



flood risk assessment

Proposed Roundabout,
Chellaston Lane, Derby

CCE/E702/BM1R-FRA-01

November 2021

For
JSC Farming and Central Land
Holdings Ltd

Document Review Sheet

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Reference	Date	Author	Checked
CCE/E702/BM1R-FRA-01	November 2021	JH	RT

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A. Existing Site

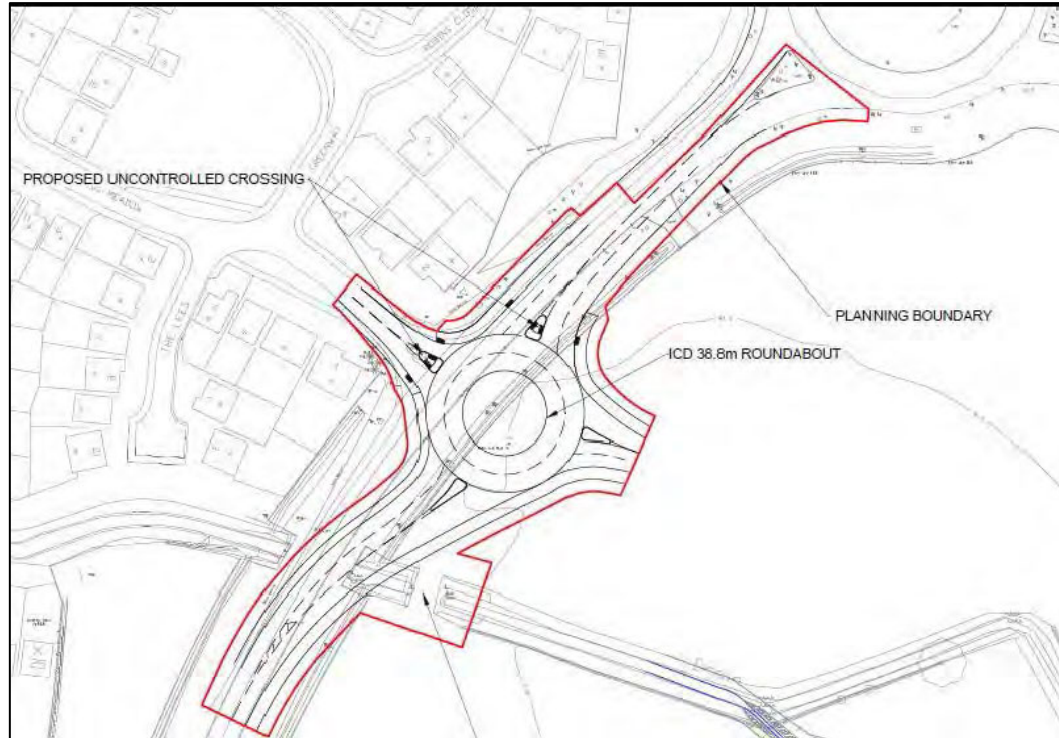
Topographical survey
Adopted sewer plans
Flood modelling report
Environment Agency correspondence

Summary Table

Site location	Chellaston Lane, Boulton Moor, Derby. Grid reference – 440009, 331947
Existing site	Highway and agricultural
Proposed development	Roundabout
Flood Zone	1 (the band of flooding reported as Flood Zone 3 indicates in-channel water rather than floodplain.
Reservoir Inundation Zone	None
Surface water flooding	Minor

1.0 Introduction

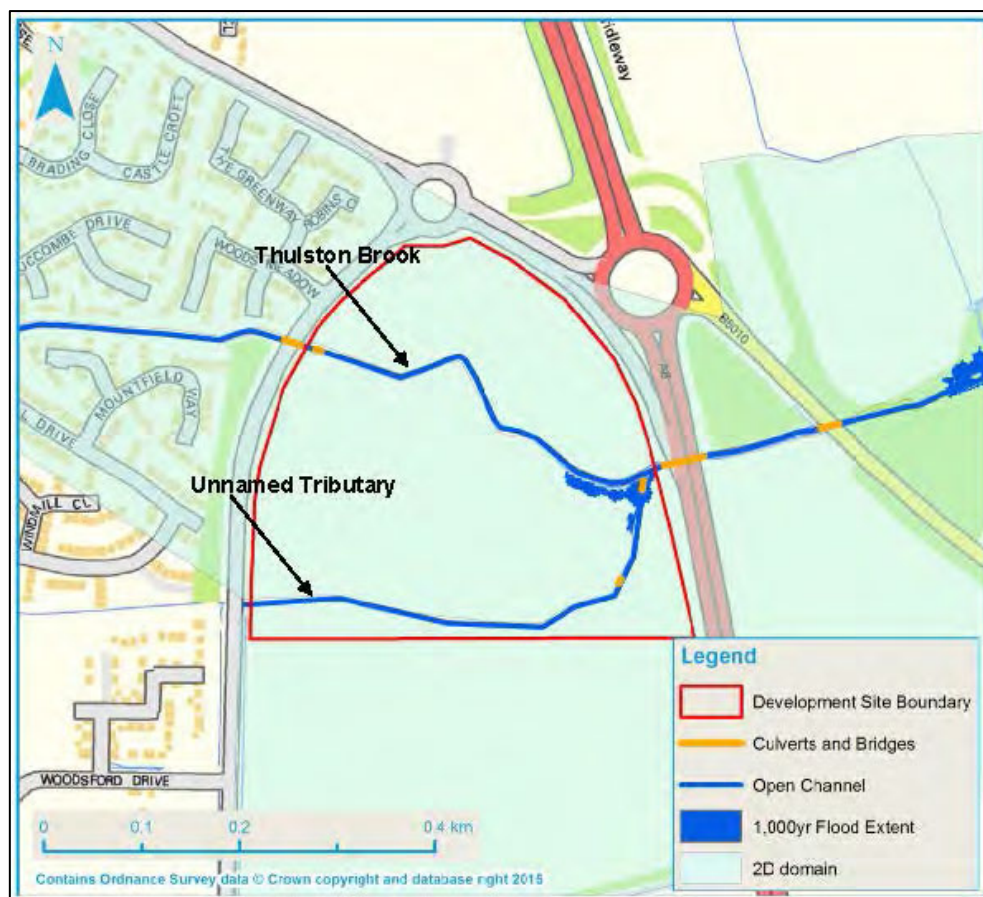
- 1.1 This Flood Risk Assessment (FRA) has been prepared for the use of JSC Farming and Central Land Holdings Ltd to support a planning application for the creation of a four arm roundabout on Chellaston Lane, Boulton Moor, in Derby (see below).



2.0 Forms of Flooding

Watercourses

- 2.1 The extent of Flood Zone 3 shown along the line of the Thulston Brook represents in channel water as opposed to an actual floodplain (i.e. water extending beyond the banks of the river).
- 2.2 The appended flood modelling report for the Thulston Brook confirms that, within the redline boundary, flows remain in channel for the 1 in 100 annual probability event (Flood Zone 3) with and without climate change, and the 1 in 1,000 annual probability event.
- 2.3 The appended flood modelling report supported a Flood Map challenge in 2016 and the results of the model were used to redraw the Flood Map for Planning in February 2017 (see correspondence in Appendix A and image below).



Extract from the JBA Thulston Brook flood model

- 2.4 The site does not therefore include land within Flood Zone 3.

Surface water flooding

- 2.5 Surface water flooding (Figure 4) is also confined to the Thulston Brook, as well as the Chellaston Lane roadside ditch.

Surface Water Sewers

- 2.6 Severn Trent sewer plans (included in Appendix A) show surface water sewers serving the residential development to the west of the site.

Groundwater

- 2.7 The ground investigation suggests that the underlying geology may support seasonal waterlogging and shallow groundwater levels.

Reservoirs

- 2.8 The site is not within a reservoir inundation zone (refer to Figure 2).

Flood Risk

- 2.9 None of the sources of source of flooding identified above are likely to result in flooding at the proposed roundabout and do not therefore post any notable risk to the development. The proposed development is also not likely to have a notable impact on any existing floodwater in the area (in terms of being able to divert or displacing it).

3.0 Surface Water Management

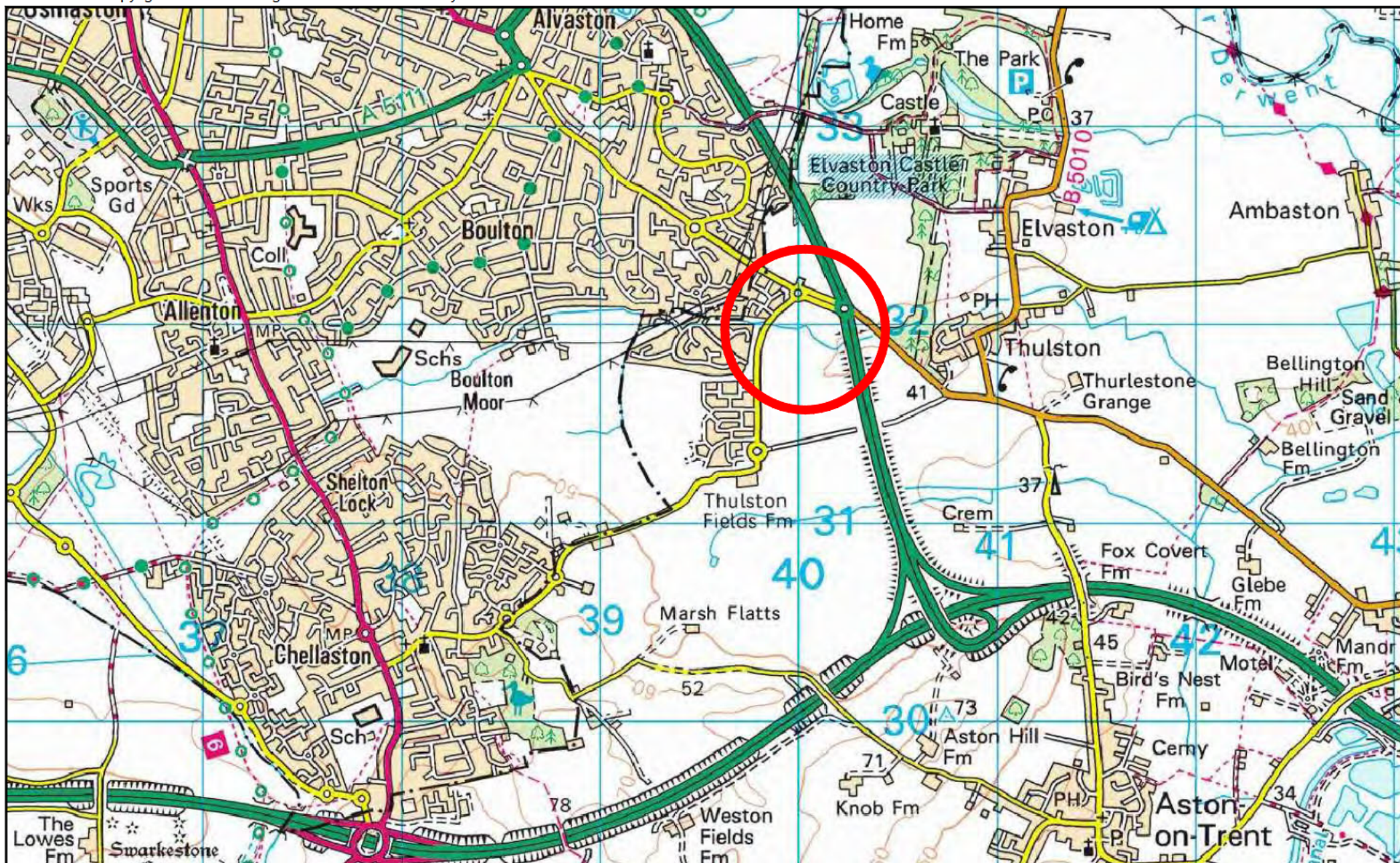
- 3.1 Intrusive ground investigations and infiltration testing in the area show that infiltration rates are low, but within a range which may support the disposal of site runoff via infiltration. In light of the potentially shallow groundwater however, surface water runoff from the proposed roundabout will be discharged (as is currently the case) to the Thulston Brook.
- 3.2 Runoff from the increased impermeable area associated with the creation of the roundabout will be attenuated and discharged at the calculated annual greenfield rate of 3.5 l/s/ha.

4.0 Conclusions

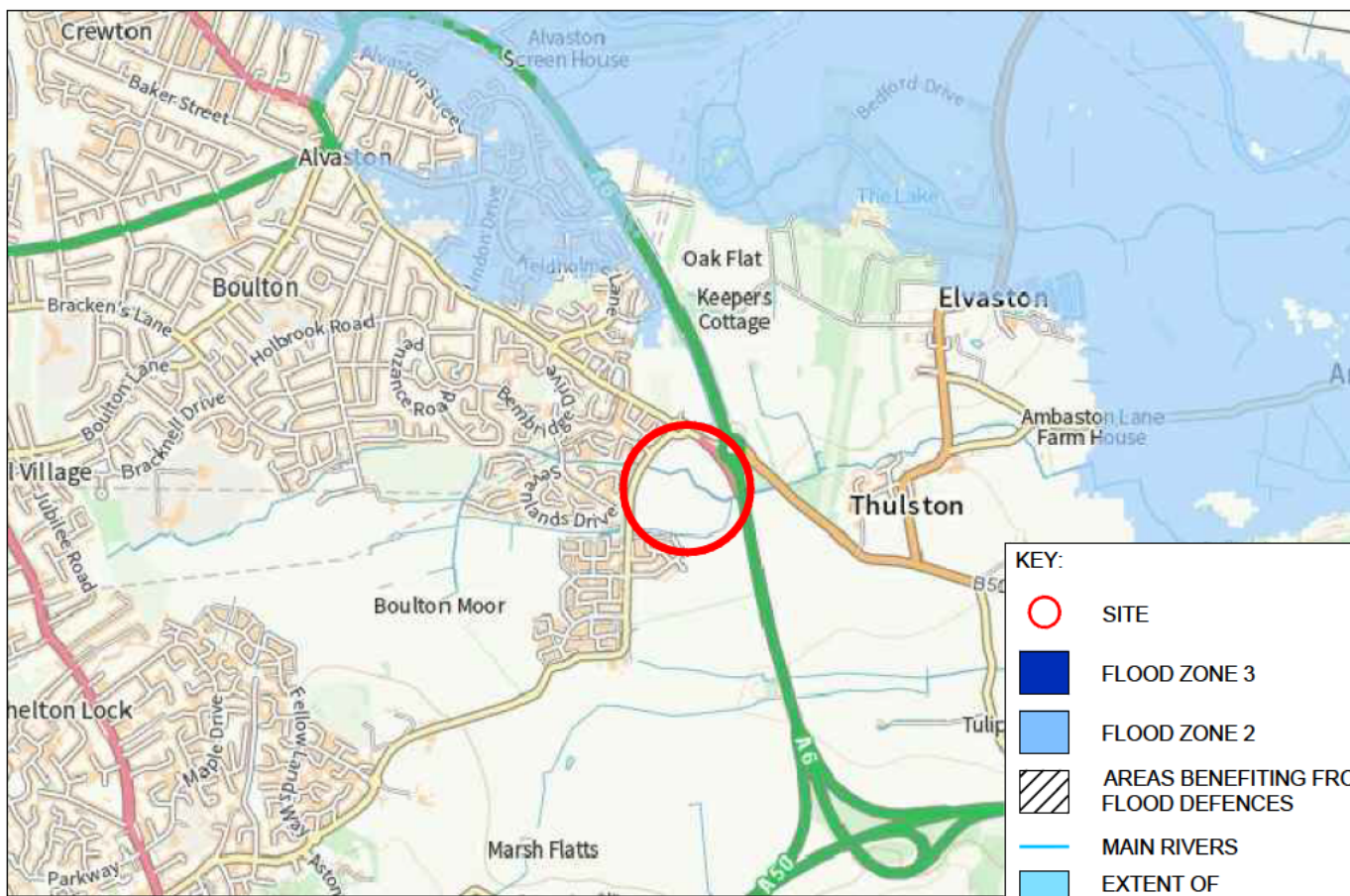
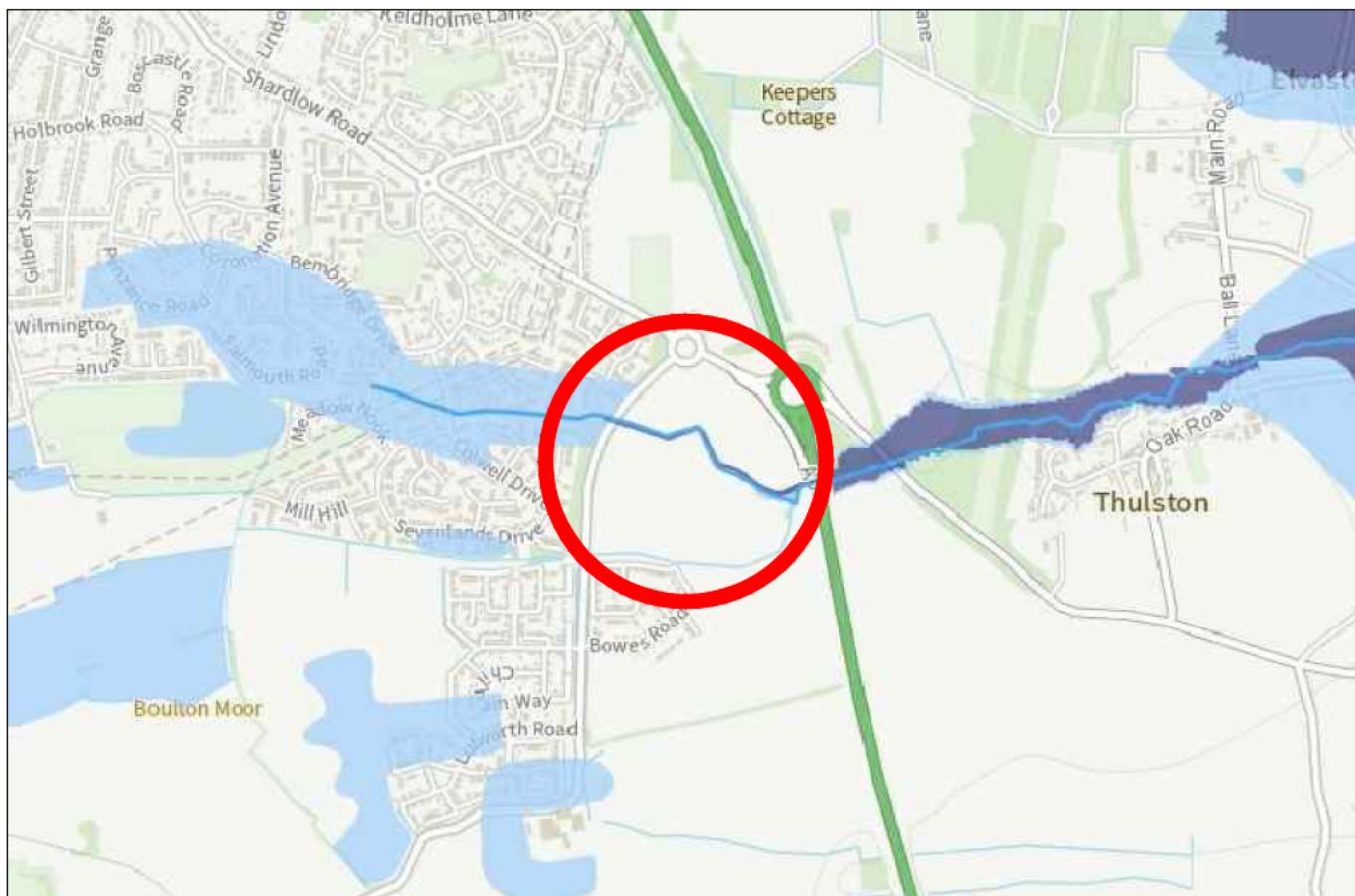
- 4.1 The proposed development is not considered to be subject to significant or unmanageable flooding from the sources identified in the Flood and Water Management Act 2010 (FWMA).
- 4.2 Surface water runoff from the increased impermeable area will be attenuated and discharged to the Thulston Brook a rate of 3.5 l/s/ha.

Figures

1. Site Location Plan
2. Flood Zone & Reservoir Inundation Map
3. Groundwater Source Protection Zone Map
4. Surface Water Flood Map



DATE 10/09/2021	PROJECT TITLE BM1	FIGURE NUMBER 1	PROJECT NO. E702	CANNON CONSULTING ENGINEERS Highways, Transport & Infrastructure Planning
DRAWN BY DP	FIGURE TITLE SITE LOCATION PLAN			
SCALE @ A4 SIZE D.N.S.				



- KEY:**
- SITE
 - FLOOD ZONE 3
 - FLOOD ZONE 2
 - AREAS BENEFITING FROM FLOOD DEFENCES
 - MAIN RIVERS
 - EXTENT OF RESERVOIR FLOODING

DATE
10/09/2021

PROJECT TITLE

BM1

DRAWING NUMBER

2

PROJECT NO.

E702

DRAWN BY
DP

FIGURE TITLE

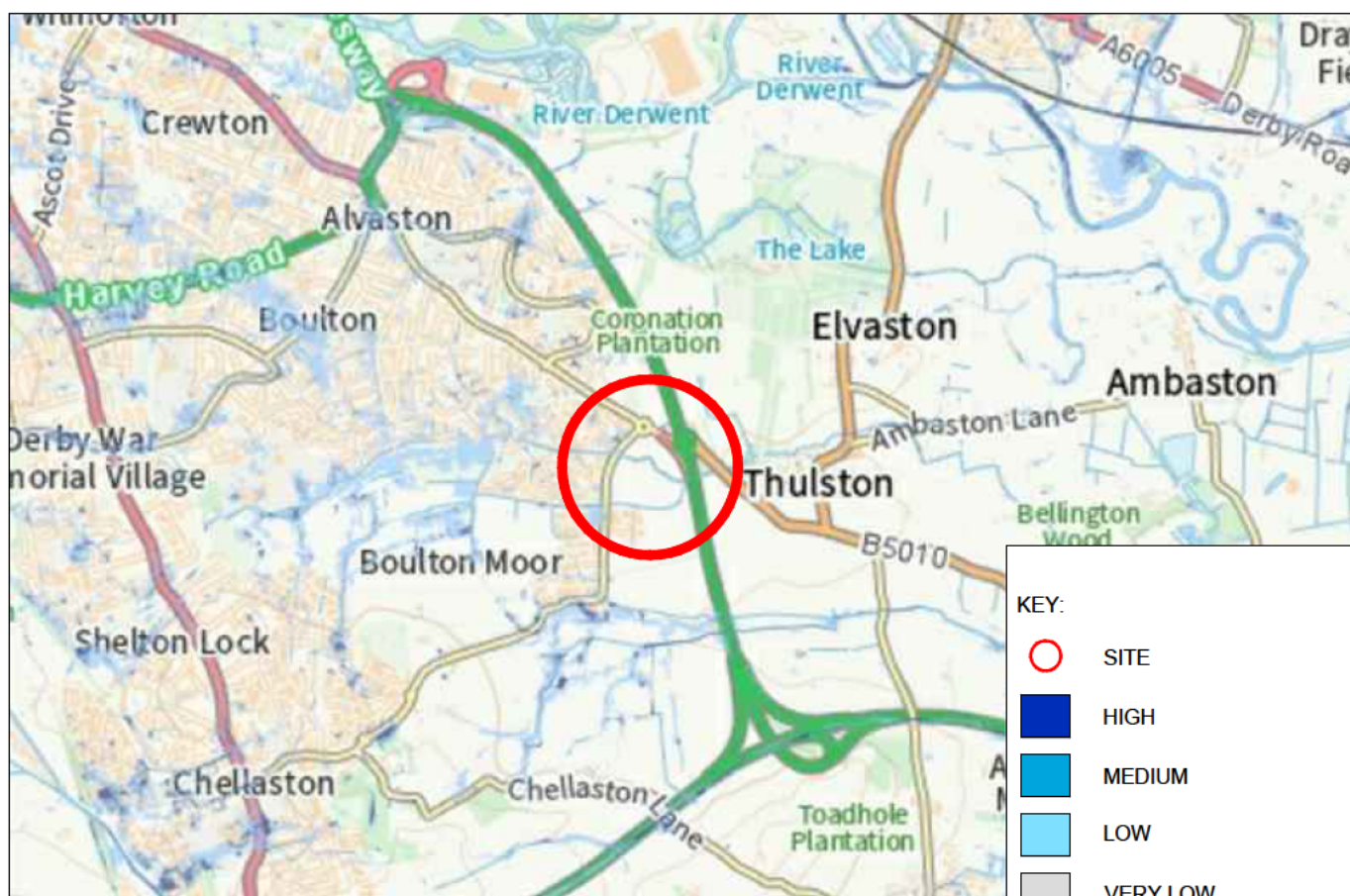
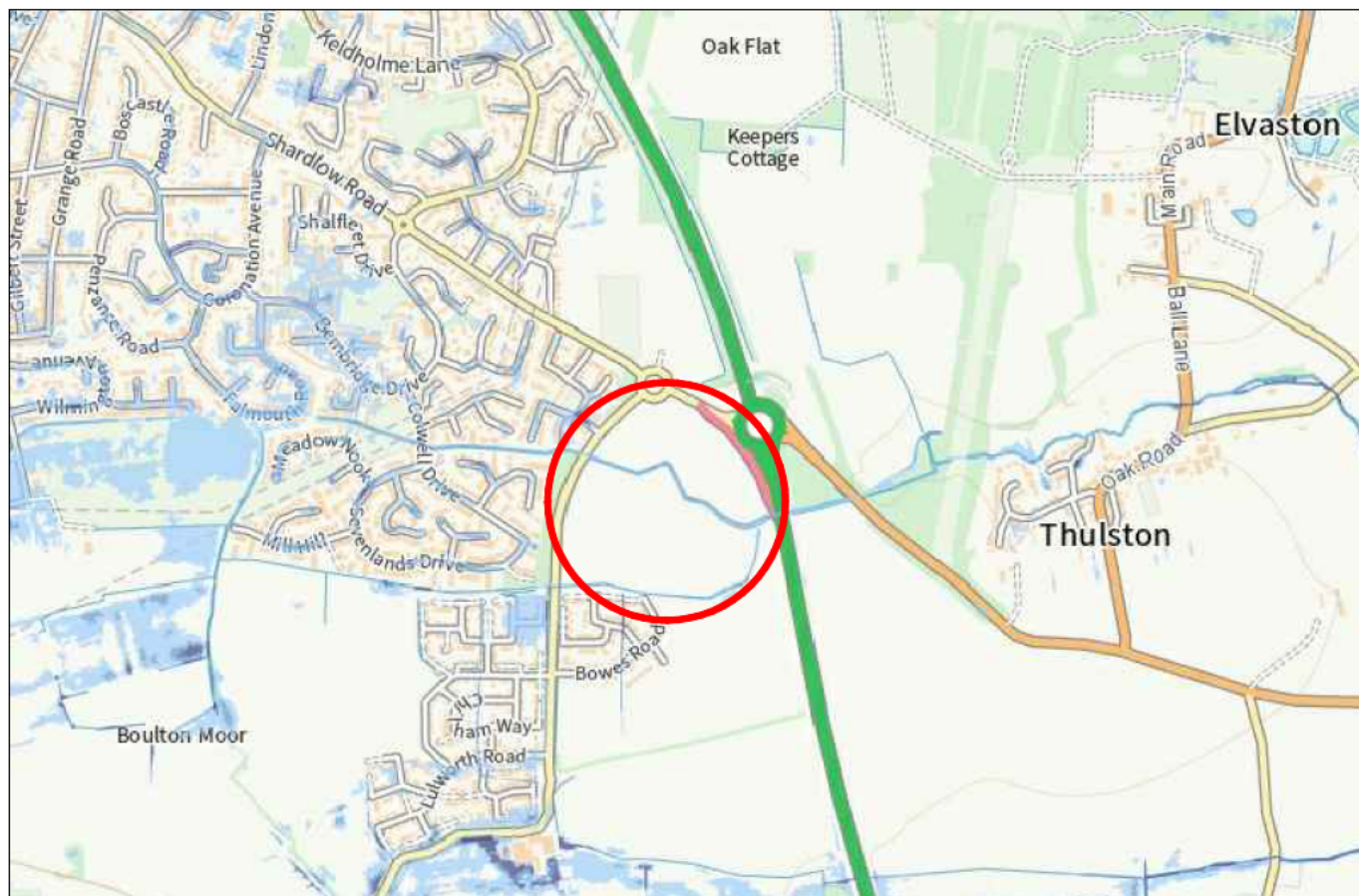
FLOOD ZONE & RESERVOIR INUNDATION PLAN

SCALE @ A4 SIZE
D.N.S.

CANNON
CONSULTING ENGINEERS
Highways, Transport & Infrastructure Planning



DATE 10/09/2021	PROJECT TITLE BM1	FIGURE NUMBER 3	PROJECT NO. E702	
DRAWN BY DP	FIGURE TITLE GROUNDWATER SOURCE PROTECTION ZONE PLAN			
SCALE @ A4 SIZE D.N.S.				



DATE 10/09/2021	PROJECT TITLE BM1	DRAWING NUMBER 4	PROJECT NO. E702	CANNON CONSULTING ENGINEERS Highways, Transport & Infrastructure Planning
DRAWN BY DP	FIGURE TITLE SURFACE WATER FLOOD MAP			
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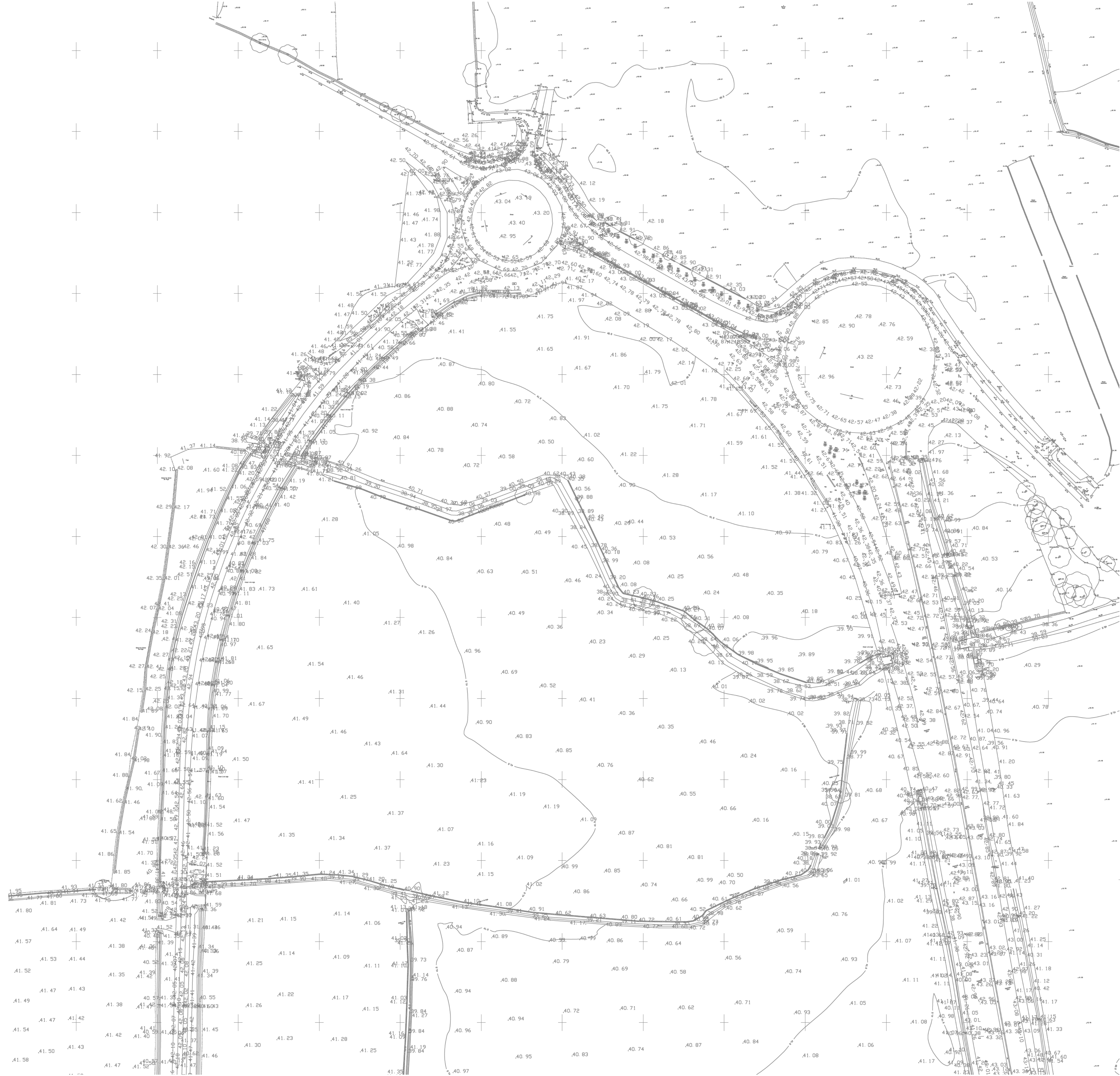
Appendix A – Existing Site

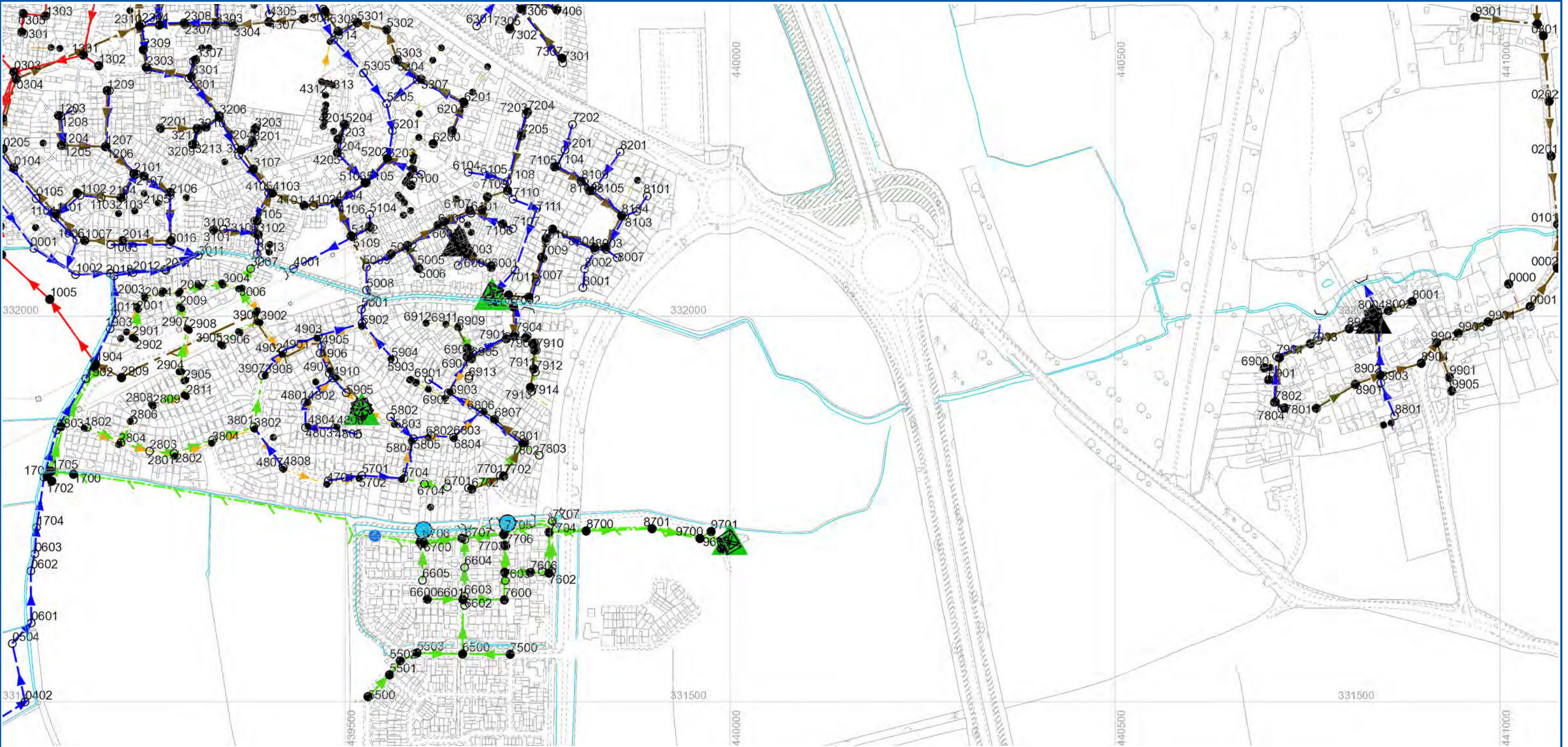
Topographical survey

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LEGEND

LandlineLine

Polygon Closing Line

Property Closing Line

Bottom Of Slope

Top Of Slope

Step

Mean High Water

Traffic Calming

Standard Gauge Track

Bottom Of Cliff

Top Of Cliff

Mean Low Water

Path

Overhead Construction

Culvert

Pylon

Ridge Or Rock Line

Narrow Gauge Track

Railway Buffer

Tunnel Edge

Line Of Posts

Drain

Default Line

Building Outline

Edge Line

Road Or Track

Building Division

Inland water Line

General Surface Natural Line

Building Overhead Line

Landform Natural Line

Historic Interest Line

Landform Manmade Line

Unclassified

LandlineArea

Other

Mixed Woodland Fill

Nonconiferous Tree Fill

Coniferous Tree Fill

Orchard Fill

Coppice Or Osiers Fill

Scrub Fill

Boulders Fill

Rock Fill

Scree Fill

Rough Grassland Fill

Heath Fill

Salmarsh Fill

Marsh Fill

Reeds Fill

Slope Fill

Cliff Fill

Ancillary

Balancing Lagoon

Grease Trap

Interceptor

Screen

Chamber

Flushing Chamber

Soakaway

Overflow

Fitting

Blind Shaft

Facility Connector

Head Node

Lamphole

Sewerage Air Valve

Sewerage Chem cal Injection Point

Sewerage Hatch Box

Sewerage Pressure Washout

Vent Column

Waste Water Outfall

Control Valve

Hydrobrake

Penstock

Sewerage Isolation Valve

Sewerage Non Return Valve

Manhole

Foul Bifurcat on Manhole

Combined Bifurcation Manhole

Surface Water Bifurcation Manhole

Dual Manhole

Foul Single Manhole

Combined Single Manhole

Surface Water Single Manhole

Tw n Manhole

Foul Adopted Manhole

Combined Adopted Manhole

Surface Adopted Manhole

Transferred Manhole

Unsurveyed Manhole

Operational Site

Waste Water Pump

S104

Transferred Asset

S102

Null STW

Adopted Sewer

None

Highway Drain

Null Private

S24

Storage

Disposal Site

Off-Line Waste Water Storage

On-Line Waste Water Storage

Wet Well

Waste Water Process Structure

Disposal Site

Off-Line Waste Water Storage

On-Line Waste Water Storage

Wet Well

Waste Water Process Structure

Disposal Site

Off-Line Waste Water Storage

On-Line Waste Water Storage

Wet Well

Waste Water Process Structure

Sludge Treatment Point

Sludge Treatment Structure

Gravity Sewer Pipe

Foul Gravity Sewer

Combined Gravity Sewer

Surface Water Gravity Sewer

S104 Surface Water Gravity Sewer

S104 Combined Gravity Sewer

S104 Foul Gravity Sewer

Private Surface Water Gravity Sewer

Private Combined Gravity Sewer

Private Foul Gravity Sewer

Surface Water Unserved Pipe

Combined Unserved Pipe

Foul Unserved Pipe

Transferred Surface Water Sewer

Transferred Combined Sewer

Transferred Foul Sewer

Disposal Pipe

Overflow Pipe

Culverted Water Course

Waste Internal Site Pipe

Sewer Service Connection

Gravity Sewer Others

Pressure Sewer Pipe

Surface Water Pressure Sewer

Combined Pressure Sewer

Foul Pressure Sewer

S104 Surface Water Pressure Sewer

S104 Combined Pressure Sewer

S104 Foul Pressure Sewer

Private Surface Water Pressure Sewer

Private Combined Pressure Sewer

Private Foul Pressure Sewer

Surface Water Vacuum Sewer

Foul Vacuum Sewer

Combined Vacuum Sewer

S104 Surface Water Vacuum Sewer

S104 Combined Vacuum Sewer

S104 Foul Vacuum Sewer

Private Surface Water Vacuum Sewer

Private Combined Vacuum Sewer

Private Foul Vacuum Sewer

Surface Water Siphon

Combined Siphon

Foul Siphon

Private Surface

Private Combined

Private Foul Siphon

S104 Surface

S104 Combined

S104 Foul Siphon

Surface Water

Combined Unserved

Foul Unserved

Disposal Pipe

Service Pipe

Surface Water

Combined Lateral

Foul Lateral Drain

S104 Surface Water

S104 Combined Lateral

S104 Foul Lateral Drain

Private Surface Water

Private Combined Lateral

Private Foul Lateral

CATEGORIES

W - WEIR

C - CASCADE

DB - DAMBOARD

SE - SIDE ENTRY

FV - FLAP VALVE

BD - BACK DROP

S - SIPHON

D - HIGHWAY DRAIN

S104 - SECTION 104

SHAPE

C - CIRCULAR

E - EGG SHAPED

O - OTHER

R - RECTANGLE

S - SQUARE

T - TRAPEZOIDAL

U - UNKNOWN

PURPOSE

C - COMBINED

E - FINAL EFFLUENT

F - FOUL

L - SLUDGE

S - SURFACE WATER

MATERIALS

- NONE

- ASBESTOS CEMENT

- BRICK

- CONCRETE BOX CULVERT

- CAST IRON

- CONCRETE

- CONCRETE SEGMENTS (BOLTED)

- CONCRETE SEGMENTS (UNBOLTED)

- DUCTILE IRON

- GLASS REINFORCED PLASTIC

- MASONRY IN REGULAR COURSES

- MASONRY RANDOMLY COURSED

- POLYETHYLENE

- PITCH

- POLYPROPYLENE

- PLASTIC STEEL COMPOSITE

- POLYVINYL CHLORIDE

- REINFORCED PLASTIC MATRIX

- SPUN (GREY) IRON

- STEEL

- UNKNOWN

- VITRIFIED CLAY

- OTHER



Severn Trent Water Limited
Asset Data Management
PO Box 5344
Coventry
CV3 9FT
Telephone: 0345 601 6616

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Thulston Brook Hydraulic Modelling Study

Final Report

August 2016

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Rev 1.0 / July 2016	Draft	James Howard and Rik Totman (Cannon Consulting Engineers)
Rev 2.0 / August 2016	Final	James Howard and Rik Totman (Cannon Consulting Engineers)

Contract

This report describes work commissioned by James Howard, on behalf of Cannon Consulting Engineers, by an email dated 16 May 2016. Cannon Consulting Engineers' representatives for the contract were James Howard and Rik Totman. Olivier Saillofest and Sophie Dusting of JBA Consulting carried out this work.

Prepared by Olivier Saillofest BEng MSc CEng MCIWEM C.WEM
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Reviewed by Sophie Dusting BSc MEPS
Analyst

Purpose

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Executive Summary

JBA carried out a hydrological assessment and a flood mapping study of the Thulston Brook and a tributary to the south in relation to the proposed re-planning of the District Centre within the Boulton Moor Phase 1 development, located in Derby.

The FEH Statistical method was used to generate flow estimates in the modelled catchment.

A 1D-2D hydraulic model of the Thulston Brook and its tributary was developed using the latest version of the Flood Modeller-TUFLOW modelling package. The 1D channel representation of the model was built with Flood Modeller, using channel survey data collected in June 2016. A composite of LIDAR data and topographic survey data was used to represent ground levels within the floodplain.

The model was run for the 20-year (5% AEP), 100-year (1% AEP), 100-year (1% AEP) with climate change and 1,000-year (0.1% AEP) fluvial flood event.

The model results indicate that the Thulston Brook and its tributary have sufficient capacity to accommodate the 1 in 100-year flows with climate change (modelled as a 30% increase in flow value) however; flooding will occur near the junction between the Thulston Brook and its tributary during the 1 in 1,000-year (0.1% AEP) flood event, with flood levels varying between 39.41m AOD and 39.73m AOD.

The results from the sensitivity analysis indicate that the model is sensitive to changes to flow values (as most of the modelled flows remain in-bank) and is moderately sensitive to changes in roughness value and downstream boundary conditions.

The results from the blockage risk analysis indicate that a 50% blockage at the A6 Road culvert will generate localised flooding at the junction between the Thulston Brook and its tributary, with peak water level of up to 39.72m AOD.

It is recommended that modelled water levels quoted in this report are considered by the Flood Risk Assessment when setting relevant flood mitigation measures (e.g. minimum Finished Floor Level).

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Abbreviations

1D	One Dimensional
2D	Two Dimensional
AEP	Annual Exceedance Probability
CC	Climate Change
DTM	Digital Terrain Model
FEH	Flood Estimation Handbook
FFL	Finished Floor Levels
Ha	Hectares
JBA	Jeremy Benn Associates
LIDAR	Light Detection and Ranging
m AOD	metres Above Ordnance Datum
ReFH	Revitalised Flood Hydrograph
TUFLOW	2D Hydraulic Modelling Software

1 Introduction

1.1 Terms of reference

Cannon Consulting Engineers commissioned JBA Consulting to undertake a hydraulic modelling study of the Thulston Brook related to the development site known as Boulton Moor Phase 1, located in Derby.

1.2 Background

The proposed development is for a re-planned District Centre on the permitted Boulton Moor Phase 1 site. The Thulston Brook flows in an easterly direction through the site. A detailed hydraulic modelling study of this watercourse was undertaken in 2014/2015 for the Boulton Moor Phase 1 land parcels to the south of Snelsmoor Lane (adjacent to the site's western boundary) however; the earlier model was insufficient to inform flood risk and flood mechanisms to this site.

1.3 General Approach

To understand flood risk and flood mechanisms that may affect the District Centre, a 1D-2D Flood Modeller-TUFLOW hydraulic model was produced to allow accurate representation of flood depths, velocities and hazard within the site boundary. Flow estimates used by the hydraulic model were derived following a hydrological analysis of the Thulston Brook catchment.

The hydraulic model's sensitivity to flow, downstream boundary and roughness values was tested in order to improve confidence in the model results within the development site boundary. Following this review, the model was used to simulate the effect of the 20-year, 100-year, 100-year with climate change and 1,000-year fluvial flood events.

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2 Approach

2.1 Model Geometry

2.1.1 Data availability

The Thulston Brook running through the proposed District Centre site has previously been partially modelled as part of the Boulton Moor residential development scheme. Unfortunately, the modelled geographical extent did not represent the land drain crossing the site and the development site was too close to the downstream model boundary. As a result, Grantham Coates Surveys (GCS) were commissioned to collect topographic survey of the channel in June 2016. The survey consisted of 17 cross sections at regular intervals along the Thulston and its tributary, and included key hydraulic structures (see Appendix B). Typically, cross section survey was gathered from the upstream face of any structure, however; on structures of considerable length (such as the A6 Road culvert) channel survey was also collected at the downstream face.

LIDAR data was obtained from the open Data Gov website to represent ground levels within the floodplain. The LIDAR data used has a grid resolution of 1m. To provide greater level of detail, site topographic survey provided by the client (see Appendix A) was also converted into a DTM and read into the model.

2.1.2 Input Data Quality Assessment

A QA check of the GCS channel survey data, compared to the topographic survey data provided by the client, was undertaken. Results highlighted a good correlation between both datasets.

Another QA check was also conducted between the topographic survey and the LIDAR data. The results highlighted a good correlation between both datasets with differences in elevation of less than 100mm within the majority of the development site.

The results from the QA check are provided in Appendix C.

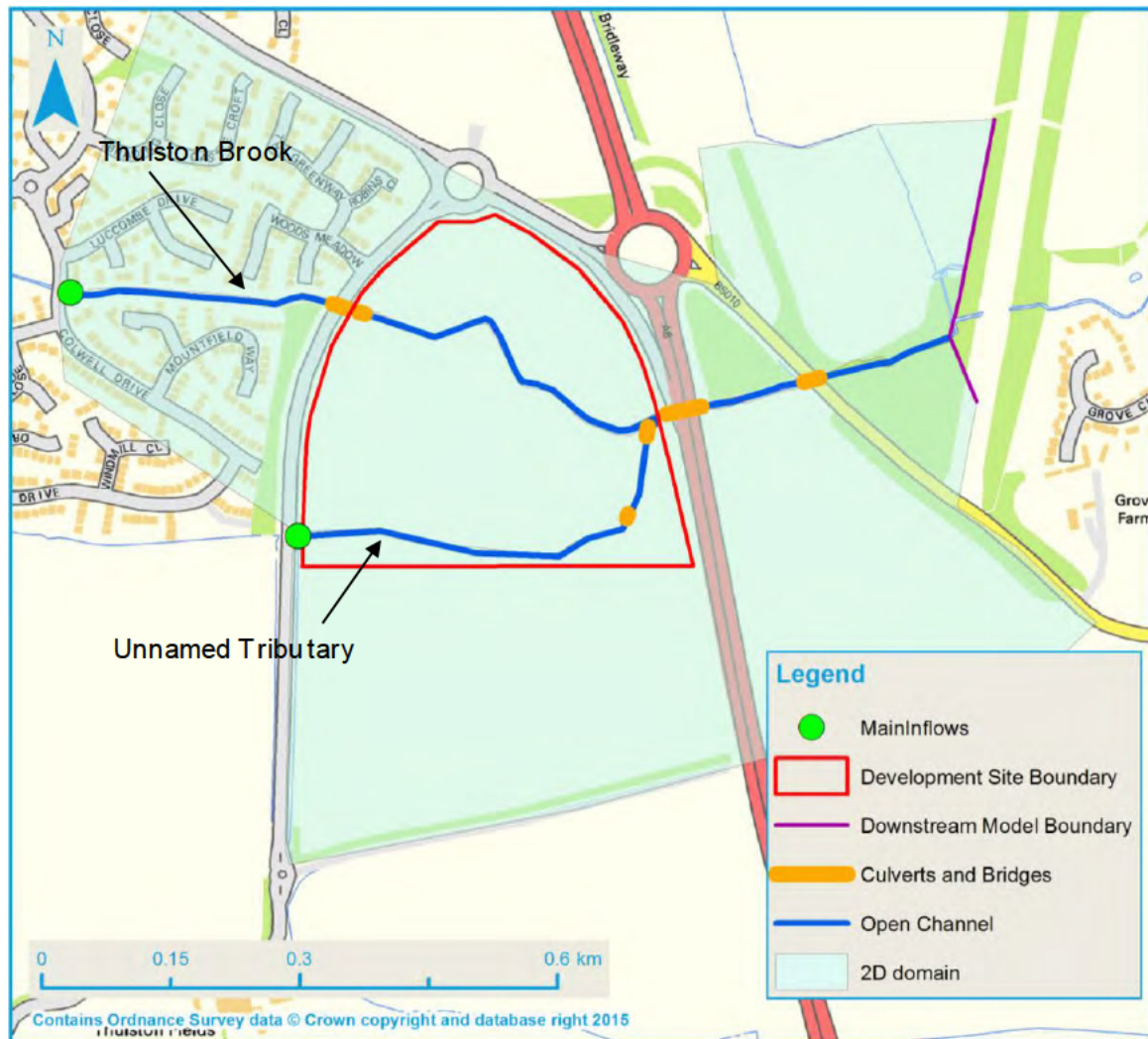
2.1.3 Model extent and build

The hydraulic model represents the Thulston Brook and its unnamed tributary (also locally known as the Southern Brook), as illustrated in Figure 2-1

The modelled reach representing the Thulston Brook extends from Colwell Drive (approximately 330m upstream of the site boundary) to 1550m downstream of the B5010 (approximately 330m downstream of the site boundary). The modelled reach representing the Thulston Brook's tributary extends from Snelsmoor Lane (south-west corner of the development site) to its confluence with its receiving watercourse, approximately 15m upstream of the A6 Road culvert. In total, the model represents approximately 1.6km of the Thulston Brook and its tributary.

The channel was represented in 1D using Flood Modeller (v4.1.5742.30303), constructed from channel topographic survey data collected in June 2016. The cross section and structure data from the channel survey was trimmed to the top of bank and linked to the 2D TUFLOW domain representing the floodplain. The TUFLOW 2D domain (modelled using the latest version of the software - 2016-03-AA-iSP-w64) has an area of 0.69km², with a 1m grid resolution. The orientation of the grid is north west to south east, representing the main direction of floodplain flows. The 1D and 2D domain can be seen in Figure 2-1.

Figure 2-1: Model extent



2.1.4 Model roughness parameters

Manning's 'n' was used to represent the channel and floodplain. The values for channel roughness were based on photographs gathered by JBA staff and by GCS during site visits. Manning's 'n' values in the floodplain were based on different land uses in the modelling extent. Land uses were defined using OS mapping and satellite imagery. Table 2-1 gives the range of Manning's 'n' values used in the 1D and 2D domains.

Table 2-1: Manning's 'n' range within the hydraulic model

Features	Channel (1D domain)
Watercourses	0.040 – 0.060
Ponds or Lakes	0.025
Roads or Tracks	0.015
Rail Track/Land	0.025
Buildings	0.300
Urban areas (exc above)	0.100
Semi-natural areas	0.070

2.1.5 Model structures

Key hydraulic structures located along the modelled watercourses were represented in the 1D domain using Flood Modeller units. Details of how these structures were modelled can be found in Appendix D.

2.2 Model Boundary Conditions

2.2.1 Model inflows

A hydrological assessment was carried out on the Thulston Brook catchment. Flow-time hydrographs for the 20-year (5% AEP), 100-year (1% AEP), 100-year with climate change, and 1,000-year (0.1% AEP) flood events were estimated using the FEH Statistical method. The hydrological assessment is documented in Appendix E.

2.2.2 Climate Change

In line with the new Guidance on Climate Change issued by the Environment Agency in February 2016¹, the effect of climate change was assessed by increasing peak flows by 30% (Humber river basin district, higher central allowance category for the 2080's).

2.2.3 Downstream boundary conditions

The downstream boundary condition in the 1D domain was set as a 'normal depth' Flood Modeller unit with a 1 in 1,332 slope; this correspond to the slope of the channel immediately downstream of the B5010 Road.

In the 2D domain, a HQ 'normal depth' boundary condition was used with a 1 in 281 slope across the Left Hand Bank (LHB) floodplain and 1 in 201 slope across the Right Hand Bank (RHB) floodplain. These slopes were derived from LIDAR data.

2.2.4 Initial Conditions

To improve the overall model stability, initial water levels were set in the model using the water levels observed by GCS during their survey in June 2016.

2.3 Calibration

No detailed historical flood records specific to the modelled reaches were received from Derby City Council or the Environment Agency.

Broad-scale historic and recorded flood outlines were initially obtained from the government dataset website² for comparison purpose but were later discarded from this modelling study as a) these outlines do not account for the last 40-50 year of urbanisation in the area and b) do not account for channel restoration work which took place in the early 1990's.

As a result, the Thulston Brook hydraulic model is uncalibrated.

2.4 Model Runs

2.4.1 Modelled Scenarios

The following flood scenarios were simulated using the Thulston Brook hydraulic model:

- [Base-line scenario] 20-year (5% AEP) flood event - existing condition scenario
- [Base-line scenario] 100-year (1% AEP) flood event - existing condition scenario
- [Base-line scenario] 100-year (1% AEP) plus Climate Change - existing condition scenario
- [Base-line scenario] 1000-year (0.1% AEP) flood event - existing condition scenario
- [Sensitivity analysis] 100-year (1% AEP) flood event with +20% increase in roughness value
- [Sensitivity analysis] 100-year (1% AEP) flood event with +20% increase in peak flows
- [Sensitivity analysis] 100-year (1% AEP) flood event with +250mm increase in peak water level at the downstream model boundary
- [Blockage risk analysis] 100-year (1% AEP) plus Climate Change flood event with a 50% blockage at the A6 Road culvert.

¹ <https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances>

² <https://data.gov.uk/dataset/recorded-flood-outlines1>

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3 Hydraulic Model Results

3.1 Existing condition / baseline scenarios

The modelled flood extent associated with the 1,000-year fluvial flood event from the Thulston Brook is represented in Figure 3-1.

Figure 3-1: Existing condition scenario - Flood Extent (1,000-year)

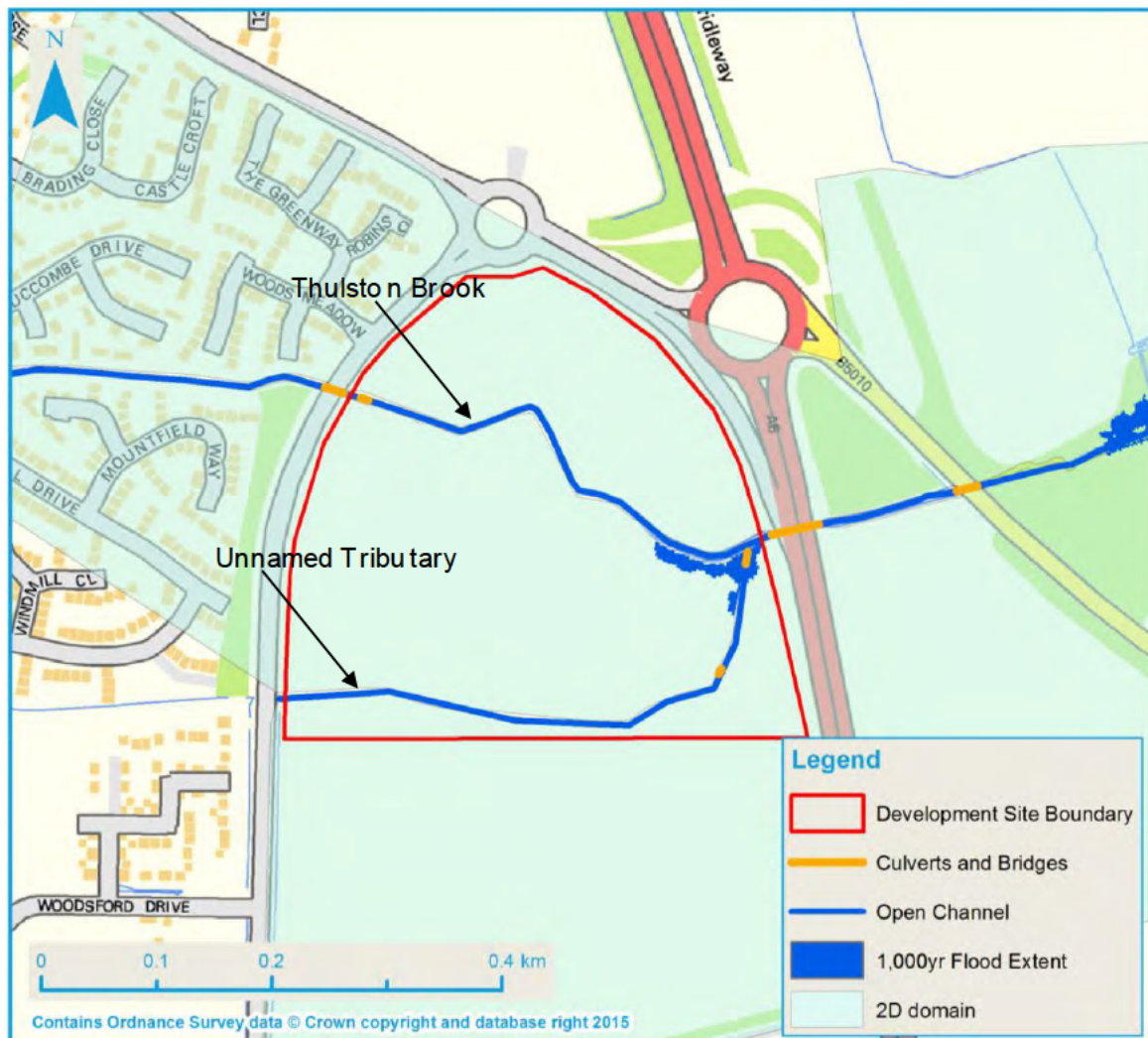


Figure 3-1 indicates that flooding would occur near the junction between the Thulston Brook and its tributary during the 1,000-year (0.1% AEP) existing condition scenario. Detailed model results indicate that the 1,000-year (0.1% AEP) flood levels at the junction vary between 39.41m AOD and 39.73m AOD.

River flows are shown to remain in-bank for the lower return period flood events (i.e. flood events up to and including the 100-year (1% AEP) with climate change event).

Peak water levels for each of the modelled baseline flood scenarios are summaries in Figure 3-2 and Table 3-1.

Figure 3-2: Node Locations

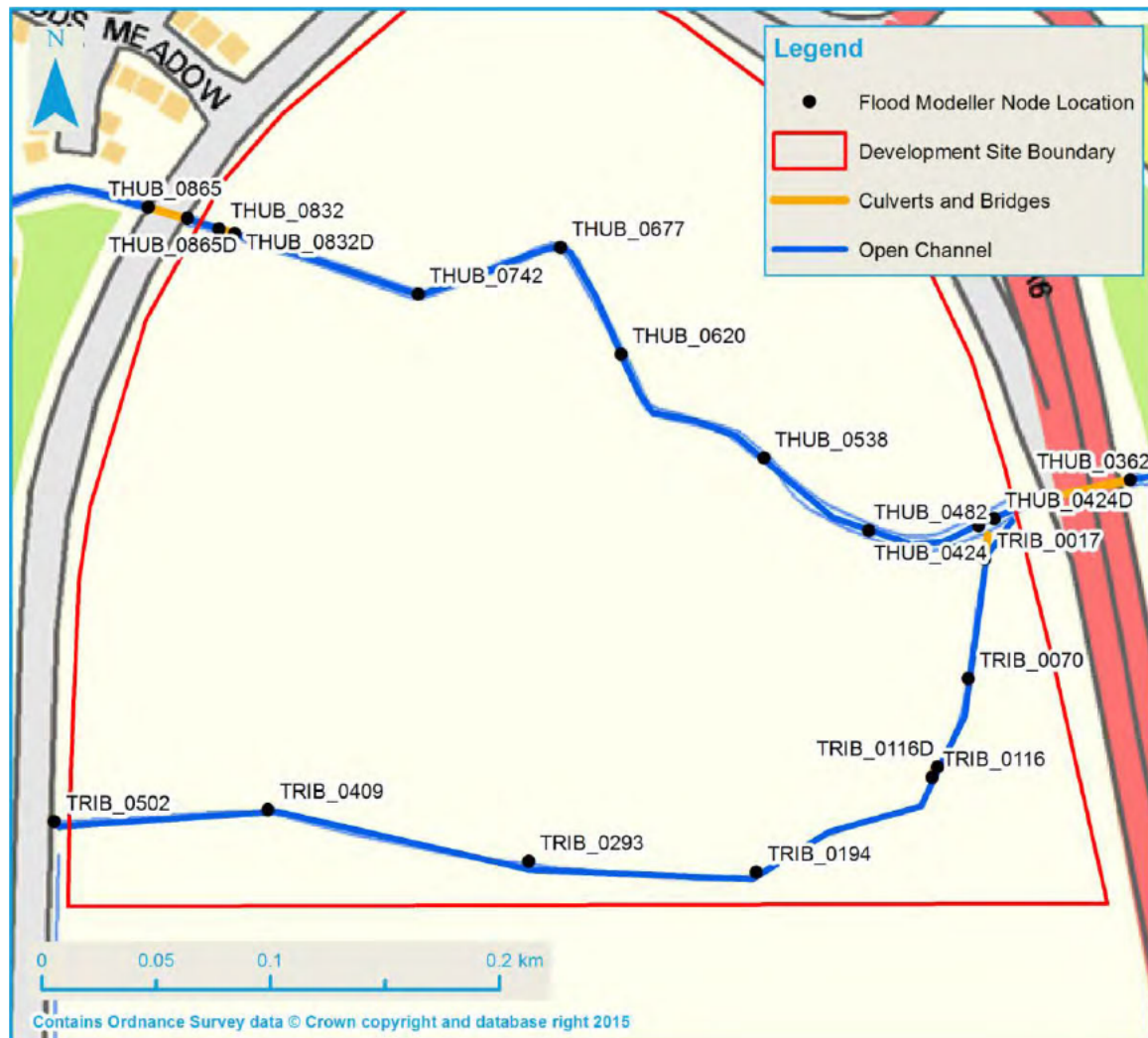


Table 3-1: Selected peak water levels - Existing condition scenario

FLOOD MODELLER cross section	Peak water level (m AOD)			
	20-year (5% AEP)	100-year (1% AEP)	100-year + CC (1% AEP + CC)	1,000- year (0.1% AEP)
THUB_0885D (Snelsmoor Lane Culvert Outlet)	39.64	39.79	39.92	40.07
THUB_0832	39.62	39.77	39.89	40.04
THUB_0742	39.53	39.67	39.78	39.91
THUB_0677	39.45	39.58	39.69	39.81
THUB_0620	39.33	39.45	39.55	39.68
THUB_0538	39.18	39.30	39.40	39.53
THUB_0482	39.13	39.25	39.34	39.47
THUB_0424 (Junction with tributary)	39.10	39.22	39.31	39.44
THUB_0405 (A6 Culvert Inlet)	39.08	39.20	39.29	39.40
TRIB_0502 (Snelsmoor Lane Culvert Outlet)	40.58	40.58	40.58	40.61
TRIB_0409	40.29	40.29	40.30	40.34
TRIB_0293	39.98	40.02	40.08	40.16
TRIB_0194	39.75	39.56	39.97	40.05
TRIB_0116	39.62	39.77	39.91	39.99
TRIB_0070	39.37	39.52	39.67	39.78

3.2 Model sensitivity

Model sensitivity was tested for increases in flow, roughness and changes to the downstream boundary. The analysis of the model sensitivity runs is included in Appendix G.

The outcome of the sensitivity analysis indicates that the Thulston Brook model results are sensitive to changes in flow values and moderately sensitive to changes in roughness and downstream boundary conditions. The sensitivity to changes in flow value is expected as the 100-year flows remain in-bank during the whole simulation.

3.3 Blockage Risk Analysis.

The effect of a 50% blockage to the 2m high x 4m wide (approximate dimension) A6 Road culvert was simulated. The 2D model results are represented in Figure 3-3.

Figure 3-3: 50% Blockage Scenario - 100-year with climate change Flood Levels

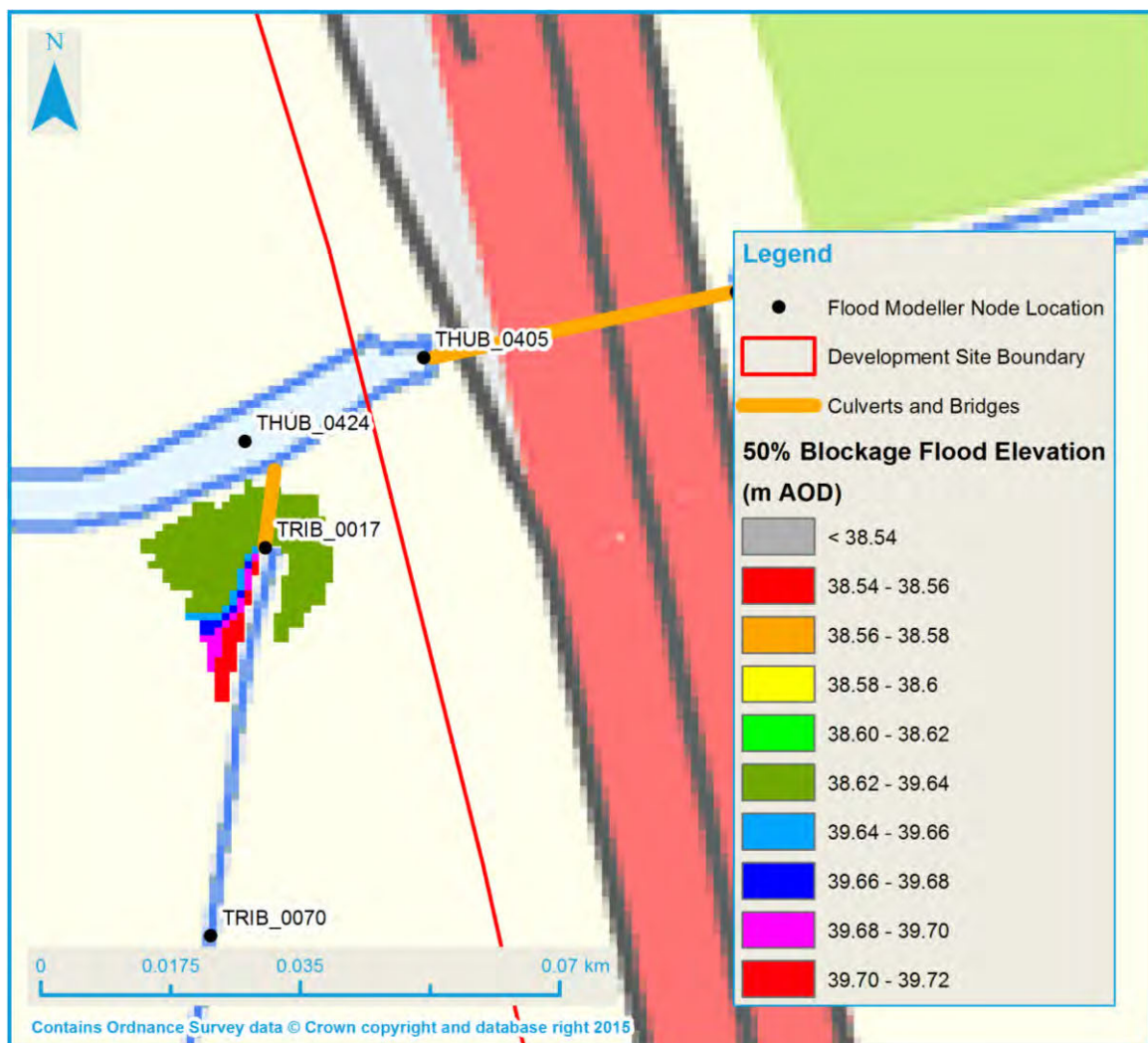


Figure 3-3 indicates that, during the 100-year with climate change flood scenario, a 50% blockage at the A6 Road culvert will generate localised flooding at the junction between the Thulston Brook and its tributary. The maximum water level recorded at this location is 39.72m AOD.

No flooding will occur within the remainder of the site.

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4 Conclusions and Recommendations

4.1 Conclusion

JBA carried out a hydrological assessment and a flood mapping study of the Thulston Brook and a tributary to the south in relation to the proposed re-planning of the District Centre within the Boulton Moor Phase 1 development, located in Derby.

The model results indicate that the Thulston Brook and its tributary have sufficient capacity to accommodate the 1 in 100-year flows with climate change (modelled as a 30% increase in flow value) however; flooding will occur near the junction between the Thulston Brook and its tributary during the 1 in 1,000-year (0.1%AEP) flood event, with flood levels varying between 39.41m AOD and 39.73m AOD.

The results from the sensitivity analysis indicate that the model is sensitive to changes to flow values (as most of the modelled flows remain in-bank) and is moderately sensitive to changes in roughness value and downstream boundary conditions.

The results from the blockage risk analysis indicate that a 50% blockage at the A6 Road culvert will generate localised flooding at the junction between the Thulston Brook and its tributary, with a peak water level of up to 39.72m AOD.

4.2 Recommendations

It is recommended that the modelled water levels quoted in this report are considered in the Flood Risk Assessment when setting relevant flood mitigation measures (e.g. minimum Finished Floor Level).

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Appendices

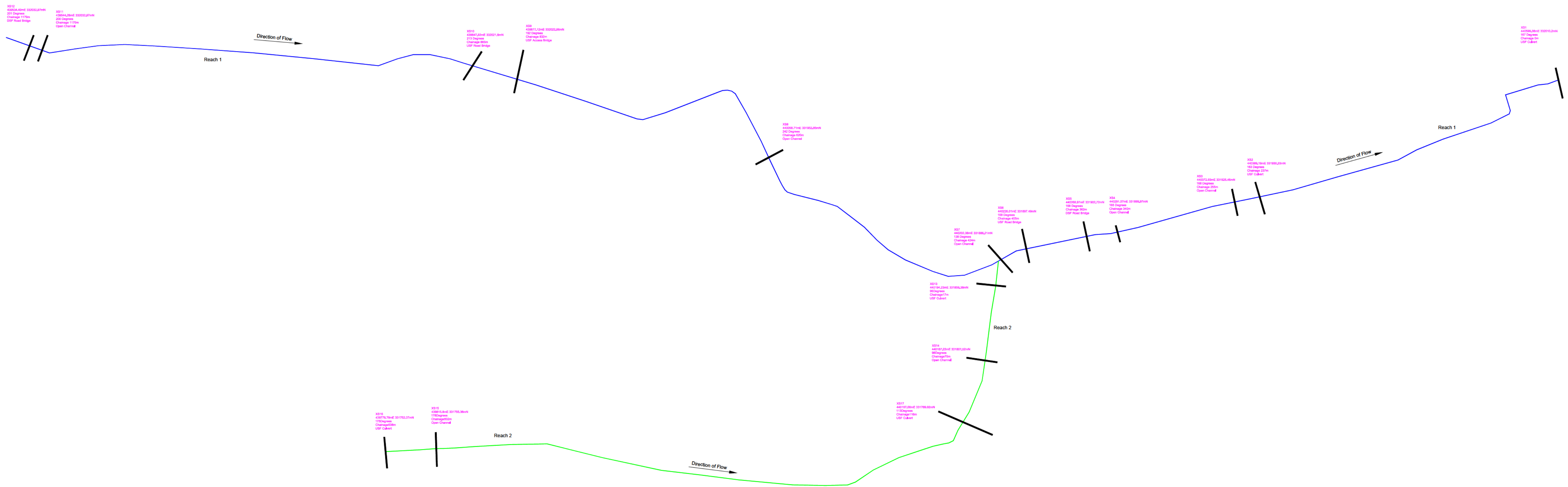
A Appendix A - Topographic survey

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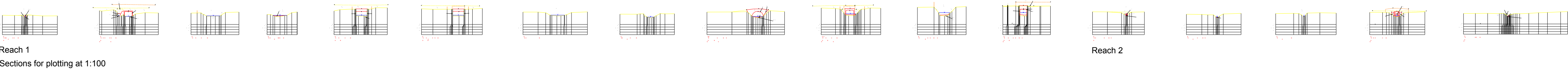


B Appendix B - Channel survey

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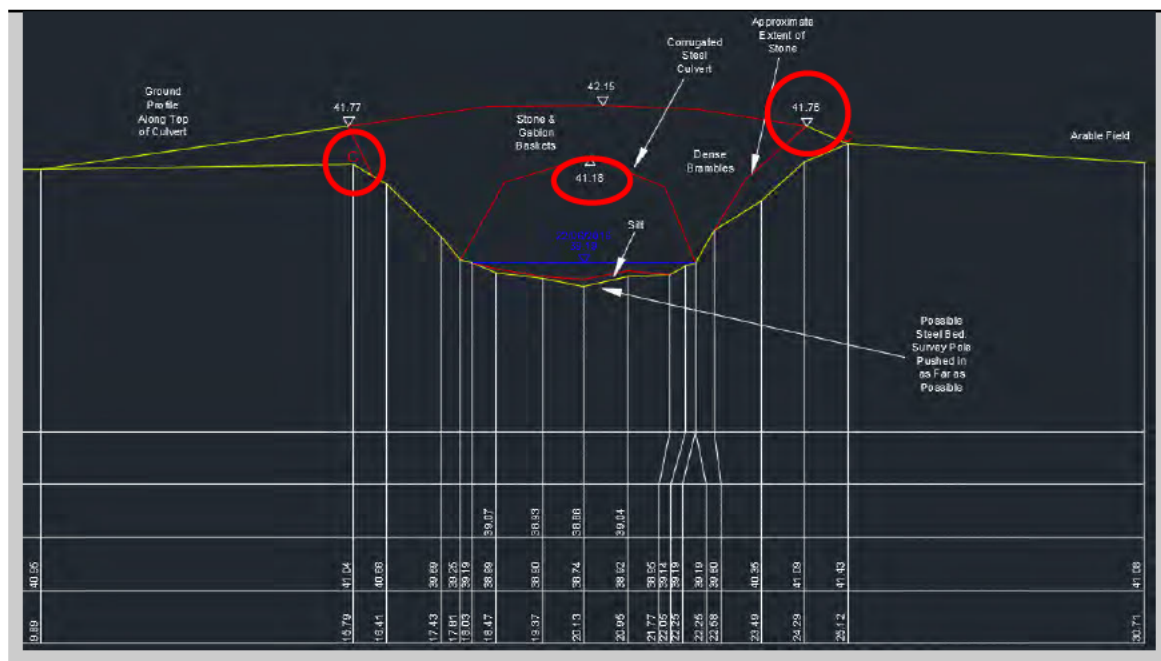
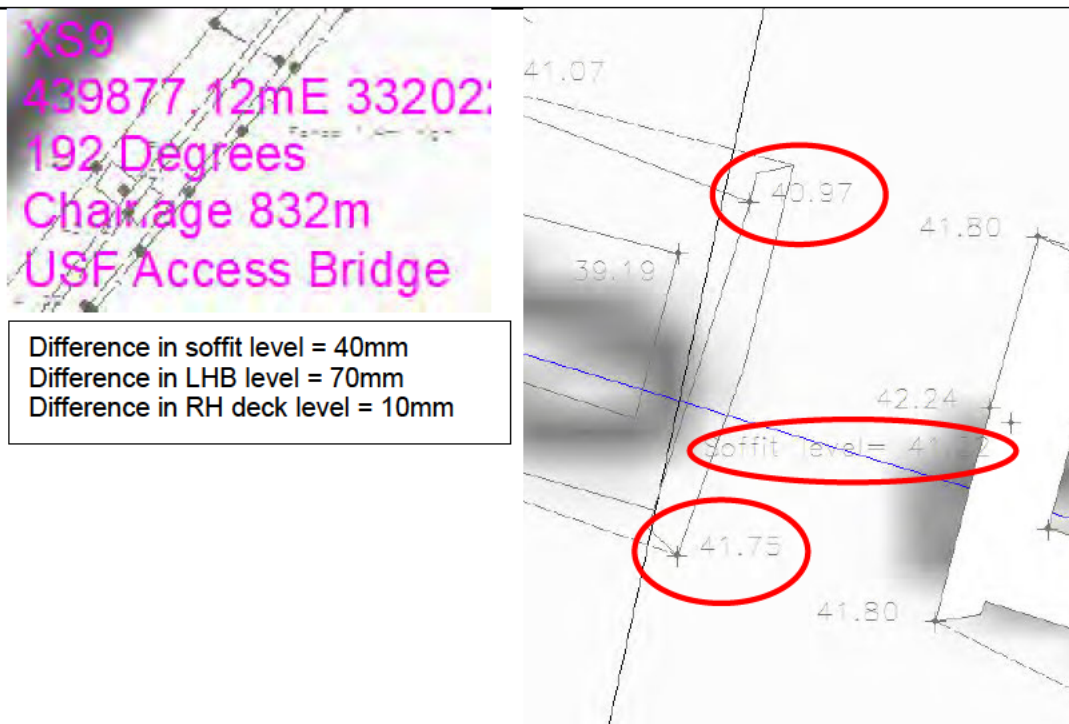


Grid and Datum			
Based upon - Grid Datum: National Grid, Level Datum: Ordnance Datum			
All levels refer to Permanent Ordnance Survey GPS Stations and related to Ordnance Datum Newlyn via the geoid model OSGM02.			
No scale factor has been applied to this survey		Surveyed June 2016	
Title: Cross Section Survey Wilne Drain (Cross Sections & Location Plan)			
Client: JBA CONSULTING The Library St Philips Courtyard Church Hill COLESHILL Warwickshire B46 3AD			
Grantham Coates Surveys Ltd. Land - Engineering - Building Surveyors Minerva Mill, Station Road, Alcester, Warwickshire, B49 5ET Tel: 01789 761386 - Fax: 01789 400447 E-Mail: info@gcsurveys.co.uk Web Site: www.gcsurveys.co.uk			
Drawing No: GCS/JBA/100516/1		Rev:	
Date:	Notes:	Name:	Rev:
Drawn: MC	Checked: JMG	Scale: 1:1	Date: 23/06/16
File Name: GCS-JBA-100516-1.DWG		Sheet size: NA	Sheet: 1 of 1



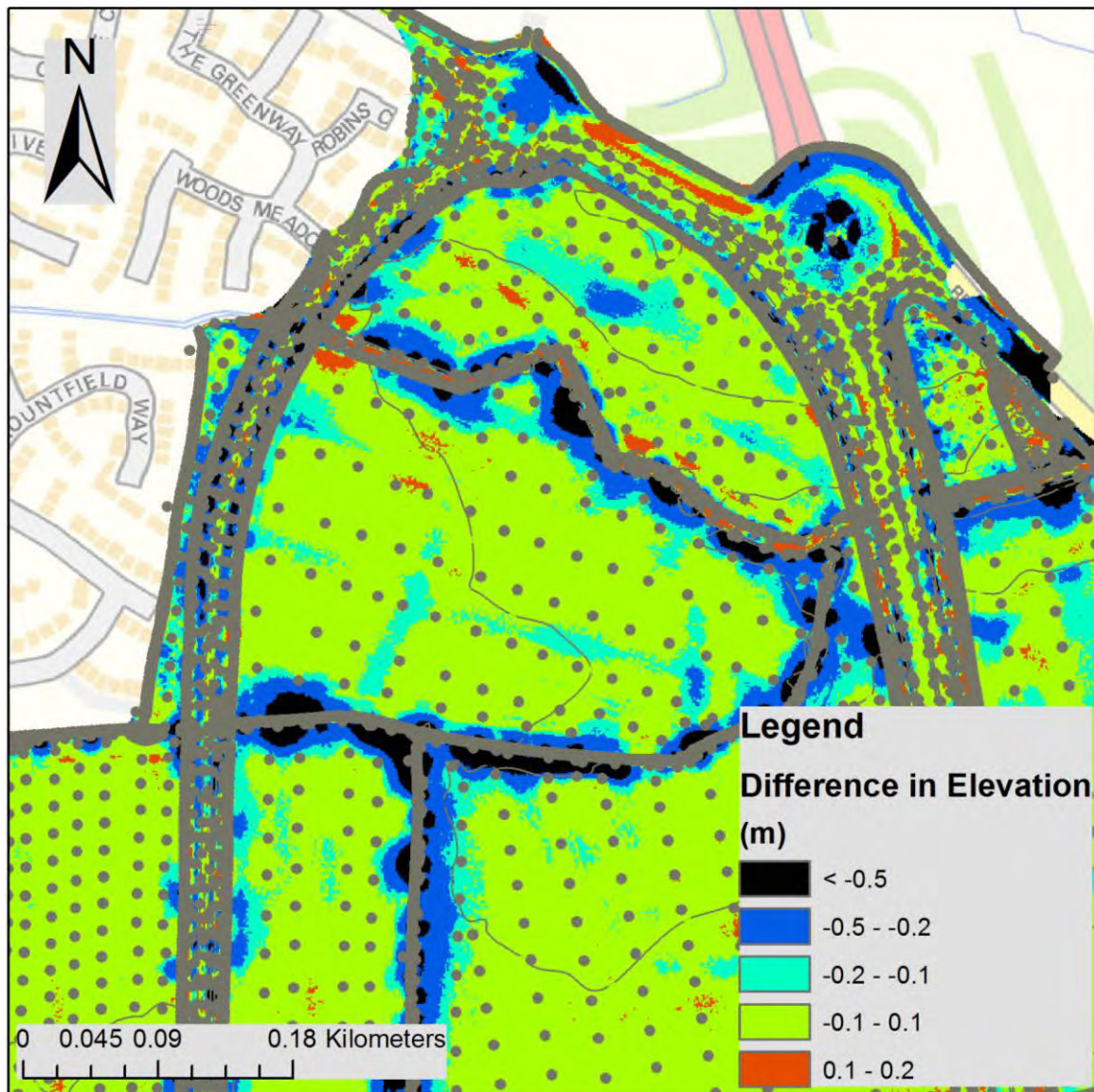
C Appendix C - Input Data Quality Assessment

C.1 Channel survey data versus topographic survey data



C.2 LIDAR data versus topographic survey data

Figure C-1: Difference in Elevation (Topographic survey data VS. LIDAR)

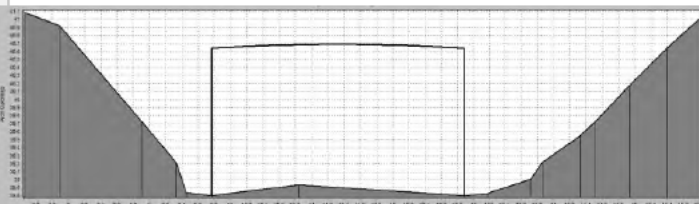


D Appendix D - Key Hydraulic Structures

D.1 Colwell Drive Road Bridge

Included in model? (state reason if not):	No (upstream end of 1D model)
Model label:	THUB_1179

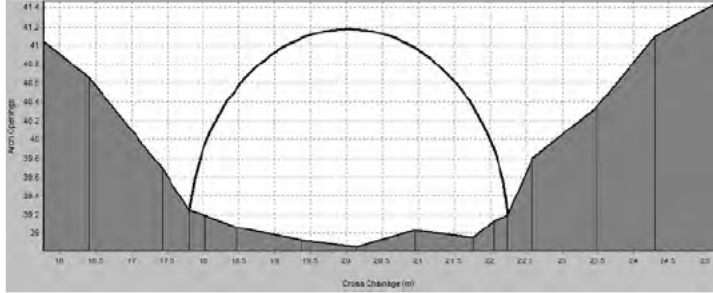
D.2 Snelssmoor Lane culvert (Thulston Brook)

Included in model? (state reason if not):	Yes								
Model label:	THUB 0865BR and THUB 0865BRD								
Type:	Rectangular concrete culvert with bevel								
How has structure been modelled?	USBPR Bridge Unit Bevel represented by setting springing level 50mm than soffit level								
Openings:	<table><tr><th>Start (m)</th><th>Finish (m)</th><th>Springing Level (m AD)</th><th>Soffit Level (m AD)</th></tr><tr><td>9.766</td><td>12.881</td><td>40.640</td><td>40.690</td></tr></table> 	Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)	9.766	12.881	40.640	40.690
Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)						
9.766	12.881	40.640	40.690						

Upstream face, looking downstream



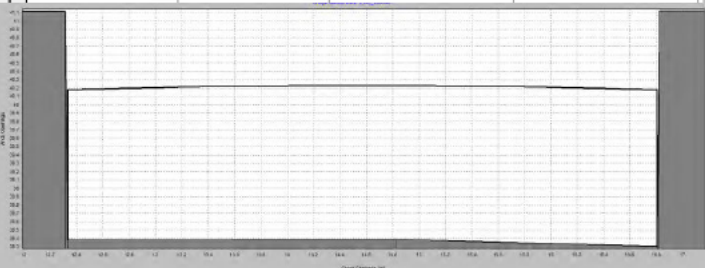
D.3 Access Bridge immediately downstream of Snelssmoor Lane culvert (Thulston Brook)

Included in model? (state reason if not):	Yes								
Model label:	THUB_0832BR and THUB_0832BRD								
Type:	Arch Bridge (galvanised culvert)								
How has structure been modelled?	USBPR Bridge Unit Openings: <table><tr><th>Start (m)</th><th>Finish (m)</th><th>Springing Level (m AD)</th><th>Soffit Level (m AD)</th></tr><tr><td>17.806</td><td>22.246</td><td>39.250</td><td>41.180</td></tr></table> 	Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)	17.806	22.246	39.250	41.180
Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)						
17.806	22.246	39.250	41.180						

Upstream face, looking downstream



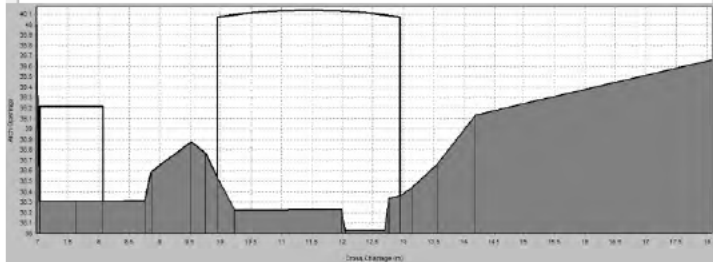
D.4 A6 Road culvert

Included in model? (state reason if not):	Yes								
Model label:	THUB 0405BR and THUB 0405BRD								
Type:	Concrete rectangular culvert								
How has structure been modelled?	USBPR Bridge Unit Bevel represented by setting springing level 50mm than soffit level								
Openings:	<table><tr><th>Start (m)</th><th>Finish (m)</th><th>Springing Level (m AD)</th><th>Soffit Level (m AD)</th></tr><tr><td>12.334</td><td>16.805</td><td>40.180</td><td>40.230</td></tr></table> 	Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)	12.334	16.805	40.180	40.230
Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)						
12.334	16.805	40.180	40.230						

Upstream face, looking downstream



D.5 B5010 Road culvert

Included in model? (state reason if not):	Yes												
Model label:	THUB 0237BR and THUB 0237BRD												
Type:	Concrete rectangular culvert												
How has structure been modelled?	USBPR Bridge Unit												
Openings:													
<table><tr><th>Start (m)</th><th>Finish (m)</th><th>Springing Level (m AD)</th><th>Soffit Level (m AD)</th></tr><tr><td>7.024</td><td>8.073</td><td>39.220</td><td>39.220</td></tr><tr><td>9.95</td><td>12.949</td><td>40.070</td><td>40.140</td></tr></table>		Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)	7.024	8.073	39.220	39.220	9.95	12.949	40.070	40.140
Start (m)	Finish (m)	Springing Level (m AD)	Soffit Level (m AD)										
7.024	8.073	39.220	39.220										
9.95	12.949	40.070	40.140										
													

Upstream face, looking downstream



D.6 Snelssmoor Lane culvert (Tributary)

Included in model? (state reason if not):	No (upstream end of 1D model)
Model label:	TRIB 0502

D.7 Access Bridge 1 (Tributary)

Included in model? (state reason if not):	Yes																																				
Model label:	TRIB_0116Ci, TRIB_0116C, TRIB_0116CD and TRIB_0116CDo																																				
Type:	Circular steel culvert																																				
How has structure been modelled?	Circular culvert unit <table border="1"> <tr> <td></td> <td>TRIB_0116</td> <td>RIVER</td> <td>SECTION</td> </tr> <tr> <td></td> <td>TRIB_0116</td> <td>JUNCTION</td> <td>OPEN</td> </tr> <tr> <td></td> <td>TRIB_0116Ci</td> <td>CULVERT</td> <td>INLET</td> </tr> <tr> <td></td> <td>TRIB_0116C</td> <td>CONDUIT</td> <td>CIRCULAR</td> </tr> <tr> <td></td> <td>TRIB_0116CD</td> <td>CONDUIT</td> <td>CIRCULAR</td> </tr> <tr> <td></td> <td>TRIB_0116CD</td> <td>CULVERT</td> <td>OUTLET</td> </tr> <tr> <td></td> <td>TRIB_0116SP</td> <td>SPILL</td> <td></td> </tr> <tr> <td></td> <td>TRIB_0116CDo</td> <td>JUNCTION</td> <td>OPEN</td> </tr> <tr> <td></td> <td>TRIB_0116D</td> <td>RIVER</td> <td>SECTION</td> </tr> </table> General Trash Screen Inlet Control Data Conduit Type Code: TYPE A K: 0.0078 M: 2 C: 0.0379 Y: 0.69 Ki: 0.5 Headloss Type: STATIC Reverse Flow Mode: CALCULATED Steel circular culvert Geometry Distance to Next Conduit: 4.200 Elevation Of Invert: 38.780 Diameter: 0.550 Friction Equation: MANNING Value Below Axis: 0.01500 Value Above Axis: 0.01500		TRIB_0116	RIVER	SECTION		TRIB_0116	JUNCTION	OPEN		TRIB_0116Ci	CULVERT	INLET		TRIB_0116C	CONDUIT	CIRCULAR		TRIB_0116CD	CONDUIT	CIRCULAR		TRIB_0116CD	CULVERT	OUTLET		TRIB_0116SP	SPILL			TRIB_0116CDo	JUNCTION	OPEN		TRIB_0116D	RIVER	SECTION
	TRIB_0116	RIVER	SECTION																																		
	TRIB_0116	JUNCTION	OPEN																																		
	TRIB_0116Ci	CULVERT	INLET																																		
	TRIB_0116C	CONDUIT	CIRCULAR																																		
	TRIB_0116CD	CONDUIT	CIRCULAR																																		
	TRIB_0116CD	CULVERT	OUTLET																																		
	TRIB_0116SP	SPILL																																			
	TRIB_0116CDo	JUNCTION	OPEN																																		
	TRIB_0116D	RIVER	SECTION																																		

Upstream face, looking downstream



D.8 Access Bridge 2 (Tributary, near junction with Thulston Brook)

Included in model? (state reason if not):	Yes																																
Model label:	TRIB_0017Ci, TRIB_0017C, TRIB_0017CD and TRIB_0017CDo																																
Type:	Circular concrete culvert																																
How has structure been modelled?	Circular culvert unit <table border="1"> <tr> <td></td> <td>TRIB_0017</td> <td>RIVER</td> <td>SECTION</td> <td></td> </tr> <tr> <td></td> <td>TRIB_0017</td> <td>JUNCTION</td> <td>OPEN</td> <td>-</td> </tr> <tr> <td></td> <td>TRIB_0017Ci</td> <td>CULVERT</td> <td>INLET</td> <td>-</td> </tr> <tr> <td></td> <td>TRIB_0017C</td> <td>CONDUIT</td> <td>CIRCULAR</td> <td></td> </tr> <tr> <td></td> <td>TRIB_0000C</td> <td>CONDUIT</td> <td>CIRCULAR</td> <td></td> </tr> <tr> <td></td> <td>TRIB_0000C</td> <td>CULVERT</td> <td>OUTLET</td> <td>-</td> </tr> </table>				TRIB_0017	RIVER	SECTION			TRIB_0017	JUNCTION	OPEN	-		TRIB_0017Ci	CULVERT	INLET	-		TRIB_0017C	CONDUIT	CIRCULAR			TRIB_0000C	CONDUIT	CIRCULAR			TRIB_0000C	CULVERT	OUTLET	-
	TRIB_0017	RIVER	SECTION																														
	TRIB_0017	JUNCTION	OPEN	-																													
	TRIB_0017Ci	CULVERT	INLET	-																													
	TRIB_0017C	CONDUIT	CIRCULAR																														
	TRIB_0000C	CONDUIT	CIRCULAR																														
	TRIB_0000C	CULVERT	OUTLET	-																													
General Trash Screen Inlet Control Data Conduit Type Code: TYPE A K: 0.0098 M: 2 C: 0.0398 Y: 0.67 Ki: 0.5 Headloss Type: STATIC Reverse Flow Mode: CALCULATED Geometry Distance to Next Conduit: 17.198 Elevation Of Invert: 38.600 Diameter: 0.600 Friction Equation: MANNING Value Below Axis: 0.02000 Value Above Axis: 0.02000																																	

Upstream face, looking downstream



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E Appendix E - Hydrological Assessment

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Flood estimation report

Introduction

This report template is based on a supporting document to the Environment Agency's flood estimation guidelines (Version 5, 2015). It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

1	Method statement	1
2	Locations where flood estimates required	5
3	Statistical method	7
4	Revitalised flood hydrograph (ReFH) method	9
6	Discussion and summary of results	10
7	Annex	13

Approval

	Name and qualifications	Date
Calculations prepared by:	Joanne Chillingworth BSc MSc MCIWEM C.WEM	07.07.16
Calculations reviewed by:	Vicky Shackle BSc PhD MCIWEM C.WEM	11.07.16

Abbreviations

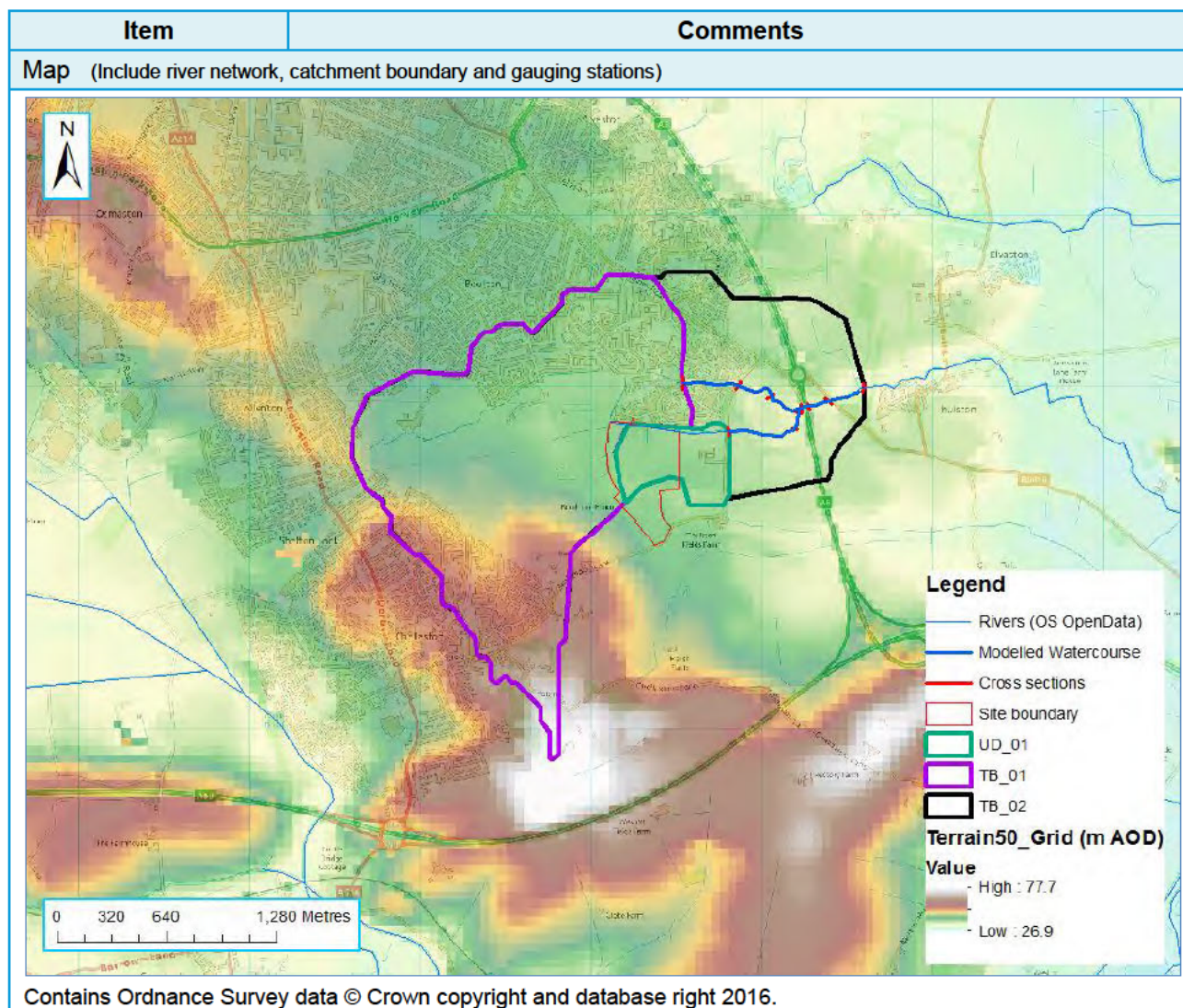
AM.....	Annual Maximum
AREA	Catchment area (km ²)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE.....	Council for the Protection of Rural England
FARL.....	FEH index of flood attenuation due to reservoirs and lakes
FEH.....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

1 Method statement

1.1 Requirements for flood estimates

Item	Comments
Overview - Purpose of study - Peak flows or hydrographs? - Range of return periods and locations	Proposals for the Boulton Moor District Centre, situated along the Thulston Brook, immediately upstream of the A6 Road Bridge. The previous hydraulic modelling study undertaken by JBA in this area did not justify representing hydraulic structures along the Brook, at the location of the site. The Brook was represented as part of the TUFLOW 2D model and was subject to a grid cell size of 2x2m. Given the location of the proposed development in relation to the Thulston Brook, the representation of the Brook will be enhanced using 1D modelling techniques and blockage scenarios to inform the setting of a minimum Finished Floor Level for the proposed building. The modelled return period flood events will be the 20-year, 100-year, 100-year plus climate change (in line with February 2016 guidance), and the 1,000-year. <i>For climate change, the relevant factor will be applied to the 100-year flow estimates in the hydraulic modelling phase.</i>

1.2 The catchment



Description Include topography, climate, geology, soils, land use and any unusual features that may affect the flood hydrology.	The site is currently designated as Greenfield and is occupied by agricultural land. The area of the site is approximately 21ha. The site is bounded to the south by Snelsmoor Lane and to the north by the residential properties on Mill Hill and Sevenlands Drive. The western and eastern boundaries of the site are existing agricultural field boundaries. The site generally slopes in a north easterly direction. The southernmost part of the site slopes in a south easterly direction. Drainage is currently provided by a network of field drains draining towards larger field drains at the site's northern and southern boundaries. The southernmost part of the site drains into the surface water sewer crossing Snelsmoor Lane and discharging into an open watercourse near the Thulston Fields Farm. This watercourse later joins the River Derwent at Church Wilne, approximately 5km east of the site. The catchment is bound by high ground to the north (Boulton), south (Chellaston) and west (Allenton), with water running off Boulton Moor towards the watercourses/ drainage networks. The urban extent follows this high ground, with rural land in the middle of the catchment. The Thulston Brook is joined by an unnamed tributary just upstream of the A6 road, on it's right bank. The model will end just downstream of this road, immediately upstream of Thulston. The site is partially located within the Environment Agency's Flood Zones 3 and 2. Flood Zone 2, at this location, originates from historical flood records. Flood Zone 3, at this location, is derived from broadscale modelling results which does not represent hydraulic structures (e.g. bridges) with a high level of accuracy.
---	---

1.3 Source of flood peak data

Source Record any changes made	Yes – Version 3.3.4, August 2014 (National River Flow Archive (NRFA) peak flow dataset)
--	---

1.4 Gauging stations (flow or level)

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

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km ²)	Type (rated / ultrasonic / level...)	Start of flow record and end if station closed
Catchment is ungauged.						

1.5 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Check flow gaugings (if planned to review ratings)	N			There are no gauges within the study catchment and no rating review was required as part of this study.
Historic flood data Include chronology and interpretation of flood history in Annex or separate report.	Y			Past flood modelling study at Boulton Moor, 2014. Modelling results will be compared.
Flow data for events	Y			There are no gauges within the study area, and no other gauges were considered suitable for QMED adjustment.
Rainfall data for events	N	N		
Potential evaporation data	N	N		
Results from previous studies	Y	N		
Other data or information (e.g. groundwater, tides)	Y (sewer data)	N		

1.6 Hydrological understanding of catchment

All catchments	
Outline the conceptual model, addressing questions such as: - Where are the main sites of interest? - What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...) - Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? - Is there a need to consider temporary debris dams that could collapse?	The main site of interest is the proposed Boulton Moor District Centre. The catchment areas are quite small, so runoff will be likely rapid from the Boulton Moor high ground surrounding the catchment, into the drainage networks.
Any unusual catchment features to take into account? e.g. - highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% - highly urbanised – seek local flow data; 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	No. The catchment is not permeable and FARL is not unusual.

1.7 Initial choice of approach

Is FEH appropriate? (it may not be for extremely heavily urbanised or complex catchments) If not, describe other methods to be used.	Yes.
Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	FEH Statistical and ReFH methods will be tested and compared. The catchments are small; UD_01 is an unnamed drain and a very small rural catchment, whereas TB_01 is just within the heavily urbanised category (URBEXT 1990 = 0.130), with TB_02 moderately urbanised (URBEXT 1990 = 0.119). The flow estimates at the top of each modelled extent will be input into the model as inflows. The lumped downstream estimate is for guidance purposes in the model, and instead a lateral catchment will be inserted into the model between the top inflows and this downstream extent. The model will use ReFH boundaries to obtain hydrographs.
Software to be used (with version numbers)	FEH CD-ROM v3.0 ¹ WINFAP-FEH v3.0.003 ² / ReFH spreadsheet

¹ FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

² WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.

2 Locations where flood estimates required

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

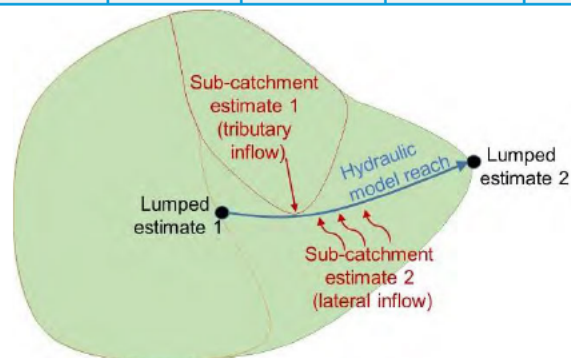
2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km ²)	Revised AREA if altered
TB_01	L	Thulston Brook	Upstream modelled extent of Thulston Brook	439950	332000	2.55	2.62
UD_01	L	Unnamed Drain	Upstream modelled extent of Unnamed Drain	440050	331650	0.51	0.25
TB_02	L	Thulston Brook	Downstream modelled extent of Thulston Brook Lumped estimate for information. The model will use the lateral catchment described below.	440350	331950	3.97	3.90
TB_LAT	S	Thulston Brook	Lateral inflow will be inserted in the model between TB_02 and TB_01 inflows and UD_01 downstream.	440350	331950	1.03	-

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.

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

The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.

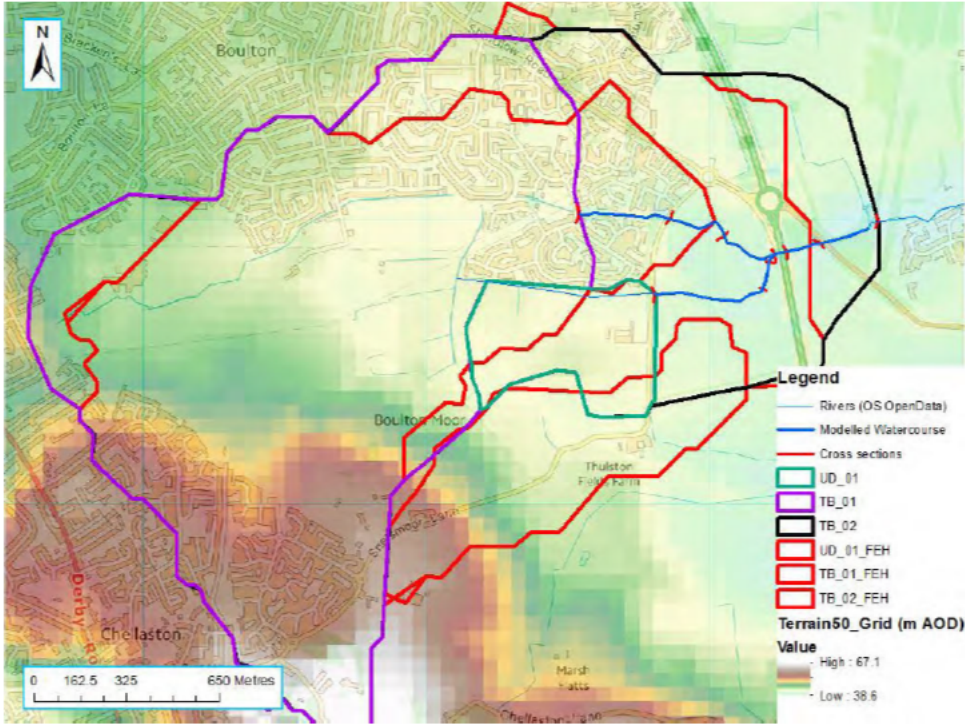


2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Red denotes catchment descriptors which have been amended due to boundary changes; AREA and DPLBAR. No changes were required for FARL and none were deemed required for URBEXT (equal areas of rural and urban removed/ added).

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000	FPEXT
TB_01	1.000	0.35	0.506	1.70	8.9	642	0.130	0.226	0.3186
UD_01	1.000	0.35	0.578	0.47	10.7	640	0.000	0.003	0.1379
TB_02	1.000	0.35	0.568	2.11	8.5	641	0.119	0.189	0.3099

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (add maps if needed)	Catchment boundaries extracted from the FEH CD-ROM were manually edited where incorrect against LIDAR (e.g. to account correctly for drainage channels). Also, a drain north-west of Thulston Farm is known to drain to the watercourses to the south, so this area north of the Snellsmoor Lane was removed. AREA and DPLBAR were subsequently amended in the catchment descriptors, but FARL and URBEXT were unchanged.  Contains Ordnance Survey data © Crown copyright and database right 2016.
Record how other catchment descriptors were checked and describe any changes. Include before/after table if necessary.	Qualitative check on FARL using mapping. BFIHOST checks using BGS soil maps.
Source of URBEXT	URBEXT₁₉₉₀ (used for ReFH1 method) URBEXT₂₀₀₀ (used for FEH Statistical method)
Method for updating of URBEXT	CPRE formula from FEH Volume 4 CPRE formula from 2006 CEH report on URBEXT₂₀₀₀

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: - Number of potential donor sites available - Distances from subject site - Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors - Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	A brief assessment of donor stations was carried out for this study using WINFAP-FEH to assess stations that are suitable for QMED within the HiFlows-UK dataset. No suitable donor stations could be located within 20km as the subject catchment is very small and moderately urbanised. One gauge was found 25km away: Henmore Brook @ Ashbourne; however, the adjustment factor lowered QMED estimates. It was felt that due to the small sizes of the study catchments, a preference for more conservative flows was adopted, using catchment descriptors.
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3.2 Overview of estimation of QMED at each subject site

Site code	QMED from CDs (m ³ /s) RURAL	Final method	Data transfer						Final estimate of QMED (m ³ /s) URBAN
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d _{ij} (km)	Power term, a	Moderated QMED adjustment factor, (A/B) ^a	If more than one donor		
							Weight	Weighted ave. adjustment	
TB_01	0.46	CD	n/a						0.63
UD_01	0.05	CD							0.05
TB_02	0.53	CD							0.72
Are the values of QMED spatially consistent?					Yes, they increase downstream and match the relative catchment areas.				
Notes Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment). When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added below. The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is (A/B) ^a times the initial estimate from catchment descriptors. If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column. Important note on urban adjustment The method used to adjust QMED for urbanisation, for both subject sites and donor sites, is that published in Kjeldsen (2010) ³ in which PRUAF is calculated from BFIHOST. The result will differ from that of WINFAP-FEH v3.0.003 which does not correctly implement the urban adjustment of Kjeldsen (2010). Significant differences will occur only on urban catchments that are highly permeable.									

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

3.3 Derivation of pooling groups

Several subject sites may use the same pooling 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	Weighted average L-moments, L-CV and L-skew, (before urban adjustment)
TB	TB_02	N	None. 542 years.	L-CV: 0.239 L-SKEW: 0.208
Notes Pooling groups were derived using the procedures from Science Report SC050050 (2008).				

3.4 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group (Error! Reference source not found.)	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
TB_01	P	WD	Generalised Logistic (GL): this is the distribution recommended for UK catchments. The GL distribution provides the best fit to the data.	Growth curve adjusted using v3 urban adjustment; no permeable adjustment made	Location: 1.000 Scale: 0.205 Shape: -0.249	2.76
UD_01	P	WD			Location: 1.000 Scale: 0.241 Shape: -0.208	2.86
TB_02	P	WD			Location: 1.000 Scale: 0.210 Shape: -0.242	2.78
Notes Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters. Urban adjustments are all carried out using the v3 method: Kjeldsen (2010). Growth curves were derived using the procedures from Science Report SC050050 (2008).						

3.5 Flood estimates from the statistical method

Site code	Flood peak (m ³ /s) for the following return periods (in years)		
	5% AEP	1% AEP	0.1% AEP
TB_01	1.19	1.74	3.00
UD_01	0.10	0.14	0.23
TB_02	1.37	2.00	3.43

Flows given to 2 decimal places due to UD_01 being so small.

4 Revitalised flood hydrograph (ReFH) method

4.1 Parameters for ReFH model (rural catchments)

Site code	Method OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	T _p (hours) Time to peak	C _{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
TB_01	CD	2.43	402	24.9	1.23
UD_01	CD	1.6	456	29.3	1.42
TB_02	CD	2.9	449	28.4	1.4
Brief description of any flood event analysis carried out (further details should be given in the annex)			n/a		

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
TB_01	Urban	Summer	3.75	-
UD_01	Urban	Summer	2.75	-
TB_02	Urban	Summer	4.75	-
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			The above storm durations are different per inflow as this method looks at lumped catchment flow estimates. However, there will be one consistent storm duration applied to the hydraulic model. This will be 4.75-hours.	

4.3 Flood estimates from the ReFH method

Site code	Flood peak (m ³ /s) for the following return periods (in years)		
	5% AEP	1% AEP	0.1% AEP
TB_01	1.2 (winter = 1.4)	1.7 (winter = 1.9)	3.5 (winter = same)
UD_01	0.1 (same summer/ winter)	0.2 (same summer/ winter)	0.4 (same summer/ winter)
TB_02	1.3 (winter = 1.6)	1.9 (winter = 2.2)	4.0 (winter = same)

6 Discussion and summary of results

6.1 Comparison of results from different methods

This table compares peak flows from various methods at example sites for two key return periods. Blank cells indicate that results for a particular site were not calculated using that method.

Site code	Peak flow comparison			
	Return period 20 years		Return period 100 years	
	ReFH (Summer)	FEH Statistical	ReFH (Summer)	FEH Statistical
TB_01	1.2	1.2	1.7	1.7
UD_01	0.1	0.1	0.2	0.14
TB_02	1.3	1.4	1.9	2.0

6.2 Final choice of method

Choice of method and reasons Include reference to type of study, nature of catchment and type of data available.	The FEH Statistical method is the preferred method for small-medium sized catchments, as a larger dataset of gauged data was used in the calibration of the method and it has been more directly calibrated to reproduce flood frequency on UK catchments. Also, it is more appropriate in terms of the representation of urbanisation in the catchment. The ReFH estimates are slightly higher in the 1,000-year event, but otherwise the same for the 20-year and 100-year return period flood events. ReFH does not represent urbanisation as well as the FEH Statistical method.
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6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It is assumed that: • QMED estimated from catchment descriptors is representative • The pooling group is representative of the study catchment • Revised catchment boundaries are representative inclusion assumptions on drain flow directions • ReFH hydrograph shape is representative of the catchment response. It is likely that there is urban influence from sewers; however, this data was not available at the time of the study.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed.	• There are only a low number of small gauged sites in the UK meaning the representation of the pooling group is not ideal. • Sewer data was not available for this study to improve the urban representation. • FEH methods are not suitable for catchments with an area less than 0.5km². • The FEH Statistical method is generally believed to only be suitable for return periods up to 200 years (0.5% AEP event). ReFH is calibrated for return periods up to 150 years (0.67% AEP event). Estimates of flows beyond these return periods are extrapolations and have a higher degree of uncertainty.
Give what information you can on uncertainty in the results, e.g. confidence limits from Kjeldsen (2014).	For the FEH Statistical method, the uncertainty will depend on a variety of factors, for example, how unusual the catchment is relative to the pooling group and donor catchment, and the uncertainty in flow measurement at other gauges. Recent guidance on the reliability of design flood estimates in the UK (Kjeldsen, 2014) quotes average UK measures of uncertainty. The 95% confidence limits for a 1% AEP event flood estimate are: • Without donor adjustment of QMED (CDs): 0.42 - 2.37 times the best estimate • With donor adjustment of QMED (DT): 0.45 - 2.25 times the best estimate A forthcoming R&D project into FEH, local data and uncertainty (Environment Agency funded consortium of JBA, CEH and others) will develop user guidance on uncertainty.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	It is emphasised that the results of the analysis should be considered in the context of the needs of this study. The results of this assessment should be revisited for use on future studies.
Give any other comments on the study, e.g. suggestions for additional work.	The un-gauged catchment would benefit from local data to refine flow estimates, perhaps a temporary flow logger to be installed on the Thulston Brook.

6.4 Checks

Are the results consistent, for example at confluences?	Yes, flows are consistent along the modelled reach.
What do the results imply regarding the return periods of floods during the period of record?	N/A – The catchment is not gauged.
What is the range of 100-year growth factors? Is this realistic?	100-year growth factor for FEH Statistical method = 2.76 – 2.86. These values are within the expected range for UK catchments. It is expected that the Urban ReFH estimates would have a steeper growth curve than the FEH Statistical method.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The 0.1% / 1% AEP event ratios when using the FEH Statistical method range between 1.6 and 1.7. The typical range of 0.1% / 1% AEP ratios is 1.3 to 1.8 so the 0.1% AEP event flows are within range.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	The results will be compared against the previous 2014 Boulton Moor study for sensibility purposes.
Are the results compatible with the longer-term flood history?	n/a
Describe any other checks on the results	Sensibility checks will be applied to the flood outlines once the flows have been routed through the model, to ensure that flow inputs result in realistic outputs.

6.5 Final results

The final flows have been derived using the FEH Statistical method.

Site code	Flood peak (m ³ /s) for the following return periods (in years)		
	5% AEP	1% AEP	0.1% AEP
TB_01	1.19	1.74	3.00
UD_01	0.10	0.14	0.23
TB_02	1.37	2.00	3.43

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	ReFH boundary units will be used in the model to obtain hydrograph shapes, scaled to the FEH Statistical peak flows. The lateral catchment will be set to 'by factor of 1' to allow ReFH to create the lateral catchment hydrograph using the catchment descriptors for the lateral catchment.
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7 Annex

A.1 Pooling Group composition

Station ref.	SDM Distance	Years of Data	QMED AM	L-CV	L-Skewness	Discordancy
27073 (Brompton Beck @ Snainton Ings)	1.319	32	0.813	0.197	-0.022	0.887
76011 (Coal Burn @ Coalburn)	3.085	35	1.840	0.169	0.333	1.442
20002 (West Pepper Burn @ Luffness)	3.356	41	3.299	0.292	0.015	1.664
27051 (Crimple @ Burn Bridge)	3.516	40	4.539	0.222	0.149	0.595
45816 (Haddeo @ Upton)	3.636	19	3.456	0.324	0.434	0.904
26802 (Gypsy Race @ Kirby Grindalythe)	3.701	13	0.109	0.261	0.199	0.435
203046 (Rathmore Burn @ Rathmore Bridge)	3.729	30	10.934	0.136	0.091	0.857
25019 (Leven @ Easby)	3.790	34	5.538	0.347	0.394	1.060
28033 (Dove @ Hollinsclough)	3.798	33	4.666	0.266	0.415	0.684
25003 (Trout Beck @ Moor House)	3.953	39	15.164	0.176	0.291	0.610
72014 (Conder @ Galgate)	3.967	45	17.703	0.193	0.059	0.769
36010 (Bumpstead Brook @ Broad Green)	4.036	45	6.759	0.418	0.228	2.337
25011 (Langdon Beck @ Langdon)	4.037	26	15.878	0.241	0.326	1.908
73015 (Keer @ High Keer Weir)	4.046	21	12.239	0.156	0.001	0.829
49003 (de Lank @ de Lank)	4.060	46	13.559	0.232	0.241	0.472
41020 (Bevern Stream @ Clappers Bridge)	4.092	43	13.490	0.214	0.208	0.546
Total		542				
Weighted means				0.239	0.208	

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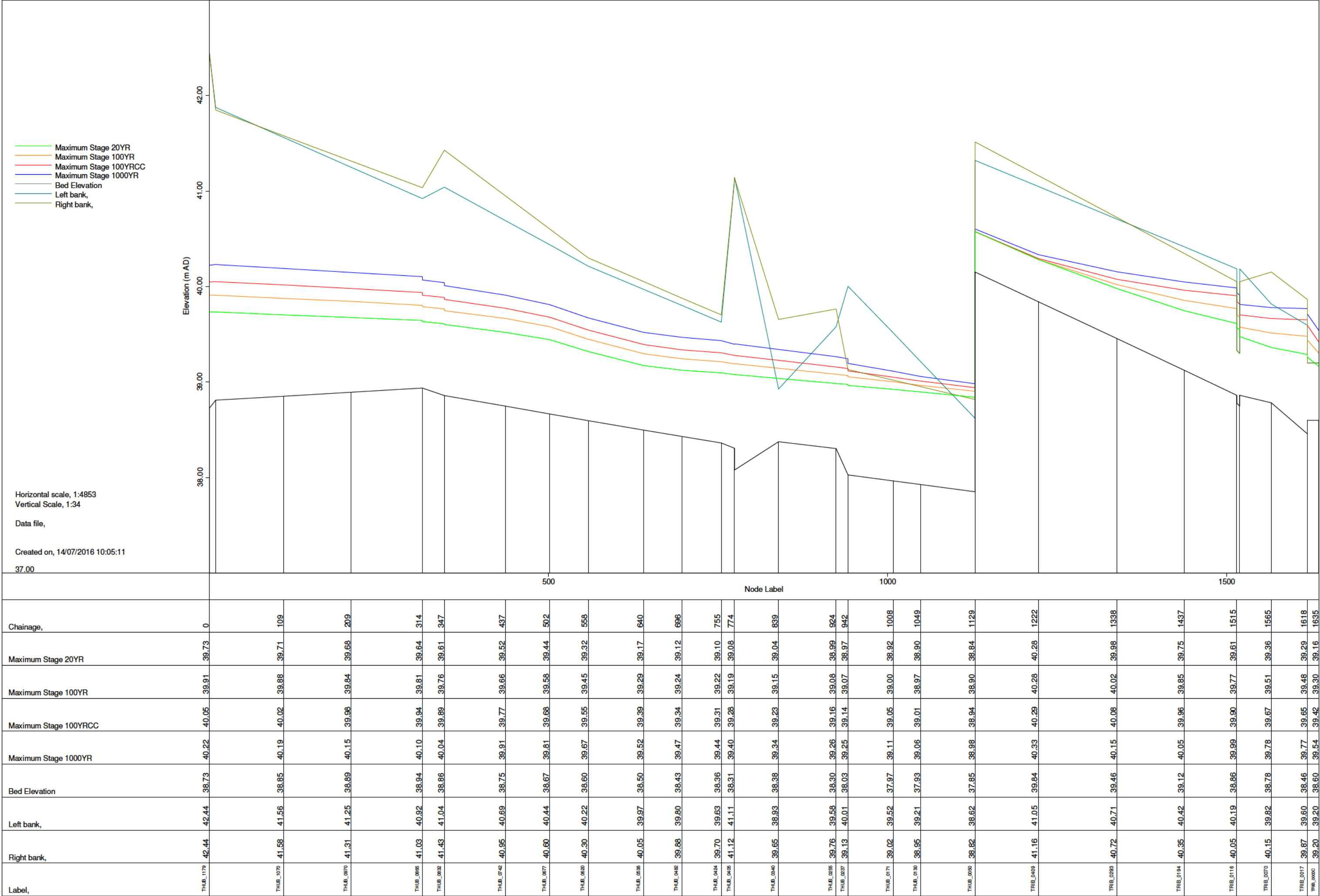
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F Appendix F - Detailed 1D Model Results

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G Appendix G - Sensitivity Analysis

The hydraulic model was tested for sensitivity to key model parameters which might impact flood risk at the proposed development site. This included the following scenarios:

- Increasing flows by 20% (i.e. the 100-year plus climate change event)
- Increasing the Manning's n values by +20%. This was both in the Flood Modeller 1D channel and in the 2D TUFLOW domain.
- Increasing the downstream boundary by 250mm in the 1D.

The following sections discuss the impacts of this sensitivity scenarios.

G.1 Sensitivity to flow

Figure D-1 shows the changes in peak water level compared to the baseline 100-year event when an increase of 20% is applied to all inflows.

Figure D-1: Change in peak water levels with the 100-year +20% increase in flow

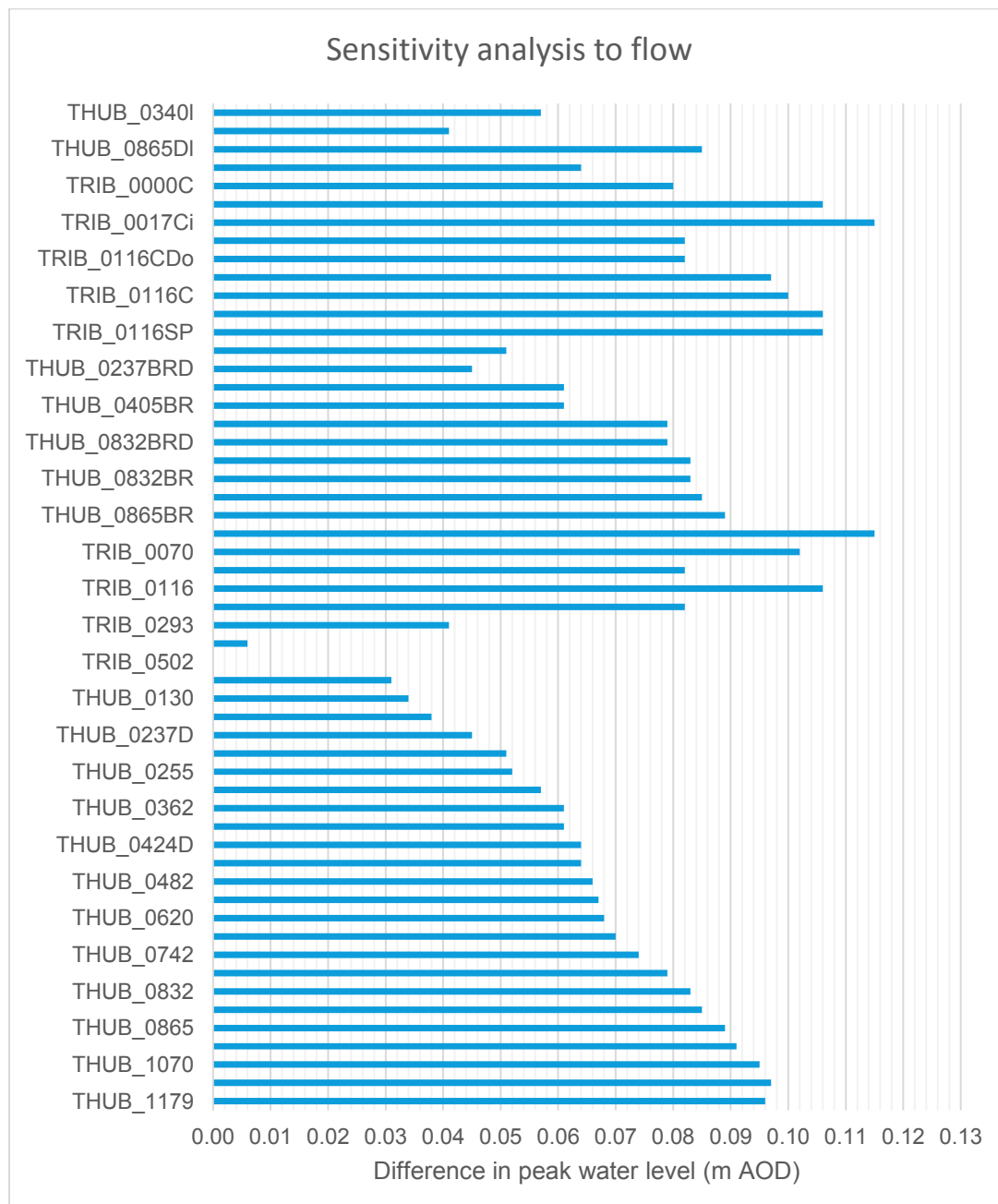


Figure D-1 indicates there is a maximum increase in peak water level of 120mm at node TRIB_0017Ci (where the unnamed tributary approaches the junction with the Thulston Brook).

Overall the model results are relatively sensitive to change in flow value. This is due to the fact that the 100-year flows remain in-bank and thus alterations made to the model will occur over a confined area.

G.2 Sensitivity to roughness

Figure D-2 shows the changes in peak water level compared to the baseline 100-year event when an increase of 20% is applied Manning's 'n' in both the 1D and 2D domains.

Figure D-2: Change in peak water levels with the 100-year +20% increase in Manning's 'n'

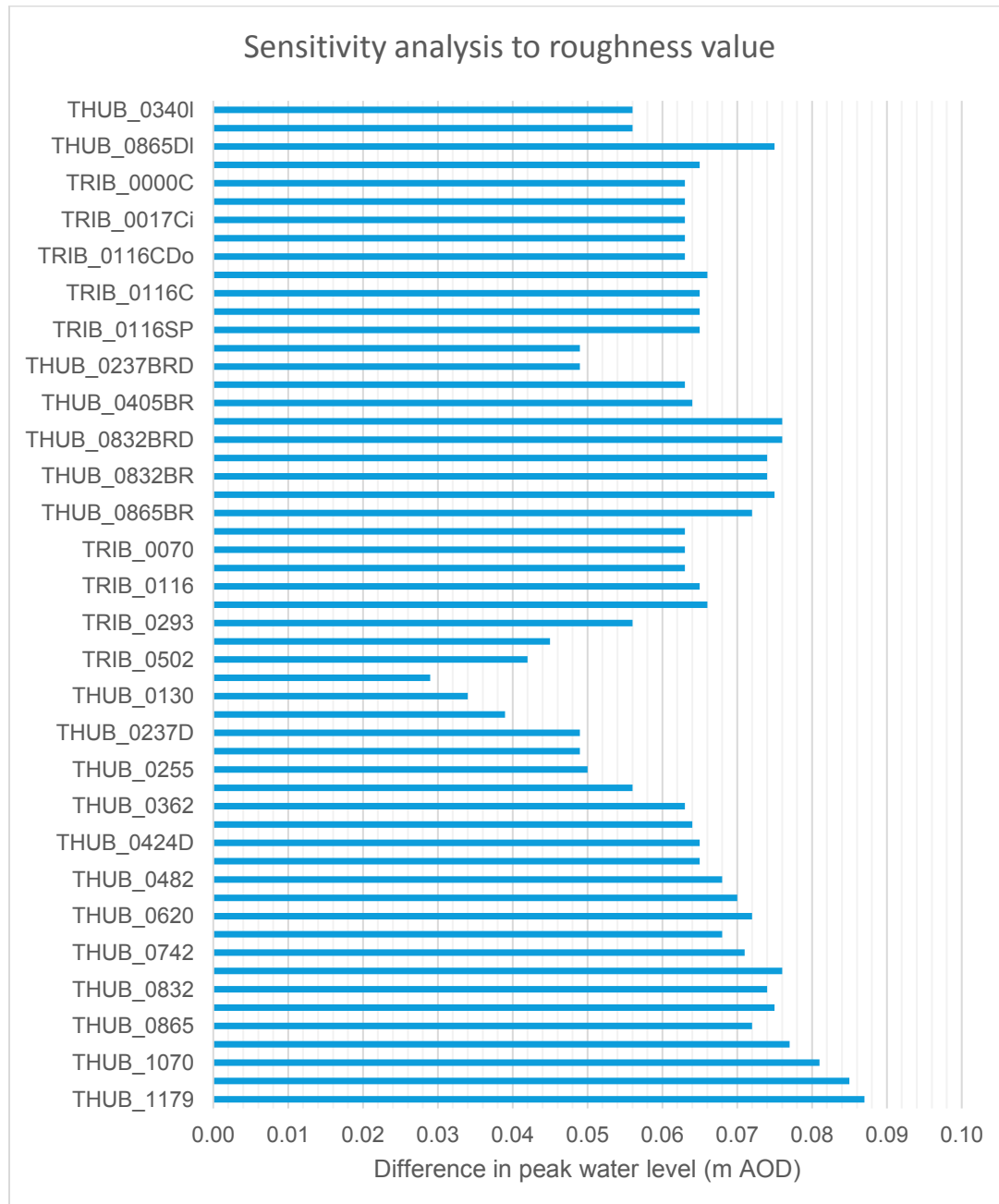


Figure D-2 indicates there is a maximum increase in peak water level of 90mm at node THUB_1179 (upstream of the site boundary). Overall the model results are moderately sensitive to change in roughness values.

G.3 Sensitivity to downstream boundary conditions

Figure D-3 shows the changes in peak water level compared to the baseline 100-year event when an increase of 250mm is applied to the downstream 'stage-time' model boundary condition.

Figure D-3: Change in peak water levels with the 100-year +250mm at the downstream boundary condition

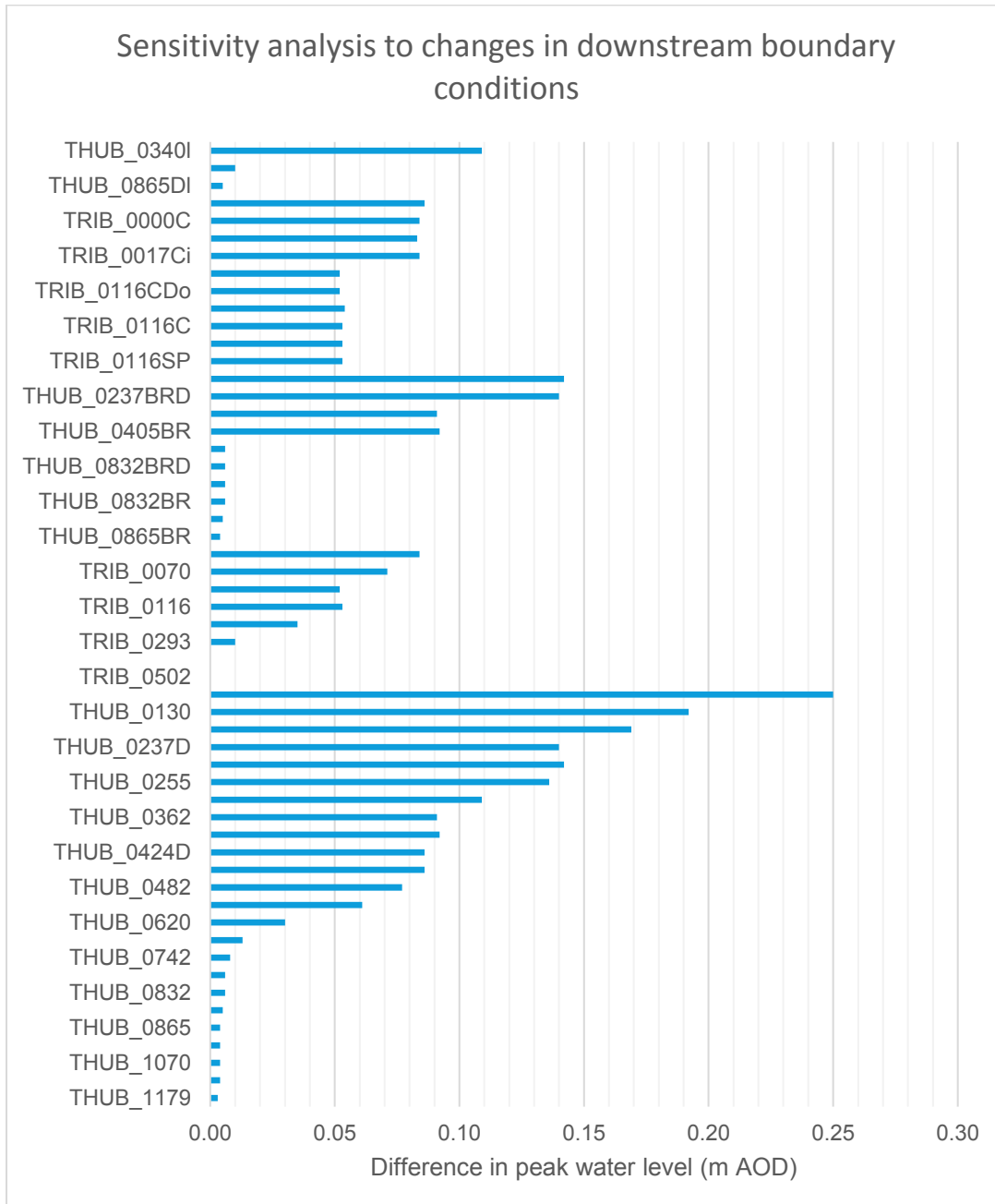


Figure D-3 indicates that the increase in boundary condition generates a maximum increase in peak water level of up to 90mm within the development site boundary (node THUB_0424D, at the upstream face of the A6 Road Culvert). This result indicates that the model is moderately sensitive to changes in downstream boundary condition.

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Date: 31/10/2016

Dear Mr Saillofest

**ENVIRONMENT AGENCY FLOOD MAP CHALLENGE, BOULTON MOOR – THULSTON
BROOK**

Thank you for your submission of evidence to challenge the Environment Agency Flood Map for Planning at Boulton Moor, Derbyshire.

I am pleased to inform you that following a review of the evidence submitted the requested amendments to the Flood Map for Planning in this location will be undertaken.

Please note that the Flood Map for Planning is a national dataset which is updated quarterly. As such the amendments made following this challenge will be published on the Environment Agency website in early February 2017.

Amendments to the Flood Map for Planning are determined on a case by case basis following review by the Environment Agency.

Yours sincerely



Mr David Turnbull
Team Leader Partnership and Strategic Overview