Castle Point Strategic Flood Risk Assessment

Fluvial Modelling Technical Note

Project Reference: Castle Point SFRA
Project Number: 60725540
Report Reference: 60725540-FF-001

November 2024

Delivering a better world

Quality information

Prepared by	Checked by	Verified by	Approved by
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Revision History

Revision	Revision date	Details	Authorized	Name	Position
01	28 Nov 24	Draft for comment	RM	Richard Moore	Project Manager

Prepared for:

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1. Introduction

AECOM has been commissioned to update the Level 1 Strategic Flood Risk Assessment (SFRA) for Castle Point Borough Council (CPBC). The purpose of the SFRA is to assess the risk to an area from flooding from all sources, now and in the future, taking account the impacts of climate change, and to assess the impact that land use changes and development in the area will have on flood risk. This report documents the assessment of fluvial flood risk within the CPBC administrative area.

For the purposes of the SFRA, flooding from fluvial sources will only be considered for two Main River watercourses, the Prittle Brook and Benfleet Hall Brook (Figure 1-1). The models for these rivers were provided by the Environment Agency on 10th January 2024 and have been used to assess the fluvial flood risk.

Figure 1-1 shows there are also several other Main Rivers on Canvey Island which currently do not have any flood zones directly associated with them (as this area is subsumed by the tidal flood zones). These Main Rivers are represented in the Canvey Island Integrated Urban Drainage (IUD) model which is being used to assess surface water flood risk for the SFRA[1]. As agreed with the Environment Agency on 11th March 2024 (Appendix A), this model has also been used to map Flood Zone 2, 3a and 3b from the Main Rivers on Canvey Island. The Canvey Island IUD model updates and results are summarised in the Surface Water Modelling Technical Note[1].

This Technical Note provides an overview of the Prittle Brook and Benfleet Brook existing models, model updates undertaken as part of this assessment, model outputs and documentation of the cumulative impact assessment.

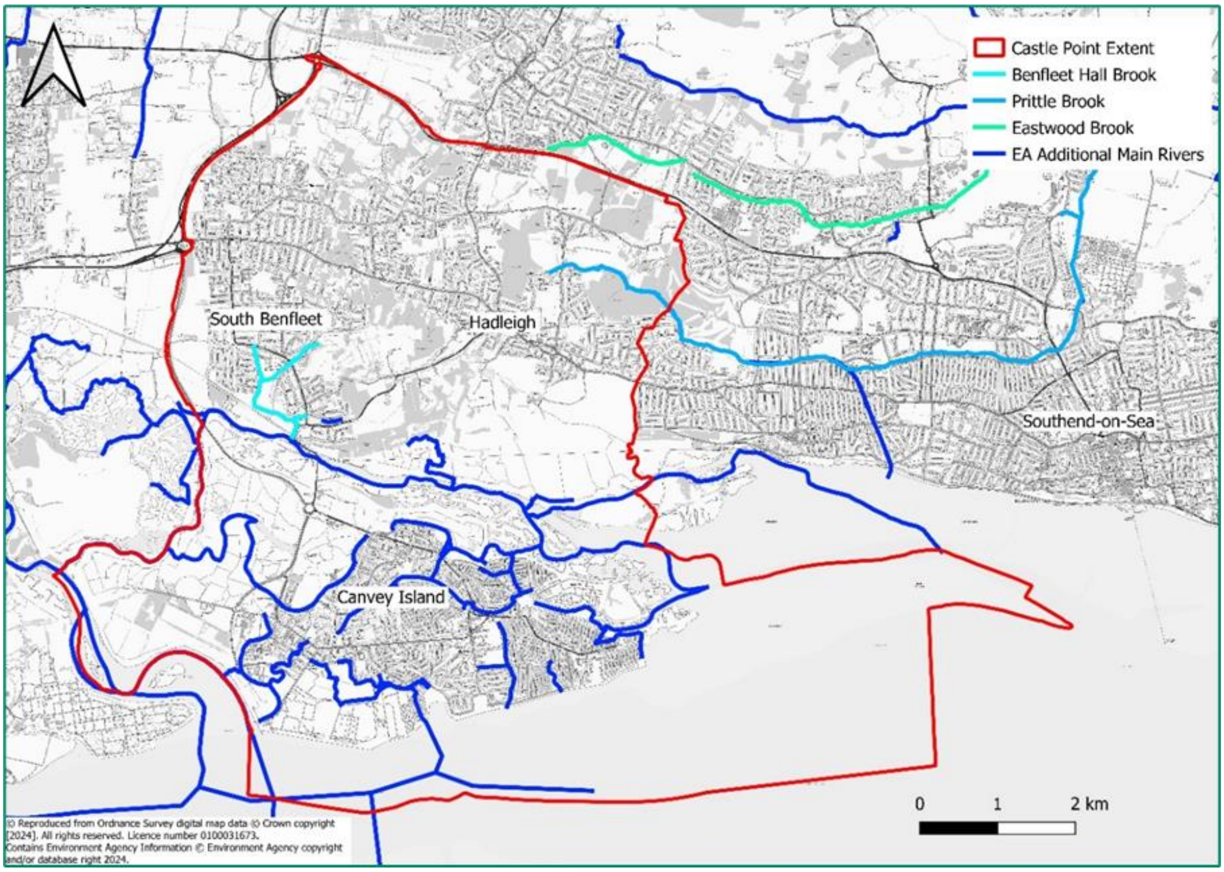


Figure 1-1: Castle Point administrative area rivers

[1] AECOM, 60725540-SWF-001 Castle Point Strategic Flood Risk Assessment, Surface Water Modelling Technical Note (2024)

2. Hydraulic Models

2.1 Prittle Brook

The Prittle Brook is located in the north-east of the Castle Point administrative area and flows east into the Southend-On-Sea Borough (Figure 1-1). Only the upstream 1.5 kilometre (km) of the Prittle Brook falls within the Castle Point administrative area and therefore this is the area of interest for the Level 1 SFRA. All areas downstream have not been considered in this assessment.

The Prittle Brook model was reviewed using AECOM's in-house quality assurance template and summarised in the Proposed Fluvial Modelling Methodology Technical Note[2]. The model is a fully linked 1D/2D Flood Modeller Pro (FMP) – TUFLOW model that covers the entire 10 km length of the Prittle Brook before it discharges into the tidal River Roach. The recommendations from the review were to simulate the model in the latest available software, along with updating the flow estimates and tidal boundary conditions based on latest guidance.

2.2 Benfleet Hall Brook

The Benfleet Hall Brook is located in the mid-west of the Castle Point administrative area. The Benfleet Hall Brook is a small, urban catchment with a lower catchment which includes a flood storage area in South Benfleet playing fields. The watercourses discharges to the East Haven Creek via a flapped tidal outfall.

The Benfleet Hall Brook model was reviewed using AECOM's in-house quality assurance template and summarised in the Proposed Fluvial Modelling Technical Note[2]. The model is a 1D-only FMP model which covers two tributaries which converge at the flood storage area with a downstream boundary at the tidal outfall. The recommendations from the review were to simulate the model in the latest available software and to update the hydrology and tidal boundary conditions based on latest guidance and software.

The key hydraulic structure on the watercourse is the flapped tidal outfall to the East Haven Creek by a culvert beneath a railway embankment. The Environment Agency confirmed on 11th March 2024 that the trash screen had been replaced (Appendix A). Design drawings of the new trash screen have been provided by the Environment Agency on 14th March 2024 and have been used to update the model.

3. Flow Estimates

Review of the hydrological analysis from the Benfleet Hall Brook and Prittle Brook models determined that the flows were derived using now superseded methodologies and shorter flow record periods. Therefore, the flows were updated using the latest Flood Estimation Handbook (FEH) methods and data available. A hydrological assessment was undertaken for both the Prittle Brook and Benfleet Hall Brook. The methodology used to obtain the flows is summarised below:

- Obtain and verify the latest catchment descriptors for each catchment from the FEH webservice[3].
- Derive new peak flow estimates for each model using ReFH2.3.
- Derive new peak flow estimates from the two approaches (ReFH2.3 and Statistical Method).
- Confirm which method is best suited based on the overall catchment and current guidance.
- Provide peak flow estimates (for 3.3%, 1% and 0.1% Annual Exceedance Probability (AEP) events) from chosen method as inflow hydrographs for both models.
- Scale hydrographs to include allowances for climate change based on the latest Environment Agency guidance (May 2022). For the purpose of the SFRA the 2080s epoch, central and higher central allowance were assessed.

The Prittle Brook hydrological analysis (Appendix B) was only updated for flow estimates upstream of the Prittlewell Gauge and flow estimates downstream of the Prittle Tunnel (P4int - P9int) were retained from the 2016 CH2M study. This approach was taken was because only flows upstream of the Prittlewell Gauge were considered to impact the maximum flood extents within the Castle Point administrative area.

[2] AECOM, 60725540-FF-001 Castle Point Strategic Flood Risk Assessment, Proposed Fluvial Modelling Methodology (2024)
[3] UK Centre for Ecology & Hydrology, Flood Estimation Handbook Web Service (2024). Available at: https://fehweb.ceh.ac.uk/Map

The hydrological analysis concluded that the Urban ReFH2.3 provided a suitable conservative estimate of flow within the upper catchment and an adjusted time to peak of the instantaneous unit hydrograph (Tp) values using local Prittlewell gauge data should be used to improve the hydrograph shape. A 4.5 hour storm duration was retained from the previous hydrological analysis of the catchment.

The FEH Statistical method results were found to be approximately 88% to 120% less than those derived using ReFH2.3. The catchment is an urban, rapid response catchment and therefore ReFH2.3 provides a better representation of the runoff from the urban area. The ReFH2.3 flows are conservative compared to the FEH Statistical flows. For the purpose of this Level 1 SFRA a conservative approach is preferable and so ReFH2.3 flows have been used, This was documented within the Proposed Fluvial Modelling Methodology Note[2] which was reviewed by the Environment Agency.

The Benfleet Hall Brook hydrological assessment (Appendix C) concluded that ReFH2.3 flow estimates should be used. Flood risk in the catchment is volume led due to the tidal locking of the outfall and the available storage within the flood storage area which therefore favours the rainfall runoff approach. The catchment is ungauged and the urban component of ReFH2.3 provides a good estimate of the different sub catchment responses in a heavily urban environment. The recommended storm duration of 5.5 hours has been used. The FEH statistical method flows were approximately 52% to 58% less than those derived from ReFH2.3 and therefore it is considered they provide a more conservative estimate which is suitable for the purposes of this Level 1 SFRA study.

The full FEH Calculation Record for Prittle Brook and Benfleet Hall Brook is provided in Appendix B and Appendix C, respectively.

4. Tidal Boundary

The downstream tidal boundary was updated for both the Prittle Brook and Benfleet Hall Brook models. This is due to updates to the Environment Agency Coastal Flood Boundary conditions for the United Kingdom (2018)[4] and updates to the Thames Estuary 2100 (TE2100)[5] data in 2022.

Tidal curves were derived based on the most recent extreme water level data and climate change predictions using Coastal Flood Boundary data[4] and TE2100 data[5]. The tidal curve boundary derivation is outlined in the Tidal and Breach Modelling Technical Note[6]. The mean high-water spring (MHWS) for node 3.33 from TE2100 was used as the downstream boundary for the Benfleet Hall Brook model. The MHWS for Coastal Flood Boundary node 4286 was used as the downstream boundary for the Prittle Brook model.

The MHWS tidal curves used for the Prittle Brook and Benfleet Hall Brook are shown in Figure 4-1.

[4] Environment Agency, Coastal Design Sea Levels – Coastal Flood Boundary Extreme Sea Levels (2018)
[5] Environment Agency, Thames Estuary Modelling Extreme Water Levels – Final Report Issue P03 (2022)
[6] AECOM, 60725540-TF-001 Castle Point Strategic Flood Risk Assessment Tidal and Breach Modelling Technical Note (2024)

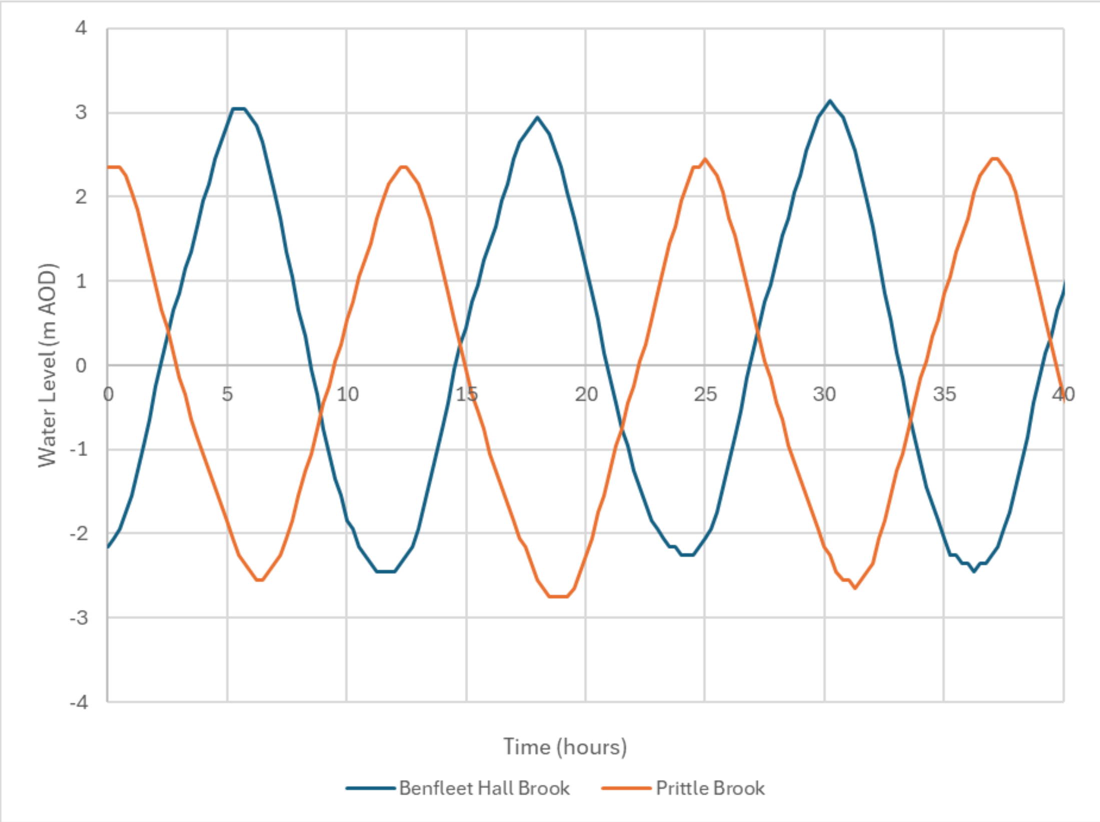


Figure 4-1: Model Tidal Boundaries.

5. Model Updates

5.1 Prittle Brook

The Prittle Brook undefended scenario model, provided by the Environment Agency, was selected to be updated in the Level 1 SFRA assessment to provide the worst-case scenario for flood risk. The only AIMS flood defence located on the Prittle Brook model is an embankment on the true left bank near Warwick Drive. This embankment is approximately 500 m long and is located 5 km outside of the Castle Point administrative area. The embankment is removed from the model for the undefended scenario, but the embankment is considered to have no impact on the model outputs in the area of interest.

The following updates were made to the undefended Prittle Brook model:

- Updated downstream tidal boundary created using the MHWS for the Environment Agency Coastal Flood Boundaries dataset[4] (Section 4).
- Updated flow estimates (IEDs) derived using the Urban ReFH2.3 approach. Refer to the Prittle Brook FEH Calculations Record (Appendix B) for details of the methodology and final flows.
- The model was updated to FMP version 7.0 and TUFLOW version 2023-03-AC.
- The model was simulated for the undefended present-day scenario with the updated inflow hydrographs for 3.3% AEP, 1% AEP; and 0.1% AEP events.
- The model was run for undefended future climate change (CC) scenarios (2080s epoch, central and higher central allowance) that represent the Flood Zones (6 simulations): 3.3% AEP + 25%CC, 3.3% AEP + 38%CC, 1% AEP + 25%CC, 1% AEP + 38%CC, 0.1% AEP + 25%CC and 0.1% AEP + 38%CC.
- Results have been post-processed and mapped within the Level 1 SFRA.

It should be noted that as only the undefended models were simulated for the SFRA, the 3.3% AEP undefended results have been used to represent Flood Zone 3b. This is considered to be acceptable for the purposes of this study.

The fluvial flood maps (detailed in Section 6) are presented and discussed in the Level 1 SFRA[7].

5.2 Benfleet Hall Brook Model

The Benfleet Hall Brook undefended model, provided by the Environment Agency, was selected to be updated in the Level 1 SFRA assessment to provide the worst-case scenario for flood risk. The formal AIMS defences (raised flood embankments around the flood storage area and the wall around the downstream tidal outfall culvert) have been removed in the undefended version of the 1D model and cross-sections extended to replace the reservoir units.

The following updates were made to the undefended Benfleet Hall Brook model:

- Flapped tidal outfall to the East Haven Creek updated to reflect upgrades and trash screen based on the drawings[8,9,10] provided by the Environment Agency on 13th March 2024. The updates included:
  - Culvert diameter updated to 1.2 m.
  - Culvert length updated to 94 m.
  - Upstream invert level updated to 0.52 m AOD.
  - Blockage updated to 0.2.
- Updated downstream tidal boundary created using MHWS from TE2100 data.
- Updated flow estimates (IEDs) derived using the ReFH2 approach. Refer to the Benfleet Hall Brook FEH Calculations Record (Appendix C) for details of the methodology and final flows.
- The model was run using FMP version 7.0 for the following nine events: 3.3% AEP, 3.3% AEP + 25%CC, 3.3% AEP + 38%CC, 1% AEP, 1% AEP + 25%CC, 1% AEP + 38%CC, 0.1% AEP, 0.1% AEP + 25%CC and 0.1% AEP + 38%CC.
- The maximum water level at each node has been used to delineate the maximum flood extent for each event based on ground levels from the latest LiDAR. These flood extents have been mapped within the Level 1 SFRA.

It should be noted that as only the undefended models were simulated for the SFRA, the 3.3% AEP undefended results have been used to represent Flood Zone 3b. This has been discussed with the Client and is considered to be acceptable for the purpose of this study.

The fluvial flood maps (detailed in Section 6) are presented and discussed in the Level 1 SFRA[7].

6. Model Outputs

Three maps have been produced using model outputs. These maps display both Benfleet Hall Brook and Prittle Brook model results within the Castle Point administrative area.

The maps are summarised in Table 6-1. These maps are presented and discussed in the Level 1 SFRA[7].

Table 6-1: Model output summary

Map	Map Title	Location in SFRA
1	Modelled Fluvial Flood Risk – Present Day & Climate Change Overview	Appendix B Map 1
2	Modelled Fluvial Flood Risk – Present Day & Climate Change Benfleet Hall Brook	Appendix B Map 2A
3	Modelled Fluvial Flood Risk – Present Day & Climate Change Prittle Brook	Appendix B Map 2B

[7] AECOM, Castle Point Borough Council Level 1 Strategic Flood Risk Assessment (2024)
[8] Jackson Hyder, South Benfleet Weedscreen 3 (2024), General Arrangement Plan Proposed New Inlet Pipe Location, Drawing ref: 0940-UA007240-Z1
[9] Jackson Hyder, South Benfleet Weedscreen 3 (2024), New Inlet Chamber Details, Drawing ref: 0941-UA007240-Z1
[10] Jackson Hyder, South Benfleet Weedscreen 3 (2024), New Manhole. General Arrangment Sheet 1, Drawing ref: 0942-UA007240-Z1

7. Cumulative Impact Testing

In Castle Point there is a concern on the cumulative impact of flooding from a high intensity rainfall event occurring at high tide. To quantify the impact of high tides on fluvial flood risk the follow methodology has been used:

- The downstream boundary in the Prittle Brook and Benfleet Hall Brook model was edited to represent a higher water level (whole stage hydrograph increased by +0.5 m). The model was setup for peak tide and peak runoff to coincide to represent the worst case flood risk scenario.
- Both models were run for the 1% AEP event.

The Prittle Brook results showed that there were no changes within the Castle Point administrative area as a result of a higher tidal level. This is to be expected as the tidal boundary is approximately 9 km downstream of the Castle Point administrative area.

The Benfleet Hall Brook results show that a higher tidal level results in a slight increase in flood extent within the flood storage area. The water level has increased by 0.02 m within this area. There are no changes in water level outside of the flood storage area. Therefore, the cumulative impact is minimal at this location. This has not been mapped as the extent difference is minimal.

8. Assumptions, Limitations and Exclusions

The following assumptions and exclusions have been made:

- The Prittle Brook hydrology is only suitable for assessment upstream of the Prittlewell Gauge. Therefore, future studies should review and update the hydrology downstream of the gauge.
- Assumed that for the fluvial assessment only the upper Prittle Brook is required as it falls within the Castle Point administrative area. Assumed that anywhere downstream of the Prittlewell Gauge has no impact on the Level 1 SFRA.
- Assumed that the flood risk associated with the Canvey Island Main Rivers is covered by the Canvey Island IUD model. Refer to the Surface Water Modelling Technical Note[1] for information on this model.
- Assumed that for fluvial sources central and higher central climate change allowances are applicable to peak river flows.
- Assumed that the Prittle Brook and Benfleet Hall Brook undefended models are suitable for the purposes of the Level 1 SFRA.
- Assumed that the topography and LiDAR used in the existing models (2011 LiDAR for Prittle Brook and 2012 for Benfleet Hall Brook) is appropriate for the purposes of the Level 1 SFRA and there have been no significant topographic changes within the catchments since the previous modelling studies have been undertaken.
- Assumed the roughness values used in the existing models are appropriate for the purposes of the Level 1 SFRA and there have been no significant land-use changes since the previous modelling studies have been undertaken.
- The cumulative impact assessment is limited to testing one event and one tidal boundary. Further investigation is recommended to gain a greater understanding of cumulative impact across a range of scenarios.
- The surface water sewer network is not represented in either of the models. The existing model representation is assumed to be suitable for the mapping of flood risk from fluvial sources for the SFRA. The surface water flood risk is covered in the Surface Water Modelling Technical Note[1].
- The Benfleet Hall Brook model is 1D only. The 1D model does not allow for routing of overland flow within the floodplain and therefore cannot account for obstructions that may impact the mapped flood extents. Mapping is therefore limited by the accuracy of the LiDAR DTM and the projected 1D water level.
- The model results are assumed to be suitable for the strategic purposes of the Level 1 SFRA. For future use these models should be updated with the latest data available.

- Sensitivity testing and calibration has not been undertaken as part of the Level 1 SFRA modelling. The testing and calibration undertaken in the previous modelling studies is assumed to be suitable for the purposes of the SFRA.

Appendix A – Environment Agency Meeting Minutes

AECOM

Minutes

Meeting name
Castle Point SFRA

Subject
Environment Agency Meeting

Attendees
Richard Moore (RM) - AECOM
Jo Somerton (JS) - AECOM
Courtenay Giles (CG) - AECOM
Amanda Parrott (AP) – CPBC
Pat Abbott (PA) – EA
Nicole Lupton (NL) - EA
Phillip Spearman (PS) - EA
Graham Robertson (GR) – EA
Lucy Hayward (LH) – EA

Apologies
None

Meeting date
11/03/24

Time
1100

Location
Virtual

Project name
Castle Point SFRA

AECOM project number
60725540

Prepared by
Richard Moore

Ref	Item	Action / Responsible	Due by
01	**Introductions**	None	n/a
02	**Overview of Project** RM provided overview of the L1 and L2 Castle Point SFRA project and purpose of the meeting.	None	n/a
03	**Tidal Modelling** <u>Discussion of Approach</u> CG provided overview of tidal modelling and shared content of report.	GR/PS to confirm breach duration as part of the review of the Tidal Modelling Note.	12/04/24
	<u>Tide Curves TE2100</u> CG confirmed that new tidal curves were being produced for the modelling using the TE2100 data although this has not yet been received from the EA.	PA/PS to follow up TE2100 data request.	12/04/24
	<u>Breach Scenarios</u>	PS to confirm approach to breach i.e. ¾ defence breach?	12/04/24
	CG confirmed that the same breach locations are to be used when compared with the 2018 SFRA. This does not include a breach at Bowers Marsh. PS confirmed that this was acceptable.	CG to provide shapefile of crest levels of defences and key breach parameters.	15/03/24
	CG to provide Tidal Modelling Note which confirms the breach parameters for each location. EA to review and provide comment.	PS to confirm key breach parameters are appropriate.	12/04/24
	GR raised the point that with the Thurrock SFRA, 18 hours was considered optimistic for breach duration and so a 30 hour duration was modelled. For Castle Point this should be agreed with asset performance team/local EA engineers to confirm accurate duration.	PS to confirm that crest level information applied to the model is accurate against EA data.	12/04/24
	GR raised the point that with Thurrock some breach locations were modelled as ½ defence rather than ¾ (in line with guidance). This was due to wave impact and defence type. CG confirmed that composite maps will be produced for the breach modelling for both depth and hazard, for all events listed in the Tidal Modelling Note. PS suggested that for breach locations CAS08 and CAS09 (tidal barrier), the results should be included in the composite	PS to review defences and confirm whether current approach of no wave action (as documented within the Tidal Modelling Note) is acceptable.	12/04/24

Ref	Item	Action / Responsible	Due by
	maps but extent related to these locations should be shown on the map. Defences Crest levels of the defences discussed. Agreed that CG will provide a shapefile detailing the crest level of the defences within the model as part of the Tidal Modelling Note with PS to confirm that these are accurate against EA data. Other CG mentioned that no functional floodplain for tidal sources will be modelled/mapped. Overtopping modelling being undertaken for Hadleigh Marsh only due to policy unit and no wave action being considered.		
04	**Fluvial Modelling** Discussion of Approach CG discussed approach to modelling the Canvey Island Main Rivers. The area is currently subsumed by tidal flood zones. The proposed approach is to use the Canvey Island IUD model (which includes representation of these watercourses) to assess non-tidal risk. PS confirmed that this approach is acceptable. CG discussed Prittle Brook and Benfleet Hall Brook fluvial models to be used. CG discussed the representation of the Benfleet Hall Brook tidal outfall. PS confirmed that this has been modified since the modelling was undertaken and should therefore be updated. CG mentioned that this model is 1D only and therefore flood extents to be generated based off LIDAR.	PS to provide drawings of Benfleet Hall Brook tidal outfall.	12/04/24
05	**Surface Water Modelling** Discussion of Approach CG discussed approach to the surface water modelling. PS confirmed the Canvey Island IUD model is complex with long run times. PS confirmed EA have access to Canvey Island IUD model and can provide. CG mentioned that critical storm durations to be retained from previous modelling.	None PA/PS to follow up Canvey Island IUD model request.	n/a
06	**Modelling Technical Notes** Review Timeframes All model notes to be sent to PA who will distribute to relevant people for review. Turnaround time on reviews likely to be 4 weeks. Cost associated with these reviews to be communicated to AP.	CG/RM to issue Modelling Technical Notes for EA and CP review.	15/03/24

Ref	Item	Action / Responsible	Due by
07	**SFRA Reporting** RM provided overview of other items of the SFRA including Cumulative Scenario Testing, Urban Greening Scenario Testing and Identifying and Costing Flood Risk Management Interventions. JS raised issues with some datasets that have not yet been received. JS to send these to PA/PS to see if they can be chased. PS confirmed that since 2018 the most significant flood management scheme is the revetment scheme at Canvey Island. Other smaller schemes include maintenance of barriers, works to pumping stations etc.	JS to provide outstanding data requests to PA/PS. PA/PS to confirm any significant flood management schemes that should be considered as part of the SFRA	15/03/24 12/04/24
08	**AOB** AP mentioned Castle Point's Flood Resilience Forum. GR raised a point around sensitivity testing relating to the location of a future Thames barrier. Three potential locations – (1) existing, (2) Long Reach, (3) Tilbury-Gravesend. GR/PS to consult internally to confirm whether this should be considered as part of the SFRA.	PS/GR to review data and confirm whether future Thames Barrier scenarios should be considered as part of SFRA	12/04/24

Appendix B – Prittle Brook FEH Calculation Record

FEH Calculation Record

Castle Point SFRA – Prittle Brook

February 2025

Delivering a better world

1 Flood estimation calculation record

Introduction

This document provides a record of the calculations and decisions made during flood estimation for the Prittle Brook, Essex in June 2024. The information given here should enable the work to be reproduced in the future.

Contents

Approval

	Name	Position
Calculations prepared by:	Ralph Collard	Senior Flood Risk Engineer
Calculations checked by:	Rob Sweet	Associate
Calculations approved by:	Helen Judd	Associate

Revision History

Revision	Revision Date	Details	Authorised	Name	Position

Abbreviations

AEP	Annual exceedance probability
AM	Annual maximum
AREA	Catchment area (km^2)
BFI	Base flow index
BFIHOST	Base flow index derived using the HOST soil classification
CPRE	Council for the Protection of Rural England
DPLBAR	Mean drainage path length (km)
DTM	Digital Terrain Model
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FPEXT	Floodplain extent
FSR	Flood Studies Report
HOST	Hydrology of soil types
NRFA	National River Flow Archive
OS	Ordnance Survey
POT	Peaks over threshold
QMED	Median annual flood (with return period ~2 years)
ReFH1	Revitalised Flood Hydrograph 1 method (2005)
ReFH2	Revitalised Flood Hydrograph 2 method (2013)
SAAR	Standard average annual rainfall (mm)
SPR	Standard percentage run-off
SPRHOST	Standard percentage run-off 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
WINFAP	Windows Frequency Analysis Package – used for FEH statistical method

2 Summary

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

Catchment location	Prittle Brook, Essex
Purpose of study and scope	Hydrological flow estimate updates for the Prittle Brook hydraulic model to support the Castle Point Borough Council SFRA Level 1 study. The Prittle Brook only flows through CPBC administrative area in the upper catchment and upstream of the Prittlewell Gauging Station. New flow estimates have only been undertaken upstream of the Prittlewell Gauge. Downstream of the gauging station the existing ReFH inflows will be retained with updated climate change allowances as required
Key catchment features	Situated in Essex the Prittle Brook is a small, urban catchment (approx. 20 km^2), that extends from the Head of Main River (HOMR) at The Gill (TQ81008805) to the Roach Estuary, downstream of Sutton Ford Bridge (TQ88398971). The watercourse's natural flow route discharges into the Roach Estuary, with a flood relief culverted channel (Prittle Tunnel) diverting flood flows into the Thames Estuary. The watercourse is either canalised or culverted for the majority of its length, with open channel reaches through Belfairs, Priory and Warners Bridge Parks
Flooding mechanisms	Rapid response from the urban catchment, peak flow dominated
Gauged / ungauged	Prittlewell Brook flow gauge (not a NRFA station)
Final choice of method	ReFH2.3
Key limitations / uncertainties in results	Flow estimates are conservative Tide locking of lower catchment Limitations and uncertainty associated with Prittlewell gauge Heavily urbanised catchment Only valid for the catchment upstream of the Prittlewell Gauge. Any future hydrological analysis must review and update the flow estimates downstream of the Prittlewell Gauge.

2.1 Note on 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; both rows can be retained, or the relevant row can be retained and the other removed, depending on the requirement of the study.

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

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

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

3 Method statement

3.1 Overview of requirements for flood estimates and hydraulic modelling

Item	Comments
Give an overview which includes: • purpose of study including a short discussion if there is existing hydrology reports and estimates, when they were done and why we are updating the hydrology (e.g. new data or superseded methods) • approximate number and type of flood estimates required • peak flows and/or hydrographs? • range of design event AEPs (%) • climate change allowances (ref. relevant guidance)	Updated hydrological estimates are required for inputs to a fluvial hydraulic model of the Prittle Brook, Castle Point Borough Council to support a Level 1 SFRA. Hydrological analysis of the Prittle Brook catchment was undertaken by CH2M in 2016[1] and since then new FEH methodologies and additional data is available for the analysis (gauged data, NRFA peak flow dataset and FEH22 rainfall). The Level 1 SFRA is only concerned with the upstream extent of the Prittle Brook that flows through Castle Point Borough Council administrative area. This accounts for 1.8km of watercourse and the administrative boundary is c. 800m upstream of the Prittlewell Gauge. Given the distance upstream of the gauge, the influence of the Prittle Tunnel and an approximate drop in elevation of c.7m from the boundary to the gauge the flow estimates downstream of the Prittlewell Gauge are not considered to significantly impact the study area. For this reason the 2016 ReFH flow estimates will be retained downstream of the Prittlewell Gauge (P4int to P9int) and only the climate change allowances will be updated Peak flow estimates and hydrographs will be required. Flow estimates required for 3.3%, 3.3% + 25%CC, 3.3% + 38%CC, 1%, 1% + 25%CC, 1% +38%CC, 0.1%, 0.1% + 25%CC, 0.1% + 38%CC events for the purposes of the SFRA.

3.2 Project Scope

Item	Comments

Give an overview which includes:
• Complexity of study e.g. simple, routine, moderate, difficult, very difficult?
• What analyses are required:
  • Rating reviews
  • Review of existing study
  • Simple/detailed flood history review
  • ReFH model parameter estimation
  • Joint probability
	Moderate complexity associated with urban catchment and flow gauge (non NRFA).
	Review of existing study.
	Update hydrological inflows to the hydraulic model in the same location as previously undertaken (CH2M 2016). Only inflows upstream of the Prittlewell Gauge will be updated.
	Downstream of the gauge existing ReFH estimates to be updated with new climate change allowances only.

[1] CH2M (2016), *Prittle Brook Interim Hydrology Report: Phase 1&2*. Environment Agency

3.3 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report. Include general catchment map and specific map of hydraulic model extents and inflow locations.	Situated in Essex, the Prittle Brook is a small, urban catchment (approx. 20km^2), that extends from the Head of Main River (HOMR) at The Gill (TQ81008805) to the Roach Estuary, downstream of Sutton Ford Bridge (TQ88398971). The watercourse's natural flow route discharges into the Roach Estuary, with a flood relief culverted channel (Prittle Tunnel) diverting flood flows into the Thames Estuary. The watercourse is either canalised or culverted for the majority of its length, with open channel reaches through Belfairs, Priory and Warners Bridge Parks
Previous Hydrology studies	2008 Faber Maunsell, Southend Watercourses Flood Risk Study Report, 2016 CH2M Prittle Brook Interim Hydrology Report: Phase 1 & 2

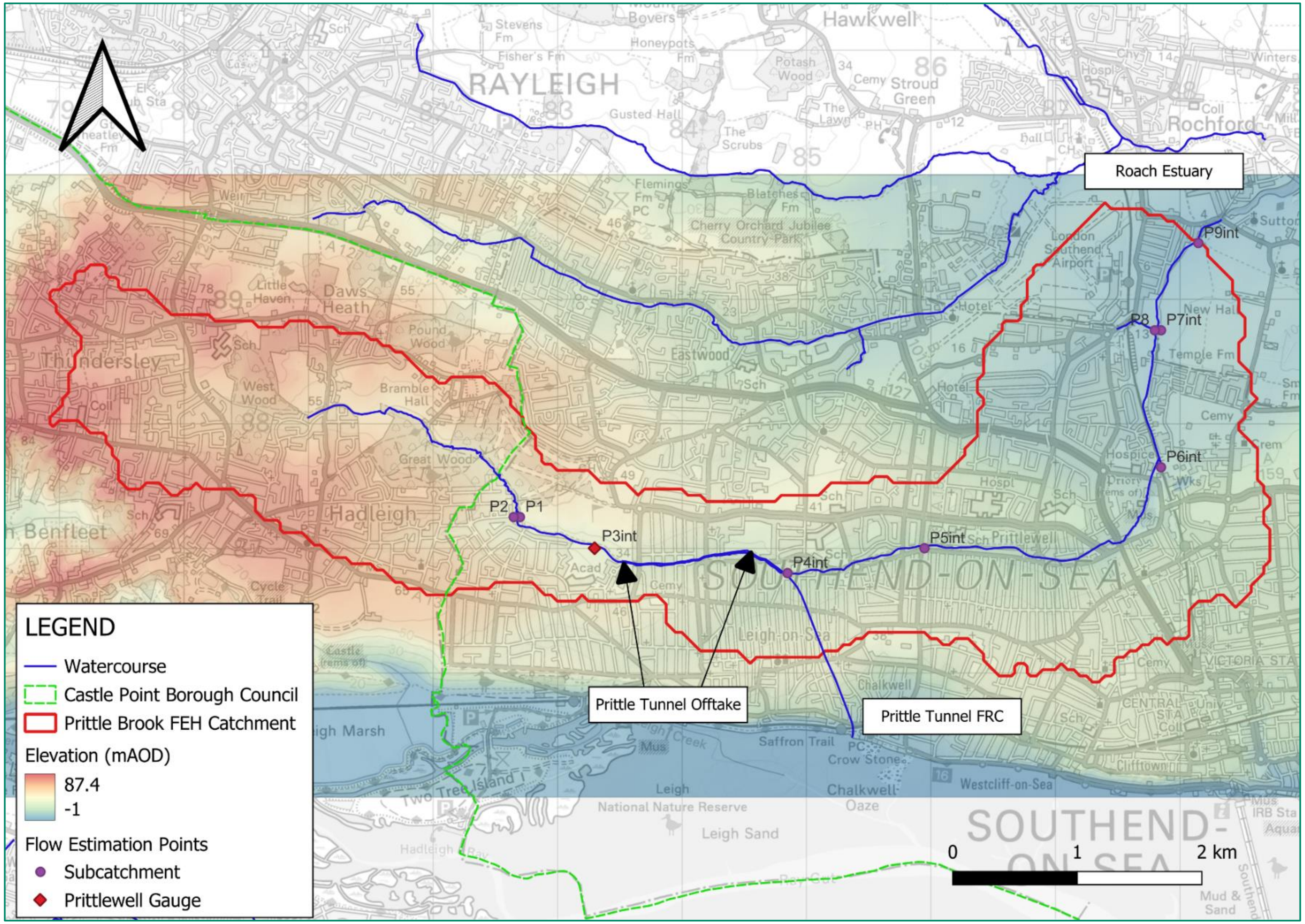


Figure 3-1: Catchment Overview (Contains Ordnance Survey Data © Crown Copyright and database right 2024)

3.4 Source of flood peak data

Item	Comments
Was the NRFA Peak Flows dataset used? If so, which version? If not, why not? Record any changes made.	NRFA peak flows dataset, Version 12.1, released November 2023. This contains data up to water year 2021-22

3.5 Flood History

A range of sources have been used to identify the flood history associated with the Prittle Brook catchment. These include a review of, information sourced from the Environment Agency, Essex County Council and Castle Point Borough Council and internet searches.

Date	Description	Source
20th October 2021	Surface water flooding caused by 1 in 28yr rainfall event	BMT - Section 19 Flood Investigation Report for Castle Point
19th September July 2014	Exceptionally intense rainfall event. Primarily surface water with surcharging of sewer network, tide locking contributing.	AECOM - Southend on Sea 19th September 2014 Flood Investigation Report
24th August 2013	Large rainfall event, surface water	2016 CH2M Prittle Brook Modelling Study

3.6 Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level)	Start of record and end if station closed
Prittle Brook	Prittlewell	037052	N/A	6.36	Crump weir	2000 – present
Eastwood Brook	Eastwood Brook at Eastwood		37033	10.4	Non-standard flat V weir	1974 - present

3.7 Gauging stations (Rain)

Gauge name	ID number	Catchment area (km²)	Type (Daily/TBR)	Start of record and end if station closed
Benfleet Barrier	E27621	Unknown	TBR 15min	03/07/2000 - present
Rayleigh	E24908	Unknown	TBR 15min	03/07/2000 - present

3.8 Data available at each flow gauging station

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Other comments on station and flow data quality
Prittlewell	Not in NFRA dataset	No update, rating review in CH2M 2016	No	No	Yes	Flow gauge is not included in the NRFA dataset and so there is limited information. The 2016 CH2M study highlights that the gauge is by-passed in the 20% AEP and hi-flows are suspect.
Eastwood Brook at Eastwood	1974 - present	No	Yes	No	Yes	Weir replaced in 1996. Telemetry in 1997.

3.9 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Comments and link to any rating reviews
Prittlewell Guage	Theoretical	No	Rating updated as part of the 2016 CH2M report. Not within the scope to undertake a new review.

3.10 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 (if planned rating review)	Yes / ~~No~~	Yes / ~~No~~	Hydrology Data Explorer	Downloaded flow data from Hydrology Data Explorer - Explore
Rating equations	Yes / ~~No~~	Yes / ~~No~~	EA	2016 CH2M Report
Historic flood data	Yes / ~~No~~	Yes / ~~No~~	EA	
Flow or level data for events	Yes / ~~No~~	Yes / ~~No~~	Hydrology Data Explorer	Downloaded flow data from Hydrology Data Explorer - Explore
Results from previous studies	Yes / ~~No~~	Yes / ~~No~~	EA	2016 CH2M FMP-TUFLOW Model results
Other information e.g. groundwater, tides etc	Yes / ~~No~~	Yes / ~~No~~	EA	Model results/tides at DS boundary

3.11 Hydrological understanding of the catchment

The Prittlewell Gauge station is the primary source of hydrometric data for the catchment. This gauge does not form part of the NRFA gauging stations and therefore confidence in the outputs are limited. The gauge now has a record of c.24 years and CH2M undertook a rating review of the gauge in 2016. Flows are known to bypass the gauge in events larger than the 20% AEP and above which reduces confidence in the high flows estimates at the gauge. Level data was not available from the Hydrology Explorer and therefore flows have been plotted to demonstrate the response to rainfall events.

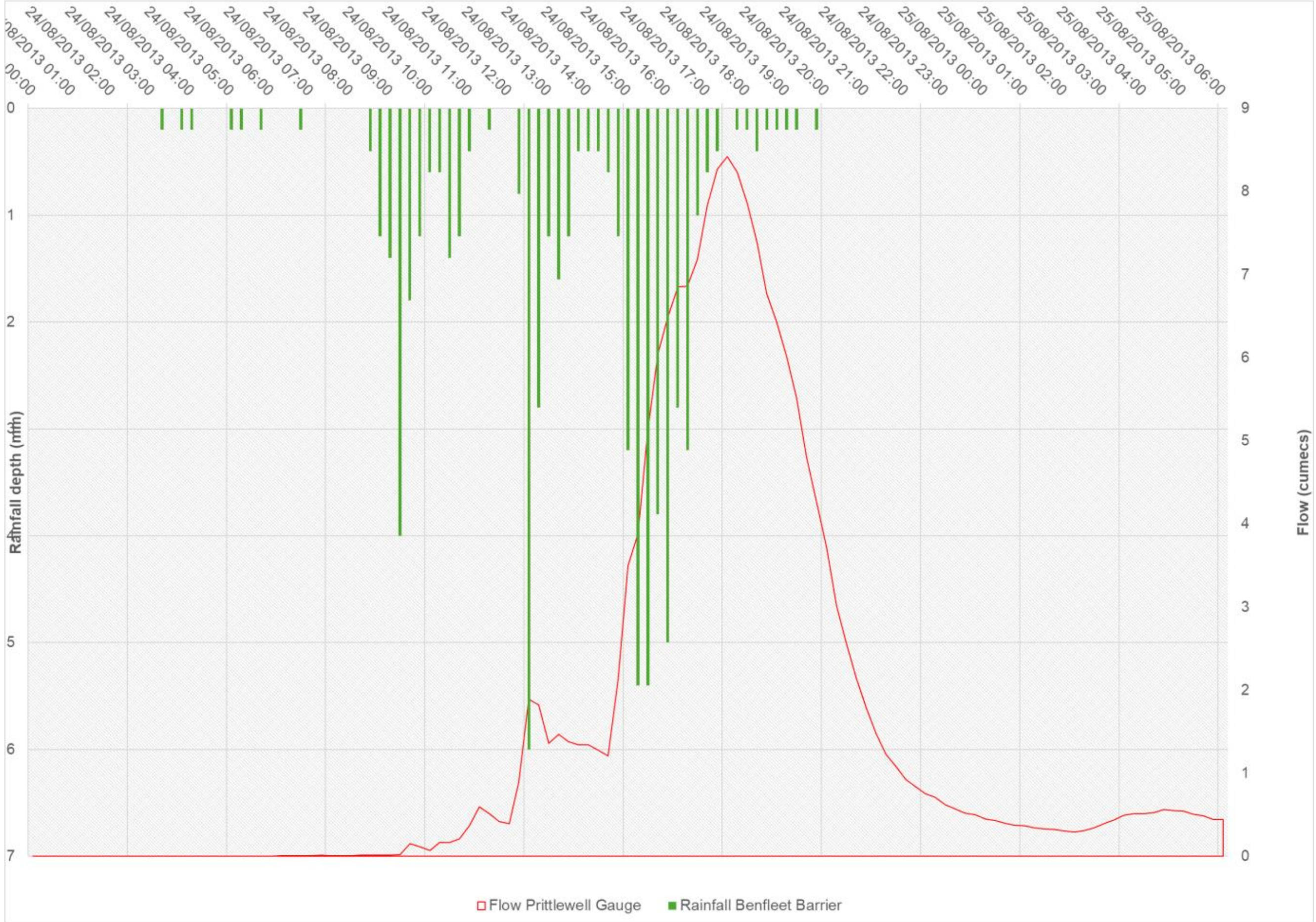
The table below shows the AMAX series derived from the 15min flow data at the gauge for reference. QMED from the AMAX series is 1.63m^3/s

Water Year	AMAX	Rank
2012 - 2013	**8.42**	**1**
2021 - 2022	**4.41**	**2**
2013 - 2014	**3.13**	**3**
2014 - 2015	**2.34**	**4**
2002 - 2003	**2.3**	**5**
2019 - 2020	**2.29**	**6**
2000 - 2001	**1.78**	**7**
2010 - 2011	**1.78**	**8**
2015 - 2016	**1.73**	**9**
2020 - 2021	**1.73**	**10**
2011 - 2012	**1.69**	**11**
2001 - 2002	**1.66**	**12**

Water Year	AMAX	Rank
2017 - 2018	**1.59**	**13**
2023 - 2024	**1.55**	**14**
2008 - 2009	**1.42**	**15**
2022 - 2023	**1.33**	**16**
2018 - 2019	**1.3**	**17**
2003 - 2004	**1.24**	**18**
2006 - 2007	**1.13**	**19**
2007 - 2008	**1.12**	**20**
2005 - 2006	**1**	**21**
2009 - 2010	**0.99**	**22**
2016 - 2017	**0.924**	**23**
2004 - 2005	**0.743**	**24**

Comments or figures

Plots of flow data and interpretation

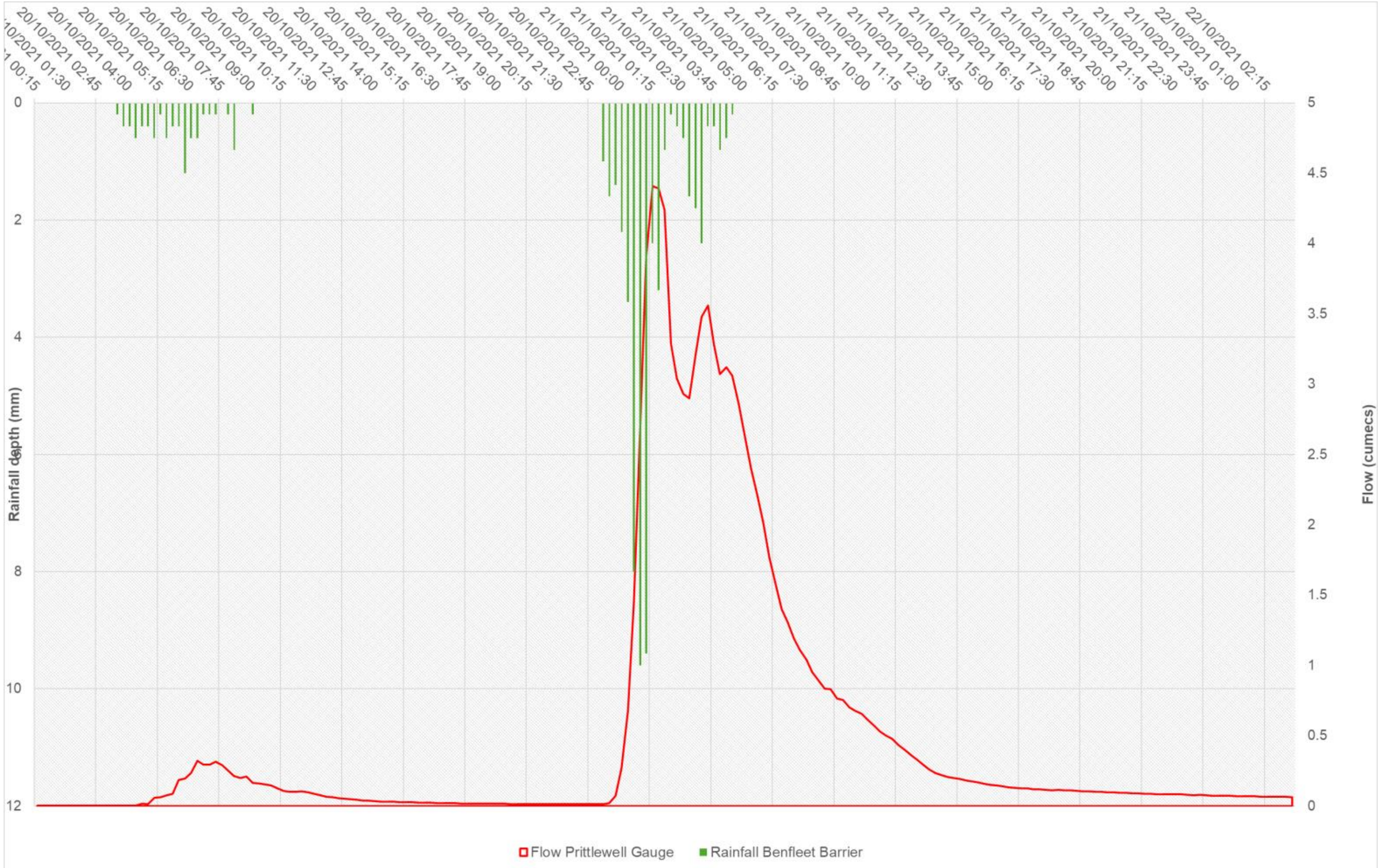


August 2013 – Rainfall: Benfleet Barrier

AMAX1 shows that three preceding rainfall events (63.6mm) and then the rapid response to the third rainfall event led to the large increase in flows within Prittle Brook. Response to the first rainfall is relatively muted.

Comments or figures

Plots of flood peak data and interpretation



October 2021 Rainfall: Benfleet Barrier

AMAX 2 October 2021 is the largest event in the Prittle Brook catchment since 2014. The rainfall depths (c.52.4mm) is commensurate with the August 2013 event however the peak flow is approximately half. The large depth of rainfall across a short period of time shows a rapid response within the Prittle Brook (0.5hrs). This indicates that surface water enters the watercourse quickly and causes a sharp response in the hydrograph at Prittlewell. The lower peak may be reflective of less intense rainfall in the upper Prittle Brook catchment and the catchment being less saturated from preceding storm events.

Conceptual model	Comments
Include information on factors such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (e.g. peak flows, flood volumes, combination of peaks, groundwater, snowmelt) • Might those locations flood from run-off generated on part of the catchment only e.g. locations located downstream of a reservoir? Is there a need to consider temporary debris dams that could collapse?	This study is only concerned with flooding from Prittle Brook within the Castle Point Borough Council administrative area. Only the upstream Prittle Brook catchment flows through CPBC areas which is approximately 1.8km of the watercourse. This is upstream of the confluence with the tributary(c.0.45km), the Prittlewell Gauge station (c.1.1km) and the Prittle Tunnel (c.1.3km). The key areas of interest are therefore mainly parts of the Hadleigh urban area. The catchment is urbanised and likely to be dominated by rapid response to rainfall events. This suggests that peak flows are the dominant flood mechanism.
Any unusual catchment features to take into account? E.g. • Highly permeable (BFIHOST >0.65). Consider permeable adjustment for statistical method if SPRHOST <20% • Highly urbanised – consider FEH statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • Pumped watercourse – consider lowland version of rainfall-runoff method • Major reservoir influence (FARL<0.90) – consider flood routing • Extensive floodplain storage – consider choice of method carefully • Historical mining or operational mining activities	SPRHOST of the catchment to the downstream boundary is 43.04%. Suggests moderately permeable catchment Heavily urbanised with URBEXT2000 of sub catchments ranging between c.0.4 – 0.8. The downstream extent may become tide locked at the Roach Estuary. This is sufficiently downstream of the area of interest that it will not impact results.

3.12 Initial choice of approach

Item	Comment
Is FEH appropriate? If not, describe why and give details of the other methods to be used.	Yes both FEH Statistical and ReFH2. FEH Statistical small catchment approach only valid for upstream of the Prittle Brook Offtake.
Initial choice of method(s) and reasons.	ReFH2.3 to be used. FEH Statistical methodology is not suitable downstream of the Prittle Tunnel FRC because of the artificial influence of Prittle Tunnel FRC. FEH Statistical small catchments to be used as a check upstream of the Prittlewell Gauge
How will hydrograph shapes be derived if needed? E.g. ReFH1, ReFH2 or average hydrograph shape from gauge data	ReFH2.3 LAG analysis to be undertaken on events in Oct 2020 and Oct 2021 in addition to the three in the 2016 Study (Aug 2013, July 2014 & Oct 2014).
Will the catchment be split into sub-catchments? If so, how?	Sub catchments will be retained from the 2016 study. Previous study delineated catchments using sewer records and LiDAR DTM. There have been no major developments in the catchment since 2016. BFIHOST19 values will be obtained for each sub catchment upstream of the Prittlewell Gauge. For intervening catchments BFIHOST19 will be obtained through area weighting. For sub catchments downstream no updates will be made to the catchment descriptors and BFIHOST will be used within ReFH.

Item	Comment
Software to be used (with version numbers) (**delete as appropriate**)	FEH Web Service[2] / WINFAP 5[3] /ReFH2.3 / Flood Modeller Pro V7

4 Locations where flood estimates are required

4.1 Summary of subject sites

The table below lists the locations of subject sites. It is noted that all catchments with the suffix "int" are intervening catchments and have been retained from the 2016 CH2M study and are shown here for completeness. The main focus of this hydrological update is upstream of the Prittlewell Gauge (P3) and therefore only a check on catchment descriptors has been completed downstream of here.

Site Code	Type of Estimate (L – lumped catchment; S- Sub-catchment)	Watercourse	Site	Grid Reference	Area on FEH Web Service (km^2)	Revised area if altered
P1	S	Prittle Brook	Upstream	582700, 187250	4.91	4.956
P2	S	Prittle Brook Tributary	Tributary	582650, 187250	0.90	
P3	S	Prittle Brook	Prittlewell Gauge Station	583300, 187000	6.356	6.972
P3int	S	Prittle Brook	Intervening Catchment to Prittlewell Gauge Station	583300, 187000	n/a	1.116
P4int	S	Prittle Brook	All catchments downstream of Prittlewell Gauge retained from 2016 CH2M Study. Not included further in the hydrology report.	584850, 186800	n/a	2.623
P5int	S	Prittle Brook		585950, 187000	n/a	1.295
P6int	S	Prittle Brook		587850, 187650	n/a	3.792
P7int	S	Prittle Brook		587850, 188750	n/a	1.155
P8	S	Prittle Brook		587800, 188750	1.33	2.419
P9int	S	Prittle Brook		588150, 189450	n/a	2.171

Reasons for choosing above locations	These locations are chosen to match the 2016 study and provide similar model inflow locations.

[2] CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, UK.
[3] WINFAP 5 © Wallingford HydroSolutions Limited 2020.

4.2 Important catchment descriptors at each subject site (original values from FEH Web Service)

Catchment descriptors in bold have been retained from the 2016 CH2M study and were estimated using Area Weighting. DPLBAR values were estimated using the DPLBAR regression equation the FEH Flood Estimation Handbook. BFIHOST19 for was estimated from Area Weighting

Site Code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
P1	1	0.22	0.402	2.7	28.5	561	42.57	0.292	0.0614
P2	1	0.21	0.368	1.09	25.8	552	44.63	0.5543	0.0418
P3	1	0.22	0.392	2.97	28.4	559	43.08	0.3264	0.0543
P3int	**1**	**0.23**		**1.06**	**30.1**	**556**	**44.09**	**0.2954**	**0.0329**
P4int	**1**	**0.22**		**1.7**	**25.8**	**544**	**44.87**	**0.5034**	**0.07**
P5int	**1**	**0.14**		**1.15**	**26.9**	**530**	**45.08**	**0.6397**	**0.0721**
P6int	**0.996**	**0.21**		**2.08**	**21.8**	**533**	**44.72**	**0.8128**	**0.0823**
P7int	**0.997**	**0.21**		**1.08**	**9.4**	**515**	**40.82**	**0.4099**	**0.1524**
P8	**1**	**0.21**	0.447	**1.62**	**13.7**	**532**	**41.52**	**0.4699**	**0.1695**
P9int	**0.999**	**0.21**		**1.53**	**12.1**	**534**	**39.42**	**0.2924**	**0.1152**

4.3 Checking catchment descriptors

Item	Comment
Record how catchment boundary was checked • Describe any changes • Refer to maps if required	Checked 2016 CH2M sub catchments against LiDAR DTM. These seem to be sensible
Record how other catchment descriptors were checked, especially soils • Describe any changes • Include a before and after table if required	Catchment boundary was checked against the 1m LiDAR DTM and adjustments from the 2016 CH2M study are valid. Sewer records are unavailable outside of the Castle Point Borough Council area. Sewer records were checked in the 2016 CH2M study and it is assumed there have been no major changes to the sewer catchments since 2016. It is assumed that the 2016 CH2M areas are acceptable. No further changes have been applied to the catchment areas. Catchment descriptors for all intervening catchments (suffix “int”) have been calculated using area weighting. No changes have been made to catchment descriptors of catchments downstream of the Prittlewell Gauge.BFIHOST19 values were checked against the British Geological Survey Viewer and Soilscapes Viewer. The predominant underlying geology is London Clay and Soilscapes indicates that downstream of P5int the soil is more free draining than the upper catchment which has impeded drainage. This is reflected in the increase in BFIHOST19 and values seems sensible. New BFIHOST19 value for P3int has been derived using Area Weighting. ReFH flows have been retained downstream of the Prittlewell Gauge and so no BFIHOST19 estimates have been used. It is acknowledged that there is uncertainty in this approach but as flows downstream of the Prittlewell Gauge will not impact the area of interest this approximation is commensurate with the requirements of this study. For all catchments downstream of the gauging station only PROPWET, BFIHOST and AREA have been reviewed.
Source of URBEXT / URBAN	URBEXT2000
Method for updating URBEXT / URBAN • Refer to WINFAP v4 Urban Adjustment procedures / guidance • CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000[4]	URBEXT2000 was updated to the present year (2024) using the following formula. • URBEXT2000 $UEF = 0.7851 + 0.2124\ \tan^{-1}\{(Year - 1967.5)/20.32\}$ A review of the aerial photography indicated that the urban extents remain broadly similar to 2000 so no further update was applied. A UEF of 1.045 was applied for the year 2024.

[4] http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD1919_5228_TRP.pdf#page=35

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

Site Code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
P1	1	0.22	0.402	2.7	28.5	561	42.57	**0.3053**	0.0614
P2	1	0.21	0.368	1.09	25.8	552	44.63	**0.5795**	0.0418
P3	1	0.22	0.392	2.97	28.4	559	43.08	**0.3412**	0.0543
P3int	1	0.23	**0.367**	1.06	30.1	556	44.09	**0.3088**	0.0329

5 Statistical method

5.1 Application of Statistical method

What is the purpose of applying this method?	Comment
Summarise reasons specific to study, for example lumped estimates at key locations for purpose of checking modelled peak flows.	Lumped estimates required for comparison with ReFH2 outputs.

5.2 Overview of QMED method

What method of QMED estimation was used?	Comments
State method/s used to estimate QMED in study and why, for example gauged data, donor transfer, multiple donor transfer, flow variability, bankfull width or user defined.	There is limited information for the Pittlewell Gauging Station. It is not within the NRFA database, is bypassed in events greater than 20% AEP and therefore is not considered suitable to use for flow estimates. The catchment is treated as ungauged. A check of QMED from the AMAX series at Prittlewell Gauge will be used as a comparison The small catchments approach has been applied in accordance with the latest EA Flood Estimation Guidance. This is a small, heavily urbanised catchment and this approach is the most up to date methodology. A single donor site has been used to improve the estimate of QMED for the site.

Summary of QMED estimates at each site:

Site code	QMED rural (from CDs) (m^3s^{-1})	QMED urban (from CDs) (m^3s^{-1})	Final method	Final estimate of QMED urbanised (m^3s^{-1})
P1	0.70	0.93	DA	1.73
P2	0.17	0.27	DA	0.51
P3	0.95	1.29	DA	2.45

Note: Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); DA – Donor Adjusted; CD – Catchment descriptors alone (with urban adjustment);

BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).

5.3 Search for donor sites for QMED

Comment on potential donor sites based on the above sections	Comments
• Number of potential donor sites available • Distances from subject site • Similarities in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data	Using the small catchment approach the single nearest donor catchment has been used to adjust QMED Heavily Urbanised site, URBEXT2000 threshold <0.6 URBEXT2000 37033 Eastwood Brook@Eastwood - This is a heavily urbanised catchment with similar AREA, BFIHOST19, FARL and SAAR to the subject sites. Distance to catchment is approximately 2-3km Retained

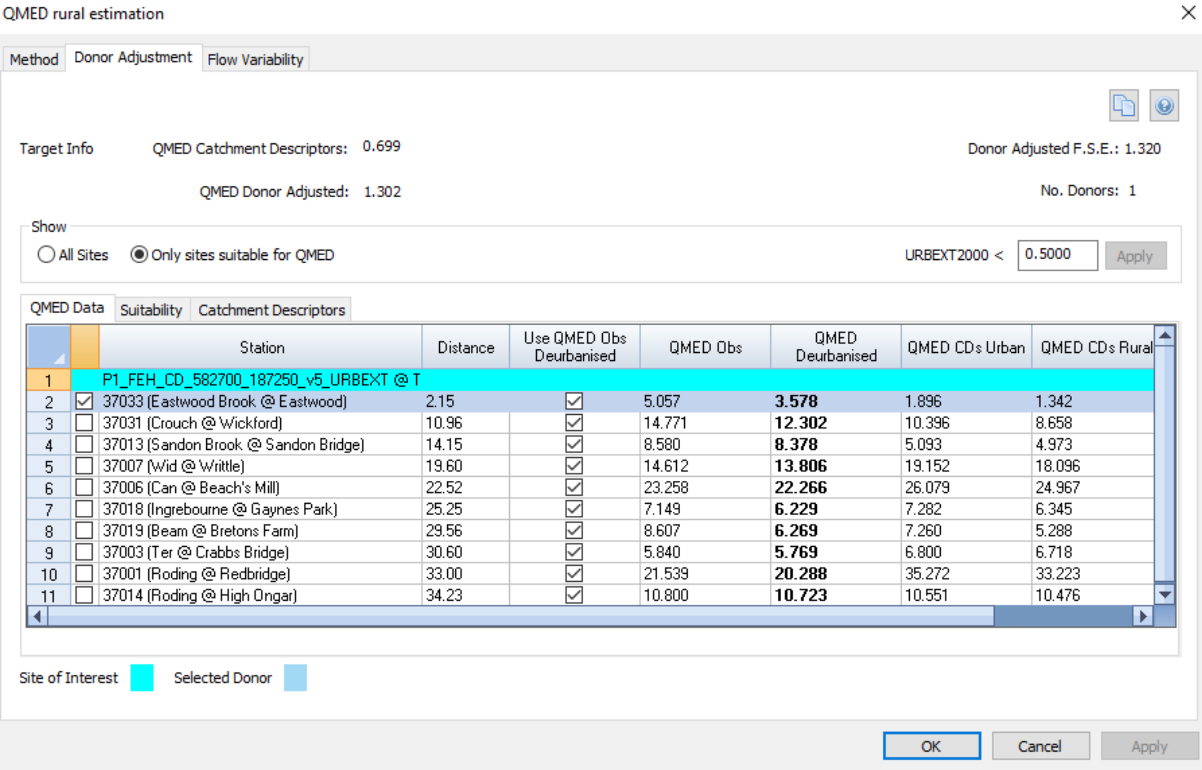
5.4 Single donor transfers and QMED adjustment

The recommended small catchment approach defaults to a single donor in the donor transfer method embedded within WINFAPv5. This has been utilised and adjustment for urbanisation has also been applied using the functionality within WINFAPv5.

The weighting of each donor catchment to provide the adjusted QMED is not provided within WINFAPv5 but is described within Kjeldsen et al 2014.

The QMED Catchment Descriptors and QMED Donor Adjusted values presented in the figures below are As-Rural estimates without the adjustment for urbanisation applied. See Section 5.2 for the final adjusted QMED value.

P1



QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info QMED Catchment Descriptors: 0.699 Donor Adjusted F.S.E.: 1.320

QMED Donor Adjusted: 1.302 No. Donors: 1

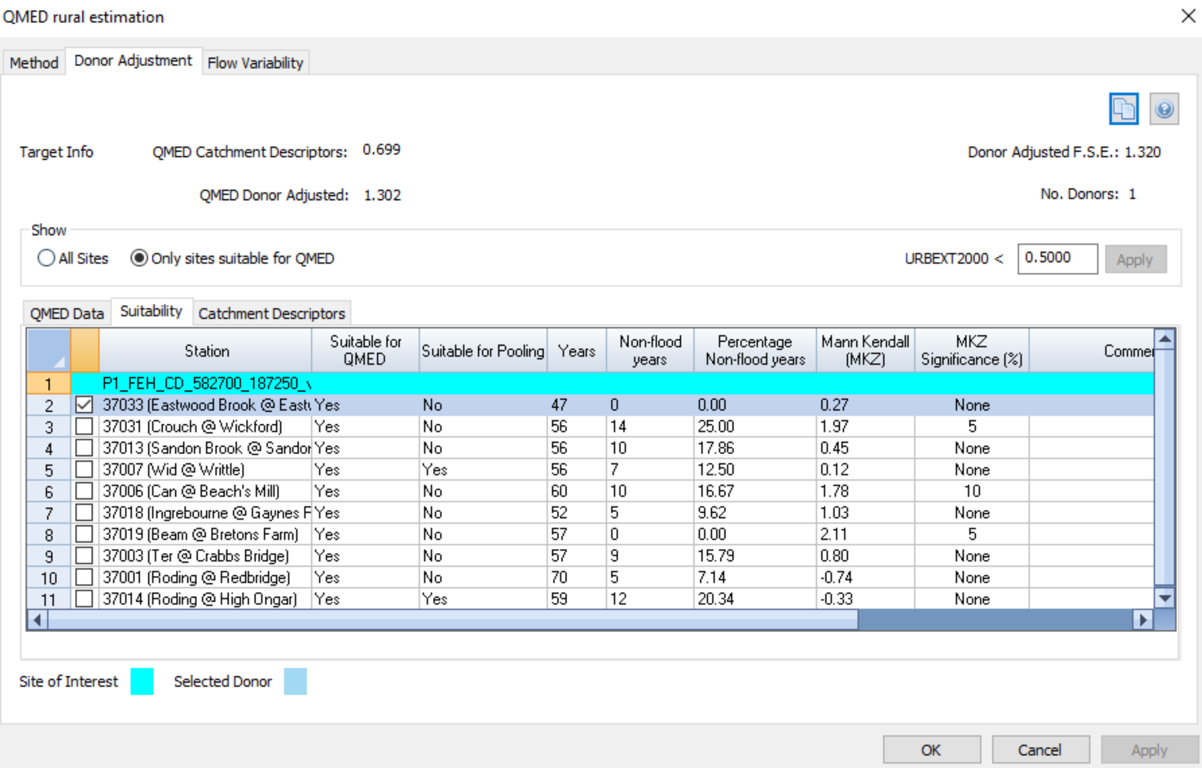
Show: All Sites / Only sites suitable for QMED URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		P1_FEH_CD_582700_187250_v5_URBEXT @ T						
2	☑	37033 (Eastwood Brook @ Eastwood)	2.15	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	10.96	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	14.15	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	19.60	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	22.52	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	25.25	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	29.56	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	30.60	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	33.00	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	34.23	☑	10.800	**10.723**	10.551	10.476

Site of Interest Selected Donor

OK Cancel Apply



QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info QMED Catchment Descriptors: 0.699 Donor Adjusted F.S.E.: 1.320

QMED Donor Adjusted: 1.302 No. Donors: 1

Show: All Sites / Only sites suitable for QMED URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Suitable for QMED	Suitable for Pooling	Years	Non-flood years	Percentage Non-flood years	Mann Kendall (MKZ)	MKZ Significance (%)	Comme
1		P1_FEH_CD_582700_187250_\								
2	☑	37033 (Eastwood Brook @ Eastw	Yes	No	47	0	0.00	0.27	None	
3	☐	37031 (Crouch @ Wickford)	Yes	No	56	14	25.00	1.97	5	
4	☐	37013 (Sandon Brook @ Sandor	Yes	No	56	10	17.86	0.45	None	
5	☐	37007 (Wid @ Writtle)	Yes	Yes	56	7	12.50	0.12	None	
6	☐	37006 (Can @ Beach's Mill)	Yes	No	60	10	16.67	1.78	10	
7	☐	37018 (Ingrebourne @ Gaynes F	Yes	No	52	5	9.62	1.03	None	
8	☐	37019 (Beam @ Bretons Farm)	Yes	No	57	0	0.00	2.11	5	
9	☐	37003 (Ter @ Crabbs Bridge)	Yes	No	57	9	15.79	0.80	None	
10	☐	37001 (Roding @ Redbridge)	Yes	No	70	5	7.14	-0.74	None	
11	☐	37014 (Roding @ High Ongar)	Yes	Yes	59	12	20.34	-0.33	None	

Site of Interest Selected Donor

OK Cancel Apply

P2

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.168 — Donor Adjusted F.S.E.: 1.316

QMED Donor Adjusted: 0.315 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.6000 [Apply]

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		P2_FEH_CD_582650_187250_v5_URBEXT @ T						
2	☑	37033 (Eastwood Brook @ Eastwood)	2.05	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	12.20	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	15.45	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	20.95	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	23.91	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	26.38	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	30.62	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	31.81	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	34.33	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	35.62	☑	10.800	**10.723**	10.551	10.476

Site of Interest — Selected Donor

OK | Cancel | Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.168 — Donor Adjusted F.S.E.: 1.316

QMED Donor Adjusted: 0.315 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.6000 [Apply]

QMED Data | Suitability | Catchment Descriptors

		Station	Suitable for QMED	Suitable for Pooling	Years	Non-flood years	Percentage Non-flood years	Mann Kendall (MKZ)	MKZ Significance (%)	Commer
1		P2_FEH_CD_582650_187250_\								
2	☑	37033 (Eastwood Brook @ Eastw	Yes	No	47	0	0.00	0.27	None	
3	☐	37031 (Crouch @ Wickford)	Yes	No	56	14	25.00	1.97	5	
4	☐	37013 (Sandon Brook @ Sandor	Yes	No	56	10	17.86	0.45	None	
5	☐	37007 (Wid @ Writtle)	Yes	Yes	56	7	12.50	0.12	None	
6	☐	37006 (Can @ Beach's Mill)	Yes	No	60	10	16.67	1.78	10	
7	☐	37018 (Ingrebourne @ Gaynes F	Yes	No	52	5	9.62	1.03	None	
8	☐	37019 (Beam @ Bretons Farm)	Yes	No	57	0	0.00	2.11	5	
9	☐	37003 (Ter @ Crabbs Bridge)	Yes	No	57	9	15.79	0.80	None	
10	☐	37001 (Roding @ Redbridge)	Yes	No	70	5	7.14	-0.74	None	
11	☐	37014 (Roding @ High Ongar)	Yes	Yes	59	12	20.34	-0.33	None	

Site of Interest — Selected Donor

OK | Cancel | Apply

P3

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info   QMED Catchment Descriptors: 0.947   Donor Adjusted F.S.E.: 1.311

QMED Donor Adjusted: 1.800   No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED   URBEXT2000 < 0.6000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		P3_FEH_CD_583300_187000_v5_URBEXT @ T						
2	☑	37033 (Eastwood Brook @ Eastwood)	1.95	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	11.37	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	14.51	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	20.03	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	22.95	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	25.63	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	29.93	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	30.93	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	33.43	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	34.65	☑	10.800	**10.723**	10.551	10.476

Site of Interest   Selected Donor

OK | Cancel | Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info   QMED Catchment Descriptors: 0.947   Donor Adjusted F.S.E.: 1.311

QMED Donor Adjusted: 1.800   No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED   URBEXT2000 < 0.6000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Suitable for QMED	Suitable for Pooling	Years	Non-flood years	Percentage Non-flood years	Mann Kendall (MKZ)	MKZ Significance (%)	Commer
1		P3_FEH_CD_583300_187000_\								
2	☑	37033 (Eastwood Brook @ Eastw	Yes	No	47	0	0.00	0.27	None	
3	☐	37031 (Crouch @ Wickford)	Yes	No	56	14	25.00	1.97	5	
4	☐	37013 (Sandon Brook @ Sandor	Yes	No	56	10	17.86	0.45	None	
5	☐	37007 (Wid @ Writtle)	Yes	Yes	56	7	12.50	0.12	None	
6	☐	37006 (Can @ Beach's Mill)	Yes	No	60	10	16.67	1.78	10	
7	☐	37018 (Ingrebourne @ Gaynes F	Yes	No	52	5	9.62	1.03	None	
8	☐	37019 (Beam @ Bretons Farm)	Yes	No	57	0	0.00	2.11	5	
9	☐	37003 (Ter @ Crabbs Bridge)	Yes	No	57	9	15.79	0.80	None	
10	☐	37001 (Roding @ Redbridge)	Yes	No	70	5	7.14	-0.74	None	
11	☐	37014 (Roding @ High Ongar)	Yes	Yes	59	12	20.34	-0.33	None	

Site of Interest   Selected Donor

OK | Cancel | Apply

5.5 Uncertainty in QMED

The estimation of QMED from the catchment descriptors alone is not advised. In particular, review of potential donor sites illustrates an under estimation of QMED using the catchment descriptor equation when compared with observed data. A review of local donor sites has been undertaken and a single donor adjustment has been applied using local stations. The influence of using a single donor site or multiple donor sites also reduces the Factorial Standard Error (F.S.E) when compared to using catchment descriptors only. The reduction in F.S.E for each site is illustrated in the following table. It should be noted that these provide adjusted QMED values (highlighted in **bold**) based on **rural** estimates only. An urban adjustment of QMED has been applied for the final QMED estimates and reflected in Section 5.2.

Subject Site	F.S.E	Donor Adjusted F.S.E
P1	1.431	1.320
P2	1.431	1.316
P3	1.431	1.311

5.6 Derivation of pooling groups

Pooling groups were created within WINFAP v5 for each of the subject sites. An URBEXT2000 threshold of 0.6 was used to create the pooling groups in order to make maximum use of gauge data similar to the subject site. The Heterogeneity statistic (H2) for the pooling groups were assessed; this provides an indication of whether a review of the pooling group is required (not required, optional, desirable or essential).

The similarity of the subject site against stations within the pooling group is assessed by the Similarity Distance Measure (SDM) and is a function of Area, SAAR, FARL and FPEXT. A new pooling method was introduced for small catchments through Science Report SC090031[5], the SDM for small catchments for this approach only uses AREA and SAAR. This method is implemented in WINFAP 5.However, it is good practice to review the pooling group to check other parameters e.g. BFIHOST and the history of the gauge, gauge record and rating quality on the NRFA website (https://nrfa.ceh.ac.uk/data/search).

As per the Environment Agency guidelines, modifications to the pooling group tend to have a relatively minor effect on the final design flow (compared with, for example, the selection of donor sites for QMED). Science Report SC050500[6] indicates that apart from the first four or five stations within a pooling group (i.e. lowest SDM), the record length at a station will only have a modest effect on its weight within the pooling group (unless the record is very short). The review of the pooling group has therefore focused on the first five stations within each pooling group, extending further where required to include stations that have moved up position following removal of others, gauges with a short record, and catchments which have extreme catchment descriptor values in comparison to the subject sites.

[5] Science Report SC090031/R0: Estimating flood peaks and hydrographs for small catchments (Phase 1) (2012). https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/review-of-methodology-for-estimating-flood-peaks-and-hydrographs-for-small-catchments
[6] Science Report SC050050: Improving flood frequency estimation (2008). https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/improving-the-flood-estimation-handbook-feh-statistical-index-flood-method-and-software

The table below summarises the pooling group used in this study, with the initial pooling group provided Annex A. Annex A also notes the reasons for removing catchments from the initial pooling group and which stations were added into the pooling group to ensure that sufficient years of data (>500) were included in the final group.

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. Include any sites that were investigated but retained in the group	Weighted average L-moments (L-CV and L-skew before urban adjustment)
Prittlewell Gauge	P3	No	- Reviewed the top 5 pooling group. - Removed 27073 (Brompton Beck @ Snainton Ings), 30013 (Heighington Beck @ Heighington), 26016 (Gypsey Race @ Kirby Grindalythe) because of very high BFIHOST19 >0.8. - 26014 (Water Forlornes @ Driffield) has a high BFIHOST but is 11th in pooling group and considered not to have a significant effect on the results so left in. - 27073 (Brompton Beck @ Snainton Ings) >20% Non-Flood Years so removed - Added 36004 (Chad Brook @ Long Melford), 30006 (Slea @ Leasingham Mill), 19017 (Gogar Burn @ Turnhouse) to ensure 500yrs of record.	L-CV = 0.302 L-Skew = 0.207

The table below details the H2 score and requirement for pooling group review for in the initial and final pooling groups for each site

Catchment	Initial Pooling Group H2 value	Recommendation for Pooling Group Review	Final Pooling Group H2 value	Recommendation for Final Pooling Group Review
P3	2.7533	This pooling group is heterogeneous and a review of the pooling group is desirable	0.4362	The pooling group is acceptably homogenous and a review of the pooling group is not required.

5.7 Derivation of flood growth curves at subject sites

A single growth curve has been derived using the P3 catchment and has been applied to the FEP for the three sub catchments P1, P2 and P8.

Site Code	Method (SS, P, ESS, FH)	If P, ESS or FH, 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 adjustment	Growth Curve Factor for 100 year return period
P1	P	Prittlewell Gauge	All GL, GV and Kappa 3 are acceptable. Kappa3 chosen as WINFAPv5 recommended best fit	Adjusted for urbanisation using WINFAPv5 small catchments approach	Location: 0.936 Scale:0.280 Shape: -0.211 H: -0.4	3.108
P2	P		All G, GV and Kappa 3 are acceptable. Kappa3 chosen as WINFAPv5 recommended best fit	Adjusted for urbanisation using WINFAPv5 small catchments approach		
P3	P		All G, GV and Kappa 3 are acceptable. Kappa3 chosen as WINFAPv5 recommended best fit	Adjusted for urbanisation using WINFAPv5 small catchments approach		

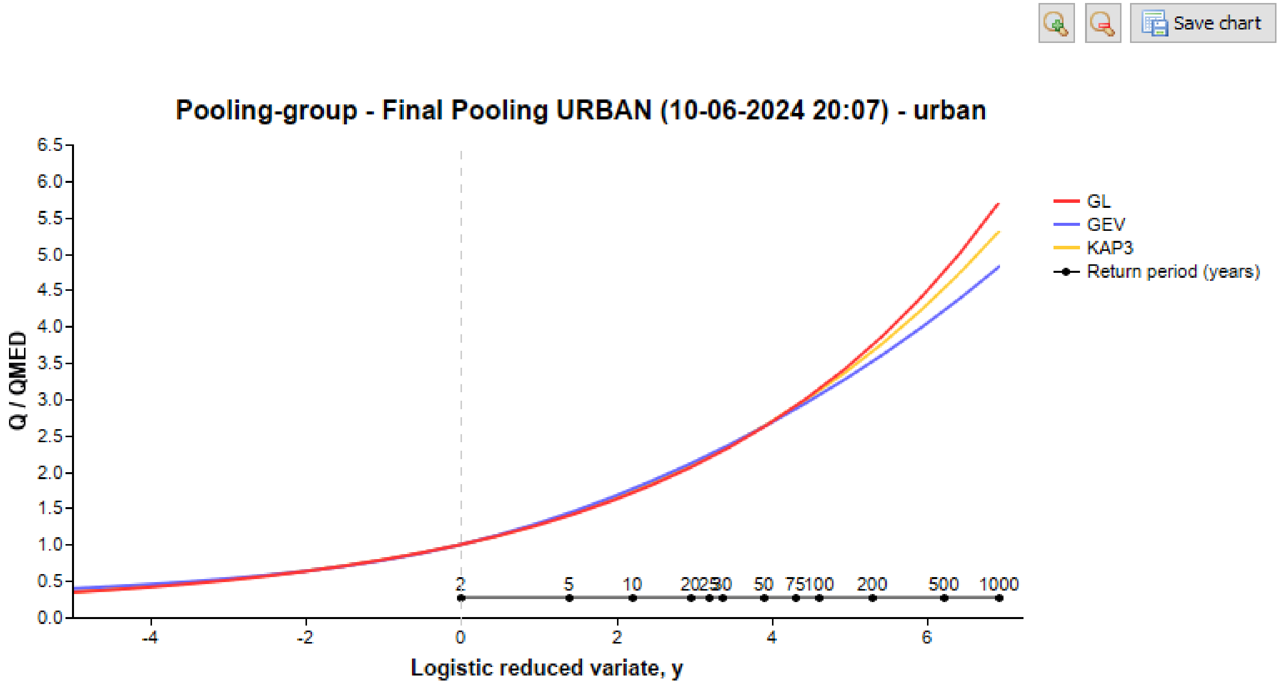


Figure 5-1: Comparison of growth curves using GL, GEV and PIII distributions

Growth Curve Factors for the following return periods for Gl, GEV and PIII distributions for Prittlewell Gauge Pooling Group

Distribution	2	5	10	20	30	50	75	100	1000
GL	1	1.398	1.708	2.059	2.291	2.617	2.907	3.132	5.693
GEV	1	1.434	1.762	2.111	2.33	2.621	2.867	3.05	4.814
Kappa 3	1	1.412	1.732	2.086	2.314	2.628	2.9	3.108	5.3

Peak flows (m^3s^{-1}) estimated for the following return periods for each statistical distribution

Distribution	2	5	10	20	30	50	75	100	1000
GL	2.5	3.4	4.2	5.0	5.6	6.4	7.1	7.7	14.0
GEV	2.5	3.5	4.3	5.2	5.7	6.4	7.0	7.5	11.8
Kappa 3	2.5	3.5	4.2	5.1	5.7	6.4	7.1	7.6	13.0

5.8 Flood estimates from the statistical method

QMED estimated using small catchment approach and single donor adjustment and adjusted using UAF at site location. The Prittlewell Gauge growth curve using Kappa 3 has been applied to all three sub catchments because it is considered to be representative of the catchment as a whole.

Flood Peak (m^3s^{-1}) for the following return periods

Site Code	2	5	10	20	30	50	75	100	1000
P1	1.7	2.4	3.0	3.6	4.0	4.5	5.0	5.4	9.2
P2	0.5	0.7	0.9	1.1	1.2	1.3	1.5	1.6	2.7
P3	2.5	3.5	4.2	5.1	5.7	6.4	7.1	7.6	13.0

6 Revitalised flood hydrograph (ReFH2) method

6.1 Application of ReFH2 model

What is the purpose of applying this method?	Comment
Summarise reasons specific to study, for example: lumped estimates at key locations for the purpose of checking modelled peak flow estimates, distributed approach to apply inflows to a hydraulic model, deriving hydrograph shapes only, extending the flood frequency curve out to extreme events (long return periods).	Distributed approach to apply inflows to hydraulic model upstream of the Prittlewell Gauge. Hydrograph shape to be assessed and flows to be compared to FEH Statistical Method. ReFH inflows from the 2016 CH2M report downstream of the Prittlewell Gauge have been retained and not re-assessed here.

6.2 Catchment sub-divisions in urban ReFH2 model

The Prittle Brook catchment is heavily urbanised with the entire catchment URBEXT2000 > 0.4. Sub catchments and intervening areas have URBEXT2000 values up to c.0.84 (P6int).

The catchments upstream of the Prittle Tunnel Offtake which form the main area of this study (P1, P2 and P3int) have URBEXT2000 0.31 – 0.56.

The previous 2016 CH2M Prittle Brook study defined 8 sub catchments based on primary sewer outfalls to Prittle Brook using the ReFH Urban methodology and defined the rural catchment, defined the sewer catchments within the natural watershed and then the sewer catchments draining into and out of the natural watershed via the surface water and combined sewer networks. Subsequent research has led to the urban extension model being incorporated into ReFH2 and improved.

The main areas that have been extended due to the sewer catchment are within intervening catchments downstream of the Prittle Tunnel Offtake and no sewers were found to flow into the catchment against the topography. These sub-catchments/intervening are downstream of the area of interest and outside the Study Area, therefore a review of the sewer records in these catchments has not been undertaken.

URBEXT2000 has been used to determine the urban extents in all sub catchments and intervening areas.

A check has been undertaken for sub-catchment P3 on the sensitivity to a +/- 20% change in parameter value for Tp urban scaling factor, IF and IRF. This has been undertaken for the critical storm duration used in the CH2M 2016 study (4.5hr) for the 1% AEP event using ReFH2. This is due to the heavily urbanised nature of the catchment and for checking against observed events at Prittlewell Gauge. This shows that the peak flow is not sensitive to these parameters and it is not necessary to invest significant time to refine them.

	Peak Flow Default settings (m^3/s)	Peak Flow +20% Parameter (m^3/s)	Peak Flow -20% Parameter (m^3/s)
Tp Scaling Factor (Default = 0.75)	5.5	5.2	5.9
IRF (Default = 0.7)		5.7	5.3
IF (Default = 0.4)		5.5	5.3

6.3 Parameters for ReFH2 model

6.3.1 LAG Analysis

The catchment response to rainfall described in Section 3.11 is shown to be rapid (0.25hrs-2.5hrs) due to the urban nature of the catchment. It was found that ReFH2 estimated Tp rural for the Prittlewell Gauge catchment is c.6.5hrs. The 2016 CH2M study used unadjusted Tp values from the ReFH analysis and were shown in calibration to perform well against the observed data. Using the recommended Tp values from ReFH2 results in a significantly longer Tp and lower peak flows. For this reason it was deemed necessary to improve the estimation of Tp LAG analysis.

The Tprural values for the three catchments upstream of the Prittlewell Gauge were found to be c.4-6hrs meaning that the urban Tp is c.3-4.5hrs. This is a much slower response time than the gauged record shows. A draft simulation of the August 2013 event shows that using the recommended Tp values results in a much longer and flatter response to the rainfall event indicating that this is too long (Section 6.3.3).

To improve the estimate of Tp the LAG analysis undertaken in the 2016 CH2M study has been extended to include additional storm events in Oct 2021 (AMAX 2) and Jan 2021 (third largest event since 2014). The January 2021 event was chosen because of the clean rainfall and response profile and similar in size to the October 2021 event.

A review of the data quality at the nearest rain gauges and at the Prittlewell Gauge was undertaken. It was found that the Benfleet Barrier Gauge provided good data for the events and was chosen as a suitable gauge.

Tp(0) was then estimated from the observed LAG using the following equation:

$$Tp(0) = 0.879LAG^{0.951}$$

The table below shows a summary of the LAG Analysis and rain gauges used:

Event	Rain Gauge	Total Rainfall (mm)	LAG (hrs)	Tp(0)
August 2013	Basildon	63.6mm (11.5hrs)	2.5	2.300
July 2014	Hullbridge	12.8mm (7hrs)	0.5	0.455
October 2014	Benfleet Barrier	19mm(5.3hrs)	0.25	2.101
January 2021	Benfleet Barrier	21.8mm (12hrs)	2.75	0.455
October 2021	Benfleet Barrier	52.4mm (5.25hrs)	0.5	0.235
Geometric Mean			0.84	**0.7485**

6.3.2 Tp Adjustment

To utilise the local data at the Prittlewell Gauge, the data from the LAG analysis (Section 6.3.1) has been used to improve the estimation of Tp(0).

The ReFH2 software estimates the Tp as a rural catchment however as the catchment is urbanised it is important account for how this influences the observed Tp recorded in Section 6.3.1. The methodology set out in the EA Flood Estimation Guidelines (December 2022 p95) has been applied at the Prittlewell Gauge to calculate a donor adjustment factor for Tp rural in ReFH2 based on catchment P3.

$$Tp\ urban\ adjustment\ factor = (1 + URBEXT2000)^{-3.36}$$

The Tp urban adjustment factor for catchment P3 is 0.3729 based upon an URBEXT2000 of 0.3412

For catchment P3 the ReFH2 estimated Tp rural is 6.926hrs.

The estimated Tp accounting for urban influence from ReFH2 catchment descriptors is 0.3412 x 6.926 = 2.5828hrs

ReFH2 Tp rural adjustment factor comparing the ReFH2 Tp urban to the observed Tp is therefore 0.7485/2.5828 = 0.2898

This factor has been applied to all Tp rural values for each sub catchment upstream of the Prittle Tunnel.

For all catchments downstream of Prittle Tunnel no adjustments have been made to the ReFH Tp values from the 2016 study.

6.3.3 Validation

A check was undertaken using the August 2013 AMAX 1 event to understand the impacts of adjusting the Tp value. Figure 6-1 below shows the ReFH2.3 observed hydrographs (P3) for the August 2013 event against the observed flows at the Prittlewell Gauge. When the recommended Tp value (6.926hrs) is applied the ReFH hydrograph is significantly lower and peaks much later than the observed hydrograph. When the adjusted Tp value is applied (2.01hrs) the shape, peak and timing of the hydrograph is greatly improved whilst still underestimating the peak flow and volume. This indicates that the adjusted Tp value provides a better representation of the flows and therefore will be adopted for the design events.

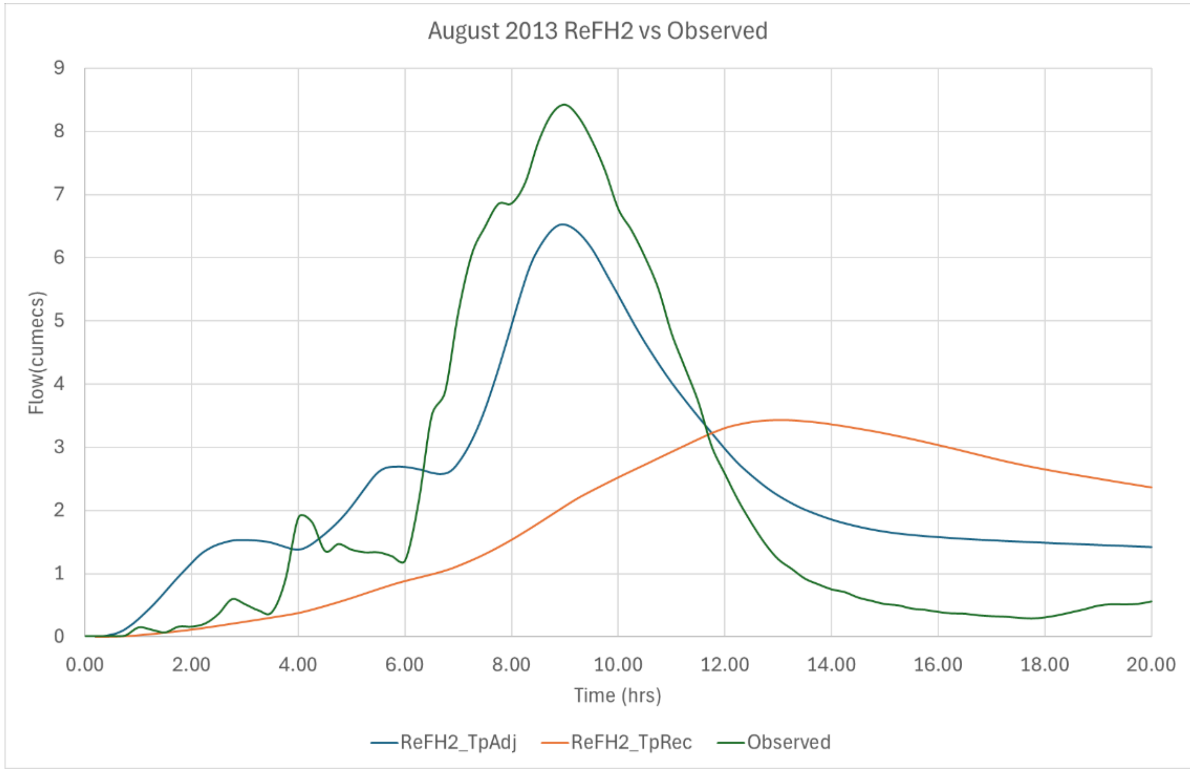


Figure 6-1: ReFH2.3 observed hydrographs (P3) for the August 2013 event against the observed flows at the Prittlewell Gauge

The hydraulic model was simulated using a 4.5hr storm with both the Tp adjustment and with the recommended ReFH2 Tp values for both the QMED and 0.1% AEP events. The following conclusions can be made:

- QMED – There is no out of bank flooding when no adjustment to the recommended ReH2 Tp value is applied. When the Tp adjustment is applied there are pockets of out of bank flooding within the Castle Point Borough Council area though these are confirmed to wooded areas and not within areas of development. Maximum stage is approximately 300-400mm greater however for the majority of the study area this is at approximately bank full level.
- 0.1% AEP – The maximum flood extents are significantly less than the existing Flood Zone 2 through the Castle Point Borough Council area when no adjustment to Tp is applied. The maximum flood extents are commensurate with the existing Flood Zone 2 outlines when the Tp adjustment is applied.

Based on these model simulations the adjusted Tp simulations provide a more conservative estimate of flows and extents whilst not increasing the maximum flood extents significantly. This follows the recommended approach in the Environment Agency Flood Estimation Guidance and is the most appropriate for this assessment.

6.3.4 ReFH2 Parameters

The following ReFH2 parameters have been used with Tp adjusted for all catchments upstream of the Prittlewell Gauge. The Tp_{urban} value has been shown as 0.75 of the Tp_{rural}.

Site Code	Details of Method OPT: Optimisation BR: base flow recession fitting CD: catchment descriptors DT: Data Transfer	Tp_{rural} (hours) Time to peak	Tp_{urban} (hours) Time to peak	C_{max} (mm) Maximum storage capacity	IRF (% runoff for impermeable surfaces)	BL (hours) Base flow lag	BR Base flow recharge (QMED)
P1	DT (Tp Only)	1.90	1.42	347.1	0.7	44.233	2.127
P2	DT (Tp Only)	1.23	0.92	320.891	0.7	35.135	1.679
P3int	DT (Tp Only)	1.04	0.78	313.97	0.7	33.452	1.645
P3	DT (Tp Only)	2.01	1.51	338.2	0.7	44.478	2.618
Brief description of any flood event analysis undertaken: Provide further details here or in a project report	See Section 6.3.1						

6.4 Design events for ReFH2 method: Lumped catchments

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Source of design rainfall statistic (FEH13 or FEH99)

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

All design events are presented as urban with Summer storm profiles. The catchments are small and therefore the recommended ARF has been retained for each sub catchment.

Site Code	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area	Reason for selecting storm	Source of design rainfall statistic
P1	Summer	4.5	-	Consistency with 2016 CH2M Study	FEH22
P2	Summer	4.5	-	Consistency with 2016 CH2M Study	FEH22

Site Code	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area	Reason for selecting storm	Source of design rainfall statistic
P3int	Summer	4.5	-	Consistency with 2016 CH2M Study	FEH22
P3	Summer	4.5	-	Consistency with 2016 CH2M Study	FEH22
Results of storm duration testing	Storm duration testing is not within the scope of this study. The 4.5hr storm has been retained from the 2016 CH2M study..				

6.6 Flood estimates from the ReFH2 method

As per the Technical Guidance Document: ReFH 2.3, the urban results are reported in the table below. These results take account of the urban extent within the catchment based on URBEXT2000 and are considered representative of existing conditions.

	Flood Peak (m^3s^{-1}) for the following return periods								
Site Code	2	5	10	20	30	50	75	100	1000
P1	3.3	4.8	6.0	7.1	7.8	8.7	9.5	10.2	18.8
P2	1.1	1.6	2.0	2.3	2.6	2.9	3.1	3.3	6.0
P3int	1.2	1.8	2.2	2.6	2.9	3.2	3.5	3.8	6.9
P3	4.7	7.0	8.5	10.2	11.2	12.5	13.6	14.5	26.7

7 Discussion and summary of results

7.1 Comparison of results from different methods

This table compares peak flows from the ReFH2 method with those from the FEH Statistical method (donor adjusted inclusive of urbanisation) at each site for two key return periods. This illustrates that flow estimates from the FEH statistical method are approximately 88% to 120% less than those derived using ReFH2.

	Return period 2 years (50% AEP)			Return Period 100 years (1% AEP)		
Site Code	Statistical	ReFH2	Ratio (ReFH2/Statistical)	Statistical	ReFH2	Ratio (ReFH2/Statistical)
P1	1.7	3.3	1.94	5.4	10.2	1.89
P2	0.5	1.1	2.20	1.6	3.3	2.06
P3	2.5	4.7	1.88	7.6	14.5	1.91

7.2 Final choice of method

Choice of method and reason Include reference to type of study, nature of catchment and type of data available	Urban ReFH2.3 with the adjusted Tp values using local gauge data. There is limited confidence in the Prittlewell Gauge as it does not form part of the NRFA dataset and therefore the flow estimates have not been used for improving QMED and Single Site or Enhanced Single Site analysis. The catchment is an urban, rapid response catchment and ReFH2.3 provides a better representation of the runoff from the urban area. The ReFH2 flows are conservative compared to the FEH Statistical flows and for the purpose of this Level 1 SFRA a conservative approach is preferable.
How will the flows be applied to a hydraulic model?	Model inflows locations to be retained from the 2016 model. P1 to be distributed throughout the upper catchment P2 direct inflow P3int to be distributed throughout the intervening area All model inflows downstream to be retained and not updated.

7.3 Assumptions, limitations, and uncertainty

List the main assumptions made specific to the study	The Prittlewell Gauge is not suitable for the estimation of QMED and Hi-Flows The critical storm duration of 4.5hrs identified in the 2016 report has been retained and considered suitable based on the 2016 CH2M study The catchment delineation using the sewer network in the 2016 CH2M study is representative of the current topographic and sewer catchments There are no significant inflows/outflows into/from the catchment due to the sewer network and the sewer network provides a balanced flow into and out of each of the sub catchments. There is no impact in the study area of change in flows downstream of the Prittlewell Gauge Assumes that the urban hydrograph Tp value is 0.75. There is no pumping of surface water into or out of the catchment.
Discuss any particular limitations For example applying methods outside the range of catchment types or return periods for which they were developed	Study only valid for flow estimates upstream of the Prittlewell Gauge Flow estimates downstream of the Prittle Tunnel Offtake (P4int – P9int) have been retained from the 2016 CH2M study and estimated in ReFH. This will use FEH13 rainfall and a different methodology for calculating flow hydrographs. Flows downstream of the gauge must be reviewed and updated as required. No calibration of ReFH2 parameters has been undertaken. Update to Tp is based upon the ReFH2 hydrograph shape only . Flows in the upper are conservative and show limited correlation to the gauged data. This is considered acceptable because of limitations at the gauge and the location of the study area upstream of the gauge.
Give what information you can on uncertainty in the design peak flows or in the methodology For example using the methods detailed in ‘Making better use of local data in flood frequency estimation’ - Science Report SC130009/R	The small catchments approach found that ReFH2 gave a lower factorial standard error than the FEH Statistical when estimating QMED on small catchments
Comment on the suitability of the results for future studies For example at nearby locations or for different purposes	These flow estimates are suitable for the Level 1 SFRA only and should not be used for areas outside of the Castle Point Borough Council administrative area. Flows are likely to be conservative and should be reviewed for future studies.
Give any other comments on the study For example suggestions for additional work	Calibration of the ReFH2 parameters Improved flow and level gauging data

7.4 Checks

Are the results consistent, for example at confluences?	Yes – comparison of QMED at P3 is commensurate with the sum of the peak flow at P1, P2 and P3int.The sum of the distributed flow is larger but this is likely driven by the urban response of the distributed catchments.
What do the results imply regarding the return periods / frequency of floods during the period of record?	The estimated ReFH2.3 flows show a QMED that is significantly larger than observed at the Prittlewell Gauge. QMED from the AMAX series is estimated c.1.6m^3/s and the adjusted Tp ReFH2 4.5hr storm is 4.7m^3/s. The largest AMAX1 flow is estimated at between a 20% - 10% AEP event.
What is the 100-year (1% AEP) growth curve factor? Is this realistic? (The guidance suggests a typical range of 2.1 – 4.0)	3 – 3.16. This is within the typical range.
If 1000 year (0.1% AEP) flows have been derived, what is the range of ratios for the 1000-year (0.1% AEP) flow over the 100-year (1% AEP) flow?	Ratio is 1.84 for the ReFH2 flows. This is appropriate.
What is the range of specific run-offs (l/s/ha) do the results equate to? Are there any inconsistencies?	Specific runoff is broadly consistent between P1 and P3 but P2 shows a significantly larger specific runoff than both these catchments. P2 is more heavily urbanised with an URBEXT2000 value c.80% larger and so will result in much more runoff.

Catchment	QMED (l/s/ha)	1% AEP
P1	6.7	20.6
P2	12.2	36.7
P3	6.7	20.8

How do the results compare with those of other studies?

Explain the difference and conclude which results should be preferred

The AECOM 2024 ReFH2.3 4.5hr storm estimates have been compared to the 2016 CH2M estimates. It is also noted that a constant inflow of 0.5cumecs is within the model and therefore is not accounted for in the estimates below.

The AECOM 2024 estimates are consistently higher than those from 2016. Within catchment P1 and P2 these are 10%-30% larger and for catchment P3int 50%-% larger. Improvements in the FEH methodologies including the ReFH2 urban model, improvements in small catchment estimation, new FEH22 DDF and improved length of record since the previous estimates should provide increased confidence in flow estimates. Based upon the above the AECOM flow estimates are considered to be more robust. They also provide a more conservative flow estimate as the peak flows are higher.

Catchment	CH2M 2016 50%	AECOM 50%	CH2M 2016 1%	AECOM 1%	CH2M 2016 0.1%	AECOM 0.1%
P1	2.5	3.3	7.6	10.2	16.4	18.8
P2	0.9	1.1	2.7	3.3	5.7	6.0
P3int	0.6	1.2	2.1	3.8	4.6	6.9

Are the results compatible with the longer-term flood history?	The results indicate that the AMAX1 at the Prittlewell Gauge (August 2013) is between a 20% and 10% AEP event. The design flows do not match the Prittlewell gauge record however confidence in the measurement of flows is reduced by the bypassing of the gauge in events larger than the 20% AEP.
Describe any other checks on the results	QMED and 0.1% AEP flows applied in the hydraulic model and compared with no Tp adjustment. See Section 6.3.3..

7.5 Final results

The final peak flow results for use in the hydraulic model are provided in the table below. The storm duration is the 4.5hr recommended duration. This includes the appropriate Central and Higher Central allowances for climate change for the 2080s in the Combined Essex Management Catchment.

	Flood Peak (m^3s^{-1}) for the following return periods									
Site Code	50%	3.33	3.33+25%CC	3.33+38%CC	1%	1%+25%CC	1%+38%CC	0.1%	0.1%+25%CC	0.1%+38%CC
P1	3.3	7.8	10.1	11.3	10.2	13.2	14.9	18.8	25.0	28.4
P2	1.1	2.6	3.3	3.7	3.3	4.3	4.8	6.0	7.8	8.9
P3int	1.2	2.9	3.7	4.2	3.8	4.9	5.5	6.9	9.2	10.5
P3	4.7	11.2	14.4	16.1	14.5	18.9	21.2	26.7	35.4	40.2

7.6 Uncertainty bounds

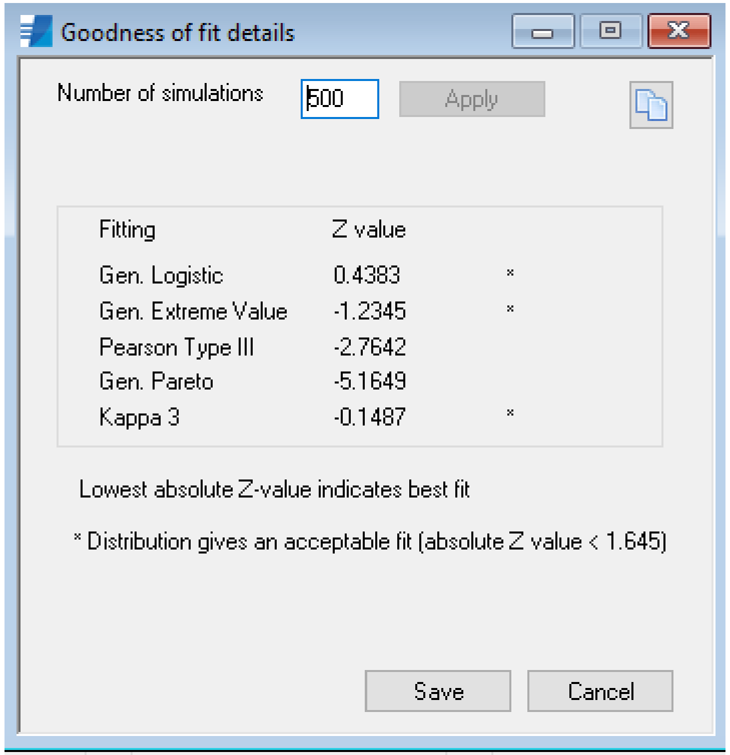
The final flow estimates are derived from ReFH2 and the uncertainty in peak flow estimates are not shown within the ReFH2 software. It is therefore not possible to provide uncertainty bounds. Wallingford HydroSolutions[7] found that the factorial standard errors from ReFH2 are comparable to those observed for the FEH pooled statistical method when the catchment is treated as ungauged.

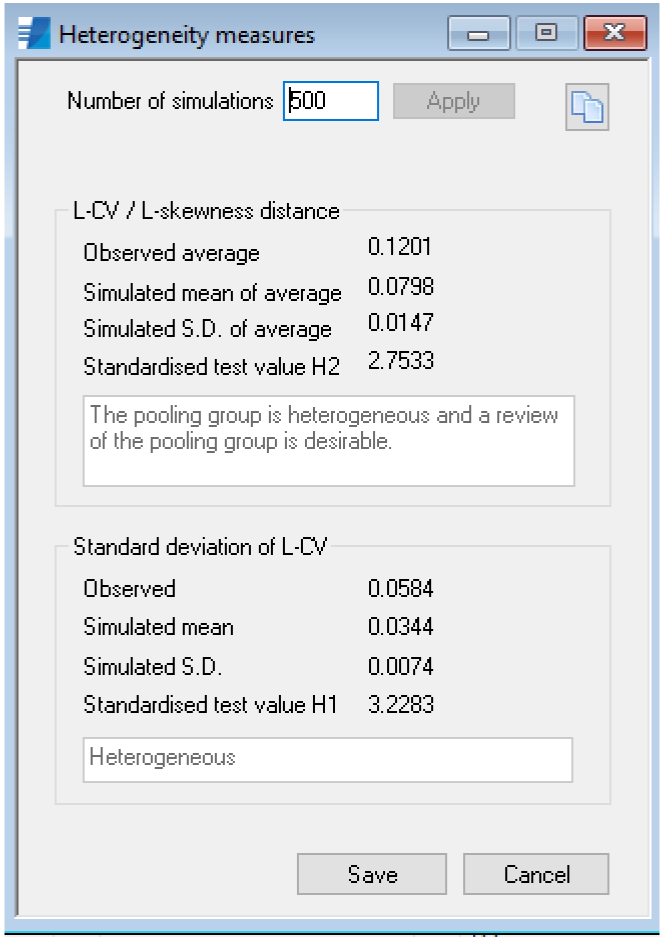
- [7] Wallingford HydroSolutions. (2019). ReFH2 Science Report: Evaluation of the Rural Design Event Model. WHS website

8 Annex A–WINFAP v5 Pooling Groups

8.1 Initial pooling group composition

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	*Comments*
23018 (Ouse Burn @ Woolsington)	0.598	31	3.265	0.296	0.177	0.177	
27073 (Brompton Beck @ Snainton Ings)	0.738	42	0.816	0.213	0.018	0.018	*High BFIHOST19 removed*
39055 (Yeading Brook West @ North Hillingdon)	0.836	20	4.236	0.341	0.162	0.162	
30013 (Heighington Beck @ Heighington)	1	46	0.648	0.38	0.422	0.422	*High BFIHOST19 removed*
26016 (Gypsey Race @ Kirby Grindalythe)	1.085	25	0.101	0.309	0.249	0.249	*High BFIHOST19 removed*
36010 (Bumpstead Brook @ Broad Green)	1.097	55	7.59	0.354	0.108	0.108	*Non-Flood Years >20% Removed*
68021 (Arrowe Brook @ Acton Lane)	1.124	16	3.997	0.287	0.42	0.42	
27081 (Oulton Beck @ Oulton Farrer Lane)	1.153	36	2.545	0.288	0.197	0.197	
27051 (Crimple @ Burn Bridge)	1.224	50	4.641	0.218	0.133	0.133	
36011 (Stour Brook @ Sturmer)	1.27	52	6.77	0.303	0.165	0.165	
25019 (Leven @ Easby)	1.287	44	5.384	0.341	0.366	0.366	
38020 (Cobbins Brook @ Sewardstone Road)	1.386	51	7.474	0.338	0.319	0.319	
39005 (Beverley Brook @ Wimbledon Common)	1.414	61	11.1	0.259	0.033	0.033	
Total		532					
Weighted means							

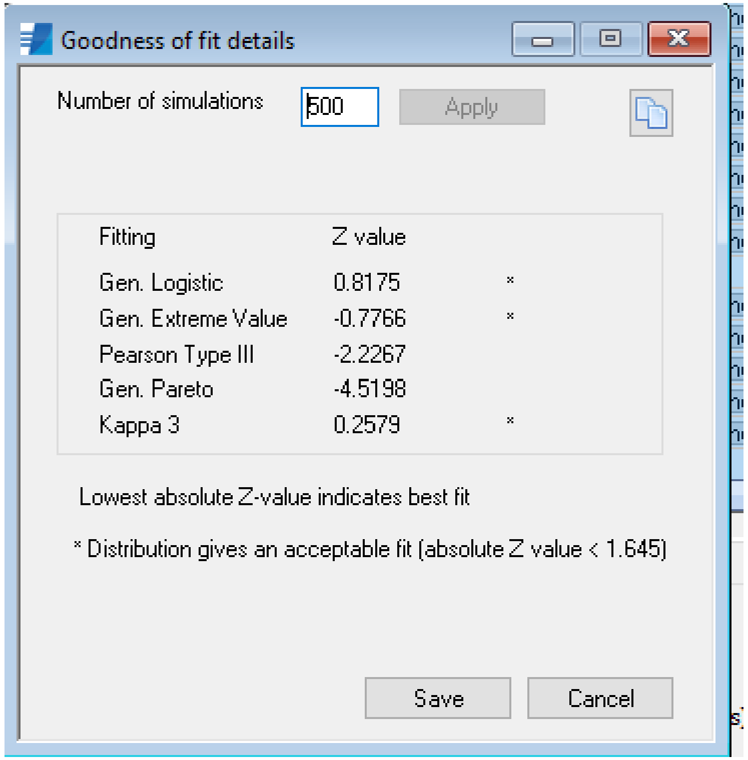

Goodness of fit details
Number of simulations
500
Apply
Fitting
Z value
Gen. Logistic
0.4383
*
Gen. Extreme Value
-1.2345
*
Pearson Type III
-2.7642
Gen. Pareto
-5.1649
Kappa 3
-0.1487
*
Lowest absolute Z-value indicates best fit
* Distribution gives an acceptable fit (absolute Z value < 1.645)
Save
Cancel

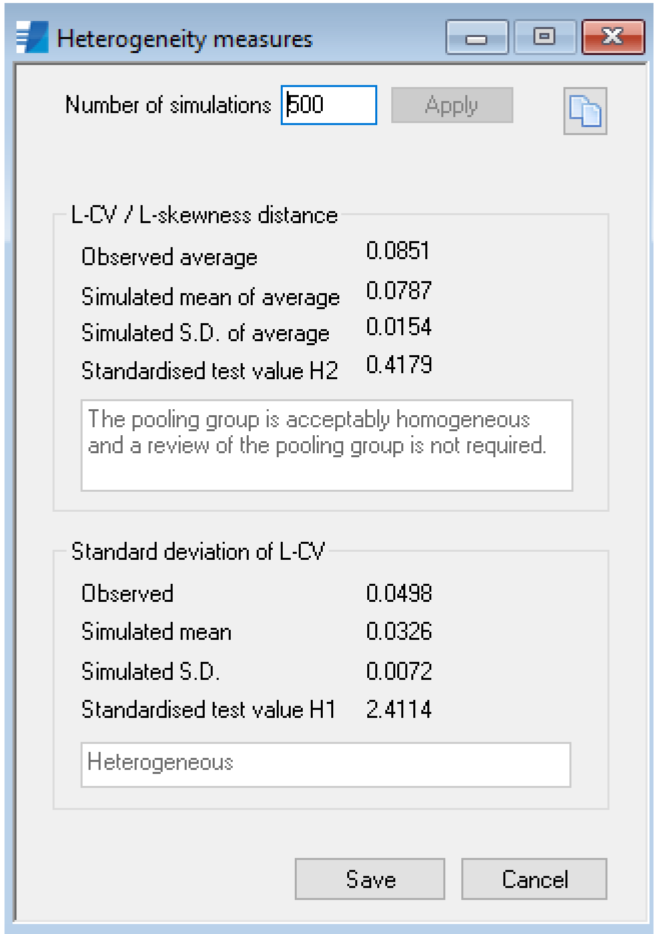

Heterogeneity measures
Number of simulations
500
Apply
L-CV / L-skewness distance
Observed average
0.1201
Simulated mean of average
0.0798
Simulated S.D. of average
0.0147
Standardised test value H2
2.7533
The pooling group is heterogeneous and a review of the pooling group is desirable.
Standard deviation of L-CV
Observed
0.0584
Simulated mean
0.0344
Simulated S.D.
0.0074
Standardised test value H1
3.2283
Heterogeneous
Save
Cancel

8.2 Final Pooling Group

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	*Comments*
23018 (Ouse Burn @ Woolsington)	0.598	31	3.265	0.296	0.177	0.108	
39055 (Yeading Brook West @ North Hillingdon)	0.836	20	4.236	0.341	0.162	1.031	
68021 (Arrowe Brook @ Acton Lane)	1.124	16	3.997	0.287	0.42	2.413	
27081 (Oulton Beck @ Oulton Farrer Lane)	1.153	36	2.545	0.288	0.197	0.077	
27051 (Crimple @ Burn Bridge)	1.224	50	4.641	0.218	0.133	0.618	
36011 (Stour Brook @ Sturmer)	1.27	52	6.77	0.303	0.165	0.769	
25019 (Leven @ Easby)	1.287	44	5.384	0.341	0.366	1.021	
38020 (Cobbins Brook @ Sewardstone Road)	1.386	51	7.474	0.338	0.319	1.422	
39005 (Beverley Brook @ Wimbledon Common)	1.414	61	11.1	0.259	0.033	1.379	
26014 (Water Forlornes @ Driffield)	1.418	24	0.431	0.319	0.184	1.722	
36004 (Chad Brook @ Long Melford)	1.571	55	4.807	0.302	0.175	0.758	
30006 (Slea @ Leasingham Mill)	1.596	37	1.84	0.314	0.198	0.671	
19017 (Gogar Burn @ Turnhouse)	1.636	30	12.77	0.206	0.196	1.01	
Total		532					
Rejected Stations							
27073 (Brompton Beck @ Snainton Ings)	0.738	42	0.816	0.213	0.018		
30013 (Heighington Beck @ Heighington)	1	46	0.648	0.38	0.422		

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	*Comments*
26016 (Gypsey Race @ Kirby Grindalythe)	1.085	25	0.101	0.309	0.249		
36010 (Bumpstead Brook @ Broad Green)	1.097	55	7.59	0.354	0.108		





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Appendix C – Benfleet Hall Brook FEH Calculation Record

AECOM

FEH Calculation Record

Castle Point SFRA – Benfleet Hall Brook

February 2025

Delivering a better world

1 Flood estimation calculation record

Introduction

This document provides a record of the calculations and decisions made during flood estimation for the Benfleet Hall Brook in April 2024. The information given here should enable the work to be reproduced in the future.

Contents

Approval

	Name	Position
Calculations prepared by:	Ralph Collard	Senior Flood Risk Engineer
Calculations checked by:	Rob Sweet	Associate
Calculations approved by:	Helen Judd	Associate

Revision History

Revision	Revision Date	Details	Authorised	Name	Position

Abbreviations

AEP	Annual exceedance probability
AM	Annual maximum
AREA	Catchment area (km^2)
BFI	Base flow index
BFIHOST	Base flow index derived using the HOST soil classification
CPRE	Council for the Protection of Rural England
DPLBAR	Mean drainage path length (km)
DTM	Digital Terrain Model
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FPEXT	Floodplain extent
FSR	Flood Studies Report
HOST	Hydrology of soil types
NRFA	National River Flow Archive
OS	Ordnance Survey
POT	Peaks over threshold
QMED	Median annual flood (with return period ~2 years)
ReFH1	Revitalised Flood Hydrograph 1 method (2005)
ReFH2	Revitalised Flood Hydrograph 2 method (2013)
SAAR	Standard average annual rainfall (mm)
SPR	Standard percentage run-off
SPRHOST	Standard percentage run-off 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
WINFAP	Windows Frequency Analysis Package – used for FEH statistical method

2 Summary

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

Catchment location	South Benfleet Brook, Essex
Purpose of study and scope	Hydrological flow estimate updates for the Benfleet Hall Brook model (9 inflows) to support the Castle Point SFRA
Key catchment features	Situated in Essex, the Benfleet Hall Brook is a small, urban catchment draining an area of 5.3km^2, including the majority of the South Benfleet urban area. The lower catchment is dominated by a flood storage area (FSA) and the urban area of South Benfleet. The modelled reach consists of two tributaries which converge at the FSA. The watercourse outfalls into the tidal Benfleet Creek, north of Canvey Island, through a flapped culvert.
Flooding mechanisms	The urban catchment is tidally locked and all runoff is stored within the South Benfleet FSA during this period. There is limited reporting of fluvial flooding within the catchment leading to the conclusions that the flooding is volume led rather than peak flow influenced
Gauged / ungauged	Ungauged
Final choice of method	ReFH2.3
Key limitations / uncertainties in results	Ungauged catchment with no calibration possible

2.1 Note on 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; both rows can be retained, or the relevant row can be retained and the other removed, depending on the requirement of the study.

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

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

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

3 Method statement

3.1 Overview of requirements for flood estimates and hydraulic modelling

Item	Comments
Give an overview which includes: • purpose of study including a short discussion if there is existing hydrology reports and estimates, when they were done and why we are updating the hydrology (e.g. new data or superseded methods) • approximate number and type of flood estimates required • peak flows and/or hydrographs? • range of design event AEPs (%) • climate change allowances (ref. relevant guidance)	This hydrological study provides an update to flow estimates undertaken in a previous 2014 JBA Essex Critical Ordinary Watercourse Modelling report[1] to provide inflows for the Benfleet Hall Brook model used as part of the Castle Point Borough Council SFRA. The 2014 JBA Benfleet Hall Brook analysis formed part of a wider study that was used for flood mapping of four former Critical Ordinary Watercourses in south-east Essex. The final choice of method was ReFHv1 for all watercourses and specifically using the urban version of ReFH for South Benfleet Brook. This allowed for design volume estimates and different routing times which are important in the urban and tidally influenced catchment. An update to the 2014 hydrology was considered required due to additional data and methods now being available for estimating flows within urban catchments. Furthermore, new climate change guidance[2] is in place and is required for this study. Flow estimates needed are 3.33% AEP, 1% AEP and 0.1% AEP with additional allowance for climate change using the central (+25%) and higher central (+38%) allowances for the 2080s in the Combined Essex Management Catchment. This is because the purpose is to update flood risk mapping for use within the Level 1 Strategic Flood Risk Assessment and therefore meets the requirements within the National Planning Policy Framework (NPPF) and associated Planning Practice Guidance (PPG) at the time of update (April 2024).

3.2 Project Scope

Item	Comments

Give an overview which includes:
 	
• Complexity of study e.g. simple, routine, moderate, difficult, very difficult?
• What analyses are required:
    • Rating reviews
    • Review of existing study
    • Simple/detailed flood history review
    • ReFH model parameter estimation
    • Joint probability
	This is a moderately complex study due the size (small) and urban nature of the catchment.

[1] JBA Consulting. (2014). *Essex Critical Ordinary Watercourse Modelling Final Report.* Environment Agency
[2] Environment Agency 2022, *Flood risk assessments: climate change allowances*. Accessed online at https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#peak-river-flow-allowances

3.3 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report. Include general catchment map and specific map of hydraulic model extents and inflow locations.	Situated in Essex, the Benfleet Hall Brook is a small, urban catchment draining an area of c.5.3km^2, including the majority of the South Benfleet urban area. Two tributaries flow in a southerly direction and meet at the South Benfleet Flood Storage Area. The larger eastern tributary drains the Boyce Hill Golf Course, is less urbanised and relatively steep, the western tributary catchment is heavily urbanised and assumed to be culverted upstream of the High Road. The lower catchment is relatively flat, dominated by a flood storage area (FSA) and contains mostly urban area of South Benfleet. The modelled reach consists of two tributaries which converge at the FSA. The watercourse outfalls into the tidal Benfleet Creek, north of Canvey Island, through a flapped culvert[1].
Previous Hydrology studies	2014 JBA Essex Ex-COWs

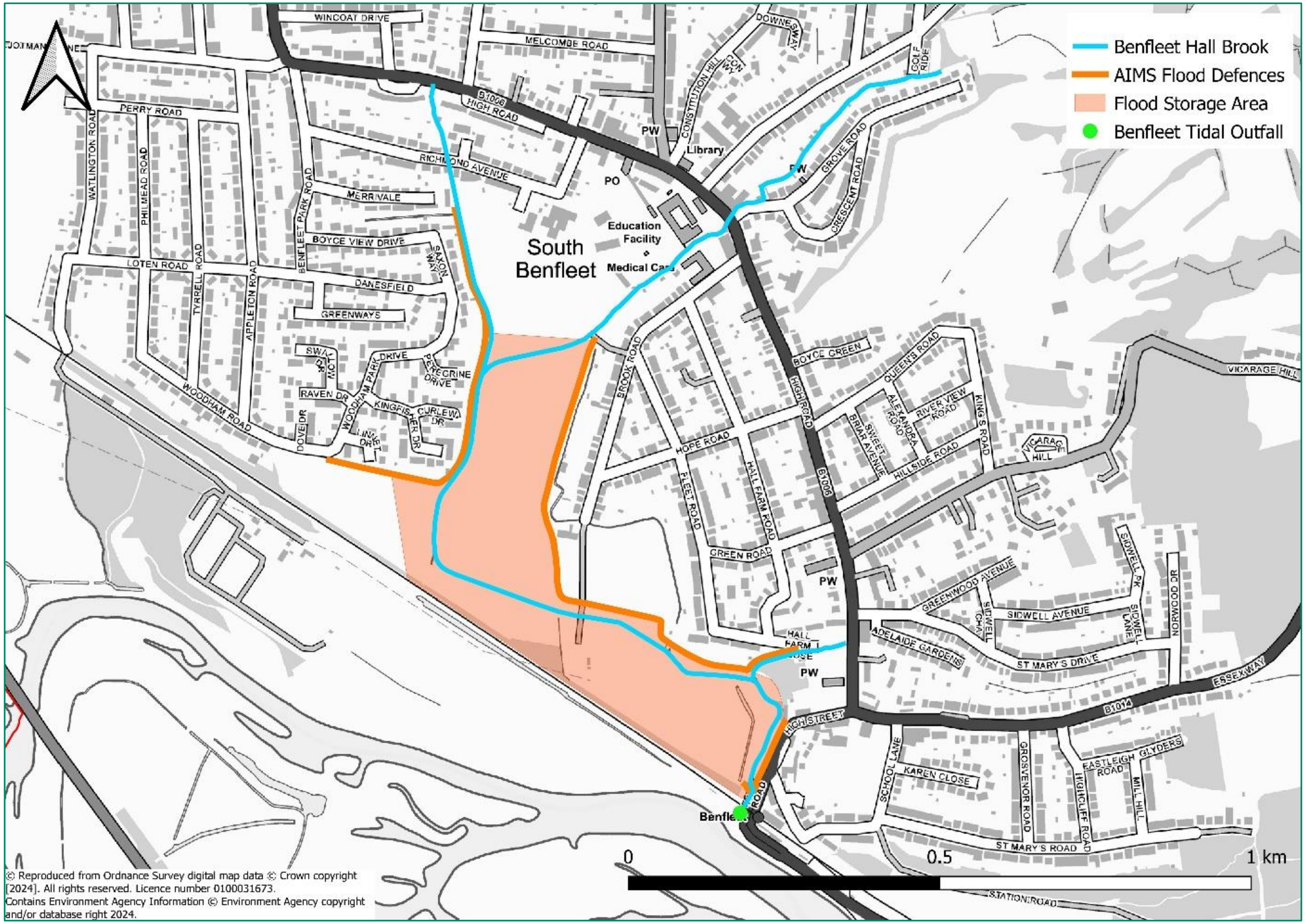


Figure 3-1: Benfleet Hall Brook Main River (Contains Ordnance Survey Data © Crown Copyright and database right 2024)

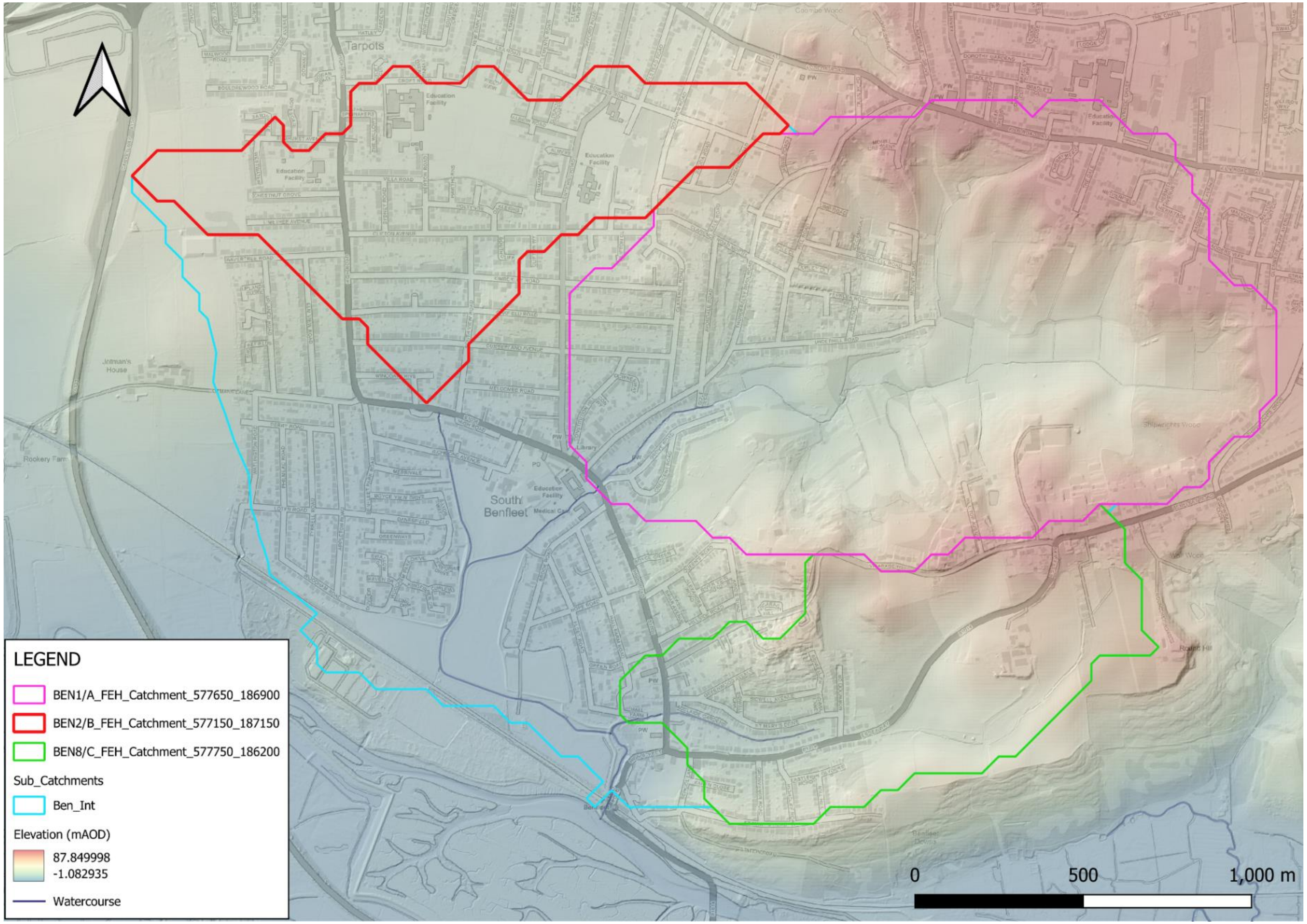


Figure 3-2: Benfleet Hall Brook Subcatchments (Contains Ordnance Survey Data © Crown Copyright and database right 2024).

3.4 Source of flood peak data

Item	Comments
Was the NRFA Peak Flows dataset used? If so, which version? If not, why not? Record any changes made.	NRFA peak flows dataset, Version 12.1, released November 2023. This contains data up to water year 2021-22.

3.5 Flood History

A range of sources have been used to identify the flood history associated with the Benfleet Hall Brook catchment. These include a review of the British Hydrological Society (BHS) Chronology of British Hydrological Events, information sourced from the Environment Agency, Essex County Council and Castle Point Borough Council and internet searches. Historic records within the vicinity of the site are highlighted in **bold.**

Date	Description	Source
20/10/2021	Heavy localised rainfall from Storm Aurore caused flash flooding within Benfleet Brook catchment. Over 50mm of rainfall fell across Benfleet and combined with high tides and blocked gullies the flooding was exacerbated. Primarily surface water flooding. This was estimated to be a 1 in 28yr event.	BMT 2022 Section 19 Flood Investigation Report for Castle Point
14/09/1968	Widespread flooding in the Benfleet area where 150mm of rainfall fell across Essex. 100 properties in Benfleet.	BMT 2022 Section 19 Flood Investigation Report for Castle Point Report from 'The Southend Standard' | Weather Events | Benfleet Community Archive (benfleethistory.org.uk)
31/01/1953	Tidal flooding caused by an extreme extratropical cyclone that coincided with high spring tides.	BMT 2022 Section 19 Flood Investigation Report for Castle Point

3.6 Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level)	Start of record and end if station closed
Eastwood Brook	Eastwood Brook@Eastwood		37033	9.85	rated	03/1974 - N/A
Crouch	Crouch@Wickford		37031	70.15	rated	01/1962 - N/A
Sandon Brook	Sandon Brook@Sandon Bridge		37013	74.70	rated	01/1963 - N/A
Wid	Wid@Writtle		37007	135.63	rated	01/1964 - N/A
Can	Can@Beach's Mill		37006	227.85	Rated	01/1960 - N/A
Ingrebourne	Ingrebourne@ Gaynes Park		37018	44.76	rated	01/1970 - N/A

3.7 Gauging stations (Rain)

Gauge name	ID number	Catchment area (km²)	Type (Daily/TBR)	Start of record and end if station closed
Benfleet Barrier	**E27621**		Daily	July 2000 – present
Rayleigh	**E24908**		Daily	July 2000 – present
Croppenburg	**E41311**		Daily	Sept 2014 - present
Scarhouse	**E46161**		Daily	Sept 2014 - present
East Haven Barrier	**E27601**		Daily	Mar 1999 - present

3.8 Data available at each flow gauging station

The following gauging stations were included as the nearest potential QMED donor stations to the Benfleet Brook Catchment. A check of the NRFA catchments was undertaken to determine the suitability for use in this study. Eastwood Brook @Eastwood is the nearest station and is considered suitable, therefore this is the recommended station based upon the small catchments approach.

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling?	Data quality check needed?	Other comments on station and flow data quality
Eastwood Brook@Eastwood	03/1974 - N/A	No	Yes	No	Yes	Heavily urbanised and very flashy catchment. Although not gauged to within 30% of QMED, rating form is confirmed by hydraulic modelling and expected perform well.. Review suggests ok to use.
Crouch@Wickford	01/1962 - N/A	No	Yes	No	Yes	Gauged above QMED. Urban influence
Sandon Brook@Sandon Bridge	01/1963 - N/A	No	Yes	No	Yes	Gauged above QMED. Responsive regime. Significant urban runoff from Billericay and Basildon. Low flows heavily influenced by STW discharge
Wid@Writtle	01/1964 - N/A	No	Yes	Yes	Yes	Gauged above QMED. Good fit to gaugings.
Can@Beach's Mill	01/1960 - N/A	No	Yes	No	Yes	Significant scatter just above QMED/bankfull but estimates thought to be reasonable.
Ingrebourne@ Gaynes Park	01/1970 - N/A	No	Yes	No	Yes	Gauged to within 27% of QMED.

3.9 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 (if planned rating review)	~~Yes~~ / No	~~Yes~~ / No	N/A	N/A
Rating equations	~~Yes~~ / No	~~Yes~~ / No	N/A	N/A
Historic flood data	Yes / ~~No~~	Yes / ~~No~~	EA/CPBC	Historic Flood Outlines, DG5 sewer flooding data
Flow or level data for events	~~Yes~~ / No	~~Yes~~ / No	EA	Ungauged catchment
Results from previous studies	Yes / ~~No~~	Yes / ~~No~~	EA	2014 Essex Ex-COWs 1D model results
Other information e.g. groundwater, tides etc	Yes / ~~No~~	Yes / ~~No~~	EA/Anglian Water	Model results/tides at DS boundary/Anglian Water Sewer Network

3.10 Hydrological understanding of the catchment

Conceptual model	Comments
Include information on factors such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (e.g. peak flows, flood volumes, combination of peaks, groundwater, snowmelt) • Might those locations flood from run-off generated on part of the catchment only e.g. locations located downstream of a reservoir? Is there a need to consider temporary debris dams that could collapse?	The urban areas of South Benfleet are the main areas of interest in this study. The South Benfleet Flood Storage Area stores water during high tide levels when the Benfleet Barrier is closed. There are limited records of fluvial flooding within the catchment and records show that recent flooding has been primarily surface water driven (October 2021). However, due to the tide locking of the flapped outfall during high tide there is potential that long duration storms may need to be stored within the catchment across multiple tide cycles leading to ponding behind the outfall. This means that the most likely flooding will be caused by flood volume rather than peak flow.
Any unusual catchment features to take into account? E.g. • Highly permeable (BFIHOST >0.65). Consider permeable adjustment for statistical method if SPRHOST <20% • Highly urbanised – consider FEH statistical or other alternatives; consider method that can account for differing sewer and topographic catchments	The catchment is highly urbanised (URBEXT2000 c. 0.3) with the upper west tributary catchment being heavily urbanised (URBEXT2000 c.0.43). Both the FEH Statistical and ReFH2 methodologies provide suitable urbanisation methods to estimate flows in this catchment.

Conceptual model	Comments
• Pumped watercourse – consider lowland version of rainfall-runoff method • Major reservoir influence (FARL<0.90) – consider flood routing • Extensive floodplain storage – consider choice of method carefully • Historical mining or operational mining activities	The South Benfleet Flood Storage Area is located at the downstream extent of the catchment where the Benfleet Hall Brook flows through the tidal outfall into Benfleet Creek. The FSA covers an area of approximately 0.16km². The tidal influence will mean thata 'check' flows flow estimation point at the downstream extent is not possible.

3.11 Initial choice of approach

Item	Comment
Is FEH appropriate? If not, describe why and give details of the other methods to be used.	Yes, both the FEH Statistical (small catchments approach) and ReFH2 approach can be applied. Given the significant urbanisation it will be important to apply the correct urban adjustment factors.
Initial choice of method(s) and reasons.	The catchment is volume led and therefore it is important to estimate runoff volumes as well as peak flow. The influence of the South Benfleet FSA and tidal influence of the Benfleet Creek means that locking of the downstream catchment will need to be considered. The influence of the FSA, tide locking and high urbanisation means that the ReFH2 methodology is more preferable.
How will hydrograph shapes be derived if needed? E.g. ReFH1, ReFH2 or average hydrograph shape from gauge data	ReFH2
Will the catchment be split into sub-catchments? If so, how?	Yes the catchment will be split into the same catchments as the 2014 Ex-COWs study. As a strategic scale modelling project it is not the intention to define the sub catchment descriptors The catchment is relatively uniform in character with high urbanisation. Instead an intervening area between Ben1, Ben2, Ben8 and Ben_DS (Outfall) will be delineated. An area weighting approach will then be applied to determine the ReFH2 hydrographs for the sub catchments defined in the 2014 Essex Ex-COWs
Software to be used (with version numbers)	FEH Web Service[3] / WINFAP 5[4] / ReFH2.3 / Flood Modeller Pro

[3] CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, UK.
[4] WINFAP 5 © Wallingford HydroSolutions Limited 2020.

4 Locations where flood estimates are required

4.1 Summary of subject sites

The table below lists the locations of subject sites.

Site Code	Type of Estimate (L – lumped catchment; S- Sub-catchment)	Watercourse	Site	Grid Reference	Area on FEH Web Service (km^2)	Revised area if altered
Ben_A	S	Benfleet Hall Brook	Upstream of FSA, eastern channel	577650, 186900	2.25	N/A
Ben_B	S	Benfleet Hall Brook	Upstream of FSA, western channel	577150, 187150	0.87	N/A
Ben_C	S	Benfleet Hall Brook	Tributary for east of FSA	577750, 186200	0.85	N/A
Ben_DS	L	Benfleet Hall Brook	Benfleet Hall Brook Outfall	577650, 185950	5.34	5.47
Ben_Int	S	Benfleet Hall Brook	Intervening area between Ben_DS and Ben_A, B & C	N/A	N/A	1.53

Reasons for choosing above locations	The first three locations were used in the 2014 Essex Ex-COWs study so this allows comparison with the previous hydrological study. They are upstream of the FSA and so are not as influenced by the FSA. Ben_DS will be used to determine flow to be split between

4.2 Important catchment descriptors at each subject site (original values from FEH Web Service)

Site Code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
Ben_A	1	0.27	0.248	1.45	90.4	557	48.94	0.2522	0.0178
Ben_B	1	0.27	0.217	0.82	33.6	583	50.61	0.4147	0.0434
Ben_C	1	0.27	0.267	1.03	88.4	548	48.19	0.2162	0.0059
Ben_DS	1	0.27	0.254	2.29	65.6	552	48.7	0.3039	0.0937
Ben_Int	1	0.27	0.254	N/A	N/A	552	48.7	0.4804	N/A

4.3 Checking catchment descriptors

Item	Comment
Record how catchment boundary was checked • Describe any changes • Refer to maps if required	Catchment boundary was checked against the 1m LiDAR DTM, Anglian Water sewer records and 1m contours. Overall the FEH catchment gives a reasonable representation of the catchment with some small areas where adjustments could be made. The Ben_DS catchment was extended to the west to improve the topographic/sewer catchment representation in this area. Sewer records were reviewed looking at surface water/combined sewer into the catchment. The records did not show significant differences in the import/export catchments. The previous 2014 study had extended the catchment to the north however on review of the sewer records there was no clear connection that could be identified. The catchments are small and therefore it is not considered that the import/export will impact the flow estimates significantly. For this reason it is assumed that the import/exports are balanced and no flow volume is increased/decreased as a consequence of the sewer network. Ben_Int is defined as the sub catchment between Ben_A, Ben_B, Ben_C and Ben_DS.
Record how other catchment descriptors were checked, especially soils • Describe any changes • Include a before and after table if required	Reviewed Soilscapes for the Benfleet Hall Brookcatchment which is predominately slow permeable clayey soil. This is consistent with the low BFIHOST19 values of 0.217 – 0.267 and high SPRHOST values of 48.19 – 50.61. The catchments are upstream of the FSA with negligible storage so a value of FARL = 1 is appropriate. No changes were made to catchment descriptors. For Ben_Int catchment descriptors were the same as Ben_DS because there is little variation across the sub catchments and they are considered representative. DPLBAR and DPSBAR were not estimated because plot scale equations will be used to estimate flows. FPEXT was not estimated because this is not required for ReFH2 calculations.
Source of URBEXT / URBAN	URBEXT2000 For Ben_Int the URBAN was estimated as the proportion of the catchment as urban on OS 1:50,000 mapping. URBEXT2000 was then estimated for Ben_Int using the calculations in FEH Volume 5 Section 6.5.5 and Bayliss and others (2007) URBEXT2000 = 0.629 URBAN
Method for updating URBEXT / URBAN • Refer to WINFAP v4 Urban Adjustment procedures / guidance	URBEXT2000 was updated to the present year (2024) using the following formula. • URBEXT2000 $UEF = 0.7851 + 0.2124\ \tan^{-1}\{(Year - 1967.5)/20.32\}$

Item	Comment
• CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000[5]	A review of the aerial photography indicated that the urban extents remain broadly similar to 2000 so no further update other than the UEF was required. A UEF of 1.045 was applied for the year 2024. It is noted that for Ben_DS URBEXT2000 was not increased with the increase in AREA because it is a relatively minor increase in catchment size.

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

Site Code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
Ben_A	1	0.27	0.248	1.45	90.4	557	48.94	**0.2637**	0.0178
Ben_B	1	0.27	0.217	0.82	33.6	583	50.61	**0.4335**	0.0434
Ben_C	1	0.27	0.267	1.03	88.4	548	48.19	**0.2260**	0.0059
Ben_DS	1	0.27	0.254	2.29	65.6	552	48.7	**0.3177**	0.0937
Ben_Int	1	0.27	0.254	N/A	N/A	552	48.7	**0.5022**	N/A

[5] http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD1919_5228_TRP.pdf#page=35

5 Statistical method

5.1 Application of Statistical method

What is the purpose of applying this method?	Comment
Summarise reasons specific to study, for example lumped estimates at key locations for purpose of checking modelled peak flows.	Peak flow estimates required at upstream locations to compare to previous study and provide estimation of flow into the catchment without the influence of the FSA. A peak flow estimate at the downstream extent of the catchment (Ben_DS) is required The Statistical method is not directly applicable to estimation of flows in the sub catchment Ben_Int and therefore has not been included in this section.

5.2 Overview of QMED method

What method of QMED estimation was used?	Comments
State method/s used to estimate QMED in study and why, for example gauged data, donor transfer, multiple donor transfer, flow variability, bankfull width or user defined.	The small catchments approach has been applied in accordance with the latest EA Flood Estimation Guidance. This is a small, heavily urbanised catchment and this approach is the most up to date methodology. A single donor site has been used to improve the estimate of QMED for the site.

Summary of QMED estimates at each site:

Site code	QMED rural (from CDs) (m^3s^{-1})	QMED urban (from CDs) (m^3s^{-1})	Final method	Final estimate of QMED urbanised (m^3s^{-1})
Ben_A	0.474	0.577	DA	0.927
Ben_B	0.213	0.289	DA	0.447
Ben_C	0.190	0.227	DA	0.358
Ben_DS	0.971	1.232	DA	1.939

Note: Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); DA – Donor Adjusted; CD – Catchment descriptors alone (with urban adjustment);

BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).

5.3 Search for donor sites for QMED

Comment on potential donor sites based on the above sections	Comments
• Number of potential donor sites available • Distances from subject site • Similarities in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data	Using the small catchment approach the single nearest donor catchment has been used to adjust QMED Heavily Urbanised site, URBEXT2000 threshold <0.5 URBEXT2000 37033 Eastwood Brook@Eastwood - This is a heavily urbanised catchment with similar AREA, BFIHOST19, FARL and SAAR to the subject sites. Distance to catchment is approximately 5km Retained

5.4 Donor transfers and QMED adjustment

The recommended small catchment approach defaults to a single donor in the donor transfer method embedded within WINFAPv5. This has been utilised and adjustment for urbanisation[6] has also been applied using the functionality within WINFAPv5.

The weighting of the donor catchment to provide the adjusted QMED is not provided within WINFAPv5 but is described within Kjeldsen et al 2014.

The QMED Catchment Descriptors and QMED Donor Adjusted values presented in the figures below are As-Rural estimates without the adjustment for urbanisation applied. See Section 5.2 for the final adjusted QMED value.

[6] Wallingford HydroSolutions (2020), WINFAP 5 Urban adjustment procedures, Wallingford HydroSolutions Ltd 2020.

Ben_A

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.474 — Donor Adjusted F.S.E.: 1.369

QMED Donor Adjusted: 0.761 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 [Apply]

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		Ben_A_FEH_CD_577650_186900_Adj @ TQ 776						
2	☑	37033 (Eastwood Brook @ Eastwood)	4.48	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	9.21	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	14.24	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	18.26	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	21.52	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	23.26	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	27.47	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	30.92	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	31.55	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	33.45	☑	10.800	**10.723**	10.551	10.476

Site of Interest — Selected Donor

OK | Cancel | Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.474 — Donor Adjusted F.S.E.: 1.369

QMED Donor Adjusted: 0.761 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 [Apply]

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Centroid X	Centroid Y	Area	SAAR	FARL	URBEXT2000	BFIHOST19	
1		Ben_A_FEH_CD_577650_1869(		578610	187323	2.245	557	1.000	0.264	0.248	
2	☑	37033 (Eastwood Brook @ Eastu	4.48	582810	188870	9.852	555	0.995	0.411	0.350	NRFA station
3	☐	37031 (Crouch @ Wickford)	9.21	570322	191348	70.147	571	0.969	0.244	0.246	NRFA station
4	☐	37013 (Sandon Brook @ Sandor	14.24	575426	201199	74.698	575	0.855	0.026	0.354	NRFA station
5	☐	37007 (Wid @ Writtle)	18.26	564210	198554	135.627	592	0.995	0.071	0.266	NRFA station
6	☐	37006 (Can @ Beach's Mill)	21.52	564069	203191	227.850	589	0.991	0.051	0.316	NRFA station
7	☐	37018 (Ingrebourne @ Gaynes F	23.26	555952	192584	44.735	594	0.985	0.166	0.311	NRFA station
8	☐	37019 (Beam @ Bretons Farm)	27.47	551364	190821	51.540	588	0.972	0.339	0.412	NRFA station
9	☐	37003 (Ter @ Crabbs Bridge)	30.92	573431	217810	77.757	570	0.994	0.012	0.445	NRFA station
10	☐	37001 (Roding @ Redbridge)	31.55	552213	204601	301.048	607	0.983	0.069	0.325	NRFA station
11	☐	37014 (Roding @ High Ongar)	33.45	558200	213825	92.645	597	0.986	0.008	0.376	NRFA station

Site of Interest — Selected Donor

OK | Cancel | Apply

Ben_B

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.213 — Donor Adjusted F.S.E.: 1.378

QMED Donor Adjusted: 0.330 — No. Donors: 1

Show: ◯ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 — Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		Ben_B_FEH_CD_577150_187150_Adj @ TQ 771						
2	☑	37033 (Eastwood Brook @ Eastwood)	5.68	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	7.80	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	13.57	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	16.92	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	20.29	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	21.83	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	26.05	☑	8.607	**6.269**	7.260	5.288
9	☐	37001 (Roding @ Redbridge)	30.17	☑	21.539	**20.288**	35.272	33.223
10	☐	37003 (Ter @ Crabbs Bridge)	30.30	☑	5.840	**5.769**	6.800	6.718
11	☐	37014 (Roding @ High Ongar)	32.28	☑	10.800	**10.723**	10.551	10.476

Site of Interest — Selected Donor

OK — Cancel — Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.213 — Donor Adjusted F.S.E.: 1.378

QMED Donor Adjusted: 0.330 — No. Donors: 1

Show: ◯ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 — Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Centroid X	Centroid Y	Area	SAAR	FARL	URBEXT2000	BFIHOST19	
1		Ben_B_FEH_CD_577150_18715		577237	187750	0.865	552	1.000	0.433	0.217	
2	☑	37033 (Eastwood Brook @ Eastw	5.68	582810	188870	9.852	555	0.995	0.411	0.350	NRFA station
3	☐	37031 (Crouch @ Wickford)	7.80	570322	191348	70.147	571	0.969	0.244	0.246	NRFA station
4	☐	37013 (Sandon Brook @ Sandor	13.57	575426	201199	74.698	575	0.855	0.026	0.354	NRFA station
5	☐	37007 (Wid @ Writtle)	16.92	564210	198554	135.627	592	0.995	0.071	0.266	NRFA station
6	☐	37006 (Can @ Beach's Mill)	20.29	564069	203191	227.850	589	0.991	0.051	0.316	NRFA station
7	☐	37018 (Ingrebourne @ Gaynes F	21.83	555952	192584	44.735	594	0.985	0.166	0.311	NRFA station
8	☐	37019 (Beam @ Bretons Farm)	26.05	551364	190821	51.540	588	0.972	0.339	0.412	NRFA station
9	☐	37001 (Roding @ Redbridge)	30.17	552213	204601	301.048	607	0.983	0.069	0.325	NRFA station
10	☐	37003 (Ter @ Crabbs Bridge)	30.30	573431	217810	77.757	570	0.994	0.012	0.445	NRFA station
11	☐	37014 (Roding @ High Ongar)	32.28	558200	213825	92.645	597	0.986	0.008	0.376	NRFA station

Site of Interest — Selected Donor

OK — Cancel — Apply

Ben_C

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.190 — Donor Adjusted F.S.E.: 1.373

QMED Donor Adjusted: 0.301 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		Ben_C_FEH_CD_577750_186200_Adj @ TQ 777						
2	☑	37033 (Eastwood Brook @ Eastwood)	4.97	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	9.63	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	15.19	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	18.84	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	22.22	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	23.44	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	27.55	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	31.89	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	32.05	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	34.20	☑	10.800	**10.723**	10.551	10.476

Site of Interest — Selected Donor

OK | Cancel | Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info — QMED Catchment Descriptors: 0.190 — Donor Adjusted F.S.E.: 1.373

QMED Donor Adjusted: 0.301 — No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED — URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Centroid X	Centroid Y	Area	SAAR	FARL	URBEXT2000	BFIHOST19	
1		Ben_C_FEH_CD_577750_1862(		578543	186329	0.850	548	1.000	0.226	0.267	
2	☑	37033 (Eastwood Brook @ Eastv	4.97	582810	188870	9.852	555	0.995	0.411	0.350	NRFA station
3	☐	37031 (Crouch @ Wickford)	9.63	570322	191348	70.147	571	0.969	0.244	0.246	NRFA station
4	☐	37013 (Sandon Brook @ Sandor	15.19	575426	201199	74.698	575	0.855	0.026	0.354	NRFA station
5	☐	37007 (Wid @ Writtle)	18.84	564210	198554	135.627	592	0.995	0.071	0.266	NRFA station
6	☐	37006 (Can @ Beach's Mill)	22.22	564069	203191	227.850	589	0.991	0.051	0.316	NRFA station
7	☐	37018 (Ingrebourne @ Gaynes F	23.44	555952	192584	44.735	594	0.985	0.166	0.311	NRFA station
8	☐	37019 (Beam @ Bretons Farm)	27.55	551364	190821	51.540	588	0.972	0.339	0.412	NRFA station
9	☐	37003 (Ter @ Crabbs Bridge)	31.89	573431	217810	77.757	570	0.994	0.012	0.445	NRFA station
10	☐	37001 (Roding @ Redbridge)	32.05	552213	204601	301.048	607	0.983	0.069	0.325	NRFA station
11	☐	37014 (Roding @ High Ongar)	34.20	558200	213825	92.645	597	0.986	0.008	0.376	NRFA station

Site of Interest — Selected Donor

OK | Cancel | Apply

Ben_DS

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info   QMED Catchment Descriptors: 0.971   Donor Adjusted F.S.E.: 1.374

QMED Donor Adjusted: 1.529   No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED   URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Use QMED Obs Deurbanised	QMED Obs	QMED Deurbanised	QMED CDs Urban	QMED CDs Rural
1		Ben_DS_FEH_CD_577650_185950_Adj @ TQ 7						
2	☑	37033 (Eastwood Brook @ Eastwood)	5.08	☑	5.057	**3.578**	1.896	1.342
3	☐	37031 (Crouch @ Wickford)	8.82	☑	14.771	**12.302**	10.396	8.658
4	☐	37013 (Sandon Brook @ Sandon Bridge)	14.34	☑	8.580	**8.378**	5.093	4.973
5	☐	37007 (Wid @ Writtle)	17.96	☑	14.612	**13.806**	19.152	18.096
6	☐	37006 (Can @ Beach's Mill)	21.32	☑	23.258	**22.266**	26.079	24.967
7	☐	37018 (Ingrebourne @ Gaynes Park)	22.76	☑	7.149	**6.229**	7.282	6.345
8	☐	37019 (Beam @ Bretons Farm)	26.94	☑	8.607	**6.269**	7.260	5.288
9	☐	37003 (Ter @ Crabbs Bridge)	31.06	☑	5.840	**5.769**	6.800	6.718
10	☐	37001 (Roding @ Redbridge)	31.20	☑	21.539	**20.288**	35.272	33.223
11	☐	37014 (Roding @ High Ongar)	33.29	☑	10.800	**10.723**	10.551	10.476

Site of Interest   Selected Donor

OK | Cancel | Apply

QMED rural estimation

Method | Donor Adjustment | Flow Variability

Target Info   QMED Catchment Descriptors: 0.971   Donor Adjusted F.S.E.: 1.374

QMED Donor Adjusted: 1.529   No. Donors: 1

Show: ○ All Sites ◉ Only sites suitable for QMED   URBEXT2000 < 0.5000 Apply

QMED Data | Suitability | Catchment Descriptors

		Station	Distance	Centroid X	Centroid Y	Area	SAAR	FARL	URBEXT2000	BFIHOST19	
1		Ben_DS_FEH_CD_577650_185		578046	187098	5.470	552	1.000	0.318	0.254	
2	☑	37033 (Eastwood Brook @ East	5.08	582810	188870	9.852	555	0.995	0.411	0.350	NRFA station
3	☐	37031 (Crouch @ Wickford)	8.82	570322	191348	70.147	571	0.969	0.244	0.246	NRFA station
4	☐	37013 (Sandon Brook @ Sandor	14.34	575426	201199	74.698	575	0.855	0.026	0.354	NRFA station
5	☐	37007 (Wid @ Writtle)	17.96	564210	198554	135.627	592	0.995	0.071	0.266	NRFA station
6	☐	37006 (Can @ Beach's Mill)	21.32	564069	203191	227.850	589	0.991	0.051	0.316	NRFA station
7	☐	37018 (Ingrebourne @ Gaynes F	22.76	555952	192584	44.735	594	0.985	0.166	0.311	NRFA station
8	☐	37019 (Beam @ Bretons Farm)	26.94	551364	190821	51.540	588	0.972	0.339	0.412	NRFA station
9	☐	37003 (Ter @ Crabbs Bridge)	31.06	573431	217810	77.757	570	0.994	0.012	0.445	NRFA station
10	☐	37001 (Roding @ Redbridge)	31.20	552213	204601	301.048	607	0.983	0.069	0.325	NRFA station
11	☐	37014 (Roding @ High Ongar)	33.29	558200	213825	92.645	597	0.986	0.008	0.376	NRFA station

Site of Interest   Selected Donor

OK | Cancel | Apply

5.5 Uncertainty in QMED

The estimation of QMED from the catchment descriptors alone is not advised. In particular, review of potential donor sites illustrates an under estimation of QMED using the catchment descriptor equation when compared with observed data. A review of local donor sites has been undertaken and a single donor adjustment has been applied using local stations. The influence of using a single donor site or multiple donor sites also reduces the Factorial Standard Error (F.S.E) when compared to using catchment descriptors only. The reduction in F.S.E for each site is illustrated in the following table. It should be noted that these provide adjusted QMED values (highlighted in **bold**) based on **rural** estimates only. An urban adjustment of QMED has been applied for the final QMED estimates and are reflected in Section 5.2..

Subject Site	F.S.E	Donor Adjusted F.S.E
Ben_A	1.431	1.369
Ben_B	1.431	1.378
Ben_C	1.431	1.373
Ben_DS	1.431	1.374

5.6 Derivation of pooling groups

Pooling groups were created within WINFAP v5 for the downstream catchment to the East Haven Creek Outfall. An URBEXT2000 threshold of 0.5 was used to create the pooling group in order to make maximum use of gauge data similar to the subject site. The Heterogeneity statistic (H2) for the pooling group was assessed; this provides an indication of whether a review of the pooling group is required (not required, optional, desirable or essential).

The similarity of the subject site against stations within the pooling group is assessed by the Similarity Distance Measure (SDM) and is a function of Area and SAAR (for the small catchments approach) or AREA SAAR, FARL and FPEXT (for catchments >40 km^2). However, it is good practice to review the pooling group to check other parameters e.g. BFIHOST and the history of the gauge, gauge record and rating quality on the NRFA website (https://nrfa.ceh.ac.uk/data/search).

As per the Environment Agency guidelines, modifications to the pooling group tend to have a relatively minor effect on the final design flow (compared with, for example, the selection of donor sites for QMED). Science Report SC050500[7] indicates that apart from the first four or five stations within a pooling group (i.e. lowest SDM), the record length at a station will only have a modest effect on its weight within the pooling group (unless the record is very short). The review of the pooling group has therefore focused on the first five stations within each pooling group, extending further where required to include stations that have moved up position following removal of others, gauges with a short record, and catchments which have extreme catchment descriptor values in comparison to the subject sites.

[7] Science Report SC050050: Improving flood frequency estimation (2008). https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/improving-the-flood-estimation-handbook-feh-statistical-index-flood-method-and-software

A new pooling method was introduced for small catchments through Science Report SC090031/R0[8]. This method is implemented in WINFAPv5.

The table below summarises the pooling group used in this study, with the initial pooling group provided Annex A. Annex A also notes the reasons for removing catchments from the initial pooling group and which stations were added into the pooling group to ensure that sufficient years of data (>500) were included in the final group.

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. Include any sites that were investigated but retained in the group	Weighted average L-moments (L-CV and L-skew before urban adjustment)
South Benfleet	Ben_DS	No	- Reviewed the top 5 pooling group. - Removed 27073 (Brompton Beck @ Snainton Ings), 30013 (Heighington Beck @ Heighington), 26016 (Gypsey Race @ Kirby Grindalythe) because of very high BFIHOST19 >0.8. - 68021 (Arrowe Brook @ Acton Lane) reviewed due of high discordancy. On review this is catchment has a relatively good similarity with Den_DS and so has been retained. - 26014 (Water Forlornes @ Driffield) has a high BFIHOST but is 9th in pooling group and considered not to have a significant effect on the results so left in. - Added 36004 (Chad Brook @ Long Melford) to ensure 500yr of data - Added 30006 (Slea @ Leasingham Mill) to ensure 500yr of data	L-CV = 0.299 L-skew = 0.208

The table below details the H2 score and requirement for pooling group review for in the initial and final pooling groups for each site

Catchment	Initial Pooling Group H2 value	Recommendation for Pooling Group Review	Final Pooling Group H2 value	Recommendation for Final Pooling Group Review
Ben_DS	2.8378	This pooling group is heterogeneous and a review of the pooling group is desirable	0.7261	The pooling group is acceptably homogenous and a review of the pooling group is not required.

[8] Science Report SC090031/R0: Estimating flood peaks and hydrographs for small catchments (Phase 2) (2024). https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/review-of-methodology-for-estimating-flood-peaks-and-hydrographs-for-small-catchments

5.7 Derivation of flood growth curves at subject sites

A single growth curve has been derived using the Ben_DS catchment and has been applied to the Flood Estimation Point (FEP) for the three sub catchments, Ben_A, Ben_B and Ben_C.

Site Code	Method (SS, P, ESS, FH)	If P, ESS or FH, 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 adjustment	Growth Curve Factor for 100 year return period
Ben_A	P	South Benfleet	Generalised Logistic recommended by WINFAP	Adjusted for urbanisation using WINFAPv5 small catchments approach	Location: 1.00 Scale:0.249 Shape: -0.255	3.348
Ben_B	P	South Benfleet	Generalised Logistic recommended by WINFAP	Adjusted for urbanisation using WINFAPv5 small catchments approach	Location: 1.00 Scale:0.249 Shape: -0.255	3.348
Ben_C	P	South Benfleet	Generalised Logistic recommended by WINFAP	Adjusted for urbanisation using WINFAPv5 small catchments approach	Location: 1.00 Scale:0.249 Shape: -0.255	3.348

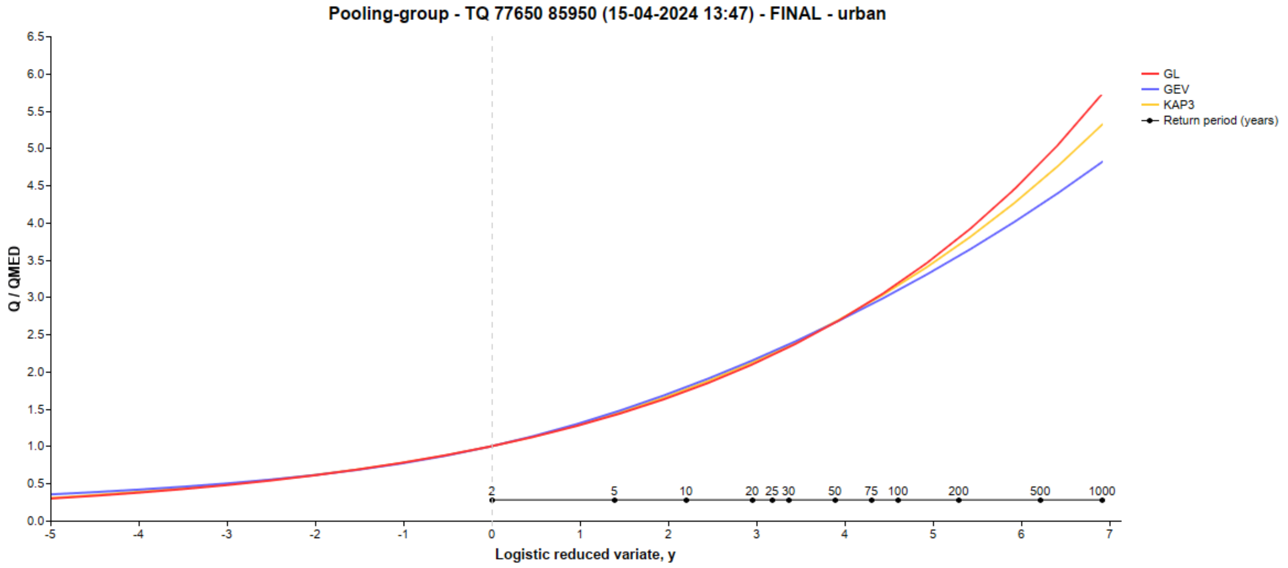


Figure 4.1: Comparison of growth curves using GL, GEV and PIII distributions.

Growth Curve Factors for the following return periods for Gl, GEV and PIII distributions for Benfleet Pooling Group

Distribution	2	5	10	20	30	50	75	100	1000
GL	1	1.414	1.734	2.094	2.33	2.66	2.953	3.179	5.719
GEV	1	1.453	1.791	2.148	2.368	2.661	2.907	3.089	4.809
PIII	1	1.43	1.76	2.122	2.353	2.67	2.944	3.151	5.308

Peak flows (m^3s^{-1}) estimated for the following return periods for each statistical distribution

Distribution	2	5	10	20	30	50	75	100	1000
GL	1.9	2.7	3.4	4.1	4.5	5.2	5.7	6.2	11.1

Distribution	Peak flows (m^3s^{-1}) estimated for the following return periods for each statistical distribution								
	2	5	10	20	30	50	75	100	1000
GEV	1.9	2.8	3.5	4.2	4.6	5.2	5.6	6.0	9.3
PIII	1.9	2.8	3.4	4.1	4.6	5.2	5.7	6.1	10.3

5.8 Flood estimates from the statistical method

QMED estimated using small catchment approach and single donor adjustment and adjusted using UAF at site location. The Benfleet growth curve using GL has been applied to all three sub catchments because it is considered to be representative of the catchment as a whole.

Site Code	Flood Peak (m^3s^{-1}) for the following return periods								
	2	5	10	20	30	50	75	100	1000
Ben_A	0.9	1.3	1.6	1.9	2.2	2.5	2.7	2.9	5.3
Ben_B	0.4	0.6	0.8	0.9	1.0	1.2	1.3	1.4	2.6
Ben_C	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.1	2.0

6 Revitalised flood hydrograph (ReFH2) method

6.1 Application of ReFH2 model

What is the purpose of applying this method?	Comment
Summarise reasons specific to study, for example: lumped estimates at key locations for the purpose of checking modelled peak flow estimates, distributed approach to apply inflows to a hydraulic model, deriving hydrograph shapes only, extending the flood frequency curve out to extreme events (long return periods).	A distributed approach is required to estimate flood hydrographs within 9 sub catchments upstream of the South Benfleet FSA as inputs to the hydraulic model. Flow estimates are applied at key sewer outfalls and will be routed in the Benfleet Hall Brook using the hydraulic model. This is important as the influence of the tidal boundary and downstream FSA means that comparisons of in channel flow estimates are not suitable for comparison. Peak flow estimates will be compared at the upstream The location of the inflows will be retained from the 2014 Essex Ex-COWs study for comparison.

6.2 Catchment sub-divisions in urban ReFH2 model

The Benfleet Hall Brook catchment is heavily urbanised with Ben_DS URBEXT2000 >0.3 and some of the sub catchments being URBEXT2000 >0.4.

The previous 2014 Essex Ex-COWs study defined 9 sub catchments based on primary sewer outfalls to Benfleet Hall Brook using the ReFH Urban methodology and defined the rural catchment, defined the sewer catchments within the natural watershed and then the sewer catchments draining into and out of the natural watershed via the surface water and combined sewer networks. Subsequent research has led to the urban extension model being incorporated into ReFH2 and improved.

The definition of the urban catchments in the 2014 Ex-COWs study are not clear and on reviewing the topographic and sewer catchments it has not been possible to identify analogous sub catchments. As such it has been decided to use a simplified approach to define the urban sub catchments. This is to use the three upper catchments Ben1, Ben2 and Ben8 as per the FEH defined for inflows and a single intervening area split by area weighting for the remaining 5 catchments.

Reviewing the sewer catchments does not show any significant sewers which are draining into or out of the natural topographic catchments and as this is a relatively small catchment this is not expected to have a significant impact on the estimated flows. As such it is assumed that the import/export by sewers is balanced. Figure 3-2 shows the defined sub catchments

For Ben_Int URBEXT2000 was estimated using the URBAN50k and converting to URBEXT2000. All other urban extents were calculated from URBEXT2000 in ReFH2.

A check has been undertaken on the sensitivity to Tp urban, IF and IRF for Ben1, 5.5hr, 1% AEP using ReFH2 as this has a relatively large URBEXT2000 value. This shows that the peak flow is not sensitive to these parameters and it is not necessary to invest significant time to refine the Tp's.

	Peak Flow Default settings (m^3/s)	Peak Flow +20% Parameter (m^3/s)	Peak Flow -20% Parameter (m^3/s)
Tp Scaling Factor (Default = 0.75)		4.45	4.71
IRF (Default = 0.7)	4.58	4.62	4.59
IF (Default = 0.4)		4.61	4.57

6.3 Parameters for ReFH2 model

The parameters have been derived from catchment descriptors for all catchments. It is noted that Ben_Int has been derived using plot scale equations.

Site Code	Details of Method OPT: Optimisation BR: base flow recession fitting CD: catchment descriptors DT: Data Transfer	Tp_{rural} (hours) Time to peak	Tp_{urban} (hours) Time to peak	C_{max} (mm) Maximum storage capacity	IRF (% runoff for impermeable surfaces)	BL (hours) Base flow lag	BR Base flow recharge (QMED)
Ben1	CD	2.521	1.891	222.831	0.7	26.257	0.717
Ben2	CD	2.491	1.868	205.591	0.7	21.385	0.459
Ben8	CD	2.088	1.566	234.104	0.7	25.486	0.909
Ben_DS	CD	3.625	2.719	226.331	0.7	29.433	0.777
Ben_Int	CD(Plot Scale)	3.782	2.837	226.331	0.7	30.58	0.777
Brief description of any flood event analysis undertaken: Provide further details here or in a project report	None undertaken as site is ungauged						

6.4 Design events for ReFH2 method: Lumped catchments

A flow estimate has been undertaken at Ben_DS as a check on the volume and peak flow described for the sub catchments.

Site Code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Source of design rainfall statistic (FEH22, FEH13 or FEH99)
Ben_DS	Urban	Summer	5.5	FEH22

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

Design events for the sub catchments have initially been set to the 5.5hr storm, consistent with the recommended storm duration for Ben_DS. The Areal Reduction Factor and Seasonal Correction factor for the subcatchments has been set to be the same as Ben_DS and is to be kept consistent for all storm durations and events.

Areal Reduction Factor 0.962 Used for all storms

Seasonal correction Factor 0.993

Site Code	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area	Reason for selecting storm	Source of design rainfall statistic (FEH22, FEH13 or FEH99)
Ben1	Summer	5.5	Same as Ben_DS	Heavily urbanised, Summer Storm consistent with the recommended small catchments approach. Duration same as the recommended wider catchment Ben_DS	FEH22
Ben2	Summer	5.5	Same as Ben_DS	Heavily urbanised, Summer Storm consistent with the recommended small catchments approach. Duration same as the recommended wider catchment Ben_DS	FEH22
Ben8	Summer	5.5	Same as Ben_DS	Heavily urbanised, Summer Storm consistent with the recommended small catchments approach. Duration same as the recommended wider catchment Ben_DS	FEH22
Ben_Int	Summer	5.5	Same as Ben_DS	Heavily urbanised, Summer Storm consistent with the recommended small catchments approach. Duration same as the recommended wider catchment Ben_DS	FEH22
Results of storm duration testing	Critical storm duration testing is not within the scope of the study and the recommended storm duration for Ben_DS will be used				

6.6 Flood estimates from the ReFH2 method

- Please indicate whether you have used urban or rural results
- We recommend that urban results are used regardless of the extent of urbanisation at the subject sites to avoid discontinuity when URBEXT reaches a given threshold.

As per the Technical Guidance Document: ReFH 2.3, the urban results are reported in the table below. These results take account of the urban extent within the catchment based on URBEXT2000 and are considered representative of existing conditions.

It is noted that the total peak flow to the downstream catchment is less than the combination of the upper three catchments plus the intervening catchment. A check has been completed on the volumes for the 3.33% AEP event which shows that the volume is also less than the combination of the upper catchmnets (c.50ML). This is likely to be caused by the higher URBEXT2000 values for the upper catchment resulting in a larger volume of runoff.

	Flood Peak (m^3s^{-1}) for the following return periods									
Site Code	**50%**	**3.33**	**3.33+25%CC**	**3.33+38%CC**	**1%**	**1%+25%CC**	**1%+38%CC**	**0.1%**	**0.1%+25%CC**	**0.1%+38%CC**
Ben1	2.1	4.8	6.2	6.9	6.3	8.2	9.2	11.9	15.6	17.5
Ben2	1.0	2.3	2.9	3.2	3.0	3.8	4.3	5.5	7.0	7.9
Ben8	0.8	1.9	2.4	2.7	2.5	3.2	3.6	4.7	6.2	7.0
Ben_Int	1.2	2.7	3.5	3.9	3.5	4.6	5.1	6.6	8.6	9.7
Ben_DS	3.9	9.0	11.5	12.9	11.8	15.3	17.2	22.3	29.2	32.9

7 Discussion and summary of results

7.1 Comparison of results from different methods

This table compares peak flows from the ReFH2 method with those from the FEH Statistical method (donor adjusted inclusive of urbanisation) at each site for two key return periods. This illustrates that flow estimates from the FEH statistical method are approximately 52% to 58% less than those derived using ReFH2. This is primarily due to the variation in the estimate of QMED between the FEH Statistical and ReFH2 methodologies.

	Return period 2 years (50% AEP)			Return Period 100 years (1% AEP)		
Site Code	Statistical	ReFH2	Ratio (ReFH2/Statistical)	Statistical	ReFH2	Ratio (ReFH2/Statistical)
Ben1	0.9	2.1	2.3	2.9	6.3	2.2
Ben2	0.4	1.0	2.5	1.4	3.0	2.1
Ben8	0.4	0.8	2.0	1.1	2.5	2.3
Ben_DS	1.9	3.9	2.1	6.2	11.8	1.9

7.2 Final choice of method

Choice of method and reason Include reference to type of study, nature of catchment and type of data available	The ReFH2 is the final method for South Benfleet Brook. Flood risk in the catchment is more volume led due to the tidal locking of the outfall and storage within the FSA which favours the rainfall runoff approach. The catchment is ungauged and urban component of ReFH2 provides a good estimate of the different sub catchment responses in a heavily urban environment. The recommended storm duration for 5.5hrs for the catchment to the Benfleet Hal Brook tidal outfall will be used. This is much shorter than the previous study which suggested 25.1hrs is the critical storm duration. This was rejected because using a storm duration so much larger than the recommended duration may generate an over estimation of flows.
How will the flows be applied to a hydraulic model?	Ben1, Ben2 and Ben8 will be applied as direct inflows. Ben_Int will be split between a further 6 inflows using an area weighting.

7.3 Assumptions, limitations, and uncertainty

List the main assumptions made specific to the study	There are no significant inflows/outflows into the catchment due to the sewer network and the sewer network provides a balanced flow into and out of each of the sub catchments. Assumes that the urban hydrograph Tp value is 0.75. Catchment descriptors are suitable for the estimation of flows as no hydrometric data is available to calibrate the hydrological model. There is no pumping of the catchment. Assumes that peak flow estimates are not impacted by the FSA at the downstream of the catchment. The flood hydrograph for Ben_Int is representative of the response for each of the sub catchments that it will be used as an inflow for. ReFH2 Plot scale equations are appropriate for the Ben_Int catchment estimates. The recommended storm duration for the Ben_DS catchment is sufficient to match all
Discuss any particular limitations For example applying methods outside the range of catchment types or return periods for which they were developed	The main limitation is that the catchment is ungauged and therefore there can be no calibration of the ReFh2 hydrological model
Give what information you can on uncertainty in the design peak flows or in the methodology For example using the methods detailed in 'Making better use of local data in flood frequency estimation' - Science Report SC130009/R	The small catchments approach found that ReFH2 gave a lower factorial standard error than the FEH Statistical when estimating QMED on small catchments
Comment on the suitability of the results for future studies For example at nearby locations or for different purposes	These flow estimates are suitable for the Level 1 SFRA only
Give any other comments on the study For example suggestions for additional work	Recommended that hydrometric data is collected along the Benfleet Hall Brook watercourse to improve flow estimates

7.4 Checks

Are the results consistent, for example at confluences?	It is noted that the total peak flow to the downstream catchment is less than the combination of the upper three catchments plus the intervening catchment. A check has been completed on the volumes for the 3.33% AEP event which shows that the volume is also less than the combination of the upper catchmnets (c.50ML). This is likely to be caused by the higher URBEXT2000 values for the upper catchment resulting in a larger volume of runoff.
What do the results imply regarding the return periods / frequency of floods during the period of record?	There are no gauges to verify results against the period of record. The 3.33% AEP is the closest to the Oct 2021 event and this shows no fluvial flooding
What is the 100-year (1% AEP) growth curve factor? Is this realistic? (The guidance suggests a typical range of 2.1 – 4.0)	The ReFH2 1% growth factor is c. 3-3.1 across the sub catchments. This is within the expected range.
If 1000 year (0.1% AEP) flows have been derived, what is the range of ratios for the 1000-year (0.1% AEP) flow over the 100-year (1% AEP) flow?	c. 1.89 for Ben_DS. And lies within the expected range
What is the range of specific run-offs (l/s/ha) do the results equate to? Are there any inconsistencies?	For ReFH2 QMED and 1% AEP the specific runoff is broadly consistent. Ben2 has a higher specific runoff than the other catchments but this has a relatively high URBEXT2000 value

Catchment	QMED (l/s/ha)	1% AEP
Ben1	9.1	27.2
Ben2	11.1	33.4
Ben8	9.4	29.4
Ben_Int	7.9	23.2
Ben_DS	7.1	21.6

How do the results compare with those of other studies? Explain the difference and conclude which results should be preferred	The AECOM 2024 estimates are shown to be approximately 100% greater than the flow estimates within the 2014 Essex Ex-COWs study. The 2014 study uses a very long duration storm of 25.5hrs. It is likely that the long duration storm has lower intensity/lower flood depths/velocities in the developed part of the catchment because the rainfall depth is spread across a longer period of time. The Level 1 SFRA is interested in the developed parts of the catchment and therefore a shorter storm duration is preferable to understand flood patterns from higher intensity events. Improvements in the FEH methodologies including the ReFH2 urban model, improvements in small catchment estimation, new FEH22 DDF and improved length of record since the previous estimates should provide increased confidence in flow estimates. Based upon the above the AECOM flow estimates are considered to be more robust. They also provide a more conservative flow estimate as the peak flows are higher.

Catchment	2014 50%	AECOM 50%	2014 1%	AECOM 1%	2014 0.1%	AECOM 0.1%
Ben1	1.2	2.1	3.4	6.3	6.5	11.9
Ben2	0.5	1.0	1.6	3.0	3.5	5.5
Ben8	0.3	0.8	0.9	2.5	2.0	4.7

Are the results compatible with the longer-term flood history?	The 3.33% AEP event shows limited flooding and water is contained mainly within channel. This is consistent with the October 2020 flood event.
Describe any other checks on the results	

7.5 Sub-catchments

The Ben_Int catchment has been split into 6 further sub-catchments to match the 2014 model inflows as shown in Figure 7-1. The ReFH2 Ben_Int hydrograph has been split using area weighting scaling for these remaining model 6 inflow locations. The Area Weighting that has been applied to the sub catchments is shown in the table below.

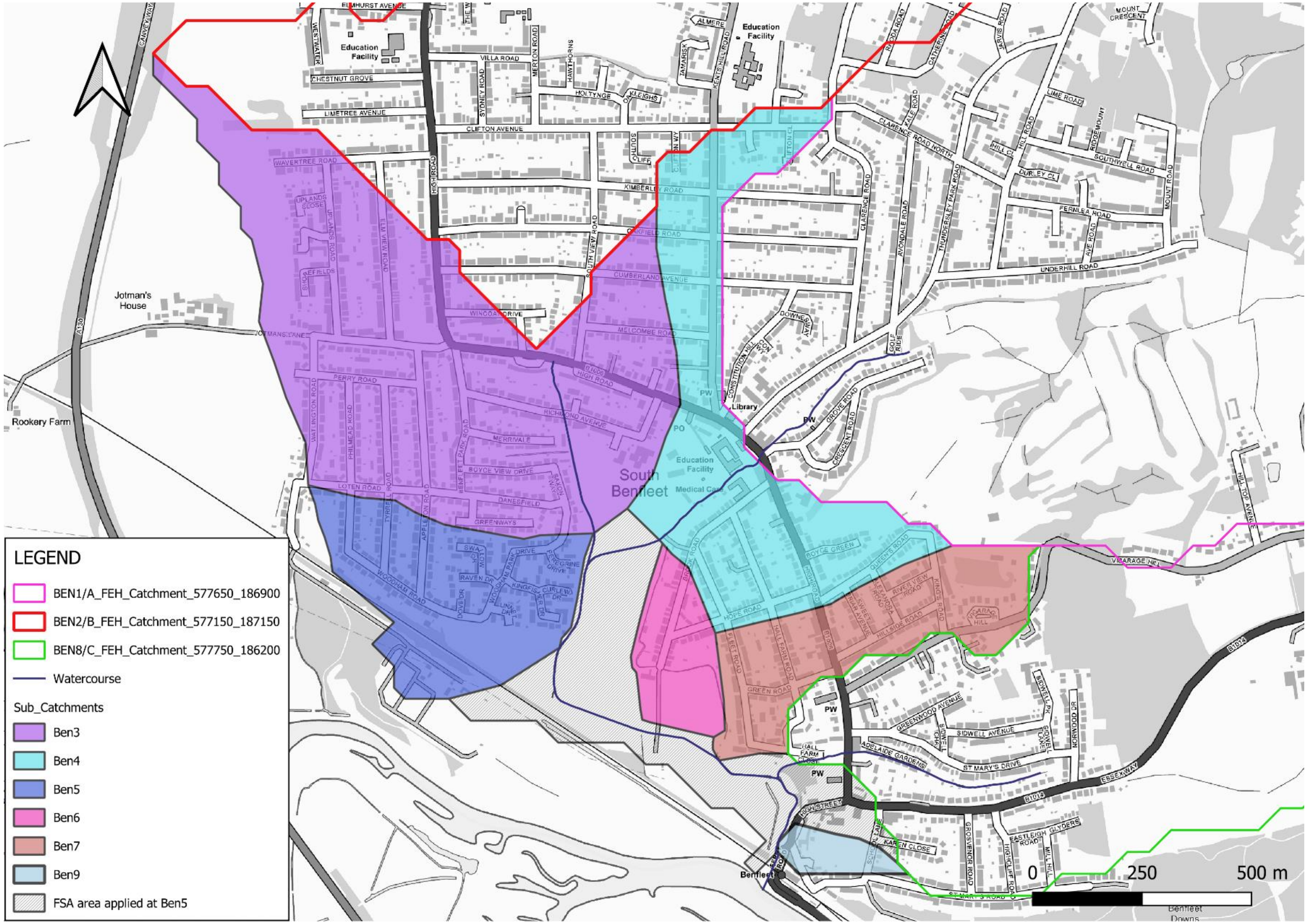


Figure 7-1: Splitting of Ben_Int Sub-catchments(Contains Ordnance Survey Data © Crown Copyright and database right 2024)

Sub-catchment	Area of Ben_Int (km^2)	Sub-catchment Area (km^2)	Area-Weighting of flows
Ben3	1.528	0.60	0.39
Ben4		0.29	0.19
Ben5		0.19 (+0.205 for FSA Areas applied at Ben5)	0.26
Ben6		0.06	0.04
Ben7		0.16	0.10
Ben9		0.03	0.01

7.6 Final results

The final peak flow results for use in the hydraulic model are provided in the table below. The storm duration is the 5.5hr recommended duration. This includes the appropriate Central and Higher Central allowances for climate change for the 2080s in the Combined Essex Management Catchment.

	Flood Peak (m^3s^{-1}) for the following return periods									
Site Code	**50%**	**3.33**	**3.33+25%CC**	**3.33+38%CC**	**1%**	**1%+25%CC**	**1%+38%CC**	**0.1%**	**0.1%+25%CC**	**0.1%+38%CC**
Ben1	2.1	4.8	6.2	6.9	6.3	8.2	9.2	11.9	15.6	17.5
Ben2	1.0	2.3	2.9	3.2	3.0	3.8	4.3	5.5	7.0	7.9
Ben8	0.8	1.9	2.4	2.7	2.5	3.2	3.6	4.7	6.2	7.0
Sub-catchments										
Ben3	0.5	1.1	1.4	1.5	1.4	1.8	2.0	2.6	3.4	3.8
Ben4	0.2	0.5	0.7	0.8	0.7	0.9	1.0	1.3	1.7	1.9
Ben5	0.3	0.7	0.9	1.0	0.9	1.2	1.3	1.7	2.2	2.5
Ben6	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.3	0.4	0.4
Ben7	0.1	0.3	0.4	0.4	0.4	0.5	0.5	0.7	0.9	1.0
Ben9	0.02	0.04	0.05	0.06	0.05	0.07	0.07	0.10	0.12	0.14
Ben_Int	1.2	2.7	3.5	3.9	3.5	4.6	5.1	6.6	8.6	9.7

7.7 Uncertainty bounds

The final flow estimates are derived from ReFH2 and the uncertainty in peak flow estimates are not shown within the ReFH2 software. It is therefore not possible to provide uncertainty bounds. Wallingford HydroSolutions[9] found that the factorial standard errors from ReFH2 are comparable to those observed for the FEH pooled statistical method when the catchment is treated as ungauged.

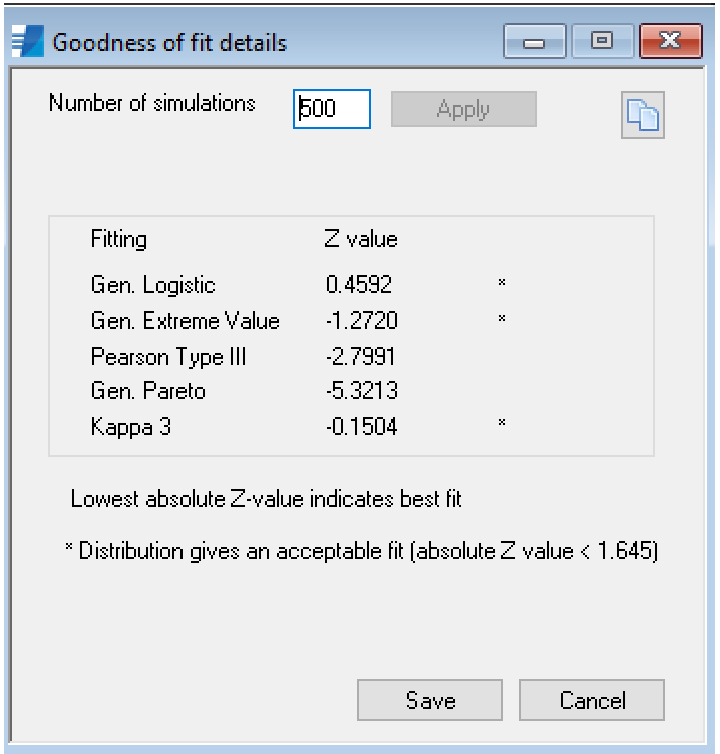
- [9] Wallingford HydroSolutions. (2019). ReFH2 Science Report: Evaluation of the Rural Design Event Model. WHS website

8 Annex A–WINFAP v5 Pooling Groups

8.1 Initial pooling group composition

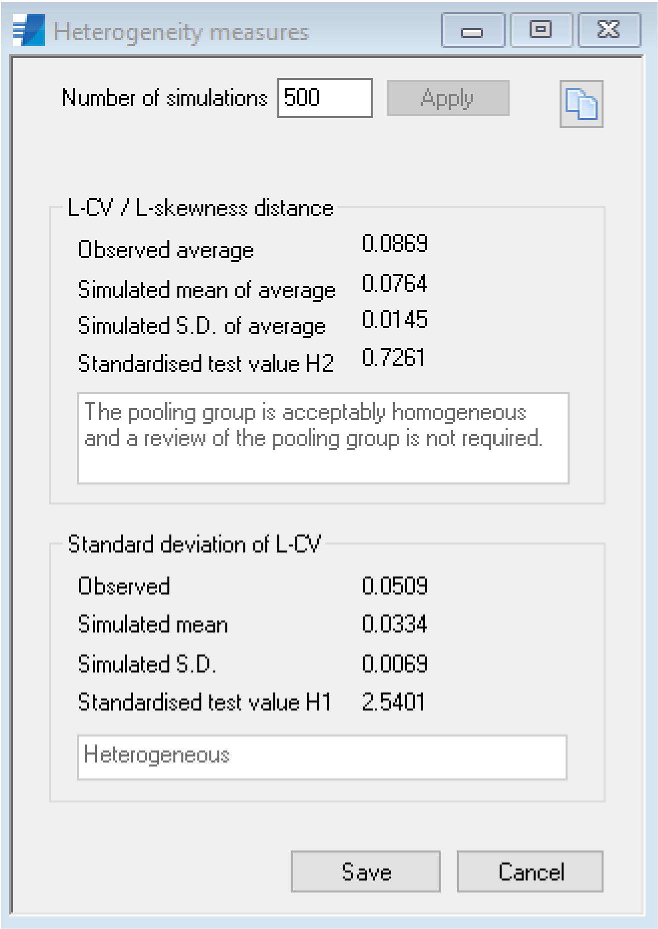
Station	Distance	Years of data	QMED AM	L-CV (Deurbanised(	L-SKEW (Deurbanised)	Discordancy	*Comments*
23018 (Ouse Burn @ Woolsington)	0.739	31	3.265	0.296	0.177	0.031	
27073 (Brompton Beck @ Snainton Ings)	0.824	42	0.816	0.213	0.018	1.044	*High BFIHOST19 removed*
30013 (Heighington Beck @ Heighington)	1.195	46	0.648	0.380	0.422	1.268	*High BFIHOST19 removed*
26016 (Gypsey Race @ Kirby Grindalythe)	1.236	25	0.101	0.309	0.249	0.077	*High BFIHOST19 removed*
68021 (Arrowe Brook @ Acton Lane)	1.284	16	3.997	0.287	0.420	2.401	
36010 (Bumpstead Brook @ Broad Green)	1.292	55	7.590	0.354	0.108	1.741	*Non-Flood Years >20% Removed*
27051 (Crimple @ Burn Bridge)	1.293	50	4.641	0.218	0.133	0.622	
27081 (Oulton Beck @ Oulton Farrer Lane)	1.340	36	2.545	0.288	0.197	0.186	
25019 (Leven @ Easby)	1.418	44	5.384	0.341	0.366	0.592	
36011 (Stour Brook @ Sturmer)	1.465	52	6.770	0.303	0.165	0.948	
38020 (Cobbins Brook @ Sewardstone Road)	1.581	51	7.474	0.338	0.319	1.132	
26014 (Water Forlornes @ Driffield)	1.602	24	0.431	0.319	0.184	1.673	*High BFIHOST19 removed*
39005 (Beverley Brook @ Wimbledon Common)	1.609	61	11.100	0.259	0.033	1.286	
Total		533					

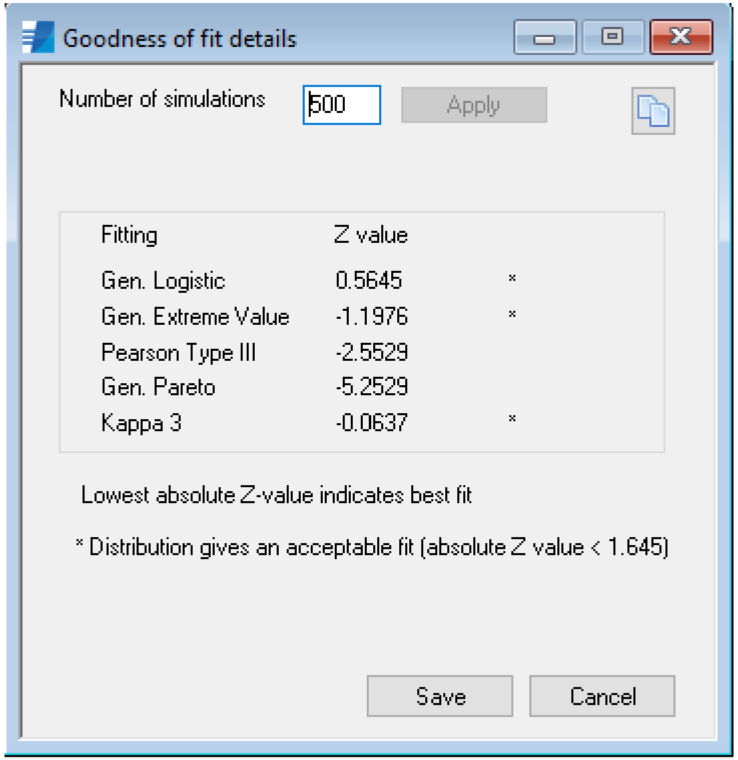
Station	Distance	Years of data	QMED AM	L-CV (Deurbanised(	L-SKEW (Deurbanised)	Discordancy	*Comments*
Weighted means							



8.2 Final pooling group composition

Station	Distance	Years of data	QMED AM	L-CV (Deurbanised(	L-SKEW (Deurbanised)	Discordancy	*Comments*
23018 (Ouse Burn @ Woolsington)	0.739	31	3.265	0.296	0.177	0.031	
68021 (Arrowe Brook @ Acton Lane)	1.284	16	3.997	0.287	0.420	2.289	
36010 (Bumpstead Brook @ Broad Green)	1.292	55	7.590	0.354	0.108	1.434	
27051 (Crimple @ Burn Bridge)	1.293	50	4.641	0.218	0.133	0.986	
27081 (Oulton Beck @ Oulton Farrer Lane)	1.340	36	2.545	0.288	0.197	0.204	
25019 (Leven @ Easby)	1.418	44	5.384	0.341	0.366	0.918	
36011 (Stour Brook @ Sturmer)	1.465	52	6.770	0.303	0.165	0.723	
38020 (Cobbins Brook @ Sewardstone Road)	1.581	51	7.474	0.338	0.319	1.483	
26014 (Water Forlornes @ Driffield)	1.602	24	0.431	0.319	0.184	1.302	
39005 (Beverley Brook @ Wimbledon Common)	1.609	61	11.100	0.259	0.033	1.578	
36004 (Chad Brook @ Long Melford)	1.766	55	4.807	0.302	0.175	0.613	
30006 (Slea @ Leasingham Mill)	1.791	37	1.840	0.314	0.198	0.439	
Total		512					
Weighted means							


Heterogeneity measures
Number of simulations 500
Apply
L-CV / L-skewness distance
Observed average 0.0869
Simulated mean of average 0.0764
Simulated S.D. of average 0.0145
Standardised test value H2 0.7261
The pooling group is acceptably homogeneous and a review of the pooling group is not required.
Standard deviation of L-CV
Observed 0.0509
Simulated mean 0.0334
Simulated S.D. 0.0069
Standardised test value H1 2.5401
Heterogeneous
Save
Cancel


Goodness of fit details
Number of simulations 500
Apply
Fitting Z value
Gen. Logistic 0.5645 *
Gen. Extreme Value -1.1976 *
Pearson Type III -2.5529
Gen. Pareto -5.2529
Kappa 3 -0.0637 *
Lowest absolute Z-value indicates best fit
* Distribution gives an acceptable fit (absolute Z value < 1.645)
Save
Cancel

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