

Flood estimation report: Coldharbour Farm Road

Introduction

This report template is based on 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.

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Approval

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Revision History

Revision reference	Date issued	Amendments	Issued to
P01	November 2021	-	Telstar Ltd
P02	February 2021	Updates following EA comments	Telstar Ltd

Abbreviations

AMAX	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification (BFIHOST19 is an updated version and addresses a number of issues in the original BFIHOST)
CPRE.....	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED.....	Median Annual Flood (with return period 2 years)
ReFH.....	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBEXT1990.....	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

Note on flood probability

This document quotes the probability of a flood magnitude in terms of a return period based on analysis of annual maximum (AMAX) floods. The return period of a flood on the AMAX scale is the average interval between AMAX floods of that magnitude or greater. The inverse of the AMAX return period is the annual exceedance probability (AEP).

Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. AEP can be helpful when presenting results to non-specialists who may associate the concept of return period with a regular rather than an average interval.

Return period can also be measured on the peaks-over-threshold (POT) scale as the average interval between floods of that magnitude or greater. The difference between AMAX and POT return periods is only important for short return periods (under 10 years).

The table below is provided to enable quick conversion between these different measures.

AMAX return period (years)	n/a	2	5	10	20	30	50	75	100	200	1,000
AEP (%)	n/a	50	20	10	5	3.33	2	1.33	1	0.5	0.1
POT return period (years)	1	1.5	4.5	9.5	20	30	50	75	100	200	1,000

1 Method statement

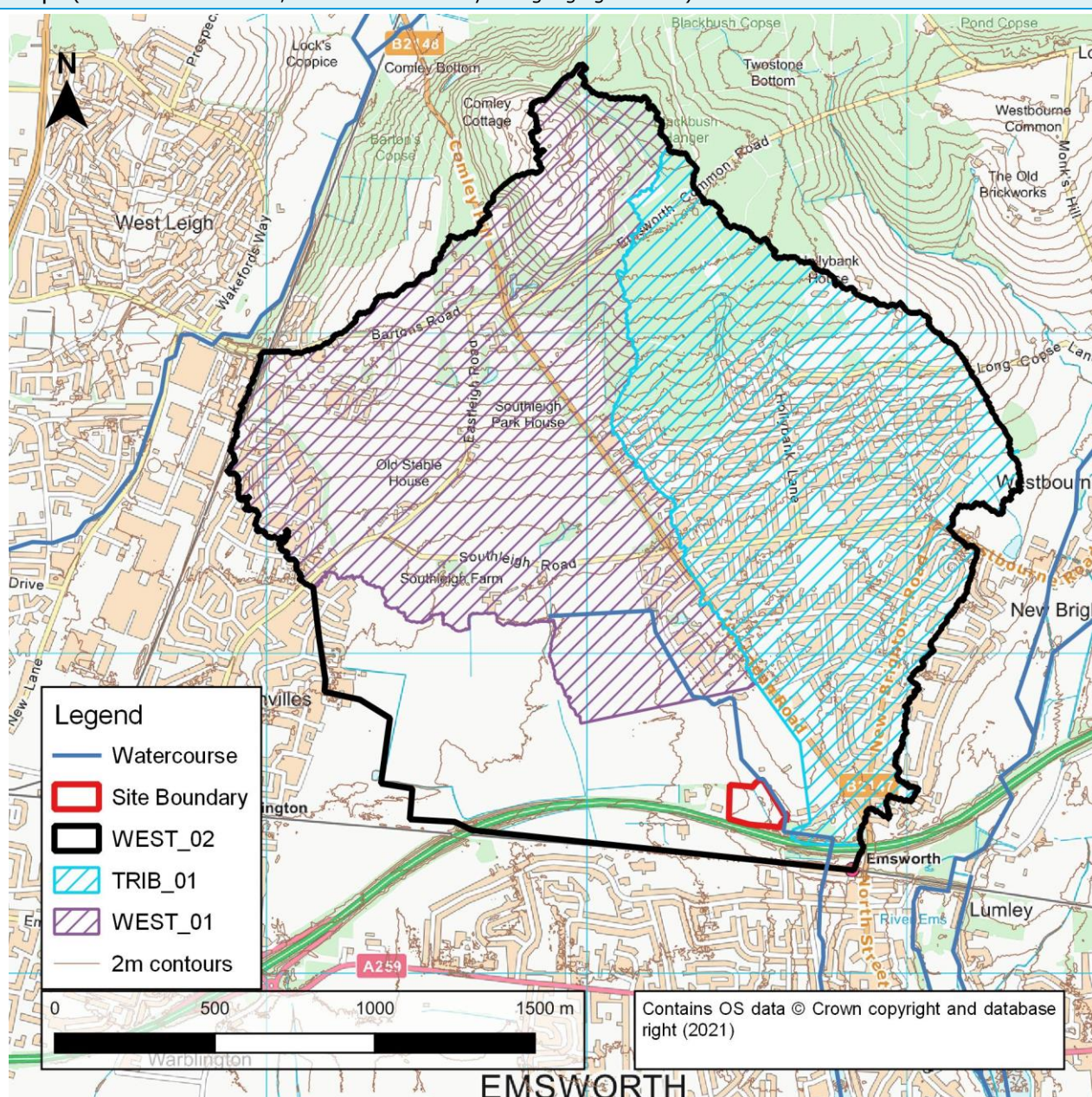
1.1 Requirements for flood estimates

Overview	The purpose of this study is to undertake a hydrological assessment of the West Brook at Emsworth, Hampshire. The aim is to provide peak flows and hydrograph shapes for input into a hydraulic model, for a flood risk assessment in relation to the proposed development site and access route at Coldharbour Farm Road, Emsworth. Design peak flow estimates and hydrographs are required at 3 locations for the following annual exceedance probability (AEP) events (%): 50, 20, 5, 1, 0.1. The effects of climate change will be assessed using the 1% AEP event and accounted for using the latest guidance¹. The Environment Agency Flood Map for Planning shows the development site to be partially located in Flood Zone 2 and 3 in the east of the site in the vicinity of the West Brook. The west of the site is located in Flood Zone 1.
Client scope	There are no NRFA river gauges in the study catchment, therefore rating reviews and ReFH parameter estimation are not relevant. It is only within the scope of this hydrological assessment to consider fluvial flows.

¹ Environment Agency (2020), "<https://www.gov.uk/guidance/flood-and-coastal-risk-projects-schemes-and-strategies-climate-change-allowances>".

1.2 The catchment

Map (Include river network, catchment boundary and gauging stations)



Description

Emsworth is a town located just north of Chichester Harbour. The development site is located west of Coldharbour Farm Road, which lies just north of the A27. The West Brook (EA main river) flows in a south easterly direction through the site. The watercourse rises north west of Emsworth in Southleigh Forest, and flows south through Emsworth to its outfall in Chichester Harbour. There are a number of drains, notably in the west of the catchment, which mapping indicates joins the West Brook. However, the flow paths and connectivity of these drains is unclear. The FEH Webservice also indicates there is a left bank tributary which joins the West Brook at Coldharbour Road Farm, but it is unknown if this watercourse exists.

A new development has recently been built at West Brook View, upstream of the proposed development site. As part of this, a flood

	attenuation features has been constructed, which may attenuate flow from the West Brook. The British Geological Survey website² 1:50,000 geology mapping shows that the West Brook catchment is primarily composed of London Clay formation – clay, silt and sand. In the upper part of the catchment soils are slowly permeable, seasonally wet, slightly acid but base-rich, loamey and clayey soils.³ In the lower part of the catchment the soils and loamy soils with naturally high groundwater. The catchment topography is relatively steep in the upper catchment, and fairly flat in the lower catchment. The eastern side of the catchment is heavily urbanised. This area drains approximately 38% of the overall catchment at WEST_02.
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1.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 10, released August 2021. This contains data up to water year 2019-20.
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1.4 Gauging stations (flow or level)

(at or very near to the sites of flood estimates)

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start of record and end if station closed
There are no NRFA gauges in the catchment.						

1.5 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	N/A	N/A	N/A
Historic flood data	Yes	Yes	Havant Borough Council – Emsworth Flood Risk Strategy Review (2015) ⁴	Flooding has occurred along the West Brook around Bridge Road, downstream of the proposed development site, where the capacity of the culvert has been exceeded. The date and frequency of the flooding is not known. No records of flooding specifically at the development site could be found.
Flow or river level data	Yes	Yes	N/A	There is an EA level gauging

² <http://mapapps.bgs.ac.uk/geologyofbritain/home.html>

³ <http://www.landis.org.uk/soilscapes/>

⁴ <https://cdn.havant.gov.uk/public/documents/Emsworth%20Flood%20Risk%20Strategy%20Review%20-%20March%202015.pdf>

for events				station on the West Brook downstream of the development site. The data from this gauge appears to be artificially influenced by a gate or similar feature, and also by the tide.
Rainfall data for events	Yes	No	N/A	N/A
Potential evaporation data	Yes	No	N/A	N/A
Results from previous studies	Yes	No	N/A	There are no known hydrological assessments of the catchment. The existing flood mapping has been produced using broadscale JFLOW modelling and is not suitable for a site-specific Flood Risk Assessment.
Other data or information (e.g. groundwater, tides, channel widths, low flow statistics)	Yes	No	N/A	N/A

1.6 Hydrological understanding of catchment

Outline the conceptual model	The main site of interest is the development site off Coldharbour Farm Road. Fluvial flooding is likely to be the main source of flooding to the site. This may be exacerbated by structures across the watercourses which can cause constriction to flow, and blockages of structures.
Any unusual catchment features to take into account?	There are a network of drains within the catchment. The connectivity of these drains is uncertain but these may have a significant impact on the catchment area. It is proposed to adopt a conservative approach to deriving the catchment boundaries (assuming a larger drainage area where uncertainties exist in drainage connections). There is also a storage area on the West Brook which has recently been constructed upstream of the development site which may attenuate flows. It is proposed that a simple 1D model of the storage area is built to assess how much flow may attenuate.

1.7 Initial choice of approach

Is FEH appropriate?	FEH flood frequency methods are considered appropriate, given the catchment area is greater than 0.5km ² (the lower limit of applicability of the methods)
Initial choice of method(s) and reasons	Both the FEH Statistical method and the ReFH2

How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	method will be applied. There is no NRFA peak flow data available in the catchment to improve the QMED estimate under the statistical method. Local donors, from nearby catchments, will, therefore, be assessed for suitability for data transfer. Consideration was given to using the level gauge at Emsworth for updating the ReFH2 Tp parameter. However, as the data appears to be influenced by an artificial structure, such as a gate, and there may be a tidal influence on the gauge, then it was decided that this data is not suitable for this purpose. As highlighted in the Environment Agency's latest flood estimation guidelines, the statistical method is generally preferred to rainfall-runoff techniques, although the performance of the ReFH2 method in such cases is greatly improved compared with ReFH1. The flow estimates from the statistical method and ReFH2 will be compared. Hydrograph shapes will be generated using the ReFH2 method, using the recommended design storm duration from catchment descriptors. These hydrographs will be fitted to the FEH Statistical peaks, if this is chosen as the preferred method, Inflows will be derived as follows: • A point inflow will be calculated at the model upstream extent. This will represent runoff from the rural area to the north-west of the site • A separate point inflow will be calculated to represent runoff from the densely urbanised eastern part of the catchment, applied as a point inflow to a downstream section of the model. • A final (laterally-applied) inflow representing the rural land in the south of the catchment, not represented in the point inflows above.
Software to be used (with version numbers)	FEH Web Service⁵ / WINFAP v5⁶ / ReFH2.3

⁵ CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, Oxon, UK.

⁶ WINFAP-FEH v5 © Wallingford HydroSolutions Limited 2021.
GBQ-JBAU-XX-XX-RP-HO-0001-S3-P02_Emsworth_Hydrology_Report

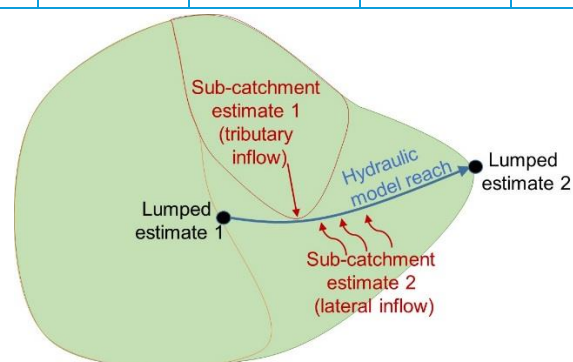
2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised AREA if altered (km ²)
WEST_01	L	West Brook	Downstream of flood attenuation feature	474400	106850	1.31	1.62
TRIB_01	L	Unknown	Densely urbanised eastern part of catchment	474700	106500	1.06	1.45
WEST_02	L	West Brook	Downstream model extent	474750	106350	2.68	3.85
WEST_02_IA	S	West Brook	Intervening area between WEST_01 and TRIB_01.	474750	106350	-	0.78

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.



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

Values shown in red have been updated

Site code	FARL	PROPWET	BFIHOST 19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
WEST_01	1.00	0.34	0.476	1.41	20.7	764	0.085	0.1051
TRIB_01	1.00	0.34	0.511	1.71	23.4	765	0.246	0.1769
WEST_02	1.00	0.34	0.509	2.28	21	762	0.130	0.1458
WEST_02_IA*	-	0.34	0.574	0.46	17.2	752	0.008	-

*Only those catchment descriptors needed for input into the ReFH2 model have been derived for the intervening area

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	The FEH Webservice catchment boundary was checked against LIDAR and OS mapping. OS mapping and LIDAR indicates there are a number of drains in the west of the catchment not included in the FEH catchment which could potentially drain into the catchment. This would increase the catchment area. A site visit ⁷ was undertaken to understand the connectivity of the drains, but these could not be accessed on site. Although the connectivity of these drains is unknown, and there is uncertainty into where these drain, they have been included in the study catchment, in order to provide a conservative approach (i.e., giving an upper bound on runoff estimates).
Record how other catchment descriptors were checked and describe any changes.	As the catchment area was updated, DPLBAR was re-calculated using the ratio of areas (previous divided by updated catchment area). URBEXT2000 was manually calculated using OS50k mapping and Bayliss <i>et al.</i>'s (2006)⁸ mapping relationship between URBAN_{50k} and URBEXT2000. A qualitative check of the FEH BFIHOST19 value was undertaken by comparing it to the geology and soils detailed in Section 1.2. The FEH value (0.476-0.509) seems sensible given the underlying geology is shown to be clay, silt and sand. Although the catchment area has been updated, BFIHOST19 has not been recalculated as it doesn't significantly vary spatially (a comparison of the BFIHOST19 values was done for the FEH catchments purchased). This was sense checked using soilscape and the increase in catchment area would not significantly alter the composition of soil types in the catchment (see Section 6.3). The FARL value is 1.000. The FEH webservice does not indicate there are any online lakes/ponds in the catchment, therefore the FARL value is considered appropriate. The storage area at West Brook view is going to be considered in the hydraulic model rather than the hydrology.
Version of URBEXT	URBEXT2000
Method for updating of URBEXT	Manually derived URBAN values from OS50k mapping
Source of BFIHOST	BFIHOST19 was used in the ReFH2 calculations, since the current release (ReFH2.3) was calibrated using BFIHOST19, and also in the FEH Statistical method, since this has been found to improve the results ⁹ .

⁷ B Gibson, JBA Consulting, 02/07/2021

⁸ Bayliss, A.C; Black, K.B; Fava-Verde, A. & Kjeldsen, T.R. (2006) *URBEXT2000 – A new FEH catchment descriptor. Calculation, dissemination and application*. R&D Technical Report FD1919/TR. London: Defra.

⁹ Griffin, A., Young, A. and Stewart, E. (2019). Revising the BFIHOST catchment descriptor to improve UK flood frequency estimates. Hydrology Research.

3 Statistical method

3.1 Overview of estimation of QMED at each subject site

Site code	Initial QMED rural (m ³ /s) (from catchment descriptors)	Final method	Data transfer					Urban adjust-ment factor (UAF)	Final QMED estimate (m ³ /s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Moderated QMED adjustment factor, (A/B) ^a	If more than one donor			
						Weight	Weighted ave. adjustment		
WEST_01	0.54	CD	N/A	N/A	N/A	N/A	N/A	1.099	0.59
TRIB_01	0.44	CD	N/A	N/A	N/A	N/A	N/A	1.322	0.58
WEST_02	1.01	CD	N/A	N/A	N/A	N/A	N/A	1.163	1.17
Are the values of QMED spatially consistent?					Yes, QMED increases downstream				
Method used for urban adjustment for subject and donor sites					WINFAP v4 ¹⁰				
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 given in Table 3.2. This 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 x QMED _{initial} x UAF									
Important note on urban adjustment									
The method used to adjust QMED for urbanisation published in Kjeldsen (2010) ¹¹ 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.									

¹⁰ Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

¹¹ Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

3.2 Search for donor sites for QMED (if applicable)

Comment on potential donor sites	There are no river flow gauging stations within the study catchment. Gauging stations in adjacent hydrometric areas were therefore, assessed for suitability for data transfer to the study watercourse. There are 11 rural NRFA stations within 40km of the study area, based on the distance between catchment centroids. Comparison of QMED_{obs} and QMED_{cds} shows there is no consistent trend among the donor stations – 4 stations show QMED_{cds} overestimates QMED_{obs} and 7 show this underestimates QMED_{obs}. Recommendations from current research¹² (and new research¹³ to be published soon) indicate that the geographically closest station to the study site tends to produce the best results. The latest research highlights that descriptors, such as AREA, are included in the regression equation for QMED, so the donor adjustment process accounts for the differences in values between the donor and subject catchments. It also explains that the overarching pattern of QMED model residuals across the UK follows a smooth spatial pattern, hence the recommendation to choose donors by proximity. The closest gauging station is 41015 (Ems @ Westbourne). The observed QMED for this station (2.25 m³/s) is slightly lower than QMED from catchment descriptors (2.41 m³/s). Given that there is no consistent trend among donor stations, it has been decided not to apply this station as a donor. Applying this donor would not have a significant impact on the results, and this would slightly reduce the flow estimates.
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3.3 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing	Method (AM or POT)	Adjustment for climatic variation ?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)
No suitable donors where found						

¹² Kjeldsen, T.R., Jones, D.A. and Bayliss, A.C. 2008. Improving the FEH statistical procedures for flood frequency estimation. Science Report SC050050, Environment Agency.

¹³ Stewart, Lisa, Duncan Faulkner, Giuseppe Formetta, Adam Griffin, Tracey Haxton, Ilaria Prosdoci, Gianni Vesuviano and Andy Young (TBC). Estimating flood peaks and hydrographs for small catchments (Phase 2). Report – SC090031/R0, Environment Agency.

3.4 Derivation of pooling groups

Several subject sites may use the same pooling group.

Sensitivity tests were carried out on the pooling groups, and small catchment method gave a slightly more conservative results than the default method so was taken forward.

Name of group	Site code from whose descriptor's group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
WEST_02 (Small catchment method)	WEST_02	No	A brief review of the pooling group was performed. 49005 (Bolingey Stream @ Bolingey Cocks Bridge) was highlighted as discordant by WINFAP. This gauge was retained as it fitted well into the growth curve and L-moments graphs, the AMAX series looked normal, and no major issues were identified on the NRFA website. The discordancy is thought to be due to the low number of years of data (10 years). 7011 (Black Burn @ Pluscarden Abbey) was removed as it had less than 8 years of data All other gauges were deemed to be suitable; no changes were made to the default pooling group	L-CV: 0.266 L-skew: 0.225
WEST_02 (Default method)	WEST_02	No	A brief review of the pooling group was performed. No changes were made to the default pooling group.	L-CV: 0.235 L-skew: 0.253

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

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	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 (location, scale and shape after adjustments)	Growth factor for 100-year return period
WEST_01	P	WEST_02 (small catchment method)	GL – gives acceptable fit and is recommended distribution for UK catchments	Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.254 Shape: -0.270	3.13
TRIB_01	P	WEST_02 (small catchment method)		Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.225 Shape: -0.240	3.05

Site code	Method (SS, P, ESS, J)	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 (location, scale and shape after adjustments)	Growth factor for 100-year return period
WEST_02	P	WEST_02 (small catchment method)		Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.246 Shape: -0.248	3.11

Notes

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

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

Urban adjustments are all carried out using the WINFAP 4 urban adjustment procedures.

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

3.6 Flood estimates from the statistical method

Site code	Flood peak (m ³ /s) for the following AEP (%) events				
	50	20	5	1	0.1
WEST_01	0.6	0.8	1.2	1.8	3.2
TRIB_01	0.6	0.8	1.2	1.8	3.2
WEST_02	1.2	1.6	2.4	3.6	6.5

4 Revitalised flood hydrograph 2 (ReFH2) method

4.1 Parameters for ReFH2 model

Site code	Method	C _{max} (mm)	T _p _{rural} (hours)	BL (hours)	Area of catchment modelled as urban (km ²)
WEST_01	CD	383.78	3.05	34.9	0.10
TRIB_01	CD	420.31	3.27	38.0	0.56
WEST_02	CD	418.13	3.99	40.36	0.78
Link to details of any lag or flood event analysis		N/A – no suitable catchment gauges to undertake lag analysis as the West Brook at Emsworth level gauge located further downstream appears to be significantly artificially influenced.			
Version of the ReFH2 model applied		ReFH2.3 using the water balance option. This treats BR (baseflow recharge) as a state variable rather than a parameter, setting it automatically in order to conserve volume. The values of BR vary with return period and so are not reported here.			
Parameters for urban runoff model		The impervious fraction of urban areas, IF, was kept at its default of 0.4. The impervious runoff factor, IRF, (which can also be interpreted as the fraction of the impervious surface that is positively drained) was kept at its default of 0.7. The depression storage was kept at its default of 0.5mm. Tp for runoff from areas modelled as positively drained was calculated as 0.75 times Tp _{rural} .			
Methods: OPT: Optimisation from fitting to observed flow data, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)					

4.2 Design events for ReFH2 method: Lumped catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours:minutes)
WEST_02	Rural	Winter	07:30
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			No, a uniform storm duration and ARF will be applied to the model. A storm duration of 7:30 and ARF of 0.97 (based on the critical duration at WEST_02) was selected. Storm duration testing was undertaken for 07:30, 11:30 and 15:30 duration storms, and 07:30 was identified to be the critical duration, producing the greatest flood flows, levels and extents at the site, so was taken forward.

4.3 Flood estimates from the ReFH2 method

Note: This table is for recording results for lumped catchments. There is no need to record peak flows from sub-catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. The critical duration for each catchment has been used to derive the flows shown below.

Site code	Flood peak (m ³ /s) for the following AEP (%) events				
	50	20	5	1	0.1
WEST_01	0.5	0.7	0.9	1.2	2.0
TRIB_01	0.5	0.6	0.9	1.2	1.9
WEST_02	1.0	1.4	1.8	2.4	4.0

5 Discussion and summary of results

5.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods.

Site code	Ratio of peak flow to FEH Statistical peak	
	Return period 2 years	Return period 100 years
	ReFH2	ReFH2
WEST_01	0.86	0.67
TRIB_01	0.82	0.66
WEST_02	0.88	0.67

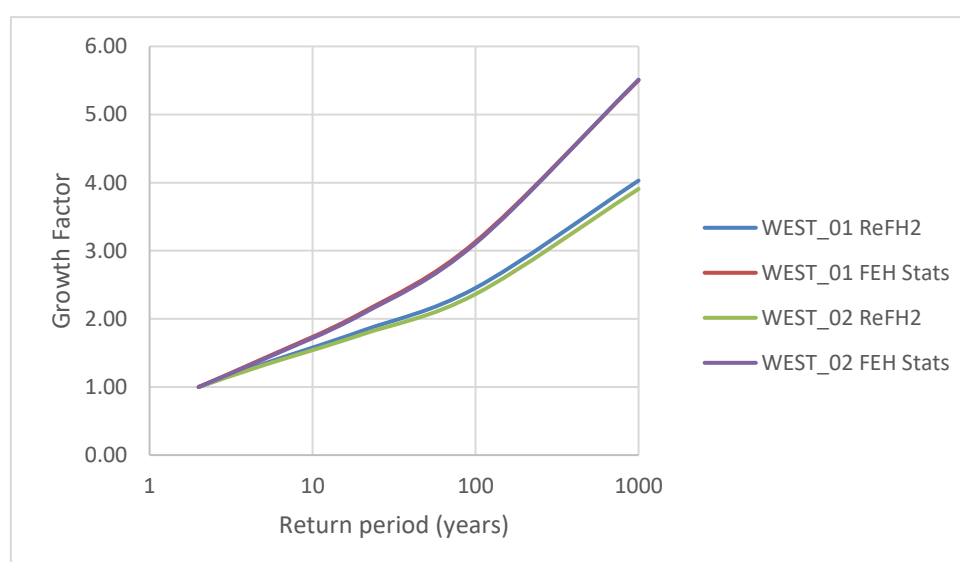


Figure 5-1: Growth factors

5.2 Final choice of method

Choice of method and reasons	FEH Statistical is the preferred method for generating the design peak flow estimates for the study catchment. The comparison of design flows presented in Section 5.1 shows that the Statistical method gives higher flows than the ReFH2 method. Figure 5-1 shows that as well as the higher QMED value, this is also due to higher growth factor. The FEH Statistical method is based on a larger dataset of flood events and has been more directly calibrated to reproduce flood frequency on UK catchments. Although the statistical method is preferred here over the ReFH2 model, there can be significant uncertainties associated with applying it to events beyond the 200-year return period, due to the typically short length of river gauge records. To reduce these uncertainties, a hybrid approach can be taken to deriving the 1000-year return period flows. The ReFH2 0.1%/1% AEP growth factors can be applied to the 1% FEH Statistical method flows, if these produce a larger flow compared to the unadjusted FEH statistical method 0.1% AEP peak flows. However, as these produce a smaller flow, the hybrid approach will not be applied.
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How will the flows be applied to a hydraulic model?	For upstream model inflows (WEST_01 and TRIB_01) ReFH2 hydrographs, scaled to fit the statistical peaks, will be applied to the model. For the intervening area, ReFH2 hydrographs will be applied to the model, with flows derived from stand-alone descriptors. The intervening area flow will be distributed across the modelled reach according to catchment area.
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5.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The main assumptions are: • The catchment boundary is representative of the topographic catchment, given the uncertainty in the drain network within the catchment • The densely urbanised region to the east is assumed to drain towards the stream being modelled, as indicated by a review of the local LIDAR data. This will have a significant effect on flows in the lower reach of the model. • BFIHOST19 can be used in the FEH Statistical method
Discuss any particular limitations	The main limitation is the lack of river flow gauge data specific to the study area. There are no river flow gauges on the watercourse at or near the area of interest and, therefore, the catchment response is unknown. There is a level gauge downstream of the study area on the West Brook, but as this record appears to be significantly artificially influenced it was deemed not to be suitable for use in this study.
Give what information you can on uncertainty in the results	It is not possible to directly quantify the uncertainty for the ReFH2 method. There is no method provided in the FEH for estimating uncertainty for the common situation of an ungauged catchment, pooled growth curve and QMED estimated from catchment descriptors. The uncertainty will depend on many factors, for example, how unusual the study catchment is relative to the pooling group, and the uncertainty in flow measurement at other gauges. A UK average measure of uncertainty is presented in a technical guidance report generated by a R&D project into the FEH, local data and uncertainty (Environment Agency funded consortium of JBA, CEH and others). The report presents results for rural catchments ($URBEXT2000 < 0.03$) and moderately urbanised catchments ($0.03 \leq URBEXT2000 < 0.15$). The 95% confidence limits for a 1% AEP flood estimate for a rural catchment are: • Without donor adjustment of QMED: 0.45 – 2.23 times the best estimate. • With donor adjustment of QMED (one donor): 0.47 – 2.12 times the best estimate. The 95% confidence limits for a 1% AEP flood estimate for a moderately urbanised catchment are: • Without donor adjustment of QMED: 0.33 – 3.01 times the best estimate

	With donor adjustment of QMED (one donor): 0.34 – 2.94 times the best estimate.
Comment on the suitability of the results for future studies,	The design peak flow estimates and hydrographs were derived for the purposes of this modelling study. If peak flow estimates and hydrographs are required for a different purpose it is recommended that, at a minimum, a review of the results is carried out.
Give any other comments on the study	There is a lack of hydrometric data within the catchment. Confidence in flow estimates and understanding of catchment response could be improved with local hydrometric data collection.

5.4 Checks

Are the results consistent, for example at confluences?	Yes, QMED increases downstream.
What do the results imply regarding the return periods of floods during the period of record?	There is no local flow data (within the study area) against which to compare the design peak flow estimates.
What is the range of 100-year growth factors? Is this realistic?	The 1% AEP growth factor range for the methods is: - FEH Statistical: 3.0-3.1 - ReFH2: 2.4-2.5 The typical range is 2.1 to 4.0. The growth factors for both methods are within this range.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The 0.1%/1% AEP growth factor range for the methods is: - FEH Statistical: 1.8 - ReFH2: 1.6-1.7
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	There are no known studies of the West Brook catchment to compare with the results of this study.
Are the results compatible with the longer-term flood history?	There is no local flow data against which to compare the design flow estimates.
Describe any other checks on the results	Modelled levels and flood extents should be sensibility-checked to ensure that flow inputs result in realistic outputs, consistent with the local flood history.

5.5 Final results

Site code	Flood peak (m ³ /s) for the following AEP (%) events				
	50	20	5	1	0.1
WEST_01	0.6	0.8	1.2	1.8	3.2
TRIB_01	0.6	0.8	1.2	1.8	3.2
WEST_02	1.2	1.6	2.4	3.6	6.5

If flood hydrographs are needed for the next stage of the study, where are they provided?	To be supplied in a spreadsheet accompanying this document
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6 Annex

6.1 Pooling group – WEST_02 (standard method)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	1.457	40	0.816	0.214	0.215	0.02
76011 (Coal Burn @ Coalburn)	1.605	43	1.84	0.167	0.167	0.303
27051 (Crimple @ Burn Bridge)	1.83	48	4.544	0.219	0.22	0.146
45816 (Haddeo @ Upton)	1.917	27	3.456	0.298	0.299	0.417
28033 (Dove @ Hollinsclough)	2.142	45	4.15	0.225	0.225	0.373
26016 (Gypsy Race @ Kirby Grindalythe)	2.361	23	0.101	0.312	0.312	0.258
25019 (Leven @ Easby)	2.38	42	5.384	0.338	0.339	0.386
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.499	10	5.972	0.256	0.257	0.136
47022 (Tory Brook @ Newnham Park)	2.535	26	5.88	0.257	0.259	0.195
25011 (Langdon Beck @ Langdon)	2.568	34	15.878	0.228	0.228	0.316
25003 (Trout Beck @ Moor House)	2.596	47	15.164	0.166	0.166	0.291
71003 (Croasdale Beck @ Croasdale Flume)	2.67	37	10.9	0.212	0.212	0.323
27010 (Hodge Beck @ Bransdale Weir)	2.736	41	9.42	0.224	0.224	0.293
206006 (Annalong @ Recorder)	2.771	48	15.33	0.189	0.189	0.052

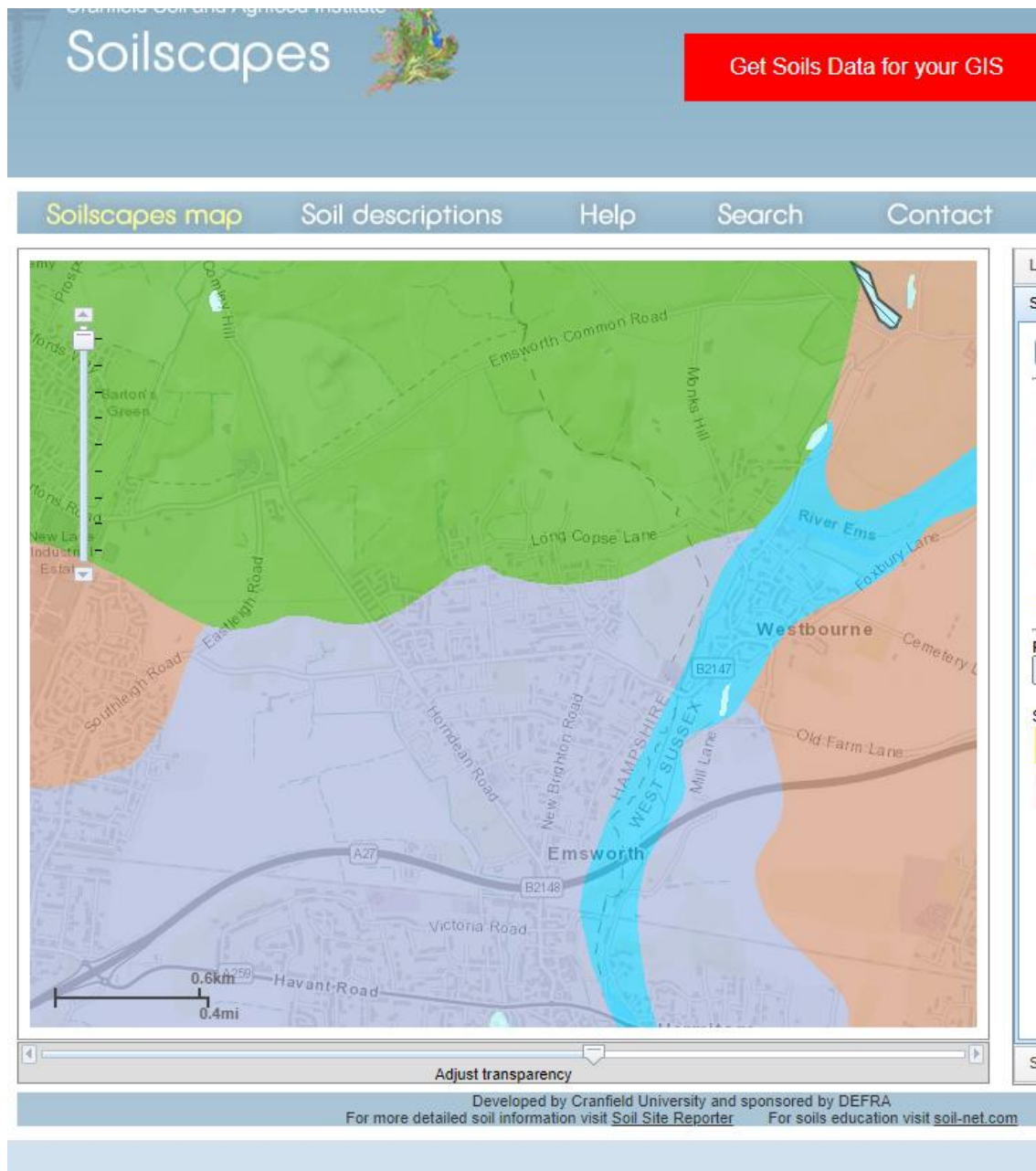
6.2 Pooling group – WEST_02 (small catchment method)

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	0.606	40	0.816	0.214	0.215	0.02
27051 (Crimple @ Burn Bridge)	0.681	48	4.544	0.219	0.22	0.146
25019 (Leven @ Easby)	1.108	42	5.384	0.338	0.339	0.386
26016 (Gypsy Race @ Kirby Grindalythe)	1.12	23	0.101	0.312	0.312	0.258
76011 (Coal Burn @ Coalburn)	1.244	43	1.84	0.167	0.167	0.303

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
45816 (Haddeo @ Upton)	1.4	27	3.456	0.298	0.299	0.417
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	1.447	10	5.972	0.256	0.257	0.136
27010 (Hodge Beck @ Bransdale Weir)	1.458	41	9.42	0.224	0.224	0.293
44008 (South Winterbourne @ Winterbourne Steepleton)	1.542	41	0.448	0.407	0.408	0.319
26014 (Water Forlornes @ Driffield)	1.693	22	0.431	0.298	0.299	0.12
36010 (Bumpstead Brook @ Broad Green)	1.726	53	7.5	0.377	0.379	0.173
28033 (Dove @ Hollinsclough)	1.727	45	4.15	0.225	0.225	0.373
41020 (Bevern Stream @ Clappers Bridge)	1.809	51	13.66	0.204	0.205	0.174
28058 (Henmore Brook @ Ashbourne)	1.879	13	8.838	0.188	0.19	-0.109

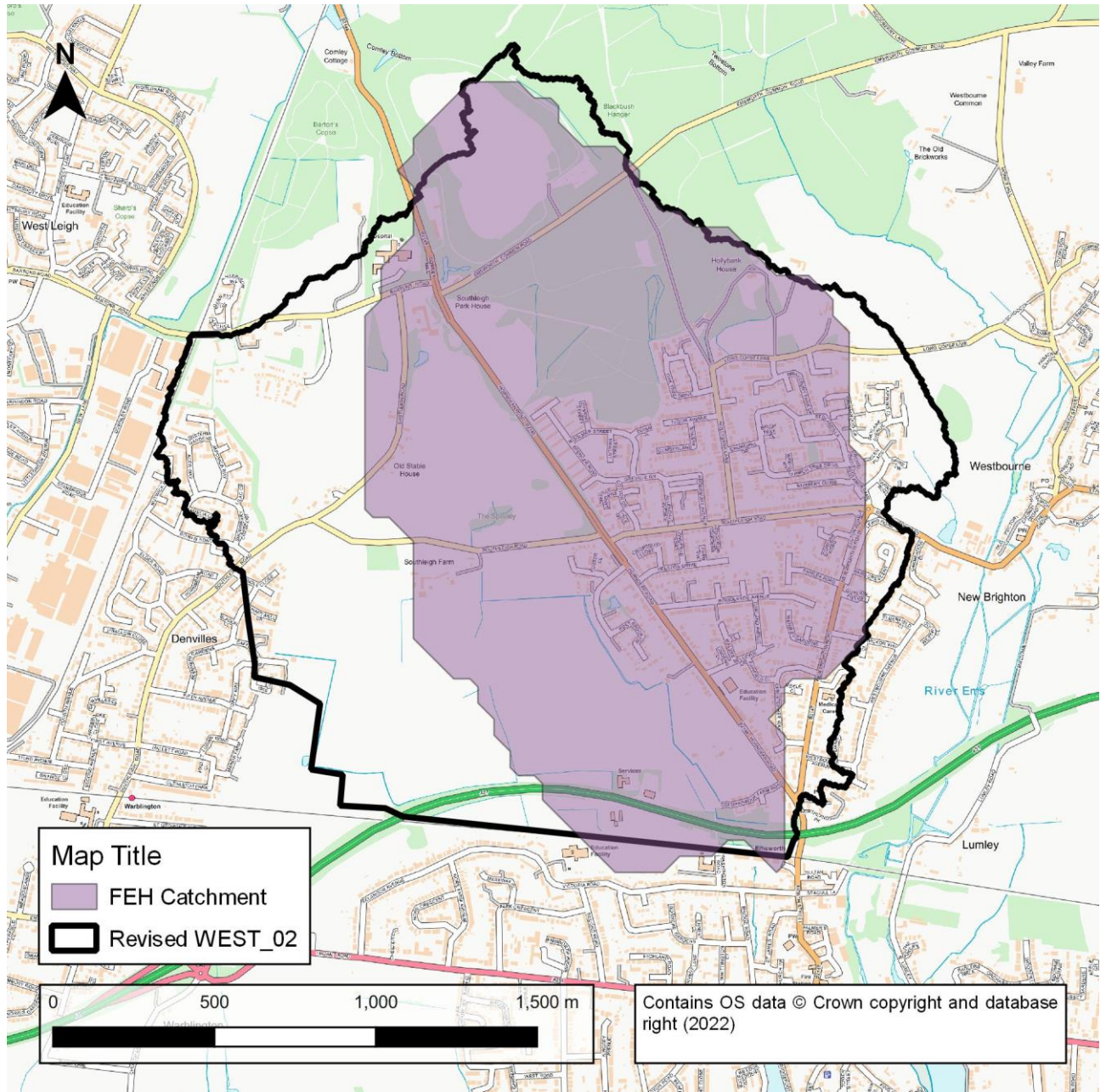
6.3 Soils

Figure 6-1: Soil types in catchment



(Source: <http://www.landis.org.uk/soilscape/>, accessed 01/02/2022)

Figure 6-2 Revised Catchment Boundary



6.4 Site Walkover

A site walkover was undertaken by JBA Consulting on 2nd July 2021. It was not possible to identify the connectivity of the drains within the catchment during the site visit. The western side of West Brook watercourse was fenced off and even if access had been possible, vegetation was high so it was unlikely to be clearly visible as shown in Figure 6-3.

Figure 6-3 Site Visit



Offices at

Coleshill
Doncaster
Dublin
Edinburgh
Exeter
Glasgow
Haywards Heath
Isle of Man
Limerick
Newcastle upon Tyne
Newport
Peterborough
Saltaire
Skipton
Tadcaster
Thirsk
Wallingford
Warrington

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