimates are considerably higher than both the FEH and the FSR estimates for most locations in Scotland for return periods of up to 1,000 years. This is mainly due to the improvements in the hourly dataset in previously sparsely gauged areas. At the test sites in England, Wales and Northern Ireland, the rainfall estimates from the new model are broadly similar to those from the FEH model for the 100-year return period. As return period increases, the new estimates tend to be lower than the FEH, especially around London and south-east England. This is illustrated in Figure 1, which shows results from the new model as a percentage of the FEH estimates at the test sites for a duration of 2 hours and return periods of 100 and 1,000 years.

For all durations, the estimates from the new model tend to be lower than those from the FEH at the 10,000-year return period which is currently used as a design standard in the assessment of reservoir flood risk.

In Figure 1, one location in the Lake District stands out because, unlike neighbouring sites, the new estimates are considerably higher than those from the FEH. This is the raingauge in the Honister Pass, which is situated at a substantially higher altitude than most of the gauges in the annual maximum dataset. The location is well known for its very high rainfalls. Although daily data from the gauge were used in the FEH analysis, the hourly annual maximum record was not sufficiently long to be included at that time. As a result, it seems that the spatial variability of the median rainfall in this mountainous area was not adequately represented in the FEH model.

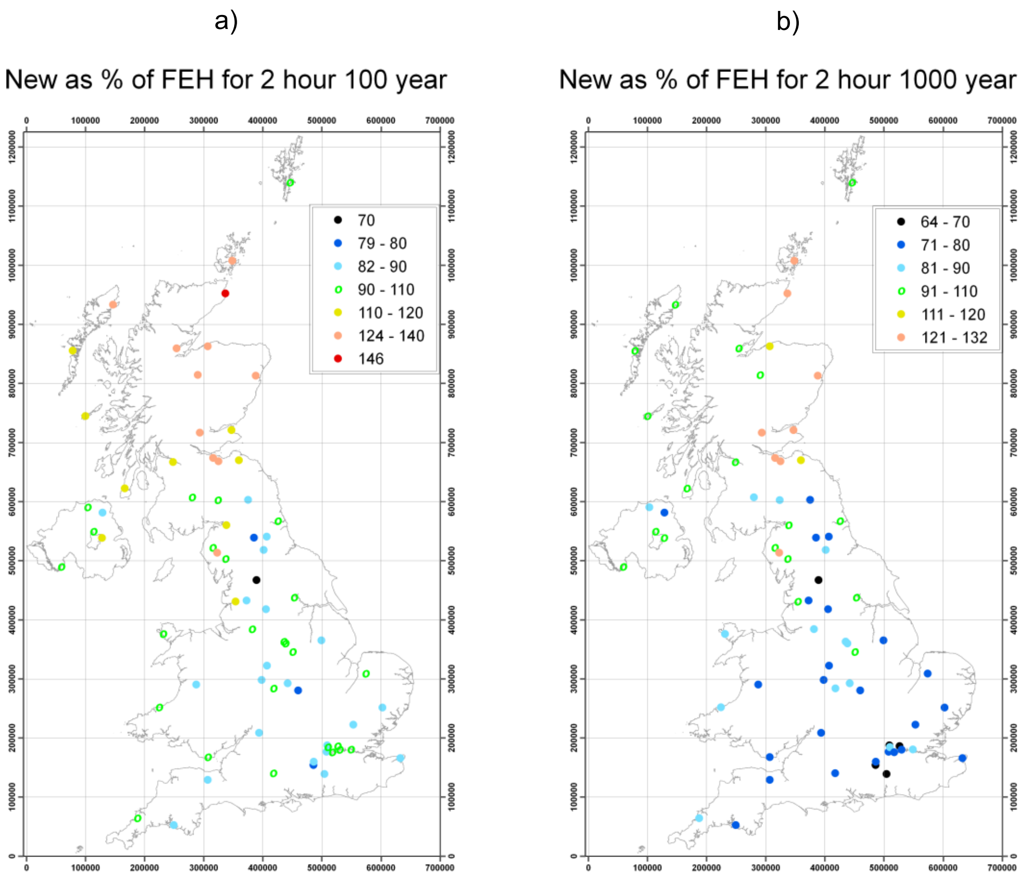


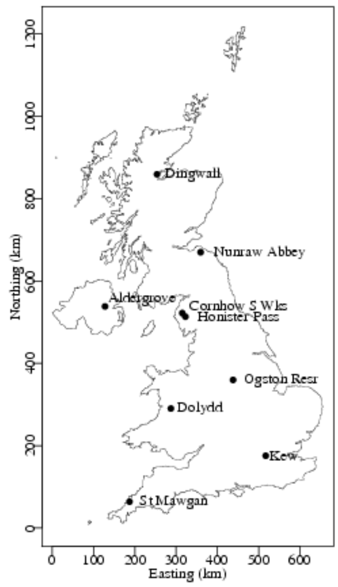
Figure 1. New rainfall estimates as a percentage of estimates from the FEH model for a duration of 2 hours and return periods of a) 100 and b) 1,000 years.

Table 1 presents comparisons between the new rainfall frequency estimates and those from the FSR and FEH models for nine sites throughout the UK. The two sites in Cumbria, Honister Pass and Cornhow Sewage Works, were chosen to illustrate the contrasting results at neighbouring sites which have very different rainfall characteristics. Cornhow has an average annual rainfall over the period 1961 to 1990 (SAAR) of 1503 mm and an altitude of 98 m, while Honister has a SAAR of 3510 mm and an altitude of 358 m. The results show that the new rainfall frequency estimates at Honister exceed those of the FSR and the FEH at all return periods, in contrast to the Cornhow estimates, which fall below the FEH model beyond a return period of 1,000 years.

In Table 1, it can be seen that the new model produces 1-hour rainfall estimates that are generally higher than those from the FSR, except in a few cases at the 10,000-year return period. Note that digitised FSR estimates were not available in Northern Ireland. The new results exceed the FEH in Scotland, Northern Ireland and at the Honister gauge for return periods of up to 1,000 years. At the remaining sites, the new results tend to be lower than the FEH for return periods exceeding 200 years.

Table 1. Rainfall frequency estimates for 1-hour duration at nine UK raingauge sites (see location map below)

Gauge Name (Reservoir)	Return period (years)	FSR rainfall (mm)	FEH DDF rainfall (mm)	New DDF rainfall (mm)	New as % FSR (%)	New as % FEH (%)
Dingwall	200	27	34	54	200	159
(Loch Ussie)	1,000	38	54	67	176	124
	10,000	63	103	84	133	82
Nunraw Abbey	200	38	34	44	116	129
(Thorters)	1,000	54	49	62	115	127
	10,000	89	85	89	100	105
Cornhow S Wks	200	49	49	49	100	100
	1,000	70	76	75	107	99
	10,000	119	142	116	97	82
Honister Pass	200	49	59	74	151	125
	1,000	70	91	117	167	129
	10,000	119	171	191	161	112
Ogston Reservoir	200	45	55	52	116	95
(Ogston)	1,000	64	90	85	133	94
	10,000	108	181	127	118	70
Dolydd	200	53	61	54	102	89
(Clywedog)	1,000	76	98	78	103	80
	10,000	128	192	117	91	61
Kew	200	46	63	57	124	90
(Pen Ponds U Lake)	1,000	66	103	79	120	77
	10,000	111	208	126	114	61
St Mawgan	200	41	53	54	132	102
(Porth)	1,000	59	85	74	125	87
	10,000	99	165	102	103	62
Aldergrove	200	-	42	51	-	121
	1,000	-	65	70	-	108
	10,000	-	122	97	-	80



5 FROM RESEARCH TO PRACTICE

Currently, results from the new DDF model are only available for the 71 raingauge sites used for testing because estimates of RMED for each of the 11 key durations are required at each location of interest. A second phase of the project is expected to start in 2010, and this will update the maps of RMED produced for the FEH analysis which, in turn, will allow the model to be fitted across the UK on a 1-km grid. The project will also develop a new software package to replace the implementation of the FEH DDF model currently available on the FEH CD-ROM 3 (CEH, 2009). In the interim, it is hoped that the maps and tables of results provided in the Phase 1 report (Stewart *et al.*, 2010) will help users to assess the likely effects of adopting the new DDF model in different regions of the UK.

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