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Our Ref: MT/5314

29th November 2021

Lesley Wells
Havant Borough Council
Development Control
Civic Offices
Civic Centre Road
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PO9 2AX

Dear Lesley

Re: Land West of Coldharbour Farm Road, Emsworth (Planning Ref: APP/19/01226)

Bellamy Roberts LLP has been instructed by Telstar Ltd to review and summarise the results of the additional flood modelling work undertaken by JBA Consulting, on behalf of the applicant, as a result of the Environment Agency's suggested planning conditions 1 and 3 in their response of 11th February 2020.

For reference, the EA response is at **Appendix 1** and the wording of conditions 1 and 3 are as follows:

"1 – Finished floor levels must be set at or above the 1 in 100 annual probability flood level plus 105% climate change of 6.9m AOD, as specified in paragraph 2.10 of the FRA"

"3 - All access roads must be at or above the 1 in 100 annual probability flood event including a 105% climate change allowance level of 6.9m AOD"

Bellamy Roberts has explored the possibility of raising the proposed access road to the level suggested by the EA, however it was not possible to raise the proposed access road to the required level to satisfy the EA. This was a particular problem at the location where the access would tie into the existing Coldharbour Farm Road.

In light of the above, it had been suggested that a separate emergency access would be required along the western boundary of the site, however such an access is not achievable.

The FRA submitted in support of the application was prepared by Cannon Consulting Engineers and considered the 'worst case' highest flood level from the EA's 2D flood model.

The 2D EA mapping available from the EA is generalised flood modelling and does not include detail of influential features within the catchment such as flood storage areas and structures. In this regard, JBA were instructed to undertake a more detailed assessment of this watercourse and develop a baseline flood risk model reflecting the current site conditions.

The model prepared by JBA simulated the following storm events:

- 5% Annual Exceedance Probability (AEP) event;
- 1% and 0.1% AEP present day events; and
- 1% AEP event with an increase to flows of 25% (reflecting EA guidance).

The full results of the JBA assessment is at **Appendix 2**, however of particular interest for the purposes of addressing the EA's suggested conditions are the results of the 1% AEP + 25% flood event. The result of this assessment reveals that only a small area of the site is predicted to flood. The depth of this flooding is shallow, being less than 0.1m, and is not expected to extend onto the footpath at the western end of Coldharbour Farm Road, or indeed the road itself.





Page 2: Land West of Coldharbour Farm Road, Emsworth (Planning Ref: APP/19/01226)

It is clear that the detailed modelling undertaken by JBA demonstrates there is no requirement for either the finished floor levels of the proposed units, or site access road, to be at or above 6.9mAOD, as previously requested by the EA.

Construction of the site access will naturally ensure the road surface is at a level greater than 0.1m above the existing ground level and will therefore be above the modelled flood level. This will ensure that dry access can be achieved to the development during this storm event, without the need for an emergency access at the western boundary of the site.

I trust this clarifies matters and will allow the EA to revise their suggested planning condition accordingly.

Yours sincerely

Matt Twinberrow BEng MCIHT
Associate Partner
Bellamy Roberts
Highway Transportation and Infrastructure Consultants

Enclosures:

EA Consultation Comments (11th February 2020)
JBA Modelling Report
JBA Flood Estimation Report

APPENDICES

APPENDIX 1

Havant Borough Council
Development Control
Civic Offices
Civic Centre Road
Havant
Hampshire
PO9 2AX

Our ref: HA/2020/121974/01-L01
Your ref: APP/19/01226
Date: 11 February 2020

Dear Sir or Madam,

**CONSTRUCTION OF 44 DWELLINGS WITH ACCESS, OPEN SPACE,
LANDSCAPING AND ASSOCIATED WORKS.**

LAND WEST OF COLDHARBOUR FARM ROAD, EMSWORTH.

Thank you for the consulting the Environment Agency on the above application.

We have reviewed the information as submitted and set out our position and comments below.

Environment Agency position

We request that the following condition be attached to any planning permission granted, and that the details in relation to the condition be submitted and approved by the Local Planning Authority.

Conditions

The development shall be carried out in accordance with the submitted Flood Risk Assessment (FRA)

(CCE/X781/FRA

FLOOD_RISK_ASSESSMENT_AND_DRAINAGE_STRATEGY_JULY_2019-

1312450, dated July 2019) and the following mitigation measures it details:

- 1. Finished floor levels must be set at or above the 1 in 100 annual probability flood level plus 105% climate change of 6.9 m AOD, as specified in paragraph 2.10 of the FRA.**
- 2. Compensatory storage shall be provided as described in paragraph 2.3 of the FRA, and proposed in Appendix B Drawing Number X781 - PL - SK – 301 and the calculations in Flood Storage Volume Result (Appendix B, pages 47 & 48 of the FRA).**

3. All access roads must be at or above the 1 in 100 annual probability flood event including a 105% climate change allowance level of 6.9 mAOD.

The mitigation measures shall be fully implemented prior to occupation and subsequently in accordance with the timing / phasing arrangements embodied within the scheme, or within any other period as may subsequently be agreed, in writing, by the Local Planning Authority.

Reasons

- To reduce the risk of flooding to the proposed development and future occupants.
- To ensure there is no increased flood risk to existing properties in the catchment.
- To ensure safe access and egress from and to the residential buildings.

The condition is in line with the Planning Practice Guidance (PPG) to the National Planning Policy Framework (NPPF) for Flood Risk and Coastal Change.

Advice to the Applicant

Flood Risk Activity Permit

The Environmental Permitting (England and Wales) Regulations 2016 require a permit to be obtained for any activities which will take place:

- on or within 8 metres of a main river (16 metres if tidal);
- on or within 8 metres of a flood defence structure or culvert (16 metres if tidal);
- on or within 16 metres of a sea defence;
- involving quarrying or excavation within 16 metres of any main river, flood defence (including a remote defence) or culvert; and/or
- in a floodplain more than 8 metres from the river bank, culvert or flood defence structure (16 metres if it's a tidal main river) and you don't already have planning permission.

Further details about Flood Risk Activity Permits can be found on the gov.uk website using the following link –

<https://www.gov.uk/guidance/flood-risk-activities-environmental-permits>.

The Applicant should note that a permit is separate to and in addition to any planning permission granted. The granting of planning permission does not necessarily lead to the granting of a permit.

To enquire further, please contact our National Customer Contact Centre on **03708 506 506** (Monday to Friday 8am to 6pm) or by emailing enquiries@environment-agency.gov.uk.

Please do not hesitate to contact me using the contact details shown below should you have any queries regarding the above information in relation to this application ref: APP/19/01226.

Yours faithfully,

Miss Anna Rabone
Sustainable Places Advisor

Direct dial: 02077 140525

Direct e-mail: anna.rabone@environment-agency.gov.uk

APPENDIX 2

West Brook, Emsworth fluvial flood risk modelling report

Final report

November 2021

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JBA Project Manager

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Revision History

Revision Ref / Date	Amendments	Issued to
P01 / November 2021	Final Report	Richard Brown (Telstar Ltd)

Contract

This report describes work commissioned by Matt Twinberrow of Bellamy Roberts, on behalf of Telstar Limited, by an email dated 9 June 2021. Telstar Limited's representative for the contract was Matt Twinberrow. Ben Gibson, Gwyn Jones and Lucy Archer-Lock of JBA Consulting carried out this work.

Prepared by Ben Gibson BSc MSc MCIWEM C.WEM

Principal Analyst

Reviewed by Alister Trendell BEng PGCE MCIWEM C.WEM

Chartered Senior Analyst

Purpose

This document has been prepared as a Final Report for Telstar Limited. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Telstar Limited.

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JBA is aiming to reduce its per capita carbon emissions.

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Abbreviations

1D	One-dimensional
2D	Two-dimensional
AEP	Annual Exceedance Probability
FEH	Flood Estimation Handbook
Flood Modeller	Proprietary modelling software developed by Jacobs (all instances of Flood Modeller in this report refer specifically to Flood Modeller 1D)
JBA	Jeremy Benn Associates Limited
LIDAR	Light Detection And Ranging
mAOD	metres Above Ordnance Datum
ReFH	Revitalised Flood Hydrograph method
TUFLOW	Two-dimensional Unsteady FLOW (Proprietary 2D modelling software developed by WBM BMT)

1 Introduction

1.1 Overview

JBA Consulting was commissioned by Bellamy Roberts on behalf of Telstar Limited to prepare fluvial (river) flood modelling and mapping for the West Brook watercourse, Emsworth. This watercourse flows along the eastern boundary of the proposed development site, which is located to the west of Coldharbour Farm Road. The information prepared from this modelling will be used by Telstar Limited as part of development planning at the site.

The existing mapping available from the Environment Agency is based on generalised 2D flood modelling, and so does not include the detail of channel hydraulic or other influential features in the catchment such as a flood storage area and structures.

Specific objectives of the project were to:

- Prepare flood flow hydrology inputs for the West Brook catchment to be used within the flood risk model;
- Develop a baseline flood risk model reflecting the current site condition;
- Simulate the model for the 5% Annual Exceedance Probability (AEP), 1% AEP and 0.1% AEP present day events, and the 1% AEP event with an increase to flood flows of 25% (reflecting the Environment Agency's guidance for considering the influence of climate change on flood flows in Flood Risk Assessments¹);
- Prepare flood risk mapping for the modelling to communicate the level of flood risk at the site;
- Prepare a report documenting the hydrology and flood risk modelling.

The current Environment Agency Flood Map for Planning, which is based on the generalised flood modelling approach, displays significant flood extents from the West Brook watercourse, extending onto the south-eastern corner of the site.

¹ Flood risk assessments: climate change allowances, Environment Agency, November 2021. Available: <https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances>

2 Site description

2.1 Proposed development site

The development site is located west of Coldharbour Farm Road, which lies just north of the A27. The site comprises open space grassland which generally slopes from west to east. A ditch is displayed on mapping to flow through the centre of the site. Although this could not be observed on site due to access issues and very long vegetation, it is expected to be a minor channel, based on the absence of formal connectivity back to the West Brook watercourse. The red line boundary for the development site is displayed in Figure 2-1.



Figure 2-1: Site location plan

2.2 West Brook watercourse and catchment

The West Brook watercourse, catchment and topography are displayed in Figure 2-2.

The catchment is primarily composed of London Clay formation – clay, silt and sand. In the upper part of the catchment soils are slowly permeable and seasonally wet, while in the lower part of the catchment the soils are loamy soils with naturally high groundwater. The catchment topography is relatively steep in the upper catchment, and fairly flat in the lower catchment.

The West Brook (Environment Agency main river) flows in a south easterly direction adjacent to the site. The watercourse rises north west of Emsworth and flows south through Emsworth to its outfall at Emsworth Mill Pond, which discharges into Chichester Harbour. There are a number of drains, notably in the west of the catchment, which mapping indicates joins the West Brook. However, the flow paths and connectivity of these drains is unclear.

The channel banks along West Brook adjacent to the development site (Figure 2-3) and downstream within woodland north of the A27 (Figure 2-4) appear overgrown, although the channel itself is relatively clear from vegetation.

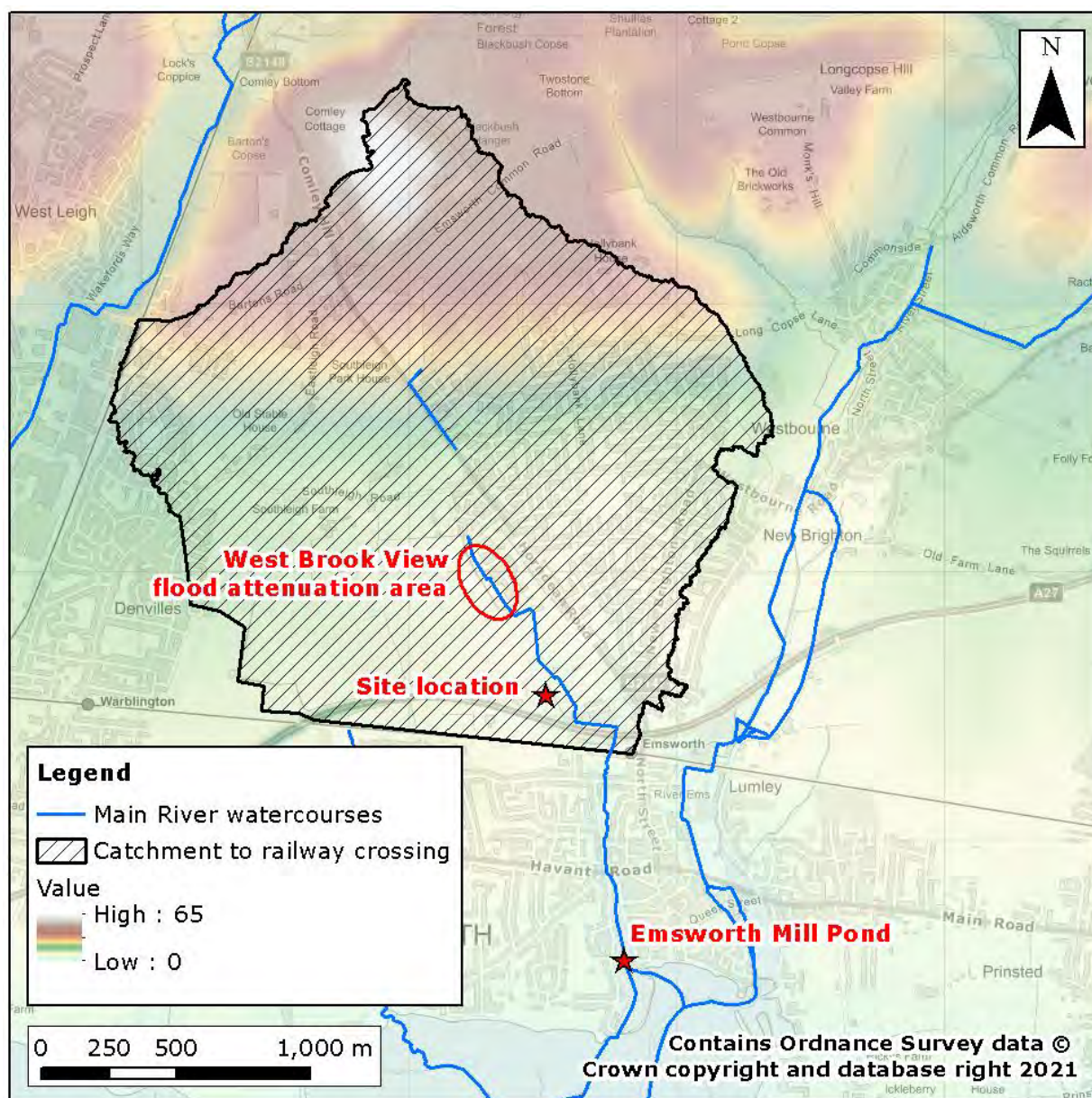


Figure 2-2: West Brook watercourse and catchment



Figure 2-3: West Brook watercourse, north of Coldharbour Farm Road and adjacent to the proposed development site (02/07/2021)



Figure 2-4: West Brook watercourse, north of the A27 (02/07/2021)

2.3 Upstream flood attenuation feature

A new development has recently been built at West Brook View, upstream of the proposed development site. As part of this, a flood attenuation feature has been constructed, which appears as though it would attenuate flow from the West Brook. The location of this in the catchment is presented in Figure 2-2. The flood attenuation feature comprises a circa 330m long wide basin with embanked sides in places, and a 0.6m diameter outlet culvert (invert level of 7.50mAOD) which has a penstock gate installed on the upstream face to allow the culvert outlet area to be adjusted. Figure 2-5 presents a view of the attenuation area and Figure 2-6 presents an image of the downstream control structure.

At the time of visiting the site (on 02/07/2021) the gate was partially lowered reducing the outflow area of the culvert. The opening area on site appeared consistent with the design drawings which indicate that the normal opening position would be 0.25m above the culvert invert (7.75mAOD). At a level 2.1m (9.60mAOD) above the culvert invert level a weir is present which would act as a spillway should levels rise sufficiently high. The minimum level of the embankments surrounding flood attenuation area are reported to be 0.2m above the weir (9.80mAOD).

Drawings for the development scheme and flood attenuation feature are available as part of planning application reference 14/00547 and 17/00358 on Havant Borough Council's planning portal website. The drawings most relevant to the geometry of the feature included drawing "APP_14_00547-CONDITION_14_-_LONG_SECTION-1032556.pdf" displaying a location plan and long-section of the flood attenuation, and drawing "APP_17_00358-FLOOD_STORAGE_AREA_CONTROL_STRUCTURE-1032788.pdf" displaying the downstream control structure. Key images of the control structure drawing are presented in Appendix A.



Figure 2-5: View of the flood attenuation area, look downstream (02/07/2021)



Figure 2-6: Flood attenuation area control structure (02/07/2021)

3 Data and methodology

3.1 Available data

Data available to inform the flood risk modelling is presented within Table 3-1.

Table 3-1: Data available to inform the flood modelling assessment

Data type	Details
Ground elevations	LIDAR data - Source: Environment Agency - Details: National LIDAR Programme 1m DTM data (2020)
	Limited topographic survey at Coldharbour Farm Road and the footpath south towards the underpass at the A27 - Source: Lewis Brown Limited - Details: Collected August 2021 (ref: C21201) The topographic survey data is presented in Appendix B The location of point elevations is presented in Figure 3-1.
Channel survey for West Brook	Channel and structure survey data - Source: Lewis Brown Limited - Details: Collected August 2021 (ref: C21201) - Open channel sections, plus structure sections at A) the culvert under the footpath beside Coldharbour Farm Road, B) the culvert under the A27 and C) the culvert under the railway line The location of survey sections is presented in Figure 3-1.

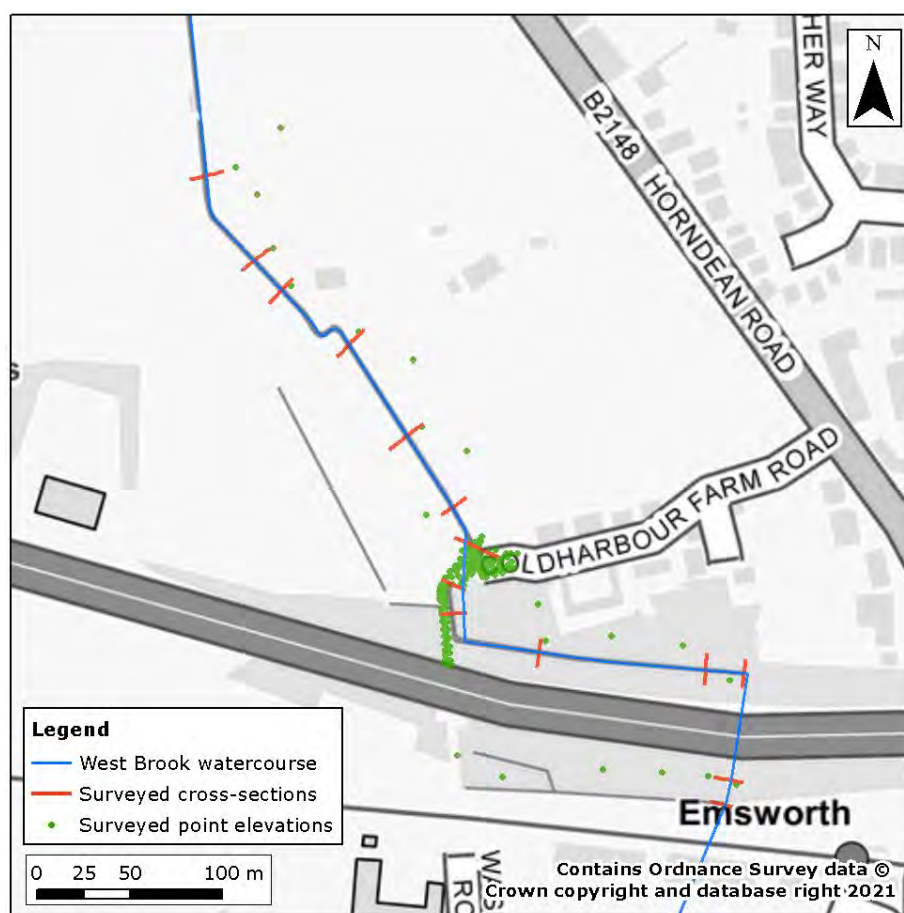


Figure 3-1: Location of survey sections and point elevation data (Lewis Brown Limited, August 2021, ref: C21021)

3.2 Site walkover and survey

A site walkover was undertaken by JBA Consulting on 02/07/2021, with Lewis Brown Limited, to inform the specification of survey (delivery ref C21021) required to inform the modelling.

3.3 Hydrology (flood flows)

Refer to the hydrology report (calculation record) provided in Appendix C for full details of the hydrology assessment.

West Brook drains a total area of 1.6km² to the downstream of the West Brook View flood attenuation area, and circa 2.3km² to the downstream extent of the site. A region of catchment, without the presence of watercourses being present, also slopes towards West Brook upstream of the railway line, meaning the total area of catchment upstream of the railway line is 3.9km².

There are a network of drains within the catchment to the west of West Brook. The connectivity of these drains is uncertain, and these may have a significant impact on the catchment area. A conservative approach to deriving the catchment boundaries was adopted, where it assumes all of these drainage channels would direct flood water towards West Brook watercourse.

Hydrological inflows for the hydraulic model were prepared for the following events:

- 5% Annual Exceedance Probability (AEP)
- 1% AEP
- 0.1% AEP
- 1% AEP, with flows increased by 25% to account for the predicted effects of climate change.

3.3.1 Flood estimation and model inflow locations

Three flood flow inputs were derived, as described below:

- 1 Inflow WEST01, representing the West Brook catchment to the downstream of the flood attenuation area
- 2 Inflow TRIB01, representing the urbanised eastern part of the catchment. This catchment does not appear to have watercourses, but the topography slopes towards West Brook where it flows under the A27
- 3 Inflow WEST02_IA, representing the intervening area of catchment between WEST01 and TRIB01.

3.3.2 Choice of method

Flood estimates were prepared using both the Flood Estimation Handbook (FEH) Statistical and Revitalised Flood Hydrograph (ReFH) 2 methods. Flood flows from the FEH Statistical method were larger than those for the ReFH2 method and were taken forward. For inflows WEST01 and TRIB01, hydrographs from the ReFH2 method were scaled to fit the statistical peaks, which for WEST02_IA, ReFH2 hydrographs were applied to the model.

3.3.3 Storm duration testing

Testing of storm durations using the ReFH2 method was completed for the 1% AEP +25% flows event, for both the flood attenuation area penstock open and partially closed scenarios. Storm durations of 7.5-hours, 11.5-hours and 15.5-hours were tested. In both scenarios, the 7.5-hour event was found to produce greatest flood flows, levels and extents at the site, and so was taken forward.

3.3.4 Inflows from TRIB01 catchment

The TRIB01 catchment is heavily urbanised and a watercourse draining to West Brook is not present, so any flood water resulting from rainfall would runoff overland. In light of the

absence of a channel system, consideration was given to removing the TRIB01 inputs from the model. This was considered to be an extreme approach (although potentially justifiable).

However, a compromised approach was taken forward whereby flows originating from the TRIB01 catchment are still applied to the model, but it was assumed that the surface water sewer system in the urbanised area captures a proportion of the runoff, meaning there are losses in terms of the flow rate that enters the watercourse.

The capacity of the sewer system was assumed to accept rainfall associated with the 3.3% AEP event (an event magnitude often considered for sewer capacity), and so the 3.3% AEP peak inflow rate for TRIB01 (1.24m³/s) was subtracted from the flood inflow rates applied to the model.

3.3.5 Final peak flood flow estimates

Final peak flow inputs to the flood mapping model for the three boundary inflows are presented in Table 3-2.

Table 3-2: Final flood flow estimates applied to the model

Inflow	Peak flow (m ³ /s) for the following AEP events			
	5% AEP	1% AEP	1% (+25%)	0.1%
WEST01	1.2	1.8	2.2	3.2
TRIB01* (*after subtraction of 3.3% AEP flow)	0	0.5	0.9	2.0
WEST02_IA	0.4	0.6	0.7	0.9

3.4 Hydraulic (flood risk) modelling

A linked 1D-2D Flood Modeller (1D) and TUFLOW (2D) model was developed and has been built in accordance with standard methods adopted for flood risk modelling and mapping. Some key aspects of the model schematisation are presented in Table 3-3. The schematisation of the flood risk mapping model is presented in Figure 3-2.

Table 3-3: Key aspects of the model schematisation

Aspect of model	Details
DTM data	LIDAR: National LIDAR Programme 2020 data, 1m resolution
Resolution of the model grid	2m
Length of model watercourse	1.3km
1D channel roughness (Manning's <i>n</i>)	Bed: 0.040-0.045 Banks: 0.060-0.080
2D floodplain roughness (Manning's <i>n</i>)	Four land cover categories, each with different hydraulic roughness values: #1, 0.050 representing grass #2, 0.080 representing woodland #3, 0.030 representing paths and roads #4, 0.300 representing buildings
Flood attenuation area	Flood Modeller 1D River Sections describing the channel: - Numerous cross-section profiles were extracted from the LIDAR data which includes elevations of the flood attenuation area - Levels of the channel invert were inspected from drawing "APP_14_00547-CONDITION_14_-_LONG_SECTION-1032556.pdf" and the LIDAR section

Aspect of model	Details
	data modified at the channel to provide a 1.5m wide base with the relevant invert applied Flood Modeller 1D structures representing flow routes allowing water out of the FSA, connected to the 2D domain downstream with SX links: • Outlet culvert (when open): Circular orifice unit • Outlet culvert (when partially closed): Rectangular orifice unit with invert and soffit levels, and bore area adjusted to reflect the partial opening • Overtopping weir: SPILL unit • Adjacent embankments: 2 no. SPILL units
West Brook downstream of attenuation area	From the FSA outlet to the upstream extent of survey (circa 300m length of channel): • 2D Z-Shape used to modify the model DEM to route water over the model grid surface, and back into the channel downstream • This approach is appropriate given that the reach of channel is upstream of the proposed development site, and flood water is directed back into the 1D channel downstream. Surveyed reach to model downstream boundary: • 1D River Sections connected to the 2D floodplain domain via HX links. • Culvert units are applied at the three culverts present within the reach. Culvert inlet and outlet units are applied where applicable. Note that testing was completed on the outlet loss unit applied to model culvert "WB01_0274" (downstream of the footpath at Coldharbour Farm Road) which was producing a spurious headloss and spike in water level predictions. The approach found to be most representative, and stable was to remove culvert outlet loss unit. This approach is representative given that the culvert discharges to a channel where little or no expansions losses are expected.
A27 and railway underpasses	TUFLOW 2D Z-Shape features apply a flow route through these features, with elevations extracted from topographic survey and LIDAR data where required.
Downstream boundary and channel sections downstream of the railway line	Two River Sections, with interpolate units, are applied to the model downstream of the railway line culvert (model culvert "WB01_0000") to extend the model and provide and appropriate downstream boundary condition. The width of these sections is informed by Ordnance Survey mapping, site observations and satellite imagery, while the invert levels are extracted from LIDAR data. The downstream boundary applied is a normal depth boundary with the slope (0.003m/m or 1 in 333 slope) informed by the channel gradient downstream of the railway line.

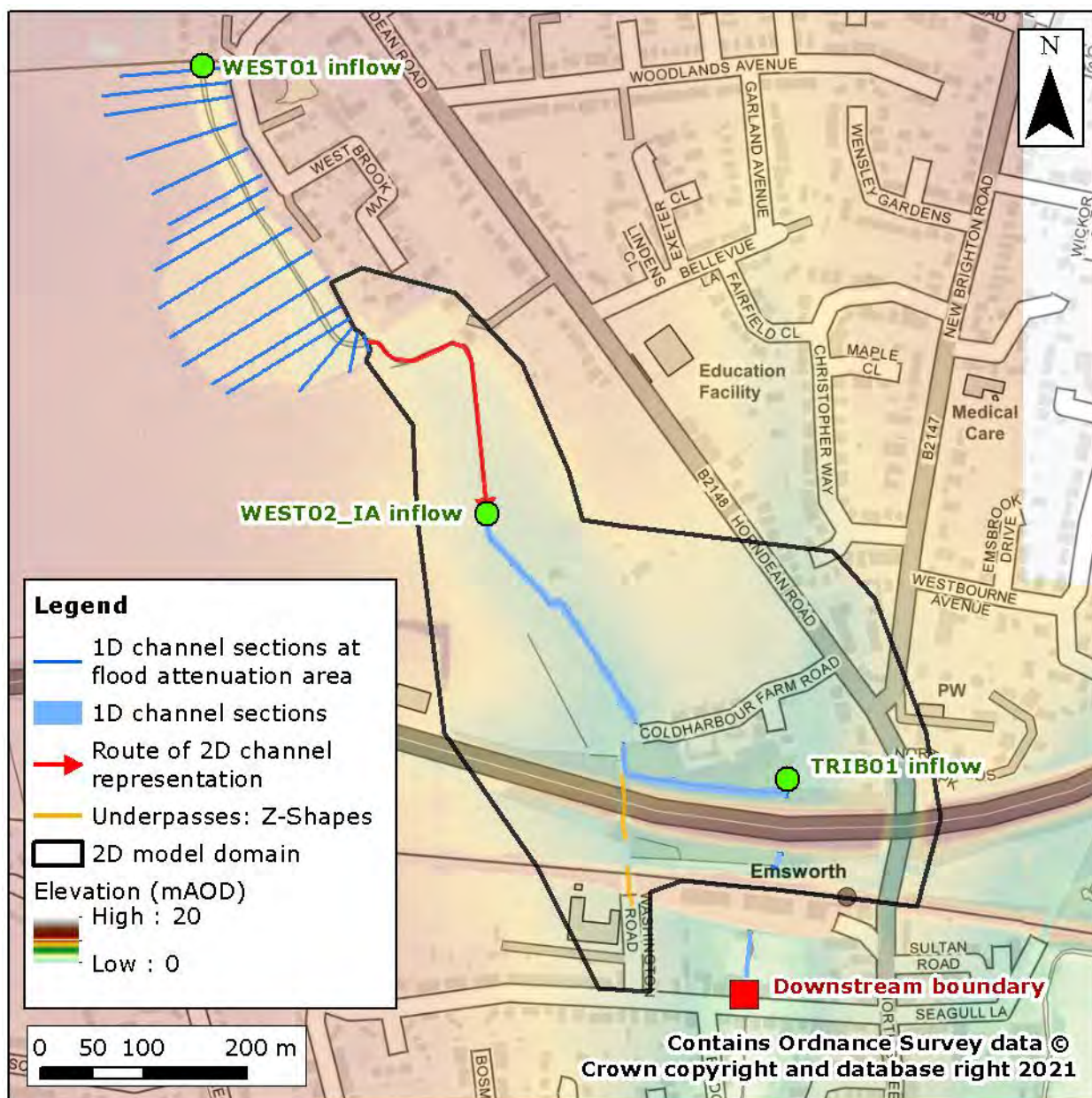


Figure 3-2: Schematisation of the flood risk mapping model

3.4.1 Flood attenuation area outlet position

The drawings available for the outlet of the flood attenuation area indicate that the normal position for the penstock gate is positioned partially obscuring the culvert, with the bottom of the gate 0.25m above the invert level of the culvert. No operating procedures for the attenuation area could be identified and so it is considered unlikely that during a flood event the penstock would be manually operated to modify the storage of flood water. However, it is possible that the penstock could be in a different position than 'normal' at the onset of a flood event, which would influence the rate of storage, and therefore attenuation upstream. This would in turn also influence the likelihood and timing of exceedance of the maximum storage level before flow passes across the weir and potentially embankments. In light of this possibility, the flood modelling prepared as part of this assessment simulated two scenarios for the penstock: 1) as per the design drawings (penstock set 0.25m above the culvert invert) and 2) penstock fully open. From these scenarios, the worst-case flood predictions are then presented.

3.4.2 Sensitivity testing

Sensitivity testing was completed for using the 1% AEP +25% flows design event, given that this event is likely to be most influential for decision-making at the proposed development site. The results described are for the scenario in which the flood attenuation area penstock gate is open, as this produces worst-case flood levels at the site. Two sensitivity test scenarios were completed, as presented below.

Hydraulic roughness (1D and 2D)

Hydraulic roughness for both the channel and the floodplain was increased by 20%. The change in flood extents between the baseline and sensitivity test are displayed in Figure 3-3. Conclusions drawn from comparison of these results with those of the baseline model are as follows:

- Peak water levels at the upstream and downstream of the culvert under the footpath beside Coldharbour Farm Road (model node WB01_0274) increase by 0.07m.
- The extent of flooding increases, with the shallow (<0.1m) depth flooding from the western bank of West Brook which extends onto the site in the baseline, flowing onto and across the footpath south of Coldharbour Farm Road. Flood depths on the footpath remain below 0.2m.
- The hydraulic roughness values selected to inform the baseline model are considered representative, but the sensitivity of predictions to hydraulic roughness should be kept in mind. The 1% AEP +25% flows event appears to represent an event where the watercourse is 'at capacity' and so any increase in flood water levels results in a more notable increase in flood extent.

Downstream boundary slope

The slope value assigned to the downstream boundary was adjusted from 0.003m/m (1 in 333 slope) to 0.002m/m (1 in 500 slope). The change in flood extents between the baseline and sensitivity test are displayed in Figure 3-4. Conclusions drawn from comparison of these results with those of the baseline model are as follows:

- Peak water levels at the upstream and downstream of the culvert under the footpath beside Coldharbour Farm Road (model node WB01_0274) increase by 0.06m.
- The extent of flooding increases, with the shallow (<0.1m) depth flooding from the western bank of West Brook which extends onto the site in the baseline, flowing onto and across the footpath south of Coldharbour Farm Road. Flood depths on the footpath remain below 0.2m.
- The downstream boundary value selected to inform the baseline model is considered representative, but the sensitivity of predictions to adjustment of this boundary should be kept in mind, as any reduction in efficiency of the system downstream (e.g. through blockage) may influence water levels at the site. The 1% AEP +25% flows event appears to represent an event where the watercourse is 'at capacity' and so any increase in flood water levels results in a more notable increase in flood extent.

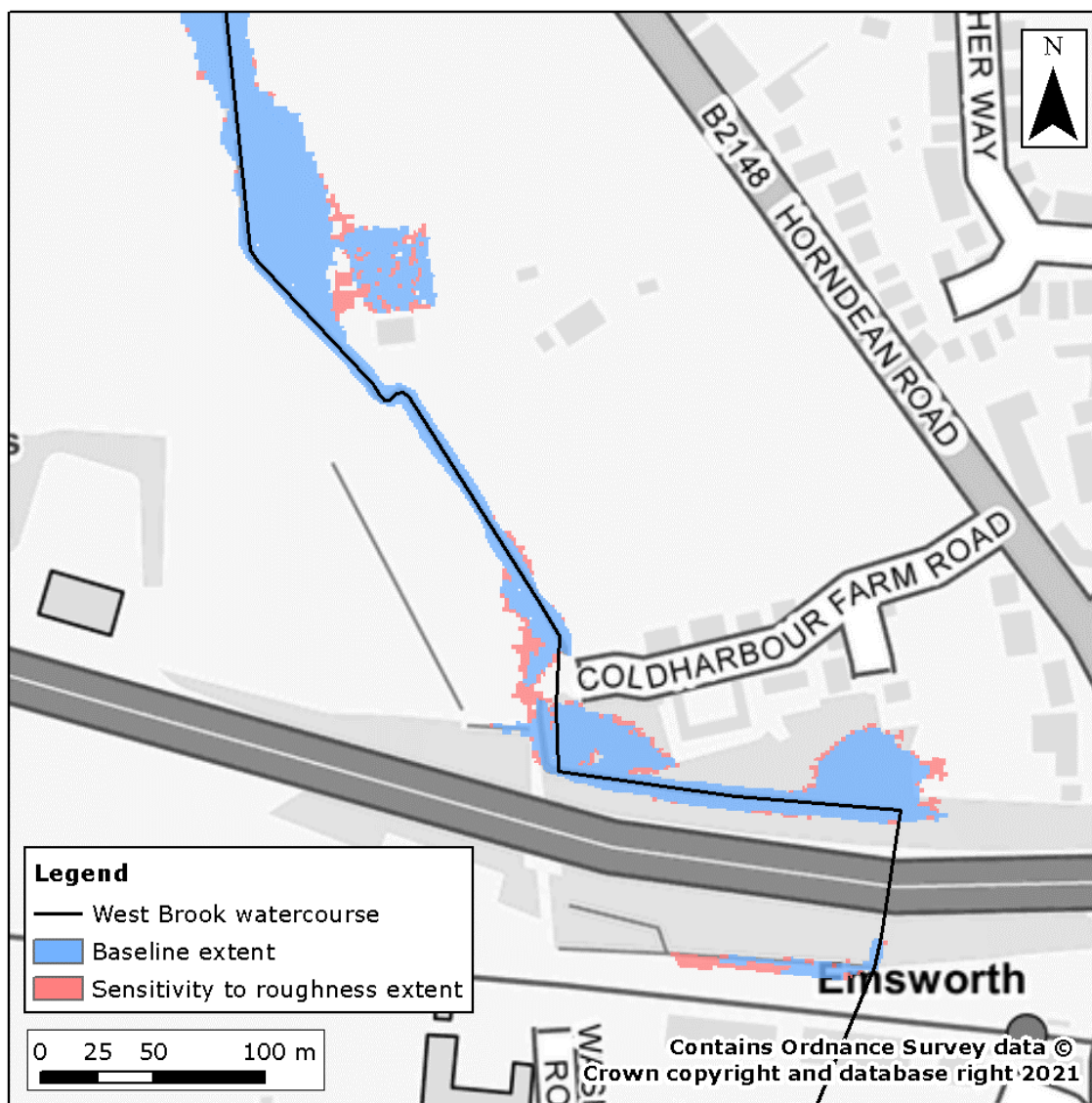


Figure 3-3: Flood extents – sensitivity to hydraulic roughness test

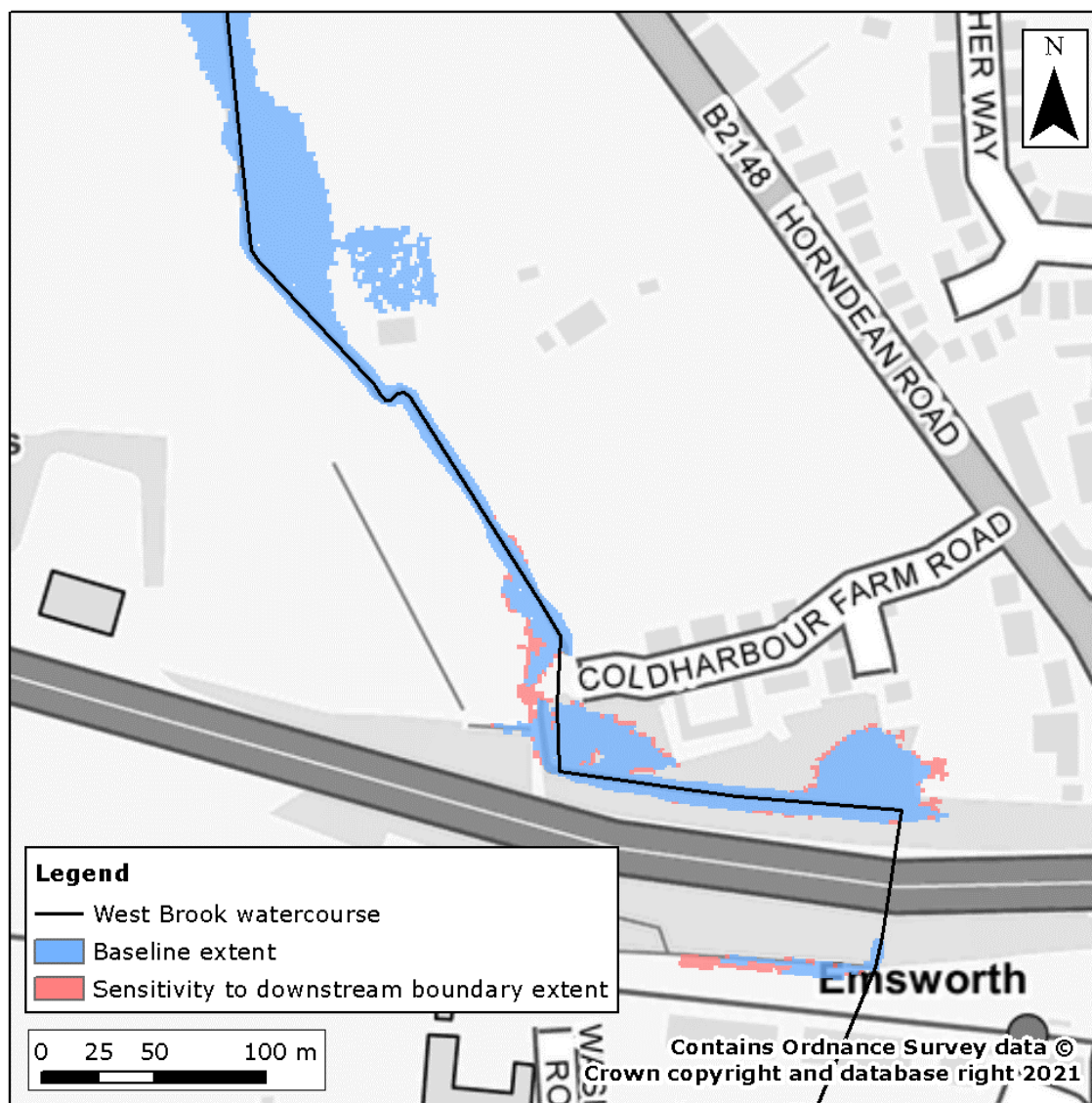


Figure 3-4: Flood extents – sensitivity to downstream boundary test

3.5 Modelling uncertainty

While the flood predictions presented within this report show information that appears definitive, in practice there are uncertainties inherent within all modelling which could mean that model predictions of extents, depth, water levels and so on, differ from what would occur in reality. Uncertainty may be introduced through aspects of the modelling including; the data used to inform the geometry of the model (e.g. ground levels), choices made regarding model parameterisation (e.g. hydraulic roughness), as well as the hydrology (flood flow) inputs.

While uncertainty is present within the modelling, the data, parameterisation and schematisation of the model is considered to be appropriate, and the model can be used to assess impacts of any proposed development with confidence.

Management of the uncertainty (and sensitivity) with the flood modelling predictions could be addressed by taking a precautionary approach to site design/levels, and/or including measures within the site design to help manage flooding, should flood levels exceed those modelled (including events that exceed the design standard).

4 Results

4.1 Change in flood risk: updated baseline

Flood depth mapping for the 1% AEP, 1% AEP +25% flows and 0.1% AEP events is presented in Appendix D. Flood water level mapping for the 1% AEP, 1% AEP +25% flows and 0.1% AEP events is presented in Appendix E.

Predicted flooding from the latest detailed modelling is notably reduced compared with the existing flood mapping published by the Environment Agency in their Flood Map for Planning.

The following observations are made regarding flooding in the updated modelling:

- Apart from for the 0.1% AEP event, flood levels within the watercourse are slightly greater in the scenario where the flood attenuation area culvert is fully open, compared with partially closed. The outputs of the scenario which provides greatest water levels in watercourse at the site have therefore been considered as they provided a conservative (more worst-case) scenario of flooding.
- Water levels within West Brook, adjacent to, and beyond the site remain in-bank for the 5% and 1% AEP events i.e. water does not flow onto the floodplain
- For the 1% AEP +25% flow event, flood water flows out of bank of the western side of West Brook, into the site immediately upstream of the culvert at Coldharbour Farm Road. Flood depths are relatively shallow (less than 0.1m) and do not extend across the footpath. Flood water flows out of bank through parts of the woodland north of the A27.
- For the 0.1% AEP event, channel exceedance is widespread and flooding of the south-eastern side of the proposed development site is predicted, including parts of Coldharbour Farm Road and the footpath west of this. Flood depths along Coldharbour Farm Road and the footpath exceed 0.5m.

5 Conclusions

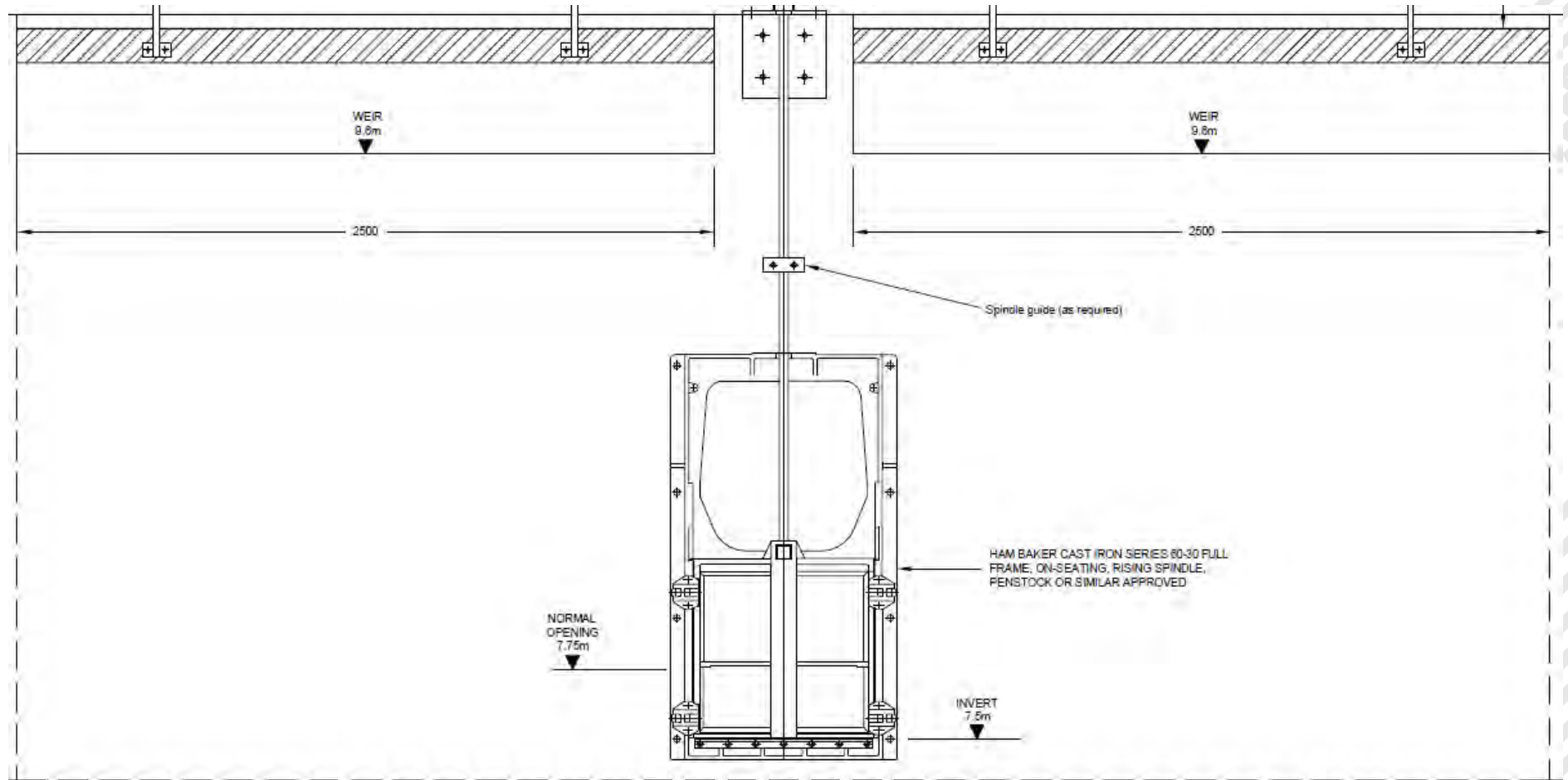
The updated hydraulic modelling, supported by new flood flow hydrology, new survey data and modelling and mapping using latest methods, has shown an improvement in the understanding of flood risk along West Brook and within the area of the proposed development site located west of Coldharbour Farm Road. For the baseline (as now) scenario, the site is not predicted to flood during the 5% or 1% AEP event. A small area at the southeast of the site is predicted to flood in the 1% AEP +25% flows event, representing the potential effects of climate change. The depth of flooding is shallow (less than 0.1m) and not predicted to extend onto the footpath west of Coldharbour Farm Road, or the road itself. During the 0.1% AEP event, flooding is widespread, and the south and southeast corner of the site are predicted to flood.

Sensitivity testing was conducted for hydraulic roughness (influencing channel and floodplain conveyance) and model conditions at the downstream extent of the model. This was completed for the 1% AEP +25% flows event, and predicted flooding at the site was not found to be sensitive to the scenarios tested.

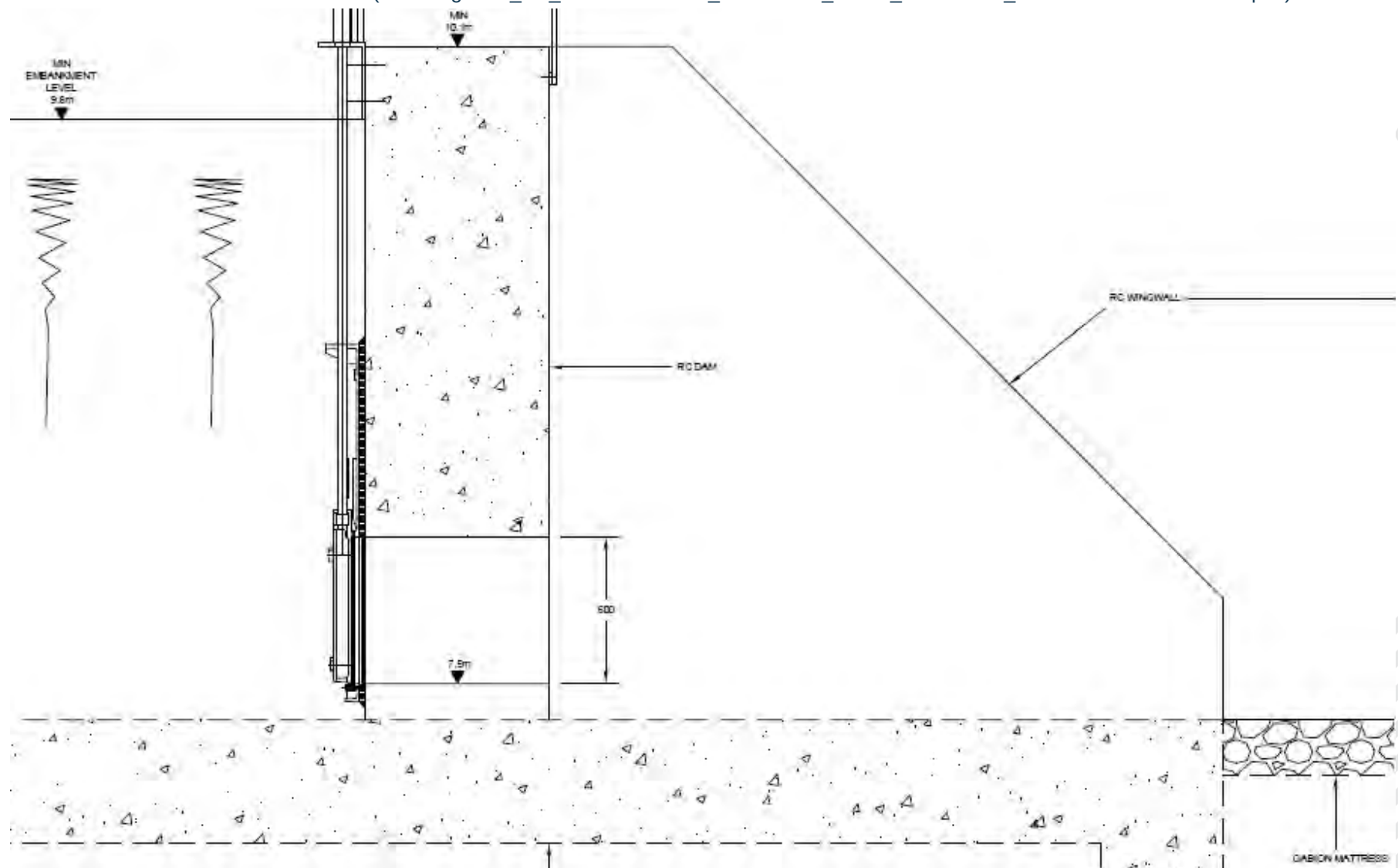
Appendices

A West Brook View flood attenuation area drawings

A.1 Flood control structure elevation (drawing APP_17_00358-FLOOD_STORAGE_AREA_CONTROL_STRUCTURE-1032788.pdf)



A.2 Flood control structure section (drawing APP_17_00358-FLOOD_STORAGE_AREA_CONTROL_STRUCTURE-1032788.pdf)

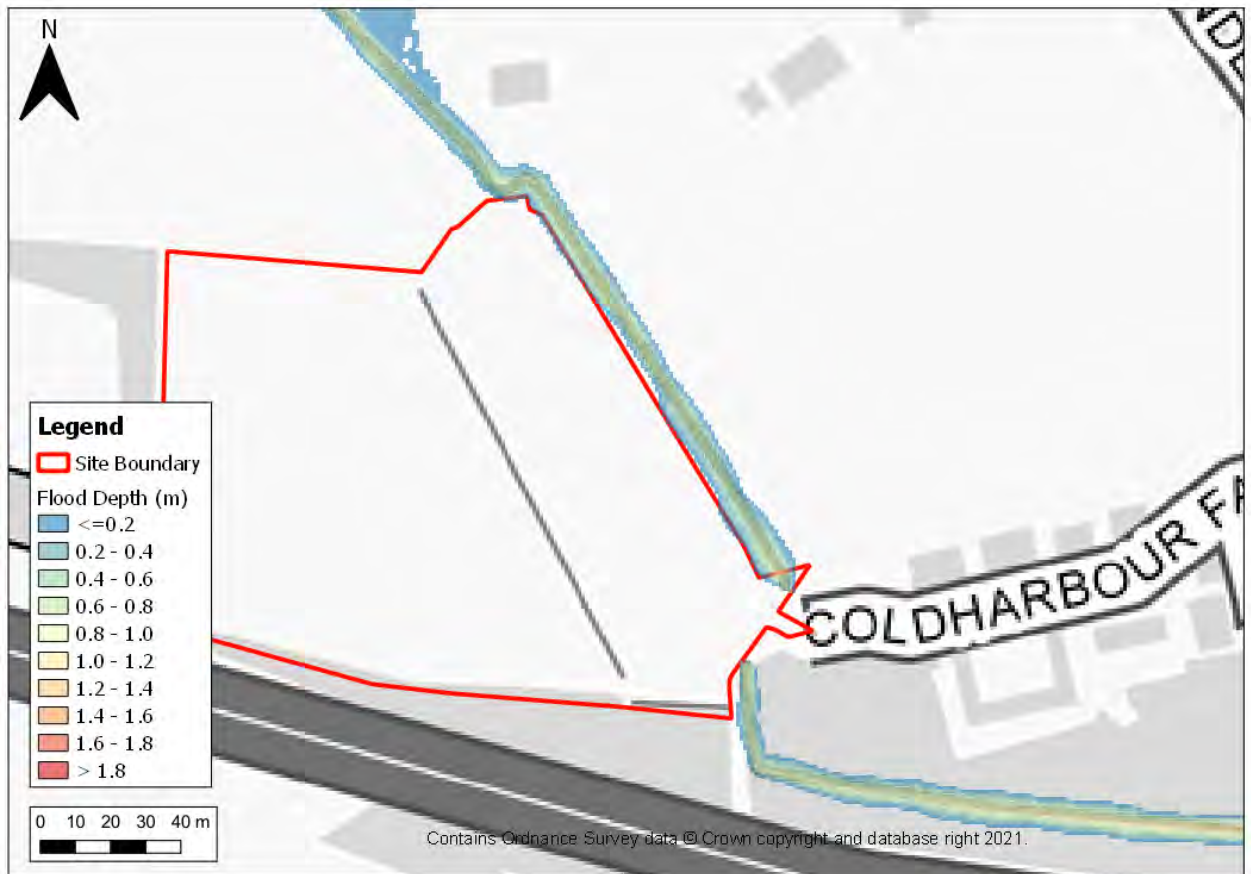


B Topographic survey at Coldharbour Farm Road and footpath
south towards A27 underpass (Lewis Brown Limited)

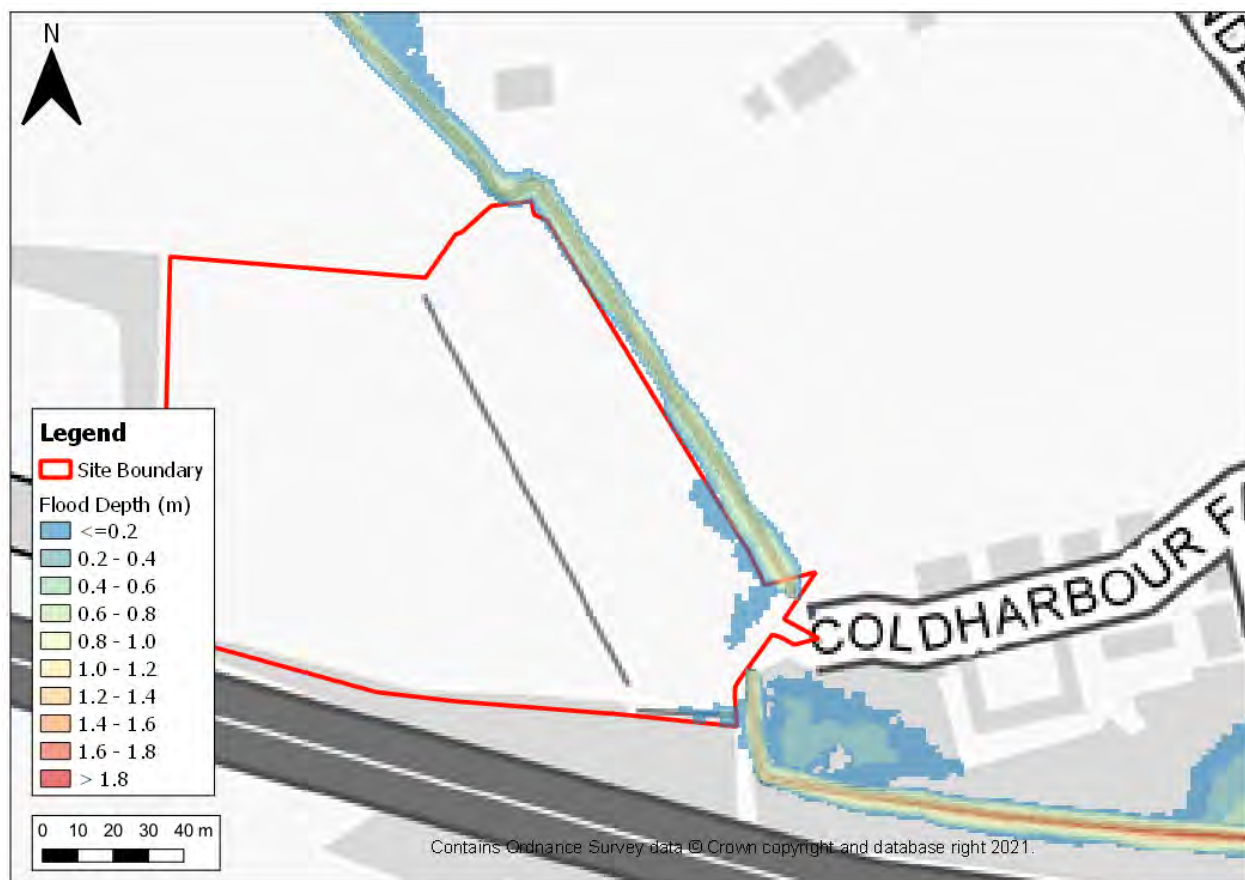
C Hydrology report (FEH Calculation Record)

D Flood mapping: flood depths

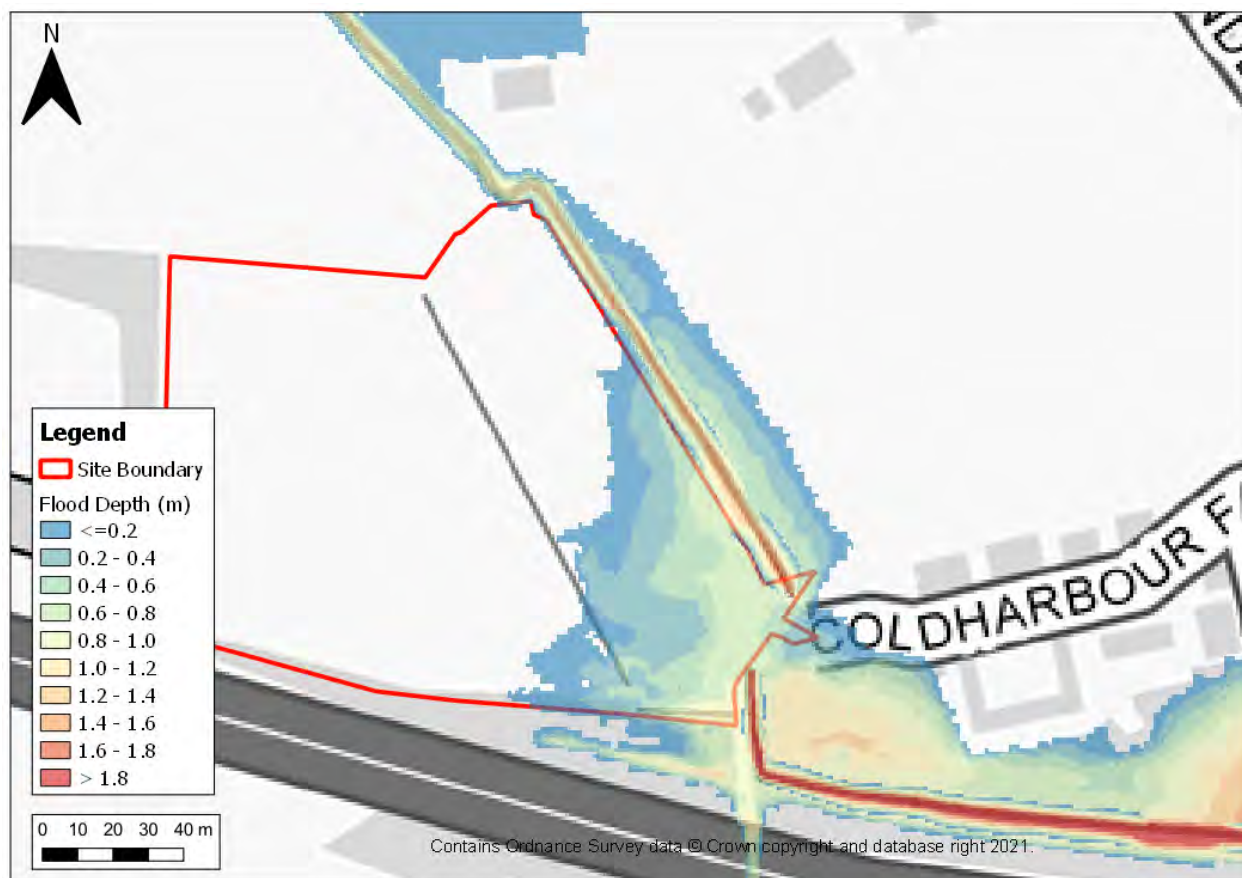
D.1 1 % AEP (present day)



D.2 1 % AEP +25 % flows (climate change)

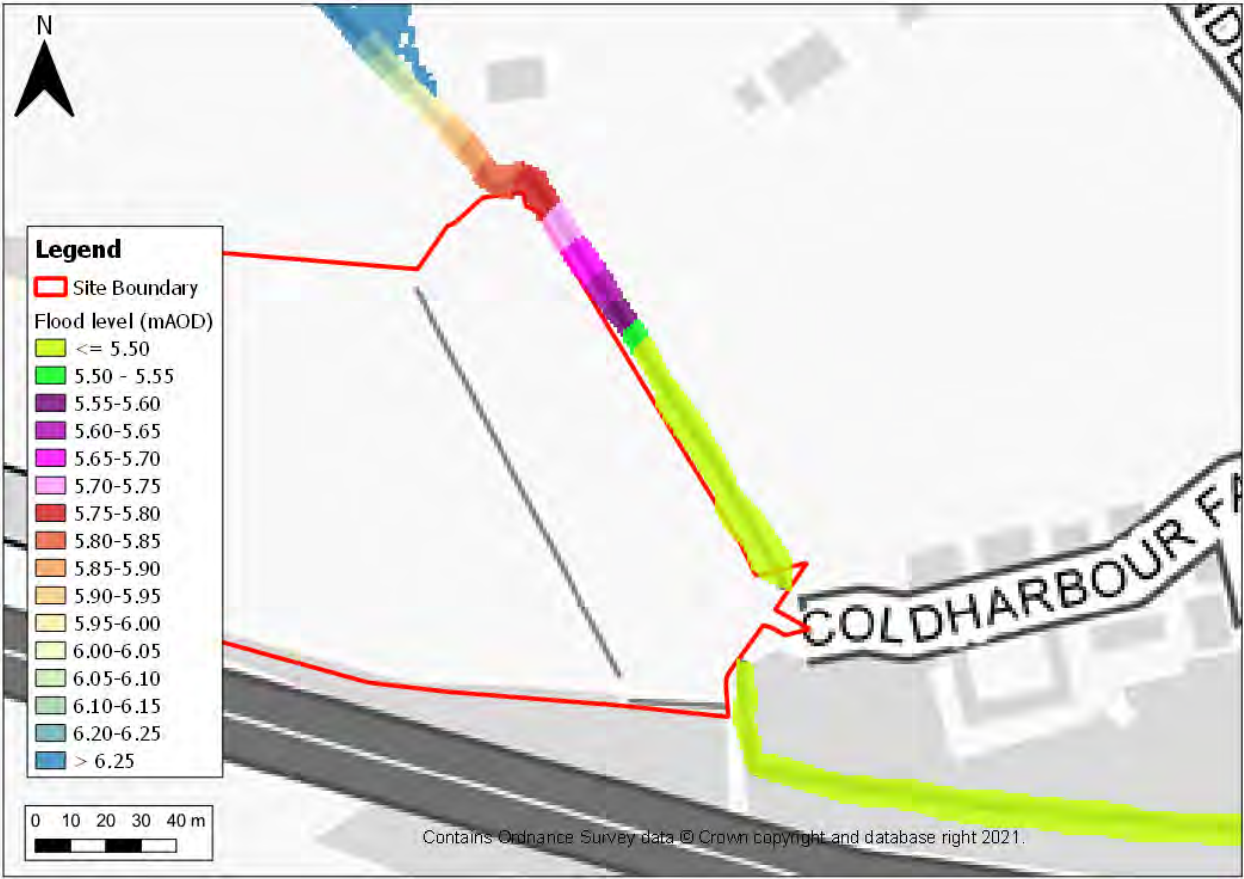


D.3 0.1 % AEP (present day)

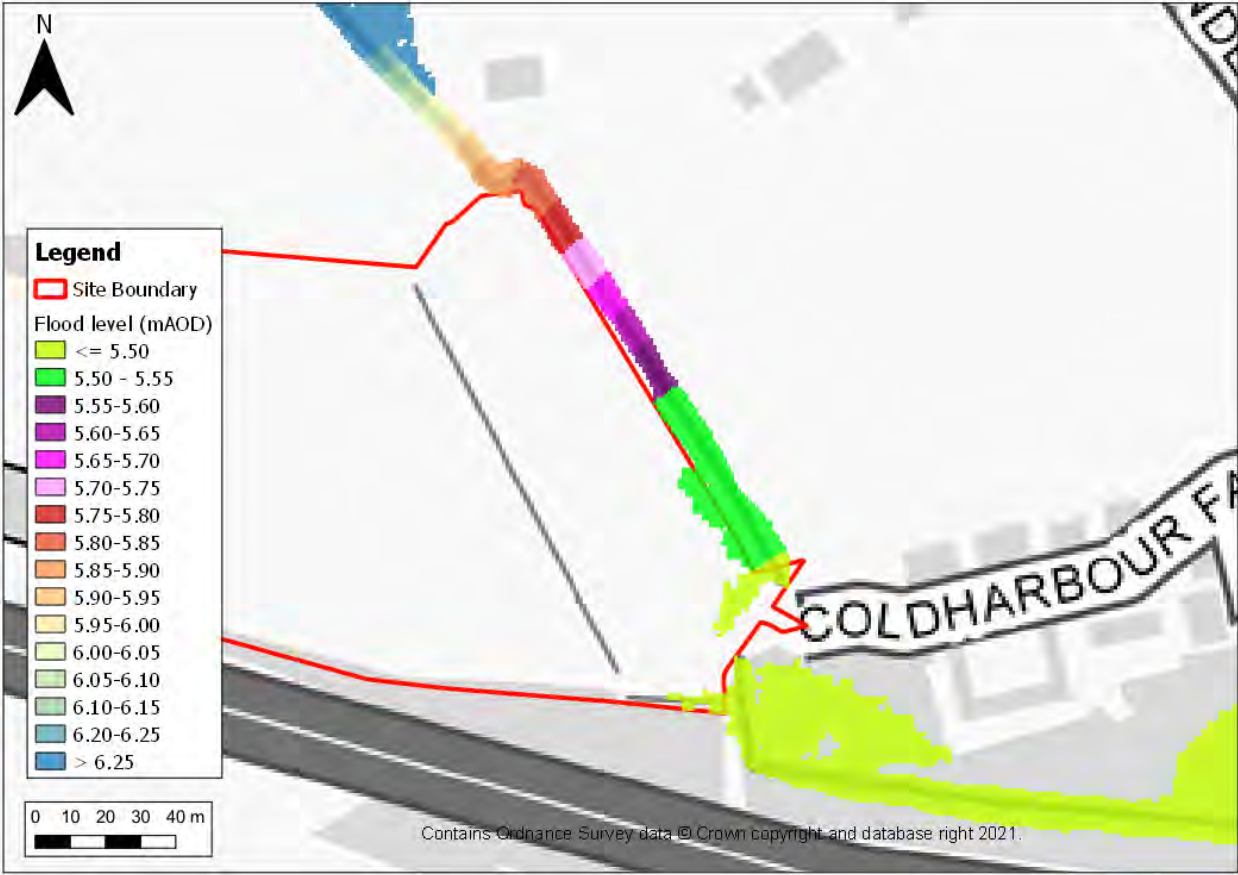


E Flood mapping: flood water levels

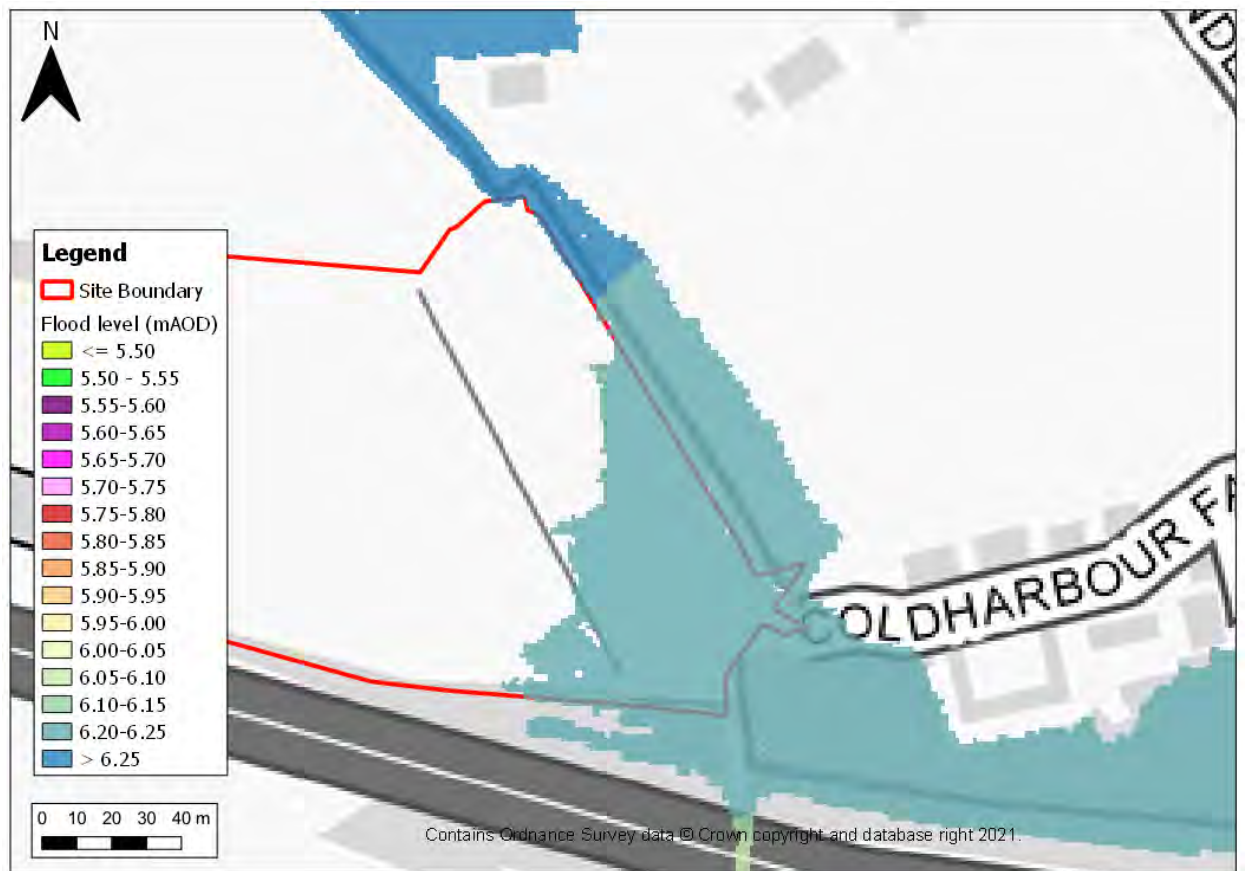
E.1 1 % AEP (present day)



E.2 1 % AEP +25 % flows (climate change)



E.3 0.1 % AEP (present day)



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Coleshill
Doncaster
Dublin
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Flood estimation report: Coldharbour Farm Road

Introduction

This report template is based on a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

1	Method statement	3
2	Locations where flood estimates required	8
3	Statistical method	10
4	Revitalised flood hydrograph 2 (ReFH2) method	13
5	Discussion and summary of results	15
6	Annex	19

Approval

	Name and qualifications	Date
Method statement prepared by:	Lucy Archer-Lock BSc	08/07/2021
Method statement reviewed by:	James Molloy BE(Hons) MEngSc	08/07/2021
Calculations prepared by:	Lucy Archer-Lock BSc	12/07/2021
Calculations reviewed by:	James Molloy BE(Hons) MEngSc	12/07/2021

Revision History

Revision reference	Date issued	Amendments	Issued to
P01	November 2021	-	Telstar Ltd

Abbreviations

AMAX	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification (BFIHOST19 is an updated version and addresses a number of issues in the original BFIHOST)
CPRE.....	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED.....	Median Annual Flood (with return period 2 years)
ReFH.....	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBEXT1990.....	FEH index of fractional urban extent
URBEXT2000.....	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

Note on flood probability

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

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

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

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

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

1 Method statement

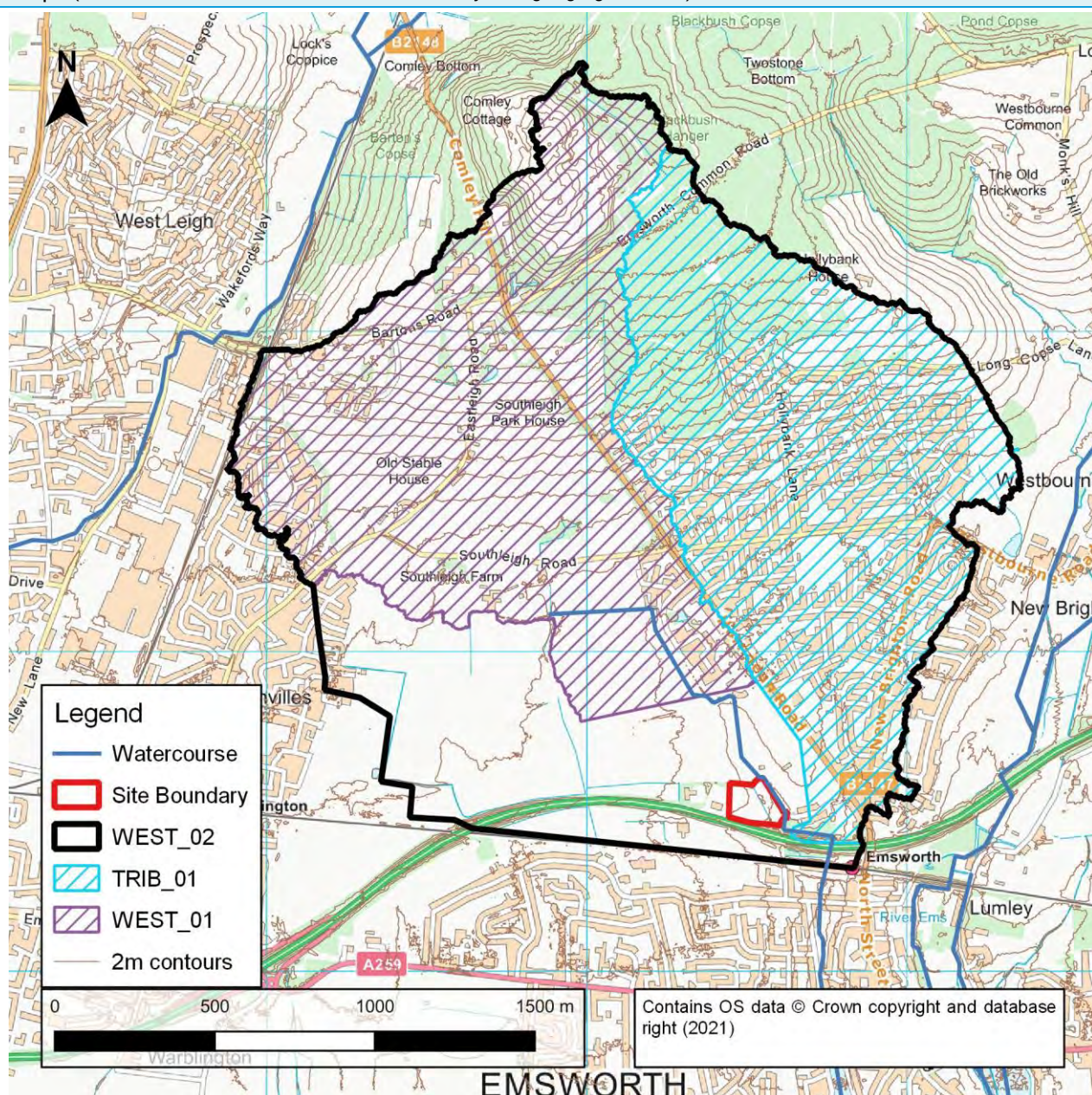
1.1 Requirements for flood estimates

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

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

1.2 The catchment

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



Description

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

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

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

1.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 9, released September 2020. This contains data up to water year 2018-19 at most gauges, and 2019-20 at some gauges that recorded exceptional floods over the winter 2019-20.
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1.4 Gauging stations (flow or level)

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

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

1.5 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Check flow gaugings	No	N/A	N/A	N/A
Historic flood data	Yes	Yes	Havant Borough Council – Emsworth Flood Risk Strategy Review (2015) ⁴	Flooding has occurred along the West Brook around Bridge Road, downstream of the proposed development site, where the capacity of the culvert has been exceeded. The date and frequency of the flooding is not known. No records of flooding specifically at the development site could be found.

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

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

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

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

1.6 Hydrological understanding of catchment

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

1.7 Initial choice of approach

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

How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	method will be applied. There is no NRFA peak flow data available in the catchment to improve the QMED estimate under the statistical method. Local donors, from nearby catchments, will, therefore, be assessed for suitability for data transfer. Consideration was given to using the level gauge at Emsworth for updating the ReFH2 Tp parameter. However, as the data appears to be influenced by an artificial structure, such as a gate, and there may be a tidal influence on the gauge, then it was decided that this data is not suitable for this purpose. As highlighted in the Environment Agency's latest flood estimation guidelines, the statistical method is generally preferred to rainfall-runoff techniques, although the performance of the ReFH2 method in such cases is greatly improved compared with ReFH1. The flow estimates from the statistical method and ReFH2 will be compared. Hydrograph shapes will be generated using the ReFH2 method, using the recommended design storm duration from catchment descriptors. It is not recommended to carry out critical storm duration analysis in this case, given that peak flows rather than volumes are likely to be the main control on flood risk in this case. These hydrographs will be fitted to the FEH Statistical peaks, if this is chosen as the preferred method, Inflows will be derived as follows: • A point inflow will be calculated at the model upstream extent. This will represent runoff from the rural area to the north-west of the site • A separate point inflow will be calculated to represent runoff from the densely urbanised eastern part of the catchment, applied as a point inflow to a downstream section of the model. • A final (laterally-applied) inflow representing the rural land in the south of the catchment, not represented in the point inflows above.
Software to be used (with version numbers)	FEH Web Service⁵ / WINFAP-FEH v3.0.003⁶ / ReFH2.3

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

⁶ WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.
GBQ-JBAU-XX-XX-RP-HO-0003-A2-P01_Emsworth_Hydrology_Report

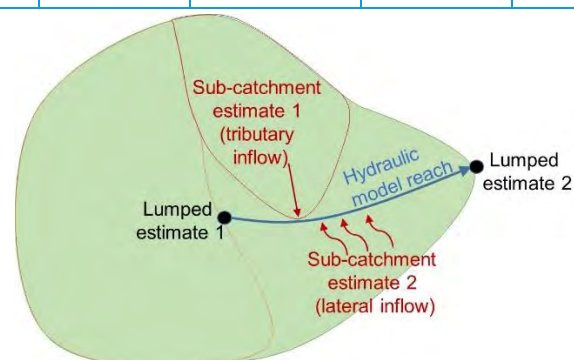
2 Locations where flood estimates required

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

2.1 Summary of subject sites

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

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



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

Values shown in red have been updated

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

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

2.3 Checking catchment descriptors

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

⁷ Bayliss, A.C; Black, K.B; Fava-Verde, A. & Kjeldsen, T.R. (2006) *URBEXT2000 – A new FEH catchment descriptor. Calculation, dissemination and application*. R&D Technical Report FD1919/TR. London: Defra.

⁸ Griffin, A., Young, A. and Stewart, E. (2019). Revising the BFIHOST catchment descriptor to improve UK flood frequency estimates. Hydrology Research.

3 Statistical method

3.1 Overview of estimation of QMED at each subject site

Site code	Initial QMED rural (m ³ /s) (from catchment descriptors)	Final method	Data transfer					Urban adjust-ment factor (UAF)	Final QMED estimate (m ³ /s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Moderated QMED adjustment factor, (A/B) ^a	If more than one donor			
						Weight	Weighted ave. adjustment		
WEST_01	0.54	CD	N/A	N/A	N/A	N/A	N/A	1.099	0.59
TRIB_01	0.44	CD	N/A	N/A	N/A	N/A	N/A	1.322	0.58
WEST_02	1.01	CD	N/A	N/A	N/A	N/A	N/A	1.163	1.17
Are the values of QMED spatially consistent?					Yes, QMED increases downstream				
Method used for urban adjustment for subject and donor sites					WINFAP v4 ⁹				
Parameters used for WINFAP v4 urban adjustment if applicable									
Impervious fraction for built-up areas, IF			Percentage runoff for impervious surfaces, PR _{imp}		Method for calculating fractional urban cover, URBAN				
0.3			70%		From updated URBEXT2000				
Notes									
Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).									
The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is: (A/B) ^a x QMED _{initial} x UAF									
Important note on urban adjustment									
The method used to adjust QMED for urbanisation published in Kjeldsen (2010) ¹⁰ in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable.									

⁹ Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

¹⁰ Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

3.2 Search for donor sites for QMED (if applicable)

Comment on potential donor sites	There are no river flow gauging stations within the study catchment. Gauging stations in adjacent hydrometric areas were therefore, assessed for suitability for data transfer to the study watercourse. There are 11 rural NRFA stations within 40km of the study area, based on the distance between catchment centroids. Comparison of QMED_{obs} and QMED_{cds} shows there is no consistent trend among the donor stations – 4 stations show QMED_{cds} overestimates QMED_{obs} and 7 show this underestimates QMED_{obs}. Recommendations from current research¹¹ (and new research¹² to be published soon) indicate that the geographically closest station to the study site tends to produce the best results. The latest research highlights that descriptors, such as AREA, are included in the regression equation for QMED, so the donor adjustment process accounts for the differences in values between the donor and subject catchments. It also explains that the overarching pattern of QMED model residuals across the UK follows a smooth spatial pattern, hence the recommendation to choose donors by proximity. The closest gauging station is 41015 (Ems @ Westbourne). The observed QMED for this station (2.25 m³/s) is slightly lower than QMED from catchment descriptors (2.41 m³/s). Given that there is no consistent trend among donor stations, it has been decided not to apply this station as a donor. Applying this donor would not have a significant impact on the results, and this would slightly reduce the flow estimates.
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3.3 Donor sites chosen and QMED adjustment factors

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

¹¹ Kjeldsen, T.R., Jones, D.A. and Bayliss, A.C. 2008. Improving the FEH statistical procedures for flood frequency estimation. Science Report SC050050, Environment Agency.

¹² Stewart, Lisa, Duncan Faulkner, Giuseppe Formetta, Adam Griffin, Tracey Haxton, Ilaria Prosdoci, Gianni Vesuviano and Andy Young (TBC). Estimating flood peaks and hydrographs for small catchments (Phase 2). Report – SC090031/R0, Environment Agency.

3.4 Derivation of pooling groups

Several subject sites may use the same pooling group.

Name of group	Site code from whose descriptor's group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
WEST_02	WEST_02	No	Reviewed and retained: 27073 (Brompton Beck @ Snainton Ings) 76011 (Coal Burn @ Coalburn) 27051 (Crimple @ Burn Bridge)	L-CV: 0.237 L-skew: 0.256
Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008).				

3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution (location, scale and shape after adjustments)	Growth factor for 100-year return period
WEST_01	P	WEST_02	GL – gives acceptable fit and is recommended distribution for UK catchments	Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.220 Shape: -0.272	3.01
TRIB_01	P	WEST_02		Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.194 Shape: -0.302	2.93
WEST_02	P	WEST_02		Urban Adjustment (WINFAP v4)	Location: 1.00 Scale: 0.213 Shape: -0.280	2.99
Notes Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters. Urban adjustments are all carried out using the WINFAP 4 urban adjustment procedures. Growth curves were derived using the procedures from Science Report SC050050 (2008).						

3.6 Flood estimates from the statistical method

Site code	Flood peak (m ³ /s) for the following AEP (%) events				
	50	20	5	1	0.1
WEST_01	0.6	0.8	1.2	1.8	3.2
TRIB_01	0.6	0.8	1.1	1.7	3.2
WEST_02	1.2	1.6	2.3	3.5	6.4

4 Revitalised flood hydrograph 2 (ReFH2) method

4.1 Parameters for ReFH2 model

In accordance with research findings, all catchments with URBEXT2000 up to 0.30 were modelled as if they were rural. Research on flood estimation in small catchments¹³ found that flood frequency estimates on such catchments were more accurate if the catchment was treated as rural. This reflects the difficulty of generalising the complex and locally-specific effects that urban development has on flood flows.

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

4.2 Design events for ReFH2 method: Lumped catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours:minutes)
WEST_02	Rural	Winter	07:30
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			No, a uniform storm duration and ARF will be applied to the model. A storm duration of 7:30 and ARF of 0.97 (based on the critical duration at WEST_02) was selected.

¹³ Stewart, Lisa, Duncan Faulkner, Giuseppe Formetta, Adam Griffin, Tracey Haxton, Ilaria Prosdociimi, Gianni Vesuviano and Andy Young (2021). Estimating flood peaks and hydrographs for small catchments (Phase 2). Report – SC090031/R0, Environment Agency.
GBQ-JBAU-XX-XX-RP-HO-0003-A2-P01_Emsworth_Hydrology_Report

4.3 Flood estimates from the ReFH2 method

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

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

5 Discussion and summary of results

5.1 Comparison of results from different methods

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

Site code	Ratio of peak flow to FEH Statistical peak	
	Return period 2 years	Return period 100 years
	ReFH2	ReFH2
WEST_01	0.86	0.70
TRIB_01	0.82	0.69
WEST_02	0.88	0.69

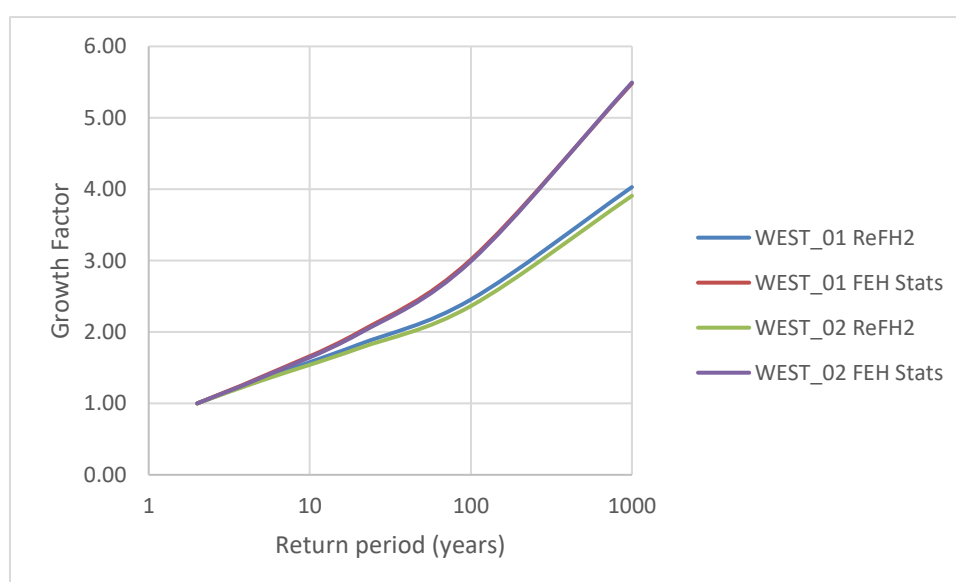


Figure 5-1: Growth factors

5.2 Final choice of method

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

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

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

5.4 Checks

Are the results consistent, for example at confluences?	Yes, QMED increases downstream.
What do the results imply regarding the return periods of floods during the period of record?	There is no local flow data (within the study area) against which to compare the design peak flow estimates.
What is the range of 100-year growth factors? Is this realistic?	The 1% AEP growth factor range for the methods is: - FEH Statistical: 2.9-3.0 - ReFH2: 2.4-2.5 The typical range is 2.1 to 4.0. The growth factors for both methods are within this range.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The 0.1%/1% AEP growth factor range for the methods is: - FEH Statistical: 1.8-1.9 - ReFH2: 1.6-1.7
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	There are no known studies of the West Brook catchment to compare with the results of this study.
Are the results compatible with the longer-term flood history?	There is no local flow data against which to compare the design flow estimates.
Describe any other checks on the results	Modelled levels and flood extents should be sensibility-checked to ensure that flow inputs result in realistic outputs, consistent with the local flood history.

5.5 Final results

FEH Statistical Method with ReFH2 0.1%/1% AEP ratio applied to the FEH Statistical 1% AEP flow for the 0.1% AEP event.

Site code	Flood peak (m ³ /s) for the following AEP (%) events				
	50	20	5	1	0.1
WEST_01	0.6	0.8	1.2	1.8	3.2
TRIB_01	0.6	0.8	1.1	1.7	3.2
WEST_02	1.2	1.6	2.3	3.5	6.4

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below)	To be supplied in a spreadsheet accompanying this document
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6 Annex

6.1 Pooling group – WEST_02

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
27073 (Brompton Beck @ Snainton Ings)	1.457	39	0.812	0.215	0.035	1.263
76011 (Coal Burn @ Coalburn)	1.605	42	1.84	0.163	0.301	0.996
27051 (Crimple @ Burn Bridge)	1.83	47	4.524	0.218	0.156	0.252
45816 (Haddeo @ Upton)	1.917	26	3.456	0.3	0.406	0.825
28033 (Dove @ Hollinsclough)	2.142	44	4.177	0.228	0.371	0.536
26016 (Gypsy Race @ Kirby Grindalythe)	2.361	22	0.1	0.321	0.266	1.201
25019 (Leven @ Easby)	2.38	41	5.09	0.342	0.386	1.637
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.499	9	5.777	0.271	0.151	2.606
47022 (Tory Brook @ Newnham Park)	2.534	25	6.176	0.257	0.191	0.456
25011 (Langdon Beck @ Langdon)	2.568	33	15.647	0.232	0.328	0.683
25003 (Trout Beck @ Moor House)	2.597	46	15.142	0.168	0.29	0.885
71003 (Croasdale Beck @ Croasdale Flume)	2.67	37	10.9	0.212	0.323	0.312
27010 (Hodge Beck @ Bransdale Weir)	2.736	41	9.42	0.224	0.293	0.116
206006 (Annalong @ Recorder)	2.771	48	15.33	0.189	0.052	2.23
Total		500				
Weighted means				0.237	0.256	

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