The Impact of the "New FEH" Depth-Duration Frequency Curves on Extreme Floods for the Nant-y-Moch Reservoir in mid-Wales

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INTRODUCTION

The Flood Estimation Handbook (FEH) method of flood estimation has undergone a number of reviews and updates following its publication in 1999. The first was the publication of the 'Revitalisation of the FSR/FEH rainfall-runoff method' (ReFH) by CEH in 2005. This refined the design flood hydrograph method for return periods of up to 1 in 150 years. More recently, CEH has undertaken research to further refine the Depth-Duration Frequency (DDF) Curves for long return period rainfall in excess of 1 in 100 years and including the 1 in 1,000 year and 1 in 10,000 year return period events for which reservoir spillways are typically designed.

CEH's latest research was prompted by work undertaken by MacDonald and Scott (2000) who compared 1 in 10,000 year rainfall depths derived using FEH DDF curves with Probable Maximum Precipitation (PMP) depths derived using Flood Studies Report (FSR) DDF curves for 12 reservoirs in England and Wales. They found that FSR and FEH rainfall depths diverge significantly at 1 in 10,000 year return periods and that at nine of the reservoirs studied, the 1 in 10,000 year FEH rainfall depths were greater than the PMP FSR depths.

Subsequent to this, the Babtie Group (2000) was commissioned by the Department for Environment, Food and Rural Affairs (Defra) to further investigate these findings. They found that 1 in 10,000 year FEH rainfall depths generally exceed PMP FSR depths by around 14%, emphasising the need for further research.

In the research to produce "New FEH" DDF curves for extreme rainfall events, CEH specifically considered:

- 1 in 100 year to 1 in 10,000 year rainfall events
- Storm durations from 1 hour to 192 hours (8 days).

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This research that led to the development of the "New FEH" DDF model is complete but is awaiting further funding to generalise the results across the UK and to enable a suitable CD-based release to the wider industry.

This paper summarises the findings a flood study that has been undertaken for Nant-y-Moch Reservoir, owned by Statkraft, using the "New FEH" DDF curves to derive a range of design storms, including the 1 in 1,000 year and 1 in 10,000 year storms. The results of this flood study were compared to the results obtained using the FSR and FEH DDF curves for the same design storms.

The work discussed in this paper was undertaken by MWH using DDF data supplied by CEH specifically for the project and as part of their wider comparative check on results using the New FEH DDF data for existing UK reservoirs. The DDF data were derived by applying the "New FEH" model at a single point in the vicinity of Nant-y-Moch Reservoir and represent provisional results only.

NANT-Y-MOCH RESERVOIR

Nant-y-Moch Reservoir (NGR 750 860) is the upper reservoir in the Rheidol cascade with Dinas Reservoir and Cwm Rheidol Reservoir downstream. It is located in West Wales approximately 18km north east of Aberystwyth and is situated on the Afon Rheidol, which the dam impounds. The reservoir has a natural catchment of 55.1km^2 and three indirect catchments, Pen Rhaiodr, Hengwn and Bugeilyn that total 6.3km^2 in area and provide a maximum inflow to the reservoir of 2.26m^3/s.

Nant-y-Moch is impounded by a massive concrete buttress dam that is approximately 50m high at its centre and approximately 350m long. At its top water level of 339.24mOD the reservoir has a capacity of approximately 29,336 ML.

The overflow facilities at Nant-y-Moch comprise five ogee profile weirs that are each 8.53m in width a crest level of 339.24mOD. The weirs are located under the crest road bridge and spill into a steep stepped concrete channel that runs down the right hand mitre of the dam. The wavewall is a substantial watertight structure that is considered to be capable of retaining floodwaters. The minimum wavewall level is 342.85mOD.

FLOOD STUDY METHODOLOGY

The flood study for Nant-y-Moch was carried out using procedures laid out in both the Flood Studies Report and the Flood Estimation Handbook (see Table 1). Both the 1 in 1,000 year and 1 in 10,000 year events were modelled.

Table 1. Flood Study Scenarios

Flood Event	Methodology	DDF Model
1 in 1,000 year	FEH	New FEH
	FEH	FEH
	FSR	FSR
1 in 10,000 year	FEH	New FEH
	FEH	FEH
	FSR	FSR

Flood routing was undertaken using the ISIS v3.4 software package to determine peak inflows, outflows and flood levels for each of the scenarios.

It was assumed that the reservoir would be at top water level at the start of each of the storm events and that only the spillway would pass outflows, i.e. that the gates to the turbine shaft and the cone valve flow regulators would be closed. This is the worst case scenario.

RAINFALL DATA

CEH provided rainfall data derived from the FSR, FEH and New FEH DDF models for Nant-y-Moch for the 1 in 1,000 year and 1 in 10,000 year rainfall events for a range of durations:

- 1 hour
- 6 hour
- 24 hour
- 192 hour.

These data were interpolated to obtain rainfall depths for the critical storm durations for all of the modelled scenarios (see Table 2). The 75% Winter profile was applied to the rainfall data in ISIS to derive the storm hyetographs for use in the flood routing.

Table 2 Critical Storm Durations and Corresponding Rainfall Depths

Flood Event (years)	Methodology	DDF Model	Storm Duration (hrs)	Rainfall Depth (mm)
1 in 1,000	FEH	New FEH	13.75	148.08
	FEH	FEH	14.25	214.29
	FSR	FSR	19.75	176.27
1 in 10,000	FEH	New FEH	12.75	178.15
	FEH	FEH	14.25	347.52
	FSR	FSR	19.75	254.71

RESULTS

1 in 1,000 year Event

The results of the flood routing for the 1 in 1,000 year event are summarised in Figure 1 and Table 3 below.

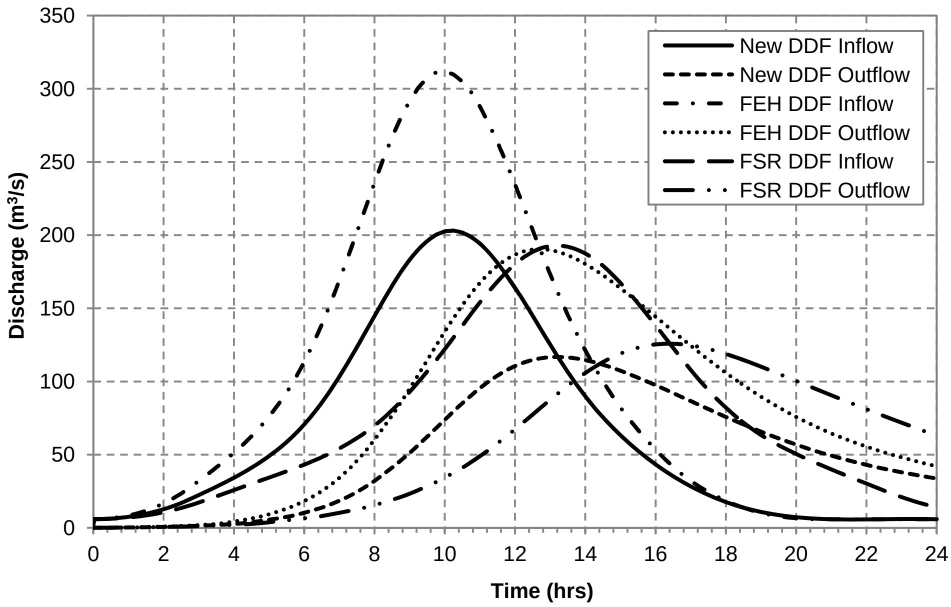

Figure 1. 1 in 1,000 year Flood Hydrographs

Table 3. Summary of 1 in 1,000 year Flood Routing Results

	New FEH	FEH	FSR
Maximum Inflow (m^3/s)	203	312	193
Maximum Outflow (m^3/s)	117	190	126
Top Water Level (mOD)	339.24	339.24	339.24
Flood Rise (m)	1.20	1.66	1.26
Maximum Stillwater Level (mOD)	340.44	340.90	340.50

The flood routing results for the 1 in 1,000 year event show that the FEH rainfall produces much higher inflows and outflows for Nant-y-Moch than the New FEH and FSR DDF rainfall.

There is a large discrepancy between the New FEH generated hydrographs and the FEH generated hydrographs. The critical storm durations differ by only 0.5 hours, with the New FEH critical storm being shorter than the FEH critical storm. However, the corresponding FEH rainfall depth is 44% larger than the New FEH rainfall depth. This results in a peak inflow to Nant-y-Moch using the FEH rainfall that is 50% greater than the corresponding inflow derived using the New FEH rainfall ($312m^3/s$ versus $203m^3/s$) and a peak outflow that is 60% greater ($190m^3/s$ versus $117m^3/s$).

The peak inflow and outflow for Nant-y-Moch derived from the New FEH rainfall compare well with the FSR generated peak inflow and outflow. The critical storm duration for the New FEH event (13.75 hours) and the corresponding rainfall depth (148.08mm) are lower than for the FSR event (19.75 hours and 176.27mm respectively), however, due to the differences between the FEH and FSR rainfall-runoff models, the inflow peaks are similar (203m³/s versus 193m³/s). As the FSR event is a longer event with a greater volume of rainfall, the total inflow to Nant-y-Moch is greater than during the New FEH event and this results in a marginally higher peak outflow during the FSR event (126m³/s versus 117m³/s).

As part of another study for Statkraft, a flood study was undertaken for the full reservoir cascade using the New FEH, FEH and FSR methodologies. The results are not discussed in detail in this paper as the rainfall data that was used only related to the Nant-y-Moch catchment and not the entire Rheidol catchment. However, it is interesting to note that in that study, in the case of the 1 in 1,000 year event the New FEH and FEH events produced comparable flood hydrographs for all three reservoirs in the cascade, whilst the FSR flood hydrographs were considerably smaller.

<u>1 in 10,000 year Event</u>

The results of the flood routing for the 1 in 10,000 year are summarised in Figure 2 and Table 4 below.

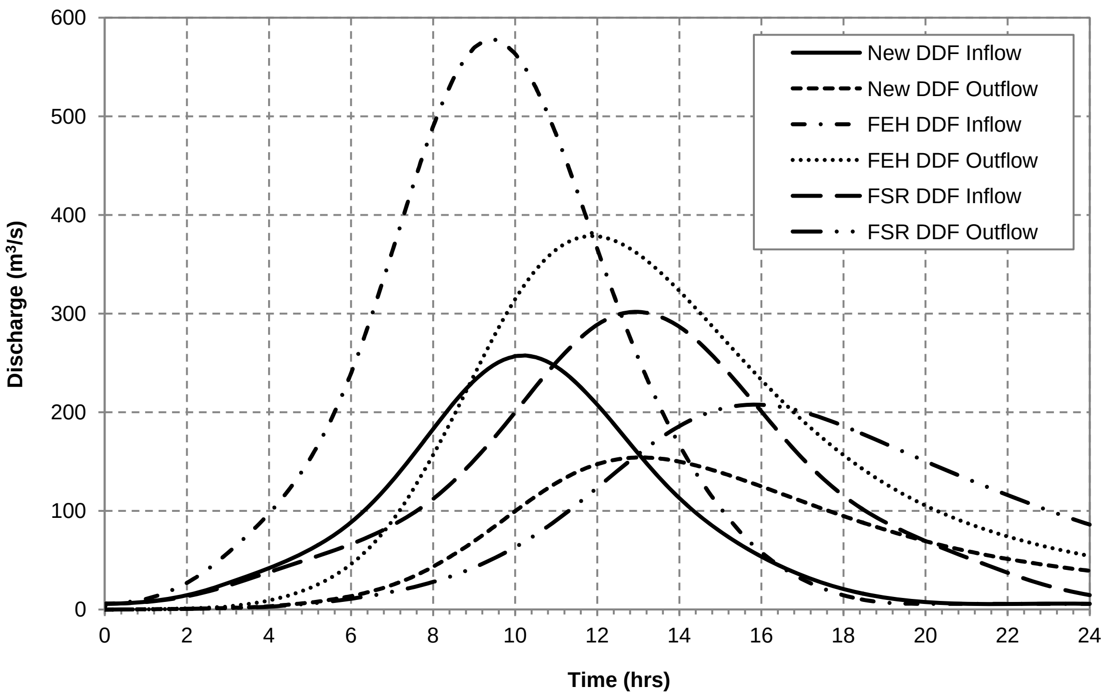

Figure 2 1 in 10,000 year Flood Hydrographs

Table 4 Summary of 1 in 10,000 year Flood Routing Results

	New FEH	FEH	FSR
Maximum Inflow (m^3/s)	258	578	302
Maximum Outflow (m^3/s)	154	379	208
Top Water Level (mOD)	339.24	339.24	339.24
Flood Rise (m)	1.44	2.64	1.76
Maximum Stillwater Level (m OD)	340.68	341.88	341.00

As for the 1 in 1,000 year event, the flood routing results for the 1 in 10,000 year event show that the FEH rainfall produces much higher inflows and outflows for Nant-y-Moch than the corresponding New FEH and FSR rainfall.

There is a large discrepancy between the New FEH generated hydrographs and the FEH generated hydrographs. The critical storm durations differ by 1.5 hours, with the New FEH critical storm being shorter than the FEH critical storm. However, the corresponding FEH rainfall depth is 95% larger than the New FEH rainfall depth. This results in a peak inflow to Nant-y-Moch using the FEH rainfall that is more than double the corresponding inflow derived using the New FEH rainfall ($578m^3/s$ versus $258m^3/s$) and a peak outflow that is 146% greater ($379m^3/s$ versus $154m^3/s$).

The 1 in 10,000 year peak inflow and outflow generated for the FEH event are also marginally higher than the peak inflow and outflow modelled for Nant-y-Moch during the Probable Maximum Flood (PMF) event. The PMF peak inflow is $551m^3/s$ and the peak outflow is $288m^3/s$.

The FSR rainfall also produces higher peak inflows and outflows for Nant-y-Moch than the New FEH rainfall. The FSR storm event is seven hours longer than the New FEH rainfall event and the rainfall depth is 43% greater. The larger FSR storm results in a peak inflow to the reservoir that is 17% greater than the New FEH peak inflow ($302m^3/s$ versus $258m^3/s$) and a peak outflow that is 35% greater ($208m^3/s$ versus $154m^3/s$).

When considering the Rheidol cascade as a whole, unlike the 1 in 1,000 year event, the flood hydrographs for the 1 in 10,000 year event show a similar pattern as those for Nant-y-Moch; the inflows and outflows generated from the FEH rainfall are significantly larger than the New FEH and FSR inflows and outflows, whilst the FSR inflows and outflows are in turn greater than those for the New FEH event.

<u>Probable Maximum Flood – Return Period</u>

The New FEH 1 in 100,000 year event was also modelled in this study to provide a reference for the PMF event as a point of interest. Although it is not considered a reliable indication, it is interesting to note that the peak inflow and outflow for this event were found to be $316m^3/s$ and $193m^3/s$, suggesting that the PMF event at Nant-y-Moch has a corresponding return period greatly in excess of 1 in 100,000 years.

CONCLUSIONS AND RECOMMENDATIONS

The flood study undertaken for Nant-y-Moch using the New FEH rainfall has reinforced the findings of MacDonald and Scott (2000) and Babtie Group (2000), which suggested that the FEH DDF model resulted in greatly overestimated flood hydrographs for extreme rainfall events up to the 1 in 10,000 year event.

At Nant-y-Moch, for both the 1 in 1,000 year and 1 in 10,000 year events, the New FEH rainfall produces peak inflows and outflows that are comparable to the FSR peak inflows and outflows and that are of a magnitude more in line with what would be expected for these events than the corresponding values derived from the FEH DDF.

Based on these findings, reservoir undertakers would be well advised to consider revising their flood studies for reservoirs for which the 1 in 1,000 year or 1 in 10,000 year events are the design events upon publication of the New FEH data. This could result in reservoirs that were previously found to have inadequate overflow facilities to safely pass the design flood being reassessed, with costly remedial works no longer necessary or greatly reduced in scale.

ACKNOWLEDGEMENTS

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REFERENCES

Babtie Group (2000). *Floods and reservoir safety - clarification on the use of FEH and FSR Design rainfalls*. Report to DEFRA.

CEH (2007). *Flood Estimation Handbook Supplementary Report No. 1, The revitalised FSR/FEH rainfall-runoff method.*

CEH (2011). *FSR, FEH and New FEH rainfall data for Nant-y-Moch Reservoir*

Institute of Hydrology (1999). *The Flood Estimation Handbook, Volumes 1- 5*

MacDonald, D.E. & Scott, C.W. (2000): *Revised design storm duration estimates obtained from the Flood Estimation Handbook (FEH),* Dams 2000 - Proceedings of 11th British Dam Society Conference, Bath, Thomas Telford Ltd, London.

NERC (1975): *Flood Studies Report Volumes 1- 5*, HMSO