Flood estimation calculation record

Introduction

This calculation record is based on a supporting document to the Environment Agency's flood estimation guidelines (Version 4, 2012). It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

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Approval

	Name and qualifications
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Abbreviations

AM.................................. Annual Maximum

AREA .... Catchment area (km^2)

BFI .... Base Flow Index

BFIHOST .... Base Flow Index derived using the HOST soil classification

CFMP.............................. Catchment Flood Management Plan

CPRE.............................. Council for the Protection of Rural England

FARL............................... FEH index of flood attenuation due to reservoirs and lakes

FEH................................. Flood Estimation Handbook

FSR................................. Flood Studies Report

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)

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

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

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations	This hydrological assessment was undertaken to inform the Surface Water Management Plan for Staplehurst, Kent. Peak flows are required for the following Annual Exceedance Probability (AEP) events; 50%, 10%, 5%, 3.33%, 2%, 1.33%, 1% and 0.1%. The effects of climate change are to be considered for the 1% AEP event. For this event, flow will be increased by 20% as stated within the FCDPAG3 Economic Appraisal (DEFRA, 2006).

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	Staplehurst is a large village located approximately 12km south of Maidstone, Kent. The drain catchments within Staplehurst are predominantly covered with Arable (Horticultural) land with a mixture of woodland and grassland. The main built-up area is Marden and part of Staplehurst is located in the upper Marden drain catchment. The total catchment area of the Staplehurst Drains is 8.6km^2. A map showing the catchment boundaries is shown in Figure **2-1**. The catchments within Staplehurst are underlain predominantly by mudstone deposits (Weald Clay formation) and therefore the catchments are quite impermeable and consequently a more flashy response is expected. This is supported by fairly low BFIHOST values in the range of 0.234 to 0.383; the average SPRHOST value is 46%. These geological formations are overlain by superficial deposits of Alluvium and River Terrace deposits which mainly consist of sands, gravel, clays and silts. The superficial deposits are mostly confined to around the centre of Staplehurst and along some of the drainage ditches. The soils within the Staplehurst predominantly consist of slowly permeable wet clayey soils with impeded drainage. There are also loamy and clayey floodplain soils with naturally high groundwater to the east of Staplehurst (associated with the floodplain of the River Beult). There is fairly shallow gradient across the catchment with the highest elevation point at approximately 40mAOD (Marden Thorn) and the lowest elevation point at approximately 15mAOD at the downstream model extent.

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 3.3.4, August 2014

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Water-course	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Ungauged catchment.							

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality e.g. information from HiFlows-UK, trends in flood peaks, outliers.
Ungauged catchment.						
Give link/reference to any further data quality checks carried out			N/A			
Note – include plots of flood peak and flood hydrograph data at relevant gauging stations along with interpretation, e.g. in the Annex.						

1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons e.g. availability of recent flow gaugings, amount of scatter in the rating.
N/A			
Give link/reference to any rating reviews carried out		N/A	

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)	N/A				
Flow data for events	N/A				
Results from previous studies	N/A				

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes. The catchments are fairly small (some catchment areas are less than 0.5km²), occasionally urbanised and they are quite impermeable. The 1% AEP floodplain extents are quite high in the Staplehurst catchments as FPEXT values are generally in excess of 0.18 with the highest FPEXT value being 0.39 i.e. 39% of the catchment being inundated during a 1% AEP event.

<table>
<tr><td></td><td>Some of the catchments within Staplehurst are heavily urbanised and therefore ReFH is not appropriate. The FEH Statistical method can be applied in order to provide the fluvial flow estimates. As the fluvial inputs will ultimately be used within a combined fluvial-surface water model, the urban drainage network will be accounted for within the Direct Rainfall ICM hydraulic model.</td></tr>
<tr><td>Outline the conceptual model, addressing questions such as:

Where are the main sites of interest?
What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…)
Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?
Is there a need to consider temporary debris dams that could collapse?
</td><td>The main area of interest is the village of Staplehurst which is located south of Maidstone in Kent. The catchments within Staplehurst are likely to be impacted by peak flows due to underlying impermeable geological deposits and also within the centre of Staplehurst due to the increase in impervious urbanised area.
There is a history of flooding within Staplehurst (see table below). It is unclear whether this flooding is associated with high levels in the adjacent River Beult catchment. This will be assessed within the flood history report which aims to determine catchment response within Marden, Staplehurst and Headcorn and whether the flood events are due to insufficient capacity within the drainage network or due to fluvial flooding. This is the main reason for undertaking Direct Rainfall analysis and fluvial analysis to derive a combined fluvial-surface water hydraulic model.
<table>
<tr><th>Date</th><th>Source</th></tr>
<tr><td>November 2009</td><td>Foul sewer, Surface water</td></tr>
<tr><td>February 2010</td><td>Foul sewer, Fluvial near Clappers Lane</td></tr>
<tr><td>March 2010</td><td>Foul sewer, Surface water</td></tr>
<tr><td>January 2014</td><td>Foul sewer</td></tr>
</table></td></tr>
<tr><td>Any unusual catchment features to take into account?
e.g.

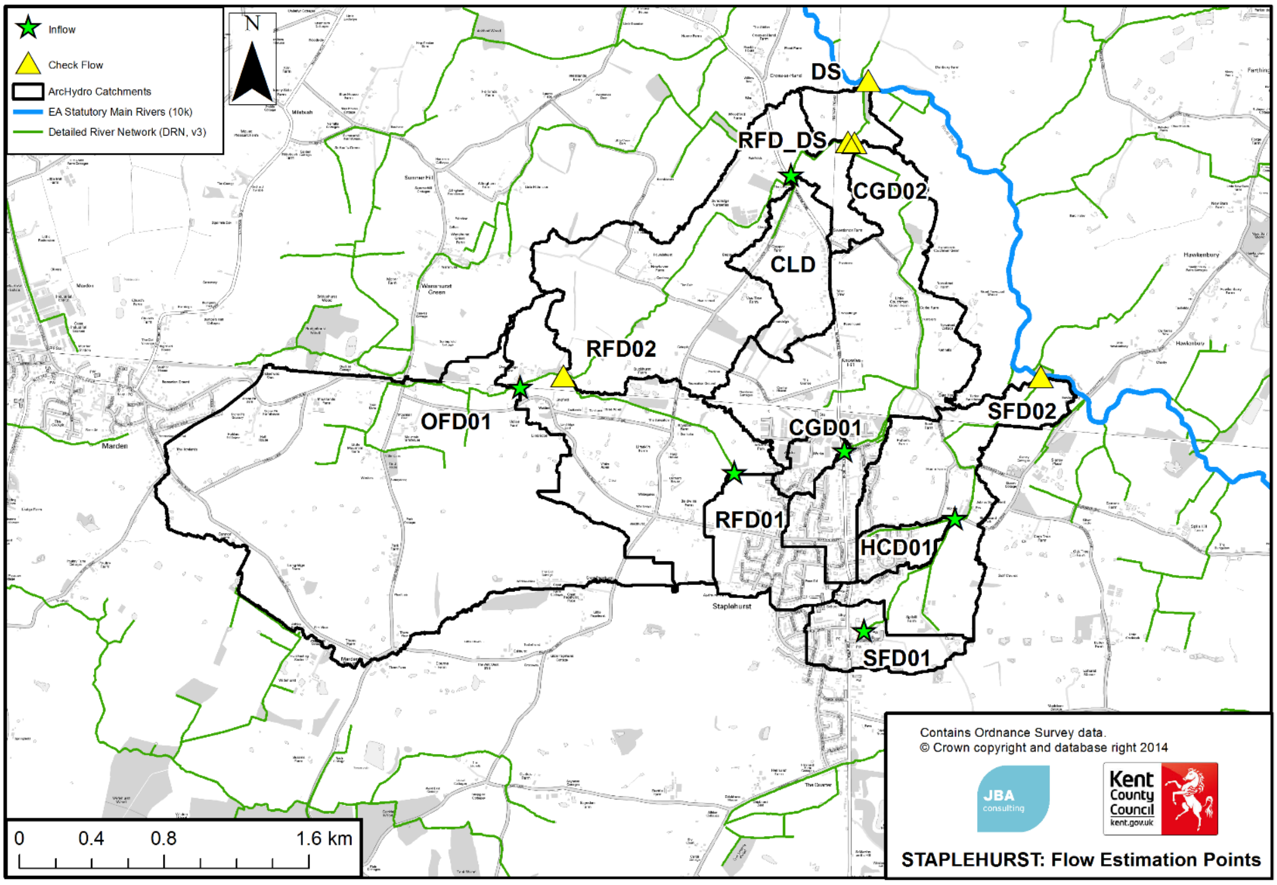
highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20%
highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments
pumped watercourse – consider lowland catchment version of rainfall-runoff method
major reservoir influence (FARL<0.90) – consider flood routing, extensive floodplain storage – consider choice of method carefully
</td><td>The catchments within Staplehurst are quite impermeable (average BFIHOST is 0.32 and SPRHOST is 46%). As some of the catchments are heavily urbanised, the standard ReFH method cannot be used to derive peak flows. Therefore the FEH Statistical method will be used to derive the fluvial flow estimates. As stated previously, the fluvial inputs will ultimately be used within a combined fluvial-surface water model. The urban drainage network will be accounted for within the Direct Rainfall ICM hydraulic model.</td></tr>
<tr><td>Initial choice of method(s) and reasons
Will the catchment be split into subcatchments? If so, how?</td><td>The FEH Statistical method will be used as some of the catchments are heavily urbanised and therefore the ReFH method is not appropriate for estimating peak flows. Inflows will be derived at the upstream model extents with check flows derived at key locations; confluences and downstream model extent. Intervening areas will be accounted for within the combined fluvial-surface water model.</td></tr>
</table>

Software to be used (with version numbers)	FEH CD-ROM v3.0[1] WINFAP-FEH v3.0.002[2]

[1] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.
[2] WINFAP-FEH v3 © Wallingford Hydro Solutions Limited and NERC (CEH) 2009.

2 Locations where flood estimates required

Figure 2-1: Locations of flow estimates



2.1 Summary of subject sites

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
OFD01	Overbridge Farm Drain	Overbridge Farm US	576700	144550	0.7*	2.8
RFD01	Royston Farm Drain	Royston Farm US	578800	144500	0.5*	0.4
RFD02	Overbridge / Royston Farm Drain	D/S of Confluence	577600	145100	2.8*	4.2
CLD	Clappers Lane Drain	Clappers Lane Drain	578261	145752	N/A	0.3
RFD_DS	Royston Farm Drain	Royston Farm Drain DS	578550	145900	4.6*	5.9
SFD01	Spilsill Farm Drain	Spilsill Farm Drain US	578750	142550	1.8	0.2
HCD01	Headcorn Road Drain	Headcorn Road Drain	579000	144200	0.6	0.1
SFD02	Spilsill Farm Drain	Spilsill Farm Drain DS	579450	145300	1.8	1.1

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km²)	Revised AREA if altered
CGD01	Couchman Green Drain	Couchman Green Drain US	578800	144500	0.5	0.3
CGD02	Couchman Green Drain	Couchman Green Drain DS	578600	145900	1.3	1.5
DS	Royston Farm Drain / Couchman Green Drain	U/S of confluence with the River Beult	578650	146200	6.0*	7.5

*Several catchments were not defined by the FEH CD-ROM (v3). For the other catchments, there were multiple discrepancies between the FEH catchments and the ArcHydro catchments. Catchment descriptors were derived for these areas by combining catchment descriptors from representative FEH catchments within the study area or subtracting areas to derive representative intervening catchment areas. Full details of the FEH catchments that were used are tabulated within the Annex.

As there is no gauged data and the geology is fairly consistent across the catchments, the upstream and downstream model extents were selected as the flow estimation points. For Headcorn Road (HCD01) and Clappers Lane Drain (CLD), the catchment area derived at the downstream extent was used to inform the model inflow for this catchment as there was no representative catchment at the upstream model extent and the catchments are fairly small.

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

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 1990	URBEXT 2000	FPEXT
OFD01	1.000	0.33	0.242	1.77	11.88	612	44.63	0.0092	0.0064	0.2334
RFD01	1.000	0.36	0.247	0.56	12.50	667	48.67	0.2765	0.3264	0.1700
RFD02	1.000	0.35	0.242	2.20	12.29	638	46.78	0.0227	0.0214	0.2138
CLD	1.000	0.36	0.318	0.54	12.40	657	45.97	0.0273	0.0219	0.2779
RFD_DS	1.000	0.35	0.257	2.64	12.20	637	46.21	0.0120	0.0075	0.2287
SFD01	1.000	0.36	0.259	0.45	20.60	687	48.18	0.0437	0.0605	0.2486
HCD01	1.000	0.36	0.253	0.30	22.80	674	48.35	0.1448	0.2242	0.1565
SFD02	1.000	0.36	0.383	1.06	14.10	670	43.03	0.1016	0.1474	0.3117
CGD01	1.000	0.36	0.247	0.27	12.50	667	48.67	0.2765	0.3264	0.1700
CGD02	1.000	0.36	0.353	1.60	9.70	660	44.63	0.1054	0.1251	0.3906
DS	1.000	0.35	0.276	3.01	11.90	644	46.12	0.0256	0.0246	0.2600

Note: Red text denotes catchment descriptor values which have been changed from the FEH CD-ROM values. URBEXT1990 and URBEXT2000 values have been updated to 2014.

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The catchment boundaries were checked using 1m resolution DTM data. In some locations the FEH catchment boundary was amended to take account of the Detailed River Network (DRN v3) so that the rivers do not cut across subcatchment boundaries. The ArcHydro 'rolling ball' analysis tool within ArcGIS was used to define the topographical catchment using a composite elevation dataset which consisted mostly of 1m resolution LIDAR data with some OS Open Terrain 50k data in the upper reaches. For the catchments where AREA has changed significantly (>10%), the FEH DPLBAR value was also updated. This is because DPLBAR is based on catchment area and should therefore be updated to reflect the change in area. The standard equation for DPLBAR, given in the FEH Volume 5, uses a power term of 0.548 which is based on research for the UK as a whole has been used to update DPLBAR where AREA has changed significantly.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	Soil values (SPRHOST and BFIHOST) were checked against the 1:250,000 Soil Survey of England and Wales map for South East England for both catchments to assess if the FEH CD-ROM values across the study area are reasonable. It was found that the FEH Catchment Descriptors represent the soil types well. However, as mentioned previously there were some discrepancies between the FEH catchments and ArcHydro catchments. Therefore several FEH catchments were combined to provide representative catchment descriptors for the flow estimation points (see Annex for details on which FEH catchments were used to derive representative catchment descriptors). The urban areas shown on the FEH CD-ROM (v3) were compared against OS 1:50,000 mapping and were deemed to be representative of the study catchment. Therefore the URBEXT values on the FEH-CD ROM (v3) were retained and updated to 2014 values using the CPRE formulae in accordance with the EA Flood Estimation Guidelines. Several FEH catchments were combined to provide representative catchment descriptors for the flow estimation points (see Annex for details on which FEH catchments were used to derive representative catchment descriptors). The FARL value was checked against the OS mapping for surface water features within the study catchment. There are no major surface water within the Staplehurst catchments. FARL values for CLD and SFD01 were changed to 1 as this corresponds with the OS 1:50,000 Mapping.
Source of URBEXT	$URBEXT_{1990}$ has been used for the ReFH method. $URBEXT_{2000}$ has been used for the FEH Statistical method.
Method for updating of URBEXT	$URBEXT_{1990}$ - CPRE formula from FEH Volume 4. $URBEXT_{2000}$ - CPRE formula from 2006 CEH report on $URBEXT_{2000}$.

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	A brief assessment of donor stations was carried out for this study using WINFAP-FEH to assess stations that are suitable for QMED within the HiFlows-UK dataset. No suitable donor stations could be located within 40km as the donor catchments were either significantly larger or they were not hydrologically similar to the subject catchments. Therefore QMED estimates were derived using catchment descriptors.

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjust-ment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)
40005	REJECT: The donor catchment is nearly 40 times larger than the subject catchments. All of the other catchment descriptors (SAAR, BFIHOST, FARL) at the donor catchment are generally consistent particularly for Couchman Green Drain and Spilsill Farm Drain. But given that the catchment is significantly larger, it is highly unlikely that the catchment response would be similar. The subject catchments are located approximately 8km away.	AM	N/A	42.1	44.0	0.957
40004	REJECT: The donor catchment is nearly 30 times larger than the subject catchments. Most of the other catchment descriptors (BFIHOST and FARL) at the donor catchment are generally consistent particularly for Couchman Green Drain and Spilsill Farm Drain. However, the SAAR value is approximately 30% higher than the subject catchments. Given that the catchment is significantly larger, it is highly unlikely that the catchment response would be similar. The donor catchment also has slightly more attenuation due to reservoirs and lakes (FARL=0.975). The subject catchments are located approximately 23km away.	AM	N/A	37.2	49.8	0.745
Other potential donor catchments that were more similar in catchments size were not hydrologically similar in terms of rainfall (SAAR), permeability (BFIHOST) and reservoir/lakes attenuation (FARL). Based on the adjustment ratios for the rejected donor sites listed above, it is likely that observed QMED estimates in similar catchments may be less than QMED derived using catchment descriptors. However, it is unclear how much lower actual QMED would be. It is important to note that the Staplehurst Drain catchments are ‘moderately’ to ‘very heavily urbanised’ and therefore the QMED estimates derived using catchment descriptors may actually be more in line with the expected QMED values for these ungauged study catchments.						

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of	Data transfer					Final estimate
			NRFA numb	Distanc e		Moderated QMED	If more than one donor	

		QMEDRURAL (m³/s)	ers for donor sites used (see 3.3)	between centroids d_{ij} (km)	Power term, a	adjustment factor, (A/B)[a]	Weight	Weighted ave. adjustment	of QMEDURBAN (m³/s)
OFD01	CD	0.8	N/A						0.8
RFD01	CD	0.2	N/A						0.2
RFD02	CD	1.2	N/A						1.3
CLD	CD	0.1	N/A						0.1
RFD_DS	CD	1.6	N/A						1.6
SFD01	CD	0.1	N/A						0.1
HCD01	CD	0.1	N/A						0.1
SFD02	CD	0.4	N/A						0.4
CGD01	CD	0.1	N/A						0.1
CGD02	CD	0.5	N/A						0.5
DS	CD	2.0	N/A						2.0

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	Yes, QMED estimates are consistent along successive locations along the same reach. OFD01, RFD01, CLD, SFD01, HCD01 and CGD01 are separate tributaries. There is a slight difference between QMED rural and QMED urban estimates but given that the catchments are fairly small, this is not observed to 1 decimal place apart from at RFD02.

Important note on urban adjustment

The method used to adjust QMED for urbanisation, for both subject sites and donor sites, is that published in Kjeldsen (2010)[3] in which PRUAF is calculated from BFIHOST. The result will differ from that of WINFAP-FEH v3.0.003 which does not correctly implement the urban adjustment of Kjeldsen (2010). Significant differences will occur only on urban catchments that are highly permeable.

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone.

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added below.

The data transfer procedure is the revised one from Science Report SC050050. The QMED adjustment factor A/B for each donor site is given in Table 3.3. 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 times the initial estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

3.4 Derivation of pooling groups

The composition of the pooling groups is given in the Annex. Several subject sites may use the same pooling group. Generic pooling groups were based on flow estimation points within the same catchment. The top three stations within the default pooling group were investigated as these stations will have a greater impact on the growth curve and therefore the final design flow estimates.

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

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
CGD_DS	CGD_DS GL*	No	Stations removed 49006 (Camel @ Camelford) • The station record is too short (6 years) and WINFAP-FEH recommends that it should be removed from the pooling group. 76011 (Coal @ Coal Burn) • Original structure reported to have leaked badly affecting overall data quality though not thought to have affected high flows. Replaced 1991 - doesn't drown at high flows. • Recent gaugings suggest that high flows may be underestimated by up to 20% and that further investigation is required. • Significant land use change during period of record and potentially substantial underestimation of high flows. Not much variability in flow following installation of new structure; no particularly large peaks. Ranked 2nd within the pooling group and should therefore be removed. Stations investigated 27073 (Brompton Beck @ Snainton Ings) • Theoretical rating but gaugings show considerable scatter. • Fully contained with no likelihood of drowning. Theoretical rating should apply for the whole range. • Not representative of the study catchment and variability in the highest AMAX peaks is low (small L-skew) however L-moments are representative of others in the group, although the growth curve is flat there is another site with a similarly shallow growth curve. • As this site is not discordant and fits well with the other stations in the group, the site was retained. 27051 (Crimple @ Burn Bridge) • Overtopped at high flows and drowns but rated excellent for high flow measurement. • Maximum recorded level only just exceeds wing wall height, and although the weir is likely drowned at this point, the theoretical equation is thought to remain a reasonable approximation for flow calculation. • Gaugings only for very low flows except one which exceeds QMED (roughly at bankful level). • Only the highest four AMAX values are above bankful therefore the majority of the	0.232, 0.194

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons Note also any sites that were investigated but retained in the group.	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
			AMAX series is probably reasonable. Therefore this site has been retained. 45816 (Haddeo @ Upton) • Possibly not particularly representative of the study catchment but not discordant and fits well with the other stations in the group. • Short AMAX series and AMAX1 is nearly 3.5 times larger than QMED. However, this is highlighted as a genuine peak on the CEH website. Steep growth curve possibly caused by this large peak in 1999. • Provides useful information with which to generate the pooled growth curve. This site is therefore retained. Total of 499 years; no stations added as unlikely to improve pooling group. The final pooling group composition can be found within the Annex.	
RFD_DS	RFD_DS GL*/GEV	No	<u>Stations removed</u> 49006 (Camel @ Camelford) • The station record is too short (6 years) and WINFAP-FEH recommends that it should be removed from the pooling group. <u>Stations investigated</u> 27073 (Brompton Beck @ Snainton Ings) – retained; see above. 20002 (West Peffer Burn @ Luffness) • Similar catchment descriptors to the subject site and no observable trend in AMAX series. Mainly impervious catchment which is consistent with the subject catchment. • Site is within the main cluster of pooling group stations on the L-CV and L-Kurtosis plots. Therefore this site was retained. 27051 (Crimple @ Burn Bridge) – retained; see above. 76011 (Coal @ Coal Burn) – station retained as it is ranked lower in the pooling group. Total of 507 years; no stations added as unlikely to improve pooling group. The final pooling group composition can be found within the Annex.	0.253, 0.206
SFD02	SFD02 GL*	No	<u>Stations removed</u> 49006 (Camel @ Camelford)	0.229, 0.206

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments,** L-CV and L-skew, (before urban adjustment)
			• The station record is too short (6 years) and WINFAP-FEH recommends that it should be removed from the pooling group. 76011 (Coal @ Coal Burn) – station removed due to data quality issues outlined above. Stations investigated 27073 (Brompton Beck @ Snainton Ings) – retained; see above. 45816 (Haddeo @ Upton) – retained; see above. 27051 (Crimple @ Burn Bridge) – retained; see above. Total of 486 years; no stations added as unlikely to improve pooling group. The final pooling group composition can be found within the Annex.	
DS	DS GL*	No	Stations investigated 27073 (Brompton Beck @ Snainton Ings) – retained; see above. 20002 (West Peffer Burn @ Luffness) – retained; see above. 203046 (Rathmore Burn @ Rathmore Bridge) • Gaugings agree well with rating at lower flows. Although does not meet numerical criteria, QMED estimates are likely to be reasonable. Measuring authority consider extrapolation of rating at high flows valid, as very minimal floodplain flow. • Rating derived from current meter gaugings. Simple extrapolation occurs beyond 2.28m (highest gauged level). However, more high flow gaugings would be useful, as there are no gaugings above QMED. • AMAX1 is approximately 1.6 times higher than QMED which is fairly low; reasonable range in AMAX series. This explains the fairly shallow growth curve for this site • Site is within the main cluster of pooling group stations on the L-Kurtosis plot and is towards the upper end on the L-CV plot. Site retained as the site growth curve is in line with the average pooling group growth curve. 76011 (Coal @ Coal Burn) – station retained as it is ranked lower in the pooling group.	0.241, 0.177

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	**Changes made to default pooling group, with reasons** Note also any sites that were investigated but retained in the group.	**Weighted average L-moments,** L-CV and L-skew, (before urban adjustment)
			Total of 532 years; no stations added as unlikely to improve pooling group. The final pooling group composition can be found within the Annex.	
Notes Pooling groups were derived using the revised procedures from Science Report SC050050 (2008). The weighted average L-moments, before urban adjustment, can be found at the bottom of the Pooling-group details window in WINFAP-FEH.				

3.5 Derivation of flood growth curves at subject sites

The rural pooled growth curves for RFD_DS, SFD02, CGD_DS and DS are shown below.

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
OFD01	P	RFD_DS	Generalised Logistic (GL) distribution selected as GL provides the best fit to all of the generic pooling groups and GL is the recommended distribution for UK catchments. Additionally, GL provides the most conservative estimates at higher return periods.	Urban adjustment made using v3 method (Kjeldsen, 2010). No permeable adjustment – SPRHOST >20%.	1.000, 0.256, -0.207	2.97
RFD01	P	RFD_DS			1.000, 0.203, -0.264	2.82
RFD02	P	RFD_DS			1.000, 0.254, -0.210	2.96
CLD	P	RFD_DS			1.000, 0.253, -0.210	2.96
RFD_DS	P	RFD_DS			1.000, 0.256, -0.207	2.97
SFD01	P	SFD02			1.000, 0.221, -0.217	2.74
HCD01	P	SFD02			1.000, 0.197, -0.245	2.68
SFD02	P	SFD02			1.000, 0.208, -0.232	2.71
CGD01	P	CGD_DS			1.000, 0.186, -0.251	2.61
CGD02	P	CGD_DS			1.000, 0.216, -0.216	2.69
DS	P	DS			1.000, 0.242, -0.181	2.73

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

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 v3 method: Kjeldsen (2010).

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

Figure 3-1: Royston Farm Drain (RFD_DS) Pooled growth curve (Rural)

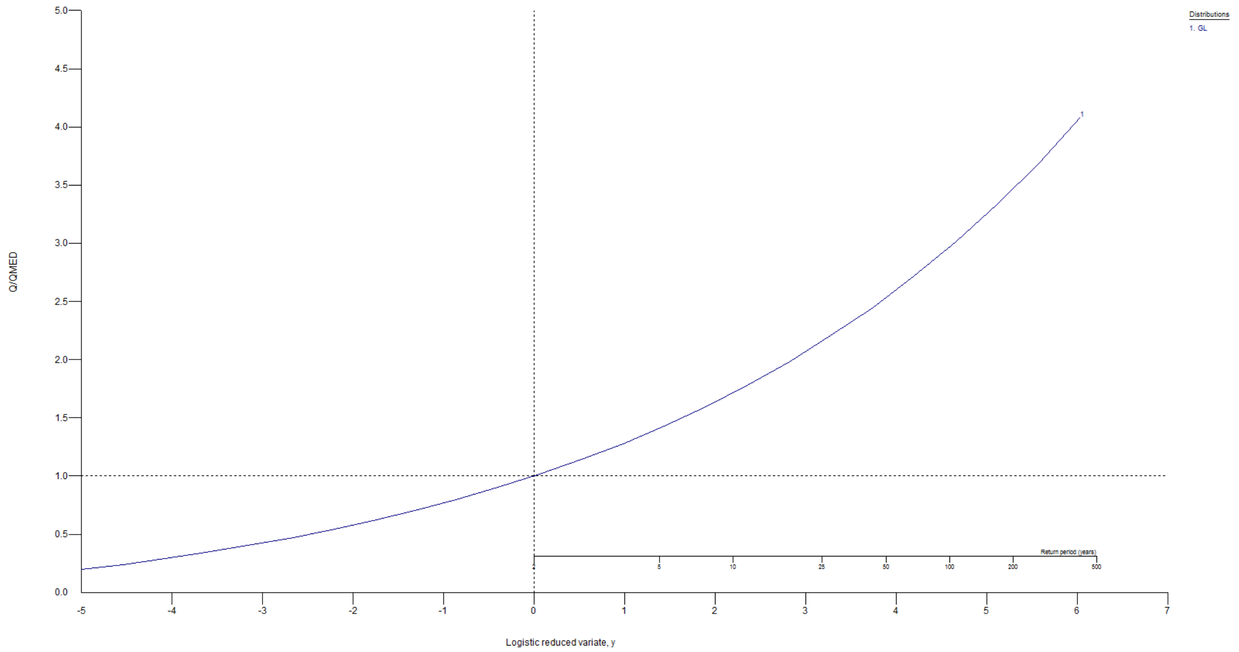


Figure 3-2: Spilsill Farm Drain (SFD02) Pooled growth curve (Rural)

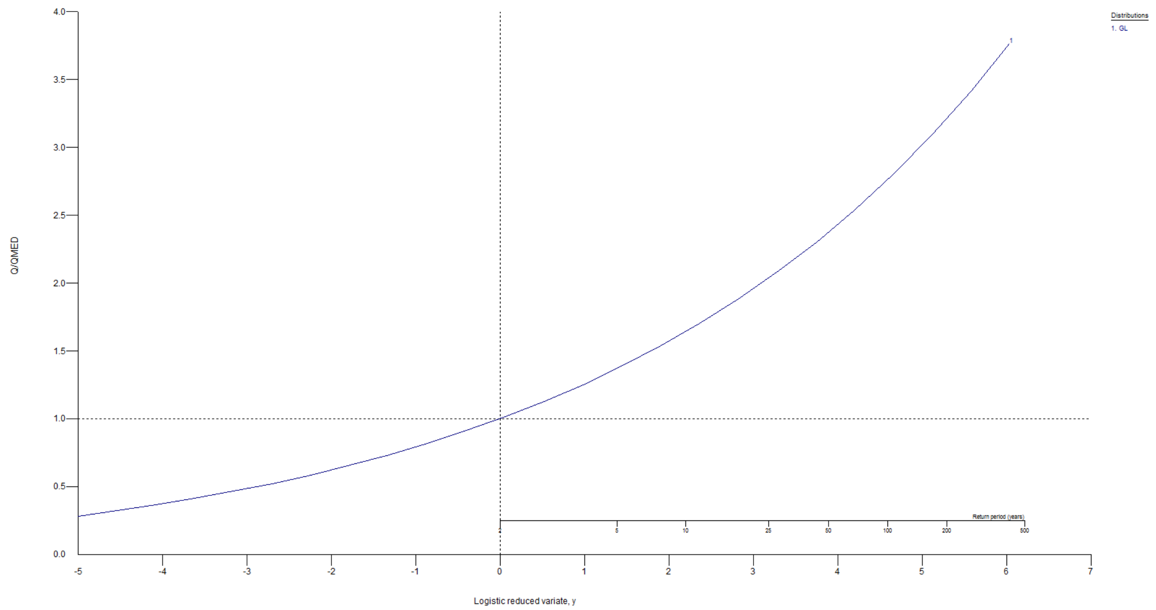


Figure 3-3: Couchman Green Drain (CGD_DS) Pooled growth curve (Rural)

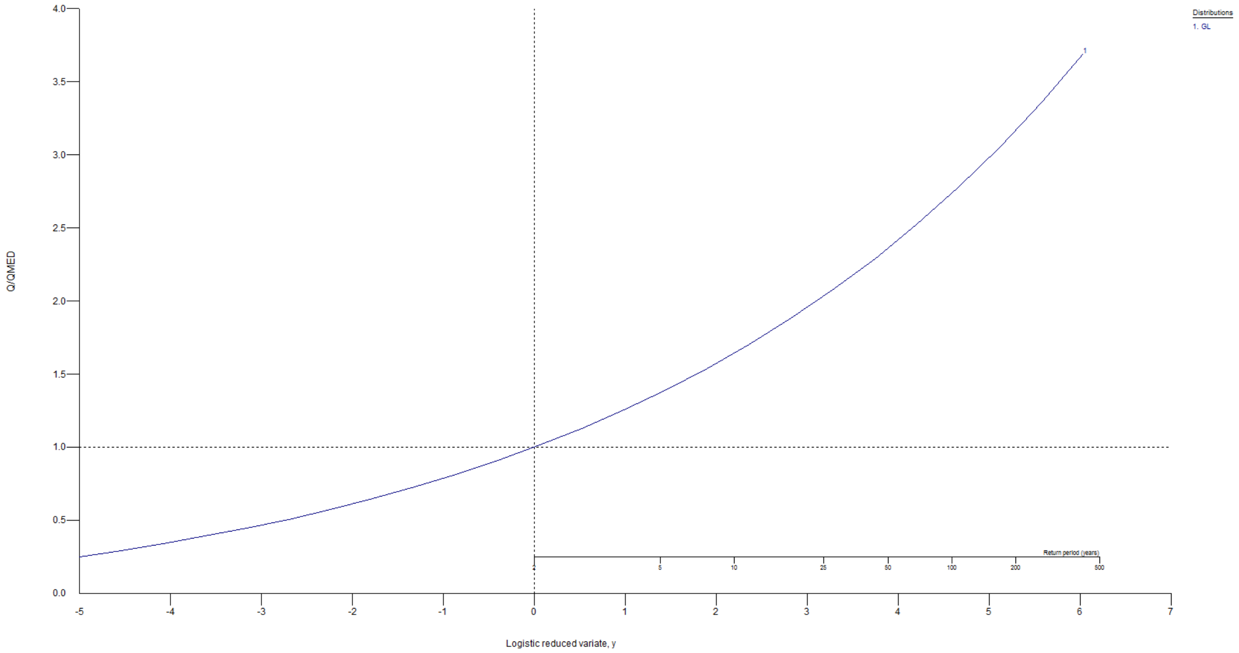
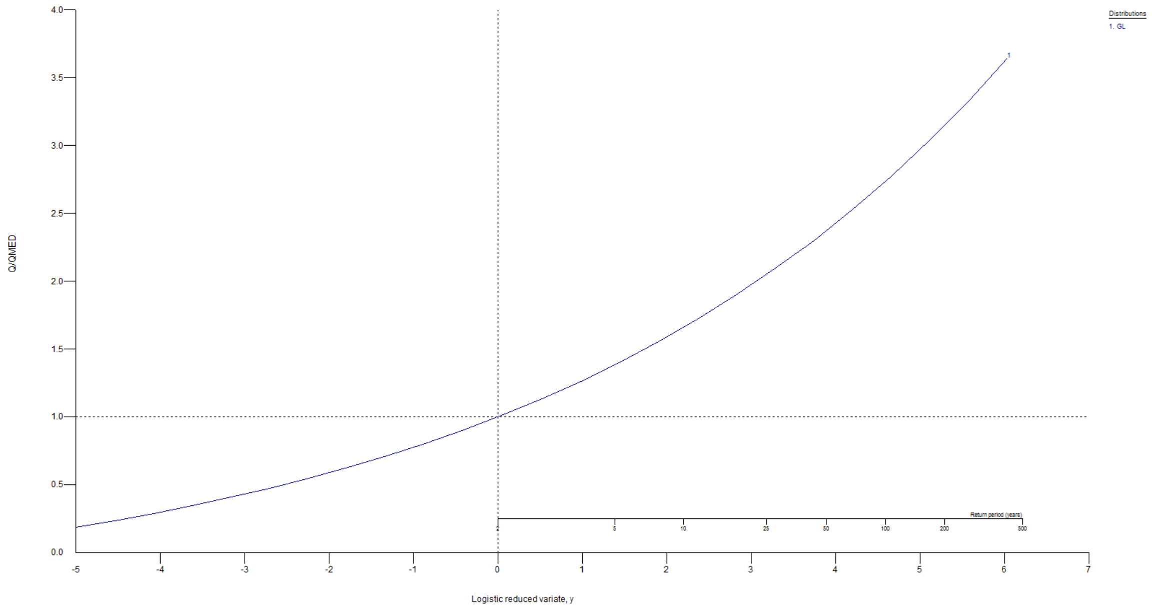


Figure 3-4: Royston Farm Drain / Couchman Green Drain (DS) Pooled growth curve (Rural)



3.6 Flood estimates from the statistical method

Site code	Flood peak (m^3/s) for the following Annual Exceedance Probabilities (%)							
	50	10	5	3.33	2	1.33	1	1 (+CC)	0.1
OFD01	0.8	1.4	1.6	1.8	2.0	2.2	2.3	2.8	3.9
RFD01	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	1.0
RFD02	1.3	2.2	2.6	2.8	3.2	3.5	3.7	4.5	6.3
CLD	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.7
RFD_DS	1.6	2.8	3.3	3.6	4.1	4.5	4.8	5.8	8.0
SFD01	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.6
HCD01	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3

Site code	Flood peak (m^3/s) for the following Annual Exceedance Probabilities (%)								
	50	**10**	**5**	**3.33**	**2**	**1.33**	**1**	**1 (+CC)**	**0.1**
SFD02	0.4	0.7	0.8	0.8	0.9	1.0	1.1	1.3	1.9
CGD01	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3
CGD02	0.5	0.8	1.0	1.1	1.2	1.3	1.4	1.7	2.3
DS	2.0	3.3	3.9	4.3	4.8	5.2	5.5	6.6	8.8

4 Revitalised flood hydrograph (ReFH) method – NOT APPLICABLE

4.1 Parameters for ReFH model

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
Brief description of any flood event analysis carried out (further details should be given below or in a project report)					

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?				

4.3 Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) for the following Annual Exceedance Probabilities (%)								
	50	10	5	3.33	2	1.33	1	1 (+CC)	0.1

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. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Ratio of peak flow to FEH Statistical peak	
	Return period 2 years	Return period 100 years
	ReFH	ReFH
-	N/A	N/A

5.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The FEH Statistical method was chosen due to the heavily urbanised subcatchments and the majority of the catchments are small. The ReFH method was not used to derive peak flow estimates at this method is not recommended for catchments with $URBEXT_{1990}$ values > 0.125. As hydrographs are required for the hydraulic model, the ReFH hydrograph shapes will be scaled to fit the FEH Statistical peak flow estimates. The urban drainage network will be accounted for within the Direct Rainfall ICM hydraulic model. Intervening areas will be accounted for within the combined fluvial-surface water model.

5.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The main assumptions in this study are that: • The pooling groups are suitably representative of the Staplehurst catchments. • ReFH hydrograph shape is representative of the catchment response; particularly the heavily urbanised tributaries.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The FEH Statistical method is generally believed to only be suitable for return periods up to 200 years. Estimates of flows beyond these return periods are extrapolations and have a higher degree of uncertainty.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	It is not possible to easily assess the uncertainty of the larger flood flow estimates. The FEH allows for calculating confidence intervals for QMED based on catchment descriptors (CDs). OFD01 – QMED: 0.4 – 1.6 (m^3/s) RFD02 – QMED: 0.6 – 2.6 (m^3/s) CLD – QMED: 0.1 – 0.3 (m^3/s) RFD_DS – QMED: 0.8 – 3.3 (m^3/s) SFD01 – QMED: 0.1 – 0.3 (m^3/s) DS – QMED: 1.0 – 4.1 (m^3/s) Providing 95% confidence intervals for QMED on the urbanised subcatchments would imply a false level of accuracy in the QMED estimates, given the uncertainty in the UAFs. For ungauged catchments it is not possible to consider uncertainty in pooled flow estimates but they are likely to be considerably larger than the uncertainty in QMED.
Comment on the suitability of the results for future studies, e.g. at	The design flow estimates have been derived for the purposes of this hydrological assessment in order to inform the fluvial component of

nearby locations or for different purposes.	a Surface Water Management Plan. If peak flow estimates are required for different purposes it is recommended that, at a minimum, a review of results is carried out.
Give any other comments on the study, for example suggestions for additional work.	As in most ungauged catchments, it is recommended that temporary flow gauges be installed to better inform the design peak flow estimates. There are no other specific suggestions relevant to this study.

5.4 Checks

Are the results consistent, for example at confluences?	Yes, the FEH Statistical peak flow estimates are consistent along reaches and at confluences.
What do the results imply regarding the return periods of floods during the period of record?	N/A, ungauged catchments.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	The 1% AEP event growth factors vary between 2.61 and 2.97 which are within the typical 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 event ratios vary between 1.58 and 1.77 which are within the typical range (1.3 – 1.8).
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The 1% AEP specific runoff range between 7.4 and 19.2 l/s/ha. The larger specific runoff estimates are associated with smaller and urbanised catchments (RFD01, CLD, SFD01, HCD01 and CGD01).
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?	TBC – will be confirmed against model outputs. There is no gauged data within these catchments to compare the design flow estimates against.
Describe any other checks on the results	N/A

5.5 Final results

Site code	Flood peak (m^3/s) for the following Annual Exceedance Probabilities (%)								
	50	**10**	**5**	**3.33**	**2**	**1.33**	**1**	**1 (+CC)**	**0.1**
OFD01	0.8	1.4	1.6	1.8	2.0	2.2	2.3	2.8	3.9
RFD01	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	1.0
RFD02	1.3	2.2	2.6	2.8	3.2	3.5	3.7	4.5	6.3
CLD	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.7
RFD_DS	1.6	2.8	3.3	3.6	4.1	4.5	4.8	5.8	8.0
SFD01	0.1	0.2	0.3	0.3	0.3	0.3	0.4	0.4	0.6
HCD01	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3
SFD02	0.4	0.7	0.8	0.8	0.9	1.0	1.1	1.3	1.9
CGD01	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3
CGD02	0.5	0.8	1.0	1.1	1.2	1.3	1.4	1.7	2.3
DS	2.0	3.3	3.9	4.3	4.8	5.2	5.5	6.6	8.8

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	Flood hydrographs are required for the hydraulic modelling and will be provided in individual ISIS Event Data (.IED) files. The recommended storm duration, based on the standard ReFH equation at the downstream extent is 7.218hrs (with a 0.44-0.88hr data interval). The storm duration and time step used for these estimates are 7.25hr and 0.25hr respectively. The ARF is 0.962 for the 7.25hr duration. A brief assessment of storm durations at key locations was carried out in order to determine the critical durations for the hydraulic model. A storm duration of 1.1 hours was found to be critical for the smaller and urbanised catchments (ARF=0.984) so therefore this storm duration should be tested within the hydraulic model.

6 Annex – supporting information

6.1 Catchment descriptors

Site code	Watercourse	Site	Easting	Northing	AREA on FEH CD-ROM (km²) / Composite Catchment
OFD01	Overbridge Farm Drain	Overbridge Farm US (summation of FEH catchment areas covering the ArcHydro catchment area)	577050	144600	1.3
			575900	144750	0.9
			575100	143700	0.6
RFD01	Royston Farm Drain	Royston Farm US (representative catchment used due to urban extent)	578800	144500	0.5
RFD02	Overbridge / Royston Farm Drain	D/S of Confluence (summation of composite catchments OFD01, RFD01 and an FEH catchment)	OFD01		2.8
			RFD01		0.4
			577600	145100	2.8
CLD	Clappers Lane Drain	Clappers Lane Drain (representative intervening area between two FEH catchments; 1.8km²)	578550	145900	4.6
			577600	145100	2.8
RFD_DS	Royston Farm Drain	Royston Farm Drain DS (summation of the composite catchment OFD01 and an FEH catchment)	OFD01		2.8
			578550	145900	4.6
DS	Royston Farm Drain / Couchman Green Drain	U/S of confluence with the River Beult	OFD01		2.8
			578650	146200	6.0
Several catchments were not defined by the FEH CD-ROM (v3). For the other catchments, there were multiple discrepancies between the FEH catchments and the ArcHydro catchments. Catchment descriptors were derived for these areas by combining catchment descriptors from representative FEH catchments within the study area.					

6.2 Pooling group composition

Table 6-1: Couchman Green Drain (CGD_DS) Final Pooling Group

Rank	Station Number	Similarity Distance Measure	Years of Data	AREA	QMED AM	L-CV	L-SKEW	Discordancy
1	27073	2.929	32	8.06	0.813	0.197	-0.022	0.833
2	27051	4.871	40	8.15	4.539	0.222	0.149	0.454
3	45816	4.885	19	6.81	3.456	0.324	0.434	1.183
4	20002	4.982	41	26.31	3.299	0.292	0.015	1.637
5	28033	5.070	33	7.93	4.666	0.266	0.415	0.820
6	26802	5.221	13	15.85	0.109	0.261	0.199	0.410
7	25003	5.248	39	11.46	15.164	0.176	0.291	0.879
8	203046	5.280	30	22.51	10.934	0.136	0.091	1.291
9	25019	5.285	34	15.07	5.538	0.347	0.394	1.482
10	47022	5.347	19	13.45	7.331	0.257	0.071	0.856
11	25011	5.410	26	12.79	15.878	0.241	0.326	1.271
12	91802	5.455	34	6.52	6.350	0.153	0.257	1.082
13	206006	5.463	48	13.66	15.33	0.189	0.052	1.874
14	49003	5.512	46	21.61	13.559	0.232	0.241	0.283
15	72014	5.518	45	28.99	17.703	0.193	0.059	0.647
	Total		499					
	Weighted					0.232	0.194	

Table 6-2: Royston Farm Drain (RFD_DS) Final Pooling Group

Rank	Station Number	Similarity Distance Measure	Years of Data	AREA	QMED AM	L-CV	L-SKEW	Discordancy
1	27073	0.511	32	8.06	0.813	0.197	-0.022	0.768
2	20002	2.381	41	26.31	3.299	0.292	0.015	1.590
3	27051	2.515	40	8.15	4.539	0.222	0.149	0.654
4	26802	2.636	13	15.85	0.109	0.261	0.199	0.464
5	76011	2.700	35	1.63	1.840	0.169	0.333	1.710
6	45816	2.729	19	6.81	3.456	0.324	0.434	0.747
7	203046	2.732	30	22.51	10.934	0.136	0.091	0.999
8	25019	2.733	34	15.07	5.538	0.347	0.394	0.779
9	28033	2.887	33	7.93	4.666	0.266	0.415	0.732
10	36010	2.988	45	27.58	6.759	0.418	0.228	1.763
11	47022	3.005	19	13.45	7.331	0.257	0.071	0.512
12	72014	3.015	45	28.99	17.703	0.193	0.059	0.739
13	27010	3.061	41	18.84	9.420	0.224	0.293	0.298
14	44008	3.078	33	20.17	0.420	0.395	0.332	1.063
15	73015	3.083	21	30.06	12.239	0.156	0.001	0.823
16	25011	3.091	26	12.79	15.878	0.241	0.326	2.358
	Total		507					
	Weighted					0.253	0.206	

Table 6-3: Spilsill Farm Drain (SFD02) Final Pooling Group

Rank	Station Number	Similarity Distance Measure	Years of Data	AREA	QMED AM	L-CV	L-SKEW	Discordancy
1	27073	2.884	32	8.06	0.813	0.197	-0.022	1.108
2	45816	4.349	19	6.81	3.456	0.324	0.434	1.174
3	27051	4.364	40	8.15	4.539	0.222	0.149	0.671
4	28033	4.564	33	7.93	4.666	0.266	0.415	0.709
5	26802	4.863	13	15.85	0.109	0.261	0.199	0.297
6	25003	4.868	39	11.46	15.164	0.176	0.291	0.622
7	20002	4.869	41	26.31	3.299	0.292	0.015	1.678
8	25019	4.903	34	15.07	5.538	0.347	0.394	1.492
9	91802	4.951	34	6.52	6.350	0.153	0.257	1.091
10	47022	4.959	19	13.45	7.331	0.257	0.071	0.998
11	25011	5.000	26	12.79	15.878	0.241	0.326	1.397
12	203046	5.045	30	22.51	10.934	0.136	0.091	0.837
13	206006	5.085	48	13.66	15.330	0.189	0.052	1.202
14	54022	5.085	37	8.69	15.031	0.155	0.168	1.562
15	27010	5.247	41	18.84	9.420	0.224	0.293	0.162
	Total		486					
	Weighted					0.229	0.206	

Table 6-4: U/S of confluence with the River Beult (DS) Final Pooling Group

Rank	Station Number	Similarity Distance Measure	Years of Data	AREA	QMED AM	L-CV	L-SKEW	Discordancy
1	27073	0.316	32	8.06	0.813	0.197	-0.022	0.659
2	20002	2.300	41	26.31	3.299	0.292	0.015	1.980
3	203046	2.740	30	22.51	10.934	0.136	0.091	0.882
4	26802	2.784	13	15.85	0.109	0.261	0.199	0.490
5	27051	2.803	40	8.15	4.539	0.222	0.149	0.980
6	25019	2.894	34	15.07	5.538	0.347	0.394	1.063
7	72014	2.963	45	28.99	17.703	0.193	0.059	0.882
8	45816	3.010	19	6.81	3.456	0.324	0.434	1.046
9	36010	3.029	45	27.58	6.759	0.418	0.228	2.288
10	73015	3.038	21	30.06	12.239	0.156	0.001	0.701
11	41020	3.045	43	35.42	13.49	0.214	0.208	0.617
12	33054	3.078	36	48.51	1.129	0.214	0.069	0.224
13	76011	3.130	35	1.63	1.840	0.169	0.333	1.610
14	28033	3.130	33	7.93	4.666	0.266	0.415	0.984
15	47022	3.139	19	13.45	7.331	0.257	0.071	0.518
16	49003	3.156	46	21.61	13.559	0.232	0.241	1.076
	Total		532					
	Weighted					0.241	0.177	

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