Botley West Solar Farm

Environmental Statement

Volume 3

Appendix 10.4: Hydrology Report

November 2024

PINS Ref: EN010147
Document Ref: EN010147/APP/6.5
Revision P0
APFP Regulation 5(2)(a); Planning Act 2008; and Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations

Approval for issue

Jonathan Alsop	15 November 2024

Prepared by:

RPS
20 Western Avenue,
Milton Park, Abingdon,
Oxfordshire, OX14 4SH
United Kingdom

Prepared for:

Photovolt Development Partners GmbH,
on behalf of SolarFive Ltd.

Contents

Tables

Glossary

Term	Meaning
The Applicant	SolarFive Ltd
The Project	The Botley West Solar Farm (Botley West) Project
Main River	A watercourse should be a main river if significant numbers of people and/or properties are liable to flood. This also includes areas where there are vulnerable groups and areas where flooding can occur with limited time for warnings.
Hydraulic Modelling	A Hydraulic model can be defined as a computational representation a river or coastal system -so basically using a computer to do calculations to represent a watercourse.
Lateral Inflow	The Uniform Lateral Inflow Hydrograph is used as an internal boundary condition. This option allows the user to bring in a flow hydrograph and distribute it uniformly along the river reach between two user specified cross section locations.
Downstream boundary	The 1D downstream boundary assumes a normal depth condition based on the local channel bed gradient of 1:1000

Abbreviations

Abbreviation	Meaning
AEP	Annual Exceedance Probability
AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CPRE	Council for the Protection of Rural England
FARM	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NFRA	National River Flow Archive
OS	Ordnance Survey
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method

Abbreviation	Meaning
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBANEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

Units

Unit	Description
%	Percentage
km^2	Square kilometres
m^2	Square meters

1 Introduction

1.1.1 This report template is a supporting document to the Environment Agency's Flood Estimation Guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results. This document can be used for one site or multiple sites. If only one site is being assessed, analysts should remove superfluous rows from tables.

1.1.2 Guidance notes (in red text) are included throughout this document in column titles or above tables. These should be deleted before finalising the document. Where relevant, references to specific sections of the Flood Estimation Guidelines document are included to indicate where further useful information can be found.

1.1.3 Note: Column size / page layout can be adapted, where necessary, to best present relevant information, for example, maps do not need to be within the tables if they would be better as a separate page.

2 Summary of Assessment

2.1 Summary

2.1.1 This table provides a summary of the key information contained within the detailed assessment in the following sections. The aim of the table is to enable quick and easy identification of the type of assessment undertaken. This should assist in identifying an appropriate reviewer and the ability to compare different studies more easily.

Table 2.1: Summary of assessment information

Catchment location	Grid Reference NY 36500 68350
Purpose of study and scope	The purpose of this study is to calculate peak flows and inflow hydrographs to be used as inflow for a hydraulic model of the River Evenlode and its tributary. This is a routine study.
Key catchment features	Upstream of the model extent is formed of two separate channels and catchments the River Evenlode and the River Glyne. These then merge to form a single river channel through the model extent, with a tributary feeding into this. Upstream of the site and through the model extent the catchment is moderately permeable. The tributary has relatively impermeable geology with watercourses dominated by surface water inputs rather than a significant baseflow component. No significant attenuation features such as reservoirs are present within the catchments. All catchments are considered rural and are not pumped.

Flooding mechanisms	The likely cause of flooding at this location is water exceeding channel capacity.
Gauged / ungauged	At the downstream extent of the catchment it is gauged; 39034 Evenlode @ Cassington Mill.
Final choice of method	A hybrid method was used, where the ReFH2 was used to generate design hydrographs and scaled using FEH statistical (pooled analysis).
Key limitations / uncertainties in results	A gauged station is located along a section of a River Evenlode. No gauging stations are present across the rest of the catchment area or the Rievr Glyme.

2.2 Note on Flood Frequencies

2.2.1 The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.

2.2.2 Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than annual exceedance probability (AEP). However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval. Results tables in this document contain both return period and AEP titles; both rows can be retained, or the relevant row can be retained and the other removed, depending on the requirement of the study.

2.2.3 The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

Table 2.2: Annual exceedance probability (AEP) and related return period reference table

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.0133	0.01	0.005	0.001
Return period (years)	2	5	10	20	30	50	75	100	200	1,000

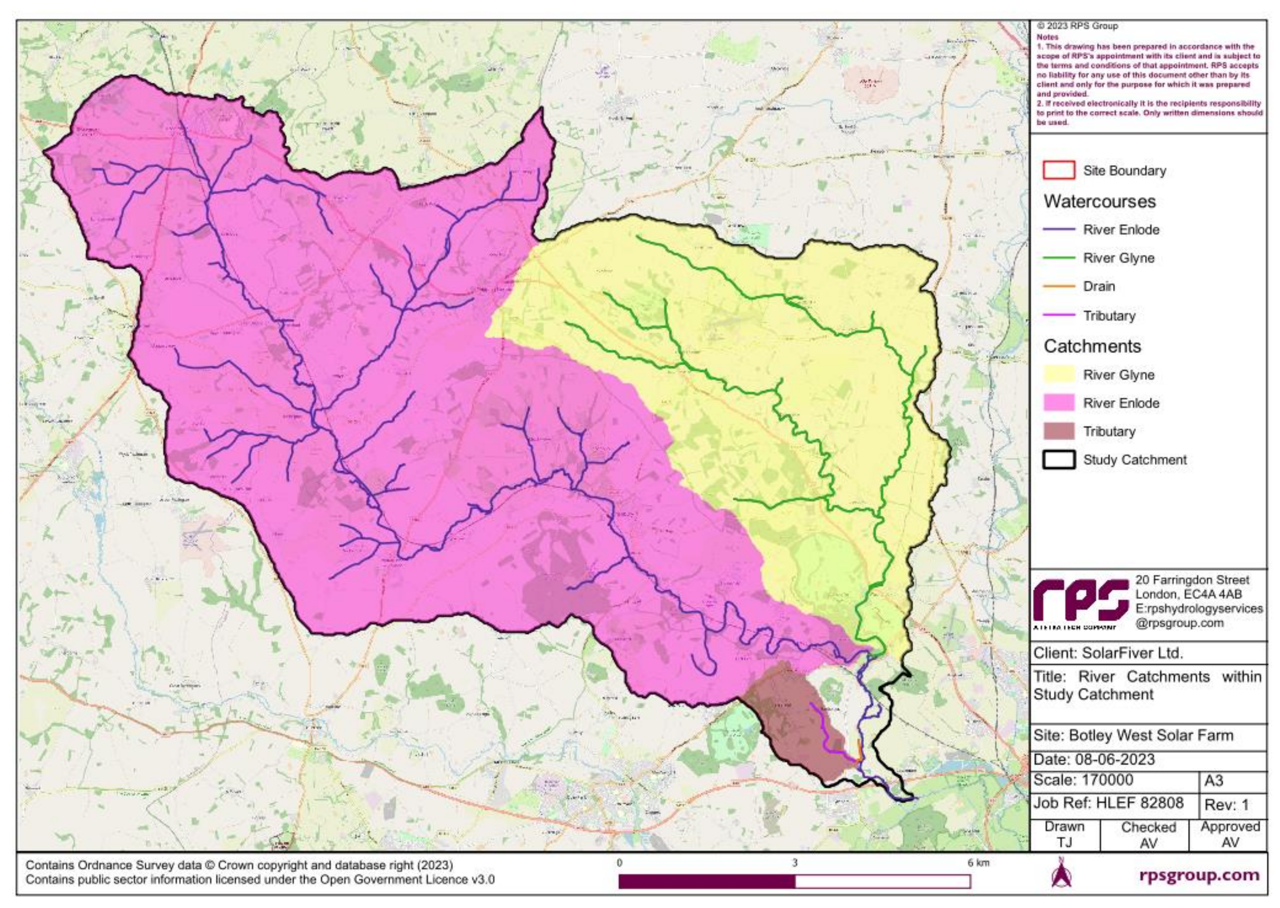
3 Method Statement

3.1 Requirements for Flood Estimates

Overview	The purpose of this study is to calculate peak flows and inflow hydrographs to be used for a hydraulic model of the River Evenlode and its tributary. The model will be used to assess the flood risk of a portion of a potential new solar farm in Oxfordshire. Design peak flow estimates will be derived for the 5%, 1%, and 1%+Climate Change (CC), 0.1% allowance AEP events (1 in 20, 100, 100 year+CC return periods and 1000 year). The flow hydrographs will be inputted as an upstream inflow combining flows of the River Evenlode and River Glyne. As well as for tributary which feeds into the River Evenlode. Two lateral flows are to be used for the residual flows between the

	upstream and downstream extent and are to be distributed across the model. This includes a proportional flow for a drain which feeds in to the River Evenlode. The latest EA Flood Estimation Guidelines from July 2022 as been used.
Project scope	This is a routine study, which will inform the hydraulic model for the River Evenlode. No previous studies are available for this watercourse. Note the hydraulic modelling report and analysis will be reported separately. The study will include flood estimation based on the standard FEH methods – Statistical and ReFH2. This document details the methods followed, outcomes and results, and the decision-making process and justification of final accepted flows.

3.2 The Catchment



Description	The subject site has an area of approximately 370 ha. It is located at about 6km north west of central Oxford and adjacent south west of Oxford Airport. To the north of the site the River Glyne converges with the River Evenlode and, the River Evenlode then flows in a southerly direction through the centre of the site. A tributary feeds in to the River Evenlode watershed towards the south of the site from the west. An additional drain joins the tributary, before it feeds into the River Evenlode. The watercourses and their catchment boundaries are shown in the figure above. The Cassington Canal runs adjacent to the River Evenlode. This watercourse is managed under the Canals and Rivers Trust and is managed through a series of locks. Therefore, it is not considered to pose a hydrological risk to the site and is therefore, not considered within this assessment.

	The River Evenlode discharges in to the River Thames approximately 1.5km south of the site. The study area, and the catchment boundaries of the River Evenlode, Glyne and the tributary are shown in Figure 10 1. The catchment is defined as essentially rural. The essentially rural nature of the catchment is reflected in the downstream catchment boundary FEH URBEXT2000 value of 0.0141. The catchment area of the River Evenlode down to the model downstream boundary (grid Ref NY 445600 209850) is 42,715.2 km^2. The FARL value for the catchment is 0.965 indicating the presence of a small proportion of storage areas in the catchment. Ponds and lakes are noted at Woodstock from OS mapping. In addition ponds are identified at Heythrop Park. The FARL values are appropriate given the size of the storage areas in comparison to the overall catchment size (42,715km2). FARL for the tributary which feeds into the river is 0.988, only a small pond is located within this tributary catchment. As such all FARL values were deemed appropriate. A review of the Soilscapes map of the area describes a mixture of soils within the catchment. The majority of the catchment has soils described as ‘Shallow lime-rich soils over chalk or limestone’ and ‘Freely, draining lime-rich soils.’ Along the River Evenlode before it converges with the River Glyne the soils are described as ‘Slightly acid loamy and clayey souls with impeded drainage’. An improved soils descriptor, BFIHOST19, is also available from the web service. This is the outcome of a comprehensive revision of the BFIHOST calculation process, which provided a set of revised BFIHOST coefficients for each of the 29 HOST classes (Griffin and others, 2019). Some coefficients are very different from those in the original HOST classification. The guidance recommends the use of BFIHOST19 descriptor, as it has been found to improve the estimation of QMED. BFIHOST19 is also recommended for use in the ReFH 2.3 method, because it provides improved predictions of model parameters, particularly on some clay and peat catchments. Therefore, the BFIHOST19 value of 0.671 (which in this case is close to the original value and confirms that the catchment is relatively permeable) was adopted for this study. The BFIHOST19 for the River Glyne catchment (HAP 1) is 0.799 which indicates high permeability. In contrast the tributary catchment has a lower BFIHOST19 of 0.484. The soils here are mostly comprised of ‘Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils’. Being in the mid low suggests relatively impermeable geology with watercourses dominated by surface water inputs rather than a significant baseflow component. The mean slope of the drainage path (m/km) within the catchment is represented by the DPSBAR value. Approximately 80% of catchments within the FEH have a DPSBAR value lower than 150. The values for DPSBAR indicate that the catchment is relatively flat - 46.4. This is confirmed from a review of LiDAR which indicates a relatively shallow gradient, concurrent with nformation regarding the general area around Oxford which is known for being generally quite low-lying.

3.3 Source of Flood Peak Data

Source	NRFA peak flows dataset, Version 10, released August 2021. This contains data up to water year 2019-20.

3.4 Gauging Stations (flow or level)

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of record and end if station closed
Evenlode	Evenlode at Cassignton Mill	NRFA	39034	430km2	Crump weir	01/1969

3.4.1 The gauging station utilises two different weir structures (crump and side spilling weir) to estimate flow for the site.

3.4.2 Daily flow data, live data and peak flow data is available for the gauge.

3.5 Rating Equations

3.5.1 Cassington is the combination of two weirs (1 Crump using BS equation & one side spill using a power law) up to 16 cumecs.

3.5.2 A modelled peak flow power law rating is used when the combined weir flow exceeds 16 cumecs and bypassing 500m upstream begins.

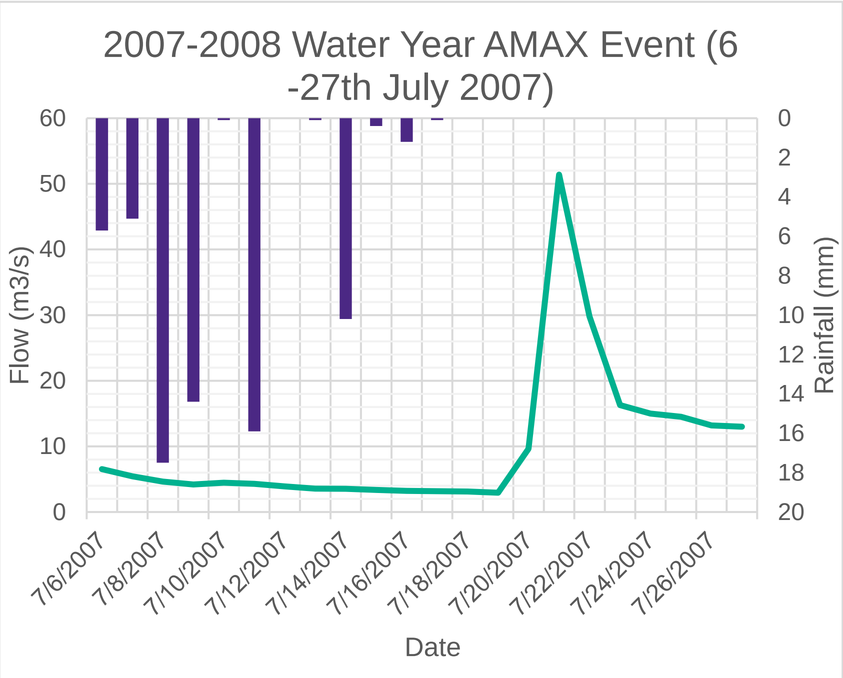
3.5.3 A detailed hydraulic modelling and review of rating was carried out after a July 2007 event, to account for spillage into the floodplain about 500m upstream which bypasses the gauging station. Rating adjusted from hydraulic modelling (EdenVale Young). One peak flow rating applied across the period of record.

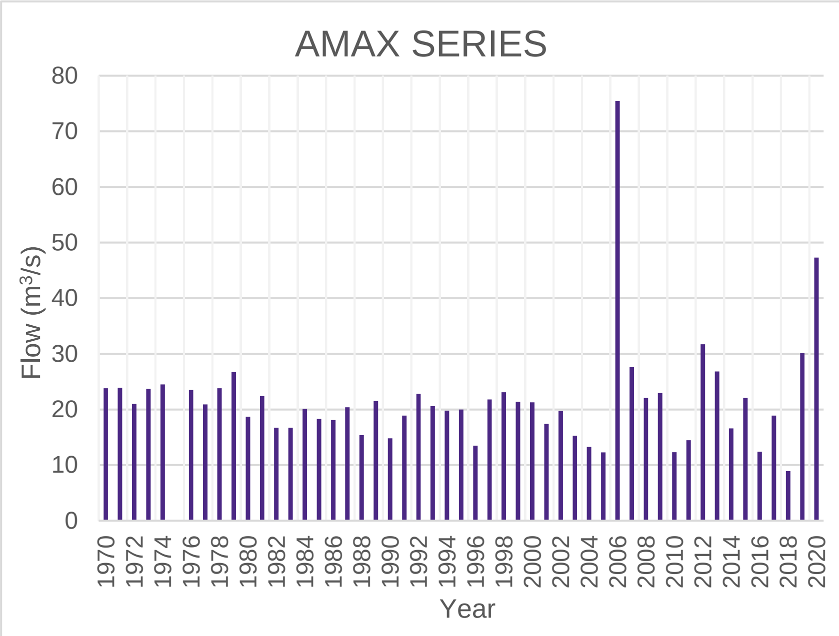
3.6 Other Data and how is has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gauging's	Yes	Yes	NFRA	Gauging station has a good data completeness with one missing year in 1976. The sensitivity of the station type is deemed to be 11.9%. Confident in hydraulic model derived rating for combined flows exceeding 16 m3s-1. One peak flow rating is applied across period of record. A review has been undertaken, post 2007 floods to account for the spillage upstream in the floodplain and the ratings have been adjusted from this hydraulic modelling work. Given the availability of the data, it is considered appropriate for use as a donor site.
Historical flood data	Yes	Yes	NFRA	Flow information for the gauging station recorded at 39034

Type of data	Data relevant to this study?	Data available?	Source of data	Details
				Evenlode at Cassington Mill. This indicates the high flows during the flood years of 2007 and 2020.
Flow or river level data for events	Yes	No	NFRA	Daily flows recorded for the years 1970-present at gauging station 39034. Max gauging flow was 75.46m3/s in 2007. Max gauging level was 47.29m in 2020. The bank full stage is noted as being 1.63m.
Rainfall data for events	No	No		
Potential evaporation data	No	No		
Results from previous studies	No	No		
Other data or information	No	No		

3.7 Hydrological Understanding of Catchment

Plots of flow data and interpretation	Evenlode gauging station (NFRA)	

Evenlode gauging station (NFRA)	 Flow data has been plotted for the entirety of the time period for the gauged station. This shows the extreme flooding which occurred in 2007 and 2020, resulting in the higher flow for these years.

Conceptual Model	The main area of interest is the area of the study site, which is It is located at about 6km north west of central Oxford and adjacent south west of Oxford Airport. The River Evenlode and Glyme run through the site flowing to the south east. The main source of potential flooding is fluvial assumed to be from overtopping of the banks and exceeding channel capacity of the watercourse and blockage of river structures. No defences are present along this section of reach. The high levels in the watercourse are most likely to be as a result of runoff in the upland areas of the upper catchment and the tributaries and channels which feed into the main channel. The flooding is driven by flood volumes in
	The catchment is not pumped nor heavily urbanised. The catchment is categorised as essentially rural in accordance with DEFRA 2007 Table 5.3 (URBEXT2000 = 0.0142) The catchment is permeable and (BFIHOST19 = 0.671). Much of the catchment has soils described as ‘Shallow lime-rich soils over chalk or limestone’ and ‘Freely, draining lime-rich soils.’ Along the River Evenlode before it converges with the River Glyne the soils are described as ‘Slightly acid loamy and clayey souls with impeded drainage’. BFIHOST 19 of 0.608. SPRHOST=24.1 (>20%) and no permeable adjustments were required. The FARL value for the catchment upstream of the site is 0.953 which indicates that there are some reservoirs in the upper catchment. However, there are no reservoirs along the main reach of Gaitle Burn, but some storages are located in the catchment if its tributary.

3.8 Initial choice of approach

Flood Estimation Handbook Appropriateness	The rural character of the catchment and size indicates that it is suitable for both FEH methods (statistical and ReFH2).
Initial Choice of Method(s)	The above information indicates that all factors are suitable for use both FEH methods (Statistical and ReFH2). Both methods will be applied and the results compared before a final decision is made. If the Statistical method is preferred over the ReFH2 method, then hybrid method will be used, where the ReFH2 will be used to generate design hydrographs and will be scaled to the FEH statistical (pooled analysis) peak flow. The flows estimated will be applied to the two top inflows for the River Evenlode and River Glyne will be applied as upstream boundary conditions. Two further lateral inflows will be applied further downstream as proportional flows. In addition the inflow of a small tributary towards the southern downstream extent will be estimated and applied as tributary flow in the model. The upstream flows of HAP1 and HAP2 will be derived separately to account for the differences in catchments and the flows will be combined for input into the model. Two lateral catchments (LATERAL_1 and LATERAL 2) will be derived by incremental catchment calculations from HAP 3 and HAP 5. These will be applied across the main River Evenlode channel, including a proportional flow for the drain. An additional inflow will be applied from the tributary (HAP 4). Critical storm duration will be calculated for the downstream catchment and applied to all catchments, ensuring consistent storm durations. Areal Reduction Factors (ARFs) will be applied to the relevant catchments using the donor station.
Software	The following software will be used: • FEH Webservice • WINFAP5 • ReFH2 Design Flood Modelling Software Version 2.3

3.9 Locations where flood estimates required

3.9.1 The table below lists the locations of subject sites. Incremental catchments have been derived as follows:

- LATERAL 1; HAP 3 – (HAP 1 + HAP 2)
- LATERAL 2; HAP 5 – (HAP 3 + HAP 4)

3.9.2 The site codes listed below are used in all subsequent tables to save space.

Table 3.1: Summary of subject sites

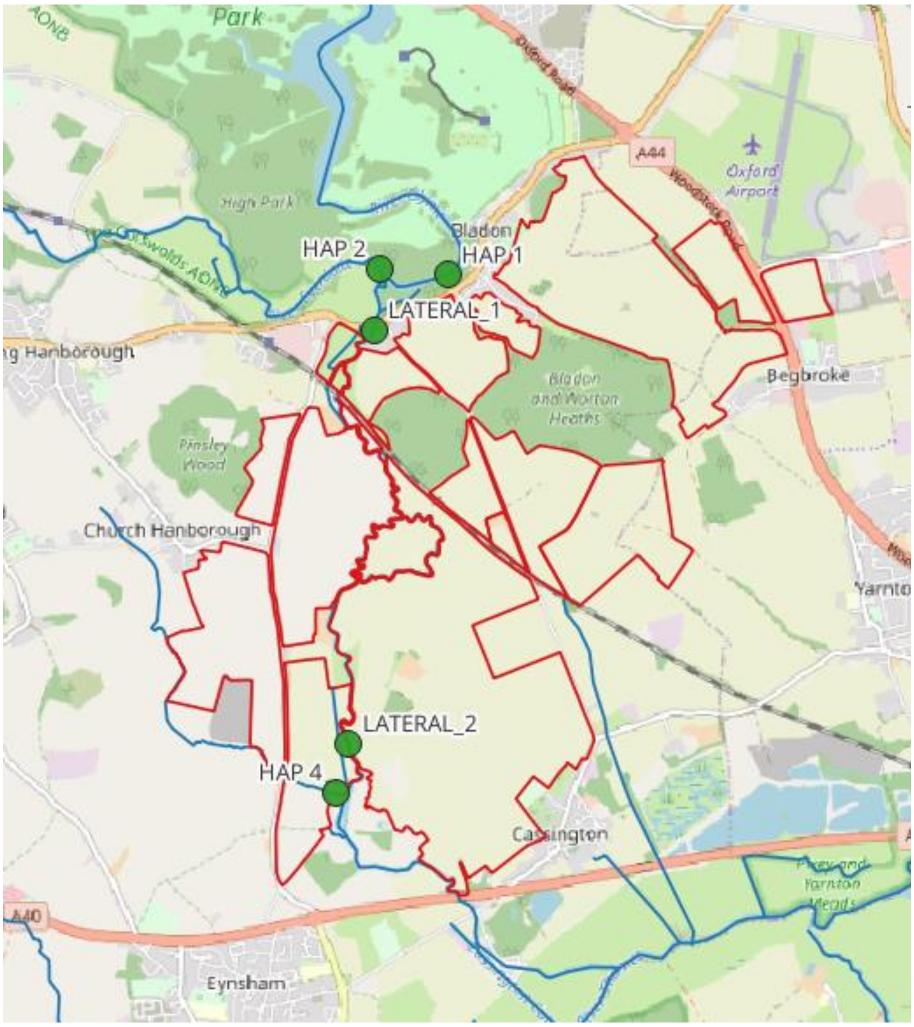
Site code	Type of estimate L: lumped catchment S: Sub-catchment	Water course	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km2)	Revised AREA if altered
HAP1	L	River Glyne	River Glyne upstream of the confluence with the River Evenlode	444600	214700	129	Not revised
HAP2	L	River Evenlode	Unnamed Tributary upstream of the confluence with River Evenlode	444100	214750	281	Not revised
HAP3	L	River Evenlode	Downstream Boundary of the site the confluence with River Evenlode	443850	211400	417	Not revised
Lateral_1	S	River Evenlode	Lateral between the confluence and the middle extent of the model, prior to the tributary	444076	214290	-	Calculated incremental
HAP 4	L	Unnamed tributary	Unnamed tributary coming from the west	443800	211000	8	Not revised
Lateral_2	L	Unnamed tributary	Lateral between the middle extent of the model, prior to the tributary and the downstream extent	443915	211353	-	Calculated incremental

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Water course	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km2)	Revised AREA if altered

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.

Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced.

The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



3.10 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	Area	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000
HAP 1	129.30	0.92	0.32	0.80	16.62	45.00	685	0.01	0.01

Site code	Area	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000
HAP 2	281.26	0.98	0.6	0.61	34.40	48.30	697	0.02	0.02
HAP 3	416.87	0.977	0.32	0.67	33.43	47.00	692	0.02	0.01
HAP 4	8.35	0.99	0.6	0.48	3.51	25.00	640	0.05	0.04

3.11 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	Catchment boundaries were checked using contour information from LiDAR. No adjustment to the catchment boundary shown on the FEH CD-ROM was considered necessary.
Record how other catchment descriptors were checked and describe any changes.	The SAAR values decrease moving down the catchment. PROPWET is suitable for the main catchments based on more permeable soils at the River Glyne compared to the main Evenlode catchment and tributary values. DPSBAR and DPLBAR are appropriate based on topography of catchment based on LiDAR mapping.
Source of URBEXT	URBEXT1990 / URBEXT2000
Method for updating of URBEXT	CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000

4 Statistical Method

4.1 Application of Statistical Method

Application of Statistical Method	Estimates of peak flow at key locations and deriving growth curves for a range of return periods. The gauged catchment has been used as a donor for HAP 2 as it is situated along this catchment reach. The donor has not been

4.2 Overview of estimation of QMED at each subject site

Site code	QMED (urban) from CDs (m3/s)	Final method	Data transfer: NRFA numbers for donor sites used (see 4.3)	Distance between centroids dij (km)	Moderated QMED adjustment factor, (A/B)a	If more than one donor: Weight	Weighted adjustment	Urban adjust-ment factor UAF	Final estimate of QMED (m3/s)
HAP 1	3.576	CD	N/A					1.04	3.770
HAP 2	20.789	Donor	1	21.2	0.301			1.04	21.603
HAP 3	21.439	Donor	1	12.4				1.04	21.439
HAP 4	1.262	CD	N/A					1.04	1.342

Are the values of QMED spatially consistent?	Yes
Method used for urban adjustment for subject and donor sites	Kjeldsen (2010)1 / WINFAP v42

Parameters used for WINFAP v4 urban adjustment if applicable

Impervious fraction for built-up areas, IF	Percentage runoff for impervious surfaces, PR_{imp}	Method for calculating fractional urban cover, URBAN
0.3	70%	From updated URBEXT2000

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).

The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial (rural) estimate from catchment descriptors.

Important note on urban adjustment

The method used to adjust QMED for urbanisation published in Kjeldsen (2010)[1] in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable. This is discussed in Wallingford HydroSolutions (2016)[2].

4.3 Search for donor sites for QMED (if applicable)

Comment on potential donor sites	By default, the WINFAP5 software selects six donor sites; however, the suitability is based only on the distance from the study area. The potential donor sites were reviewed. As the catchment was gauged at the downstream extent it was proposed to use this gauge (39034 Evenlode at Cassignton Mill) as a sole donor to update QMED values. This donor site had similar size, and descriptor values to the downstream catchment extent. With QMED observed at 20.8 compared to the downstream catchment at 19.75.

[1] Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

[2] Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

	The NFRA observed QMED was compared against the CD estimated QMED, the difference ratio was 0.984 with observed QMED slightly less than that estimated from catchment descriptors. As such this was used as the sole donor for the site. This was applied for the HAP 2 inflow, as all other catchments had differing catchments.

4.4 Donor Sites chosen and QMED Adjustment Factors

NRFA no.	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
39034	AM	No	20.8	21.88	0.984

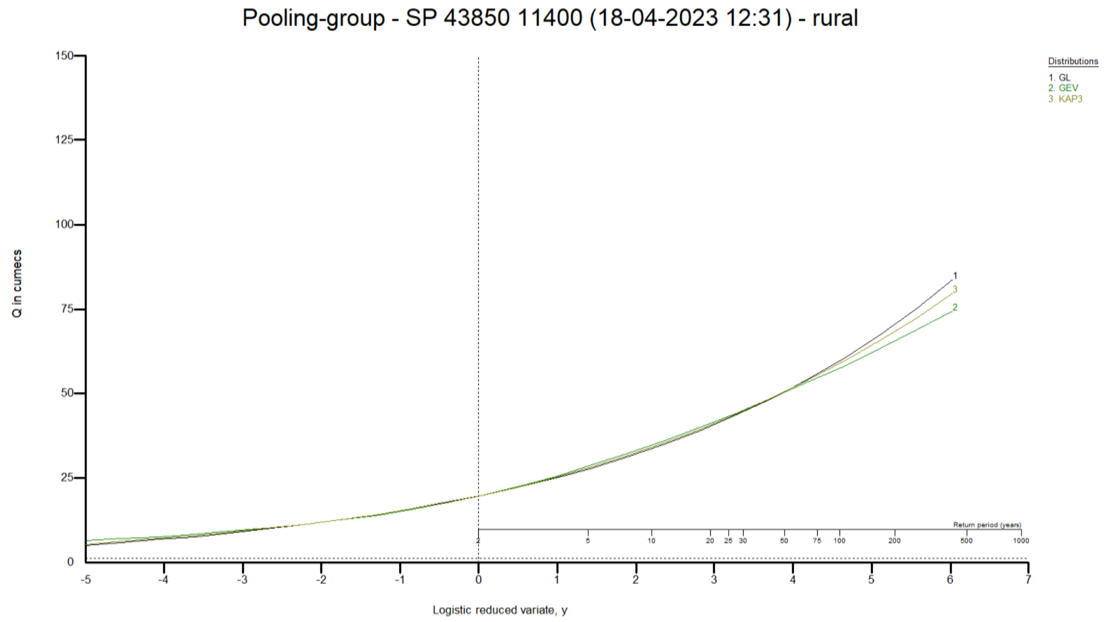
4.5 Derivation of pooling groups

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Weighted average L-moments L-CV and L-skew, (before urban adjustment)
Evenlode Pooling Group	HAP 3	No	33005 (Bedford Ouse @ Thornborough Mill) removed as negative L skew Total number of data years after removal is 510	L-CV 0.249 Lskew 0.241

Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008).

Table 4.1: Derivation of flood growth curves at subject sites

Site code	Method	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 100-year return period / 1% AEP
HAP 3	P	Evenlode Pooling Group	The GL distribution was selected with goodness of fit 2.478. This was the best goodness of fit out of all the distributions.	No permeable adjustments were made. A consideration of urban extent was made within the final QMED calculations	L-CV 0.248 Lskew 0.232	3.266



Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

Urban adjustments are all carried out using the method of Kjeldsen (2010).

Growth curves were derived using the procedures from Science Report SC050050 (2008).

4.6 Flood Estimates from the statistical method

Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events							
	50	20	10	5	2	1	0.5	0.1
HAP 1	3.77	5.37	6.61	8.02	10.25	12.31	14.77	22.51
HAP 2	21.48	30.58	37.67	45.70	58.41	70.14	84.12	128.23
HAP 4	1.34	1.91	2.35	2.86	3.65	4.38	5.26	8.01
LATERAL_1	0.40	0.57	0.70	0.84	1.08	1.30	1.55	2.37
LATERAL_2	0.27	0.38	0.47	0.57	0.73	0.87	1.05	1.60

5 Revitalised Flood Hydrograph (REFH) Method

5.1.1 N/A

6 Revitalised Flood Hydrograph 2 (REFH 2) Method

6.1 Application of Revised ReFH2 Method

What is the purpose of applying this method?	The purpose of applying this method is the lumped estimates at key locations for the purpose of checking and comparing modelled peak flow estimates obtained from the Statistical method and deriving hydrograph shapes.

6.2 Catchment sub-divisions for ReFH2 model

6.2.1 The sub-division approach is set out in the above sections.

6.3 Parameters for ReFH2 model

Site code	Method	Tp_{rural} (hours)	Tp_{urban} (hours)	C_{max} (mm)	PR_{imp} % runoff for impermeable surfaces	BL (hours)	BR
HAP 1	CD	10.468		899.532		84.101	3.124
HAP 2	CD	15.518		547.703		83.516	2.332
HAP 4	CD	5.182		396.879		44.210	2.538
Brief description of any flood event analysis carried out			N/A				

Methods: OPT: Optimisation, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)

Table 6.1. Design events for ReFH2 method: Lumped Catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
HAP 1	Urban	Winter*	26:25**
HAP 2	Urban	Winter	26:25
HAP 4	Urban	Winter	26:25
LATERAL_1	Urban	Winter	26:25
LATERAL_2	Urban	Winter	26:25

*The EA's Flood Estimation Guidelines recommends the use of winter profile for rural catchments. Although the urban extent has been captured in the overall profile, the overall urbanisation factor is low (0.665). As such the winter profile was selected for this analysis.

**The critical duration was selected by calculating the point were the flow plateaued.

6.4 Design events for ReFH2 method: Sub-catchments and intervening areas

6.4.1 N/A

6.5 Flood Estimates from the ReFH2 method

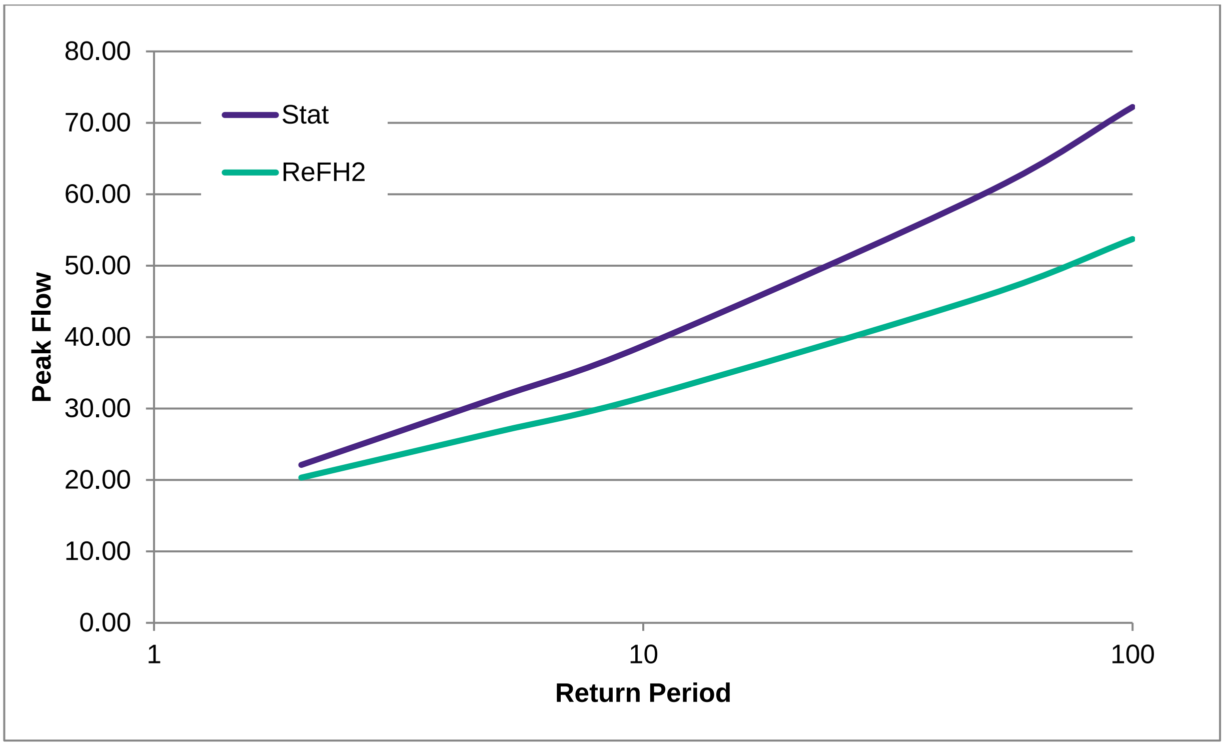
Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events							
	50	20	10	5	2	1	0.5	0.1
HAP 1	4.49	56.09	7.31	8.67	10.83	12.90	15.40	22.50
HAP 2	18.27	23.91	28.22	33.13	40.82	47.75	55.64	76.32
HAP 4	1.55	2.05	2.42	2.82	3.45	4.02	4.69	6.42

7 Discussion and Summary of Results

7.1 Comparison of Results from Different Methods

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years / 50% AEP			Return period 100 years / 1% AEP		
	ReFH	ReFH2	Statistical	ReFH	ReFH2	Statistical
HAP 1		4.49	3.77		1.7	1.8
HAP 2		18.27	21.48		1.6	1.8
HAP 4		1.55	21.33		1.6	1.8

7.2 Flood Frequency Curves for the different methods investigated (HAP 2)



7.3 Final Choice of Method

Choice of method and reasons	**Statistical Method** High confidence can be placed on the QMED estimated using the Statistical method and amended using the gauged catchment at the downstream extent for relevant catchments. The catchments have some storage features and the Statistical method is suitable for use in this type of catchments. In addition, the statistical method uses a sole donor for the HAP2 catchment; 39034 Evenlode at Cassington Mill gauge. **ReFH2** Peak flows based on catchment descriptors alone produced reasonable growth curves, which follow similar trend to the FEH statistical method (pooled analysis) growth curves. However with the increase of the return periods, the values become significantly lower. The catchment includes sub-catchments with widely differing flood responses, and there is no peak flow record downstream of their confluence, which makes it suitable for flood estimations with ReFH2. However, the peak flows resulting from the ReFH2, using the catchment descriptors are significantly lower than the flows estimated using the Statistical method. **Conclusion** The FEH Statistical method results in much higher flood estimates and incorporates the gauged catchment which places more confidence in this method The EA guidance advises that the FEH statistical method is based on much larger database of flood events and has been more directly calibrated to reproduce flood frequency on UK catchments and is therefore preferred to other rainfall run-off approaches. As such a hybrid method was used, where the ReFH2 was used to generate design hydrographs and scaled using FEH statistical (pooled analysis). The flows will be applied to a hydraulic model in line with the map in Section 10.3.2.
How will the flows be applied to a hydraulic model?	Refer to the map in Section 3.1.

7.4 Assumptions, Limitations and Uncertainty

List the main assumptions made (specific to this study)	FEH Statistical estimates are derived using catchment descriptors. In this case it has been calibrated and amended to gauged flows where appropriate. It is assumed that the empirical equations and the pooling groups derived from the catchment descriptors provide a good estimate of the flows in the subject watercourse. Assumed that the Winter Profile for deriving the hydrograph shape from the ReFH2 method is appropriate, based on the relatively rural nature of the catchment.
Discuss any particular limitations,	Amendment to donor site only undertaken for HAP 2 due to the sizes and differences in nature of the other catchments. As such some other inputs rely solely on catchment descriptors.

Provide information on the uncertainty in the design peak flow estimates and the methodology used	The uncertainty will depend on many factors, for example, how unusual the study catchment is relative to the pooling group and donor catchment, and the uncertainty in flow measurement at other gauges. However, a UK average measure of uncertainty has been produced by Kjeldsen (2014). The 95% confidence limits for a 1% AEP flood estimate are: • Without donor adjustment of QMED: 0.42 – 2.37 times the best estimate • With donor adjustment of QMED: 0.45 – 2.25 times the best estimate
Comment on the suitability of the results for future studies	The results from this study are consistent at different node locations and catchment areas. They could be used for future hydraulic modelling studies after sensitivity testing the results from the hydraulic modelling.

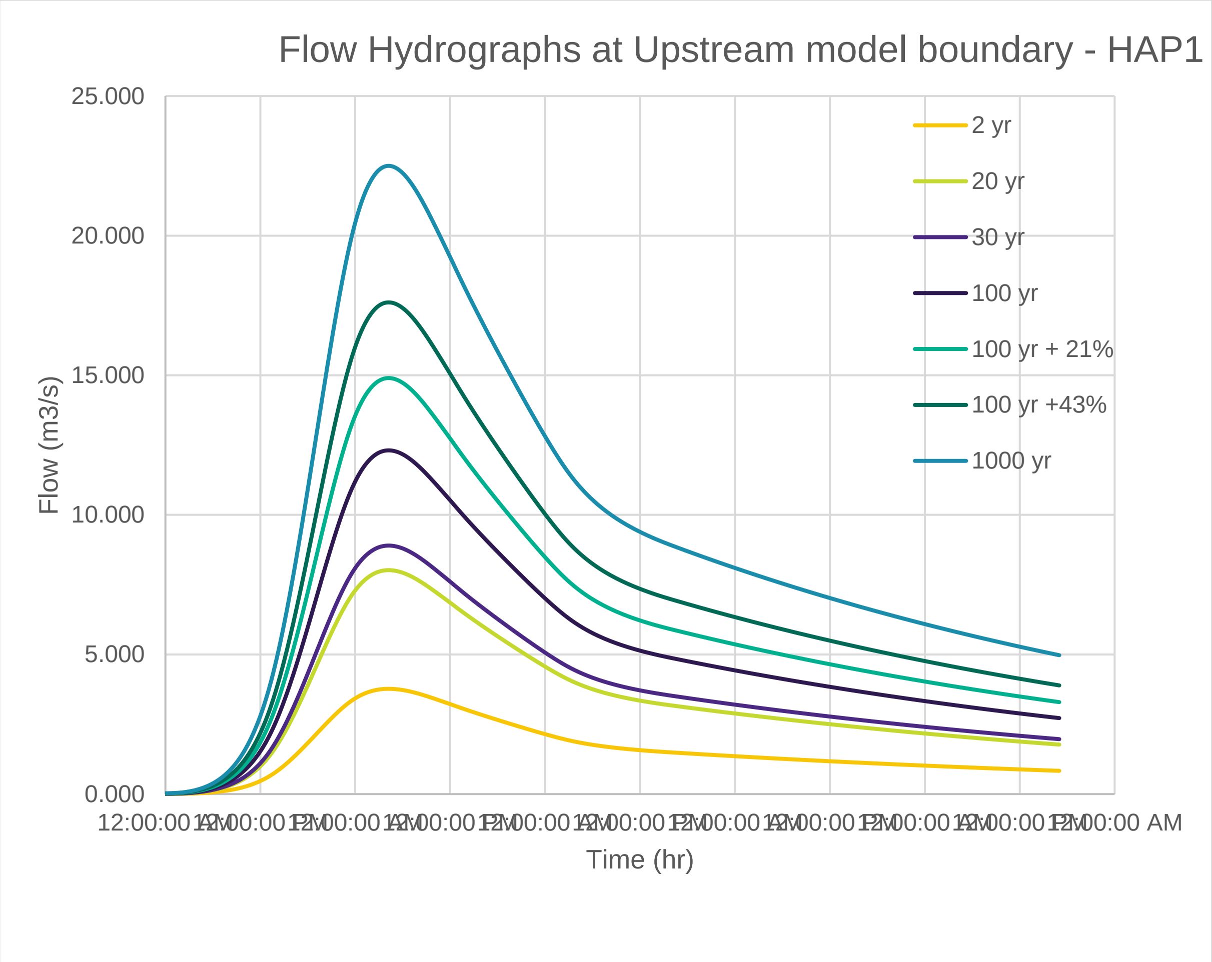
7.5 Checks

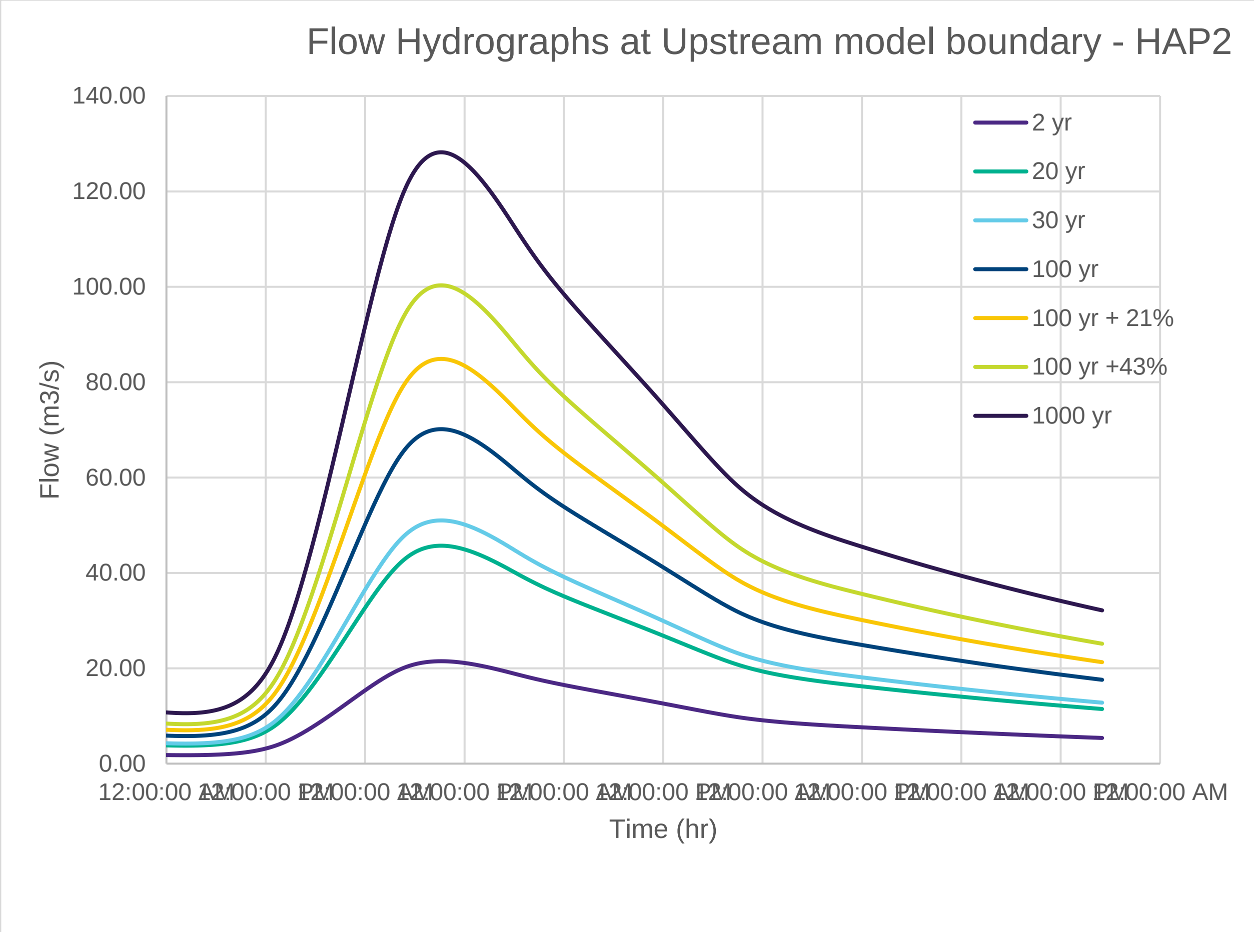
Are the results consistent, for example at confluences?	N/A
What do the results imply regarding the return periods / frequency of floods during the period of record?	The results show that with increased return period there is increased flow, proportionally, according to the growth curves in which there is good confidence.
What is the range of 100-year / 1% AEP growth factors? Is this realistic?	Growth factors are: Statistical method – 1.8 ReFH2 method – 1.6 to 1.7 The factors are realistic
If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?	Statistical method – 1.8 ReFH2 method – 1.6
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	N/A
Are the results compatible with the longer-term flood history?	N/A
Describe any other checks on the results	No flood history for the study area was available.
	N/A

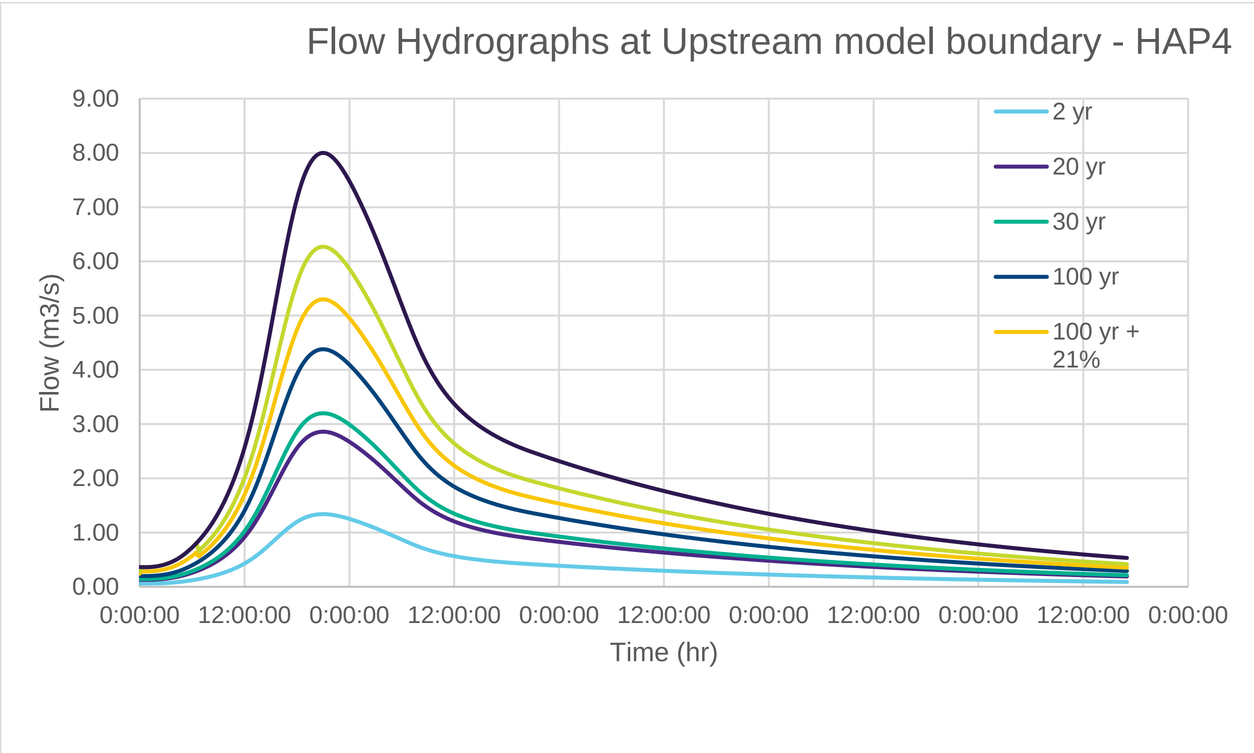
7.6 Final Results

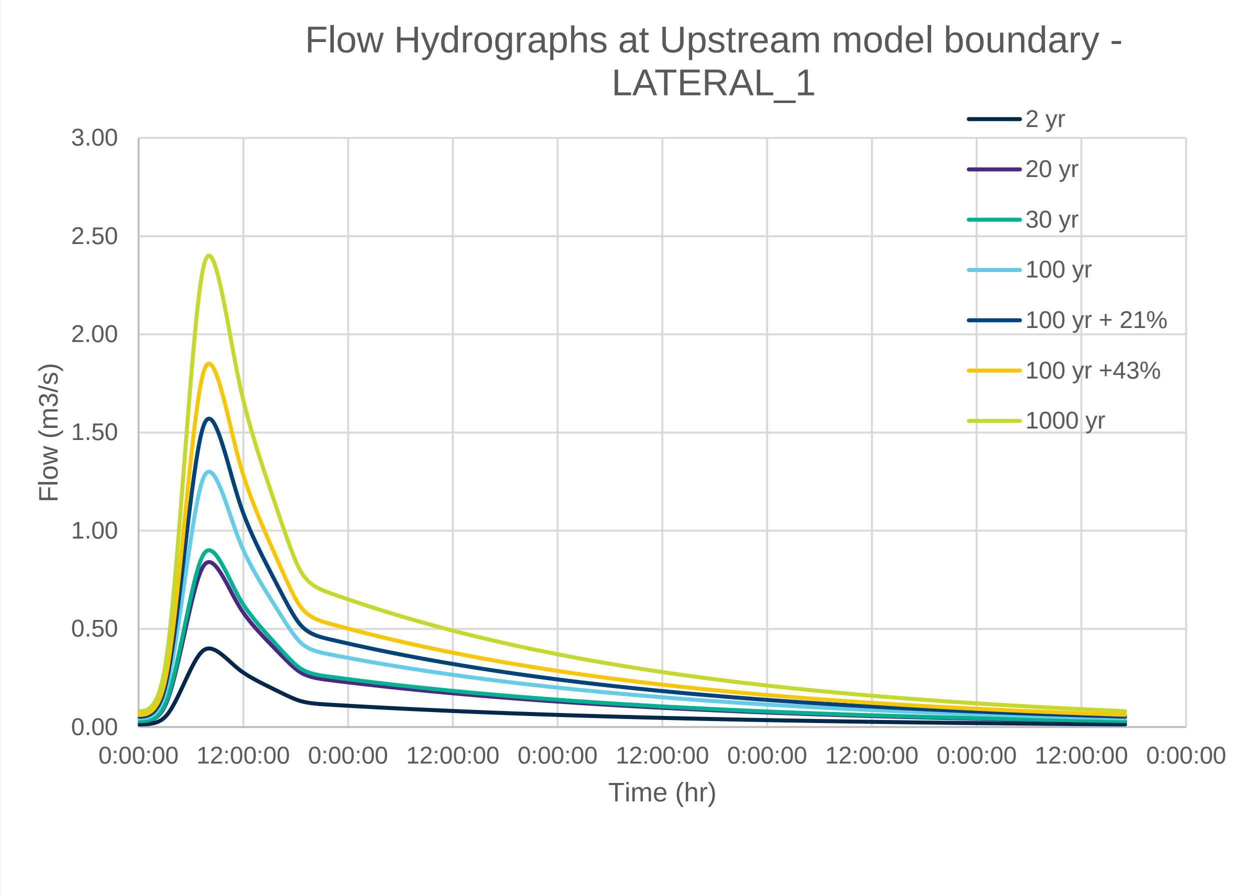
Table 7.1. Flood peak (m3/s)

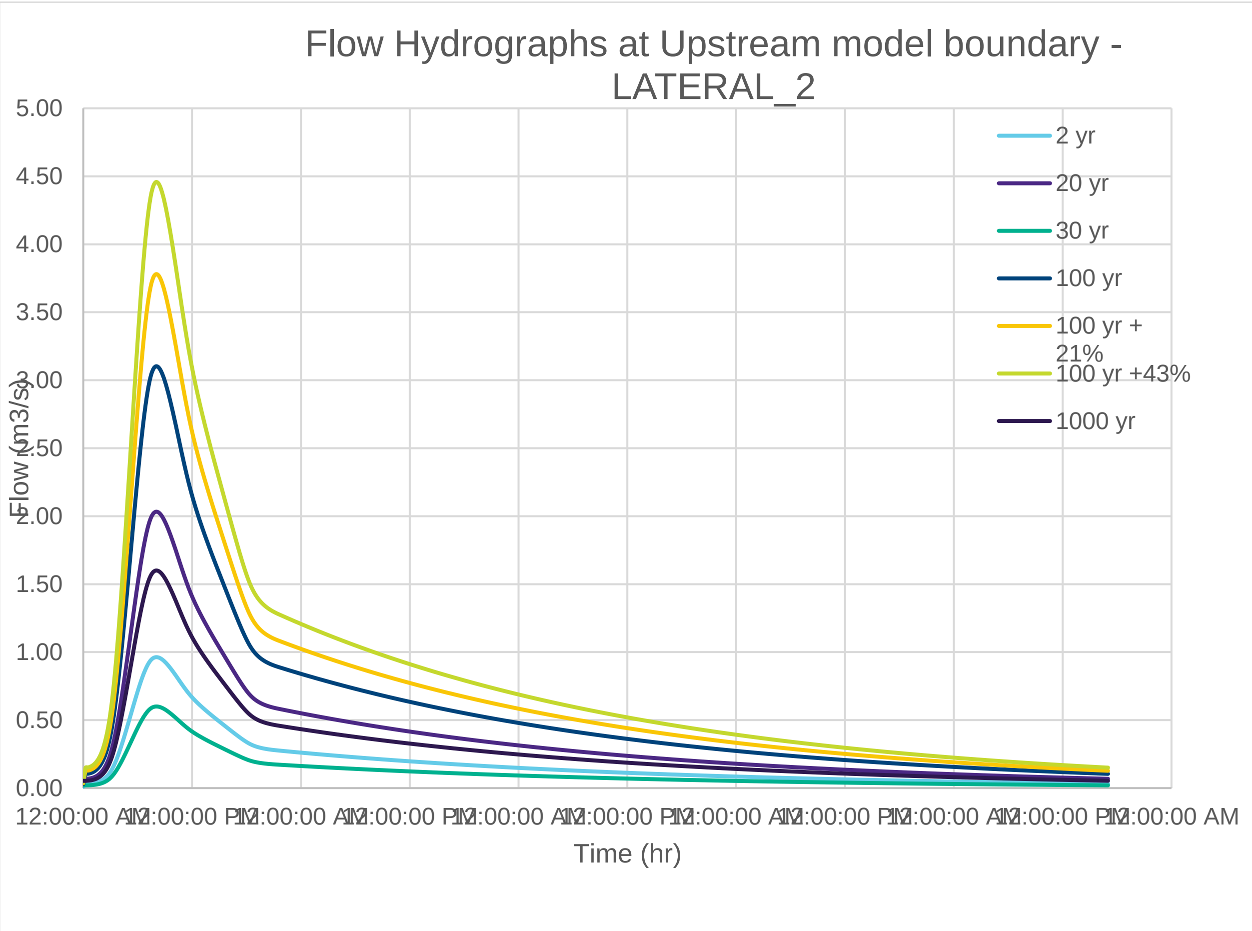
Site code	Flood peak (m^3/s) for the following return periods (in years)							
	2	5	10	20	50	100	200	1000
	Flood peak (m^3/s) for the following AEP (%) events							
	50	20	10	5	2	1	0.5	0.1
HAP 1 Statistical	3.77	5.37	6.61	8.02	10.25	12.31	14.77	22.5
HAP 1 ReFH2	4.49	6.09	7.31	8.67	10.83	12.90	15.40	22.50
HAP 2 Statistical	21.48	30.58	37.67	45.70	58.41	70.14	84.12	128.2
HAP 2 ReFH2	23.91	28.22	33.13	23.91	40.82	47.75	55.64	76.32
HAP 4 Statistical	1.34	1.91	2.35	2.86	3.65	4.38	5.26	8.0
HAP 4 ReFH2	2.05	2.42	2.82	2.05	3.45	4.02	4.69	6.42
LATERAL_1 Statistical	0.40	0.57	0.70	0.84	1.08	1.30	1.55	2.4
LATERAL_1 ReFH2	1.72	2.08	2.46	1.72	3.04	3.57	4.18	5.89
LATERAL_2 Statistical	0.27	0.38	0.47	0.57	0.7	0.87	1.05	1.6
LATERAL_2 ReFH2	0.48	0.59	0.70	0.48	0.87	1.03	1.22	1.75




Flow Hydrographs at Upstream model boundary - HAP2
Flow (m3/s)
Time (hr)
2 yr
20 yr
30 yr
100 yr
100 yr + 21%
100 yr +43%
1000 yr


Flow Hydrographs at Upstream model boundary - HAP4
Flow (m3/s)
Time (hr)
2 yr
20 yr
30 yr
100 yr
100 yr + 21%


Flow Hydrographs at Upstream model boundary - LATERAL_1
2 yr
20 yr
30 yr
100 yr
100 yr + 21%
100 yr +43%
1000 yr
Flow (m3/s)
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0:00:00
12:00:00
0:00:00
12:00:00
0:00:00
12:00:00
0:00:00
12:00:00
0:00:00
12:00:00
0:00:00
Time (hr)


Flow Hydrographs at Upstream model boundary - LATERAL_2
2 yr
20 yr
30 yr
100 yr
100 yr + 21%
100 yr +43%
1000 yr
Flow (m3/s)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Time (hr)

7.7 References

Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrology Research v.41. p. 391-405.

Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

8 Annex

8.1 Pooling Group Composition

Site Number / Name	Initial Years of Data	QMED
27010 (Hodge Beck @ Bransdale Weir)	41	9.42
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	10	5.972
44008 (South Winterbourne @ Winterbourne Steepleton)	41	0.448
25019 (Leven @ Easby)	42	5.384
44013 (Piddle @ Little Puddle)	28	0.895
73015 (Keer @ High Keer Weir)	29	12.421
72014 (Conder @ Galgate)	52	16.779
28041 (Hamps @ Waterhouses)	35	26.5
27051 (Crimple @ Burn Bridge)	48	4.544
41020 (Bevern Stream @ Clappers Bridge)	51	13.66
24006 (Rookhope Burn @ Eastgate)	20	24.62
49004 (Gannel @ Gwills)	51	14.975
28058 (Henmore Brook @ Ashbourne)	13	8.838
51003 (Washford @ Beggearn Huish)	52	6.113
27010 (Hodge Beck @ Bransdale Weir)	41	9.42
Total	**513**	