

Flood Estimation Report: Lodge Road, Hurst.

Prepared by SLR on behalf of MacTaggart & Mickel Group Ltd.

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Approval

Revision stage	Analyst:	Approved by:	Amendments	Date
Flow Estimation Methodology Report	AH			05/06/25
Revision v2	CN	KS	The calculations and this accompanying calculation record have been revised following third party review comments provided by Arcadis.	07/07/2025

Abbreviations

Abbreviation	Short for
AEP	annual exceedance probability
AMAX	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST19	Base Flow Index derived using the HOST soil classification, revised in 2019
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
GEV	Generalised Extreme Value
GLO	Generalised Logistic
HOST	Hydrology of Soil Types
IF	Impervious Fraction
IRF	Impervious Runoff Factor
LF	Low flow statistics (flow duration curve)
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
T _p	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP	Windows Frequency Analysis Package (software that can be used for FEH statistical method)

1. Summary of assessment

1.1 Summary

Catchment location:

The catchment is located in Hurst, Berkshire, and is centred on National Grid Reference (NGR) SU 79545 73455. The catchment drains to an unnamed tributary of the River Loddon. The catchment extent has been delineated based on Environment Agency (EA) 1m resolution LiDAR data and a flow tracing algorithm within a GIS package, the EA 'Most Probable Overland Flow Pathway's dataset'¹, Ordnance Survey (OS) mapping and aerial imagery.

Purpose of study and complexity:

The purpose of the study is to derive peak fluvial flows and net rainfall estimates for input into a hydraulic model to quantify flood risk to land proposed for residential development.

The study assesses fluvial and pluvial (rainfall) generated surface water flood risk. The fluvial and pluvial scenario assessments are assessed separately and the methodologies and inputs used for each scenario are detailed within the relevant sections herein.

Key catchment features:

The catchment has an upstream area of less than 0.5 km² and is characterised by low topographic relief with little variation in elevation. The catchment URBEXT₂₀₀₀ value (updated to the present year of 2025) is 0.12 and is hence classified by the FEH definition as being a 'slightly to moderately urbanised catchment'.

The adopted BFIHOST19 value of 0.63 does not classify the catchment as being highly permeable, by FEH definitions (BFIHOST19 > 0.65), however based on the underlying soil and geology, the catchment is considered moderately permeable.

The catchment has a low annual average rainfall (SAAR) value of 641mm.

Flooding mechanisms:

Based on the NaFRA 2 'flood zone' data (published 25 March 2025) the Site is generally located within fluvial Flood Zone 1 (Low Probability) defined as land having a less than 0.1% annual probability of river or sea flooding. The western

¹ [Overland Flow Pathways](#)

Site boundary is shown to encroach into Flood Zone 2 and 3, although this encroachment is minimal in extent. Along the unnamed watercourse and to the east towards Tape Lane at NGR 79569 SU 73737, there are areas of surface water flooding shown.

Initial model runs and sensitivity testing has demonstrated that fluvial flooding is volume driven with longer storm durations and hence longer duration hydrographs resulting in increased flooding. The catchment is formed wholly over naturally wet, loamy soils with high groundwater² which may act to exacerbate flooding from either fluvial or pluvial sources.

Gauged / ungauged:

The catchment is ungauged.

Final choice of method:

Fluvial flood estimates have been derived based on the FEH Statistical method, using the small catchment procedures and compared against flood estimates derived by the ReFH2 rainfall-runoff method. The final fluvial flood estimates are based on the more precautionary i.e., larger estimates produced by the ReFH2 rainfall-runoff methodology.

Design net rainfall has been derived within the ReFH2 software and based on the EA standards³ with which surface water modelling practices and model outputs need to comply.

Key limitations / uncertainties in results:

The catchment is ungauged and hence no level or flow data is available for informing the sensibility of the fluvial flows derived, nor to use in model validation. The assumption is made that the fluvial estimates are representative. In support of this assumption, there is general agreement between the ReFH2 and FEH Statistical estimates derived for the study, however the absence of gauged empirical information must be acknowledged as a limitation to the confidence in either the hydrological analysis or fluvial hydraulic model outputs.

Similarly, whilst the net rainfall adopted in the study has followed the standards as set out in Risk of Surface Water Flooding (RoSWF) Appendix A – Modelling standards; there is an absence of a suitably located rain gauge within the catchment which provides a sufficiently long record to allow statistical analysis to infer probable rainfall totals.

² [LandIS - Land Information System - Soilscales soil types viewer](#)

³ [River modelling: technical standards and assessment - GOV.UK](#)

Given the mixed rural and urban components comprising the subject catchment, variable losses are applied to the rainfall directly within ReFH2. This is an accepted approach that is documented within the EA Flood Estimation Guidelines and is adopted due to the need to simplify the methodology of applying the losses over the catchment. It is assumed that the resulting net rainfall is representative of actual storm events and losses however, it is important for the reader to understand the limitations and the assumption made.

Uncertainty with respect to the hydraulic model and outputs are inherent from the adopted model parameters but also the input hydrology, topography, and crucially the ability to validate the model. As stated, the catchment is ungauged and hence there is limited information by which to validate the model. Sensitivity testing of model inflows, adopted hydraulic roughness and downstream boundary conditions has been undertaken and hence provides a range of flood scenarios by which to quantify the potential uncertainty.

1.2 Flood frequencies

- 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.
- Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than 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.
- The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

AEP (%)	50	20	10	5	3.3	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.013	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

2. Method Statement

2.1 Requirements for flood estimates

Overview and Project Scope:

SLR Consulting (SLR) has been appointed by MacTaggart & Mickel Group Limited to undertake hydraulic modelling of flood risk to land located east of Lodge Road, Hurst (the “Site”), centred on National Grid Reference (NGR) SU 79440 73648. Specifically, the assessment focuses on the unnamed tributary of the River Loddon that flows close to the western site boundary.

The Site has previously been refused planning permission with an objection from the Environment Agency (EA) on flood risk grounds. The objection states that detailed site-specific modelling is required to calculate an appropriate and precautionary design flood level for the 1% annual probability flood including an allowance for climate change (1% CC flood event).

A hydrological analysis is required to derive peak flow hydrographs, and total net rainfall hyetographs which are input into the hydraulic model to simulate both fluvial and pluvial surface water flooding in the vicinity of the Site. The fluvial and pluvial scenario assessments are assessed separately and the methodologies and inputs used for each scenario are detailed within the relevant sections herein.

Fluvial hydrographs and net rainfall hyetographs are derived and reported for the 3.3%, 3.3% + Climate Change (CC), 1%, 1% + CC, 0.1% and 0.1% + CC AEP events only.

NaFRA2 Context:

Based on the New NaFRA2 ‘flood zone’ data, published 25 March 2025, the Site is generally located within fluvial Flood Zone 1 (Low Probability) defined as land having a less than 0.1% annual probability of river or sea flooding. The western Site boundary is shown by the EA Flood Map for Planning to encroach into Flood Zone 2 and 3, although as shown on Figure 2-1 this encroachment is minimal in its extent.

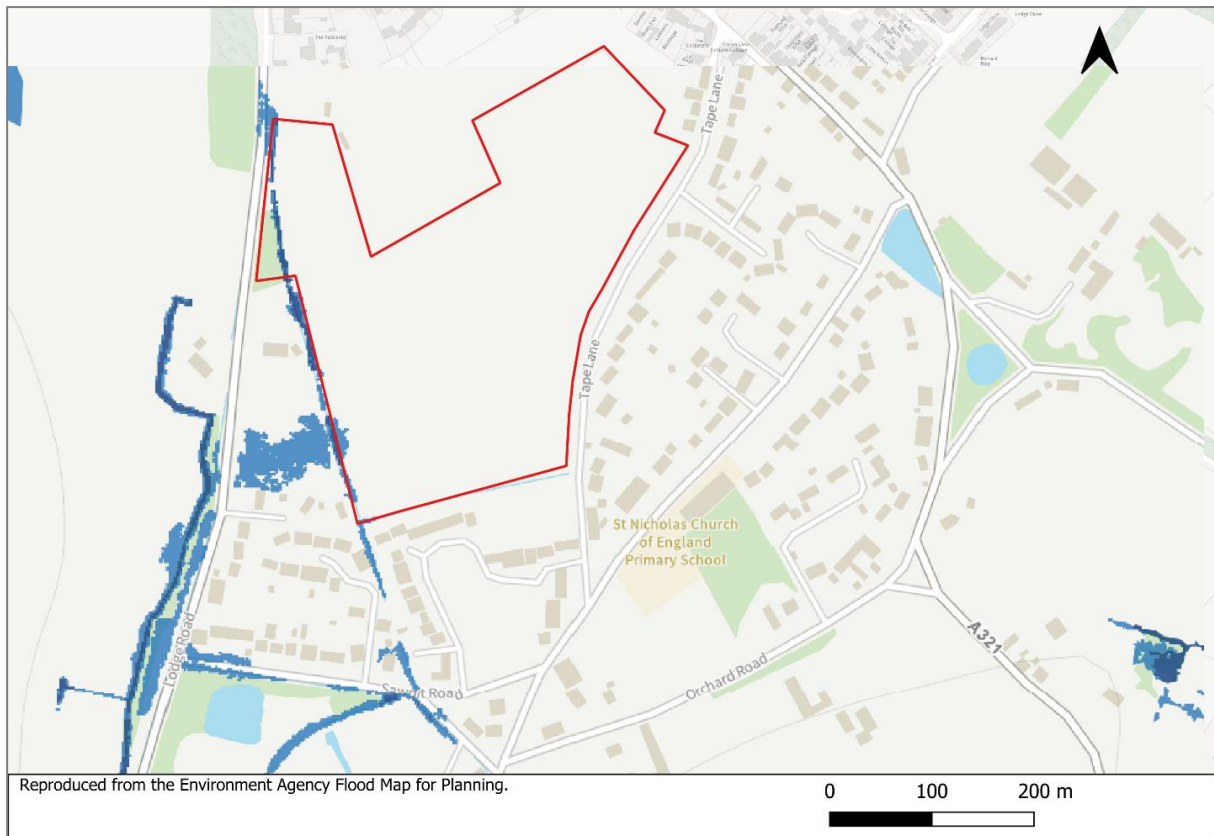


Figure 2-1 Risk of Flooding from Rivers and Sea Flood Zones

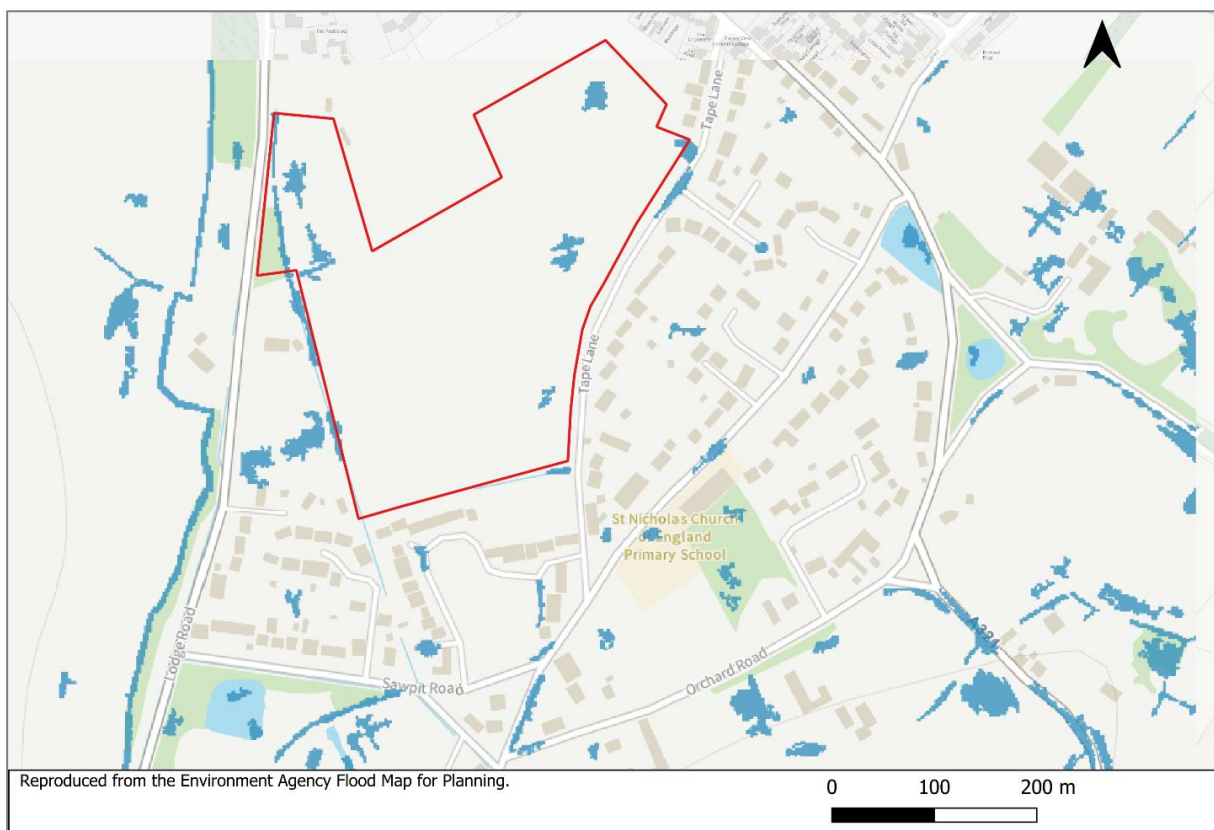


Figure 2-2 Risk of Flooding from Surface Water (RoFSW) 1 in 100 Annual likelihood of flooding

Along the unnamed watercourse and to the east i.e., at NGR SU 79307 73815 and towards Tape Lane at NGR 79569 SU 73737 there are areas of surface water flooding shown. The surface water flood risk for the 1 in 100 annual likelihood of flooding (1% AEP) is shown in Figure 2-2

The EA Flood Map for Planning is indicative and does not provide information regarding how likely an individual property will flood nor for example, about flood risk from sources such as blocked drainage infrastructure. The EA Flood Map for Planning is suitable for checking only whether a proposed development is in Flood Zone 1, 2 or 3. Hence, a site specific hydraulic model of the unnamed watercourse is required to quantify the fluvial flood risk and surface water flood risk to the site and to confirm or otherwise the extent of flooding shown by the EA Flood Map for Planning.

2.2 The Catchment

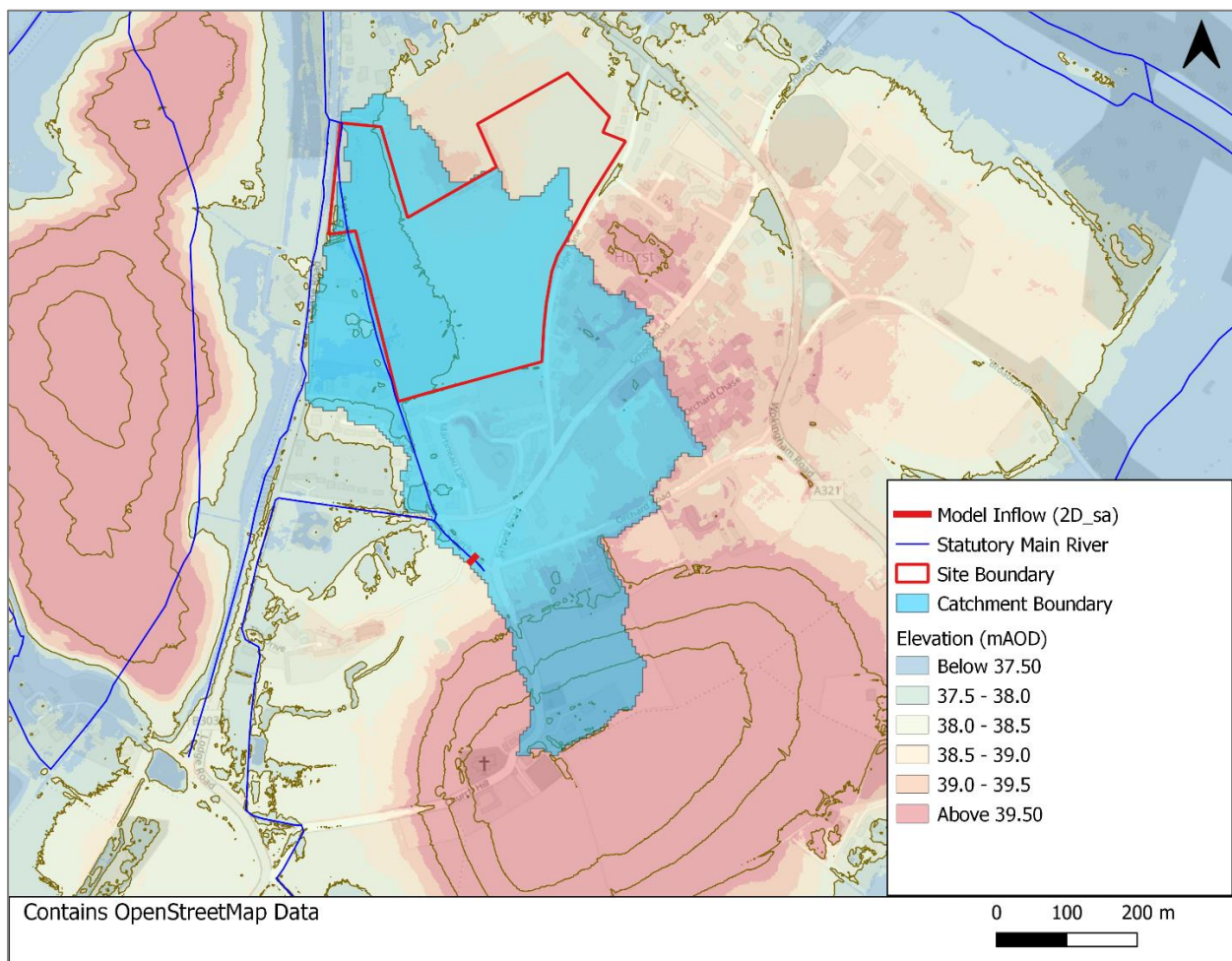


Figure 2-3 Location Plan Showing Statutory Main Rivers, Subject Catchment Area, Model Inflow Location and Site Boundary

Catchment Description:

The catchment covers an area of approximately 0.27 km², draining from southeast to northwest and is characterised by low topographic relief with little variation in elevation. Elevations range from a maximum 46.2 mAOD in the catchment headlands to 37.5 mAOD at the catchment outlet.

As the catchment is <0.5 km² and hence not defined by the FEH Web Service, Catchment Descriptors (CDs) for the site were obtained for the downstream catchment outlet at National Grid Reference (NGR) SU 79750 74550.

A review of the British Geological Survey (BGS) GeoIndex Mapping⁴ indicates that the catchment is largely underlain by moderately permeable bedrock of the Lambeth Group. The southern (upstream) portion of the catchment is underlain by the London Clay Formation. The bedrock geology is overlain by superficial deposits of the Kempton Park Gravel member, comprising of sand and gravel. Based on Soilscales Mapping, produced by Cranfield University; the catchment is shown in Figure 2-4 to be formed wholly over naturally wet, loamy soils with high groundwater⁵.

⁴ [GeoIndex - British Geological Survey](#)

⁵ [LandIS - Land Information System - Soilscales soil types viewer](#)

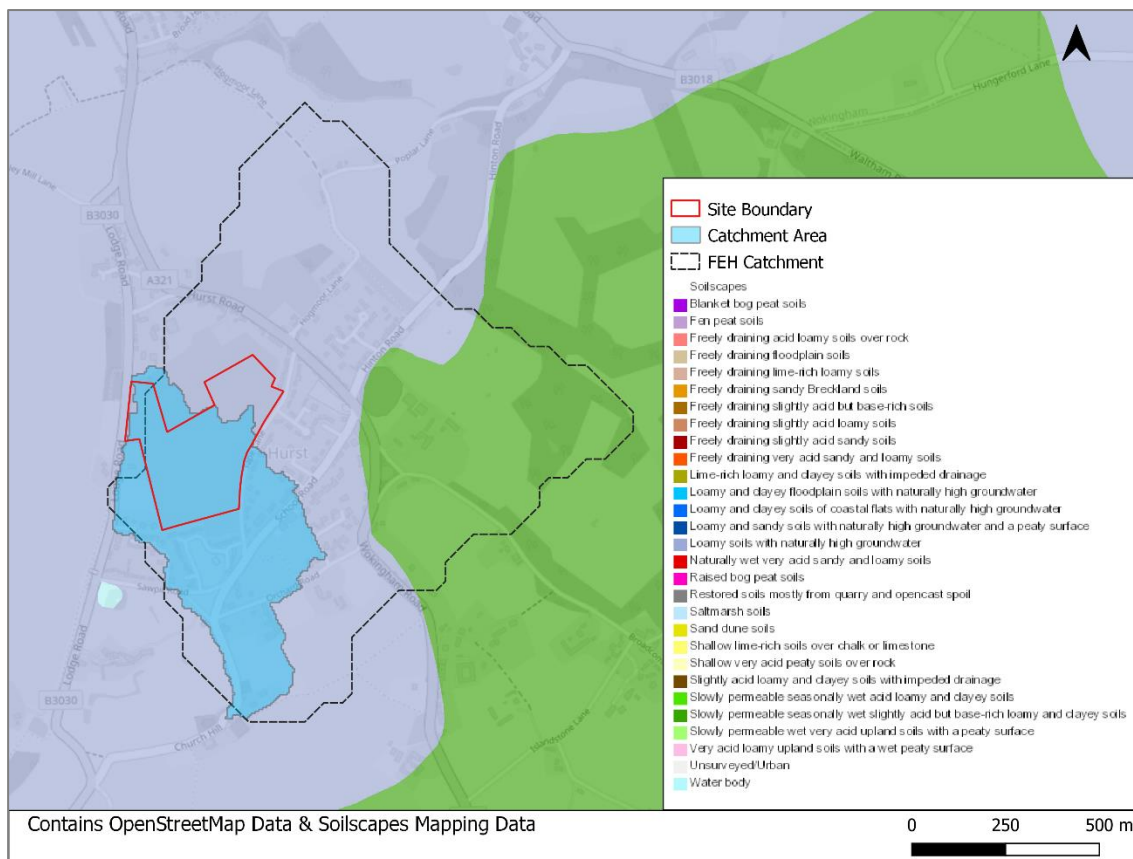


Figure 2-4 Location Plan Showing Soil Distribution

The catchment BFIHOST19 value of 0.498, for the downstream catchment outlet, where FEH CDs were obtained, is not reflective of the moderate permeable nature of the subject catchment geology and overlying soils. Figure 2-4 shows the FEH 'donor' catchment and the subject catchment. The subject catchment is shown to be formed wholly over naturally wet, loamy soils with high groundwater whilst the FEH 'donor' catchment includes the soil type (shown in green) which is described as slowly permeable and seasonally wet. FEH point scale data has been obtained for a 1 km grid square at NGR SU 79435 73733 centred over the subject catchment to provide an improved representation of the BFIHOST19 value.

The adopted BFIHOST19 value of 0.63 does not classify the catchment as being highly permeable by FEH definitions (BFIHOST19 > 0.65) however, based on the underlying soil and geology, the catchment is considered moderately permeable.

The catchment URBEXT₂₀₀₀ value (updated to the present year of 2025) is 0.12 and is hence classified by the FEH definition as being a 'slightly to moderately urbanised catchment'.

The catchment has a moderately low annual average rainfall (SAAR) value of 641 mm; this is consistent between the point and catchment data obtained and hence no revisions were made to the FEH value of SAAR. The adopted Catchment Descriptors are presented under Section 3.2 'Catchment Descriptors'.

2.3 Hydrometric Data

Source of flood peak data:

NRFA peak flows dataset, Version 13, released on 29th August 2024. This contains data up to the end of September 2023.

Gauging stations (flow and level):

The study watercourse is ungauged.

Other data available and how it has been obtained:

Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Check flow gaugings	No	No	NA	The subject catchment is ungauged and hence no check flow gaugings or other hydrometric data.
Historical flood data	Yes	Yes	Environment Agency Historic Flood Map ⁶	Limited flood extent information is available for the site (one record). Flood extent information, derived from aerial photography following occurrence of a storm event between 23/12/2002 and 12/01/2003 is available. The EA comments suggest that flooding appears to be SW rather than fluvial which given the disconnectivity from the watercourse, seems reasonable. The 3 monthly rainfall totals (between october_december-2002) were 151% of the 1961-1990 long term average. Hence it is likely that the catchment antecedent conditions, specifically high ground water levels, exacerbated the flooding. The usefulness of the flood outline for validating model results is limited.

⁶ [Historic Flood Map](#)

Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Flow or river level data for events	No	No	NA	The subject catchment is ungauged.
Rainfall data for events	No	No	FEH Web Service	There is no rain gauge located within the catchment itself nor with sufficient length of record to derive design rainfall. The nearest rain gauge is >5 km from the site. It is not anticipated to use event rainfall and hence FEH22 design rainfall data is instead sourced from FEH Web Service.
Potential evaporation data	No	No	NA	No modelling of storm events is anticipated hence no requirement for PET data.
Results from previous studies	No	No	NA	There are no other known studies made or readily available to review the current flood estimates against
Other data or information	No	No	NA	NA

2.4 Hydrological understanding of the catchment

Conceptual model:

The target watercourse is ungauged and as such a conceptual approach has been applied. The main site of interest is a proposed residential development at NGR SU 79440 73648. The 'red line' boundary of the site is shown previously on Figure 2-3. The primary flooding mechanism at the site is expected to be from fluvial flooding originating from the minor unnamed watercourse which flows along the western site boundary. Initial model runs and sensitivity testing has demonstrated that fluvial flooding is volume driven with longer storm durations (and hence longer hydrograph durations) resulting in increased flooding. The catchment is formed wholly over naturally wet, loamy soils with high groundwater⁷ which may act to exacerbate flooding from either fluvial or pluvial sources.

⁷ [LandIS - Land Information System - Soilscape soil types viewer](#)

Unusual catchment features:

The catchment has an URBEXT₂₀₀₀ value (updated to the present year of 2025) of 0.12 and is hence classified by the FEH definition as being a 'slightly to moderately urbanised catchment'. The catchment is characterized by low topographic relief with little variation in elevation. This combined with an extensive drainage network makes defining the topographic catchment difficult.

The adopted BFIHOST19 value of 0.63 does not classify the catchment as being highly permeable by FEH definitions (BFIHOST19 > 0.65) however based on review of underlying soil and geology, the catchment is moderately permeable.

2.5 Initial choice of approach

Are FEH methods appropriate?

Despite the catchment being classified as slightly to moderately urbanised and exhibiting moderate permeability, the catchment does not exhibit features that limit the application of standard FEH methodologies.

Initial choice of method(s) and reasons:

Whilst the ReFH2 rainfall runoff method is suitable for estimating design flood hydrographs on highly permeable catchments (BFIHOST > 0.65), findings from the Small Catchment Research Programme reported:

- There is a general overestimation of QMED and rarer flood peaks in high-BFIHOST catchments, across all methods.
- The FEH statistical method should be prioritised for estimation of QMED in drier urban catchments (URBEXT₂₀₀₀ ≥ 0.03, SAAR < 800). However, ReFH2 performs almost equally well and is more strongly recommended for wetter urban catchments (SAAR ≥ 800).
- All methods overestimated Q30 and Q100 considerably in permeable catchments (in the 'high-quality' data set).
- FEH statistical method performed better than ReFH2 in permeable catchments so should be preferred for permeable catchments.

Within application of the FEH Statistical method for small catchments, the following is suggested:

- For small catchments (under 25 km²), using the existing FEH equation is recommended over the retuned or new equations reported by the research.
- For small catchments, using one donor selected by centroid distance only is recommended for refining QMED estimates made by the existing FEH statistical equation. Catchment characteristics should not be used to eliminate potential donors.
- It is recommended that for small catchments, the new SDM should be used to determine the most suitable catchments for a pooling-group analysis.

The ReFH2 rainfall-runoff method and the FEH Statistical method, adopting the small catchment procedures, will be undertaken and the resulting fluvial flow estimates compared.

How will hydrograph shapes be derived if needed?

The adopted hydrographs are estimated within the ReFH2 software based on the assessed critical storm duration, taken as that duration which resulted in the largest peak flow. In application of the ReFH2 approach, a 75% “winter” storm profile is adopted to derive the fluvial estimates, and further detailed information is provided under the relevant sections herein. As previously stated, the catchment is ungauged and hence no flow or level data is available to refine the ReFH2 model parameters, for example, the hydrograph time to peak value (T_p).

Will the catchment be split into sub-catchments? If so, how?

The conceptual model adopted, applies a single catchment in a lumped modelling approach whereby the design peak flow estimates are derived at the downstream catchment outlet and applied to the upstream model inflow. This approach is conservative and was selected due to the minor size of the subject catchment area and the lack of notable contributing sub-catchment inflows.

Software to be used:

WINFAP v5, ReFH2 2.3 (v4.1.8985)

3. Locations where flood estimates are required

3.1 Summary of subject sites

A lumped modelling approach was applied with a single catchment being defined based on local topography to the downstream catchment outlet . The catchment is shown previously in Figure 2-3 and the key catchment details presented below.

Site code	Type of estimate : lumped (L) or sub-catchment (S)	Watercourse	Easting	Northing	AREA on FEH Web Service (km ²)	Revised AREA (if altered) (km ²)
INFLOW_01	L	Unnamed	479435	173733	1.17	0.27

3.2 Catchment Descriptors

Final catchment descriptors at each subject site:

Final catchment descriptors including revisions made to the default FEH values are presented below. Where values have been estimated manually, these are indicated in bold text.

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT ₂₀₀₀	FPEXT
INFLOW_01	1.0	0.29	0.603	0.727	5.6	641	0.116	0.414

URBEXT source and method for updating:

URBEXT₂₀₀₀ has been recalculated following revisions to the FEH 'donor' catchment boundary. The fraction of the catchment area shown as urbanised on Ordnance Survey 1:50,000 scale mapping has been derived and URBEXT₂₀₀₀

calculated based on the equation reported in R&D Technical Report FD1919/TR⁸ and reproduced below:

$$\text{URBEXT}_{2000} = 0.629 \text{ URBAN}$$

The adopted urban area is 0.049 km² and the adopted catchment area is 0.27 km² giving a fraction of 0.18 which is used in the URBEXT₂₀₀₀ equation above.

The URBEXT₂₀₀₀ value has then been updated to be appropriate for the present year (2025) using the equation:

$$UEF = 0.7851 + 0.2124 \tan^{-1}\{(Year - 1967.5)/20.32\}$$

It should be noted here that the OS mapping adopted was accessed through the OS API Portal and is hence thought to be valid for the present day and therefore no adjustment to the current year (2025) is required. The application of subsequent urban adjustments and resulting calculation of flood estimates for the purpose of assessment can hence be considered conservative.

⁸ Defra/EA (2006). URBEXT - A new FEH catchment descriptor Calculation, dissemination and application. R&D Technical Report FD1919/TR

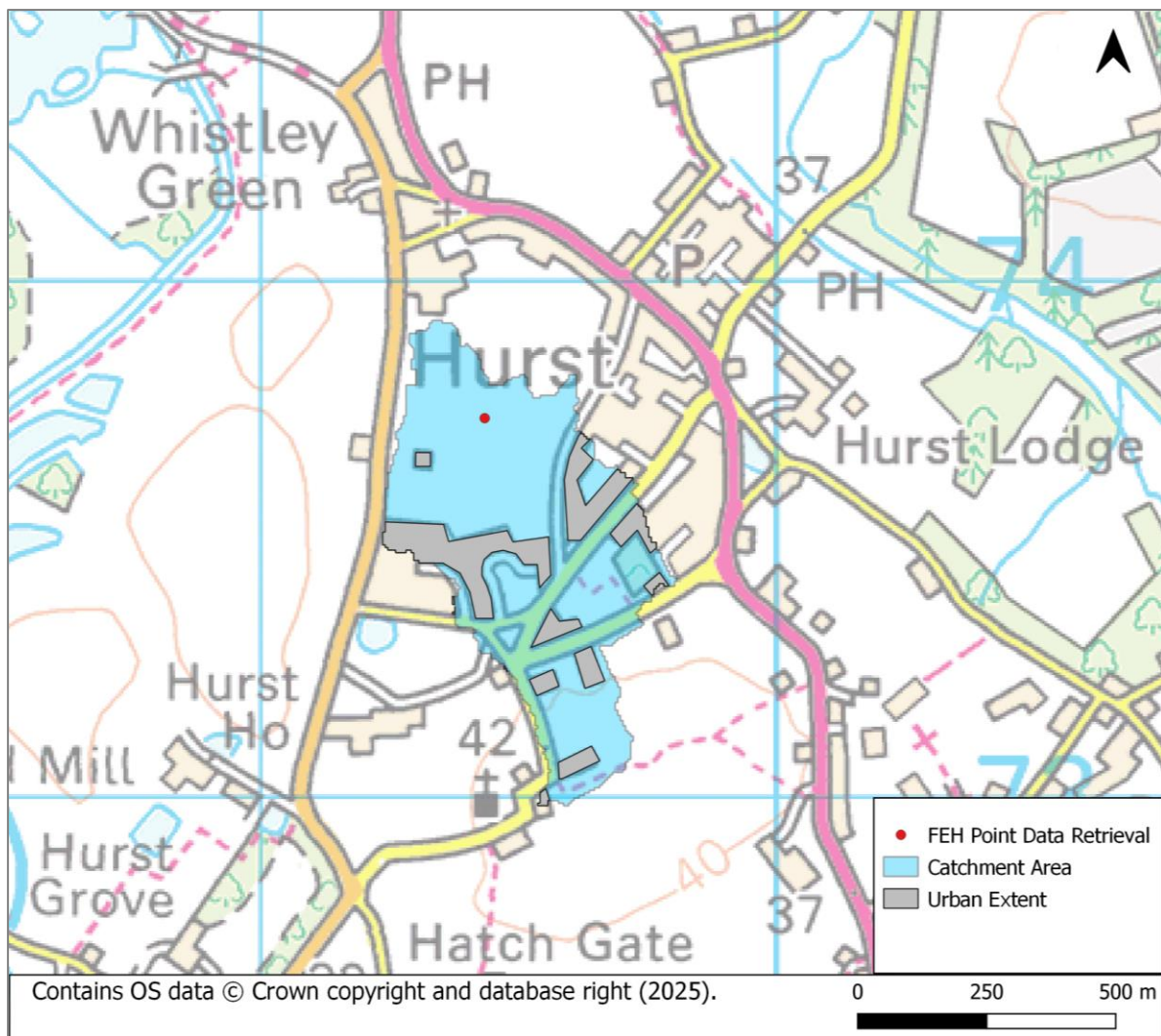


Figure 2-5 Location Plan Showing Catchment URBAN50k extent

BFIHOST source, checks and updates:

The adopted BFIHOST19 value of 0.63 was sourced from the FEH Web Service Point Data at NGR SU 79435 73733 as shown in Figure 2-5 and is considered to more accurately reflect the moderate permeability of the superficial sand and gravel deposits, and the moderately permeable bedrock upon which the subject catchment is formed. The justification for this is discussed previously under Section 2.2 'The Catchment'.

Checks and revisions to other catchment descriptors:

All key catchment descriptors, i.e., those used in assessment of design flows have been reviewed to determine their suitability for the subject catchment.

With the exception of revisions made to the FEH values of AREA, URBEXT₂₀₀₀, and BFIHOST19, which the justifications are already reported for their revisions; only the FEH descriptor DPLBAR has been revised. The value of DPLBAR for

the subject catchment has been revised by obtaining an exponent by regression on the catchment area for the donor catchment using the following equation:

$$\text{DPLBAR} = \text{Revised AREA}^{\text{LOG}(\text{FEH DPLBAR}, \text{FEH AREA})}$$

Stationary statistical methods

4.1 Method overview

What is the purpose of applying these methods?

The FEH Statistical method, adopting the small catchment procedures, are adopted for direct comparison with fluvial flood estimates derived by the ReFH2 rainfall-runoff method.

What methods will be used to estimate QMED and growth curves?

Site code	Methods used for QMED	Methods used for growth curves
INFLOW_01	Existing (2008) FEH QMED equation	Small Catchment SDM

4.2 Estimating QMED

QMED at ungauged subject sites:

Site code	Method (CD/DT/BCW)	Initial QMED (rural) from CDs (m ³ /s)	Donors used (NRFA numbers)	Donor distances from subject centroid (km)	Individual donor weights	Combined and weighted donor adjustment factor	Urban adjustment factor	Final QMED (m ³ /s)
INFLOW_01	CD	0.044	39027	26.4	1.0	0.725	1.150	0.050

Methods: CD - Catchment descriptors alone; DT - catchment descriptors with donor transfer; BCW - catchment descriptors with bankfull channel width.

Urban adjustment of QMED:

Urban adjustments have been undertaken using the Urban Adjustment Procedures introduced in WINFAP 4. The parameters used for the urban adjustment are based on the standard reported values where the impervious fraction for built-up areas (IF) = 0.3 and the percentage runoff for impervious surfaces (Primp) = 70%.

Search for donor sites:

The Environment Agency 'Estimating flood peaks and hydrographs for small catchments' guidelines, advocates using one donor selected by centroid distance only where the existing FEH equation is used to calculate QMED. The guidelines further state that catchment characteristics should not be used to eliminate potential donors. As such, the closest donor in terms of centroidal distance is 39027 and hence is adopted as the chosen donor for refining the estimate of QMED within the FEH Statistical method.

Donor sites chosen and QMED adjustment factors:

NRFA no.	Method (AM/POT/LF)	Adjustment for climatic variation?	QMED from flow data (m ³ /s)	De-urbanised QMED from flow data (m ³ /s) (A)	QMED from catchment descriptors (m ³ /s) (B)	Adjustment ratio (A/B)
39027	AM	No	2.140	2.081	6.817	0.305

Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

4.3 Estimating growth curves

Derivation of growth curves at subject sites:

Methods: SS - Single Site; P - Pooled; ESS - Enhanced Single Site; H - Historical. Pooled growth curves were derived

Site code	Method (SS, P, ESS, H.)	If P or ESS, name of pooling group	Distribution used and reason for choice	Any urban or non-flood years adjustments	Parameters of distribution (location, scale and shape after adjustments)	Growth factor for 100-year return period
INFLOW_01	P (small catchment procedures)	PG1	GL, provides acceptable fit based on z statistic and is the default distribution used for UK flood data	Urban adjustment and non-flood year adjustments applied	Location 1.0, Scale 0.257, Shape -0.259	3.210

using the small catchment pooling procedure from Science Report SC090031 (2021) as implemented in WINFAP v5.

Urban adjustments are carried out using the Urban Adjustment Procedures introduced in WINFAP 4.

Derivation of pooling groups:

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (ESS)	URBEXT2000 threshold applied to pooling group selection?	L-moments deurbanised (including subject site for ESS)?	Small catchment pooling procedure applied?
PG1	INFLOW-01	No	Default (0.030)	Yes	Yes

Methods: The small catchment pooling procedure is given in the report on Phase 2 of project SC090031 (2021) and implemented in WINFAP v5.

Pooling group composition:

Name of group	Changes made to default pooling group, with reasons	Weighted average L-moments
PG1	Removed: 27073, 26016, 44008, 26014 on account of BFIHOST >0.65 47022 on account of BFIHOST >0.65 and FARL <0.95 Added: 25011, 24007, 73015 and 36004.	L-CV 0.257 L-SKEW 0.259

4.4 Final choice of QMED and growth curves

Method choice and reasons:

Site code	Final choice of QMED and reasons	Final choice of flood growth curve method and reasons
INFLOW_01	0.037 m ³ /s determined by donor transfer and application of moderation term 'a'	GL is the default distribution used for UK flood data and is the distribution implemented in the non-flood year adjustment. The GL growth curve is also shown as being the more conservative.

Final flood estimates from stationary statistical methods:

Flood peak in m³/s for the return periods in years or AEP (%) events.

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
INFLOW_0 1	0.04	0.05	0.06	0.07	0.08	0.10	0.11	0.12	0.14	0.28

Note that the reported FEH Statistical 0.1% AEP flow, is derived by multiplying the FEH Statistical estimate of the 1% AEP fluvial flow by the ratio obtained from the ReFH2 0.1% / 1% AEP fluvial flow estimates. This 'hybrid' approach is adopted due to greater confidence in rainfall frequency curves over flood frequency curves for longer return periods. More details are provided within the relevant sections.

4. Revitalised flood hydrograph 2 (ReFH2) method

4.1 Method Overview

What is the purpose of applying this method?

The ReFH2 rainfall-runoff method, is adopted for:

1. Direct comparison with fluvial flood estimates derived by the FEH Statistical method.
2. To derive design hydrograph shape; and
3. to derive total net rainfall hyetographs.

Version of ReFH2 applied:

ReFH2.3 (Version: 4.1.8985) with FEH22 rainfall data.

4.2 Model Parameters

Summary of model parameters:

A summary of the ReFH2 model initial conditions and parameters is provided in the subsequent sections. Note that these vary between the approach for deriving fluvial flow and the approach for deriving net rainfall. The differences where relevant and justifications for, are explicitly stated.

A lumped approach was applied to both the peak flow and rainfall estimation. By this, we mean that the fluvial and rainfall estimates are derived based on the total catchment area and urban fraction as determined for the downstream catchment outlet. In both cases, the catchment area is set as 0.27 km² and the urban area is set as 0.05 km² to achieve a resultant URBEXT₂₀₀₀ value of 0.12 (which is [conservatively] updated to the year 2025).

The ReFH2 model's urbanisation parameters have been maintained as their default values (Impervious runoff factor of 0.7 and Imperviousness factor of 0.4) and the Tp scaling factor has been maintained as 0.75, as per the EA Small Catchment Guidance based on the catchment BFIHOST19 and URBEXT₂₀₀₀ values⁹.

⁹ Environment Agency, 2024, SC090031/R0 – Small Catchment Guidance Phase 2 Overview report

A summary of the ReFH2 model parameters is provided in the following table. Note that these are applicable for the approach applied for deriving fluvial flow estimates and the approach for deriving net rainfall.

Site code	Method	Tp (hour) rural	Cmax (mm)	BL (hours)	Area modelled as urban (km ²)	TP urban scaling factor	IF	IRF	DS
INFLOW_01 (FLUVIAL)	CD	3.786	592	38.48	0.05	0.75	0.4	0.7	0.5
RAINFALL	CD	3.786	592	38.48	0.05	0.75	0.4	0.7	0.5

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD:

Catchment descriptors, DT: Data transfer, CAL: model calibration.

4.3 Model inputs for (fluvial) design events

Design events for lumped catchments:

The default FEH-recommended storm duration for the lumped catchment based on a catchment area of 0.27 km² has a duration 6.5 hours. As the catchment is not classified as a heavily urbanised catchment (URBEXT $\geq$ 0.30) and does not have a BFIHOST19 value greater than 0.65 (i.e., highly permeable), the default winter storm seasonal profile (75%) has been used for the generation of hydrographs for input into the fluvial model.

The Areal Reduction Factor (ARF) and Seasonal Correction Factor (SCF) were maintained at the FEH default values defined by the ReFH2.3 software.

Site code	Rainfall DDF model	Urban or rural	Highly permeable?	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO
INFLOW_01	FEH22	Moderately urbanised	Moderate permeability	Winter	6.5	81.483	0.003

Storm duration testing:

The recommended duration in ReFH2 is based on the hydrograph time to peak (Tp) and generally, does not represent the critical storm duration for a catchment. The critical storm duration, defined here as that duration which results in the largest peak flow was found to be 6.5 hours (i.e., the recommended duration) for the 3.33% AEP and 1% AEP design events whilst for the 0.1% AEP storm event, the critical duration was assessed as 7.5 hours.

4.4 Final choice of ReFH2 flow estimates

Method choice and reasons:

Site code	Final choice of design inputs and model parameters
INFLOW_01	The adopted storm duration is based on the assessed critical storm duration which for the 3.33% and 1% AEP events is ~6.5 hours and for the 0.1% AEP event is ~7.5 hours.

Final (fluvial) flood estimates from ReFH2 method:

The ReFH2 peak flow estimates (m^3/s) based on the respective quoted critical storm duration are shown in the following table.

Site code	30-year (3.3%)	30-year CC (3.3%) CC	100- year (1%)	100-year CC (1%) CC	1000 (0.1%)	1000 CC (0.1%) CC
INFLOW_01	0.10	0.15	0.13	0.19	0.22	0.32

4.5 Model inputs for (pluvial / rainfall) design events

Total net rainfall estimates are derived for the 1, 3, 6 and 12-hour storm durations as per the Environmental Agency standards as set out in Risk of Surface Water Flooding (RoSWF) 'Appendix A – Modelling standards'. The catchment aerial reduction factor is set as 1.0 and a summer seasonal rainfall profile (50%) adopted with the Seasonal Correction Factor set as 1.0. This aligns with the minimum requirements outlined in the quoted guidance. Rainfall losses are applied directly within the ReFH2 software at a variable temporal rate which, for the catchment scale, is reported as an acceptable approach within the Environment Agency Flood Estimation Guidelines.

Site code	Rainfall DDF model	Urban or rural	Highly permeable?	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO
INFLOW_01	FEH22	Moderately urbanised	Moderate permeability	Summer	1,3,6 & 12	43.286	0.002

Total net rainfall (mm)

Storm Duration (hrs)	30	30 CC	100	100 CC	1000	1000 CC
	3.3%	3.3%CC	1%	1% CC	0.1%	0.1% CC
1	5.31	7.65	7.34	11.26	12.67	20.03
3	7.61	11.14	10.23	15.97	18.00	29.05
6	9.13	13.48	12.21	19.25	22.15	36.18
12	10.55	15.70	14.08	22.39	26.07	42.99

5. Discussion and summary of results

5.1 Comparison of results from different methods

Site code	e.g., Ratio of ReFH2 to stationary statistical peak, 50% AEP	e.g., Ratio of ReFH2 to stationary statistical peak, 1% AEP
INFLOW_01	1.91 ReFH2 flows ~91% greater	1.10 ReFH2 flows ~10% greater

5.2 Final choice of method

Choice of method and reasons:

The final choice of method has been based on the adoption of a conservative approach to dispel concerns regarding flood risk at the site. The fluvial flow estimates derived by the ReFH2 rainfall-runoff method are hence adopted. This method is appropriate for the estimation of peak flows and rainfalls for the small and ungauged target catchment and are accepted by way of a precautionary approach.

How will the 0.1% AEP flows be estimated?

The adopted ReFH2 0.1% AEP peak flows have been estimated directly using the rainfall-runoff method whilst the FEH Statistical flows, used in comparison, are derived by multiplying the FEH Statistical estimate of the 1% AEP fluvial flow by the ratio obtained from the ReFH2 0.1% / 1% AEP fluvial flow estimates. This 'hybrid' approach is adopted due to greater confidence in rainfall frequency curves over flood frequency curves for longer return periods.

How will the flows be applied to a hydraulic model?

The event peak flow hydrograph(s) derived at the downstream catchment outlet are applied as model inflows to the model upstream extent, this is a conservative approach and is again aligned with taking a precautionary approach in assessment of fluvial flood risk at the site.

The rainfall hyetographs were modelled separately and are applied in a rain-on-grid model approach across the entire 2D domain. For further details on the hydraulic modelling methodology the reader is directed to the Flood Risk Modelling Report.

5.3 Final results

The final fluvial design peak flows and the total net rainfall adopted in the hydraulic modelling are shown in the following table.

Site code	30 3.3%	30 CC 3.3% CC	100 1%	100 CC 1% CC	1000 0.1%	1000 CC 0.1% CC
Peak Flow (m³/s)	0.10	0.15	0.13	0.19	0.22	0.32
1-hour Total Net Rainfall (mm)	5.31	7.65	7.34	11.26	12.67	20.03
3-hour Total Net Rainfall (mm)	7.61	11.14	10.23	15.97	18.00	29.05
6-hour Total Net Rainfall (mm)	9.13	13.48	12.21	19.25	22.15	36.18
12-hour Total Net Rainfall (mm)	10.55	15.70	14.08	22.39	26.07	42.99

Design storms applied in the hydraulic model:

For the direct rainfall modelling, to determine surface water flooding to the site, a 1, 3, 6, and 12-hour storm duration were tested and the results combined to produce a map of the worst-case flooding outcome for each model cell.

For the fluvial (river) modelling, the critical storm duration was determined and adopted as described in Section

Climate change allowances:

The catchment is located within the Loddon and tributaries Management Catchment basin region. Based on the most recent climate change advice as provided by the Environment Agency¹⁰; the upper allowance for the 2070s epoch has been selected. This is suitable for development with a lifetime between 2061 and 2125. A +35% uplift in peak rainfall intensity allowances is recommended to represent the anticipated impact of climate change for the 3.3% AEP rainfall event and +40% uplift in peak rainfall intensity for the 1% AEP rainfall event. This is applied directly within the ReFH2 software. For the fluvial flood estimates, a climate change uplift of +46% is applied to the 3.3% 1% and 0.1% AEP events derived by either the ReFH2 or FEH Statistical methods.

5.4 Checks

Growth factor checks:

The ratio of the 0.1% AEP flow to the 1% AEP flow for the ReFH2 6.5-hour duration is shown in the following table.

Site code	0.1% AEP / 1% AEP ratio
INFLOW_01	1.62

¹⁰ [Peak rainfall climate change allowances by management catchment - GOV.UK \(www.gov.uk\)](https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61222/peak_rainfall_climate_change_allowances_by_management_catchment.pdf)

Specific discharge:

The specific discharge values (flow in l/s/ha) are shown in the following table. Flow estimates have been derived at a single location with no sub-catchment division to allow comparison of catchment runoff contribution, hence, the reporting of specific discharge is purely for completeness.

Site code	30 3.3%	100 1%	100 CC 1% CC	1000 0.1%	1000 CC 0.1% CC
INFLOW_01	3.63	4.68	6.83	7.89	11.5

Flood peak in l/s/ha for the return periods in years or AEP (%) events.

Spatial consistency of results:

As stated above, only a single flood estimation point is considered. This section is therefore non applicable to the study.

Return periods for notable historic floods:

The catchment is ungauged and hence no comment can be provided with regards to how the estimated flows translate to return periods of notable historic flood events. This section is therefore non applicable to the study.

Compatibility with longer-term flood history:

The EA Historic Flood Map indicates historic flood extents within the site area. The flood extents appear to be associated with surface water as opposed to the unnamed watercourse. The hydraulic model outputs appear to represent previous flooding behaviour. This is discussed further in the Flood Risk Modelling Report.

Comparisons with previous studies:

There are no known previous studies with which the results could be compared.

Checks on hydraulic model results:

It is not possible to fully validate the model due to the absence of gauged data as previously discussed. Sensitivity testing has been undertaken within the application of the hydraulic modelling and is detailed further in the main deliverable, Flood Risk Modelling Report.

5.5 Assumptions, limitations, and uncertainty

Assumptions (specific to this study):

The catchment is ungauged and hence no level or flow data is available for informing the sensibility of the fluvial flows derived, nor to use in model validation. The assumption is made that the fluvial estimates (and adopted hydrographs) are representative. In support of this assumption, there is general agreement between the ReFH2 and FEH Statistical estimates derived for the study, however the absence of gauged empirical information must be acknowledged as a limitation to the confidence in either the hydrological analysis or fluvial hydraulic model outputs.

Similarly, whilst the net rainfall adopted in the study has followed the standards as set out in Risk of Surface Water Flooding (RoSWF) Appendix A – Modelling standards; there is an absence of a suitably located rain gauge within the catchment which provides a sufficiently long record to allow statistical analysis to infer probable rainfall totals. However, normal practice is to adopt design rainfall.

Given the mixed rural and urban components comprising the subject catchment, variable losses are applied to the rainfall directly within ReFH2. This is an accepted approach that is documented within the EA Flood Estimation Guidelines and is adopted due to the need to simplify the methodology of applying the losses over the catchment. It is assumed that the resulting net rainfall is representative of actual storm events and losses however, it is important for the reader to understand the limitations and the assumption made.

Given that the confidence is greater in rainfall growth curves than in flood growth curves for longer return periods, the 0.1% AEP growth factors are estimated from the ReFH2 rainfall-runoff approach, the study assumes there is a higher confidence in the ReFH2 peak flows estimates at longer return periods i.e., the 0.1% AEP and hence adopts the more precautionary ReFH2 estimates as the adopted design flows.

Limitations:

The limitations of this study are discussed under assumptions and summarised here:

- The lack of gauged data on the target watercourses by which to verify the derived peak flow estimates.
- The lack of rainfall records within the lumped catchment.
- The limited historic flood records in the target area.

Uncertainty:

ReFH2 was utilised for the final flow estimation. As described in Section 5.4 of the Flood Estimation Guidelines, it is difficult to quantify uncertainty from the

ReFH2 rainfall-runoff model and no definitive method is published. As per Dixon et. al. (2017) Science Report – SC130009/R¹¹, uncertainty in ReFH2 estimates may derive from a number of sources including:

- measurement error in the flood and rainfall event data used to calibrate the model
- sampling error
- model error related to the form of the rainfall-runoff model

Whilst the report outlines how quantifying uncertainty may be undertaken i.e., by using ‘randomised’ values in the initial conditions and model parameters to provide an indication of how variable the ReFH2 estimates are once uncertainty in the parameters is taken into account; there is no published guidance on undertaking such assessment and in any case is beyond the scope of the study presented herein.

It is assumed that uncertainty in the ReFH2 results may be in the same magnitude as for those derived by the FEH Statistical method and hence the 95% confidence intervals reported for design flows at an ungauged site on a moderately urbanised catchment within Table 3 of the FEH Guidelines are applied. It is acknowledged that this is not an accepted method and is adopted as a pragmatic approach to indicatively quantify uncertainty in the ReFH2 results

Site code	3.3% AEP Lower 95%	3.3% AEP Upper 95%	1% AEP Lower 95%	1% AEP Upper 95%	0.1% AEP Lower 95%	0.1% AEP Upper 95%
INFLOW_01	0.059	0.169	0.075	0.223	0.115	0.408

The availability of gauged data would allow the ReFH2 parameters to be refined, potentially reducing uncertainty. However, there are no gauging stations within the catchment.

Uncertainty with respect to the hydraulic model and outputs are inherent from the adopted model parameters but also the input hydrology, topography, and crucially the ability to validate the model. As stated, the catchment is ungauged and hence there is limited information by which to validate the model. Sensitivity testing of model inflows has been undertaken and hence provides a range of flood scenarios by which to quantify the potential uncertainty. The reader is directed to the main Hydraulic Modelling Report produced for the study.

¹¹ [Making better use of local data in flood frequency estimation - GOV.UK](#)

Suitability of results for future studies:

The results are suitable for the purpose of the current study.

Recommendations for future work:

A key recommendation for further work that would improve the understanding of flood frequency estimates would be installing monitoring equipment within the catchment i.e., installing a river gauge on the unnamed watercourse. Further to this, the available historic information with respect to flooding is limited and detailed recording of flood extents and depths would be useful to validate future studies. Site-specific rainfall monitoring would also aid in the validation of results.