Annexe D: Drainage Assessment

Appendix M

Haweswater Aqueduct Resilience Programme

Surface Water Drainage Assessment

Date: 7th May 2020

Version: 1

Version	Purpose / summary of changes	Date	Written By	Checked By	Approved By
1	Task 3 Deliverable	07/05/2020	M Lloyd		

Appendix M

Contents

Appendix M

1. Introduction

During establishment of each tunnel shaft/portal site it will be necessary to construct concrete or blacktop surfaces to provide a tunnel working platform, an offices/welfare/parking area and a temporary haul road. These will introduce impermeable surfaces to the existing greenfield sites, resulting in increased volumes of surface water runoff during rainfall events.

To comply with planning legislation it is necessary to apply the principles of Sustainable Drainage Systems (SuDS) to any significant development, including the temporary sites found on this project.

The SuDS approach involves slowing down and reducing the quantity of surface water runoff from a developed area to manage downstream flood risk, and reducing the risk of that runoff causing pollution. This is achieved by harvesting, infiltrating, slowing, storing, conveying and treating runoff on site and, where possible, on the surface rather than underground.

Owing to the temporary nature of the tunnel shaft/portal sites, many of the SuDS techniques are not appropriate. However, the following techniques are relevant:

- Infiltration drainage;
- Attenuation storage.

Each site has been assessed to determine how best to apply the above techniques, and the detailed procedure is discussed below.

Additional water flows will be generated by the tunnelling activities and flow rates have been estimated by the tunnelling team. An allowance has been included in the drainage assessment of each site, to take account of these estimated flows.

Flood risk has also been assessed for each tunnel shaft/portal site. This is not intended to represent a formal flood risk assessment (as required for a planning application) but can be used to inform decisions regarding the site layout.

2. Assessment Approach

Each tunnel shaft/portal site has been assessed using the following procedure:

i. Determine the likelihood and extent of flood risk from:
   - Fluvial sources (i.e. rivers and other watercourses);
   - Surface water runoff (i.e. overland flow).

ii. Confirm the existing surface water drainage regime:
   - Determine the local soil type and its standard percentage runoff value (using www.uksuds.com);
   - Reference to Ordnance Survey 1:2500 mapping, overlain with Lidar-derived 1 metre contours, to determine drainage flow paths and receiving watercourses;
   - Using Google Earth aerial photography for visual confirmation of the drainage flow paths and watercourses.

iii. Quantify mitigation measures to protect this drainage regime:
   - Quantify the impermeable areas that will be created;
   - Consider the suitability of infiltration drainage systems (e.g. soakaways, roadside swales) for selected areas;
   - Where an infiltration drainage system may be effective, confirm that the site does not lie within a groundwater source protection zone (https://magic.defra.gov.uk/MagicMap.aspx);
   - For the remaining areas, obtain a preliminary attenuation storage volume and acceptable discharge rate;
   - Increase the attenuation storage arrangements by an appropriate factor to allow for additional water flows arising from the tunnelling activities.
   - Assess the topography to identify a suitable location for the attenuation storage and water treatment plant, plus a drainage route to a suitable watercourse. Gravity drainage systems are preferred, with pumped systems only being shown as a last resort in particularly difficult situations.
   - The point of discharge is selected (using OS mapping, Lidar contours and Google Earth information) where the watercourse appears to have sufficient capacity to receive the planned discharges. This will, in due course, require site survey to confirm assumptions that have had to be made.

3. Basis of Analysis

3.1 Infiltration Drainage

When detailed soil infiltration rates are not available, it is usual to consider soils with a standard percentage runoff of 30% (or less) to have potential for infiltration drainage systems. This approach has been adopted for this high level assessment.

A preliminary soakaway volume estimate has been produced for each soakaway location, to confirm land availability for the required soakaway dimensions. However each calculation is based on an assumed local infiltration rate, which may be highly inaccurate. For this reason the calculated soakaway dimensions are not quoted in this report.

It is recommended that infiltration tests be conducted at locations where infiltration systems are being considered, in order to confirm (or exclude) their application.

Where infiltration drainage is proposed, a check has been made (using https://magic.defra.gov.uk/MagicMap.aspx) to confirm that the site is not in a groundwater source protection zone.

3.2 Attenuation Storage

Attenuation storage volume estimates have been obtained using a storage assessment method developed by HR Wallingford (www.uksuds.com/drainage-calculation-tools/surface-water-storage).

The surface water storage volume estimation tool is based on correlations between storage requirements and hydrological and hydraulic characteristics of sites. This methodology is based on the premise that the flow rate discharge constraints for storm water runoff from the site are defined by the greenfield runoff rates for the 1 year, 30 year and 100 year return periods.

The drainage design criteria applied are in line with best practice in the SuDS Manual and the SuDS Standards in England, Wales and Northern Ireland.

The methodology takes into consideration the partial use of infiltration, along with whether or not permeable areas contribute runoff. It also makes allowances for different hydrological regions, climate change and other factors.

A minimum discharge rate of 5 l/s has been applied, as this is generally regarding as a practical minimum for static flow controls. For some of the sites this flow rate is larger than the calculated greenfield runoff from the catchment area.

3.3 Generated Water Flows

Additional water flows will be generated by the tunnelling activities. The tunnelling team has prepared an estimate of these flows for each tunnel shaft/portal site, and this has previously been supplied to United Utilities. This report does not consider these generated flows in detail, but an indicative flow allowance is included for each shaft/portal site in Table 1.

It is anticipated that water recycling will be implemented within each tunnelling shaft/portal site, to be used for washdown activities. This will significantly reduce the demand for potable water and will also reduce the flow rate of generated water that has to discharged to a watercourse.

3.4 Water Quality

The tunnelling activities will result in contaminated runoff from the working platform. These areas are considered unsuitable for infiltration owing to the risk of introducing contaminants into the underlying soils. So it is recommended that these areas be drained via an attenuation lagoon/tank to a packaged water treatment plant (WTP), to ensure that the WTP receives a steady inflow (avoiding the peak flows caused by intense rainfall events). The cleaned water will then be discharged to the receiving watercourse.

Runoff from temporary haul roads, and also the offices/welfare/parking areas, will be relatively uncontaminated. This water can be drained either by infiltration (where possible), or into an attenuation lagoon/tank before discharge to the receiving watercourse. Sometimes this runoff will also pass through the water treatment plant, where the site layout favours this arrangement.

4. Results

The results of these analyses are included in Table 1 below.

For each site, these results provide an indication of whether infiltration systems may be appropriate for parts of the proposed impermeable areas. For areas that cannot be drained by infiltration, an estimate of the required attenuation storage volume is given along with the allowable discharge rate (as discussed above).

The site layout drawings (see Appendix E) include the key features of each drainage system, and the location of each drainage outfall.

For each tunnel shaft/portal site this report also includes the following:

i. **Flood Map For Planning** (https://flood-map-for-planning.service.gov.uk)

A plan showing the following fluvial flood risk zones:

Flood Zone	Definition
Zone 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding. (Land shown in dark blue on the Flood Map)
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)

ii. **Long Term Flood Risk Map** (https://flood-warning-information.service.gov.uk/long-term-flood-risk)

A plan showing the following surface water flood risk categories:

Flood Category	Definition
Very Low Risk	Land having a less than 1 in 1,000 annual probability of surface water flooding. (Shown as 'clear' on the flood map – all land outside the Low, Medium and High Risk Zones)
Low Risk	Land having between a 1 in 100 and 1 in 1,000 annual probability of surface water flooding. (Land shown in light blue on the flood map)
Medium Risk	Land having between a 1 in 30 and 1 in 100 annual probability of surface water flooding. (Land shown in medium blue on the flood map)
High Risk	Land having greater than 1 in 30 annual probability of surface water flooding. (Land shown in dark blue on the flood map)

iii. **Surface Water Storage Volume Estimation** (https://www.uksuds.com/drainage-calculation-tools/surface-water-storage)

A one page report summarises the hydrological and hydraulic analysis, as described in the 'Attenuation storage' section.

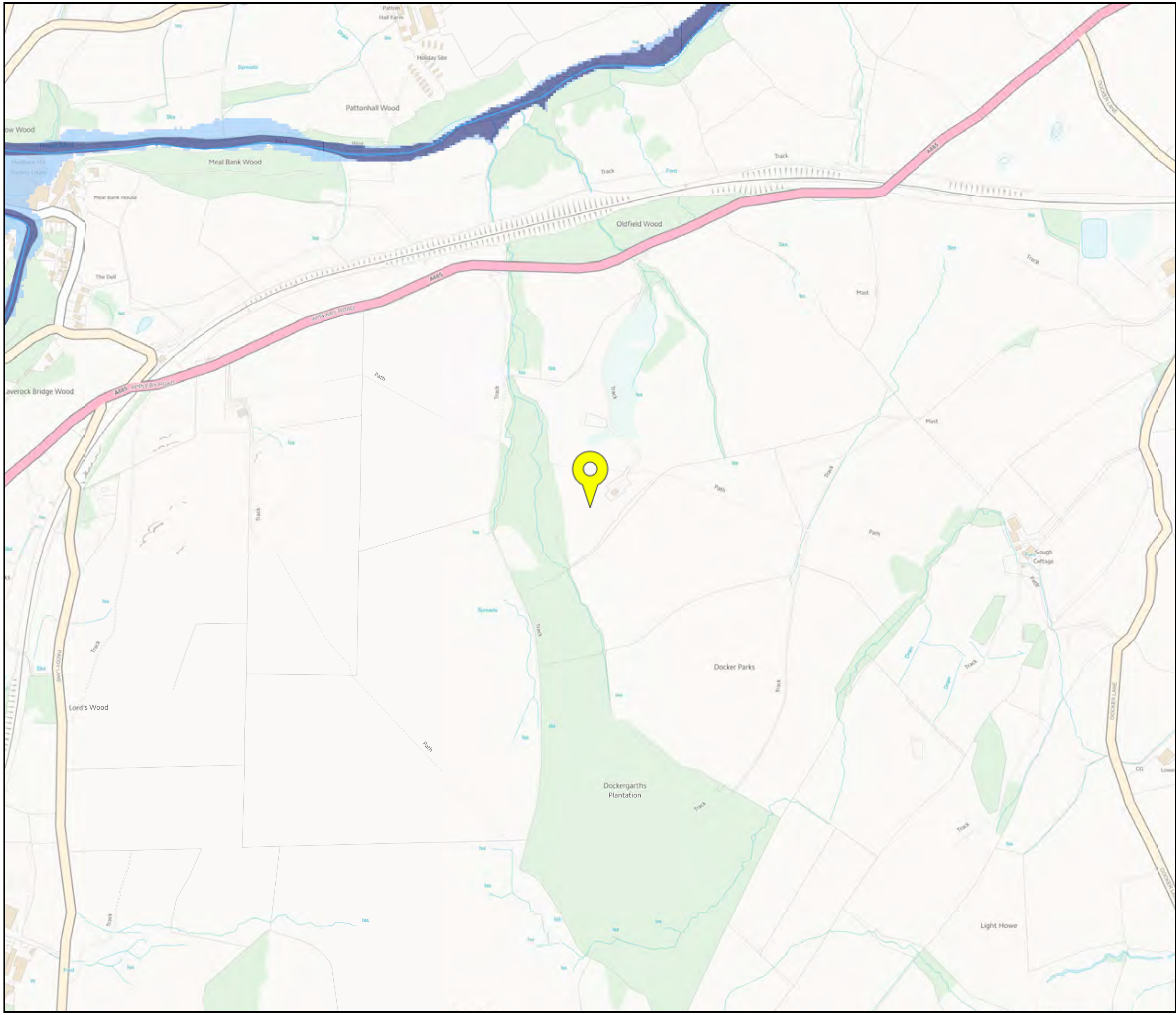
Table 1 - Tunnelling shaft/portal sites - Summary of drainage assessment

SITE DETAILS			FLOOD RISK		SOIL DATA & HYDROGEOLOGY				IMPERMEABLE CATCHMENT			ATTENUATION DATA		GENERATED FLOWS
Site name	Drive / Reception	Coords (shaft) E, N	Fluvial flood risk	Surface water flood risk	SOIL type	SPR %	Source Protection Zone	Suitability for infiltration drainage	Impermeable area ha	Area drained to infiltration ha	Area drained to attenuation pond/tank ha	Attenuation storage volume cu.m	Pond/tank maximum discharge rate l/s	Estimated discharge from tunnelling activities l/s
TR1-A	Reception	355099, 495089	Zone 1 (low risk)	Very low risk	2	30%	No	Yes	1.11	0.61	0.5	280	5.0	2.5
TR1-C	Drive	356540, 492325	Zone 1 (low risk)	Very low risk	2	30%	No	Yes	1.05	0.24	0.81	675	5.0	4
TR2-A	Reception	357580, 489485	Zone 1 (low risk)	Very low risk	2	30%	No	Yes	0.5	0.12	0.38	193	5.0	2.5
TR2-B	Drive	359600, 483925	Zone 1 (low risk)	Very low risk	2	30%	No	Yes	1.24	0.51	0.73	426	5.0	4
TR2-B-1	Reception	360253, 483533	Zone 1 (low risk)	Very low risk	2	30%	No	Yes	0.77	0.14	0.63	347	5.0	2.5
TR3-A	Reception	363590, 465537	Zone 1 (low risk)	Very low risk	4	47%		No	0.61	0	0.61	481	6.3	2.5
TR3-C	Drive	368914, 450480	Zone 1 (low risk)	Very low risk	4	47%		No	0.8	0	0.8	568	9.7	4
TR4-A	Reception	369700, 448918	Zone 1 (low risk)	Very low risk	4	47%		No	0.53	0	0.53	366	6.2	2.5
TR4-B	Drive	371012, 445010	Zone 1 (low risk)	Very low risk	4	47%		No	0.97	0	0.97	706	10.0	4

SITE DETAILS			FLOOD RISK		SOIL DATA & HYDROGEOLOGY				IMPERMEABLE CATCHMENT			ATTENUATION DATA		GENERATED FLOWS
Site name	Drive / Reception	Coords (shaft) E, N	Fluvial flood risk	Surface water flood risk	SOIL type	SPR %	Source Protection Zone	Suitability for infiltration drainage	Impermeable area ha	Area drained to infiltration ha	Area drained to attenuation pond/tank ha	Attenuation storage volume cu.m	Pond/tank maximum discharge rate l/s	Estimated discharge from tunnelling activities l/s
TR5-A	Reception	377077, 430167	Zone 1 (low risk)	Medium risk	4	47%		No	0.5	0	0.5	284	5.0	2.5
TR5-I	Dual drive	379724, 422064	Zone 1 (low risk)	Very low risk	5	53%		No	1.7	0	1.7	1055	23.0	6
TR5-I	Offices /welfare /parking		Zone 1 (low risk)	Very low risk	5	53%		No	0.7	0	0.7	435	9.5	---
TR6-G	Reception	382229, 412158	Zone 1 (low risk)	Very low risk	5	53%		No	0.5	0	0.5	264	5.5	2.5

Shaft / Portal Sites – Drainage Assessment Data

TR1-A	Reception Site
TR1-C	Drive Site
TR2-A	Reception Site
TR2-B	Drive Site
TR2-B1	Drive Site
TR3-A	Reception Site
TR3-C	Drive Site
TR4-A	Reception Site
TR4-B	Drive Site
TR5-A	Reception Site
TR5-I	Dual Drive Site
TR6-G	Reception Site



Environment Agency

Flood map for planning

Your reference
TR1-A

Location (easting/northing)
355083/495116

Scale
1:10000

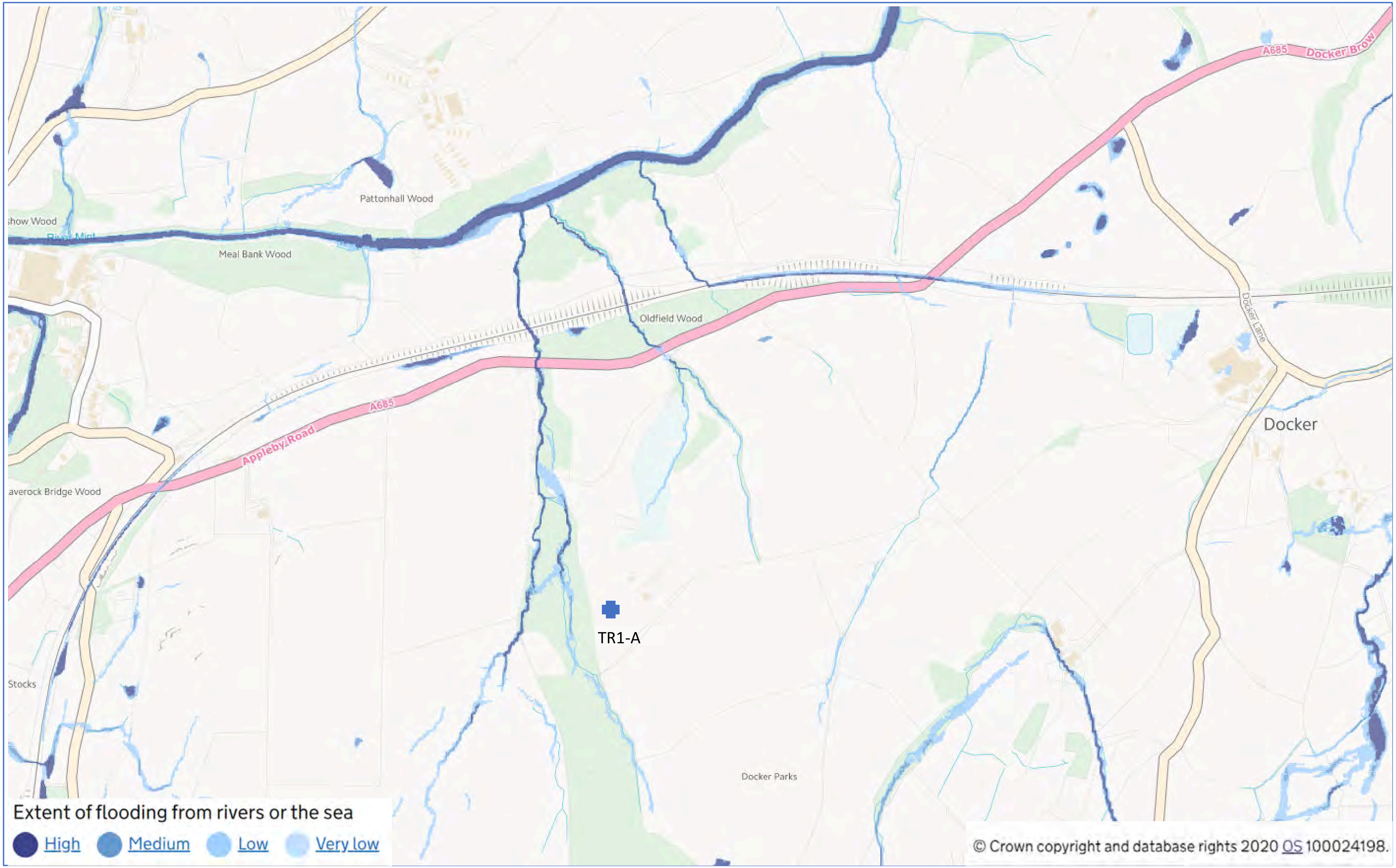
Created
7 May 2020 13:25

Selected point
Flood zone 3
Flood zone 3: areas benefitting from flood defences
Flood zone 2
Flood zone 1
Flood defence
Main river
Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR1-A

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR1-A
Site location:	LA8 0DA

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.34858° N
Longitude:	2.69099° W
Reference:	2563754087
Date:	Apr 21 2020 12:34

Site characteristics

Total site area (ha):	0.5
Significant public open space (ha):	0
Area positively drained (ha):	0.5
Impermeable area (ha):	0.5
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.5
Net impermable area for storage volume design (ha):	0.5
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	2	2
SPR:	0.3	0.3

Hydrological characteristics

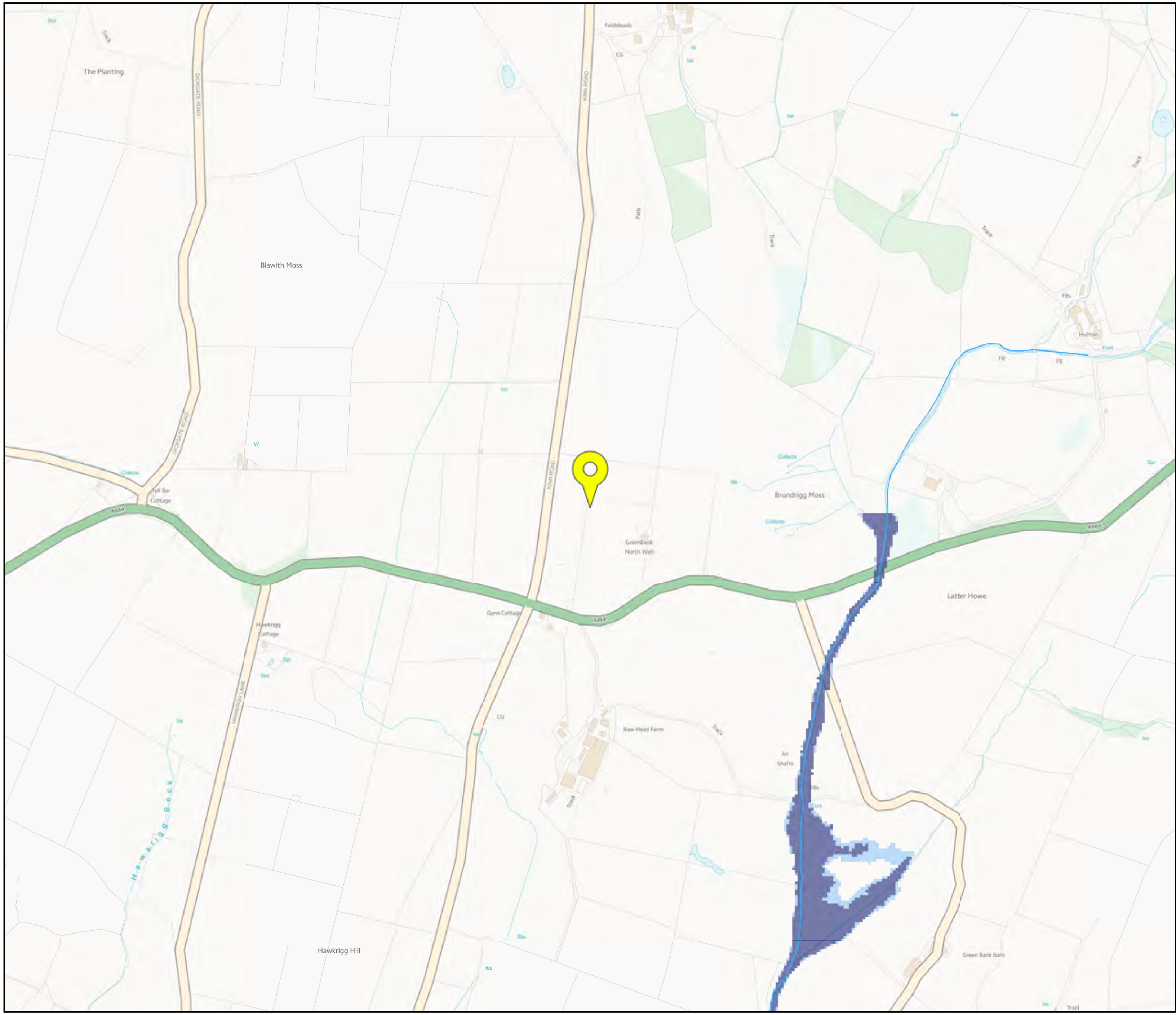
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	101.97
FEH / FSR conversion factor:	1	0.99
SAAR (mm):	1428	1428
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	2.1	2.1
Q_{BAR} for net site area (l/s):	2.1	2.1

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	280	276
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	280	276



Environment Agency

Flood map for planning

Your reference
TR1-C

Location (easting/northing)
356540/492325

Scale
1:10000

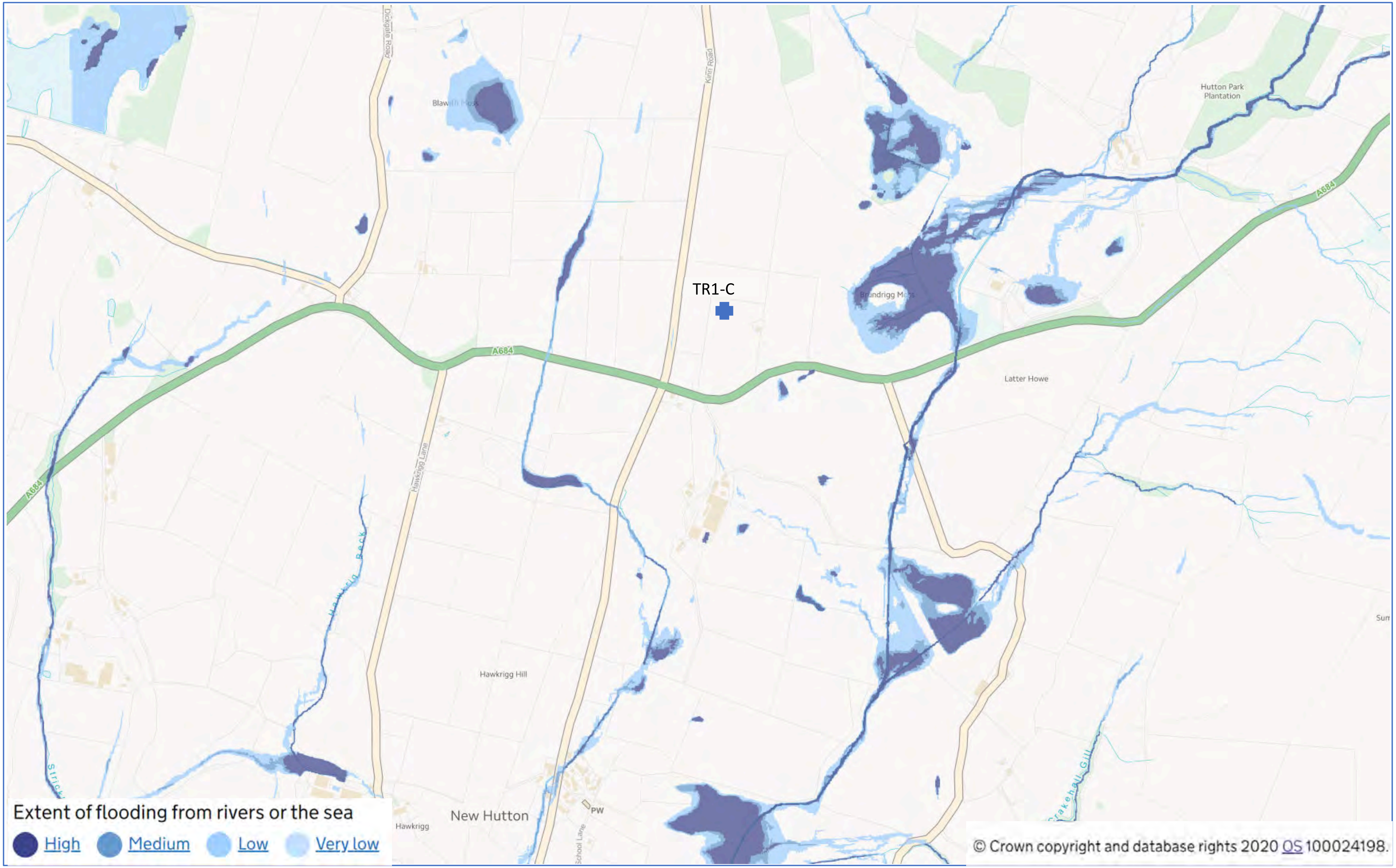
Created
7 May 2020 14:43

- Selected point
- Flood zone 3
- Flood zone 3: areas benefitting from flood defences
- Flood zone 2
- Flood zone 1
- Flood defence
- Main river
- Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR1-C

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR1-C
Site location:	LA8 0AR

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.32451° N
Longitude:	2.66833° W
Reference:	788290056
Date:	Apr 22 2020 08:02

Site characteristics

Total site area (ha):	0.81
Significant public open space (ha):	0
Area positively drained (ha):	0.81
Impermeable area (ha):	0.81
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.81
Net impermable area for storage volume design (ha):	0.81
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	2	2
SPR:	0.3	0.3

Hydrological characteristics

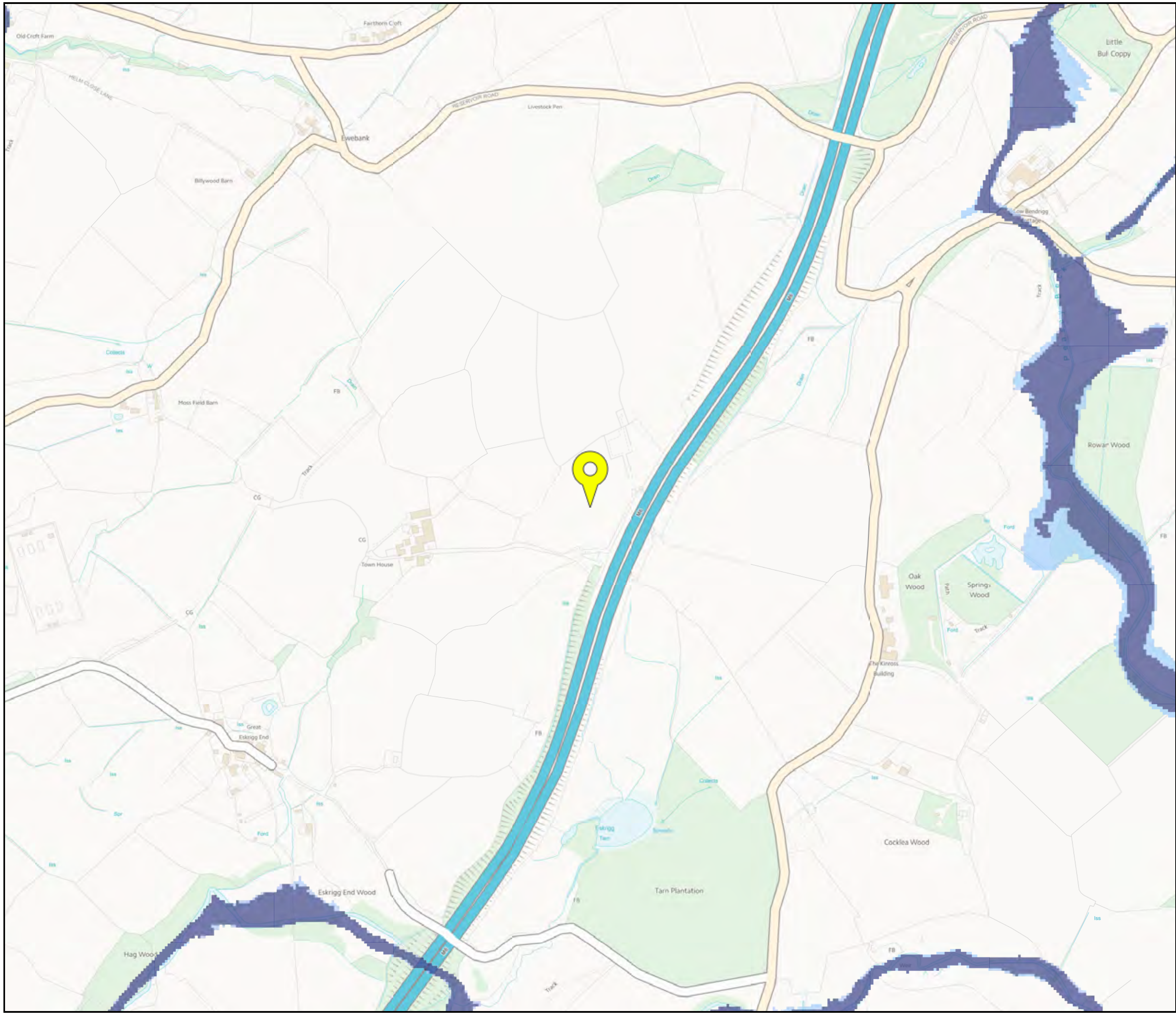
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	101.97
FEH / FSR conversion factor:	1.04	0.99
SAAR (mm):	1418	1418
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	3.37	3.37
Q_{BAR} for net site area (l/s):	3.37	3.37

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	734	675
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	734	675



Environment Agency

Flood map for planning

Your reference
TR2-A

Location (easting/northing)
357580/489485

Scale
1:10000

Created
7 May 2020 13:47

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

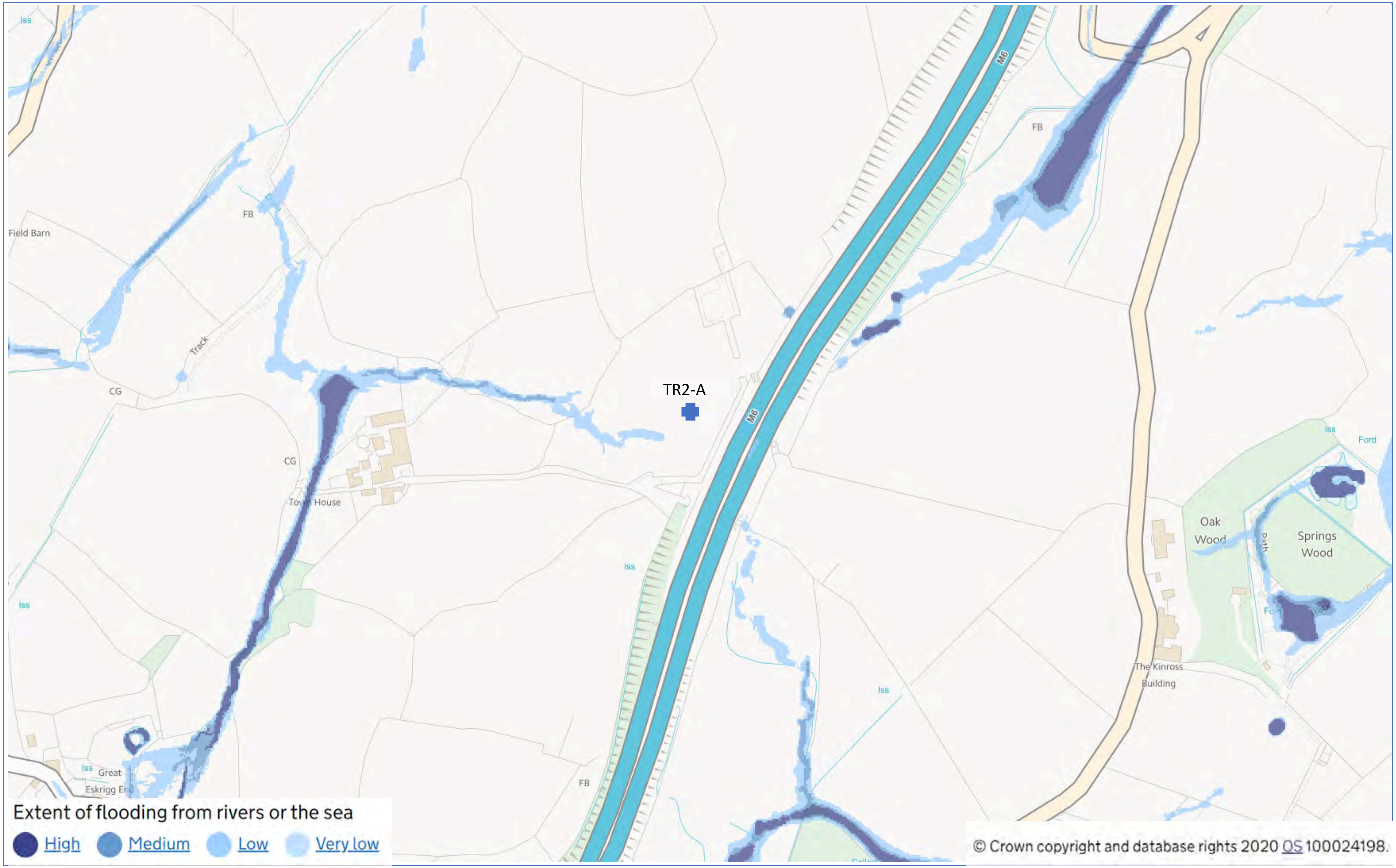
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR2-A

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR2-A
Site location:	LA8 0NR

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.30042° N
Longitude:	2.65254° W
Reference:	3267767033
Date:	Apr 20 2020 14:41

Site characteristics

Total site area (ha):	0.38
Significant public open space (ha):	0
Area positively drained (ha):	0.38
Impermeable area (ha):	0.38
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.38
Net impermable area for storage volume design (ha):	0.38
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	2	2
SPR:	0.3	0.3

Hydrological characteristics

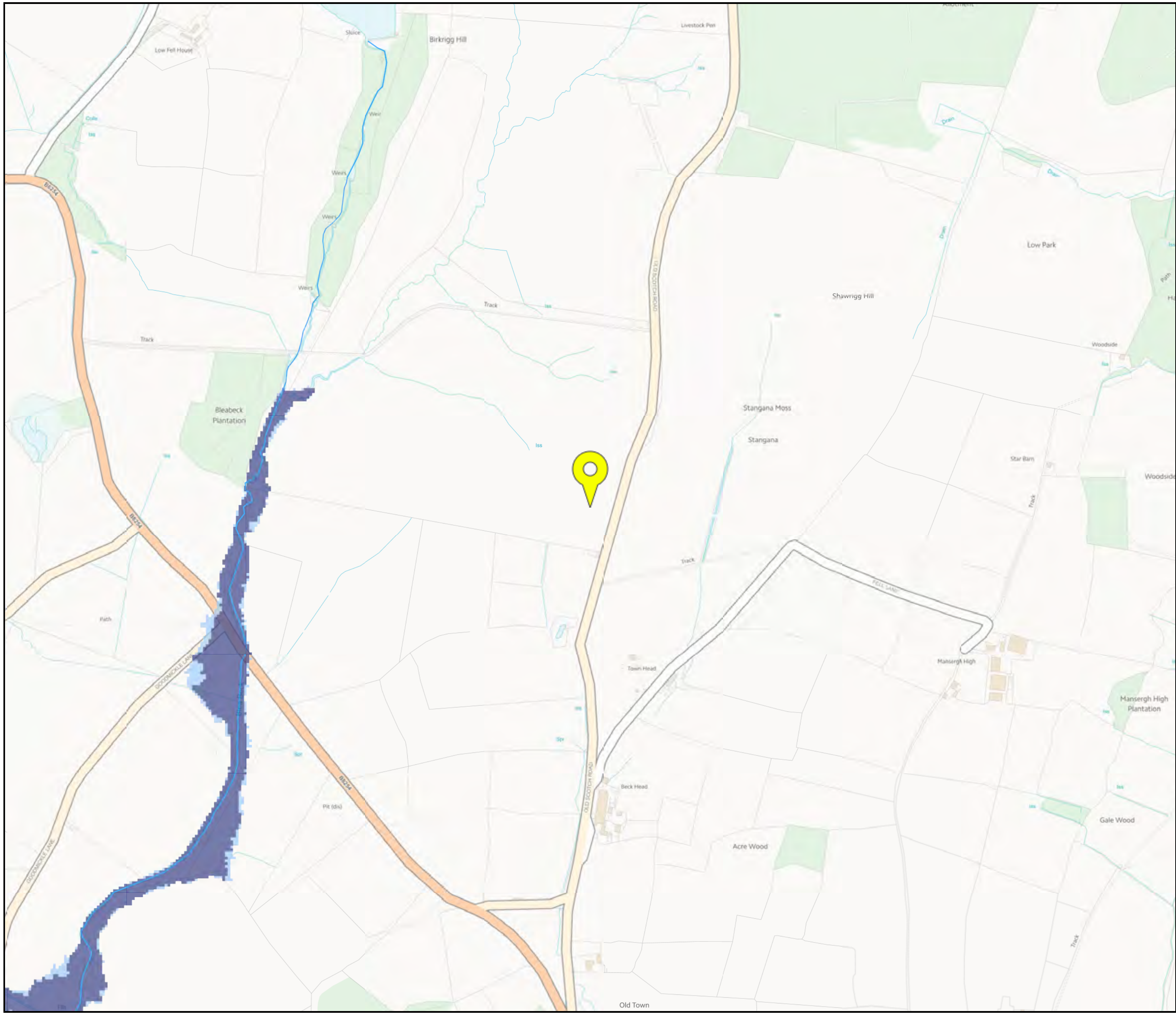
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	101.97
FEH / FSR conversion factor:	1.06	0.99
SAAR (mm):	1375	1375
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	1.53	1.53
Q_{BAR} for net site area (l/s):	1.53	1.53

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	193	172
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	193	172



Environment Agency

Flood map for planning

Your reference
TR2-B

Location (easting/northing)
359600/483925

Scale
1:10000

Created
29 Apr 2020 12:31

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

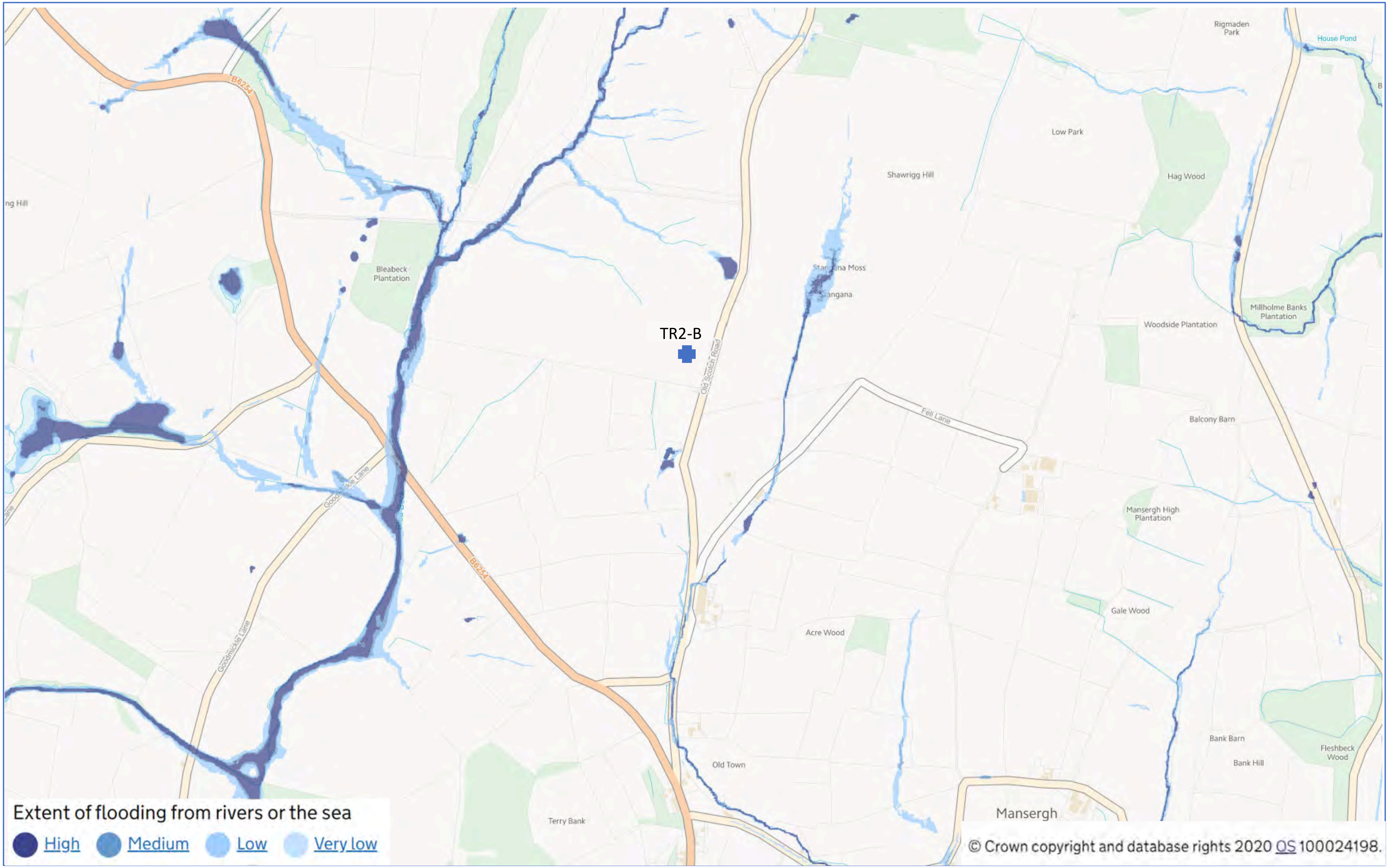
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR2-B

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR2-B Working Platform
Site location:	LA6 2ER

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.24976° N
Longitude:	2.62189° W
Reference:	2331891271
Date:	Apr 29 2020 14:58

Site characteristics

Total site area (ha):	0.73
Significant public open space (ha):	0
Area positively drained (ha):	0.73
Impermeable area (ha):	0.73
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.73
Net impermable area for storage volume design (ha):	0.73
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	2	2
SPR:	0.3	0.3

Hydrological characteristics

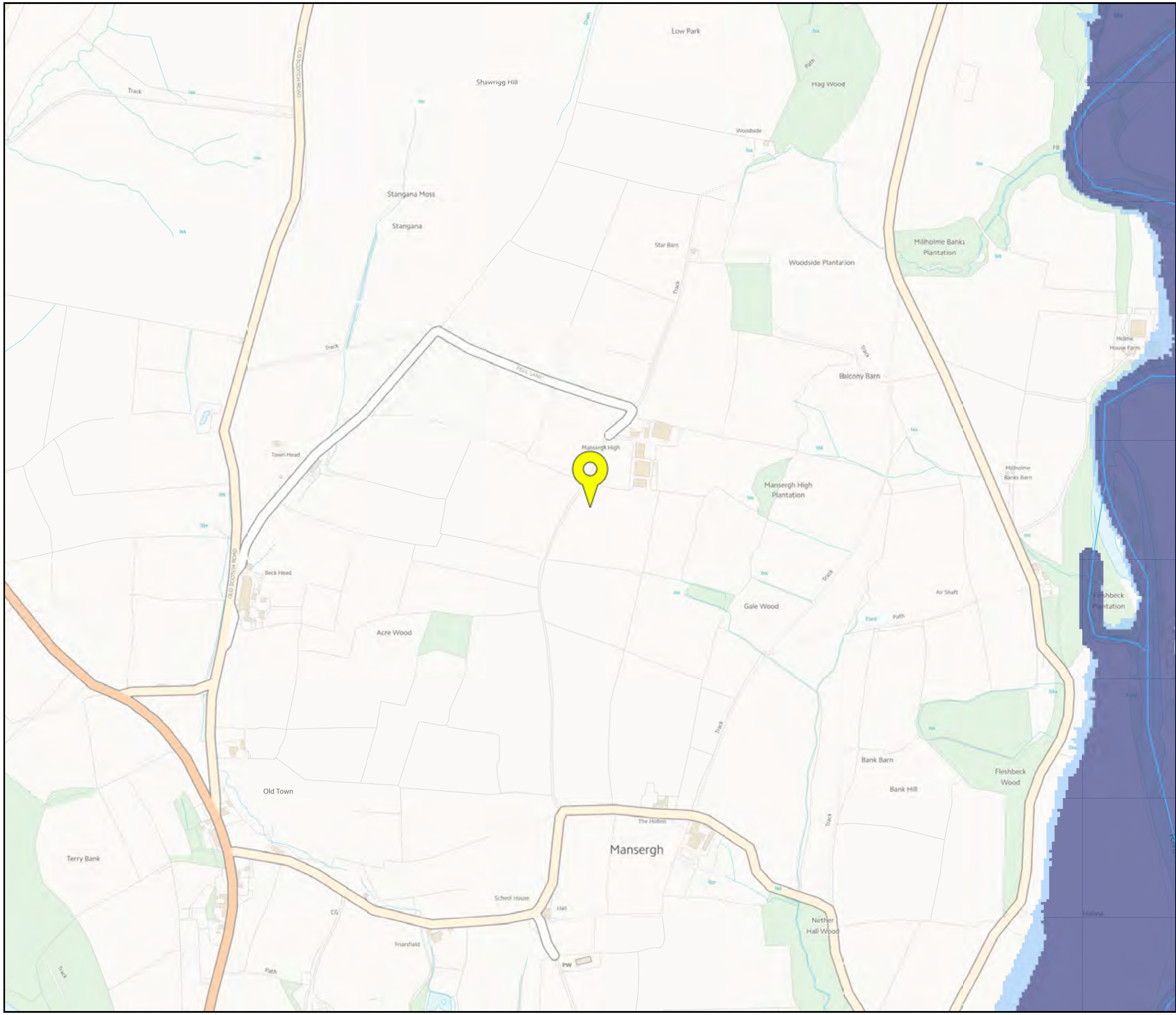
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	70
Rainfall 100 yrs 12 hrs:	--	93.24
FEH / FSR conversion factor:	1.11	1.11
SAAR (mm):	1304	1304
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.3	0.3
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	2.75	2.75
Q_{BAR} for net site area (l/s):	2.75	2.75

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	426	426
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	426	426



Environment Agency

Flood map for planning

Your reference
TR2-B1

Location (easting/northing)
360253/483533

Scale
1:10000

Created
7 May 2020 13:50

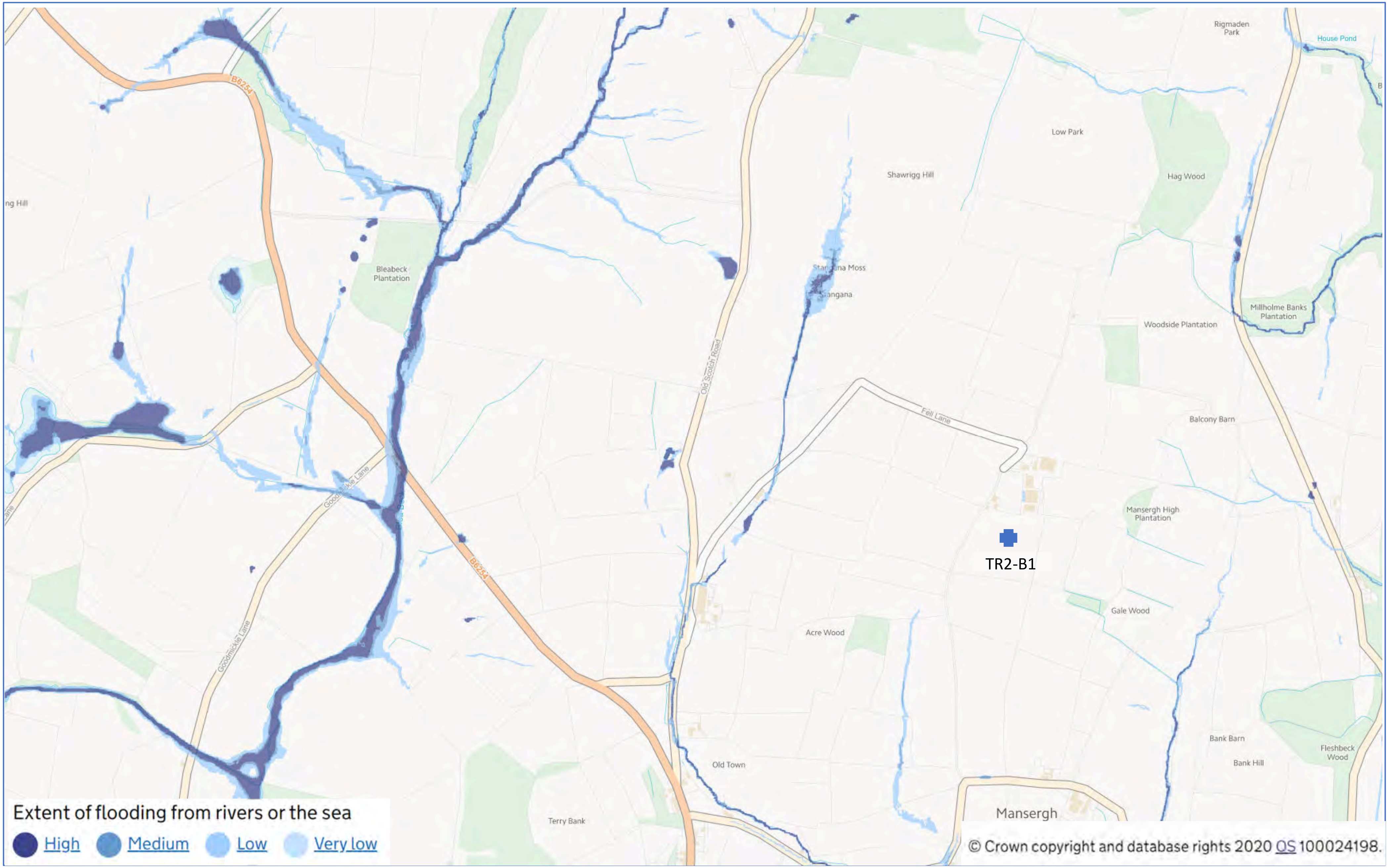
Selected point
Flood zone 3
Flood zone 3: areas benefitting from flood defences
Flood zone 2
Flood zone 1
Flood defence
Main river
Flood storage area

0 100 200 300m

Page 2 of 2

Long Term Flood Risk Map – TR2-B1

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR2-B1
Site location:	LA6 2EW

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.24598° N
Longitude:	2.61117° W
Reference:	3667468301
Date:	May 07 2020 15:01

Site characteristics

Total site area (ha):	0.63
Significant public open space (ha):	0
Area positively drained (ha):	0.63
Impermeable area (ha):	0.63
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.63
Net impermable area for storage volume design (ha):	0.63
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	2	2
SPR:	0.3	0.3

Hydrological characteristics

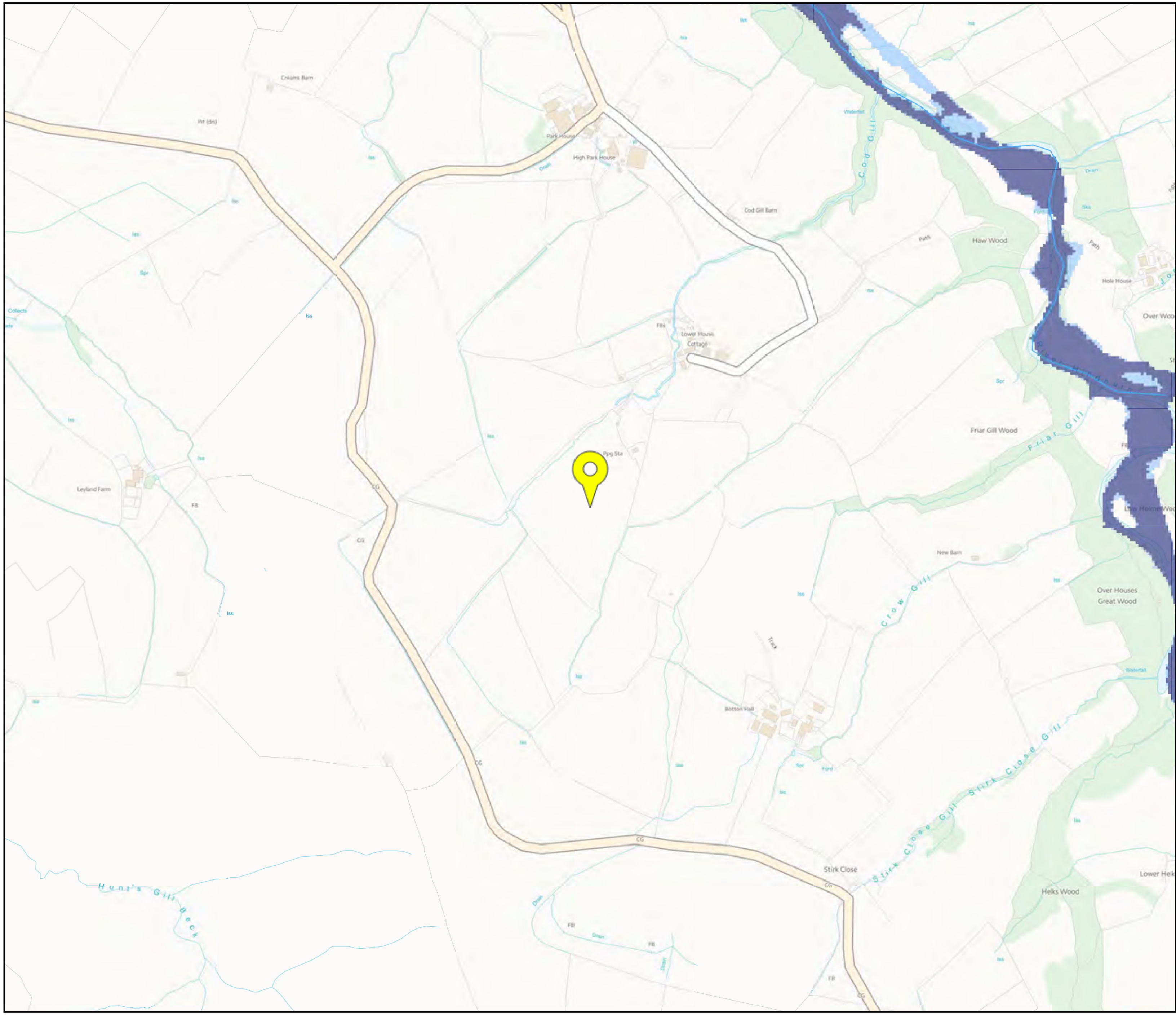
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	70
Rainfall 100 yrs 12 hrs:	--	93.24
FEH / FSR conversion factor:	1.11	1.11
SAAR (mm):	1317	1317
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.3	0.3
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	2.41	2.41
Q_{BAR} for net site area (l/s):	2.41	2.41

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	347	347
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	347	347



Environment Agency

Flood map for planning

Your reference
TR3-A

Location (easting/northing)
363590/465537

Scale
1:10000

Created
7 May 2020 13:52

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

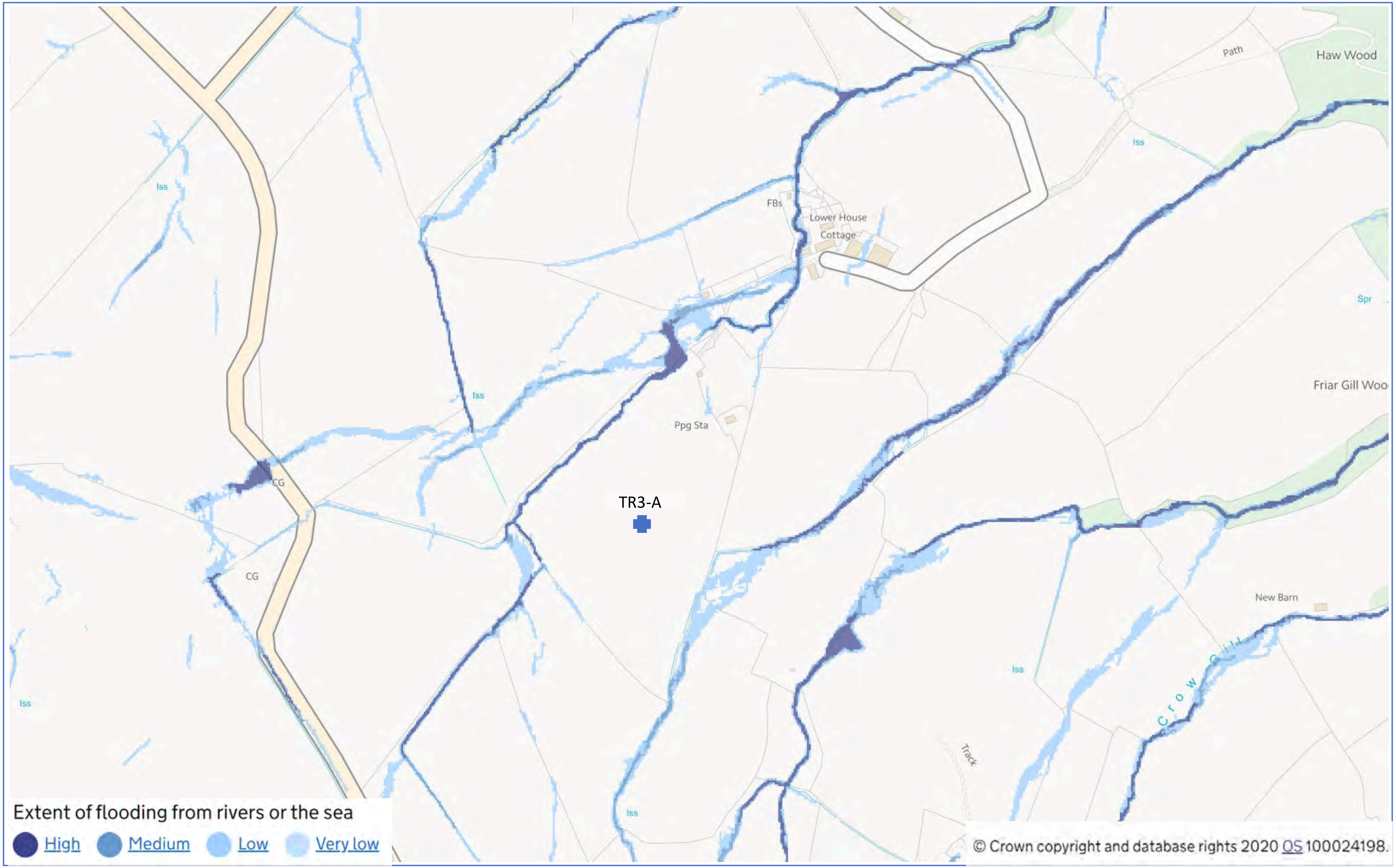
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR3-A

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

HR Wallingford — Working with water

Calculated by:	Michael Lloyd
Site name:	TR3-A
Site location:	LA2 8QU

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	54.08500° N
Longitude:	2.55708° W
Reference:	4216924200
Date:	Apr 28 2020 12:02

Site characteristics

Total site area (ha):	0.61
Significant public open space (ha):	0
Area positively drained (ha):	0.61
Impermeable area (ha):	0.61
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.61
Net impermable area for storage volume design (ha):	0.61
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	4	4
SPR:	0.47	0.47

Hydrological characteristics

	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	118.45
FEH / FSR conversion factor:	1.15	1.15
SAAR (mm):	1349	1349
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	6.35	6.35
Q_{BAR} for net site area (l/s):	6.35	6.35

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5.5	5.5
1 in 30 years (l/s):	6.3	6.3
1 in 100 year (l/s):	6.3	6.3

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m³):	481	481
Long term storage 1/100 years (m³):	0	0
Total storage 1/100 years (m³):	481	481

Environment Agency

Flood map for planning

Your reference
TR3-C

Location (easting/northing)
368914/450480

Scale
1:10000

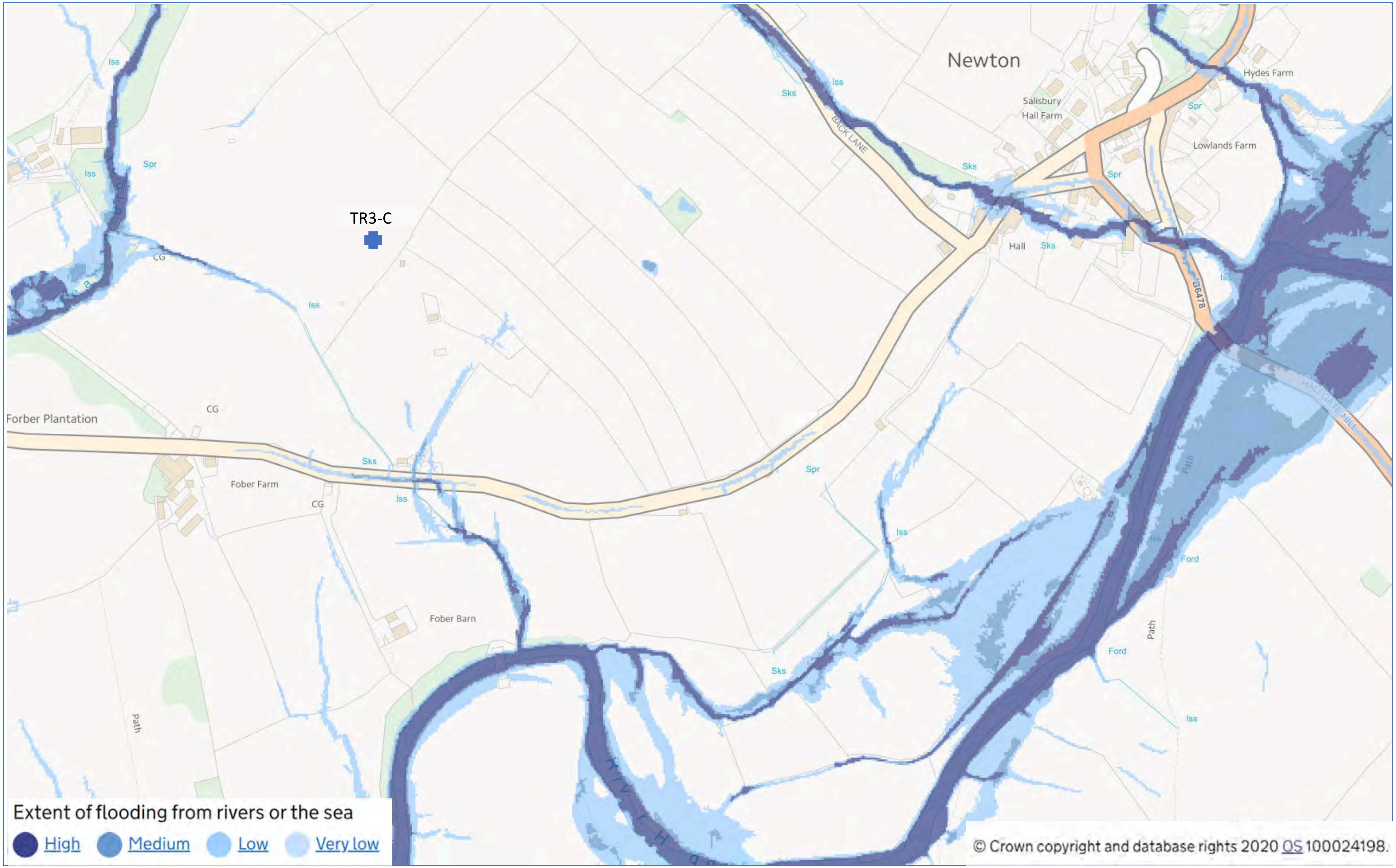
Created
7 May 2020 13:55

- Selected point
- Flood zone 3
- Flood zone 3: areas benefitting from flood defences
- Flood zone 2
- Flood zone 1
- Flood defence
- Main river
- Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR3-C

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR3-C Portal & Approach road
Site location:	BB7 3ED

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.94825° N
Longitude:	2.47474° W
Reference:	1042874444
Date:	Apr 30 2020 18:55

Site characteristics

Total site area (ha):	0.8
Significant public open space (ha):	0
Area positively drained (ha):	0.8
Impermeable area (ha):	0.8
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.8
Net impermable area for storage volume design (ha):	0.8
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	4	4
SPR:	0.47	0.47

Hydrological characteristics

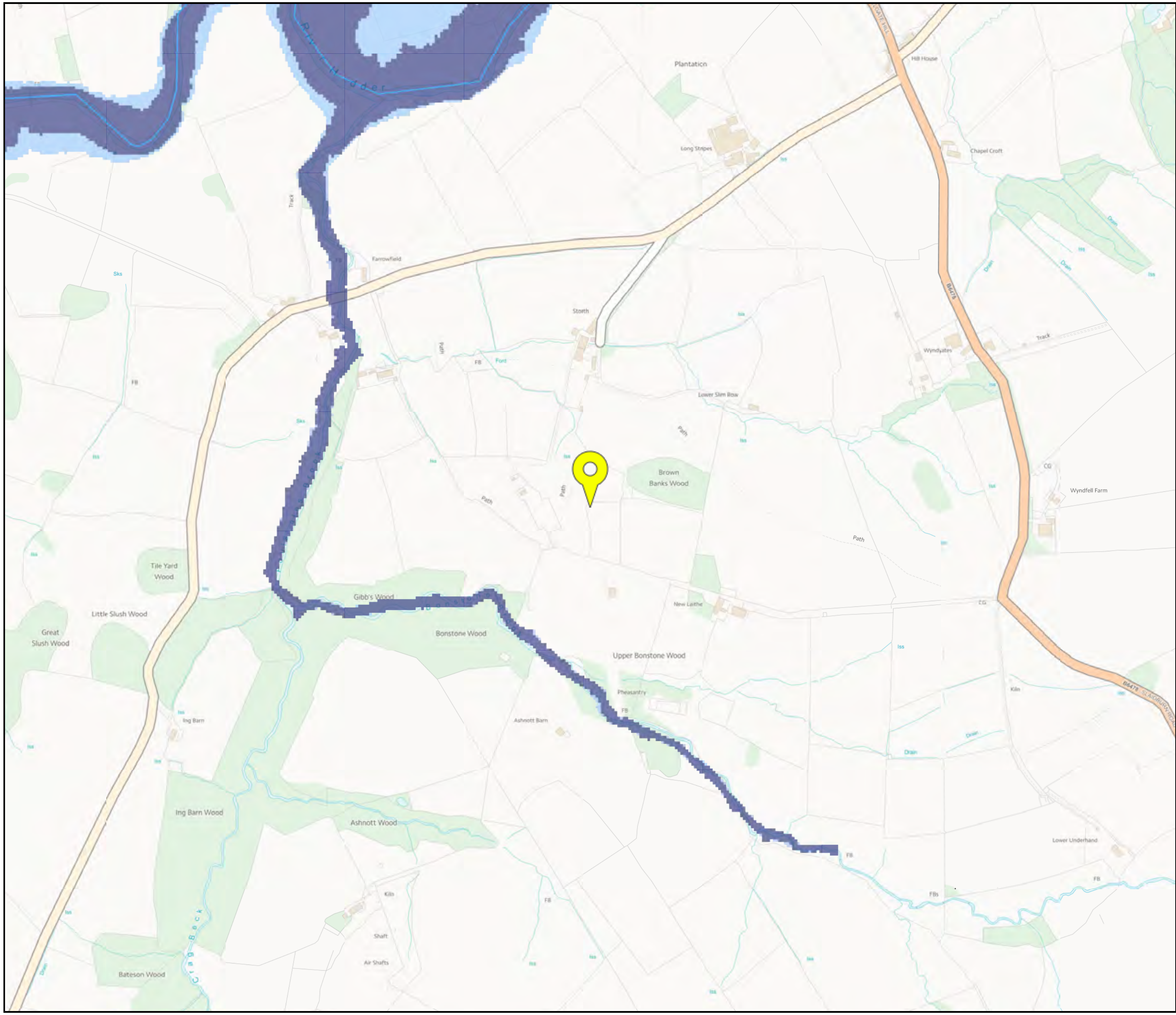
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	118.45
FEH / FSR conversion factor:	1.15	1.15
SAAR (mm):	1535	1535
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	9.68	9.68
Q_{BAR} for net site area (l/s):	9.68	9.68

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	8.4	8.4
1 in 30 years (l/s):	9.7	9.7
1 in 100 year (l/s):	9.7	9.7

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	568	568
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	568	568



Environment Agency

Flood map for planning

Your reference
TR4-A

Location (easting/northing)
369700/448918

Scale
1:10000

Created
7 May 2020 13:57

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

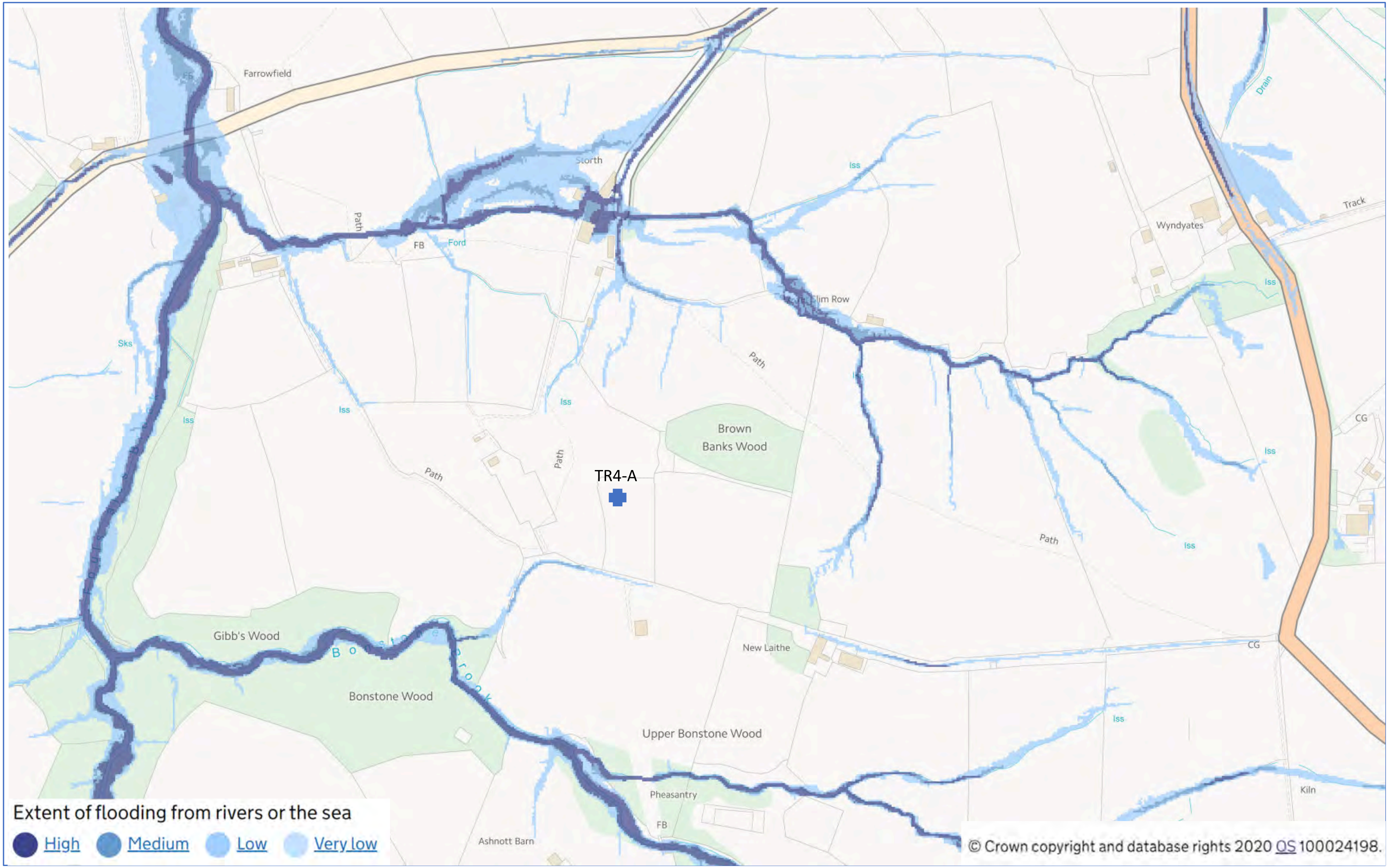
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR4-A

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

HR Wallingford
Working with water

Calculated by:	Michael Lloyd
Site name:	TR4-A
Site location:	BB7 3AB

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance “Rainfall runoff management for developments”, SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.93698° N
Longitude:	2.46171° W
Reference:	2651495097
Date:	Apr 22 2020 16:08

Site characteristics

Total site area (ha):	0.53
Significant public open space (ha):	0
Area positively drained (ha):	0.53
Impermeable area (ha):	0.53
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.53
Net impermable area for storage volume design (ha):	0.53
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	4	4
SPR:	0.47	0.47

Hydrological characteristics

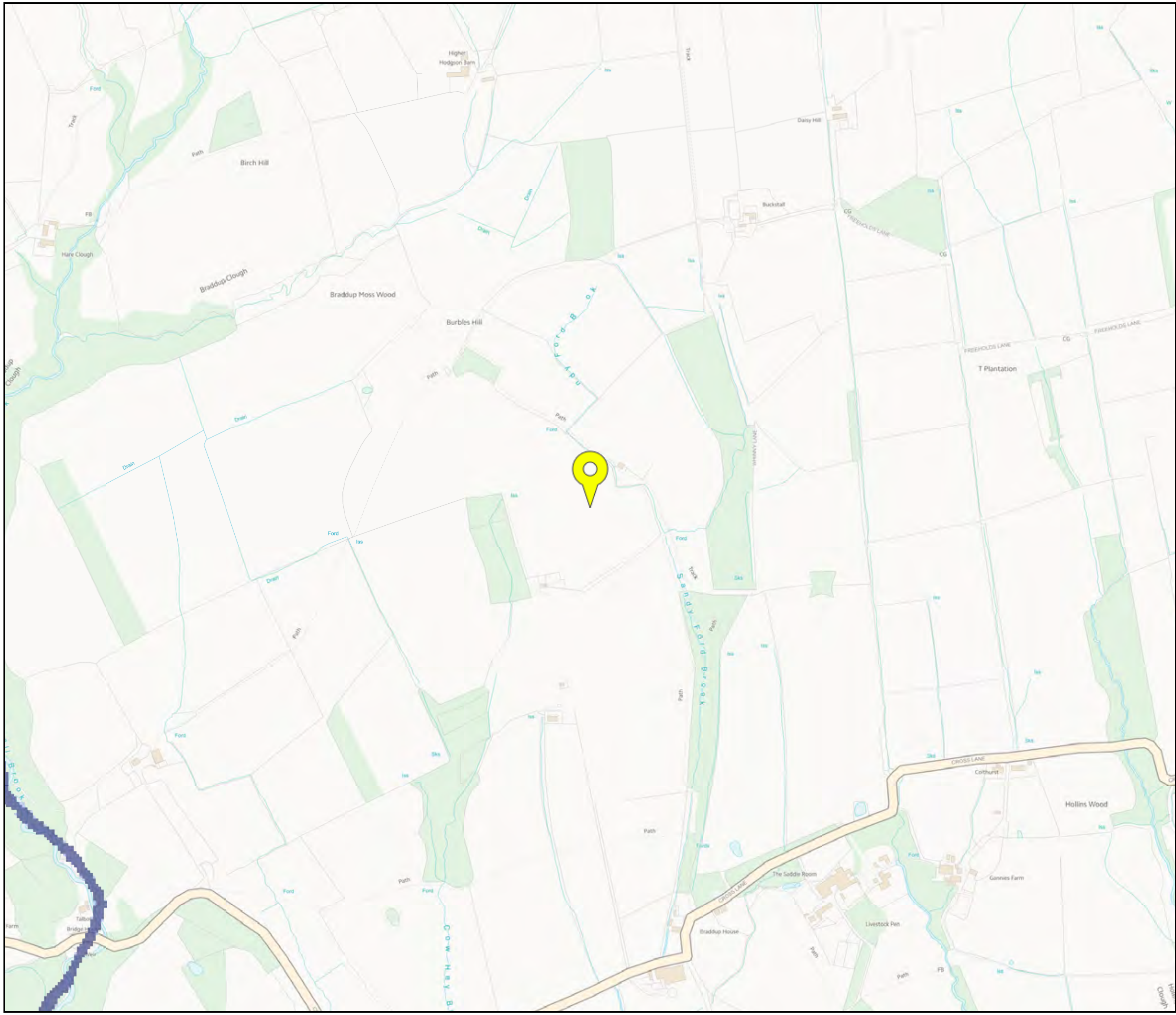
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	114.33
FEH / FSR conversion factor:	1.11	1.11
SAAR (mm):	1484	1484
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	6.16	6.16
Q_{BAR} for net site area (l/s):	6.16	6.16

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5.4	5.4
1 in 30 years (l/s):	6.2	6.2
1 in 100 year (l/s):	6.2	6.2

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	366	366
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	366	366



Environment Agency

Flood map for planning

Your reference
TR4-B

Location (easting/northing)
371012/445010

Scale
1:10000

Created
7 May 2020 14:00

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

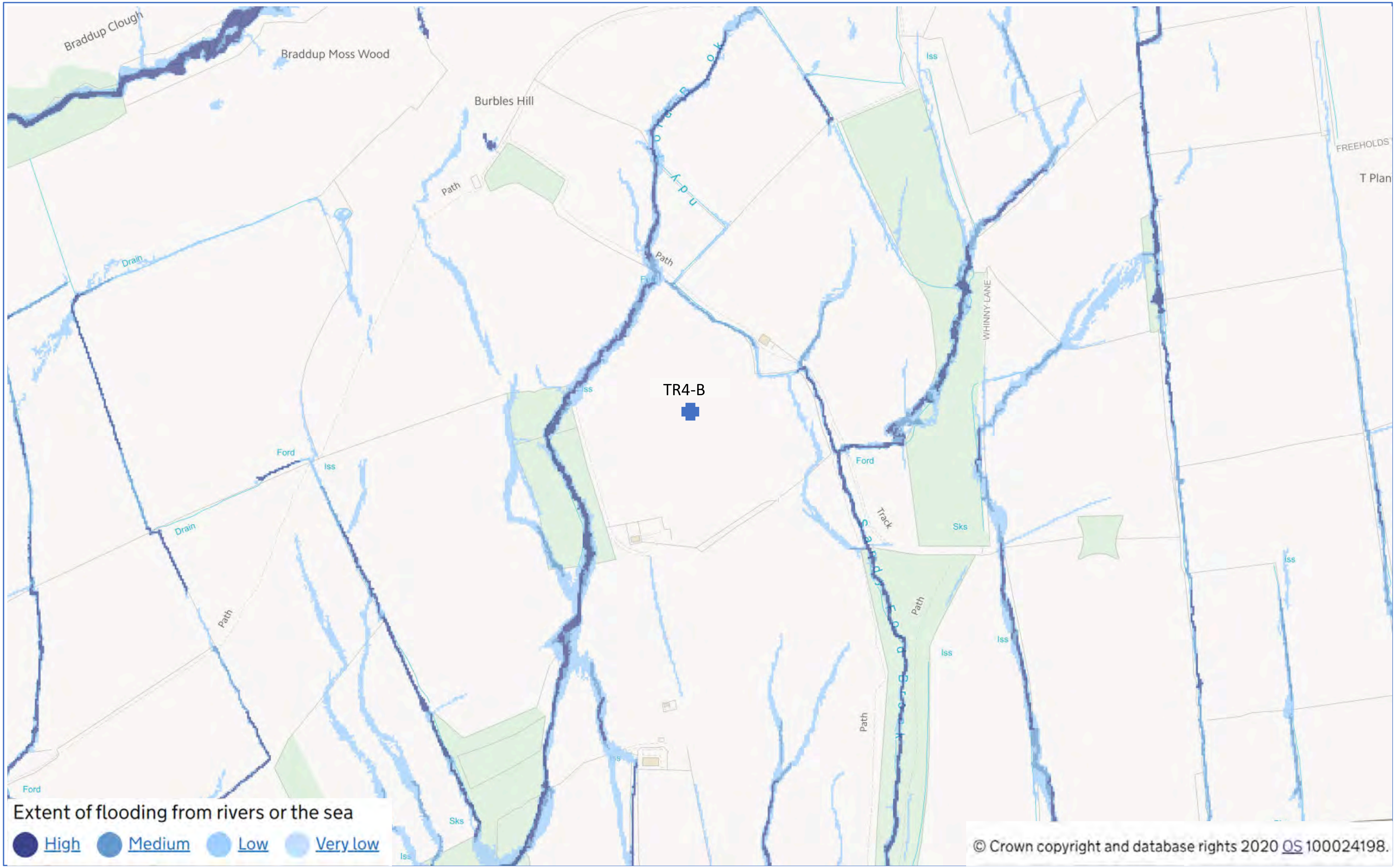
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR4-B

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR4-B
Site location:	BB7 3JH

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance “Rainfall runoff management for developments”, SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.90003° N
Longitude:	2.44297° W
Reference:	2411790616
Date:	Apr 22 2020 17:51

Site characteristics

Total site area (ha):	0.97
Significant public open space (ha):	0
Area positively drained (ha):	0.97
Impermeable area (ha):	0.97
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.97
Net impermable area for storage volume design (ha):	0.97
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	4	4
SPR:	0.47	0.47

Hydrological characteristics

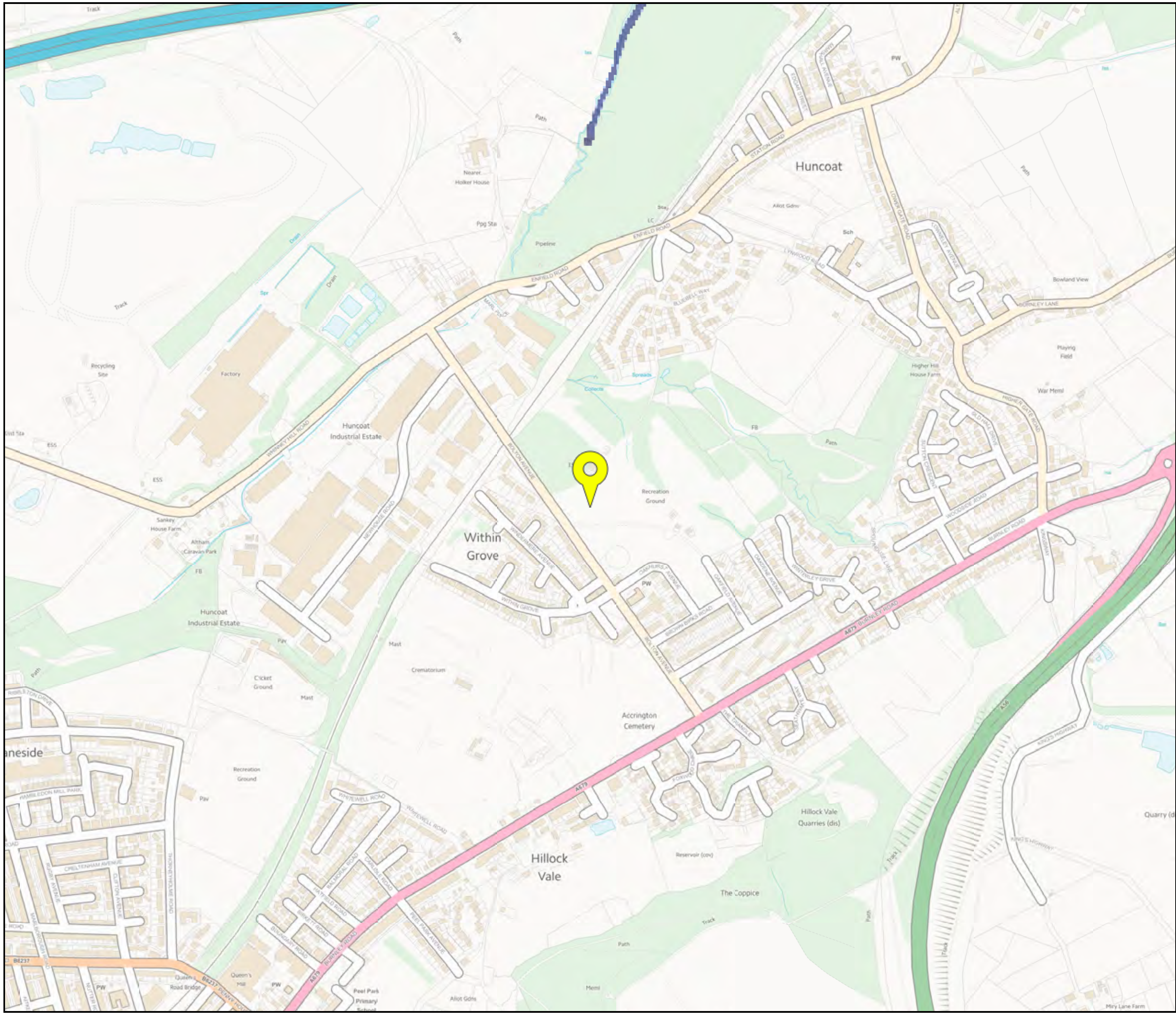
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	112.27
FEH / FSR conversion factor:	1.09	1.09
SAAR (mm):	1341	1341
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	10.02	10.02
Q_{BAR} for net site area (l/s):	10.02	10.02

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	8.7	8.7
1 in 30 years (l/s):	10	10
1 in 100 year (l/s):	10	10

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	706	706
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	706	706



Environment Agency

Flood map for planning

Your reference
TR5-A

Location (easting/northing)
377077/430167

Scale
1:10000

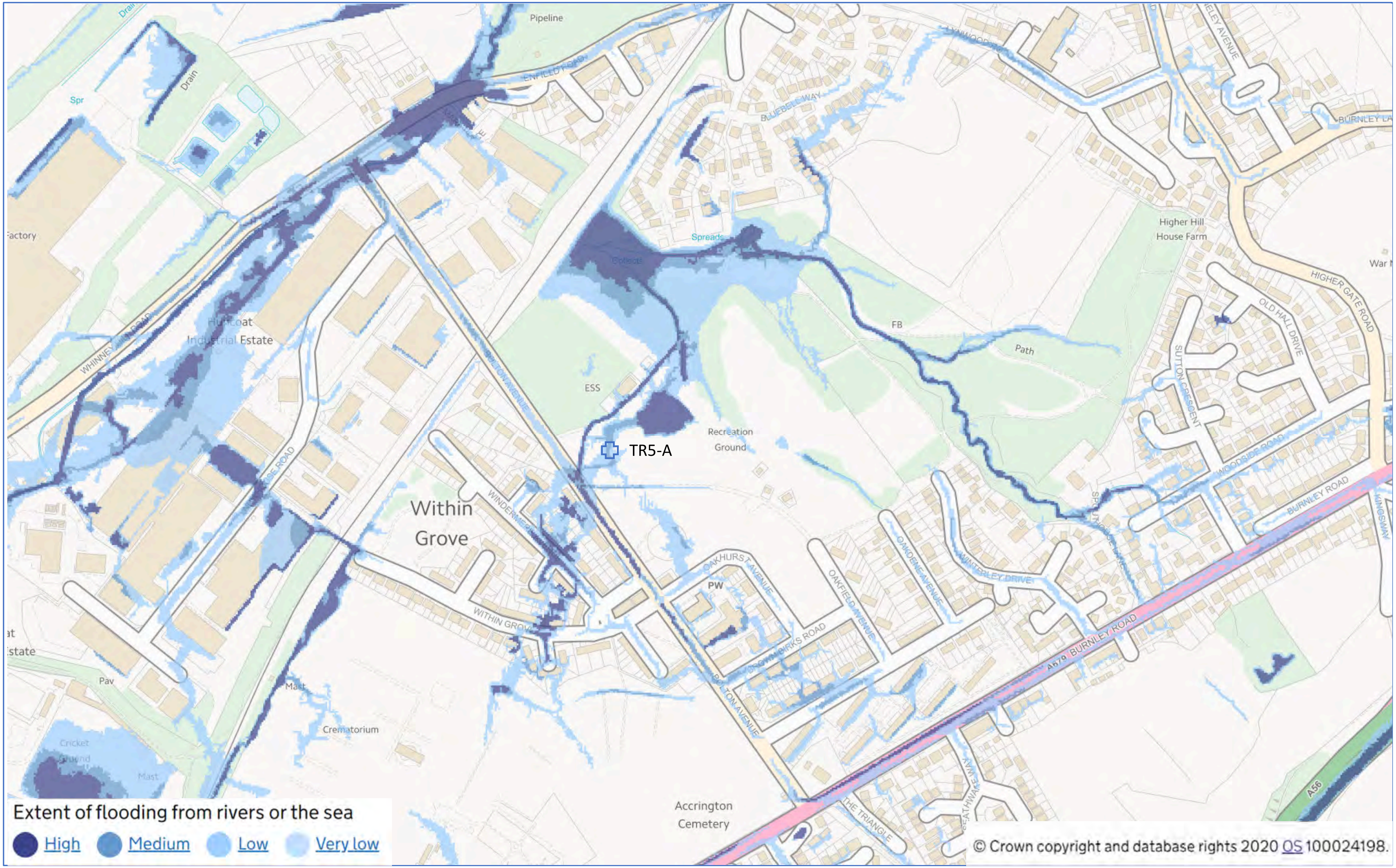
Created
7 May 2020 14:18

- Selected point
- Flood zone 3
- Flood zone 3: areas benefitting from flood defences
- Flood zone 2
- Flood zone 1
- Flood defence
- Main river
- Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR5-A

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

HR Wallingford — Working with water

Calculated by:	Michael Lloyd
Site name:	TR5-A
Site location:	BB5 6HT

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.76744° N
Longitude:	2.34914° W
Reference:	1935695554
Date:	Apr 23 2020 18:33

Site characteristics

Total site area (ha):	0.5
Significant public open space (ha):	0
Area positively drained (ha):	0.5
Impermeable area (ha):	0.5
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.5
Net impermable area for storage volume design (ha):	0.5
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	4	4
SPR:	0.47	0.47

Hydrological characteristics

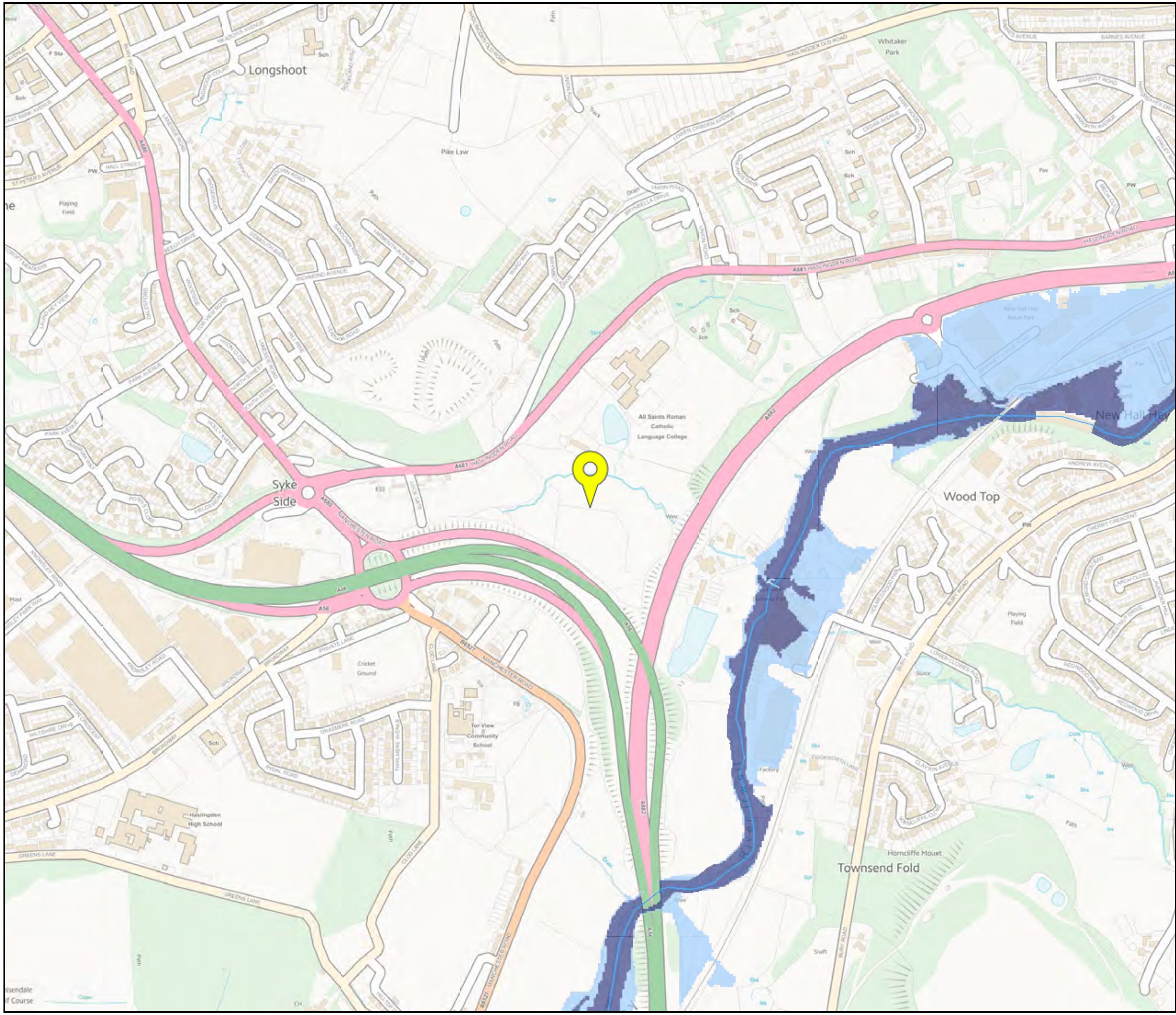
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	70
Rainfall 100 yrs 12 hrs:	--	92.4
FEH / FSR conversion factor:	1.1	1.1
SAAR (mm):	1180	1180
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.3	0.3
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	4.45	4.45
Q_{BAR} for net site area (l/s):	4.45	4.45

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5	5
1 in 100 year (l/s):	5	5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	284	284
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	284	284



Environment Agency

Flood map for planning

Your reference
TR5-I

Location (easting/northing)
379769/422099

Scale
1:10000

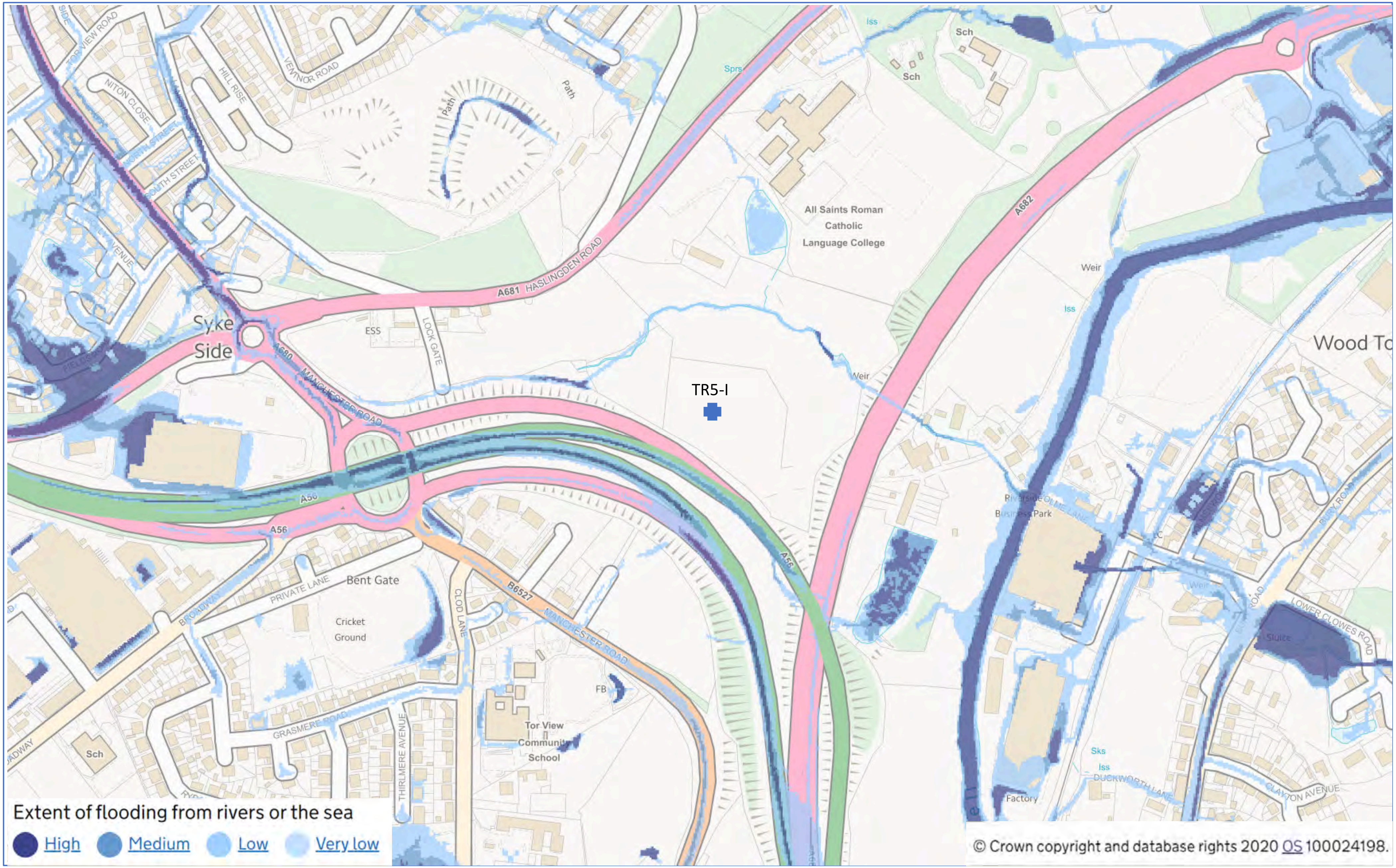
Created
6 Apr 2020 18:18

- Selected point
- Flood zone 3
- Flood zone 3: areas benefitting from flood defences
- Flood zone 2
- Flood zone 1
- Flood defence
- Main river
- Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR5-I

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR5-I Working platform
Site location:	BB4 6QG

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance “Rainfall runoff management for developments”, SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.69436° N
Longitude:	2.30712° W
Reference:	2921664057
Date:	May 07 2020 14:34

Site characteristics

Total site area (ha):	1.7
Significant public open space (ha):	0
Area positively drained (ha):	1.7
Impermeable area (ha):	1.7
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	1.7
Net impermable area for storage volume design (ha):	1.7
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	5	5
SPR:	0.53	0.53

Hydrological characteristics

	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	115.36
FEH / FSR conversion factor:	1.12	1.12
SAAR (mm):	1361	1361
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	23.19	23.19
Q_{BAR} for net site area (l/s):	23.19	23.19

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	20.2	20.2
1 in 30 years (l/s):	23.2	23.2
1 in 100 year (l/s):	23.2	23.2

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	1055	1055
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	1055	1055

Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR5-I Offices/welfare/parking & Access road
Site location:	BB4 6QG

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance “Rainfall runoff management for developments”, SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.69436° N
Longitude:	2.30712° W
Reference:	2292463481
Date:	May 07 2020 14:36

Site characteristics

Total site area (ha):	0.7
Significant public open space (ha):	0
Area positively drained (ha):	0.7
Impermeable area (ha):	0.7
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.7
Net impermable area for storage volume design (ha):	0.7
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	5	5
SPR:	0.53	0.53

Hydrological characteristics

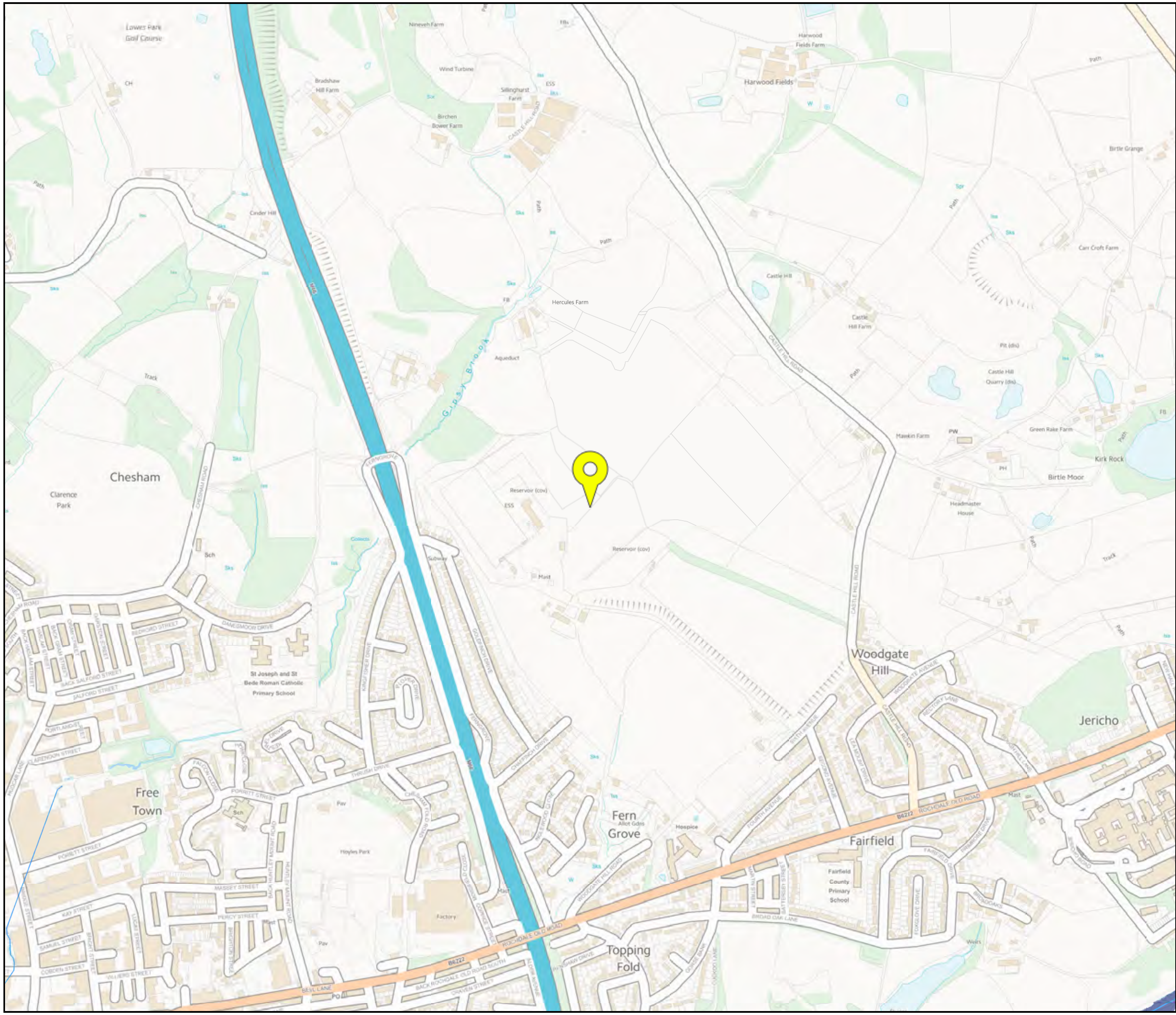
	Default	Edited
Rainfall 100 yrs 6 hrs:	--	82
Rainfall 100 yrs 12 hrs:	--	115.36
FEH / FSR conversion factor:	1.12	1.12
SAAR (mm):	1361	1361
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.2	0.2
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	9.55	9.55
Q_{BAR} for net site area (l/s):	9.55	9.55

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	8.3	8.3
1 in 30 years (l/s):	9.5	9.5
1 in 100 year (l/s):	9.5	9.5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	435	435
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	435	435



Environment Agency

Flood map for planning

Your reference
TR6-G

Location (easting/northing)
382229/412158

Scale
1:10000

Created
1 May 2020 18:22

Selected point

Flood zone 3

Flood zone 3: areas benefitting from flood defences

Flood zone 2

Flood zone 1

Flood defence

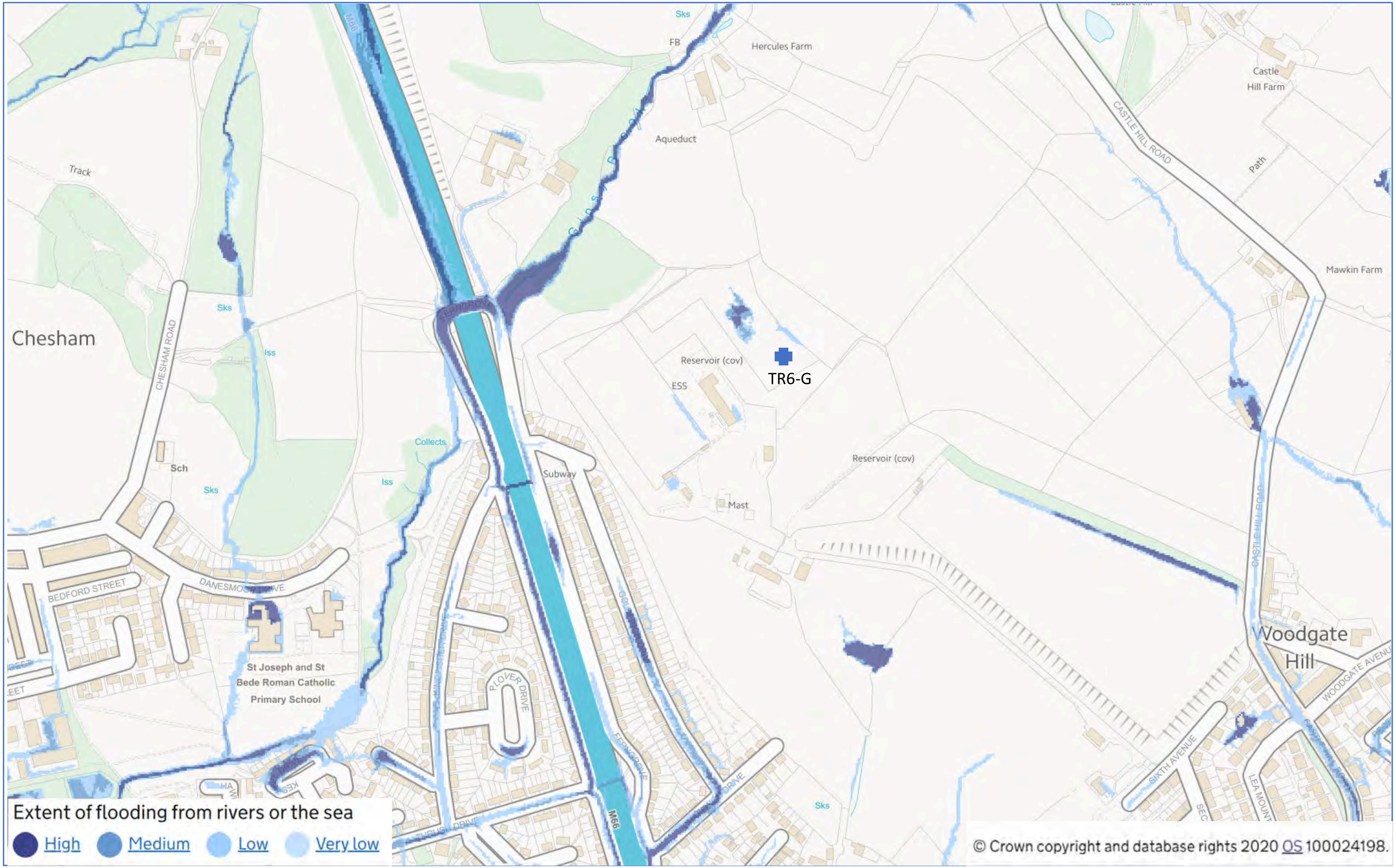
Main river

Flood storage area

0 100 200 300m

Long Term Flood Risk Map – TR6-G

The results shown below are an indicator of the area's flood risk, particularly the likelihood of surface water flooding.



Surface water storage requirements for sites

www.uksuds.com | Storage estimation tool

Calculated by:	Michael Lloyd
Site name:	TR6-G
Site location:	BL9 7LE

This is an estimation of the storage volume requirements that are needed to meet normal best practice criteria in line with Environment Agency guidance "Rainfall runoff management for developments", SC030219 (2013), the SuDS Manual C753 (Ciria, 2015) and the non-statutory standards for SuDS (Defra, 2015). It is not to be used for detailed design of drainage systems. It is recommended that hydraulic modelling software is used to calculate volume requirements and design details before finalising the design of the drainage scheme.

Site Details

Latitude:	53.60590° N
Longitude:	2.27131° W
Reference:	1709637230
Date:	Apr 22 2020 21:38

Site characteristics

Total site area (ha):	0.5
Significant public open space (ha):	0
Area positively drained (ha):	0.5
Impermeable area (ha):	0.5
Percentage of drained area that is impermeable (%):	100
Impervious area drained via infiltration (ha):	0
Return period for infiltration system design (year):	10
Impervious area drained to rainwater harvesting (ha):	0
Return period for rainwater harvesting system (year):	10
Compliance factor for rainwater harvesting system (%):	66
Net site area for storage volume design (ha):	0.5
Net impermable area for storage volume design (ha):	0.5
Pervious area contribution to runoff (%):	30

* where rainwater harvesting or infiltration has been used for managing surface water runoff such that the effective impermeable area is less than 50% of the 'area positively drained', the 'net site area' and the estimates of Q_{BAR} and other flow rates will have been reduced accordingly.

Design criteria

Climate change allowance factor:	1.0
Urban creep allowance factor:	1.0
Volume control approach	Flow control to max of 2 l/s/ha or Qbar
Interception rainfall depth (mm):	0
Minimum flow rate (l/s):	5

Methodology

esti	IH124
Q_{BAR} estimation method:	Calculate from SPR and SAAR
SPR estimation method:	Calculate from SOIL type

Soil characteristics

	Default	Edited
SOIL type:	5	5
SPR:	0.53	0.53

Hydrological characteristics

	Default	Edited
Rainfall 100 yrs 6 hrs:	--	70
Rainfall 100 yrs 12 hrs:	--	93.24
FEH / FSR conversion factor:	1.11	1.11
SAAR (mm):	1126	1126
M5-60 Rainfall Depth (mm):	20	20
'r' Ratio M5-60/M5-2 day:	0.3	0.3
Hydological region:	10	10
Growth curve factor 1 year:	0.87	0.87
Growth curve factor 10 year:	1.38	1.38
Growth curve factor 30 year:	1.7	1.7
Growth curve factor 100 years:	2.08	2.08
Q_{BAR} for total site area (l/s):	5.46	5.46
Q_{BAR} for net site area (l/s):	5.46	5.46

Site discharge rates

	Default	Edited
1 in 1 year (l/s):	5	5
1 in 30 years (l/s):	5.5	5.5
1 in 100 year (l/s):	5.5	5.5

Estimated storage volumes

	Default	Edited
Attenuation storage 1/100 years (m^3):	264	264
Long term storage 1/100 years (m^3):	0	0
Total storage 1/100 years (m^3):	264	264

Annexe E: Hydraulic modelling report

Haweswater Aqueduct Resilience Programme - Proposed Bowland Section

Environmental Statement

Volume 4

Appendix 8.1 Flood Risk Assessment

Annexe E River Hodder Hydraulic Modelling Report

June 2021

Haweswater Aqueduct Resilience Programme - Proposed Bowland Section

Project No:	B27070CT
Document Title:	Proposed Bowland Section Environmental Statement Volume 4 Appendix 8.1 :Flood Risk Assessment Annexe E River Hodder Hydraulic Modelling Report
Document Ref:	LCC_RVBC-BO-TA-008-001
Revision:	0
Date:	June 2021
Client Name:	United Utilities Water Ltd
Client No:	B27070CT

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Contents

1. Introduction

1.1 Purpose of the report

1) United Utilities propose to construct a temporary access road and river crossing of the River Hodder, near Newton-in-Bowland, to service the construction phase of the Proposed Bowland Section. The design life for the temporary works is estimated to be five years.

2) A Flood Risk Assessment (FRA) is required to meet relevant local and national planning legislation and inform the design and planning process. Hydraulic modelling was required to support the FRA. This took the form of computational hydraulic model of the River Hodder with associated catchment hydrology. The impact of the proposed scheme on water level both upstream and downstream and the associated flood envelope was determined for a range of storm flood events.

3) To inform the design of the temporary bridge crossing, hydraulic modelling was required to:

- Define baseline flood extents and set peak flood design levels
- Test the performance of outline bridge design options to inform the design process
- Provide information required to support the future permitting application.

4) This report details the methodology and the results of the hydraulic modelling carried out for the River Hodder, to assess the baseline situation and the consequences of the temporary bridge and any flood risk mitigation measures required. This is a technical report, focused on the hydraulic modelling, and therefore the intended audience is those with a reasonable understanding and knowledge of hydraulic modelling principles, although no specific knowledge of particular software is needed.

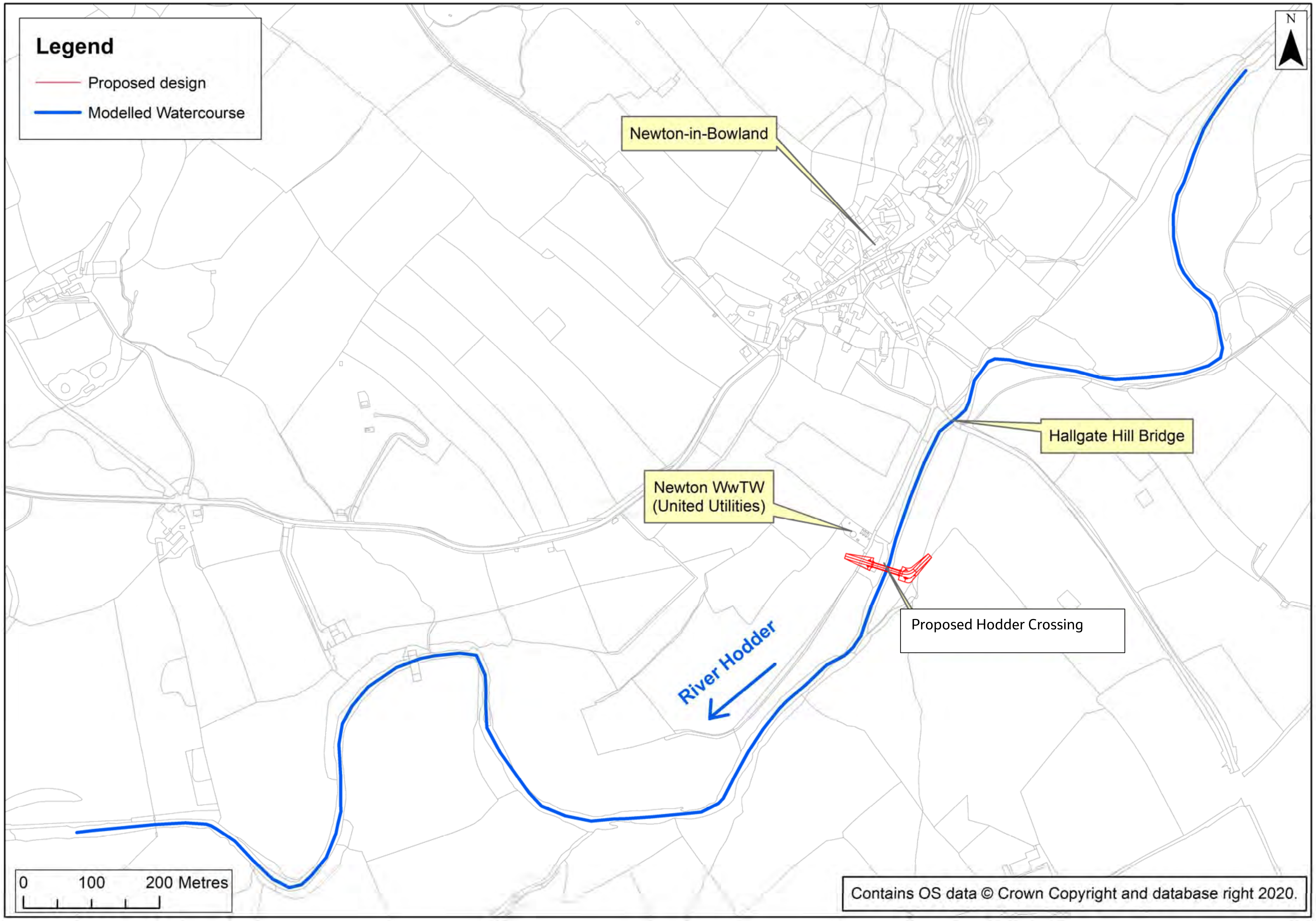
1.2 Methodology

5) The hydraulic model of the River Hodder uses a linked one-dimensional/two-dimensional (1D/2D) schematisation, where the river channel is represented as a 1D component and is linked to the floodplain, which is represented by a 2D domain. The 1D component was constructed using the river modelling package Flood Modeller Pro version 4.6 (Jacobs, 2020), and the 2D component was constructed using TUFLOW version 2018-03-AE-iSP-w64 (BMT WBM, 2018).

1.3 Study Area

6) The River Hodder is situated in Lancashire and drains much of the Forest of Bowland. The section of the River Hodder under investigation in this study is approximately 3km long and flows southwest (Illustration 1). 4.6 km upstream at the head of the Hodder valley lies Stocks Reservoir, which holds a total water volume of 12,000,000 m^3 and feeds into the river. The River Hodder then collects several tributaries from the valleys of Bowland, including Easington Brook and Foulscales Brook. The village of Newton-in-Bowland is situated adjacent to the modelled river reach on its right bank and can be accessed by the B6478 road, Hallgate Hill, that crosses the river.

Illustration 1: Modelled reach of River Hodder at Newton-in-Bowland



2. Input Data

7) The data used to construct the hydraulic model for the River Hodder is summarised in Table 1.

Table 1: Data used to build the hydraulic model.

Data	Description	Source
LiDAR	2m resolution filtered Digital Terrain Model (DTM) from LiDAR (Light Detection and Ranging) data. Used to inform the hydraulic model (2D floodplain) with ground level information.	Environment Agency
OS Mastermap	Land use data. Used to specify roughness values across the 2D floodplain model.	United Utilities
Channel Survey	In-channel cross-sections and hydraulic structures. Used for 1D model representation of the channel.	United Utilities, 2020
Site Visit	Photographs taken upstream and downstream of each surveyed cross-section.	Jacobs, 2020
Hydrological Analysis	Calculation of inflow hydrographs into the model.	Jacobs, 2020
Outline Design Drawings	Drawings of the scheme design.	United Utilities, 2020
Flood Zone Mapping	EA Flood Zone 2 flood maps.	Environment Agency

3. Hydrology

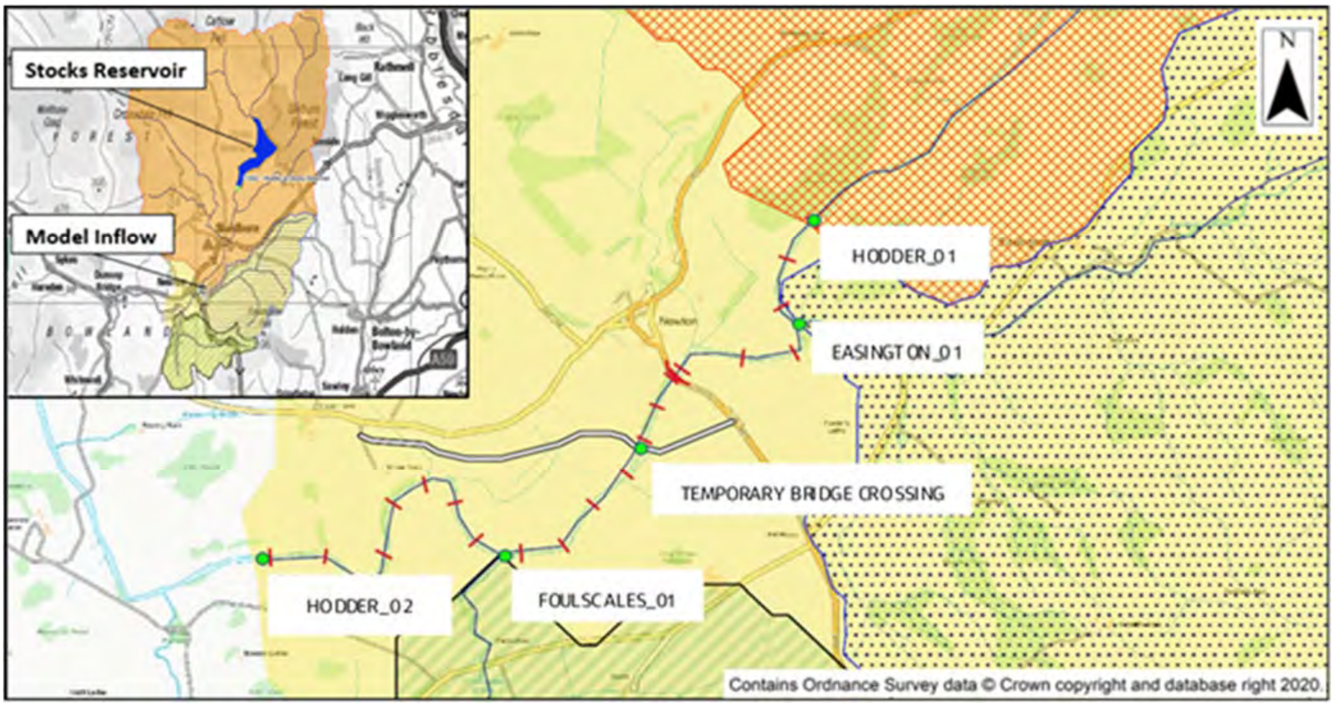
3.1 Background

8) To inform the design of the temporary bridge crossing of the River Hodder, hydrological analysis of the River Hodder catchment is required to derive:

- estimates of peak flood flow at four flood estimation points (FEPs) over a range of Annual Exceedance Probability (AEP) flood events (50 %, 20 %, 10 %, 3.33 %, 1.33 % and 1 %)
- design flood hydrographs at three identified inflow locations (upstream model inflow from the River Hodder and an inflow for each of Easington Brook and Foulscales Brook).

9) Refer to Figure 3-1 for the modelling extent and flow estimation locations.

Illustration 2: Location of the temporary bridge crossing, the proposed model extent and flow estimation points (in green)



3.2 Overview of modelled catchment inflows

10) The modelled catchment inflows form part of the wider River Hodder catchment. Underlying geology is comprised of moderate permeability Millstone Grit and Carboniferous Limestone while catchment soils are typically formed of slowly permeable, seasonally wet, clayey soils. Land use is mixed farming in the lower reaches and peat moorland in the catchment headwaters. The catchments are rural and generally natural in nature, however Stocks Reservoir controls approximately 50 % of the catchment at the upstream model inflow location and approximately 38 % of the catchment at the downstream model extent. Table 2 lists the subject sites (shown in Illustration 2) alongside their contributing upstream catchment area.

Table 2: Summary of subject sites

Flow Estimation Point	Watercourse	Site	Easting	Northing	Catchment Area (km2)
HODDER_01	River Hodder	Hodder @ Newton	370200	450700	73.6
HODDER_02	River Hodder	Hodder @ Giddy Br.	368550	449650	96.7
EASINGTON_01	Easington Brook	Hodder / Easington Confluence	370250	450450	13.1
FOULSCALES_01	Foulscales Brook	Hodder / Foulscales Confluence	369300	449650	7.0

3.3 Methodology

11) The scope of work called for estimation of design peak flood flows using two methods (FEH Statistical and ReFH2).

12) Catchment FARL at the location of the River Hodder upstream inflow is 0.90[1] which could be argued to lie just within the limits of applicability for use of the statistical method QMED equation.

13) Standard application of the ReFH2 method does not account for the attenuating effect of upstream reservoirs. To account for the reservoir's impact on peak flow, the initial ReFH2 hydrograph was routed through a modelled representation of the reservoir to determine the impact on outflow.

14) Given the nature of the study (i.e. estimation of peak flood flows downstream of an impounding reservoir) and the need for design hydrographs to serve as inflow boundaries for the River Hodder hydraulic model; the ReFH2 rainfall runoff method was considered the more appropriate method and flood estimates derived by the FEH statistical method have been derived to serve as a comparison.

15) For deriving the ReFH2 flood estimates, a distributed rainfall runoff approach, i.e. also considering flows from the Easington Brook and Foulscales Brook sub-catchments, was adopted. Hence, a common design storm (in terms of both storm duration and catchment areal reduction factor) was applied to each sub-catchment.

16) The scope of work called for deriving design model inflows and hydrographs based on the 'theoretical' critical storm duration for each of the agreed AEP events. The critical duration is defined here as that which gives the highest flow at the flow estimation point and has been assessed through an iterative process whereby the storm duration was incrementally increased until flow was no longer observed to increase but rather decrease.

17) Assessment of the critical storm duration at the upstream and downstream model extent was identical and assessed as 7.5 hours. Storm duration and areal reduction factor (ARF) were calculated for the River Hodder catchment at the downstream model extent and used to derive the ReFH2 peak inflow and peak flow hydrograph at all flow estimation points, i.e. for the Easington Brook and Foulscales Brook as well as the flow estimation points on the main River Hodder.

18) The ReFH2 hydrographs derived for the River Hodder, based on the critical storm duration, were routed through a model representation of the reservoir to determine the impact on outflow. As the subject site (i.e. River Hodder at Newton-in-Bowland) is located some distance (4.6 km) downstream of the reservoir, the modelled impact on outflow is approximate, the actual degree of attenuation and hence impact of the upstream reservoir, would be expected to decrease with downstream distance and hence the degree of attenuation is considered a slight over estimate. In order to incorporate the influence of Stocks Reservoir on flow estimates at the downstream model extent (HODDER_02), the attenuation ratios calculated for the upstream model inflow (HODDER_01) were applied.

[1] Catchment descriptors at each subject site are presented in the Hydrology Calculation Record presented in Appendix A of this report.

19) A single flow hydrograph representing residual flow was also calculated. Residual flow is defined as an inflow distributed across multiple river reaches as opposed to applying a point inflow. The hydrograph was distributed over the model reach according to reach length and accounted for an area of 3.1 km^2.

20) Full details of the hydrological analysis undertaken, and decisions made are contained within the Hydrology Calculation Record presented in Appendix A of this report.

3.4 Climate change allowance

21) Due to the temporary nature of the bridge structure, as per the scope of work, no allowance for climate change was required to be applied to the estimated design peak flood flows.

3.5 Final results

22) Flood flows derived from the ReFH2 method were adopted as the final flows for the following reasons:

- For the main inflow to the hydraulic model (HODDER_01) the estimate of the 1 % AEP flood was 25 % greater than is estimated by the FEH statistical method. Adopting the higher flows offers a degree of freeboard for uncertainty;
- The flows estimated by the ReFH2 method were based on routing the hydrograph through a representation of the Stocks Reservoir and may offer a better estimate of the reservoirs impact on outflow than data transfer from the downstream gauge located on the River Hodder; and
- The ReFH2 rainfall runoff method underpins the approach for deriving the inflow hydrographs. Directly adopting the ReFH2 method avoided losing information such as runoff volume.

23) Final flood estimates from the ReFH2 method, based on the critical storm duration and areal reduction factor as calculated at HODDER_02, are presented in Table 3, while flood hydrographs are plotted in Illustration 3 to Illustration 6.

Table 3: Final adopted flood estimates

Flow Estimation Point	Flood peak (m^3/s) for the following AEP flood events					
	50 %	**20 %**	**10 %**	**3.33 %**	**1.33 %**	**1 %**
HODDER_01	60.4	78.1	92.3	117	144	153
HODDER_02	72.2	93.6	111	140	171	183
EASINGTON_01	12.0	15.7	18.4	23.5	28.4	30.3
FOULSCALES_01	8.1	10.9	12.8	16.5	19.8	21.0

Illustration 3: Flood hydrographs - HODDER_01

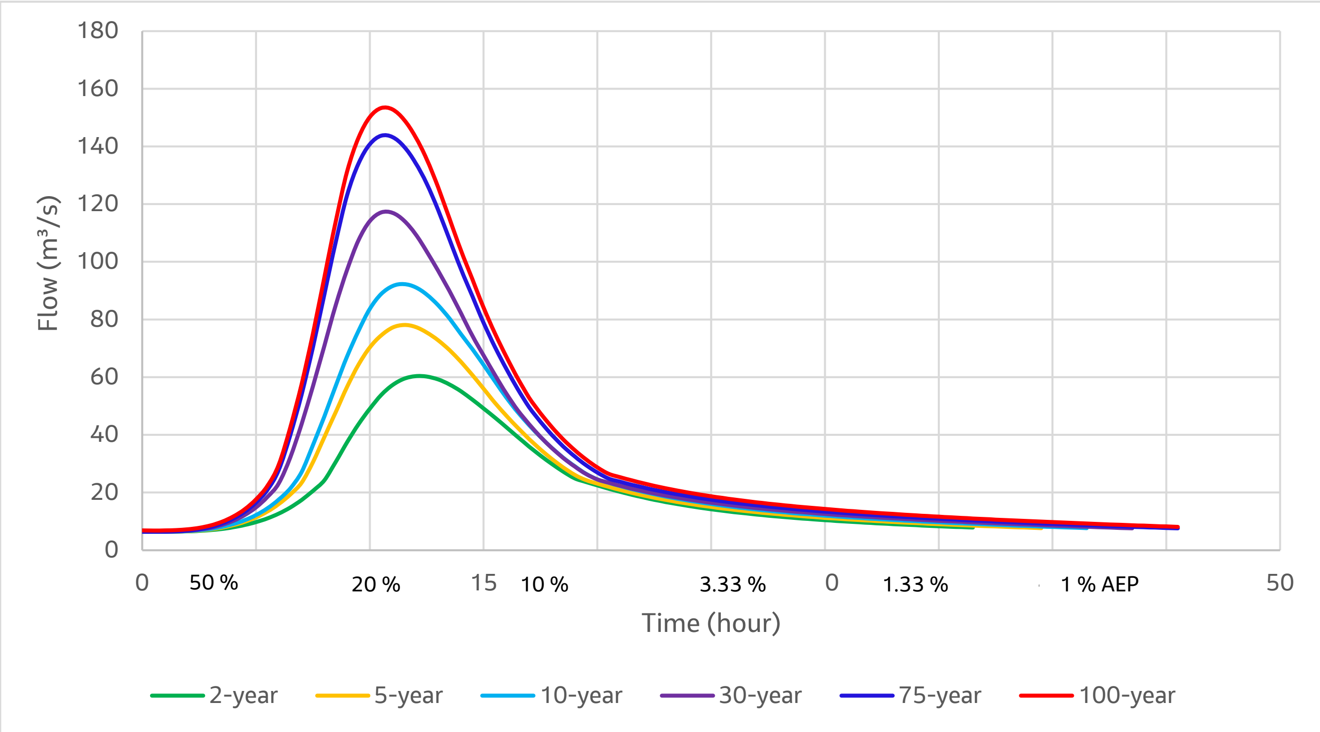


Illustration 4: Flood hydrographs - EASINGTON_01

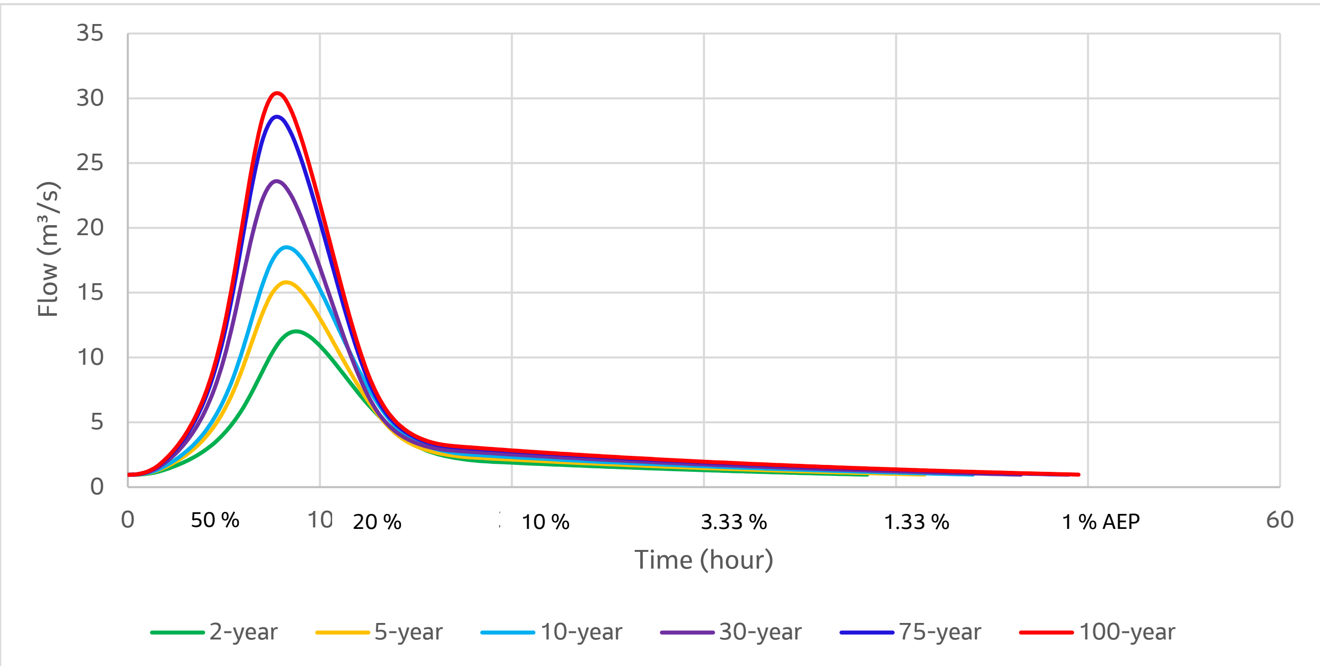


Illustration 5: Flood hydrographs - FOULSCALES_01

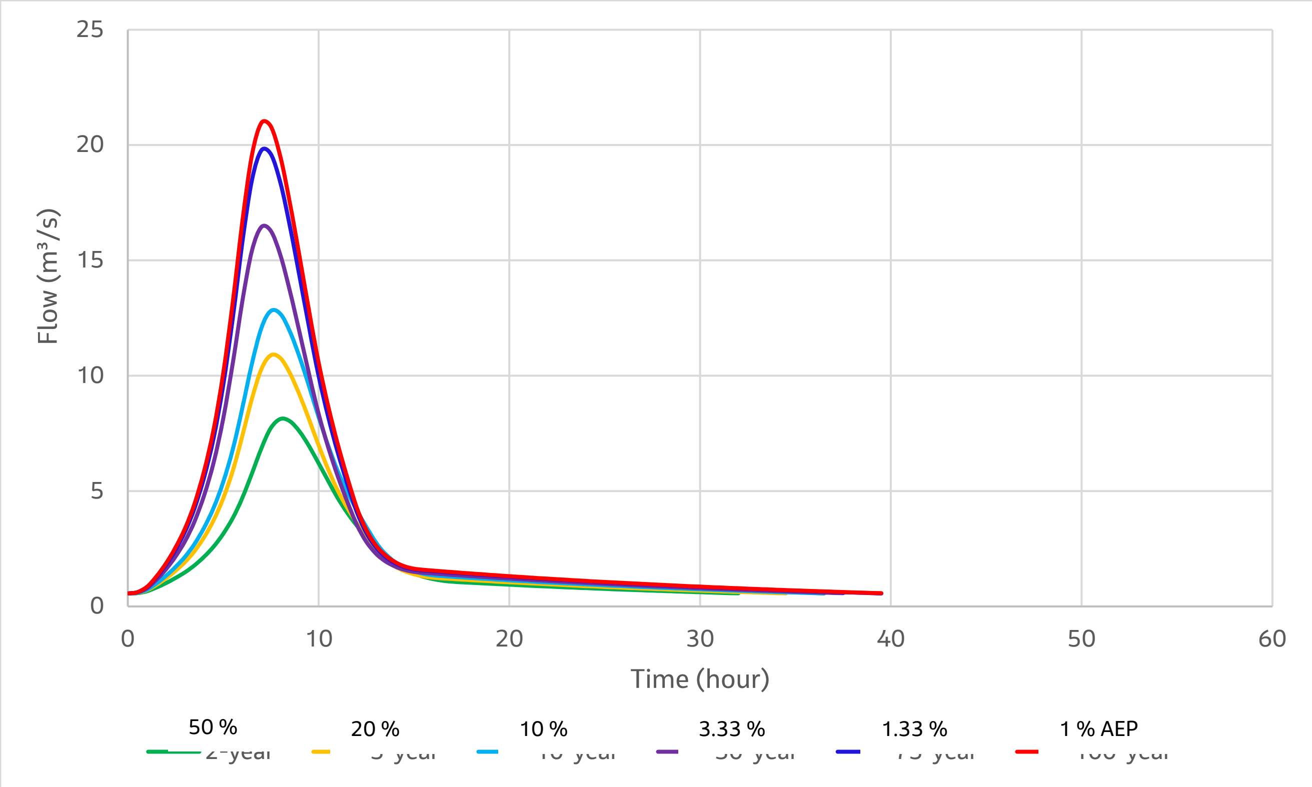
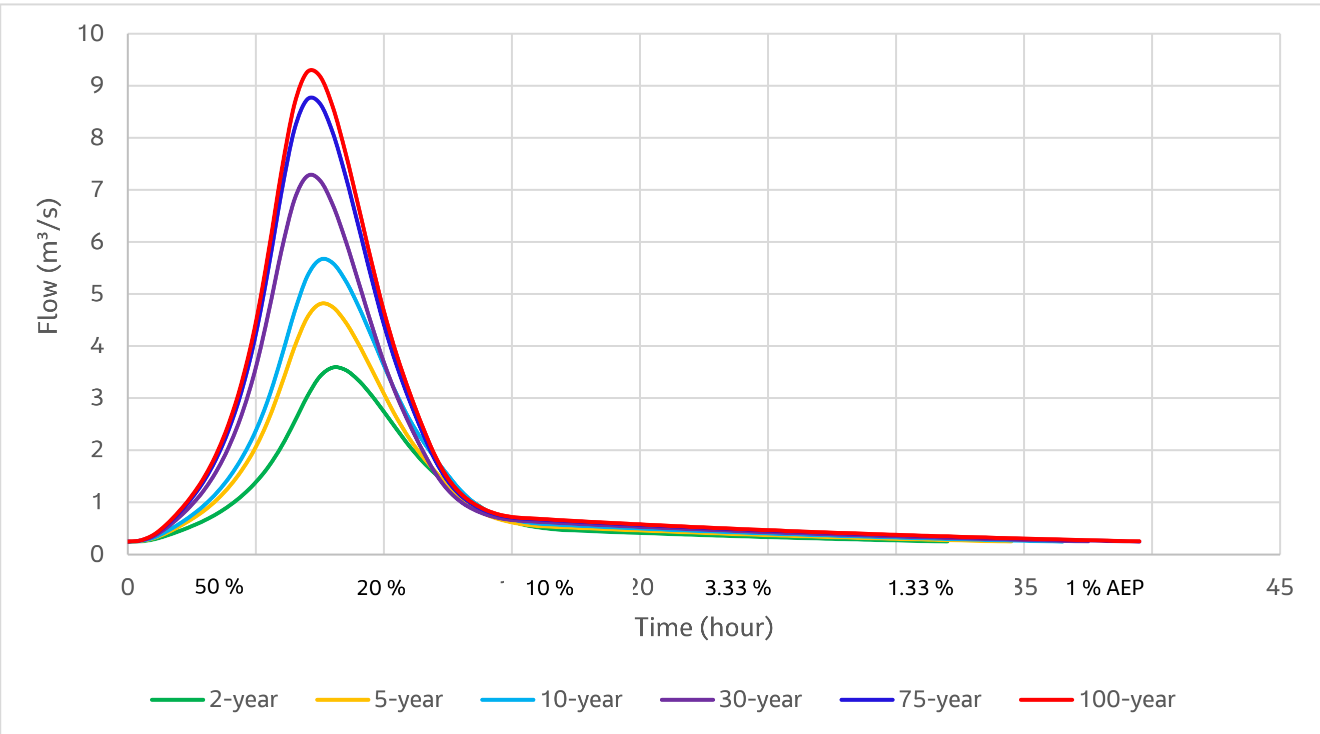


Illustration 6: Flood hydrographs – Residual flow



4. Baseline Modelling

4.1 Watercourse Schematisation – 1D Domain

River Geometry

24) Surveyed cross-section data has been used to inform the in-channel geometry of the modelled watercourse. The locations of the surveyed cross-sections are shown in Illustration 7.

25) To aid model performance, interpolated cross-sections were added between the surveyed cross-sections where the distance between two consecutive cross-sections was more than 200 m.

Hydraulic Friction

26) Hydraulic roughness (Manning's 'n' coefficient) values were determined primarily using site photographs taken during the survey. Generally, the left bank is covered in grass pastures while the right bank is scattered with heavy vegetation and trees alongside the river reach. In some cases, roughness on the left bank was increased where trees were present. Illustration 8 shows a typical section of the River Hodder at Newton-in-Bowland.

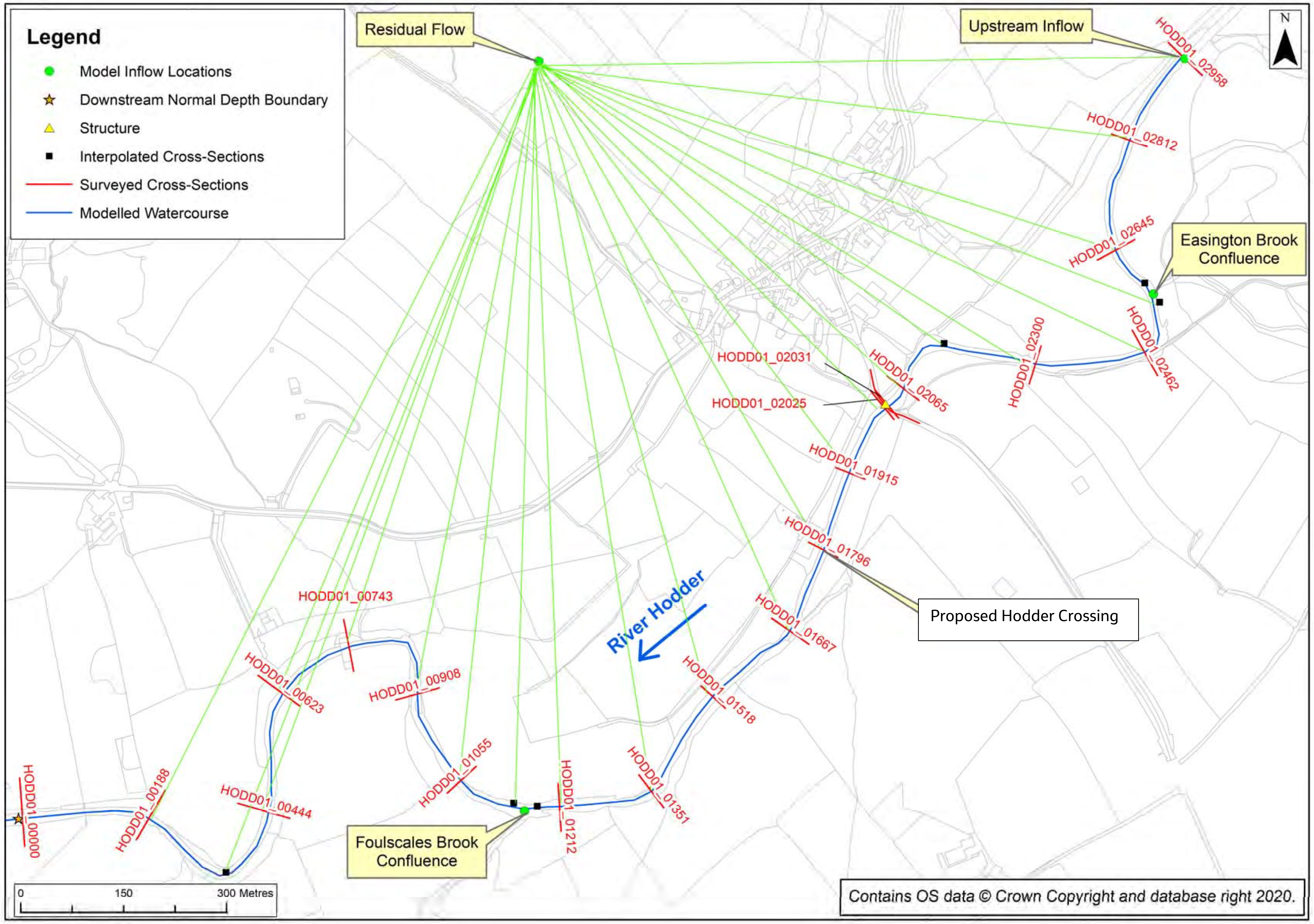
Illustration 8: Site visit photograph facing downstream of cross-section HODD01_02812

27) The Manning's 'n' coefficients used in the model are shown in Table 4. Roughness values adopted were taken from standard guidance (Chow, 1959).

Table 4: Manning's 'n' coefficients of roughness - 1D domain

<table>
<tr><th>Flood Modeller Node</th><th>Bed Manning’s ‘n’</th><th>Left Bank top Manning’s ‘n’</th><th>Right Bank top Manning’s ‘n’</th></tr>
<tr><td>HODD01_02958</td><td rowspan="11">0.035</td><td>0.05</td><td rowspan="11">0.07</td></tr>
<tr><td>HODD01_02812</td><td>0.07</td></tr>
<tr><td>HODD01_02645
to
HODD01_02553</td><td>0.05</td></tr>
<tr><td>HODD01_02462
HODD01_02300</td><td>0.07</td></tr>
<tr><td>HODD01_02065
to
HODD01_01518</td><td>0.05</td></tr>
<tr><td>HODD01_01351</td><td>0.07</td></tr>
<tr><td>HODD01_01212
to
HODD01_01055</td><td>0.05</td></tr>
<tr><td>HODD01_00908</td><td>0.07</td></tr>
<tr><td>HODD01_00743
HODD01_00623</td><td>0.05</td></tr>
<tr><td>HODD01_00444</td><td>0.07</td></tr>
<tr><td>HODD01_00188
HODD01_0000</td><td>0.05</td></tr>
</table>

Illustration 7: Schematisation of 1D model domain and inflows



Structure

28) One hydraulic structure was included in the baseline model. An arch bridge unit was used to represent the river crossing at Hallgate Hill (B6478), which is pictured in Illustration 9 . The location of the structure is shown in Illustration 10.

Illustration 9: Site visit photograph upstream of Hallgate Hill bridge (facing downstream)

Boundary Conditions

29) The upstream and downstream boundary conditions applied to the 1D domain are described in Table 5. Derivation of the hydrological boundaries are detailed in Section 3. Inflow locations are shown in Illustration 7.

Table 5: Boundary conditions - 1D domain

Type of Boundary	Flood Modeller Node	Description
ReFH2 Boundary	HODD01_US	Applied at the upstream end of the modelled reach of the River Hodder
ReFH2 Boundary	HODD01_EB	Applied at the confluence with Easington Brook
ReFH2 Boundary	HODD01_FB	Applied at the confluence with Foulscales Brook
ReFH2 Boundary	HODD01_Lat01	Applied laterally between the upstream and downstream ends of the modelled reach of the River Hodder

Type of Boundary	Flood Modeller Node	Description
Normal Depth Downstream Boundary	HODD01_00000	Applied to the downstream end of the modelled reach of the River Hodder. A normal depth boundary calculates a flow-head relationship based on the channel characteristics. This downstream boundary type is considered suitable as there is no influence of downstream structures. The suitability of the downstream boundary is further discussed in Section 6.4.3.

4.2 Floodplain Schematisation – 2D Domain

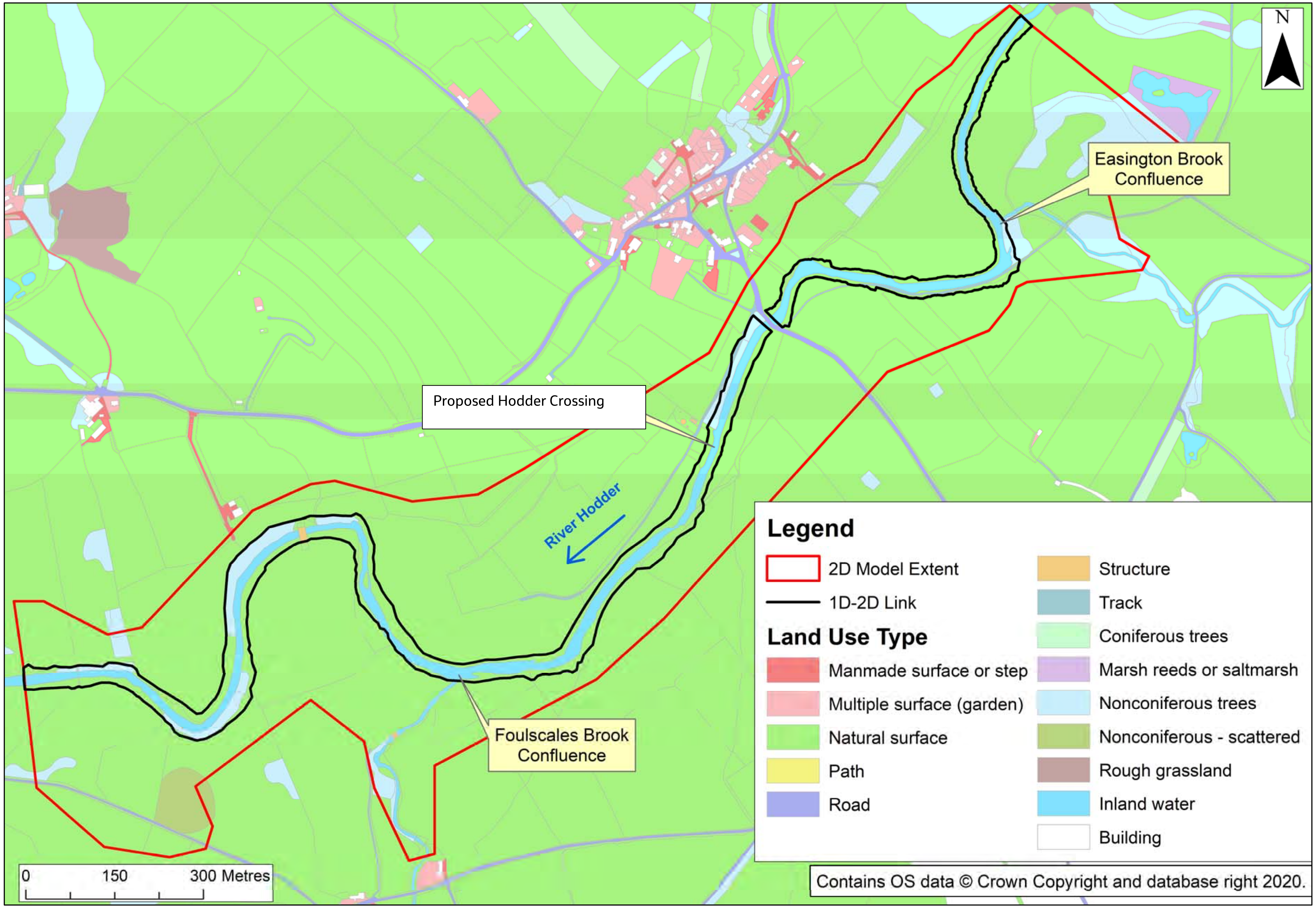
30) The 2D domain covers an area of 0.8 km^2.

31) The topography of the floodplain is represented in the model using a 5 m resolution square grid. The levels for the grid cells are based on a DTM derived from 2 m resolution LiDAR data.

32) Breaklines were applied at the bridge location to represent the parapet on both the upstream and downstream faces of the bridge. A review of the floodplain using available aerial and OS mapping has shown that there are no existing structures within the floodplain that require representation in the model. Therefore, no other modifications were made to the LiDAR DTM.

33) Illustration 10 shows the 2D model extent, links between the 1D and 2D model components and the land use type, which was used in the 2D representation of the floodplain.

Illustration 10: 2D model schematisation



34) Hydraulic roughness coefficients are applied over each grid cell of the 2D domain, as shown in Table 6, depending on land use taken from OS Mastermap data. Roughness values adopted were based on commonly-used values for each land use type with reference to standard guidance (Chow, 1959).

Table 6: Manning's 'n' coefficients of roughness - 2D domain

Land Use	Manning's 'n'
Manmade surfaces	0.025
Natural surfaces	0.04
Inland Water	0.02
Gardens	0.05
Roads/Tracks/Paths	0.025
Thick Vegetation	0.07
Structures	0.025

35) No inflow has been applied directly in the 2D domain. Any flow across the 2D domain is as a result of the 1D channel being overtopped, simulating out of bank conditions. No downstream boundary was required in the 2D domain as all flows remained in bank at the downstream model extent.

36) The link between the 1D and 2D domains was defined along the bank tops of the River Hodder, using a "HX" schematisation which directly transfers the water levels between the 1D and 2D domains. The grid cell levels along the 1D-2D boundary alignment were based on the LiDAR data without any adjustment.

5. Modelled Events

37) Table 7 shows the Annual Exceedance Probability (AEP) events and model scenarios that were simulated with the hydraulic model.

38) In order to test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the baseline 1 % AEP event. The assessed hydraulic parameters were: Manning's 'n' roughness coefficients, hydrological inflows and downstream boundary slope.

Table 7: Modelled events

Scenario	AEP Event					
	50 %	20 %	10 %	3.33 %	1.33 %	1 %
Baseline	✓	✓	✓	✓	✓	✓
Roughness Sensitivity (1D and 2D)						✓
Hydrological Inflow Sensitivity						✓
Downstream Boundary Sensitivity						✓
With Scheme	✓	✓	✓	✓	✓	✓

6. Model Proving

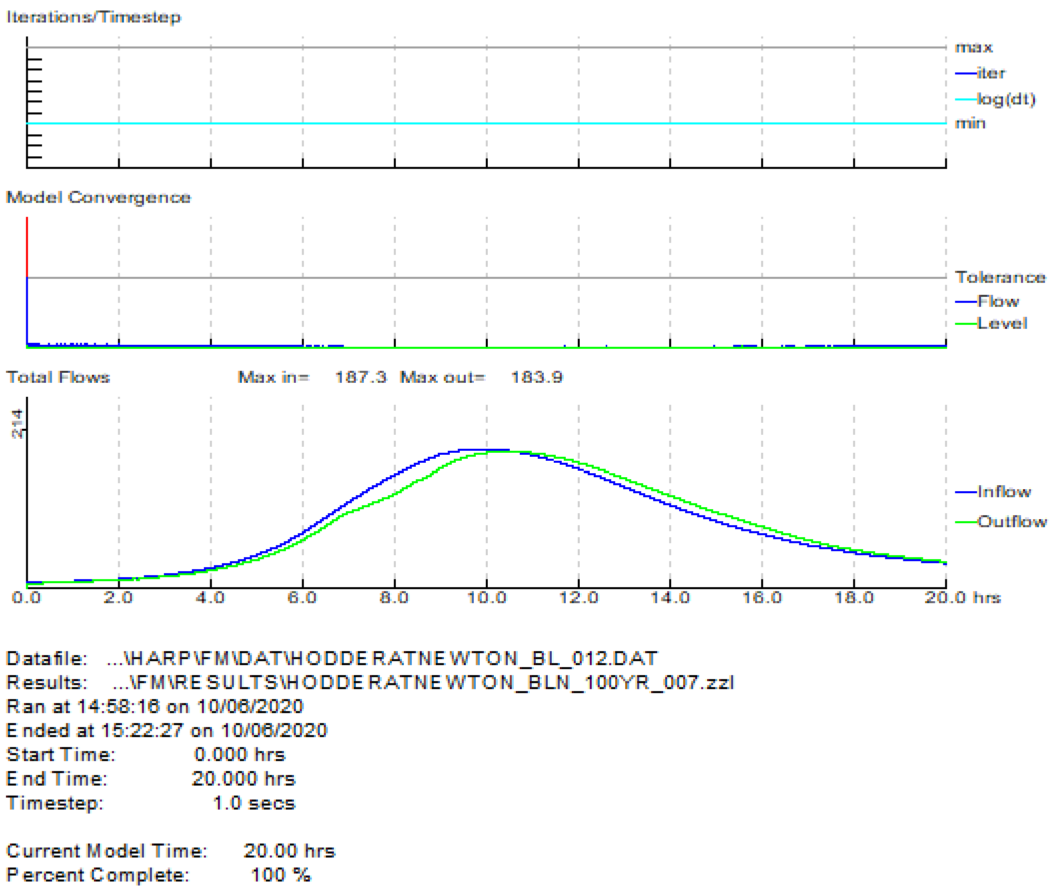
6.1 Introduction

39) The following sections discuss the model numerical performance and the verification process. In addition, details relating to the additional runs carried out to test the sensitivity of the model to key variables are also discussed.

6.2 Model Numerical Performance

40) Run performance has been monitored throughout the model build process and then during each simulation carried out, to ensure a suitable model convergence was achieved. Convergence refers to the ability of the modelling software to arrive at a stable solution within a specified number of iterations, for each model timestep. The convergence of the 1D model was checked and seen to be within the tolerance recommended by the software developer for the entire simulation. The 1D model mass balance error, relative to the boundary inflow volume was 0.1 %. These model diagnostics are considered to be well within the acceptable range, providing good confidence in the computational solution. Illustration 11 shows a typical convergence plot for the events modelled.

Illustration 11: Flood Modeller 1D convergence plot - 1 % AEP event - baseline scenario

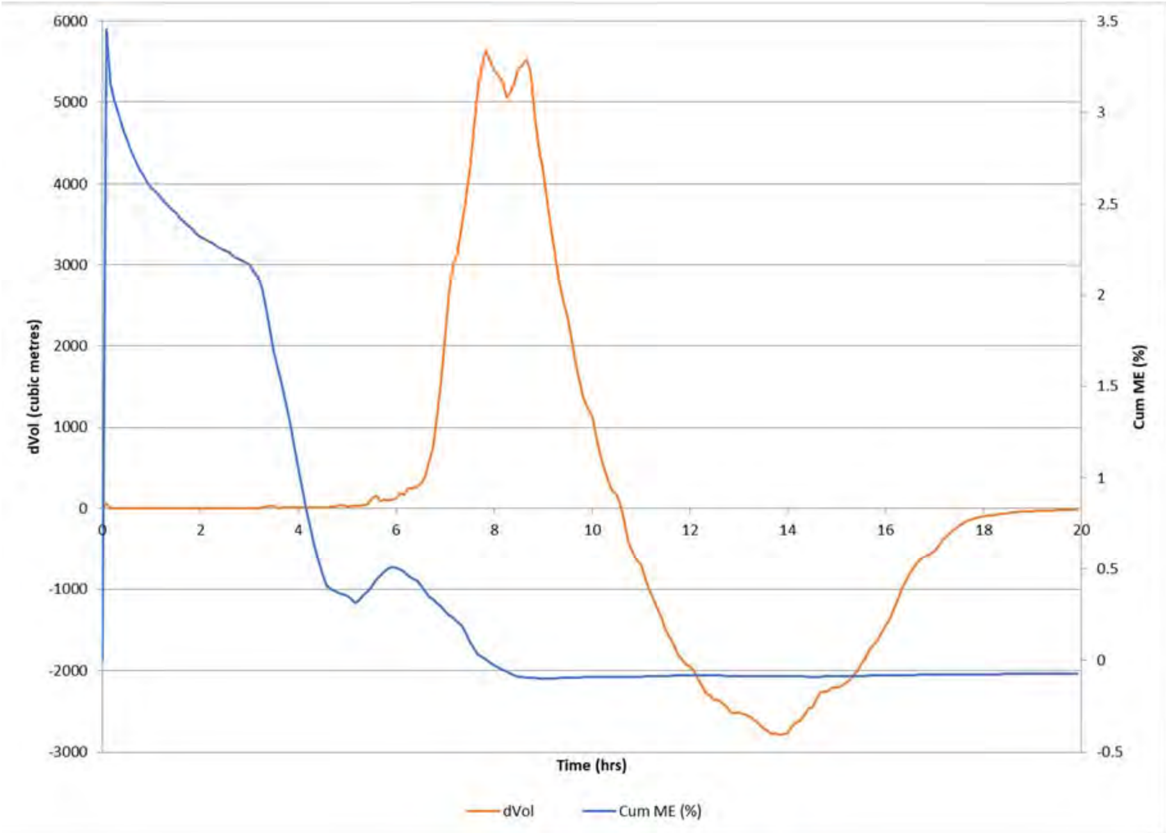


41) The cumulative mass error (Cum ME) reports output from the TUFLOW 2D model have been checked for all simulated events. The accepted tolerance range recommended by the software manual is +/-1 % mass balance error. Illustration 12 shows that for the 1 % AEP flood event Cum ME is well within this tolerance range for most of the duration of the run. The high mass error at the beginning of the

simulation is expected and relates to the onset of water flow from 1D to 2D. Mass error then decreases to acceptable values close to zero before any significant volume of water is present in the 2D domain.

42) Smooth variation of the change in volume (dVol) through the model simulation is another indicator of good convergence in the 2D model (Illustration 12). These 2D mass error and dVol diagnostics are typical for all events simulated.

Illustration 12: Cumulative Mass Error and change in volume plots - 1 % AEP event – baseline scenario



6.3 Calibration and Verification

6.3.1 Calibration

43) Calibration of the hydraulic model was not possible because the River Hodder is ungauged within the study area.

6.3.2 Verification Using Historical Data

44) EA historic flood maps show the maximum extent of all individual recorded flood events and areas of land that have been previously subject to flooding in England. An assessment of this data showed that there is no historic flood data for the River Hodder at this location.

6.3.3 Verification Using Environment Agency (EA) Flood Maps

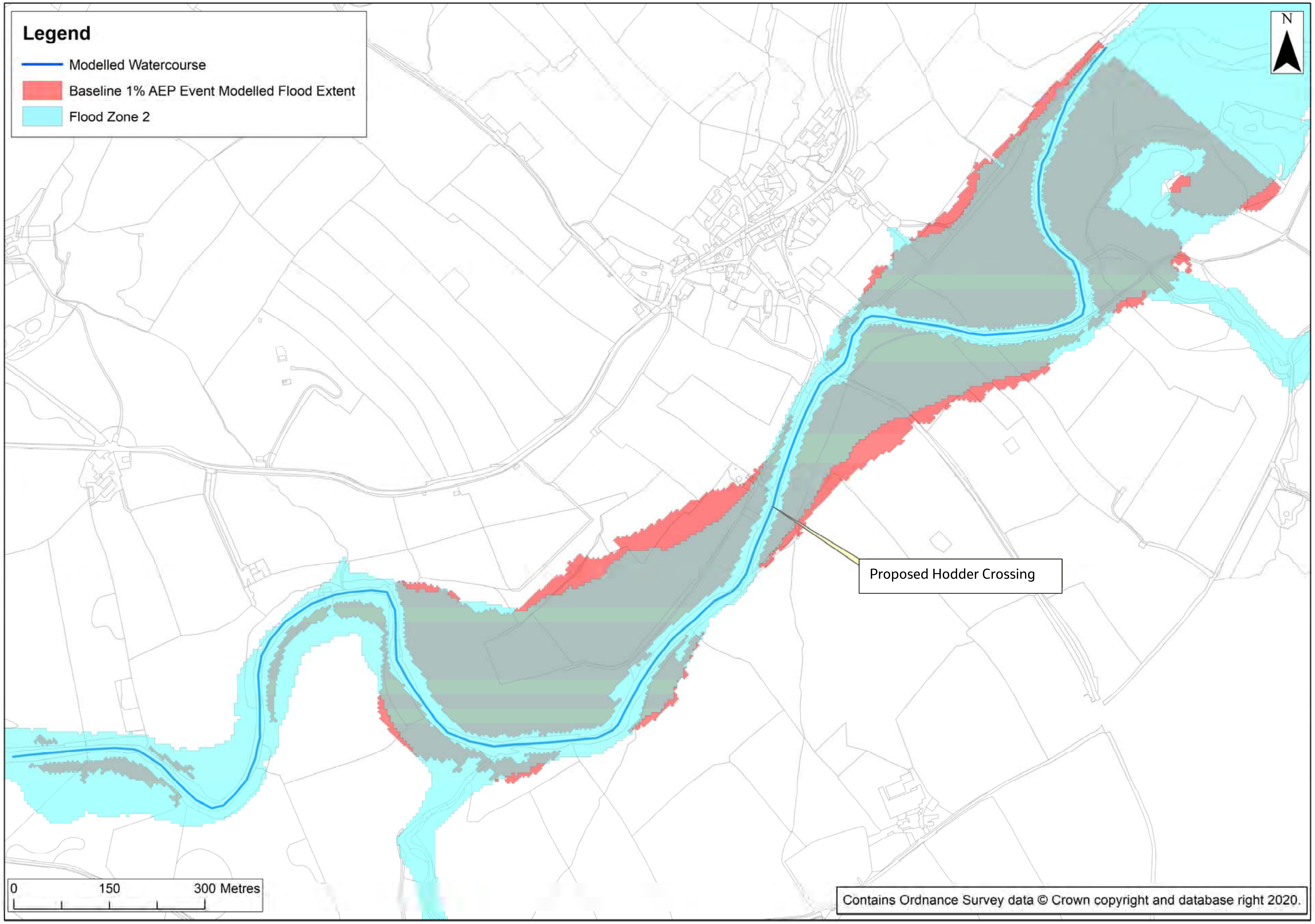
45) Illustration 13 shows the modelled 1 % AEP flood extent and the EA published Flood Zone 2, respectively. The comparison shows that the model predicts a slightly larger flood extent than the EA flood map on the right floodplain downstream of the proposed scheme. Approximately 800 m downstream of Foulscales Brook, water remains in bank in the model whereas the EA flood maps show flooding at this location. A review of the topography at this location shows an area of low ground adjacent to the watercourse. The present modelling shows that this low area would not flood as it is

separated from the watercourse by an embankment which is presumably not captured by the coarse scale EA flood map model.

6.3.4 Verification Conclusion

46) In conclusion, there is limited data available for verification of the River Hodder model. There are some discrepancies between the EA flood map and the model. This is due to the present study being a more detailed assessment of flooding than the EA flood map.

Illustration 13: Baseline 1 % AEP event modelled flood extent compared to the EA Flood Zone 2 mapping



6.4 Sensitivity Analysis

47) Sensitivity tests have been carried out to investigate the robustness of the model and quantify uncertainty. The following sensitivity tests have been carried out for the 1 % AEP event and compared to the baseline 1D water levels and 2D flood extents.

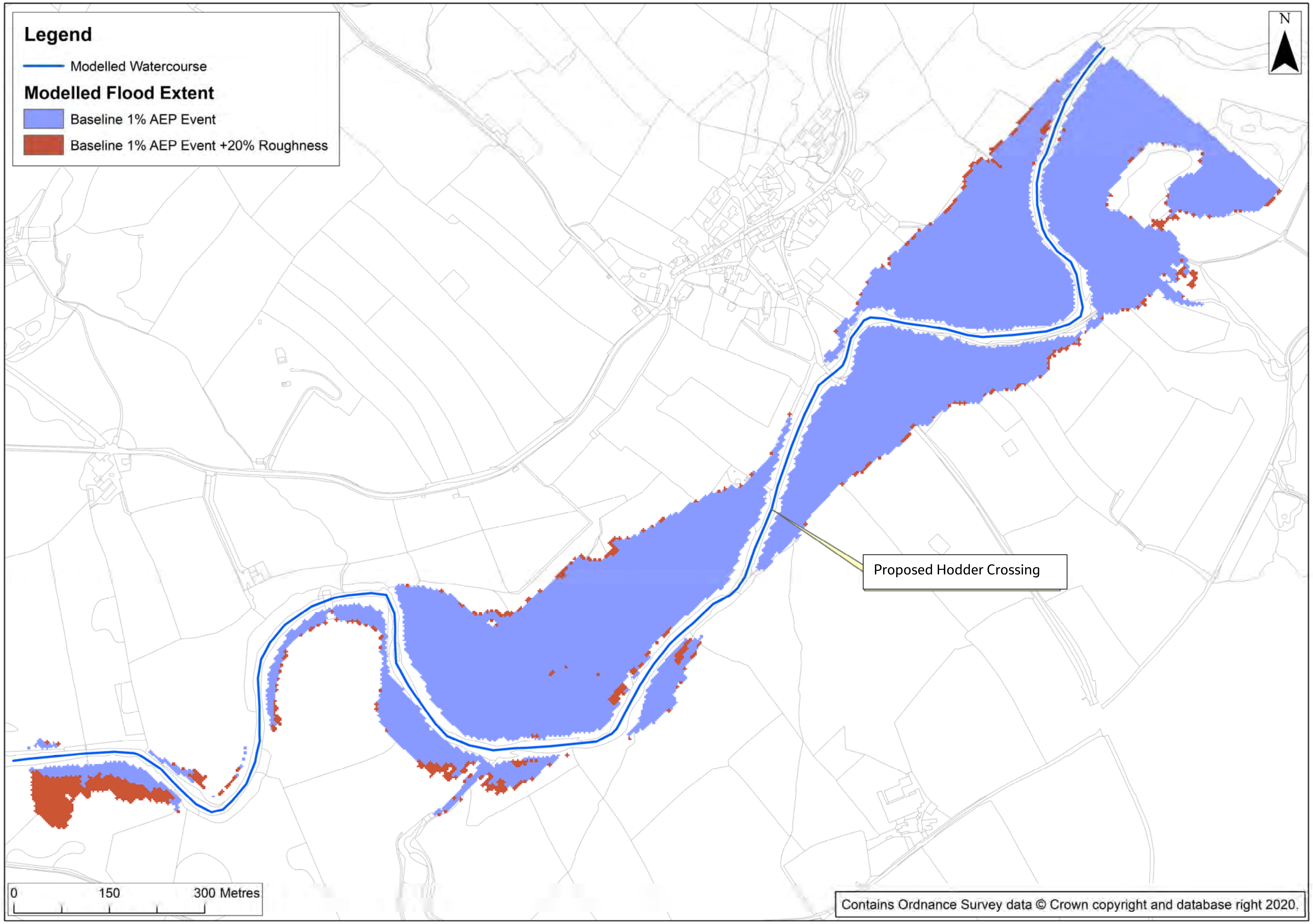
6.4.1 Roughness Sensitivity

48) In-channel and floodplain roughness coefficients (Manning's 'n') were adjusted by +20 % and -20 %. Table 8 shows the impact of changing the model roughness on predicted peak water levels. The results show that the in-channel water levels are moderately sensitive to changes in roughness. Within the floodplain, the most sensitive area is local to the downstream boundary where flood extent varies significantly along the left floodplain for 250 m of the river reach, as illustrated in Illustration 14.

Table 8: Roughness sensitivity results

Sensitivity	Water Level Difference (m)		
	Max	Min	Average
+20 % Roughness	+0.285	+0.027	+0.125
-20 % Roughness	-0.481	-0.013	-0.146

Illustration 14: Difference in modelled flood extents when in-channel and floodplain roughness values are increased by 20 %



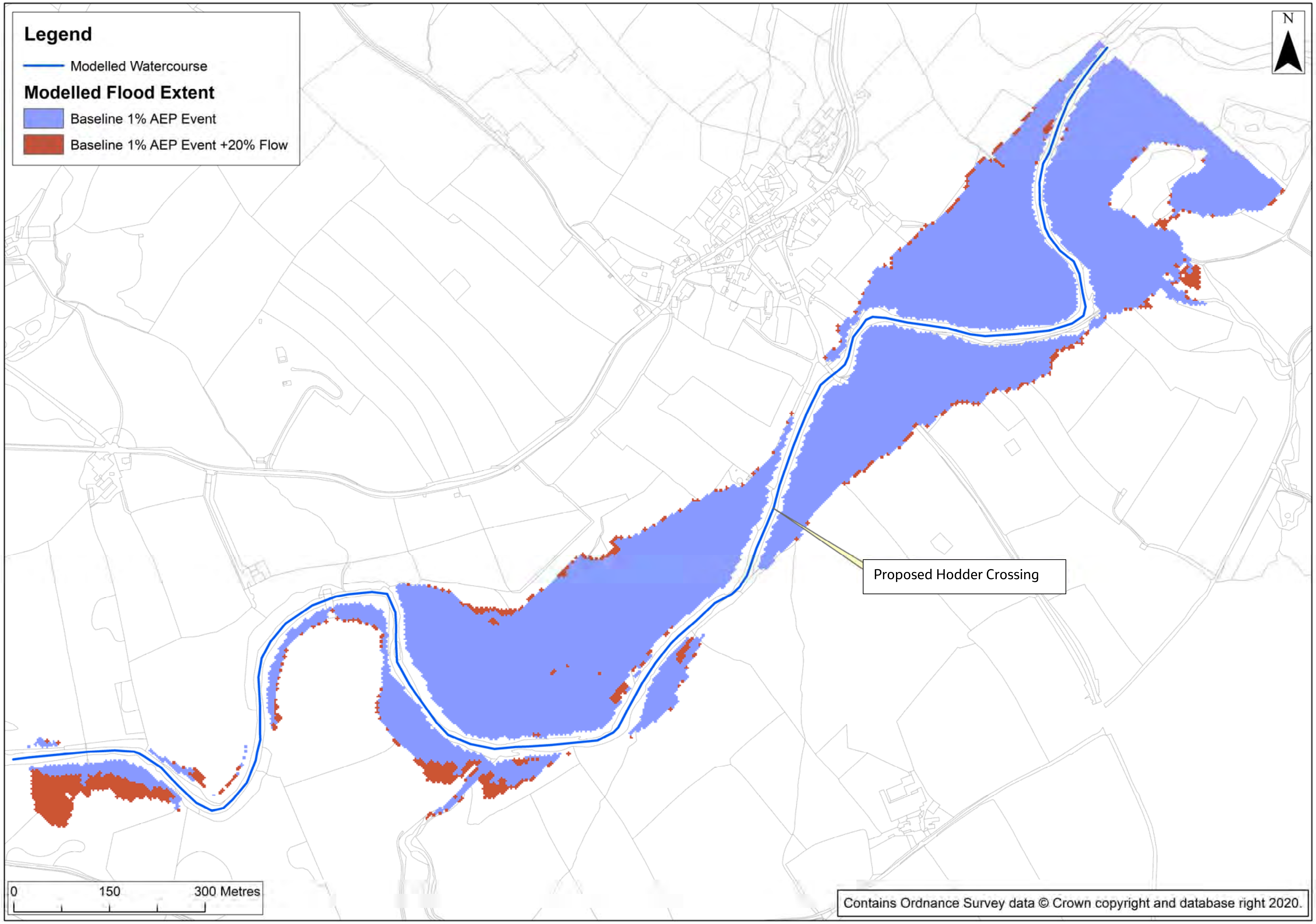
6.4.2 Hydrological Inflow Sensitivity

49) The flows into the model were adjusted by +20 % and -20 %. Table 9 shows the impact of changing the model inflows on predicted peak water levels. The results show that the in-channel water levels are moderately sensitive to changes in flow. The reduction in flow results in several small dry islands on the right floodplain downstream of the scheme location, while a 20 % increase in flow causes a notable increase in flood extent local to the downstream boundary and at the confluence with Foulscales Brook, as illustrated in Illustration 15.

Table 9: Hydrological inflow sensitivity results

Sensitivity	Water Level Difference (m)		
	Max	Min	Average
+20 % Flow	+0.416	+0.033	+0.167
-20 % Flow	-0.563	-0.018	-0.176

Illustration 15: Difference in modelled flood extents when hydrological inflows to the model are increased by 20 %



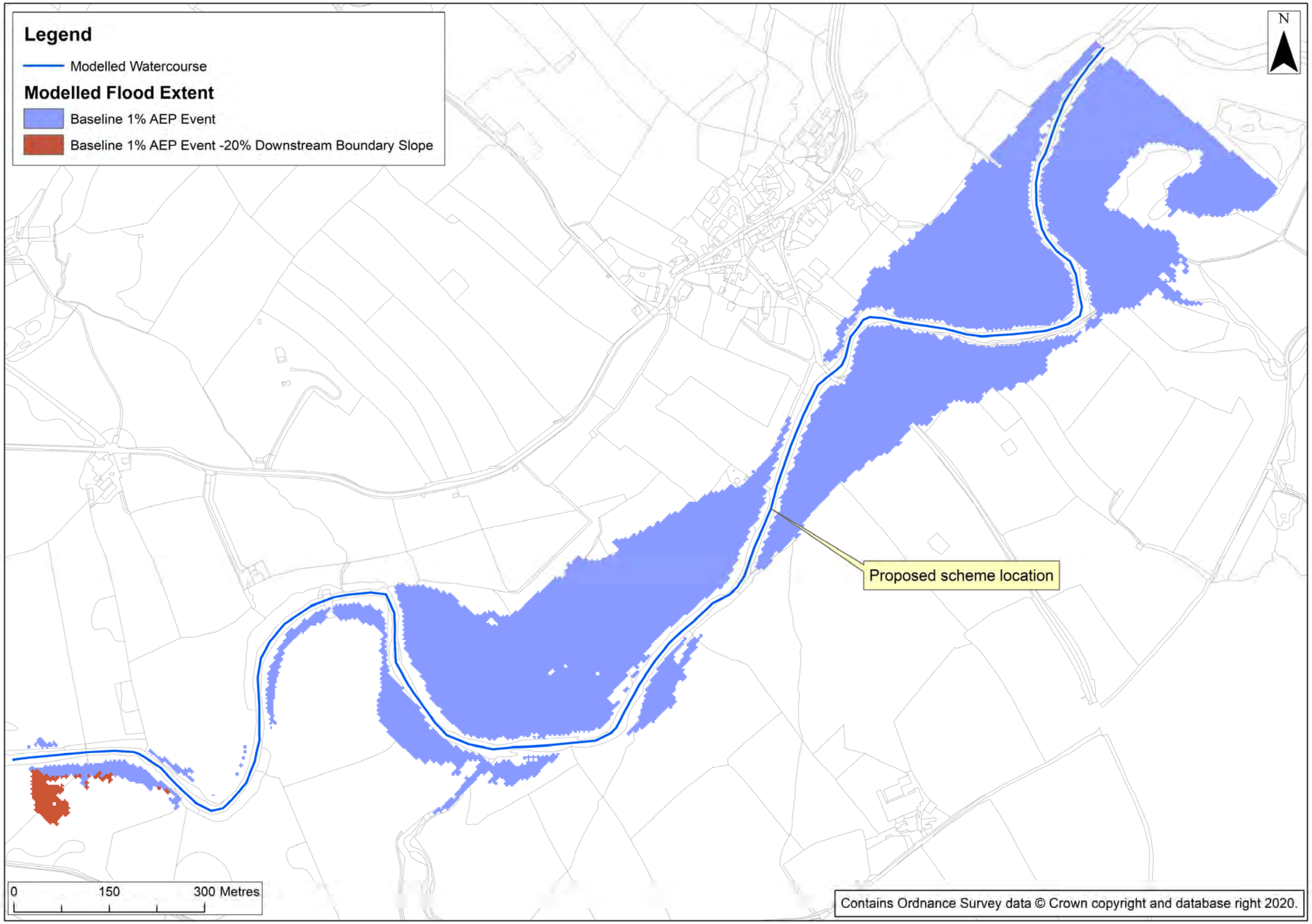
6.4.3 Downstream Boundary Condition Sensitivity

50) The slope of the normal depth downstream boundary was adjusted in the 1D domain by +20 % and -20 %. Table 10 shows the response at the downstream end of the model (Flood Modeller node HODD01_00000). The location at which there is no change in water level as a result of changing the downstream boundary has been identified. Distances from this location, in relation to the downstream end of the model (tailwater distance) and in relation to the proposed scheme are also shown. The results show that the effect of the downstream boundary does not reach the scheme location. The flood outline also remains unchanged at the scheme location, with just minor changes in extent local to the downstream boundary (see Illustration 16). This indicates that the downstream boundary is suitably removed from the area of interest and the boundary assumption is appropriate.

Table 10: Downstream boundary slope sensitivity results

Sensitivity	Water Level Difference (m) at HODD01_00000	Tailwater Distance (m)	Distance to Proposed Scheme (m)
+20 % Slope	-0.186	444	1352
-20 % Slope	+0.103	444	1352

Illustration 16: Difference in modelled flood extents when slope at the downstream boundary is decreased by 20 %



7. Proposed Scheme Design

51) The bridge will act as a temporary crossing for heavy vehicles to gain access to a construction site that will be located downstream of the scheme on the right hillside. The bridge will be in service for 5-6 years and then removed.

7.1 Design Options

52) Two initial design options were tested; a single-span bridge and a three-span bridge. However, after an initial modelling phase the three-span option was dismissed due to disproportionate sustainability impacts.

53) The single-span option is a simple bridge design consisting of a basic concrete slab over the channel with slopes either side (see Illustration 17). As part of the EA instruction, a freeboard of 600 mm is recommended above the 1 % AEP event maximum in-channel water level at the scheme location.

54) To reduce potential adverse impacts of the proposed bridge on the existing flood risk, further options were tested with the inclusion of flood relief culverts in the left and right floodplains. Invert levels were made equal to the existing ground level. The location of each culvert was decided based on the existing topography and invert levels were set at the existing ground levels.

55) The full list of options tested are as follows:

- Option A1 – 600 mm freeboard above baseline 1 % AEP event maximum in-channel water level
- Option A1b – 600 mm freeboard with a single 1m circular culvert under each ramp
- Option A1c – 600 mm freeboard with a single 4x1m box culvert under each ramp.

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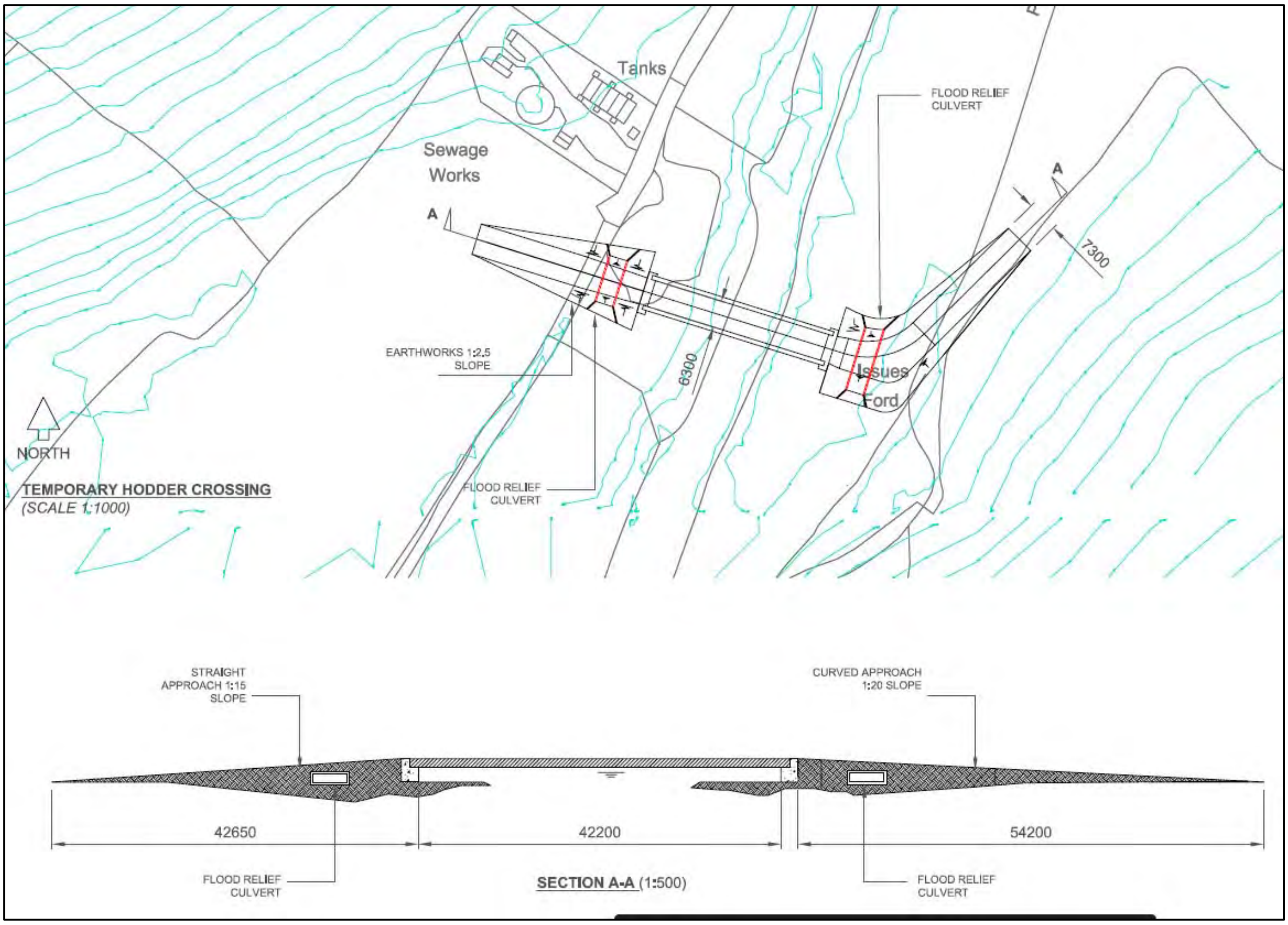
Illustration 17: Proposed scheme bridge design – Option A1c shown as an example



7.2 Model Schematisation

56) The bridge was represented by a 1D Flood Modeller USBPR bridge unit where the soffit level for each option was input into the model. The topography of the floodplain was adapted in the 2D model using a Z-shape feature to represent the ramps either side of the bridge.

57) For the culverted options, the culverts were represented in the model using embedded 1D “Estry” elements within the 2D domain. A Manning’s ‘n’ roughness value of 0.015 was applied as this is a standard value often used when modelling concrete culverts.

58) No other modifications to the hydraulic model were required.

8. Model Results

8.1 Baseline Results

59) In-channel maximum water levels have been inspected at key locations in relation to the proposed scheme.

60) Table 11 shows in-channel maximum water levels for the 1 % AEP event. The in-channel water levels at key locations for all modelled events are shown in Appendix A.

61) Illustration 18 shows the maximum flood depths and velocity vectors for the 1 % AEP event. The flood extents for all modelled events are shown in Appendix C.

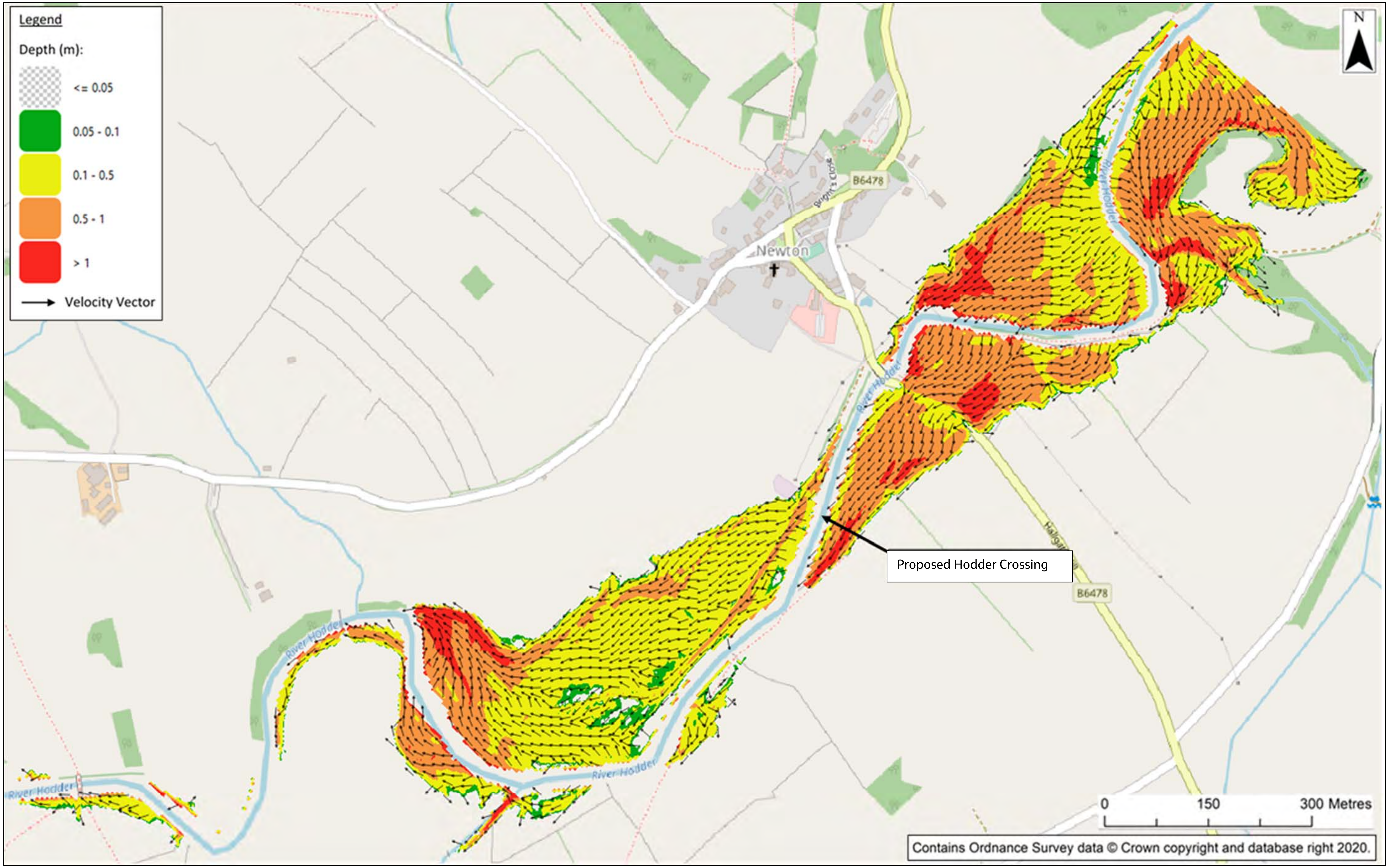
62) The bridge at Hallgate Hill has a freeboard of 1.1m between the 1 % AEP maximum water level and the bridge soffit. The road experiences flooding to the east of the bridge for all events except the two smallest (50 % and 20 % AEP events). Water levels are approximately 650 mm higher upstream of the road compared to downstream for the 1 % AEP event as a result of the bridge afflux. This feature constitutes a "hydraulic break" whereby conditions downstream from the bridge have only limited effect on water levels upstream.

63) The results show that the River Hodder experiences significant out of bank flow at the scheme location for storm events in excess of 10 % AEP, with the local fields forming a functional floodplain. There is significant freeboard of around 5 m between properties in Newton-in-Bowland and the modelled water levels on the river. The main flood risk receptor is the United Utilities WwTW, where the 1.33 % and 1 % AEP events cause inundation of the site, to depths of up to 280 mm due to overtopping of the right bank upstream of the site. The footpath between the WwTW and the river channelises flow, conveying it downstream away from the WwTW.

64) At the location of the proposed scheme on the left bank, water flows out of bank during the three largest modelled events (3.33 %, 1.33 % and 1 % AEP) and reaches a maximum flood depth of 1.2 m. The field on the left bank between the scheme and Hallgate Hill Road experiences depths of up to 0.8-1.1 m.

65) Due to the site topography there is little variation in flood extent for the three largest events.

Illustration 18: Baseline 1 % AEP event modelled maximum flood depth and velocity vectors. Depths below 0.05 m and velocity arrows below 0.7 m/s are not shown for visual clarity



8.2 Option Testing Results

66) Preliminary option testing of all the options was carried out. Table 12 summarises the water level differences for each option at the United Utilities WwTW (right bank) and at the field immediately upstream of the scheme (left bank) compared to the baseline 1 % AEP event.

Table 12: Difference in water level between the baseline 1 % AEP event and the design options at the United Utilities WwTW (right bank) and the upstream field (left bank)

Option	Water Level Difference (m) Right Bank	Water Level Difference (m) Left Bank
A1	+0.19	+0.20
A1b	+0.19	+0.18
A1c	+0.16	+0.13

67) Results show that Option A1c (600 mm freeboard with 4x1 m box culverts) produces the smallest increase in flood depth at the scheme and so this option was selected as the final design. Throughout the rest of this report, the "scheme" refers to this design option.

8.3 With Scheme Results

68) The impact from the scheme on the existing flood risk has been assessed by comparing peak water levels in both river channel and floodplain against the baseline flood risk. Illustration 19 shows maximum depths and velocity vectors for the 1 % AEP event, while Illustration 20 displays the water level difference compared to the baseline 1 % AEP event.

69) The bridge ramps cut across the active floodplain leading to some adverse effect on the baseline flood risk. Although flood relief culverts under the ramp intend to reinstate some form of floodplain connectivity, flows through these (12 m^3/s for a 1 % AEP) are not enough to mitigate the adverse effect.

70) Within the channel, the greatest increase in water level is located approximately 120 m upstream of the scheme. An increase in water level of up to 175 mm is predicted for the 1 % AEP event (see Table 13).

71) The Design 1 % AEP event water level immediately upstream of the bridge is 128.103 m AOD. Therefore, the soffit level of the proposed bridge opening needs to be set at 128.703m AOD to provide 600 mm freeboard. The full tailwater effect extends 666 m from the scheme. However, the hydraulic break at the Hallgate Hill location results in much lower differences between the scheme and baseline upstream from the Hallgate Hill bridge.

72) Within the floodplain, maximum water levels upstream of the scheme on the left bank farmland and at the United Utilities WwTW increase by approximately 100mm during flood events in excess of the 3.33 % AEP event. These high magnitude events also cause up to 10mm increase in water level on the road surface of the Hallgate Hill crossing, where flows are passing over the road. However, the model indicates no significant change to the onset of flooding to the road.

73) Flow along the right bank floodplain is diverted around the proposed bridge ramp, redistributing flood depths downstream of the bridge during the large events, in excess of the 3.33 % AEP event. The difference is most significant in the 3.33 % AEP event, where flood depths in the northern periphery of the right bank immediately downstream of the scheme increase by more than 100 mm (see Appendix D). There is some associated betterment, with reduced maximum water levels local to the channel.

74) Due to the nature of the topography, existing flood extents remain largely unchanged as they are constrained by the steep valley sides.

Table 13: In-channel maximum water level at key locations for the 1 % AEP event

Node	Description	Baseline 1 % AEP Event Max Stage (m AOD)	Scheme 1 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16 km upstream of the scheme.	130.649	130.649	0.000
HODD01_02065	30 m upstream from Hallgate Hill Bridge	128.912	128.934	0.022
HODD01_01915	120 m upstream of the scheme.	128.270	128.445	0.175
HODD1_01796	Immediately upstream of the scheme.	128.014	128.103	0.089
HODD01_00000	Downstream end of the River Hodder. 1.8 km downstream of the scheme.	122.039	122.039	0.000

Illustration 19: Design scenario 1 % AEP event modelled maximum flood depths and velocity vectors. Depths below 0.05 m and velocity arrows below 0.7 m/s are not shown for visual clarity

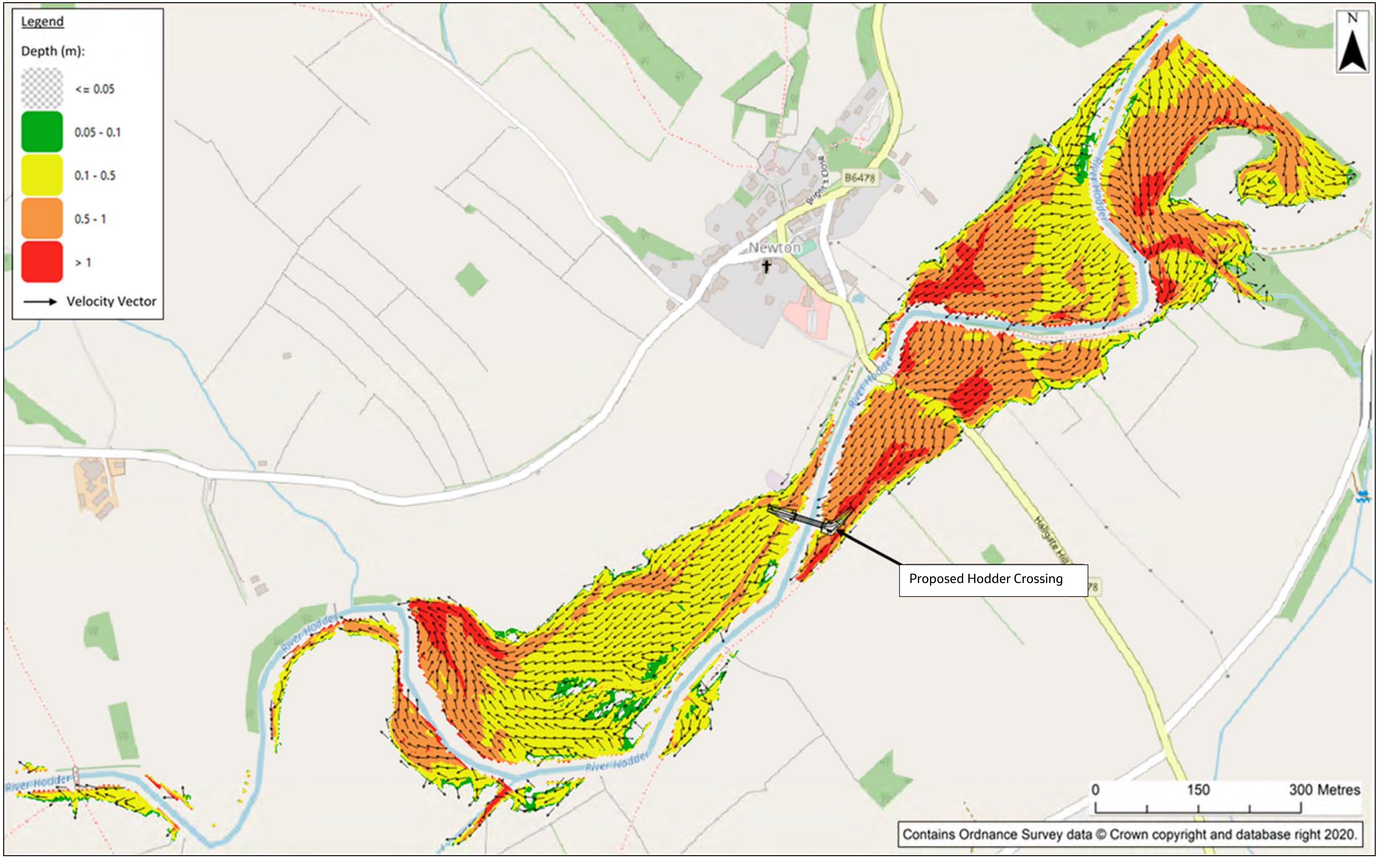
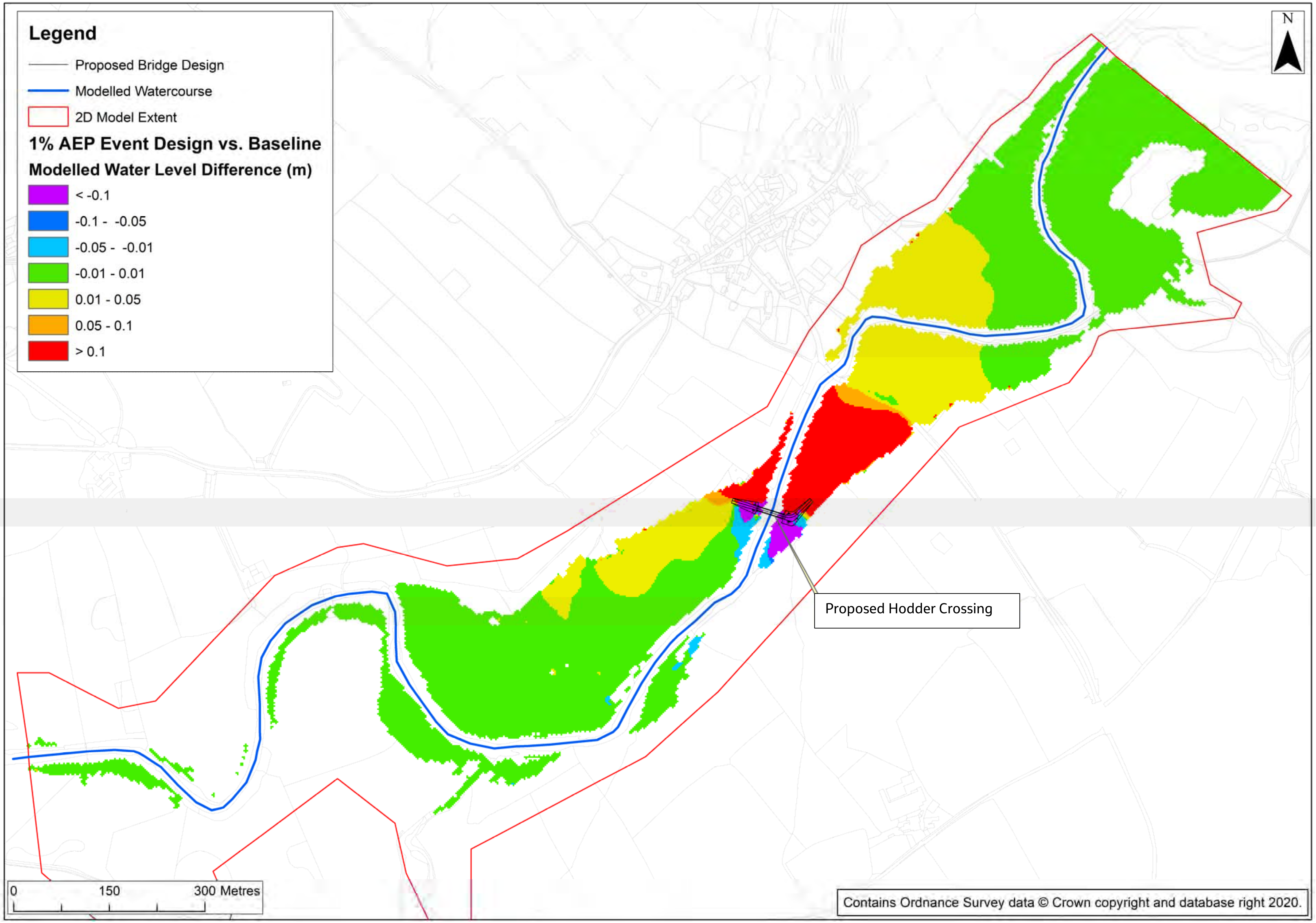


Illustration 20: Flood level difference map for the 1 % AEP event. With-scheme scenario minus baseline scenario



9. Model Assumptions and Limitations

75) The accuracy and validity of the hydraulic model results are heavily dependent on the accuracy of the hydrological and topographic data included in the model. While the most appropriate available information has been used to construct the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

76) Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. The assumptions made are considered to be generally conservative for modelled water levels at the proposed scheme and are therefore appropriate for the flood risk assessment.

9.1 Hydrology

77) The key sources of uncertainty and the limitations associated with the hydrological analysis undertaken for the River Hodder are as follows:

- The River Hodder is highly regulated by Stocks Reservoir, no useable gauge is located upstream of the study site (i.e. the location of the temporary bridge structure). The study assumes that the design hydrograph derived by the ReFH2 method and routed through a representation of the Stocks Reservoir is a satisfactory estimate of the peak flows and hydrographs generated at the study site
- As the subject site is located some distance (4.6 km) downstream of the reservoir, the modelled impact on outflow is approximate, the actual degree of attenuation and hence impact of the upstream reservoir, would be expected to decrease with downstream distance and hence the degree of attenuation is considered a slight over estimate
- With regards to quantifying uncertainty in the adopted flood estimates, hydrological analysis is subject to multiple sources of uncertainty and there is currently no published method of quantifying uncertainty in the results derived by the ReFH2 method.

9.2 Hydraulic Modelling

78) The key sources of uncertainty and the limitations associated with the modelling undertaken for the River Hodder are as follows:

- Channel roughness has been assigned using the best available information (survey data and aerial photographs). The roughness values used are based on available guidance (Chow, 1959)
- Hydraulic coefficients for structures have been applied using available guidance within the Flood Modeller and TUFLOW software. The dimensions for structures have been based on detailed survey measurements
- A normal depth boundary was used at the downstream end of the model. The sensitivity analysis has shown that changed to the downstream boundary do not impact upon modelled levels at the area of interest. Therefore, it was deemed appropriate to use a normal depth boundary
- The LiDAR data is assumed to appropriately represent the floodplain
- A 5 m grid has been used. This is deemed to provide a sufficient level of detail to represent floodplain topography and flooding mechanisms demonstrated by the model
- No calibration was possible.

10. Conclusion

79) This report has detailed the modelling carried out to assess the flood risk for the River Hodder with reference to the location of the proposed scheme.

80) The results of the baseline scenario have shown that at the proposed scheme location, water flows out of bank for the 10 %, 3.33 %, 1.33 % and 1 % AEP event.

81) The United Utilities WwTW is shown to be flooded during storm events of 3.33 % AEP event and above. Flooding of the WwTW is largely caused by out of bank flows conveyed from further upstream rather than overtopping of the Hodder at the scheme location.

82) Construction of the temporary access bridge adversely impacts the flood risk as the proposed bridge ramps cut across the active floodplain. The most severe impacts are located on both banks between the scheme and the B6478 road, Hallgate Hill. Although flood relief culverts under the ramp intend to reinstate some form of floodplain connectivity, flows through these are not enough to mitigate the adverse effect.

83) Downstream of the scheme, on the right bank, the bridge ramps cause a significant increase in flood depth in the farmland for the 3.33 % AEP event, due to the redistribution of flows within the floodplain there is an area that receives associated reduction in flood depth.

84) The scheme causes an increase in in-channel maximum water level for the 1 % AEP event, which needs to be considered when designing the bridge to allow for a 600 mm freeboard above this level.

Appendix A. Hydrology Calculation Record

Introduction

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

Contents

Approval

	Name and qualifications	Signature	Date
Calculations prepared by:	K. Samson		01/05/2020
Calculations checked by:	A Janes	A Janes	15/05/2020
Calculations approved by:	K Bhattarai	K.P. Bhattarai	18/05/2020

Abbreviations

AM	Annual maximum
AREA	Catchment area (km^2)
BFI	Base flow index
BFIHOST	Base flow index derived using the HOST soil classification
DPLBAR	Mean drainage path length (km)
DPSBAR	Mean drainage path slope (m/km)
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
POT	Peaks over a threshold
QMED	Median annual flood (with return period 2 years)
ReFH	Revitalised flood hydrograph method – used for rainfall runoff method
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
URBEXT2000	Revised index of urban extent
WINFAP	Windows Frequency Analysis Package – used for FEH statistical method

A.1 Method Statement

A.1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: ▪ purpose of study ▪ approximate number of flood estimates required ▪ peak flows or hydrographs ▪ range of return periods and locations approximate time available	To inform the design of a temporary bridge crossing of the River Hodder at National Grid Reference (NGR) SD 697 500, hydraulic modelling is required, and hence appropriate design hydrology is required to derive: ▪ estimates of peak flow at four flow estimation points (FEPs) over a range of AEP flood events (50 %, 20 %, 10 %, 3.33 %, 1.33 % and1 %); and ▪ design flood hydrographs at three identified inflow locations (US model inflow from River Hodder and an inflow for each of Easington Brook and Foulscales Brook). Refer to Figure 1.1 for the modelling extent and flow estimation locations. Due to the temporary nature of the bridge structure, as per the scope of work, no allowance for climate change is required to be applied to the estimated design peak flood flows.

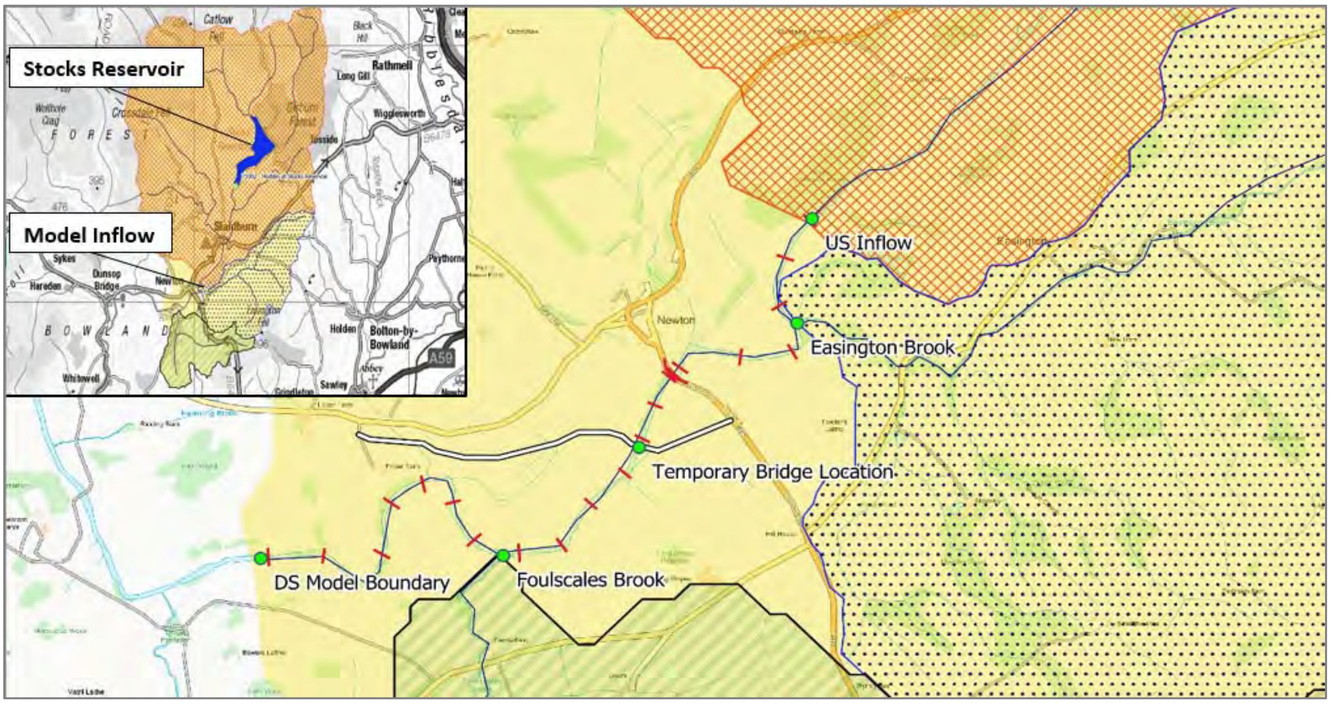


Figure 1.1: Location of temporary bridge crossing, the proposed model extent and flow estimation points

A.1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report. Include maps where necessary.	The study catchments form part of the River Hodder catchment. Underlying geology is comprised of Millstone Grit and Carboniferous Limestone. Land use is mixed farming in the lower reaches and peat moorland in headwaters. The catchments are rural and generally natural in nature, however Stocks Reservoir controls approximately 50 % of the catchment at the upstream model inflow location and approximately 38 % of the catchment at the downstream model extent.

A.1.3 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.	Version 8 of the NRFA Peak Flow Dataset, released on 25th September 2019. No changes made.

A.1.4 Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of flow record and end if station closed
Croasdale Beck	Croasdale Flume	N/A	71003	10.4	Rated	01/1957 -
Bottoms Beck	Bottoms Beck flume	N/A	71005	10.6	Rated (theoretical)	01/1960 - 12/1974
River Dunsop	Footholme Flume	711086	71015	25	Level	10/1995 -
River Hodder	Stocks Reservoir	711007	71002	37.4	Level	01/1968 -
River Hodder	Hodder Place	711610	71008	261	Rated	01/1969 -

A.1.5 Data available at each flow gauging station

Station Name	Start and end date on NRFA	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow quality e.g. information from NRFA Peak Flows, trends in flood peaks, outliers
Croasdale Flume	04/05/1957 - 20/12/2013	No	Yes	Yes	N/A	
Bottoms Beck flume	N/A	No	No	No	N/A	
Footholme Flume	N/A	No	No	No	N/A	
Stocks Reservoir	N/A	No	No	No	N/A	
Hodder Place	17/10/1969 - 01/10/2017	No	Yes	Yes	N/A	

A.1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical, degree of extrapolation	Rating review needed?	Reasons e.g. availability of recent flow gaugings, amount of scatter in the rating
Croasdale Flume	Empirical	N/A	Outwith scope of study
Bottoms Beck flume	Theoretical	N/A	Outwith scope of study
Hodder Place	Empirical	N/A	Outwith scope of study
Include a link or reference to any rating reviews carried out			

A.1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings (if planned to review ratings)	No, N/A			Rating reviews outwith scope of study.
Historic flood data – give link to historic review if carried out	No flood review undertaken			Assumed that any historic flood data has been made available to modelling team.
Flow data for events	No			The gauge recording flow from Stocks Reservoir to the River Hodder is located on an overflow weir downstream of the reservoir and does not represent a typical hydrograph

Type of data	Data relevant to this study?	Data available?	Source of data	Details
				nor flows within the downstream River Hodder. Station 71003 and 71005 are located on tributary branches, are no longer operational and have relatively short records (17-years and 14-years, respectively).
Rainfall data for events	No			Not applicable for this study.
Results from previous studies	No			Brief internet search for previous studies did not identify and relevant work to compare flood estimates against.
Other data or information e.g. groundwater, tides	No			No tidal influence and groundwater not considered.

A.1.8 Initial choice of approach

Item	Comment
Outline the conceptual model. Address questions 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, tides) ▪ Might those locations flood from runoff generated on part of the catchment only e.g. downstream of a reservoir?	The main site of interest is the location of the temporary bridge crossing of the River Hodder. To determine flow and level at the proposed bridge crossing, estimates of flow are required at the upstream model inflow, the contributing flow from two tributary branches, and a flow estimate at the downstream model extent for the purpose of flow reconciliation. Flooding is suspected to result from a combination of peak flows and flood volumes that exceed the capacity of the channel. Additionally, flooding is suspected to be influenced by the combination and timing of peaks. Flood mechanisms will be confirmed during the course of the hydraulic modelling.
Any unusual catchment features to take into account? e.g. ▪ highly permeable (BFIHOST> 0.65) – consider permeable catchment adjustment for statistical method if SPRHOST<20 % ▪ highly urbanised – consider choice of method carefully; consider method that can account for differing sewer and topographic catchments ▪ pumped watercourse – consider lowland catchment version of rainfall-runoff method ▪ major reservoir influence (FARL<0.90) – consider flood routing ▪ extensive floodplain storage – consider choice of method carefully	The River Hodder's flow regime is regulated by upstream Stocks reservoir with the reservoir controlling approximately 50 % of the catchment at the upstream model inflow location and approximately 38 % of the catchment at the downstream model extent.

Item	Comment
Initial choice of method(s) and reasons ▪ Are FEH statistical and/or ReFH appropriate? ▪ If not appropriate, describe why and give details of the other methods to be used. ▪ Will the catchment be split into sub-catchments/intervening areas? If so, how will flows for intervening areas be estimated?	The scope of work calls for estimation of design peak flood flows using two methods (FEH Statistical and ReFH2). Catchment FARL at the location of the River Hodder upstream inflow is 0.90 which could be argued to lie just within the limits of applicability for use of the statistical method QMED equation. Standard application of the ReFH2 method does not account for the attenuating effect of upstream reservoirs . To account for the reservoir's impact on peak flow, the initial ReFH2 hydrograph is routed through a model representation of the reservoir to determine the impact on outflow. A distributed rainfall runoff approach, considering design flows from the Easington Brook and Foulscales Brook sub-catchments, is adopted for deriving the ReFH2 peak flow estimates and inflow hydrographs. Estimation of residual flow (if required) will require consideration of the already included Easington Brook and Foulscales Brook so as not to double count the flow contribution from these watercourses.
Software to be used (with version numbers) edit or delete as applicable, or add others	WINFAP [v4] ReFH [v2.3]

A.2 Locations where flood estimates are required

A.2.1 Summary of subject sites

The table below lists the locations of subject sites (shown on Illustration 1).

Site code	Watercourse	Site	Easting	Northing	AREA on FEH Web Service (km2)	Revised AREA if altered
HODDER_01	River Hodder	Hodder @ Newton	370200	450700	73.6	N/A
HODDER_02	River Hodder	Hodder @ Giddy Br.	368550	449650	96.7	N/A
EASINGTON_01	Easington Brook	Hodder / Easington Confl.	370250	450450	13.1	N/A
FOULSCALES_01	Foulscales Brook	Hodder / Foulscales Confl.	369300	449650	7.0	N/A
Reasons for choosing above locations	Flow estimation points are based on model extent					
Notes	Flow contribution from the residual catchment i.e. the remaining 3.08 km^2 is discussed in Section 5.6					

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

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT 2000	FPEXT
HODDER_01	0.90	0.60	0.31	9.3	111	1646	48.7	0.001	0.05
HODDER_02	0.92	0.60	0.31	10.7	108	1600	48.1	0.001	0.05
EASINGTON_01	1.00	0.60	0.33	4.0	94	1427	45.3	0.000	0.06
FOULSCALES_01	1.00	0.60	0.29	2.7	116	1488	52.1	0.000	0.02

A.2.3 Checking catchment descriptors

Item	Comment
Record how catchment boundary was checked ▪ describe any changes ▪ refer to maps if needed	Catchment boundaries checked against the surface water network as depicted on Ordnance Survey mapping. No changes to the FEH catchment boundary made.
Record how other catchment descriptors were checked, especially soils ▪ describe any changes ▪ include a before and after table if necessary	Values for BFIHOST / SPRHOST sense checked against Soilscapes 1:250,000 scale soils dataset and British Geological Survey 1:625,000 scale geology mapping. FARL values sense checked by a review of Ordnance Survey mapping. No changes made to default catchment descriptors.
Source of URBEXT / URBAN	URBEXT 2000
Method for updating URBEXT / URBAN ▪ Refer to WINFAP4 Urban Adjustment procedures/guidance	CPRE formula from 2006 CEH report on URBEXT2000. Urban Adjustment Factor (UAF) based on WINFAP v4 procedure.

A.3 Statistical method

A.3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites **Mention:** **number of potential donor sites available** **distances from subject site** **similarities in terms of AREA, BFIHOST, FARL and other catchment descriptors** **quality of flood peak data**	From the five nearby gauging stations identified in Section 1.4, only 71008 - Hodder at Hodder Place and 71003 - Croasdale Beck at Croasdale Flume are suitable for flood frequency analysis. The gauge on the River Hodder offers potential for refining the estimate of QMED for the FEPs located on the River Hodder while Croasdale Beck has potential for refining QMED estimates for the tributary branches (Easington Brook and Foulscales Brook)

A.3.2 Donor sites chosen and QMED adjustment factors

NRFA number	Reasons for choosing or rejecting	Method (AM or POT)	Adjusted for climatic variation?	QMED from flow data (gauged) (m3/s)	QMED from flow data with urban influence removed (A) (m3/s)	QMED rural from catchment descriptors (B) (m3/s)	Adjustment ratio (A/B)
71008	**ACCEPTED:** Closest station on same watercourse.	AM	No	222	221.954	187.420	1.18
71003	**REJECTED:** Issues with record before station re-opened in 2003. Remaining record (11-years) insufficient for QMED estimation.	N/A	N/A	N/A	N/A	N/A	N/A

A.3.3 Overview of estimation of QMED at each subject site

Site code	QMED rural from CDs (m3/s)	Method*	NRFA numbers for donor site/s used (see 3.2)	Distance between centroids dij (km)	Moderated QMED adjustment factor (A/B)a	If more than one donor		Final estimate of QMED rural (m3/s)	Final estimate of QMED urban (m3/s)
						Weight (if WINFAP4 method not used)	Weighted average QMED adjustment factor		
HODDER_01	53.7	DT	71008	7.9	1.069	N/A	N/A	57.4	57.5
HODDER_02	70.6	DT	71008	6.7	1.073	N/A	N/A	75.8	75.8
EASINGTON_01	14.1	CD	N/A	N/A	N/A	N/A	N/A	14.1	14.1
FOULSCALES_01	9.5	CD	N/A	N/A	N/A	N/A	N/A	9.5	9.5

Has the Kjeldsen (2014) urban adjustment method (as used in WINFAP4) been applied? If not, why?	Yes
How are the weights derived?	N/A
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	Yes, estimates of QMED on the main River Hodder increase with downstream distance.

* Methods: CD catchment descriptors alone; DT data transfer; BCW catchment descriptors and bankfull channel width; FV flow variability (using flow duration statistics)

A.3.4 Derivation of pooling groups

The composition of pooling groups is given in the Annex.

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
HODDER	HODDER_02	Yes	Initial approach was to undertake pooling analysis at the location of the DS model extent and to adopt stations whose catchments have similar levels of catchment attenuation (FARL). A peak-flow rated gauge (71008) is located approx. 25km DS of the study location however the resulting pooling group at the DS model extent does not include this station due to the distance measure of hydrologically similarity being greater than other stations located on other watercourses. Simply including the station located on the Hodder to the pooling group places the station at the bottom of the group list meaning that little weight is given to its data. Hence, in order to make better use of the station data ESS undertaken. No changes to default 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
EASINGTON	EASINGTON_01	No	**Removed:** 47022 (Tory Brook @ Newnham Park) due to a low FARL value (0.94) 44008 (South Winterbourne @ Winterbourne Steepleton) due to SPRHOST <20 % **Investigated but retained:** 71003 (Croasdale Beck @ Croasdale Flume) Problems reported in record before station re-opened in 2003, lack of high flow gaugings, and limited survey for model flow gaugings. Period of record pre-1977 disregarded (most recent rating based on gaugings between1980s & 2000s). 48009 (st Neot @ Craigshill Wood) cautionary note however, structure believed to stay modular. 48004 (Warleggan @ Trengoffe) cautionary note however, structure is thought to be modular across full range (of flows). **Added:** 45816 (Haddeo @ Upton) 25019 (Leven @ Easby) to increase total number of station years.
FOULSCALES	FOULSCALES_01	No	**Removed:** 47022 (Tory Brook @ Newnham Park) due to a low FARL value (0.94) **Investigated but retained:** 71003 (Croasdale Beck @ Croasdale Flume) Problems reported in record before station re-opened in 2003, lack of high flow gaugings, and limited survey for model flow gaugings. Period of record pre-1977 disregarded (most recent rating based on gaugings between1980s & 2000s). 91802 (Allt Leachdach @ Intake) Reported that suitable for pooling with caution - based on FSR quality grade of A2. Full period of record retained. **Added:** 49003 (de Lank @ de Lank) added to increase total number of station years.
URBEXT2000 threshold used to create pooling group(s)	Rural sites i.e. URBEXT2000 <0.03		

A.3.5 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, FH)	If P, ESS, or FH, name of pooling group (3.4)	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
HODDER_01	ESS	HODDER	GL, best fit as indicated by Z-value	Growth curve adjusted using WINFAP v4 urban adjustment procedure. No permeable adjustment required.	Location: 1.00 Scale: 0.158 Shape: -0.179	2.13
HODDER_02	ESS	HODDER	GL, best fit as indicated by Z-value		Location: 1.00 Scale: 0.158 Shape: -0.179	2.13
EASINGTON_01	P	EASINGTON	GL, best fit as indicated by Z-value		Location: 1.00 Scale: 0.221 Shape: -0.267	2.99
FOULSCALES_01	P	FOULSCALES	GL, best fit as indicated by Z-value		Location: 1.00 Scale: 0.209 Shape: -0.242	2.77

SS: single site; P: pooled; ESS: enhanced single site; FH: single site with flood history

A.3.6 Derivation of flood growth curves at subject sites Flood estimates from the statistical method

Flood peak (m3/s) for the following return periods (years)						
Site code	2	5	10	30	75	100
HODDER_01	57.5	71.8	81.9	99.4	116	122
HODDER_02	75.8	94.6	108	131	153	161
EASINGTON_01	14.1	19.4	23.5	31.1	39.3	42.3
FOULSCALES_01	9.5	12.8	15.3	19.9	24.6	26.3

A.4 Revitalised flood hydrograph (ReFH2) method

A.4.1 Parameters for ReFH2 model

Site code	Details of method*	Tp (hours) Time to peak	Cmax (mm) maximum storage capacity	BL (hours) baseflow lag	BR 2-year baseflow recharge
HODDER_01	CD	2.764	221.216	31.386	0.688
HODDER_02	CD	3.01	225.275	32.752	0.744
EASINGTON_01	CD	1.808	236.058	27.408	0.947
FOULSCALES_01	CD	1.343	216.104	23.544	0.712
Brief description of any flood event analysis carried out Provide further details either here or in a project report					

* OPT: optimisation; BR: base flow recession fitting; CD: catchment descriptors; DT: data transfer

A.4.2 Design events for ReFH2 method

Site code	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)	Source of design rainfall statistic (FEH13 or FEH99)
HODDER_01	Winter	7.5hr	Catchment area	FEH13
HODDER_02	Winter	7.5hr	Catchment area	FEH13
EASINGTON_01	Winter	4.25hr	Catchment area	FEH13
FOULSCALES_01	Winter	3.25hr	Catchment area	FEH13
Detail any changes to the default ReFH2 urbanisation model parameters				
Are the storm durations likely to be changed in the next stage of the study For example by optimisation within a hydraulic model?	The scope of work calls for deriving design model inflows and hydrographs based on the 'theoretical' critical storm duration for each of the agreed AEP events. The critical duration is defined here as that which gives the highest flow at the flow estimation point and has been assessed through an iterative process whereby the storm duration is incrementally increased until flow is no longer observed to increase but rather decrease. The assessed critical storm duration is reported below.			

A.4.3 Assessed critical storm duration

Site code	Critical storm duration (hours) for the following return periods (years)					
	2	5	10	30	75	100
HODDER_01	12.5	11.5	11.5	10.5	10.5	10.5
HODDER_02	12.5	11.5	11.5	10.5	10.5	10.5
EASINGTON_01	8.25	7.25	6.25	6.25	6.25	6.25
FOULSCALES_01	6.25	6.25	5.25	5.25	5.25	5.25

A.4.4 Flood estimates from the ReFH2 method (urban) – catchment specific storm duration/ARF

Flood estimates from the ReFH2 method are shown below based on the default storm duration calculated by the ReFH2 software and also based on the assessed critical storm duration. Flood estimates based on the critical storm duration are shown in brackets.

Site code	Flood peak (m3/s) or volumes (m3) for the following return periods (years)					
	2	5	10	30	75	100
HODDER_01	70.9 (75.0)	93.1 (96.7)	110 (113)	139 (141)	170 (172)	181 (184)
HODDER_02	83.3 (89.1)	110 (115)	129 (134)	164 (168)	200 (203)	213 (217)
EASINGTON_01	11.6 (12.9)	16.0 (17.2)	19.3 (20.5)	25.0 (26.2)	30.6 (32.1)	32.7 (34.2)
FOULSCALES_01	8.2 (9.2)	11.7 (12.6)	14.3 (15.1)	18.7 (19.5)	22.9 (23.8)	24.4 (25.2)

(based on critical storm duration)

A distributed rainfall runoff approach, i.e. also considering flows from the Easington Brook and Foulscale Brook sub-catchments, is adopted. Hence a common design storm (in terms of both duration and areal reduction factor) is applied to each sub-catchment.

Assessment of the critical storm duration at the upstream and downstream model extent is identical. Storm duration and areal reduction factor (ARF) are calculated for the River Hodder catchment at the downstream model extent and used to derive the ReFH2 peak inflow and peak flow hydrograph at all flow estimation points, i.e. for the Easington Brook and Foulscale Brook as well as the flow estimation points on the main River Hodder.

A.4.5 Flood estimates from the ReFH2 method (urban) – common storm duration/ARF

Site code	Flood peak (m3/s) or volumes (m3) for the following return periods (years)					
	2	5	10	30	75	100
HODDER_01	74.5	95.9	112	140	170	182
HODDER_02	89.1	115	134	168	203	217
EASINGTON_01	12.0	15.7	18.4	23.5	28.4	30.3
FOULSCALES_01	8.1	10.9	12.8	16.5	19.8	21.0

A.4.6 River Hodder hydrograph routing

Standard application of the ReFH2 method does not account for the attenuating effect of upstream reservoirs. To account for the impact of Stocks Reservoir on peak flow, the ReFH2 hydrographs derived for the River Hodder based on the critical storm duration are routed through a model representation of the reservoir to determine the impact on outflow.

United Utilities have previously commissioned Jacobs UK Ltd to undertake a flood study for the Stocks Reservoir[2] and a hydraulic routing model built for that study is available to route the current hydrographs and hence determine the impact on outflow.

As the subject site (i.e. River Hodder at Newton-in- Bowland) is located some distance (4.6km) downstream of the reservoir, the modelled impact on outflow is approximate, the actual degree of attenuation and hence impact of the upstream reservoir, would be expected to decrease with downstream distance and hence the degree of attenuation is considered a slight over estimate.

Details of the model build are included in 6.3 of the Annex to this calculation record.

A.4.7 Routed flow (HODDER_01)

Return period (years)	Inflow (m^3/s)	Outflow (m^3/s)	Attenuation ratio
2	74.5	60.4	0.811
5	95.9	78.1	0.815
10	112	92.3	0.827
30	140	117	0.836
75	170	144	0.843
100	182	153	0.843

The resulting attenuation ratio for the simulated 100-year return period is 0.833 which is counter intuitive as the degree of attenuation should decrease with increasing event magnitude. A possible cause for this discrepancy may relate to differing hydrograph durations. Hence, the 75-year attenuation ratio is applied to the 100-year inflow and the 75-year hydrograph scaled to the recalculated 100-year outflow to capture the same degree of hydrograph attenuation.

In order to incorporate the influence of Stocks Reservoir on flow estimates at the downstream model extent (HODDER_02), the attenuation ratios calculated for the upstream model inflow (HODDER_01) are applied. Final flood flow from the ReFH2 method, based on the critical storm duration and areal reduction factor as calculated at HODDER_02, are shown in 4.8.

A.4.8 Final flood estimates from the ReFH2 method (following routing)

Flood peak (m3/s) for the following return periods (years)						
Site code	2	5	10	30	75	100
HODDER_01	60.4	78.1	92.3	117	144	153
HODDER_02	72.2	93.6	111	140	171	183
EASINGTON_01	12.0	15.7	18.4	23.5	28.4	30.3
FOULSCALES_01	8.1	10.9	12.8	16.5	19.8	21.0

[2] Jacobs (2015). Stocks Reservoir Flood Study and Review of Wave Analysis. Project No: B16000EP

A.5 Discussion and summary of results

A.5.1 Comparison of results from different methods

This table compares peak flows from the ReFH method with those from the FEH Statistical method at each site for two key return periods.

Site code	Return period 2 years (QMED)			Return period 100 years		
	Statistical	ReFH	Ratio (ReFH / statistical)	Statistical	ReFH	Ratio (ReFH / statistical)
HODDER_01	57.5	60.4	1.05	122	153	1.25
HODDER_02	75.8	72.2	0.95	161	183	1.13
EASINGTON_01	14.1	12.0	0.85	42.3	30.3	0.72
FOULSCALES_01	9.5	8.1	0.85	26.3	21.0	0.80

A.5.2 Final choice of method

Choice of method and reasons Include reference to type of study, nature of catchment, and type of data available	Flood flows derived from the ReFH2 method are adopted as the final flows for the following reasons: The 100-year return period flood flow is to be adopted as the critical design flow for informing design of the temporary bridge structure. For the main inflow to the hydraulic model (HODDER_01) the estimate of the 100-year return period flood is 25 % greater than is estimated by the FEH statistical method. Adopting the higher flows offers a degree of freeboard for uncertainty. For the Easington Brook and Foulscales Brook, the estimated 100-year return period flood derived by the ReFH2 method is 28 % and 20 % less respectively, relative to flow estimated by the statistical method. The main flow contribution considered to influence water level at the temporary bridge location on the River Hodder is that of HODDER_01 i.e. the main upstream model inflow. Adopting the statistical method over the ReFH2 method would result in lower flows in the main River Hodder. Adopting the ReFH2 flows for the main River Hodder and the statistical method for the tributary branches would result in an inconsistent approach which has implications for flow reconciliation at the downstream model extent. The flows estimated by the ReFH2 method are based on routing the hydrograph through a representation of the Stocks Reservoir and may offer a better estimate of the reservoirs impact on outflow than data transfer from the downstream gauge located on the River Hodder. The ReFH2 rainfall runoff method underpins the approach for deriving the inflow hydrographs. Directly adopting the ReFH2 method avoids losing information such as runoff volume.

A.5.3 Assumptions, limitations, and uncertainty

List the main assumptions made specific to the study	The River Hodder is highly regulated by Stocks Reservoir, no useable gauge is located upstream of the study site. The study assumes that the design hydrograph derived in ReFH2 and routed through a representation of the Stocks Reservoir is a satisfactory estimate of the peak flows and hydrographs generated at the study site. As the subject site (i.e. the model inflow location) is located some distance (4.6km) downstream of the reservoir, the modelled impact on outflow is approximate, the actual degree of attenuation and hence impact of the upstream reservoir, would be expected to decrease with downstream distance and hence the degree of attenuation is considered a slight over estimate.
Discuss any particular limitations **For example applying methods outside the range of catchment types or return periods for which they were developed**	Application of the statistical method at the upstream model inflow can be argued to constitute the limit of the applicability of the method due to the low FARL value (0.90) indicating significant attenuation.
Give what information you can on uncertainty in the results **For example using the methods detailed in 'Making better use of local and historic data, and estimating uncertainty in FEH design flood estimation (FEH Local) SC130009**	The flows derived by the ReFH2 method are adopted. There is currently no published method of quantifying uncertainty in the results derived by the ReFH2 method.
Comment on the suitability of the results for future studies **For example at nearby locations or for different purposes**	The results of this study are suitable for the purpose of meeting the scope of work. Future studies should not rely upon these results without a check of the suitability of results.
Give any other comments on the study **For example suggestions for additional work**	The purpose of the study is to inform temporary works, hence no further additional work is suggested.

A.5.4 Checks

Are the results consistent, for example at confluences?	Results are sensible. Sum of inflows generally consistent with most downstream flow estimate.
What do the results imply regarding the return periods of floods during the period of record?	N/A
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 - 4.0)	100-year growth factor at HODDER_01 is 2.13 and 2.44 for the statistical method and ReFH2 method, respectively.
If 1000-year flows have been derived, what is the range of ratios for the 1000-year flow over 100-year flow?	N/A 1000-year return period not requested
What is the range of specific runoffs (l/s/ha)? Are there any inconsistencies?	Site code / 2-year (l/s/ha) / 100-year (l/s/ha): HODDER_01 / 8.2 / 20.8 EASINGTON_01 / 9.1 / 23.1 FOULSCALES_01 / 11.6 / 30.0
How did the results compare with those of other studies? Explain any differences and conclude which results should be preferred	A brief internet search did not reveal any other useable studies freely available.
Are the results compatible with the longer-term flood history?	N/A
Describe any other checks on the results	N/A

A.5.5 Final results

Flood peak (m3/s) for the following return periods (years)						
Site code	2	5	10	30	75	100
HODDER_01	60.4	78.1	92.3	117	144	153
HODDER_02	72.2	93.6	111	140	171	183
EASINGTON_01	12.0	15.7	18.4	23.5	28.4	30.3
FOULSCALES_01	8.1	10.9	12.8	16.5	19.8	21.0

If flood hydrographs are needed for the next stage of the study, where are they provided? For example give a name of spreadsheet, name of hydraulic model, or reference to table below	River Hodder Hydraulic Modelling - Hydrographs.xlsx Also included in 6.2 of the Annex of this calculation record.

A.5.6 Consideration of inflows from the residual catchment

Residual flow in the form of a single flow hydrograph which will be distributed over the model reach according to reach length is requested. The residual area is 3.1 km^2 however, the sum of inflows is already greater than the estimate of flow at the downstream model extent. This prevents providing residual flow based on simple subtraction.

The specific 100-yr discharge (l/s/ha) calculated for the catchment of each contributing inflow is shown to vary from 20.8 to 30.0 l/s/ha. Greater attenuation in the Hodder catchment partly explains the reduced catchment discharge (other factors such as growth curve also have bearing). BFIHOST and SPRHOST values are generally consistent over the study catchments (BFIHOST = 0.29 to 0.33; SPRHOST = 45 % to 52 %). Using the catchment descriptor FPEXT as an indicator of catchment attenuation, the catchment of the Foulscales Brook shows lesser attenuation than either the Hodder or Easington (FPEXT = 0.02 versus either 0.05 or 0.06). The small hillside streams that make up the residual area are arguably more similar to Foulscales catchment in terms of area, attenuation etc. and hence the specific discharge calculated for the Foulscales Brook is multiplied by the residual area to provide an estimate of the flow generated over the residual catchment.

Flood peak (m3/s) for the following return periods (years)						
Site code	2	5	10	30	75	100
RESIDUAL	3.59	4.81	5.66	7.27	8.74	9.26

A.5.7 Flow reconciliation

To make sure that the model results are consistent with respect to estimates of flow at the downstream model extent (HODDER_02), flow reconciliation may be necessary. This may involve adjusting the timing of inflow hydrographs with regards to hydrograph peak and/or reviewing lateral flow contributions from the residual catchment (i.e. that not fully accounted for by the three main inflows (US inflow, Easington Brook and Foulscales Brook)). Of importance when considering flow reconciliation at the downstream model extent is the attenuation factor applied to the estimates of flow on the main River Hodder. As previously stated, the level of attenuation assumed is considered a slight over estimate. Initial model runs will provide a better understanding as to whether flow reconciliation is required.

A.6 Annex – supporting information

A.6.1 Pooling group composition

Initial (and final) Enhanced Single Site Analysis Group – River Hodder

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
71008 (Hodder @ Hodder Place)	0	49	221.954	0.157	0.185	0.434	258.14	1602	0.055	0.97	0.002
79005 (Cluden Water @ Fiddlers Ford)	0.285	43	106.947	0.122	0.249	1.734	237.23	1422	0.062	0.985	0.001
72005 (Lune @ Killington)	0.298	49	266.227	0.199	0.142	0.722	219.24	1670	0.048	0.995	0.002
3002 (Carron @ Sgodachail)	0.307	44	177.63	0.149	0.162	0.045	237.14	1784	0.038	0.974	0.000
60013 (Cothi @ Pont Ynys Brechfa)	0.315	10	122.902	0.207	0.256	0.979	243.01	1538	0.034	0.997	0.001
46003 (Dart @ Austins Bridge)	0.329	60	232.785	0.167	0.105	0.648	249.99	1771	0.036	0.995	0.007
25018 (Tees @ Middleton in Teesdale)	0.332	47	210.304	0.186	0.133	0.549	242.01	1533	0.034	0.939	0.001
73005 (Kent @ Sedgwick)	0.376	45	162.6	0.223	0.318	1.069	212.24	1726	0.074	0.976	0.018
60002 (Cothi @ Felin Mynachdy)	0.378	58	176.803	0.209	0.237	0.512	298.73	1551	0.032	0.997	0.001
27096 (Wharfe @ Netherside Hall)	0.386	15	189.395	0.122	0.137	1.806	215.18	1583	0.035	0.998	0.002
59001 (Tawe @ Ynystanglws)	0.401	44	253.254	0.123	0.238	1.784	227.45	1890	0.05	0.996	0.024
78005 (Kinnel Water @ Bridgemuir)	0.433	27	123.004	0.091	-0.083	2.679	229.28	1397	0.078	0.996	0.000
84014 (Avon Water @ Fairholm)	0.465	53	162.547	0.173	0.152	0.106	263.07	1264	0.057	0.986	0.010
12007 (Dee @ Mar Lodge)	0.475	31	186.205	0.153	0.237	0.934	292	1334	0.033	0.989	0.000
Total		**575**									
Weighted means				**0.159**	**0.178**						

Final Pooling Group – Easington Brook

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
25011 (Langdon Beck @ Langdon)	0.503	32	15.5	0.235	0.334	0.924	12.79	1463	0.012	1.00	0.00
206006 (Annalong @ Recorder)	0.542	48	15.3	0.189	0.052	2.415	14.44	1704	0.023	0.98	0.00
25003 (Trout Beck @ Moor House)	0.612	45	15.1	0.167	0.302	0.803	11.4	1905	0.041	1.00	0.00
49003 (de Lank @ de Lank)	0.749	52	14.0	0.223	0.209	0.1	21.61	1628	0.064	1.00	0.00
71003 (Croasdale Beck @ Croasdale Flume)	0.752	18	10.1	0.116	0.203	1.577	10.71	1882	0.016	1.00	0.00
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	0.768	8	6.5	0.262	0.049	3.271	16.08	1044	0.023	0.99	0.01
27032 (Hebden Beck @ Hebden)	0.847	52	3.9	0.207	0.244	0.188	22.25	1433	0.021	1.00	0.00
48009 (st Neot @ Craigshill Wood)	0.89	12	8.5	0.245	0.373	0.434	22.97	1511	0.023	0.98	0.00
28033 (Dove @ Hollinsclough)	0.901	43	4.2	0.231	0.369	0.423	7.92	1346	0.007	1.00	0.00
48004 (Warleggan @ Trengoffe)	0.963	49	10.0	0.255	0.257	0.441	25.26	1445	0.035	0.98	0.00
25012 (Harwood Beck @ Harwood)	0.987	49	33.3	0.19	0.225	0.661	24.58	1577	0.021	1.00	0.00
27010 (Hodge Beck @ Bransdale Weir)	1.019	41	9.4	0.224	0.293	0.047	18.82	987	0.009	1.00	0.00
45816 (Haddeo @ Upton)	1.092	25	3.5	0.306	0.399	0.874	6.81	1210	0.011	1.00	0.01
25019 (Leven @ Easby)	1.135	40	5.4	0.343	0.378	1.841	15.09	830	0.019	1.00	0.00
Total		**514**									
Weighted means				**0.225**	**0.267**						

Final Pooling Group – Foulscales Brook

Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy	AREA	SAAR	FPEXT	FARL	URBEXT 2000
28033 (Dove @ Hollinsclough)	0.294	43	4.205	0.231	0.369	0.552	7.92	1346	0.007	1.00	0.00
45816 (Haddeo @ Upton)	0.408	25	3.456	0.306	0.399	1.051	6.81	1210	0.011	1.00	0.01
71003 (Croasdale Beck @ Croasdale Flume)	0.748	18	10.073	0.116	0.203	1.053	10.71	1882	0.016	1.00	0.00
25011 (Langdon Beck @ Langdon)	0.85	32	15.533	0.235	0.334	1.146	12.79	1463	0.012	1.00	0.00
25003 (Trout Beck @ Moor House)	0.865	45	15.12	0.167	0.302	0.77	11.4	1905	0.041	1.00	0.00
54022 (Severn @ Plynlimon Flume)	1.032	38	14.988	0.156	0.171	0.504	8.75	2481	0.01	1.00	0.00
91802 (Allt Leachdach @ Intake)	1.054	34	6.35	0.153	0.257	1.012	6.54	2554	0.003	0.99	0.00
206006 (Annalong @ Recorder)	1.054	48	15.33	0.189	0.052	1.892	14.44	1704	0.023	0.98	0.00
27051 (Crimple @ Burn Bridge)	1.084	46	4.539	0.219	0.148	0.267	8.17	855	0.013	1.00	0.01
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	1.349	8	6.511	0.262	0.049	3.192	16.08	1044	0.023	0.99	0.01
57017 (Rhondda Fawr @ Tynewydd)	1.549	17	24.06	0.136	0.018	1.13	16.64	2458	0.012	1.00	0.02
25019 (Leven @ Easby)	1.55	40	5.384	0.343	0.378	2.121	15.09	830	0.019	1.00	0.00
27010 (Hodge Beck @ Bransdale Weir)	1.596	41	9.42	0.224	0.293	0.106	18.82	987	0.009	1.00	0.00
27032 (Hebden Beck @ Hebden)	1.621	52	3.923	0.207	0.244	0.143	22.25	1433	0.021	1.00	0.00
49003 (de Lank @ de Lank)	1.662	52	13.985	0.223	0.209	0.062	21.61	1628	0.064	1.00	0.00
Total		**539**									
Weighted means				**0.212**	**0.242**						

A.6.2 Hydrographs

A.6.2.1 Hydrographs EASINGTON_01

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
0.00	0.95	0.95	0.95	0.95	0.95	0.95
0.50	1.00	0.99	0.98	0.97	0.97	0.96
1.00	1.19	1.18	1.14	1.08	1.06	1.02
1.50	1.58	1.55	1.45	1.31	1.26	1.16
2.00	2.22	2.15	1.96	1.68	1.57	1.38
2.50	3.04	2.93	2.61	2.14	1.97	1.65
3.00	4.07	3.90	3.43	2.70	2.45	1.97
3.50	5.37	5.14	4.47	3.39	3.04	2.36
4.00	7.07	6.73	5.80	4.24	3.77	2.82
4.50	9.31	8.85	7.57	5.33	4.71	3.40
5.00	12.29	11.65	9.88	6.73	5.90	4.12
5.50	16.12	15.25	12.85	8.50	7.41	5.01
6.00	20.58	19.43	16.27	10.70	9.27	6.11
6.50	24.96	23.52	19.59	13.18	11.37	7.44
7.00	28.40	26.73	22.17	15.58	13.38	8.91
7.50	30.18	28.38	23.46	17.44	14.94	10.32
8.00	30.27	28.44	23.47	18.39	15.71	11.40
8.50	29.08	27.31	22.51	18.43	15.72	11.95
9.00	27.05	25.40	20.94	17.76	15.15	11.97
9.50	24.57	23.08	19.03	16.64	14.19	11.57
10.00	21.84	20.52	16.95	15.25	13.01	10.90
10.50	19.02	17.88	14.80	13.72	11.72	10.08
11.00	16.17	15.22	12.65	12.13	10.38	9.16
11.50	13.41	12.65	10.57	10.57	9.07	8.21
12.00	10.90	10.31	8.68	9.09	7.82	7.27
12.50	8.75	8.30	7.06	7.71	6.67	6.39
13.00	7.09	6.75	5.81	6.49	5.65	5.60
13.50	5.86	5.61	4.89	5.43	4.76	4.88
14.00	4.98	4.79	4.22	4.60	4.07	4.23
14.50	4.37	4.21	3.75	3.98	3.55	3.66
15.00	3.92	3.79	3.41	3.53	3.17	3.20
15.50	3.60	3.49	3.17	3.20	2.89	2.86
16.00	3.38	3.29	3.00	2.96	2.68	2.60
16.50	3.24	3.16	2.88	2.78	2.53	2.41
17.00	3.16	3.08	2.81	2.64	2.42	2.26
17.50	3.10	3.02	2.76	2.55	2.34	2.15
18.00	3.05	2.97	2.71	2.49	2.28	2.06
18.50	2.99	2.91	2.66	2.45	2.24	2.00
19.00	2.94	2.86	2.61	2.40	2.20	1.96
19.50	2.88	2.81	2.57	2.36	2.16	1.92
20.00	2.83	2.76	2.52	2.32	2.12	1.89
20.50	2.78	2.71	2.47	2.28	2.08	1.85
21.00	2.73	2.66	2.43	2.24	2.05	1.82
21.50	2.68	2.61	2.38	2.20	2.01	1.79
22.00	2.63	2.56	2.34	2.16	1.97	1.75
22.50	2.58	2.52	2.30	2.12	1.94	1.72
23.00	2.54	2.47	2.26	2.08	1.90	1.69

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
23.50	2.49	2.43	2.22	2.04	1.87	1.66
24.00	2.45	2.38	2.18	2.00	1.83	1.63
24.50	2.40	2.34	2.14	1.97	1.80	1.60
25.00	2.36	2.30	2.10	1.93	1.77	1.57
25.50	2.32	2.26	2.06	1.90	1.74	1.54
26.00	2.28	2.21	2.02	1.86	1.70	1.52
26.50	2.23	2.17	1.99	1.83	1.67	1.49
27.00	2.19	2.14	1.95	1.80	1.64	1.46
27.50	2.15	2.10	1.92	1.76	1.61	1.44
28.00	2.11	2.06	1.88	1.73	1.58	1.41
28.50	2.08	2.02	1.85	1.70	1.56	1.38
29.00	2.04	1.99	1.81	1.67	1.53	1.36
29.50	2.00	1.95	1.78	1.64	1.50	1.33
30.00	1.97	1.91	1.75	1.61	1.47	1.31
30.50	1.93	1.88	1.72	1.58	1.45	1.29
31.00	1.90	1.85	1.69	1.55	1.42	1.26
31.50	1.86	1.81	1.66	1.52	1.39	1.24
32.00	1.83	1.78	1.63	1.50	1.37	1.22
32.50	1.79	1.75	1.60	1.47	1.35	1.20
33.00	1.76	1.72	1.57	1.44	1.32	1.17
33.50	1.73	1.68	1.54	1.42	1.30	1.15
34.00	1.70	1.65	1.51	1.39	1.27	1.13
34.50	1.67	1.62	1.48	1.37	1.25	1.11
35.00	1.64	1.59	1.46	1.34	1.23	1.09
35.50	1.61	1.57	1.43	1.32	1.21	1.07
36.00	1.58	1.54	1.41	1.29	1.18	1.05
36.50	1.55	1.51	1.38	1.27	1.16	1.03
37.00	1.52	1.48	1.35	1.25	1.14	1.01
37.50	1.50	1.46	1.33	1.22	1.12	1.00
38.00	1.47	1.43	1.31	1.20	1.10	0.98
38.50	1.44	1.40	1.28	1.18	1.08	0.96
39.00	1.42	1.38	1.26	1.16	1.06	
39.50	1.39	1.35	1.24	1.14	1.04	
40.00	1.37	1.33	1.21	1.12	1.02	
40.50	1.34	1.30	1.19	1.10	1.00	
41.00	1.32	1.28	1.17	1.08	0.99	
41.50	1.29	1.26	1.15	1.06	0.97	
42.00	1.27	1.24	1.13	1.04		
42.50	1.25	1.21	1.11	1.02		
43.00	1.22	1.19	1.09	1.00		
43.50	1.20	1.17	1.07	0.98		
44.00	1.18	1.15	1.05	0.97		
44.50	1.16	1.13	1.03			
45.00	1.14	1.11	1.01			
45.50	1.12	1.09	0.99			
46.00	1.10	1.07	0.98			
46.50	1.08	1.05	0.96			
47.00	1.06	1.03				
47.50	1.04	1.01				
48.00	1.02	0.99				
48.50	1.00	0.97				

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
49.00	0.98	0.96				
49.50	0.97					

A.6.2.2 Hydrographs FOULSACALES_01

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
0.00	0.56	0.56	0.56	0.56	0.56	0.56
0.50	0.62	0.62	0.61	0.59	0.59	0.58
1.00	0.85	0.84	0.79	0.73	0.70	0.66
1.50	1.30	1.26	1.16	1.00	0.93	0.82
2.00	1.87	1.81	1.62	1.33	1.22	1.01
2.50	2.56	2.46	2.17	1.71	1.54	1.23
3.00	3.39	3.25	2.84	2.16	1.93	1.48
3.50	4.48	4.28	3.70	2.72	2.41	1.79
4.00	5.88	5.61	4.82	3.42	3.00	2.15
4.50	7.71	7.33	6.26	4.29	3.75	2.60
5.00	10.10	9.59	8.14	5.39	4.69	3.15
5.50	13.21	12.51	10.56	6.82	5.89	3.84
6.00	16.66	15.76	13.22	8.59	7.39	4.70
6.50	19.55	18.47	15.41	10.51	8.99	5.75
7.00	20.97	19.78	16.45	12.08	10.29	6.86
7.50	20.80	19.60	16.27	12.81	10.89	7.74
8.00	19.47	18.34	15.21	12.67	10.76	8.13
8.50	17.47	16.46	13.66	11.91	10.10	8.02
9.00	15.16	14.30	11.88	10.81	9.17	7.58
9.50	12.79	12.07	10.05	9.53	8.09	6.94
10.00	10.57	9.99	8.35	8.21	6.99	6.21
10.50	8.67	8.21	6.90	6.96	5.94	5.44
11.00	7.05	6.69	5.65	5.87	5.03	4.70
11.50	5.59	5.32	4.54	4.96	4.27	4.06
12.00	4.29	4.10	3.55	4.18	3.61	3.51
12.50	3.31	3.18	2.80	3.45	3.01	3.06
13.00	2.65	2.56	2.29	2.78	2.45	2.66
13.50	2.22	2.15	1.96	2.27	2.03	2.28
14.00	1.93	1.88	1.73	1.92	1.73	1.91
14.50	1.74	1.70	1.58	1.68	1.53	1.62
15.00	1.63	1.60	1.50	1.52	1.40	1.42
15.50	1.59	1.56	1.46	1.42	1.30	1.28
16.00	1.55	1.53	1.43	1.35	1.25	1.19
16.50	1.52	1.49	1.40	1.31	1.21	1.12
17.00	1.49	1.46	1.37	1.29	1.19	1.07
17.50	1.46	1.43	1.34	1.26	1.16	1.05
18.00	1.43	1.40	1.31	1.23	1.14	1.02

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
18.50	1.40	1.37	1.28	1.21	1.12	1.00
19.00	1.37	1.34	1.26	1.18	1.09	0.98
19.50	1.34	1.32	1.23	1.16	1.07	0.96
20.00	1.31	1.29	1.20	1.13	1.05	0.94
20.50	1.28	1.26	1.18	1.11	1.02	0.92
21.00	1.26	1.23	1.15	1.09	1.00	0.90
21.50	1.23	1.21	1.13	1.06	0.98	0.88
22.00	1.20	1.18	1.11	1.04	0.96	0.86
22.50	1.18	1.16	1.08	1.02	0.94	0.85
23.00	1.15	1.13	1.06	1.00	0.92	0.83
23.50	1.13	1.11	1.04	0.98	0.90	0.81
24.00	1.11	1.09	1.02	0.96	0.88	0.79
24.50	1.08	1.06	0.99	0.94	0.86	0.78
25.00	1.06	1.04	0.97	0.92	0.85	0.76
25.50	1.04	1.02	0.95	0.90	0.83	0.74
26.00	1.02	1.00	0.93	0.88	0.81	0.73
26.50	0.99	0.98	0.91	0.86	0.79	0.71
27.00	0.97	0.96	0.89	0.84	0.78	0.70
27.50	0.95	0.94	0.88	0.82	0.76	0.68
28.00	0.93	0.92	0.86	0.81	0.75	0.67
28.50	0.91	0.90	0.84	0.79	0.73	0.66
29.00	0.89	0.88	0.82	0.77	0.71	0.64
29.50	0.88	0.86	0.80	0.76	0.70	0.63
30.00	0.86	0.84	0.79	0.74	0.68	0.61
30.50	0.84	0.82	0.77	0.73	0.67	0.60
31.00	0.82	0.81	0.75	0.71	0.66	0.59
31.50	0.80	0.79	0.74	0.70	0.64	0.58
32.00	0.79	0.77	0.72	0.68	0.63	0.56
32.50	0.77	0.76	0.71	0.67	0.62	
33.00	0.75	0.74	0.69	0.65	0.60	
33.50	0.74	0.73	0.68	0.64	0.59	
34.00	0.72	0.71	0.66	0.63	0.58	
34.50	0.71	0.70	0.65	0.61	0.57	
35.00	0.69	0.68	0.64	0.60		
35.50	0.68	0.67	0.62	0.59		
36.00	0.66	0.65	0.61	0.57		
36.50	0.65	0.64	0.60	0.56		
37.00	0.64	0.63	0.58			
37.50	0.62	0.61	0.57			
38.00	0.61	0.60				
38.50	0.60	0.59				
39.00	0.58	0.57				
39.50	0.57	0.56				

A.6.2.3 Hydrographs HODDER_01

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
0	6.88	6.45	6.45	6.45	6.45	6.45
0.5	6.85	6.42	6.42	6.42	6.42	6.42
1	6.89	6.46	6.45	6.44	6.44	6.43
1.5	7.02	6.58	6.55	6.51	6.49	6.46
2	7.29	6.83	6.76	6.66	6.62	6.55
2.5	7.79	7.30	7.15	6.94	6.86	6.71
3	8.62	8.09	7.80	7.40	7.26	6.99
3.5	9.90	9.28	8.80	8.10	7.86	7.40
4	11.72	10.98	10.23	9.09	8.71	7.98
4.5	14.24	13.35	12.21	10.43	9.87	8.76
5	17.69	16.58	14.90	12.21	11.41	9.77
5.5	22.32	20.92	18.51	14.55	13.42	11.07
6	29.72	27.86	23.24	17.59	16.03	12.73
6.5	42.57	39.91	32.21	21.46	19.35	14.84
7	57.64	54.04	43.79	27.15	23.44	17.45
7.5	75.23	70.52	56.97	36.53	30.58	20.62
8	94.66	88.74	70.90	46.40	39.28	24.28
8.5	114.03	106.89	85.02	57.04	47.91	30.68
9	131.36	123.14	97.25	67.24	56.69	37.46
9.5	143.03	134.08	107.47	76.07	64.37	43.71
10	150.22	140.82	114.14	83.74	70.35	49.11
10.5	153.32	143.73	117.13	88.87	74.53	53.86
11	152.81	143.25	116.99	91.63	77.23	57.33
11.5	149.31	139.97	114.33	92.29	78.12	59.45
12	143.39	134.42	109.70	91.20	77.45	60.36
12.5	135.60	127.12	103.57	88.67	75.50	60.24
13	125.81	117.94	96.87	84.96	72.81	59.23
13.5	114.92	107.73	89.83	80.32	69.39	57.49
14	104.01	97.51	82.21	74.97	65.34	55.13
14.5	94.05	88.17	74.43	69.80	60.81	52.28
15	84.06	78.80	67.53	64.25	55.99	49.14
15.5	75.12	70.42	60.74	58.55	51.08	45.99
16	67.07	62.87	54.28	52.93	46.66	42.65
16.5	59.59	55.87	48.52	47.85	42.48	39.26
17	52.88	49.58	43.70	43.38	38.55	35.95
17.5	47.50	44.53	39.33	39.24	34.93	32.82
18	42.67	40.01	35.44	35.48	31.66	29.91
18.5	38.41	36.01	32.01	32.12	28.73	27.27
19	34.69	32.52	29.02	29.13	26.13	24.94
19.5	31.48	29.51	26.44	26.52	24.34	23.68
20	28.72	26.93	24.56	24.56	23.12	22.48
20.5	26.51	24.85	23.42	23.36	21.98	21.34

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
21	25.33	23.75	22.37	22.25	20.92	20.27
21.5	24.25	22.74	21.41	21.23	19.95	19.28
22	23.26	21.81	20.53	20.29	19.06	18.37
22.5	22.35	20.95	19.71	19.42	18.24	17.52
23	21.51	20.16	18.97	18.63	17.49	16.75
23.5	20.73	19.43	18.28	17.90	16.80	16.04
24	20.01	18.76	17.64	17.23	16.16	15.39
24.5	19.34	18.13	17.04	16.61	15.58	14.79
25	18.72	17.55	16.49	16.03	15.03	14.23
25.5	18.15	17.01	15.98	15.50	14.53	13.72
26	17.61	16.51	15.50	15.00	14.06	13.25
26.5	17.10	16.03	15.06	14.54	13.62	12.81
27	16.63	15.59	14.64	14.11	13.22	12.40
27.5	16.19	15.17	14.25	13.71	12.84	12.02
28	15.77	14.78	13.88	13.33	12.48	11.67
28.5	15.37	14.41	13.53	12.97	12.14	11.33
29	15.00	14.06	13.20	12.64	11.83	11.02
29.5	14.65	13.73	12.88	12.32	11.53	10.73
30	14.31	13.42	12.59	12.03	11.25	10.45
30.5	13.99	13.12	12.30	11.74	10.98	10.19
31	13.69	12.83	12.03	11.47	10.73	9.95
31.5	13.40	12.56	11.78	11.22	10.49	9.71
32	13.12	12.30	11.53	10.97	10.26	9.49
32.5	12.85	12.05	11.30	10.74	10.04	9.28
33	12.59	11.81	11.07	10.52	9.83	9.08
33.5	12.35	11.57	10.85	10.30	9.63	8.89
34	12.11	11.35	10.64	10.10	9.44	8.70
34.5	11.88	11.13	10.44	9.90	9.25	8.53
35	11.65	10.93	10.24	9.71	9.07	8.36
35.5	11.44	10.72	10.05	9.52	8.90	8.19
36	11.23	10.53	9.87	9.35	8.73	8.04
36.5	11.03	10.34	9.69	9.17	8.57	7.88
37	10.83	10.15	9.52	9.01	8.42	
37.5	10.64	9.98	9.35	8.84	8.26	
38	10.45	9.80	9.19	8.69	8.12	
38.5	10.27	9.63	9.03	8.53	7.97	
39	10.10	9.47	8.87	8.38	7.83	
39.5	9.92	9.30	8.72	8.24	7.70	
40	9.76	9.15	8.57	8.10		
40.5	9.59	8.99	8.43	7.96		
41	9.43	8.84	8.28	7.82		
41.5	9.27	8.69	8.15	7.69		
42	9.12	8.55	8.01			
42.5	8.97	8.41	7.88			

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
43	8.82	8.27	7.75			
43.5	8.68	8.13	7.62			
44	8.53	8.00				
44.5	8.40	7.87				
45	8.26	7.74				
45.5	8.12	7.62				

A.6.2.4 Hydrographs RESIDUAL

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
0.00	0.25	0.25	0.25	0.25	0.25	0.25
0.50	0.27	0.27	0.27	0.26	0.26	0.25
1.00	0.38	0.37	0.35	0.32	0.31	0.29
1.50	0.57	0.56	0.51	0.44	0.41	0.36
2.00	0.83	0.80	0.71	0.59	0.54	0.45
2.50	1.13	1.08	0.96	0.76	0.68	0.54
3.00	1.50	1.44	1.25	0.95	0.85	0.66
3.50	1.98	1.89	1.64	1.20	1.06	0.79
4.00	2.60	2.48	2.13	1.51	1.33	0.95
4.50	3.40	3.24	2.77	1.90	1.66	1.15
5.00	4.46	4.24	3.60	2.38	2.07	1.39
5.50	5.83	5.53	4.66	3.01	2.60	1.69
6.00	7.36	6.96	5.84	3.80	3.26	2.08
6.50	8.64	8.16	6.81	4.64	3.97	2.54
7.00	9.26	8.74	7.27	5.33	4.55	3.03
7.50	9.19	8.66	7.19	5.66	4.81	3.42
8.00	8.60	8.10	6.72	5.60	4.75	3.59
8.50	7.71	7.27	6.03	5.26	4.46	3.54
9.00	6.70	6.31	5.25	4.77	4.05	3.35
9.50	5.65	5.33	4.44	4.21	3.57	3.07
10.00	4.67	4.41	3.69	3.63	3.09	2.74
10.50	3.83	3.63	3.05	3.08	2.62	2.40
11.00	3.11	2.95	2.50	2.59	2.22	2.08
11.50	2.47	2.35	2.01	2.19	1.89	1.79
12.00	1.89	1.81	1.57	1.84	1.60	1.55
12.50	1.46	1.41	1.24	1.52	1.33	1.35
13.00	1.17	1.13	1.01	1.23	1.08	1.17
13.50	0.98	0.95	0.86	1.00	0.90	1.01
14.00	0.85	0.83	0.76	0.85	0.76	0.84
14.50	0.77	0.75	0.70	0.74	0.68	0.72
15.00	0.72	0.71	0.66	0.67	0.62	0.63
15.50	0.70	0.69	0.64	0.63	0.58	0.57
16.00	0.69	0.67	0.63	0.60	0.55	0.52

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
16.50	0.67	0.66	0.62	0.58	0.54	0.49
17.00	0.66	0.65	0.60	0.57	0.53	0.47
17.50	0.64	0.63	0.59	0.56	0.51	0.46
18.00	0.63	0.62	0.58	0.54	0.50	0.45
18.50	0.62	0.61	0.57	0.53	0.49	0.44
19.00	0.60	0.59	0.55	0.52	0.48	0.43
19.50	0.59	0.58	0.54	0.51	0.47	0.42
20.00	0.58	0.57	0.53	0.50	0.46	0.42
20.50	0.57	0.56	0.52	0.49	0.45	0.41
21.00	0.55	0.54	0.51	0.48	0.44	0.40
21.50	0.54	0.53	0.50	0.47	0.43	0.39
22.00	0.53	0.52	0.49	0.46	0.42	0.38
22.50	0.52	0.51	0.48	0.45	0.42	0.37
23.00	0.51	0.50	0.47	0.44	0.41	0.37
23.50	0.50	0.49	0.46	0.43	0.40	0.36
24.00	0.49	0.48	0.45	0.42	0.39	0.35
24.50	0.48	0.47	0.44	0.41	0.38	0.34
25.00	0.47	0.46	0.43	0.40	0.37	0.34
25.50	0.46	0.45	0.42	0.40	0.37	0.33
26.00	0.45	0.44	0.41	0.39	0.36	0.32
26.50	0.44	0.43	0.40	0.38	0.35	0.32
27.00	0.43	0.42	0.40	0.37	0.34	0.31
27.50	0.42	0.41	0.39	0.36	0.34	0.30
28.00	0.41	0.40	0.38	0.36	0.33	0.30
28.50	0.40	0.40	0.37	0.35	0.32	0.29
29.00	0.40	0.39	0.36	0.34	0.32	0.28
29.50	0.39	0.38	0.36	0.33	0.31	0.28
30.00	0.38	0.37	0.35	0.33	0.30	0.27
30.50	0.37	0.36	0.34	0.32	0.30	0.27
31.00	0.36	0.36	0.33	0.31	0.29	0.26
31.50	0.36	0.35	0.33	0.31	0.28	0.25
32.00	0.35	0.34	0.32	0.30	0.28	0.25
32.50	0.34	0.33	0.31	0.29	0.27	
33.00	0.33	0.33	0.31	0.29	0.27	
33.50	0.33	0.32	0.30	0.28	0.26	
34.00	0.32	0.31	0.29	0.28	0.26	
34.50	0.31	0.31	0.29	0.27	0.25	
35.00	0.31	0.30	0.28	0.26		
35.50	0.30	0.29	0.28	0.26		
36.00	0.29	0.29	0.27	0.25		
36.50	0.29	0.28	0.26	0.25		
37.00	0.28	0.28	0.26			
37.50	0.28	0.27	0.25			
38.00	0.27	0.26				

Time (hr)	Return Period					
	100-year	75-year	30-year	10-year	5-year	2-year
38.50	0.26	0.26				
39.00	0.26	0.25				
39.50	0.25	0.25				

A.6.3 Routing model details

5 Hydraulic Model

Version 3.7.0 of the ISIS river modelling software package was used for modelling the Stocks Reservoir system. The double precision engine was used to ensure model accuracy.

5.1 Model Schematisation

Initially the ISIS model fully represented the Stocks reservoir and the spillway arrangement which is composed of three 2.4m diameter pipes with a channel above the pipes. The chute operates as an overflow when the pipe capacity is exceeded. The spillway chute and pipes re-join in the stilling basin approximately 180m downstream of the inlets (Photographs showing reservoir spillway are illustrated in Figure 5-1).

Figure 5-1 ISIS routing model schematic (Full model)

i. Looking downstream from tumble bay
ii. Looking upstream to tumble bay

However, the steep nature of the spillway chute and pipes resulted in the modelled headloss at the pipe inlets to be high due to the high velocity in the chute; this resulted in the estimated flows within the pipes being lower than expected (this was confirmed by hand calculations).

As such it was decided that since the primary objective of this study was to estimate the peak still water level of the PMF event, the model should be simplified by removing the spillway component and manually deriving a rating curve for the Stocks Reservoir spillweir (see Section 5.3).

The simplified representation of the Stocks reservoir routing model is illustrated in Figure 5-2 below. It is composed of the following components:

- A reservoir unit representing the available reservoir storage
- A weir unit represented by a simplified overflow arrangement
- Downstream boundary

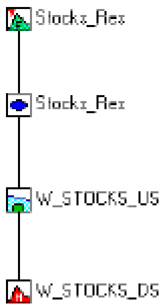


Figure 5-2 ISIS Stocks reservoir routing model schematisation

5.2 Reservoir Storage

Storage available in Stocks reservoir was represented using an ISIS reservoir unit informed with an area/elevation relationship.

Available topographical survey drawing[10] was used to determine the reservoir geometry; however, the survey drawing did not include contour data around the entirety of the reservoir. As such, bank profile gradients were derived for a number of locations for which contour data was available which allowed an area/elevation relationship to be derived (see Table 5-A).

Level (mLD)	Area (m^2)	Source
180.57	1320000	2014 Topographical survey
183.57	1368000	2014 Topographical survey

Table 5-A Derived area/elevation relationship for Stocks reservoir

5.3 Overflow Modelling

Stocks Reservoir has a single primary overflow which discharges into a tumble bay where the flows turn through 90 degrees and proceeds down to the relatively complex spillway chute structure (composed of 3no. pipes and a spillway overflow chute directly above the pipes. The Spillway arrangement for Stocks Reservoir is presented in Figure 5-3 below.

It is noted that the hydraulic performance of the overflow structure is relatively complex due to the immediate 90 degree change in flow direction in the tumble bay and the hydraulic interactions between the 3no. pipes and the overflow spillway. The

[10] United Utilities (2010) 0304_NL01_A.dwg – Topographical survey at Stocks reservoir

hydraulic performance of the overflow structure has been shown to be outside the normal operating parameters of standard 1D hydraulic modelling tools such as ISIS. The representation of the overflow arrangements was therefore simplified and assessed using a range of standard 1D hydraulic calculation (See Appendix E) to develop a composite reservoir discharge rating curve (Table 5-B). The derived rating represents the progression of flow from free broad crested weir equation to downstream channel control (Figure 5-4).

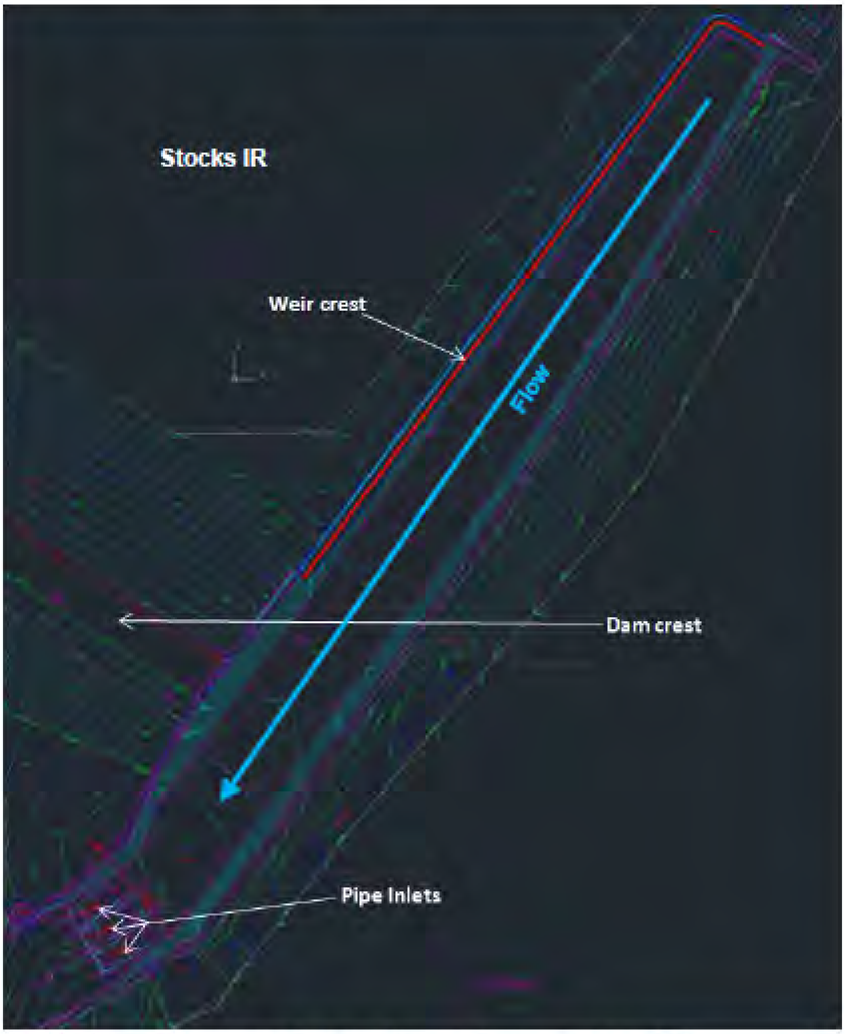


Figure 5-3 Spillway arrangements for Stocks Reservoir (Topographic survey 2014)

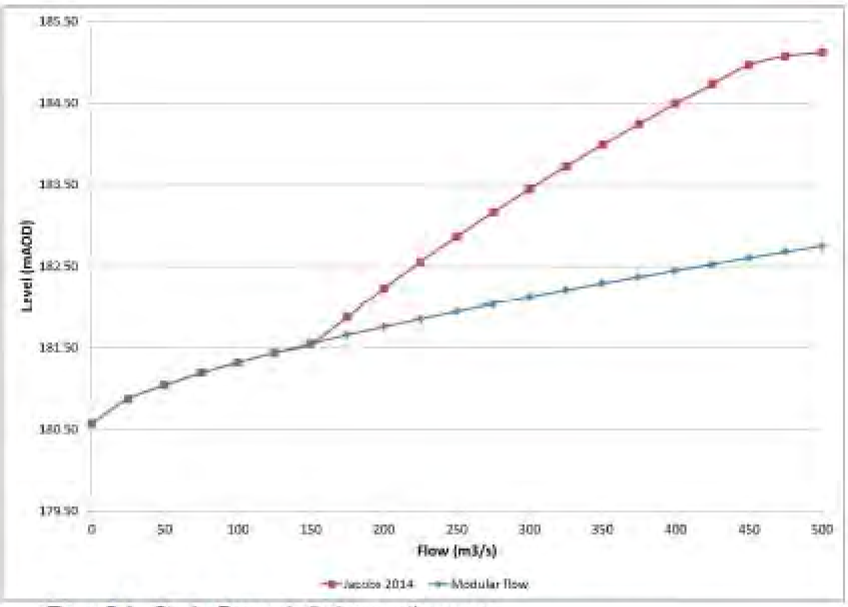


Figure 5-4 – Stocks Reservoir discharge rating curves
Jacobs 2014 = composite overflow weir rating derived for the current study
Modular Flow = Broad crested weir rating, for comparison

Flow (m^3s^{-1})	Reservoir Level (mLD)	Flow Description	Dam Overtopping?	Freeboard to wave wall crest (m)
0	180.57	weir control	flood contained	4.03
25	180.87	weir control	flood contained	3.73
50	181.04	weir control	flood contained	3.56
75	181.19	weir control	flood contained	3.41
100	181.32	weir control	flood contained	3.28
125	181.43	weir control	flood contained	3.17
150	181.55	weir control	flood contained	3.05
175	181.88	channel control	flood contained	2.72
200	182.22	channel control	flood contained	2.38
225	182.55	channel control	flood contained	2.05
250	182.86	channel control	flood contained	1.74
275	183.16	channel control	flood contained	1.44
300	183.45	channel control	flood contained	1.15
325	183.72	channel control	dam overtopped	0.88
350	183.99	channel control	dam overtopped	0.61
375	184.24	channel control	dam overtopped	0.36
400	184.49	channel control	dam overtopped	0.11
425	184.73	channel control	wave wall overtopped	-0.13
450	184.96	channel control	wave wall overtopped	-0.36
475	185.07	channel control	wave wall overtopped	-0.47
500	185.12	channel control	wave wall overtopped	-0.52

Table 5-B Stocks Reservoir spill-weir rating curve

5.4 Downstream Boundary

Flow out of the model is represented as an ISIS stage/time (H/T) boundary unit set to a constant level nominally low to provide free flow conditions.

Appendix B. In-Channel Water Levels

Table B-1 In-channel maximum water level at key locations for the 50 % AEP event

Node	Description	Baseline 50 % AEP Event Max Stage (m AOD)	Scheme 50 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16km upstream of the scheme.	130.327	130.327	0.000
HODD01_02065	30m upstream from Hallgate Hill Bridge	127.709	127.731	0.022
HODD01_01915	120m upstream of the scheme location.	127.170	127.222	0.052
HODD01_01796	Immediately upstream of the scheme location.	126.924	126.999	0.075
HODD01_00000	Downstream end of the River Hodder. 1.8km downstream of the scheme.	120.913	120.913	0.000

Table B-2 In-channel maximum water level at key locations for the 20 % AEP event

Node	Description	Baseline 20 % AEP Event Max Stage (m AOD)	Scheme 20 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16km upstream of the scheme.	130.448	130.448	0.000
HODD01_02065	30m upstream from Hallgate Hill Bridge	128.108	128.137	0.029
HODD01_01915	120m upstream of the scheme location.	127.487	127.545	0.058
HODD01_01796	Immediately upstream of the scheme location.	127.218	127.306	0.088
HODD01_00000	Downstream end of the River Hodder. 1.8km downstream of the scheme.	121.160	121.158	-0.002

Table B-3 In-channel maximum water level at key locations for the 10 % AEP event

Node	Description	Baseline 10 % AEP Event Max Stage (m AOD)	Scheme 10 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16km upstream of the scheme.	130.523	130.523	0.000
HODD01_02065	30m upstream from Hallgate Hill Bridge	128.413	128.432	0.019
HODD01_01915	120m upstream of the scheme location.	127.724	127.785	0.061
HODD01_01796	Immediately upstream of the scheme location.	127.467	127.558	0.091
HODD01_00000	Downstream end of the River Hodder. 1.8km downstream of the scheme.	121.356	121.354	-0.002

Table B-4 In-channel maximum water level at key locations for the 3.33 % AEP event

Node	Description	Baseline 3.33 % AEP Event Max Stage (m AOD)	Scheme 3.33 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16km upstream of the scheme.	130.621	130.621	0.000
HODD01_02065	30m upstream from Hallgate Hill Bridge	128.675	128.699	0.024
HODD01_01915	120m upstream of the scheme location.	128.033	128.138	0.105
HODD01_01796	Immediately upstream of the scheme location.	127.831	127.899	0.068
HODD01_00000	Downstream end of the River Hodder. 1.8km downstream of the scheme.	121.653	121.654	0.001

Table B-5 In-channel maximum water level at key locations for the 1.33 % AEP event

Node	Description	Baseline 1.33 % AEP Event Max Stage (m AOD)	Scheme 1.33 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16 km upstream of the scheme.	130.640	130.640	0.000
HODD01_02065	30 m upstream from Hallgate Hill Bridge	128.861	128.885	0.024
HODD01_01915	120 m upstream of the scheme location.	128.216	128.369	0.153
HODD01_01796	Immediately upstream of the scheme location.	127.979	128.059	0.080
HODD01_00000	Downstream end of the River Hodder. 1.8 km downstream of the scheme.	121.947	121.948	0.001

Table B-6 In-channel maximum water level at key locations for the 1 % AEP event

Node	Description	Baseline 1 % AEP Event Max Stage (m AOD)	Scheme 1 % AEP Event Max Stage (m AOD)	Water level difference (m)
HODD01_02958	Upstream extent of the River Hodder. 1.16 km upstream of the scheme.	130.649	130.649	0.000
HODD01_02065	30 m upstream from Hallgate Hill Bridge	128.912	128.934	0.022
HODD01_01915	120 m upstream of the scheme location.	128.270	128.445	0.175
HODD01_01796	Immediately upstream of the scheme location.	128.014	128.103	0.089
HODD01_00000	Downstream end of the River Hodder. 1.8 km downstream of the scheme.	122.039	122.039	0.000

Appendix C. Modelled Flood Extents

Illustration C-1: Baseline 50 % AEP event modelled maximum flood extent

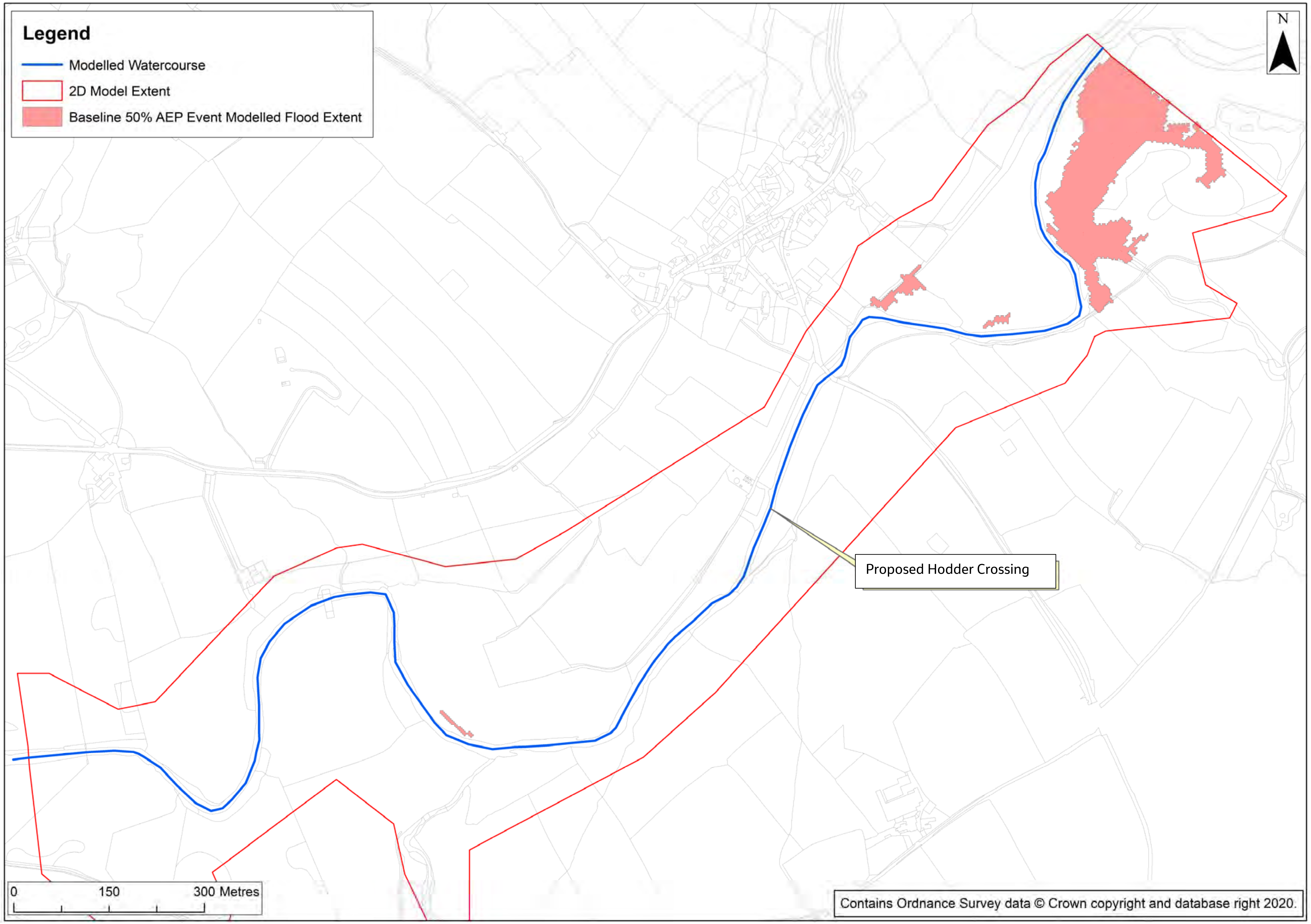


Illustration **C-2**: **Baseline 20 % AEP event modelled maximum flood extent**

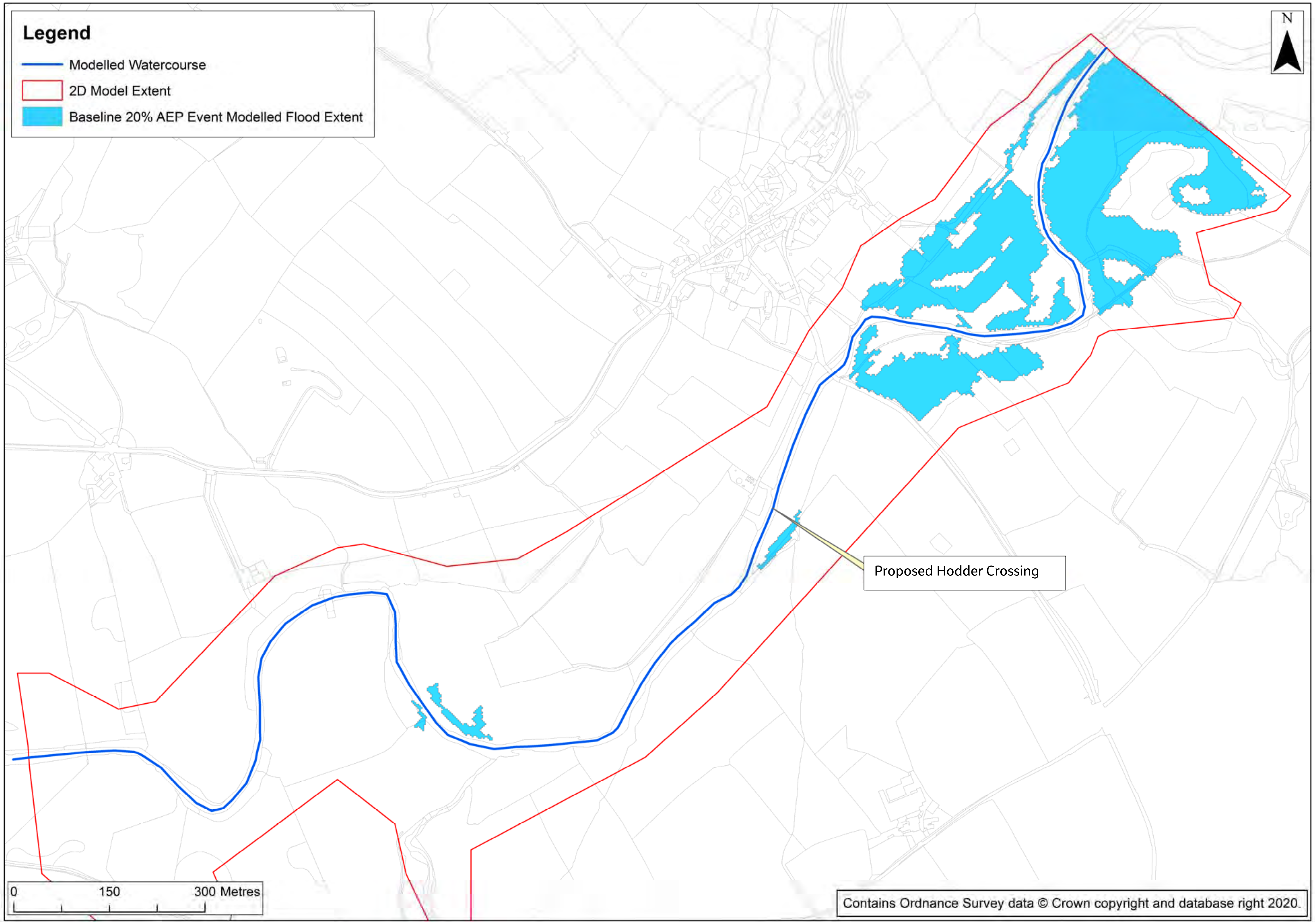


Illustration C-3: Baseline 10 % AEP event modelled maximum flood extent

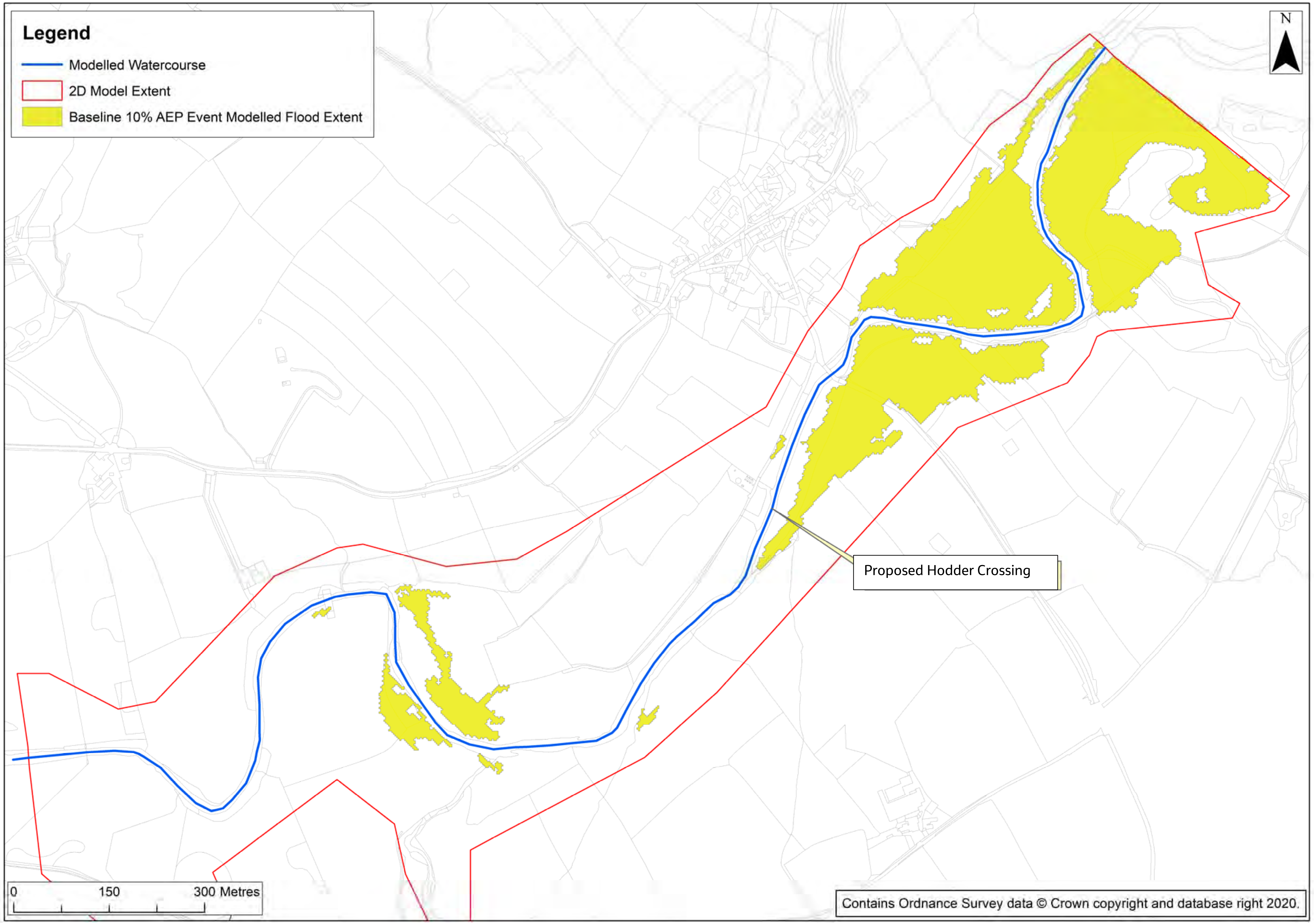


Illustration C-4: Baseline 3.33 % AEP event modelled maximum flood extent

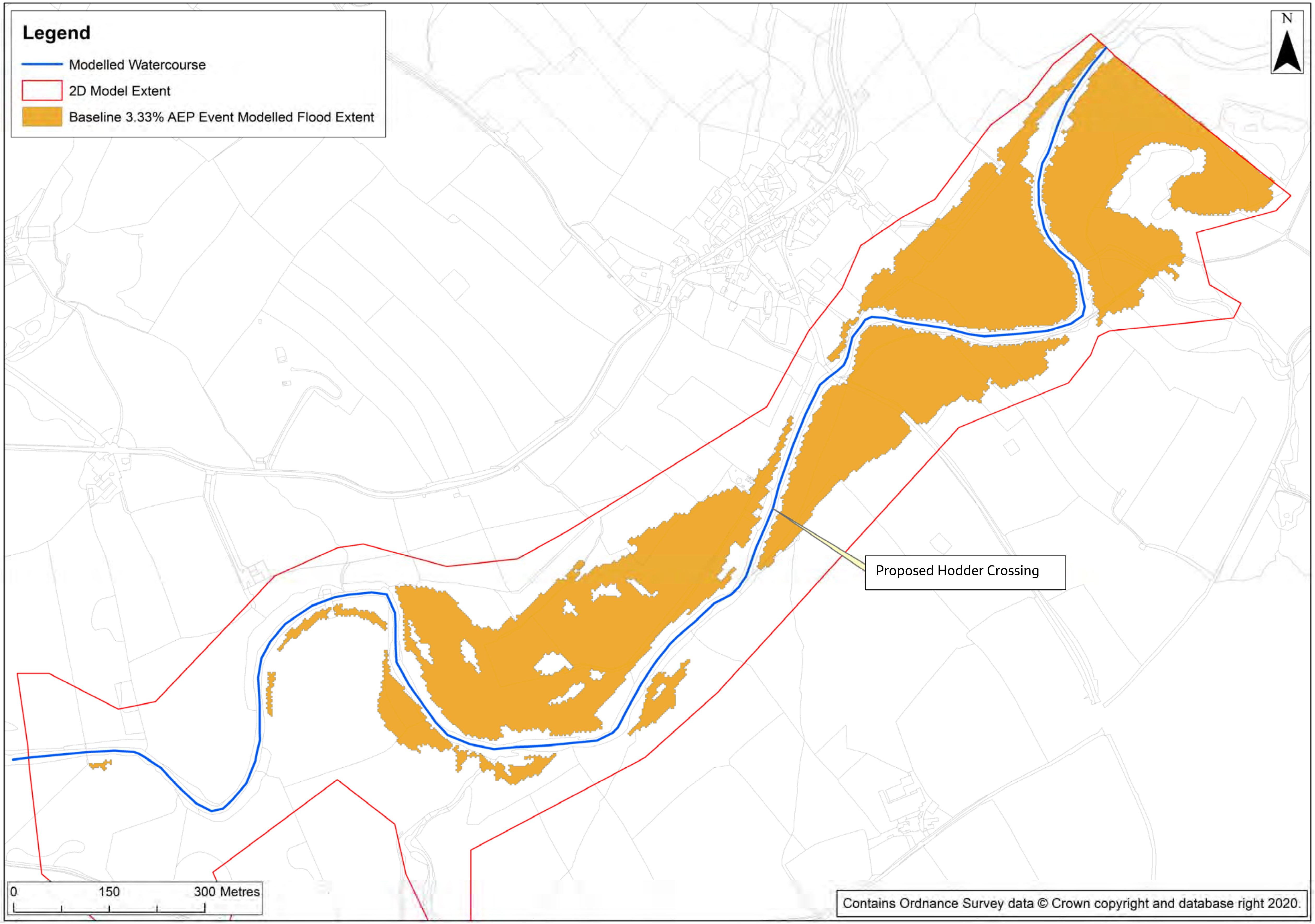


Illustration C-5: Baseline 1.33 % AEP event modelled maximum flood extent

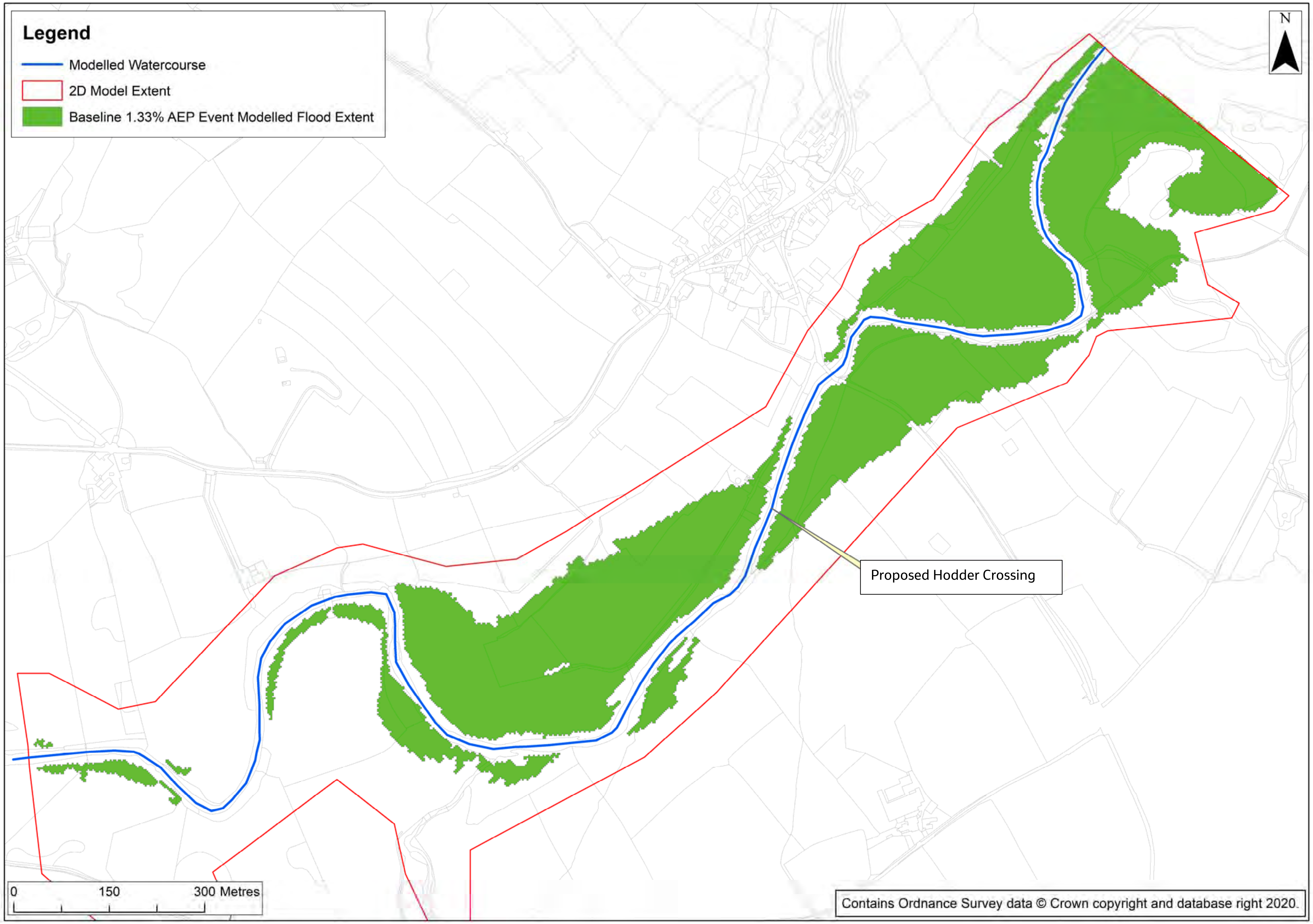


Illustration C-6: Baseline 1 % AEP event modelled maximum flood extent

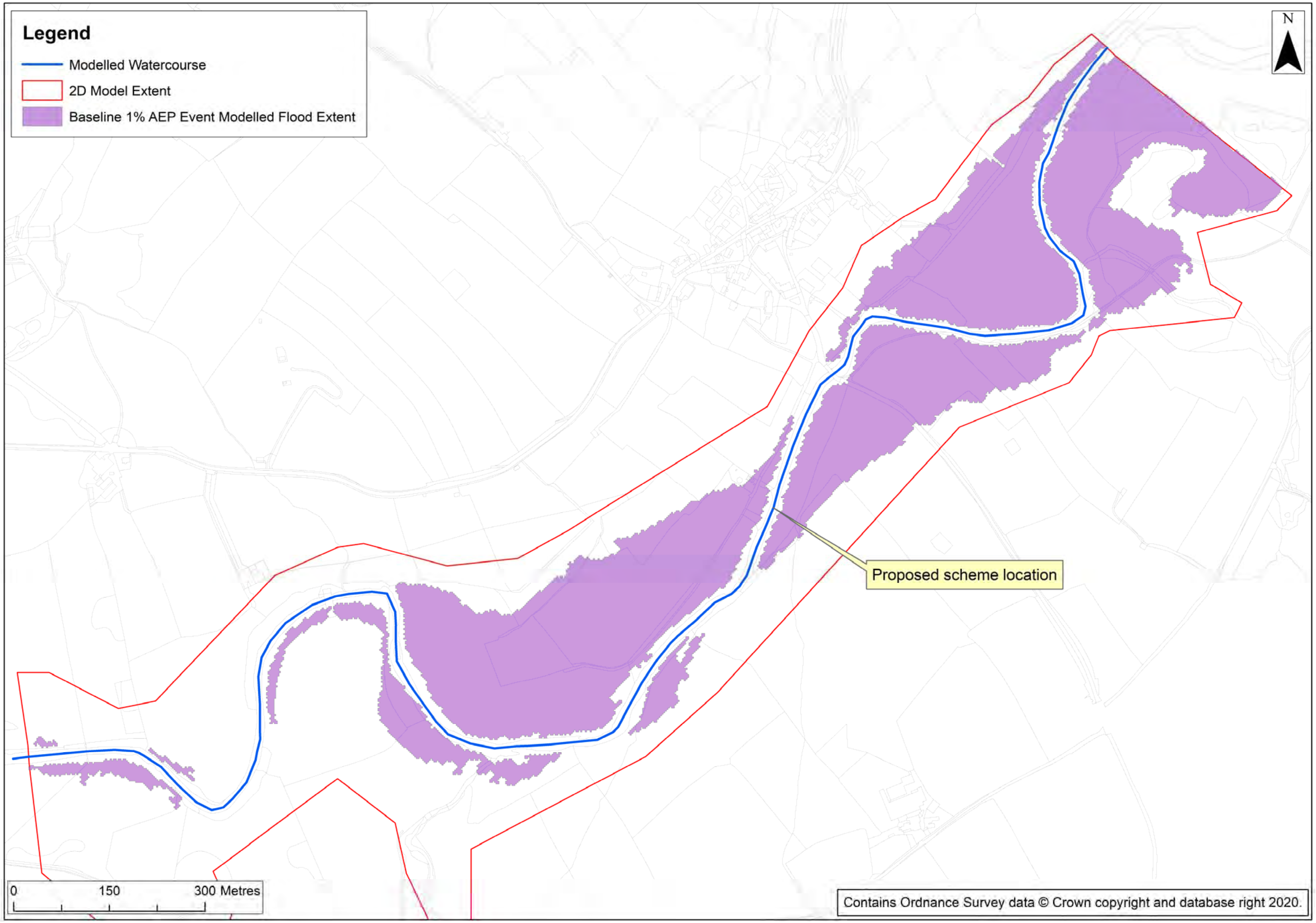


Illustration C-7: With scheme 50 % AEP event modelled maximum flood extent

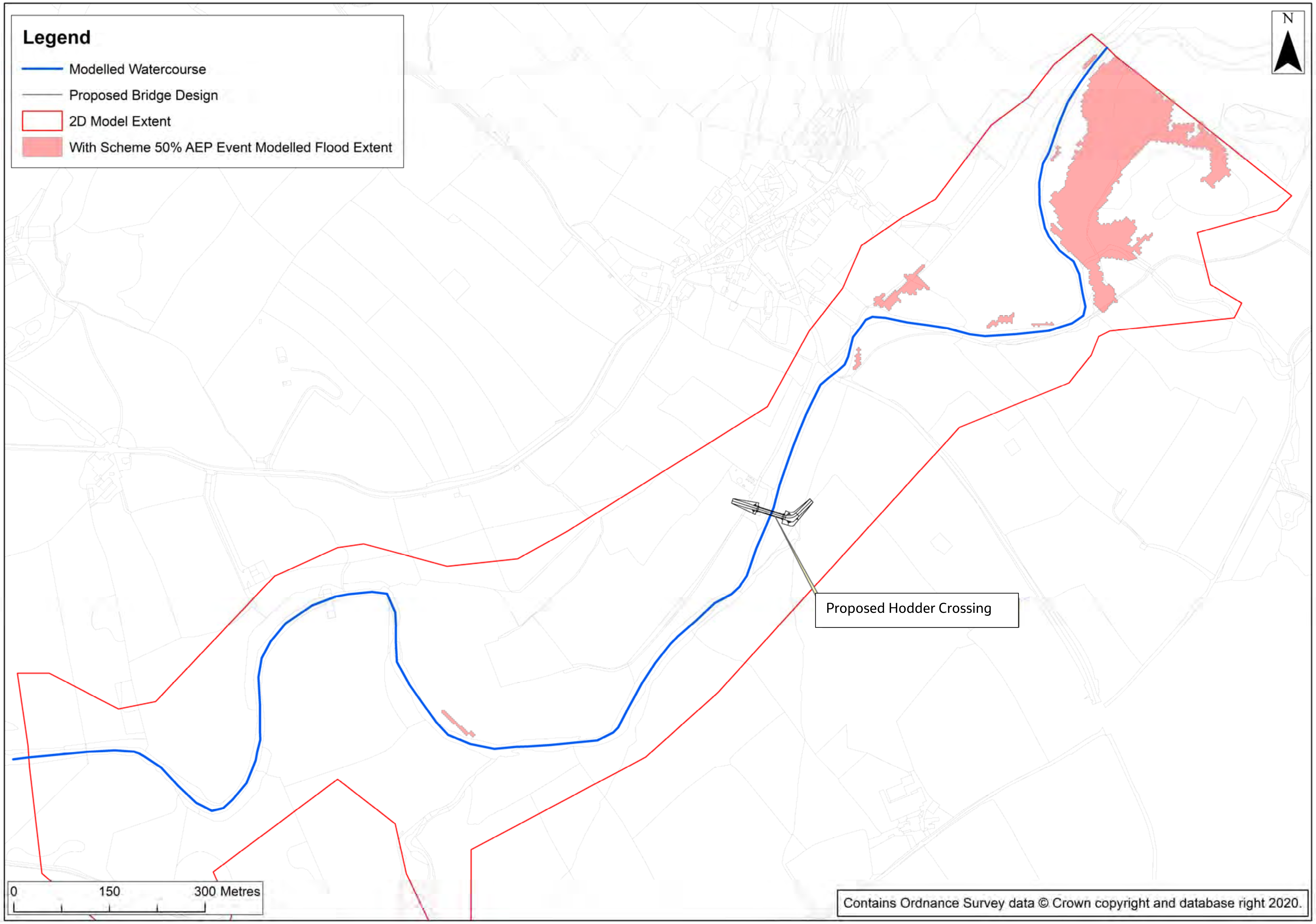


Illustration C-8: With Scheme 20 % AEP event modelled maximum flood extent

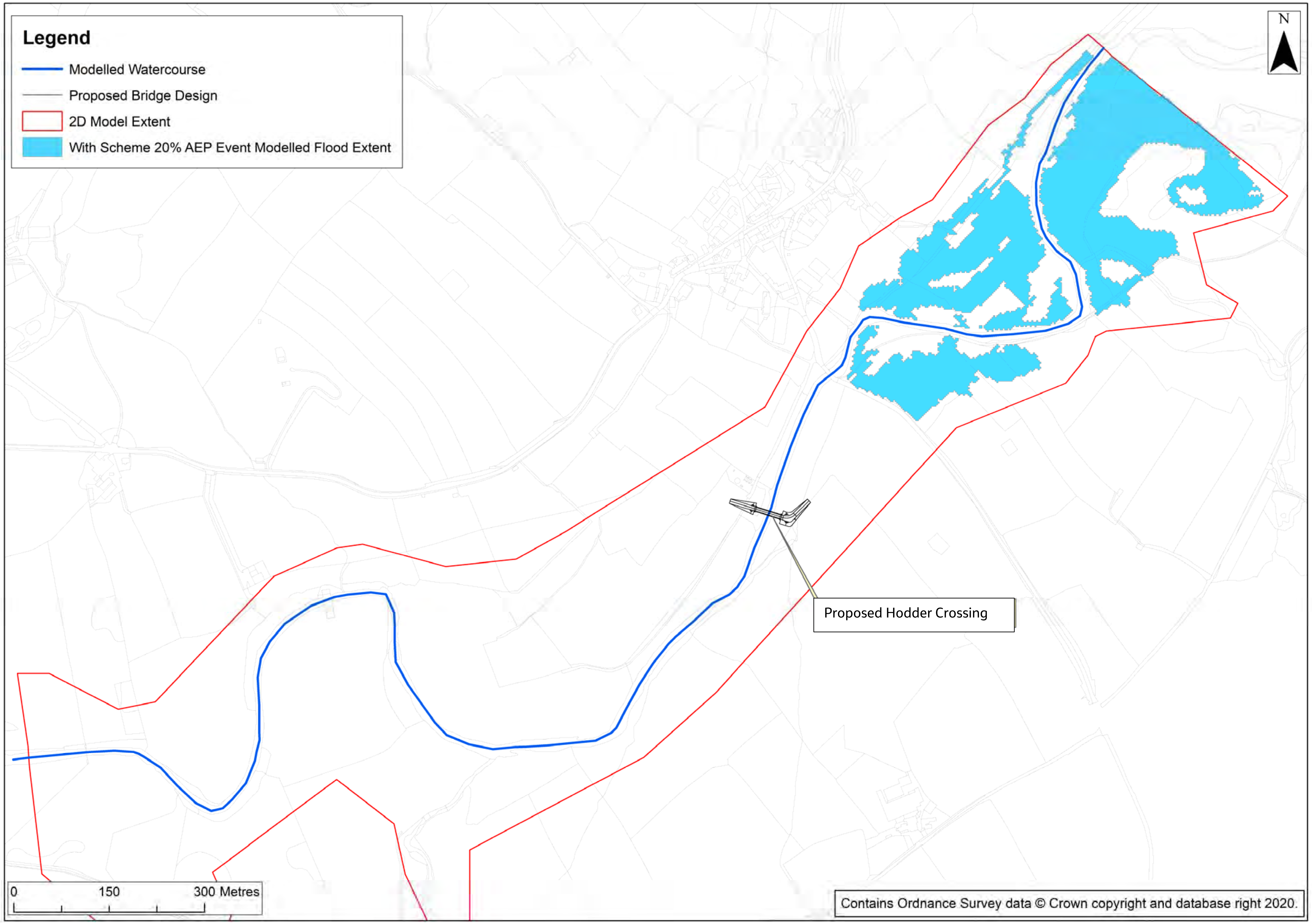


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Illustration C-9: With scheme 3.33 % AEP event modelled maximum flood extent

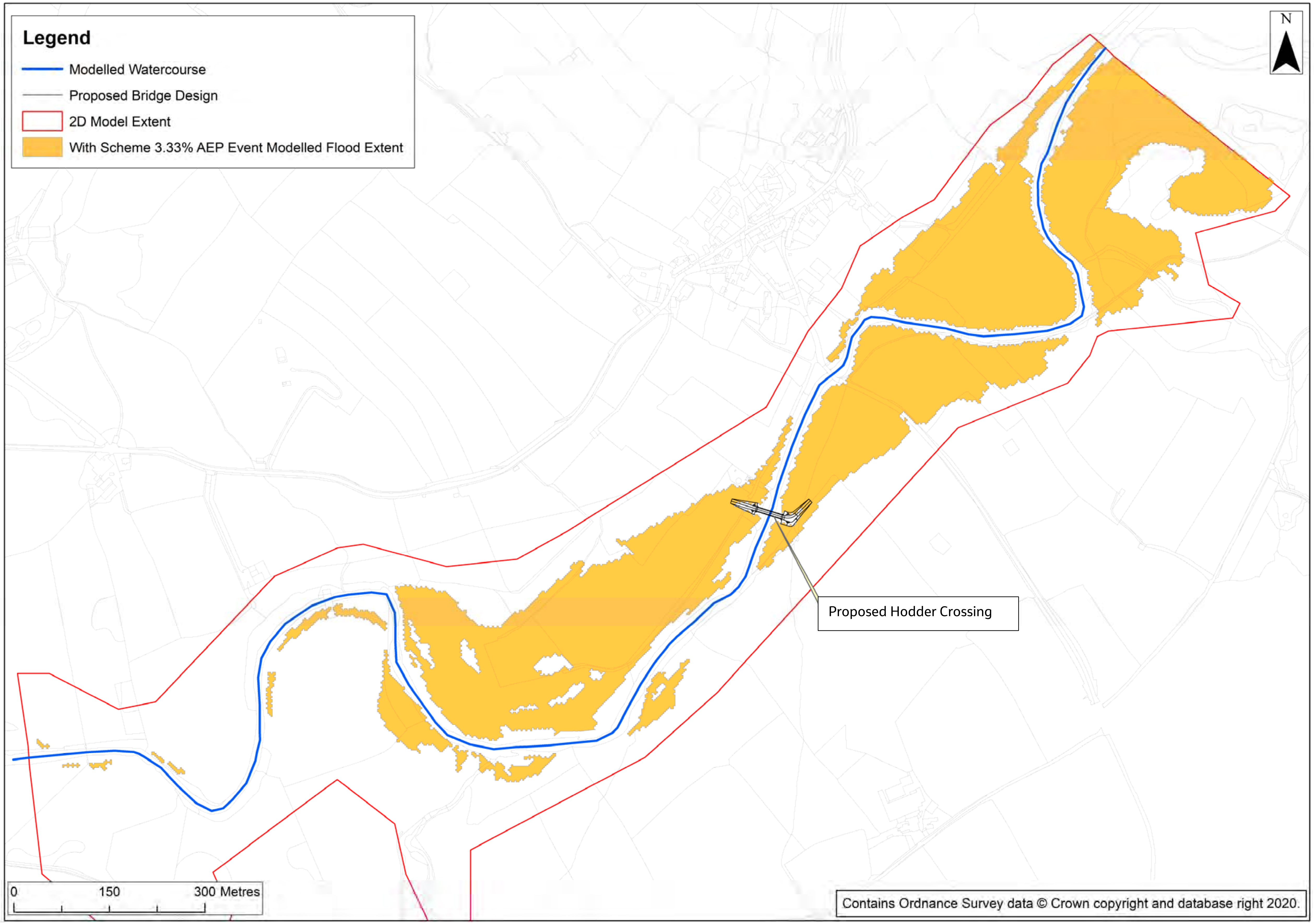


Illustration C-10: With scheme 1.33 % AEP event modelled maximum flood extent

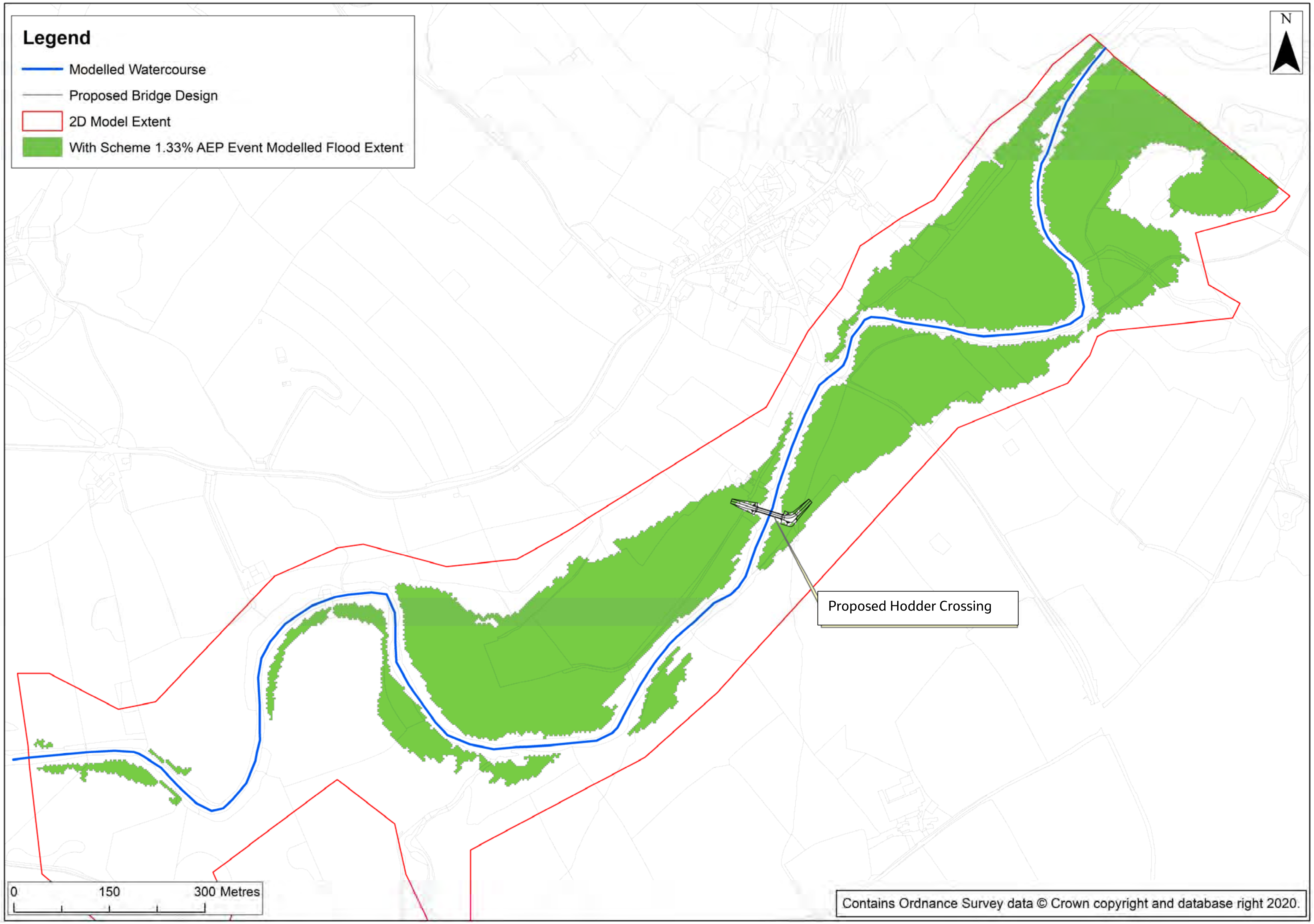
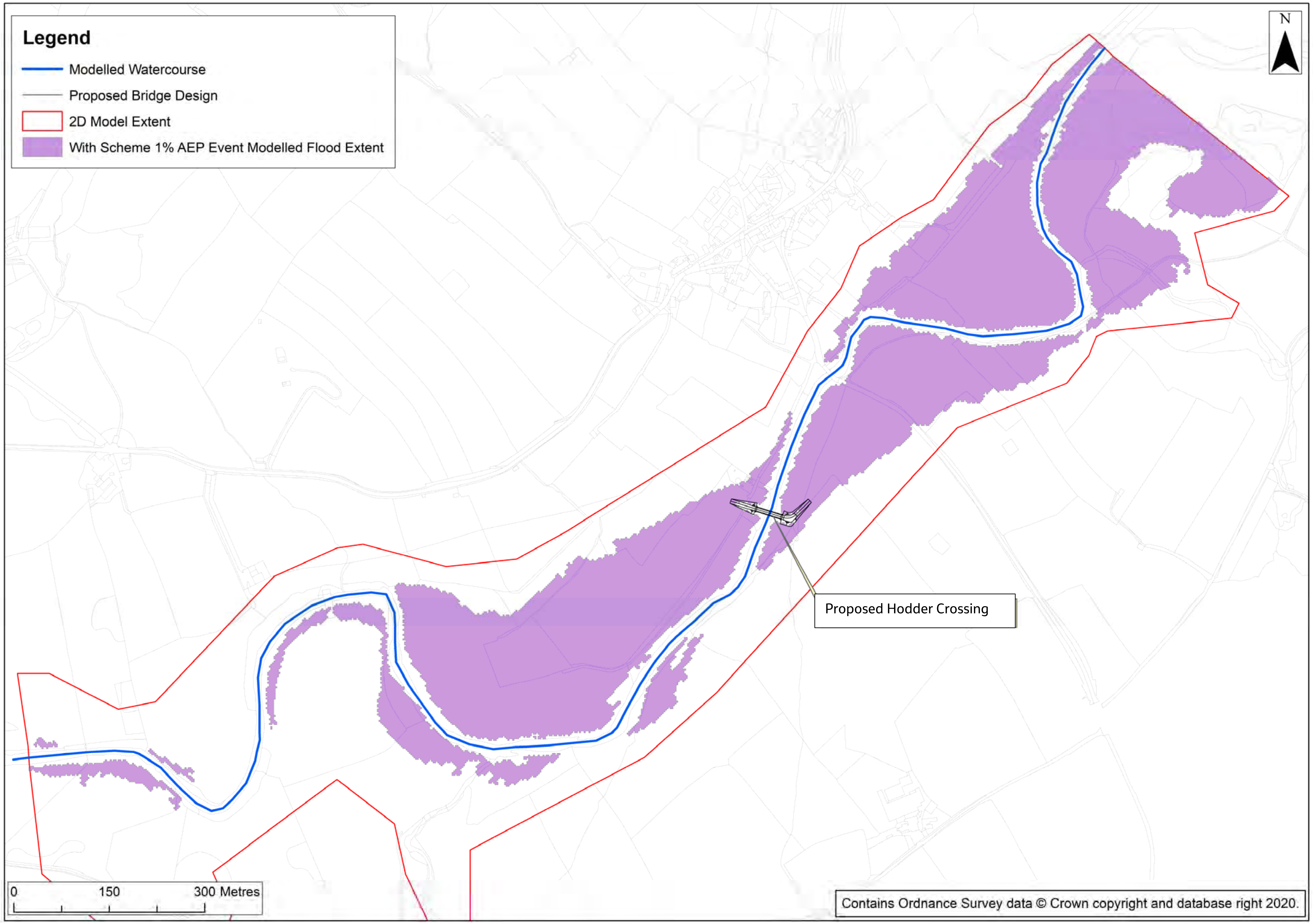


Illustration C-11: With scheme 1 % AEP event modelled maximum flood extent



Appendix D. Water Level Difference Maps

Illustration D-12: Flood level difference map for the 50 % AEP event. With-scheme scenario minus baseline scenario

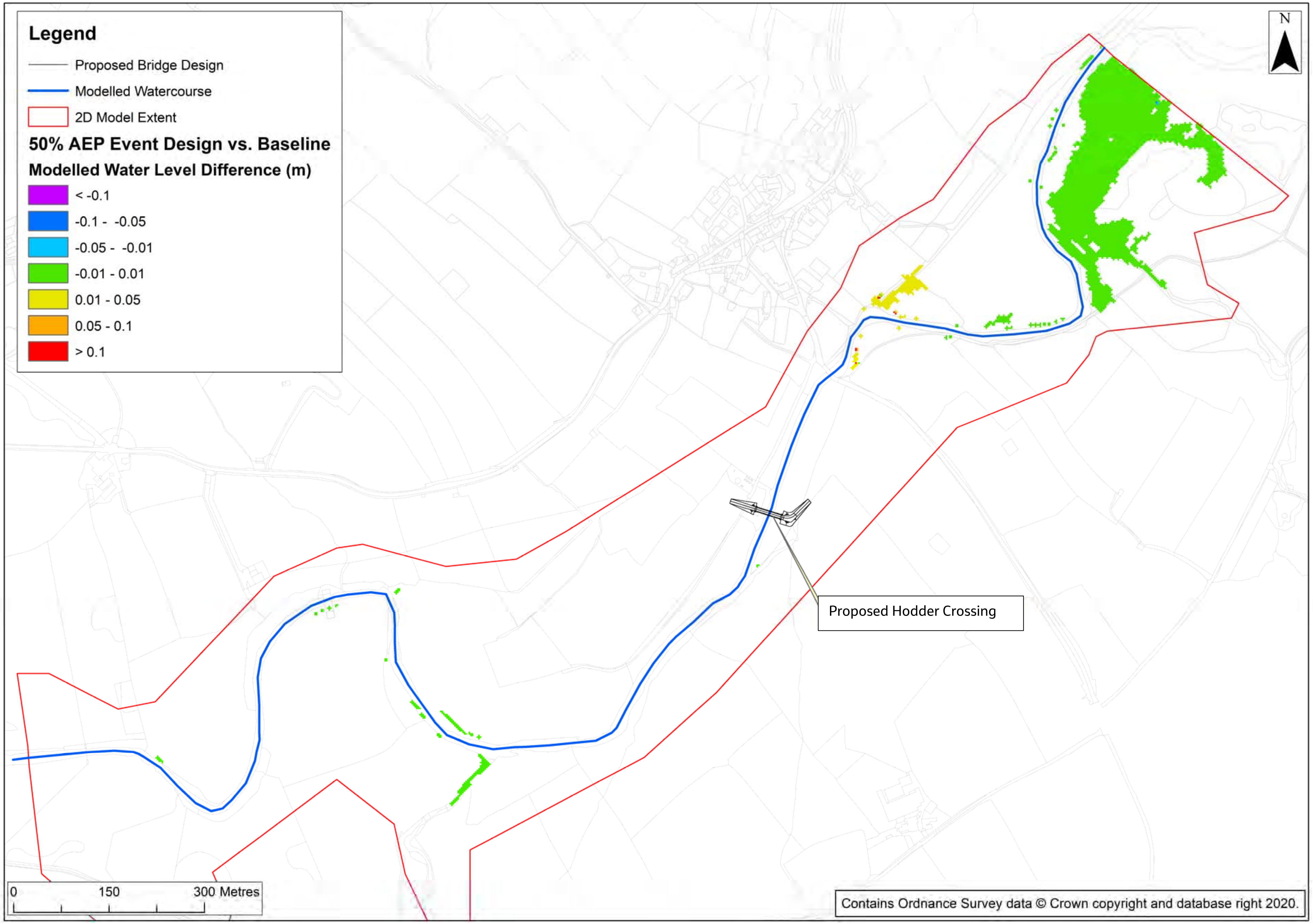


Illustration D-13: Flood level difference map for the 20 % AEP event. With-scheme scenario minus baseline scenario

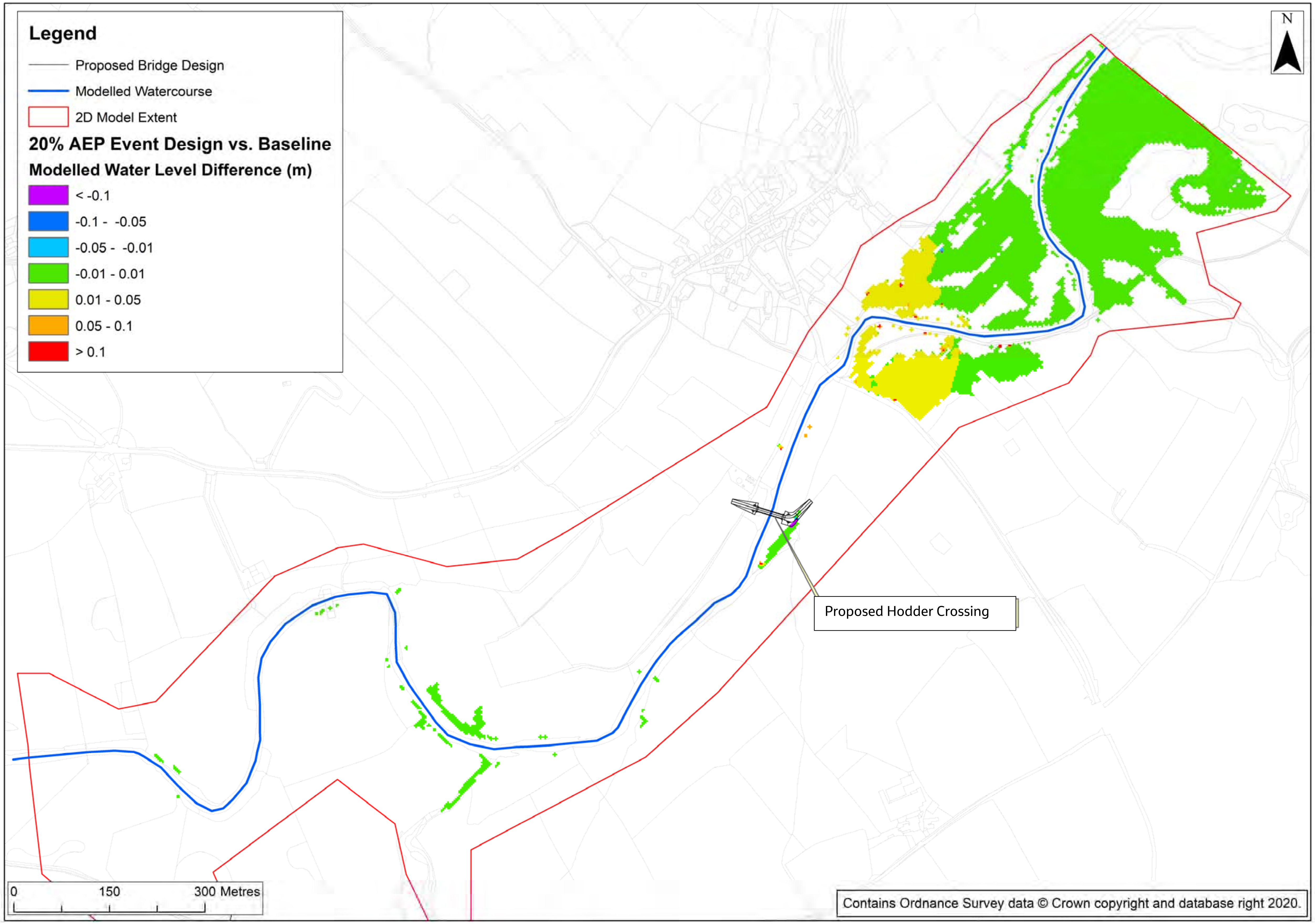


Illustration D-14: Flood level difference map for the 10 % AEP event. With-scheme scenario minus baseline scenario

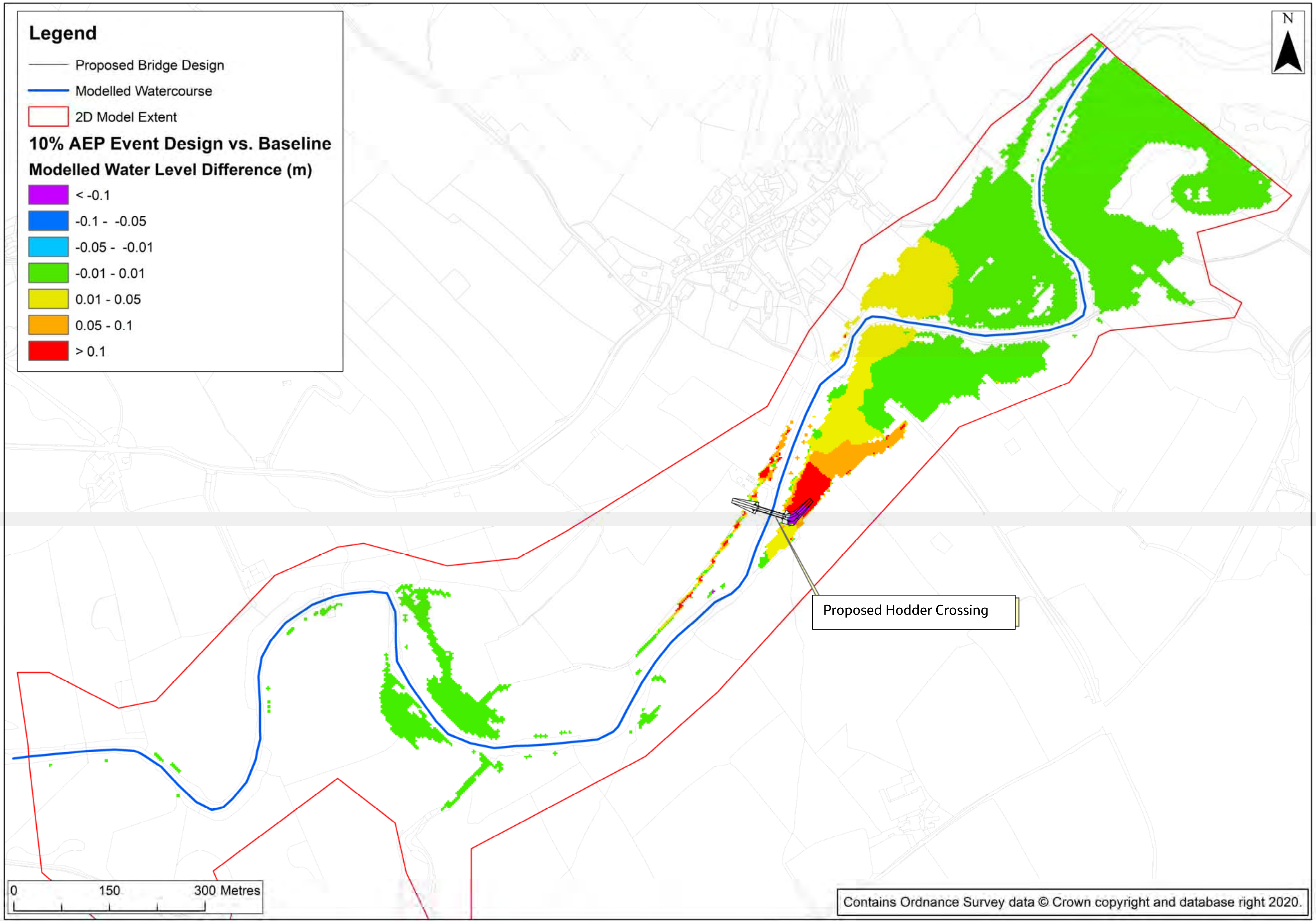


Illustration D-15: Flood level difference map for the 3.33 % AEP event. With-scheme scenario minus baseline scenario

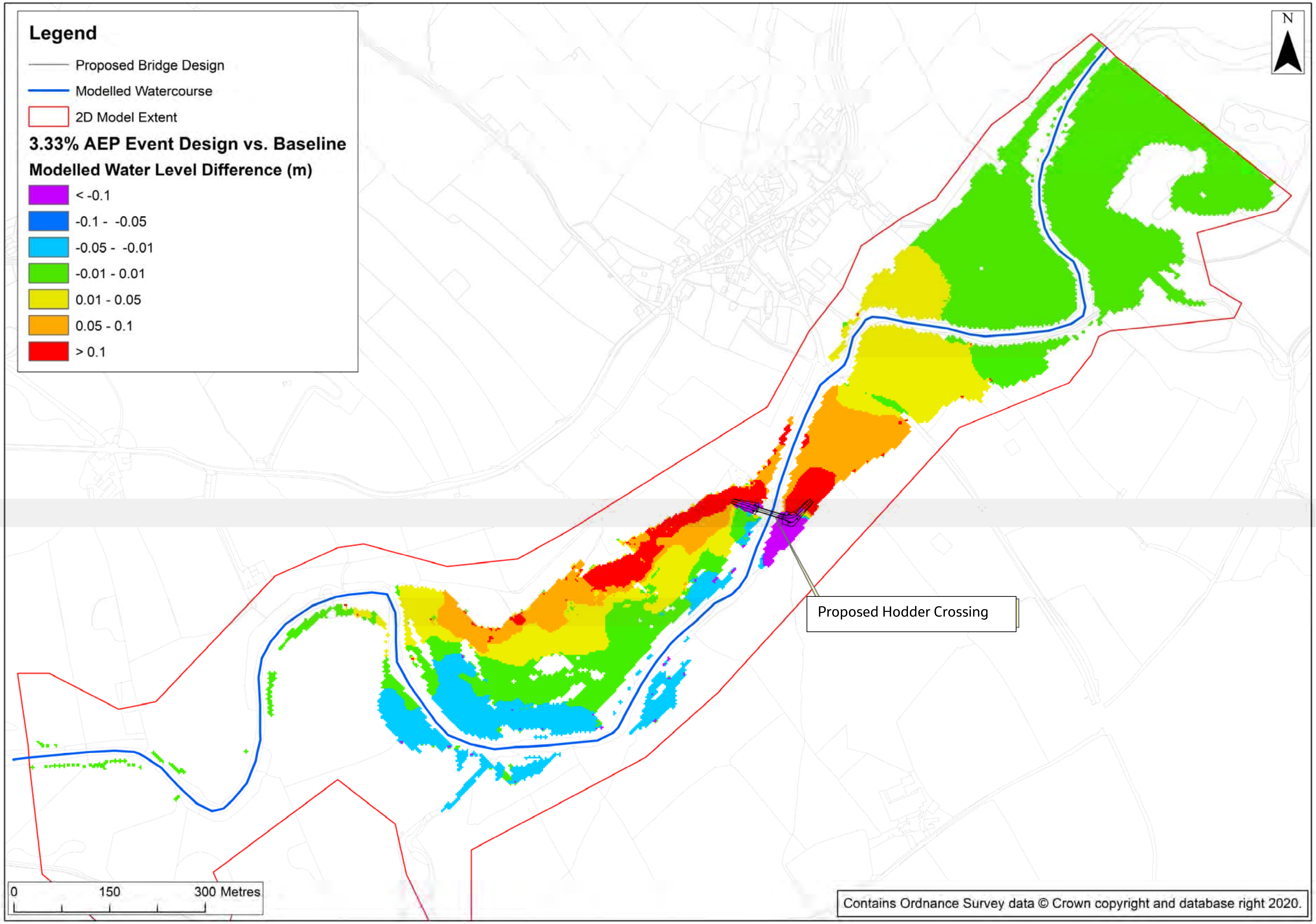


Illustration D-16: Flood level difference map for the 1.33 % AEP event. With-scheme scenario minus baseline scenario

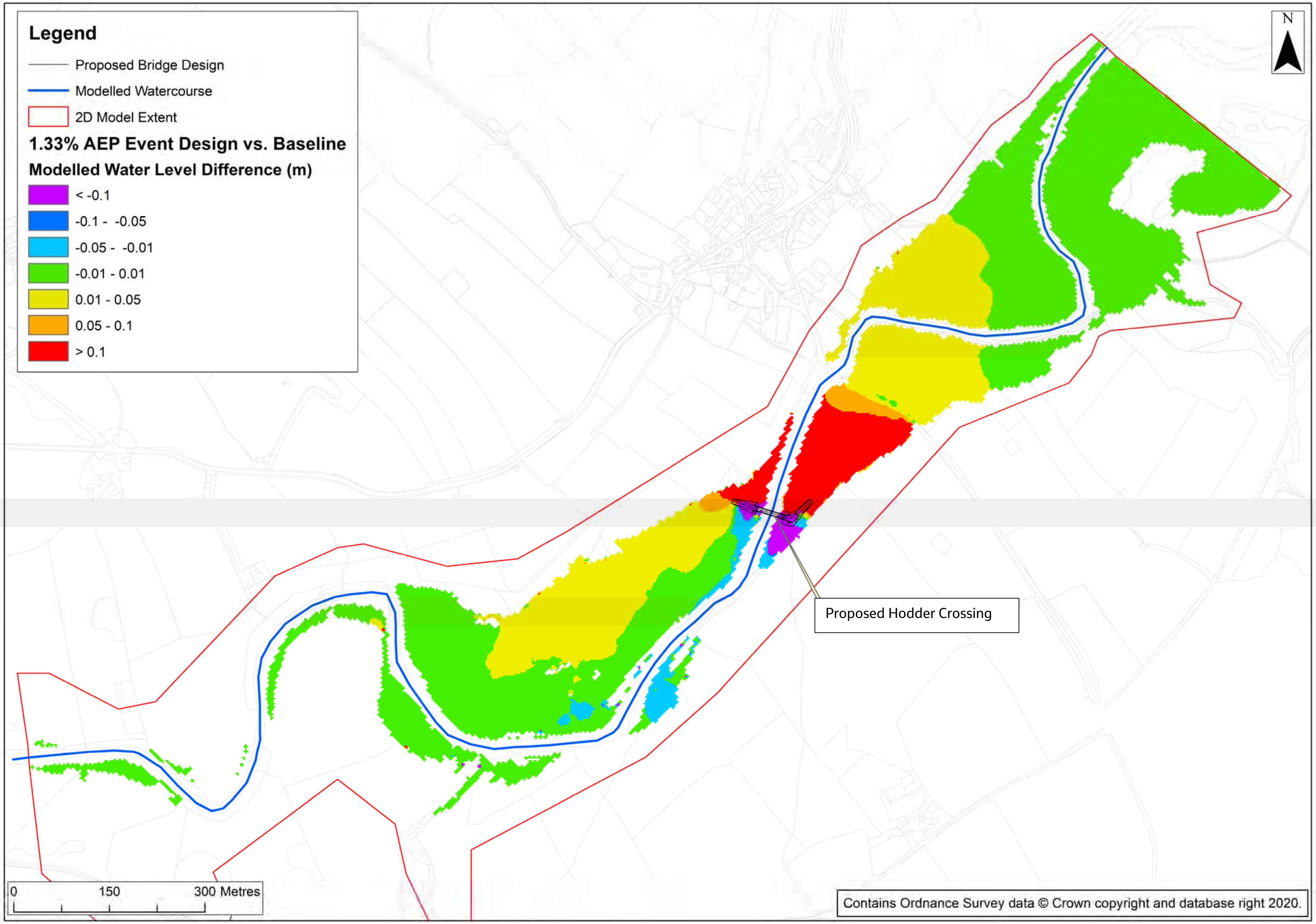


Illustration D-17: Flood level difference map for the 1 % AEP event. With-scheme scenario minus baseline scenario