

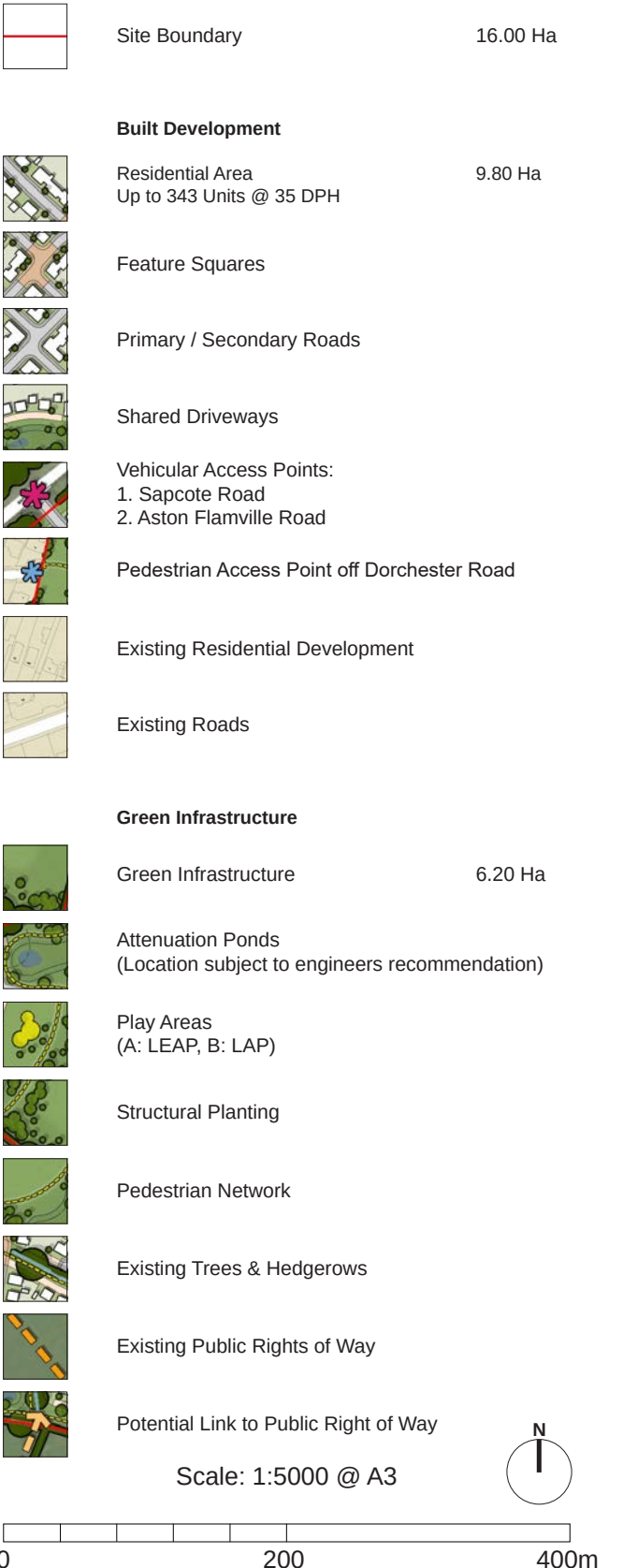
# Appendix I

## Site Plan



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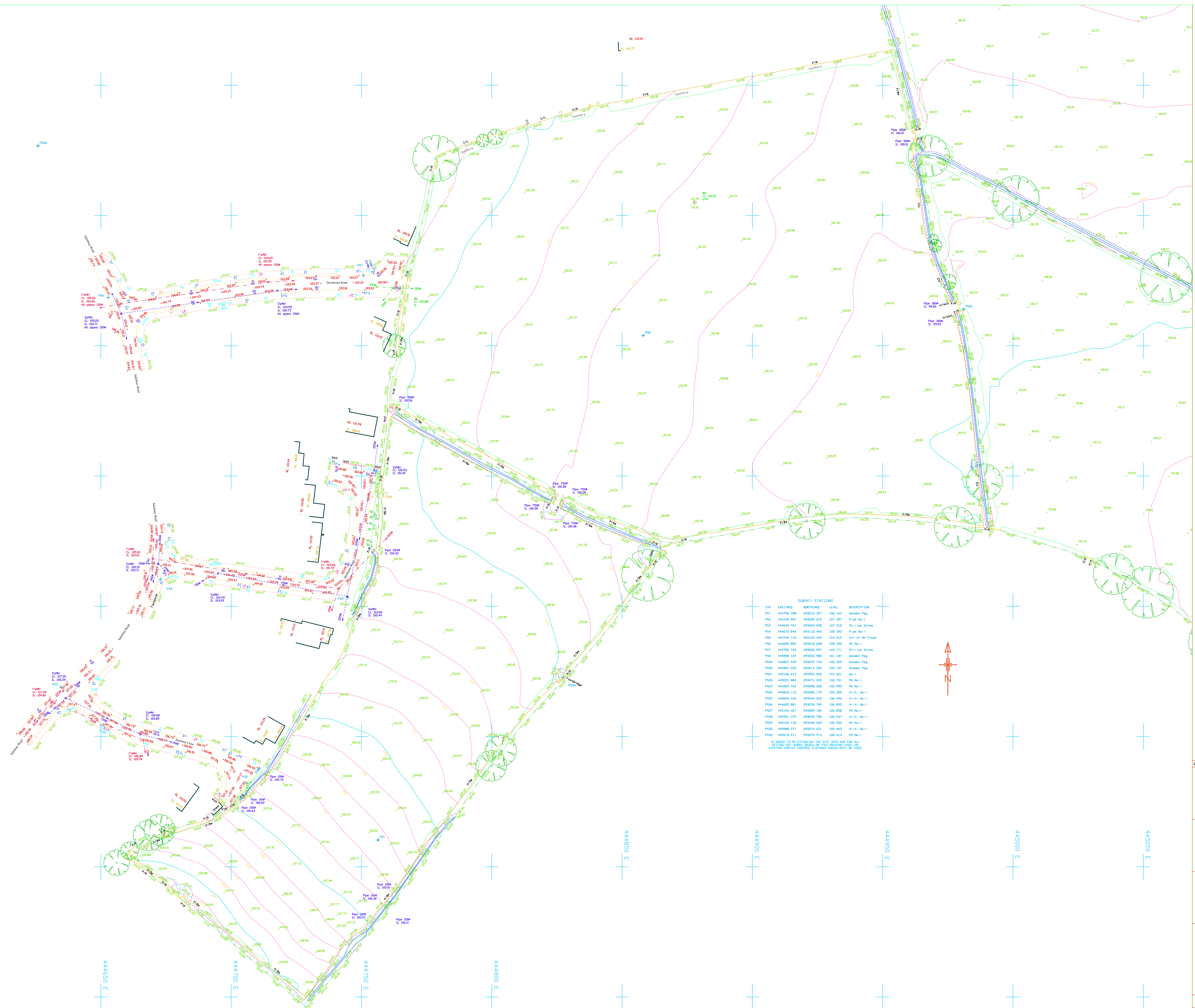
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# Appendix II

## Topographical Survey



## SURVEY NOTES

1. THE SURVEY GRID (COSOB36) WAS ESTABLISHED WITH GPS AND THEN A ONE POINT SITE CENTRED TRANSFORMATION CARRIED OUT TO ELIMINATE SCALE FACTOR. IN ORDER TO RE-ESTABLISH THE SITE GRID THEN THE EXISTING SURVEY CONTROL STATIONS MUST BE USED

[illegible]

INFORMATION SHOWN ON THIS DRAWING IS TO BE USED TO DETERMINE THE SCOPE OF THE BASE SCALE SHOWN IN THE LEGEND.

MAN ENTRY TO SEWERS HAS NOT BEEN UNDERTAKEN. DEPTHS AND SIZES ARE MEASURED/ESTIMATED FROM THE GROUND. ALL SEWER DETAILS TO BE CHECKED WITH LOCAL AUTHORITY RECORDS OR ON SITE PRIOR TO COMMENCEMENT OF WORKS.

BOUNDARIES SHOWN ARE PHYSICAL. FEATURES AND MAY NOT REPRESENT LEGALLY CONVEYED OWNERSHIP.

ALL TREE HEIGHTS AND SPREADS ARE APPROXIMATE. TREE TYPES WHICH HAVE BEEN IDENTIFIED SHOULD BE CONFIRMED BY A TREE SURVEILLIST.

WHERE ADJACENT BUILDINGS HAVE BEEN SURVEYED REMOTELY NOT ALL EXTERNAL WALLS MAYBE SHOWN DUE TO OBSTRUCTIONS ALONG LINE OF SIGHT.

| SURVEY STATIONS |            |            |         |             |
|-----------------|------------|------------|---------|-------------|
| STN             | EASTINGS   | NORTHINGS  | LEVEL   | DESCRIPTION |
| P51             | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |
| P52             | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |
| P53             | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |
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| P55             | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |
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| P95             | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |
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| P100            | 444675.298 | 930900.337 | 106.163 | Wooden Peg  |

IN ORDER TO RE-ESTABLISH THE SITE GRID AND FOR ALL  
SETTING OUT WORKS BASED ON THIS DRAWING THEN THE  
EXISTING SURVEY CONTROL STATIONS SHOWN MUST BE USED.

|     |          |                          |     |     |
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| REV | DATE     | DESCRIPTION              | BY  | APP |



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Project Title

Dorchester Road  
Burbage

| Drawing Title |
|---------------|
|---------------|

Topographical Survey  
Sheet 1 of 3

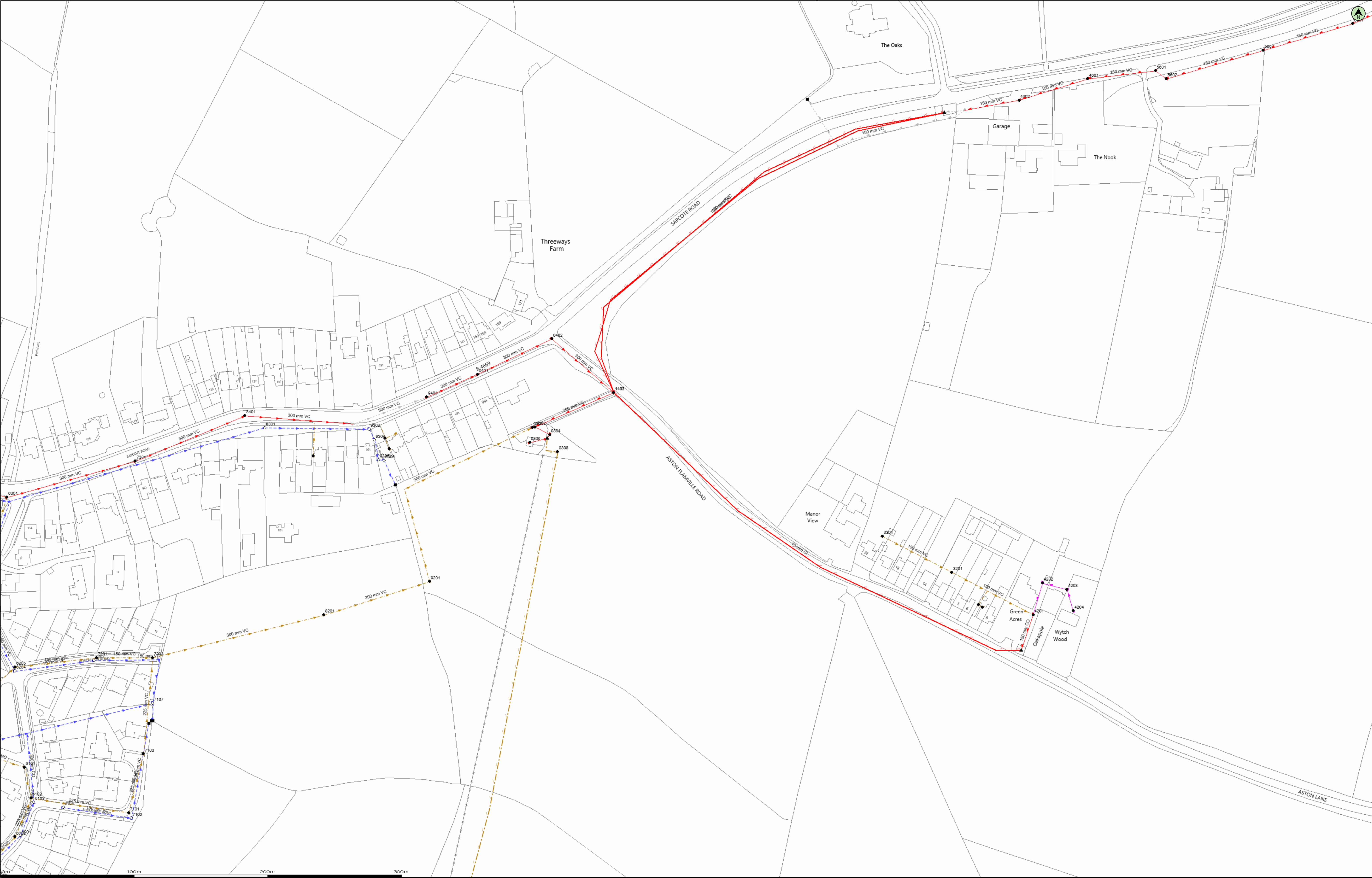
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| Drawn<br>GRA         | Checked<br>ALB | Approved<br>SAR  |
| Date<br>04/04/2013   | Scale<br>1/500 | Sheet Size<br>A0 |
| Dwg. No.<br>S3396-01 |                | Rev<br>A         |





## **Appendix III**

### **Severn Trent Water Asset Maps**



Do not scale off this Map. This plan and any information supplied with it is furnished as a general guide, is only valid at the date of issue and no warranty as to its correctness is given or implied. In particular this plan and any information shown on it must not be relied upon in the event of any development or works (including but not limited to excavations) in the vicinity of SEVERN TRENT WATER assets or for the purposes of determining the suitability of a point of connection to the sewerage or distribution systems. On 1 October 2011 most private sewers and private lateral drains in Severn Trent Water's sewerage area, which were connected to a public sewer as at 1 July 2011. Transferred to the ownership of Severn Trent Water and became public sewers and public lateral drains. A further transfer takes place on 1 October 2012. Private pumping stations, which form part of these sewers or lateral drains, will transfer to ownership of Severn Trent Water on or before 1 October 2016. Severn Trent Water does not possess complete records of these assets. These assets may not be displayed on the map. Reproduction by permission of Ordnance Survey on behalf of HMSO. © Crown Copyright and database right 2004. All rights reserved. Ordnance Survey licence number: 100031673. Document users other than SEVERN TRENT WATER business users are advised that this document is provided for reference purpose only and is subject to copyright, therefore, no further copies should be made from it.

|                                  |                                  |               |              |
|----------------------------------|----------------------------------|---------------|--------------|
| Public Sewer (Joint/Joint Drain) | Public Sewer (Joint/Joint Drain) | Highway Foot  | Manhole Foot |
| Public Sewer (Joint/Joint Drain) | Public Sewer (Joint/Joint Drain) | Drainage Foot | Manhole Foot |
| Public Sewer (Joint/Joint Drain) | Public Sewer (Joint/Joint Drain) | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |
| Private Sewer                    | Private Sewer                    | Drainage Foot | Manhole Foot |

kazi.hasan@gva.co.uk

Burbage





**GENERAL CONDITIONS AND PRECAUTIONS TO BE TAKEN WHEN CARRYING OUT WORK ADJACENT TO SEVERN TRENT WATER'S APPARATUS**

Please ensure that a copy of these conditions is passed to your representative and/or your contractor on site. If any damage is caused to Severn Trent Water Limited (STW) apparatus (defined below), the person, contractor or subcontractor responsible must inform STW immediately on:  
**0800 783 4444 (24 hours)**

- a) These general conditions and precautions apply to the public sewerage, water distribution and cables in ducts including (but not limited to) sewers which are the subject of an Agreement under Section 104 of the Water Industry Act 1991(a legal agreement between a developer and STW, where a developer agrees to build sewers to an agreed standard, which STW will then adopt); mains installed in accordance with an agreement for the self-construction of water mains entered into with STW and the assets described at condition b) of these general conditions and precautions. Such apparatus is referred to as "STW Apparatus" in these general conditions and precautions.
- b) Please be aware that due to The Private Sewers Transfer Regulations June 2011, the number of public sewers has increased, but many of these are not shown on the public sewer record. However, some idea of their positions may be obtained from the position of inspection covers and their existence must be anticipated.
- c) On request, STW will issue a copy of the plan showing the approximate locations of STW Apparatus although in certain instances a charge will be made. The position of private drains, private sewers and water service pipes to properties are not normally shown but their presence must be anticipated. This plan and the information supplied with it is furnished as a general guide only and STW does not guarantee its accuracy.
- d) STW does not update these plans on a regular basis. Therefore the position and depth of STW Apparatus may change and this plan is issued subject to any such change. Before any works are carried out, you should confirm whether any changes to the plan have been made since it was issued.
- e) The plan must not be relied upon in the event of excavations or other works in the vicinity of STW Apparatus. It is your responsibility to ascertain the precise location of any STW Apparatus prior to undertaking any development or other works (including but not limited to excavations).
- f) No person or company shall be relieved from liability for loss and/or damage caused to STW Apparatus by reason of the actual position and/or depths of STW Apparatus being different from those shown on the plan.

In order to achieve safe working conditions adjacent to any STW Apparatus the following should be observed:

1. All STW Apparatus should be located by hand digging prior to the use of mechanical excavators.
2. All information set out in any plans received from us, or given by our staff at the site of the works, about the position and depth of the mains, is approximate. Every possible precaution should be taken to avoid damage to STW Apparatus. You or your contractor must ensure the safety of STW Apparatus and will be responsible for the cost of repairing any loss and/or damage caused (including without limitation replacement parts).
3. Water mains are normally laid at a depth of 900mm. No records are kept of customer service pipes which are normally laid at a depth of 750mm; but some idea of their positions may be obtained from the position of stop tap covers and their existence must be anticipated.
4. During construction work, where heavy plant will cross the line of STW Apparatus, specific crossing points must be agreed with STW and suitably reinforced where required. These crossing points should be clearly marked and crossing of the line of STW Apparatus at other locations must be prevented.
5. Where it is proposed to carry out piling or boring within 20 metres of any STW Apparatus, STW should be consulted to enable any affected STW Apparatus to be surveyed prior to the works commencing.
6. Where excavation of trenches adjacent to any STW Apparatus affects its support, the STW Apparatus must be supported to the satisfaction of STW. Water mains and some sewers are pressurised and can fail if excavation removes support to thrust blocks to bends and other fittings.
7. Where a trench is excavated crossing or parallel to the line of any STW Apparatus, the backfill should be adequately compacted to prevent any settlement which could subsequently cause damage to the STW Apparatus. In special cases, it may be necessary to provide permanent support to STW Apparatus which has been exposed over a length of the excavation before backfilling and reinstatement is carried out. There should be no concrete backfill in contact with the STW Apparatus.
8. No other apparatus should be laid along the line of STW Apparatus irrespective of clearance. Above ground apparatus must not be located within a minimum of 3 metres either side of the centre line of STW Apparatus for smaller sized pipes and 6 metres either side for larger sized pipes without prior approval. No manhole or chamber shall be built over or around any STW Apparatus.
9. A minimum radial clearance of 300 millimetres should be allowed between any plant or equipment being installed and existing STW Apparatus. We reserve the right to increase this distance where strategic assets are affected.
10. Where any STW Apparatus coated with a special wrapping is damaged, even to a minor extent, STW must be notified and the trench left open until the damage has been inspected and the necessary repairs have been carried out. In the case of any material damage to any STW Apparatus causing leakage, weakening of the mechanical strength of the pipe or corrosion-protection damage, the necessary remedial work will be recharged to you.
11. It may be necessary to adjust the finished level of any surface boxes which may fall within your proposed construction. Please ensure that these are not damaged, buried or otherwise rendered inaccessible as a result of the works and that all stop taps, valves, hydrants, etc. remain accessible and operable. Minor reduction in existing levels may result in conflict with STW Apparatus such as valve spindles or tops of hydrants housed under the surface boxes. Checks should be made during site investigations to ascertain the level of such STW Apparatus in order to determine any necessary alterations in advance of the works.
12. With regard to any proposed resurfacing works, you are required to contact STW on the number given above to arrange a site inspection to establish the condition of any STW Apparatus in the nature of surface boxes or manhole covers and frames affected by the works. STW will then advise on any measures to be taken, in the event of this a proportionate charge will be made.
13. You are advised that STW will not agree to either the erection of posts, directly over or within 1.0 metre of valves and hydrants,
14. No explosives are to be used in the vicinity of any STW Apparatus without prior consultation with STW.

**TREE PLANTING RESTRICTIONS**

There are many problems with the location of trees adjacent to sewers, water mains and other STW Apparatus and these can lead to the loss of trees and hence amenity to the area which many people may have become used to. It is best if the problem is not created in the first place. Set out below are the recommendations for tree planting in close proximity to public sewers, water mains and other STW Apparatus.

15. Please ensure that, in relation to STW Apparatus, the mature root systems and canopies of any tree planted do not and will not encroach within the recommended distances specified in the notes below.
16. Both Poplar and Willow trees have extensive root systems and should not be planted within 12 metres of a sewer, water main or other STW Apparatus.
17. The following trees and those of similar size, be they deciduous or evergreen, should not be planted within 6 metres of a sewer, water main or other STW Apparatus. E.g. Ash, Beech, Birch, most Conifers, Elm, Horse Chestnut, Lime, Oak, Sycamore, Apple and Pear. Asset Protection Statements Updated May 2014
18. STW personnel require a clear path to conduct surveys etc. No shrubs or bushes should be planted within 2 metre of the centre line of a sewer, water main or other STW Apparatus.
19. In certain circumstances, both STW and landowners may wish to plant shrubs/bushes in close proximity to a sewer, water main of other STW Apparatus for screening purposes. The following are shallow rooting and are suitable for this purpose: Blackthorn, Broom, Cotoneaster, Elder, Hazel, Laurel, Privet, Quickthorn, Snowberry, and most ornamental flowering shrubs.





# **Appendix IV**

## **JBA Consulting Flood Modelling Report**

# Hydraulic Modelling Study at Sherborne Road, Burbage

Final Report

July 2021

[www.jbaconsulting.com](http://www.jbaconsulting.com)

Avison Young  
3 Brindley Place  
Birmingham  
B1 2JB

**AVISON  
YOUNG**

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B46 3AD

## Revision History

| Revision Ref / Date | Amendments   | Issued to                  |
|---------------------|--------------|----------------------------|
| January 2021        | Draft Report | David Hoppe (Avison Young) |
| July 2021           | Final Report | David Hoppe (Avison Young) |
|                     |              |                            |

## Contract

This report describes work commissioned by David Hoppe, on behalf of Avison Young, by an email dated 13/07/2020. Copper Lewis and Alice Blanchard of JBA Consulting carried out this work.

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Olivier Saillofest BEng MSc CEng MCIWEM C.WEM

Technical Director

## Purpose

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## Executive summary

JBA Consulting was commissioned by Avison Young to undertake a hydraulic modelling study to develop an understanding of the flood risk posed from an ordinary watercourse to a proposed residential development site (at Sherborne Road, Burbage, Leicestershire).

A channel survey was carried out by Grantham Coates Survey (GCS) Ltd in July 2020. The survey consisted of 12 cross sections along the watercourse and at key hydraulic features. The floodplain topography and model domain were informed by combining site-specific topographic survey data provided by the client with LiDAR data (flown in 2017 and obtained from the Open Data website, with a grid resolution of 1m).

The hydraulic model was run for the 20-year, 100-year, 100-year plus climate change (+30% and +50%) and for the 1,000-year fluvial flood scenarios. The model was also tested for its sensitivity to changes in Manning's roughness, downstream boundary and increase in flow.

Results from the baseline hydraulic modelling results show that:

- Flooding occurs in all modelled events due to the lack of capacity of the channel and undersized culverts which act to constrict flow and hinder the conveyance of flood water downstream
- Exceedance flows generate widespread flooding across the floodplain. Flood depths along these overland flow routes are very shallow due to the steep topography of the site.
- The peak flood depth across the site is located near the confluence between the tributary and unnamed watercourse and is estimated as 0.28m and 0.29m for the 100-year with 30% and 50% climate change scenarios, respectively.
- Water levels at the site are generally not sensitive to changes in flow, roughness value or downstream boundary conditions.

A number of post-development options were tested to reduce flood risk to the site without increasing flood risk elsewhere. Option 4 was chosen as the preferred option at this development site (Figure 0-1).

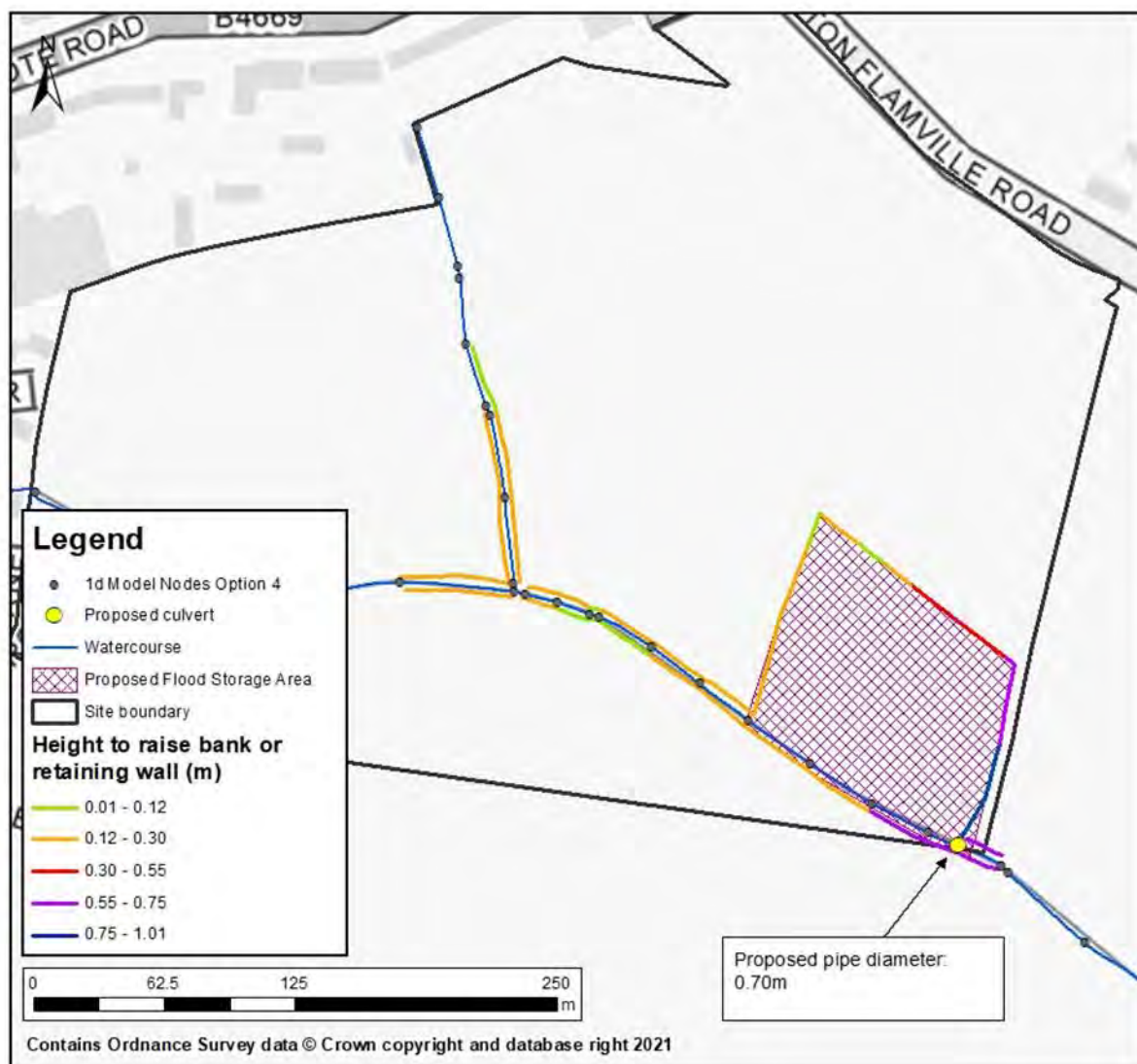


Figure 0-1 Option 4 – key design features

This option includes:

1. The removal of three undersized culverts
2. Raising of the banks of the two modelled watercourses
3. The creation of a flood storage area with flow control structure at the southern end of the site
4. A 1m deep low flow channel running alongside the FSA with a lowered left-hand bank to allow excess water to spill directly into the FSA.

The above combination of flood mitigation features will prevent flood water from overtopping the river channel (and thus prevent wide-spread flooding across the site) without increasing flood risk elsewhere.

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## Abbreviations

|     |                           |
|-----|---------------------------|
| 1D  | One Dimensional           |
| 2D  | Two Dimensional           |
| CC  | Climate Change            |
| DTM | Digital Terrain Model     |
| EA  | Environment Agency        |
| FEH | Flood Estimation Handbook |
| FFL | Finished Floor Levels     |
| FM  | Flood Modeller            |

|       |                              |
|-------|------------------------------|
| Ha    | Hectares                     |
| HQ    | Head-Flow                    |
| JBA   | Jeremy Benn Associates       |
| LiDAR | Light Detection and Ranging  |
| m AOD | Metres Above Ordnance Datum  |
| ReFH  | Revitalised Flood Hydrograph |

# 1 Introduction

## 1.1 Terms of Reference

JBA Consulting (JBA) were commissioned by Avison Young to undertake a hydraulic modelling study at a proposed residential development site at Sherborne Road, Burbage. Details of the site location can be seen below in Table 1-1. An unnamed ordinary watercourse flows from northwest to southeast along the southern boundary of the site with an additional tributary crossing from the northwest boundary of the site through the centre to meet the main channel at the southern boundary. The primary purpose of the hydraulic modelling was to develop an understanding of the flood risk posed to the site from the ordinary watercourses.

Table 1-1 Site location

| Site Name                  | Land adjacent to Sherborne Road, Burbage |
|----------------------------|------------------------------------------|
| Site area                  | 0.148km <sup>2</sup>                     |
| Existing land-use          | Agricultural                             |
| OSGNR                      | SP448932                                 |
| County                     | Leicestershire                           |
| Country                    | United Kingdom                           |
| Local Planning Authorities | Hinckley and Bosworth Borough Council    |
| Lead Local Flood Authority | Leicestershire County Council            |

Legend

- Site boundary
- Watercourse

0 125 250 500 m

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## 2 Approach

### 2.1 Hydraulic Modelling

#### 2.1.1 Data availability

A 1D-2D hydraulic model was developed using Flood Modeller-TUFLOW to represent the changing depth, velocity and hazard at the site during modelled flood events. Grantham Coates Survey (GCS) Ltd was commissioned to collect channel survey data along the ordinary watercourse and the tributary channel in July 2020, collecting a total of 12 cross-sections (Figure 2-1). This included structures such as access bridges across the channel and culverted sections of the watercourse. In these locations, survey was typically collected at the upstream face of the structures however, for longer structures sections were also captured at the downstream face. A copy of the channel survey drawings can be found in Appendix A.

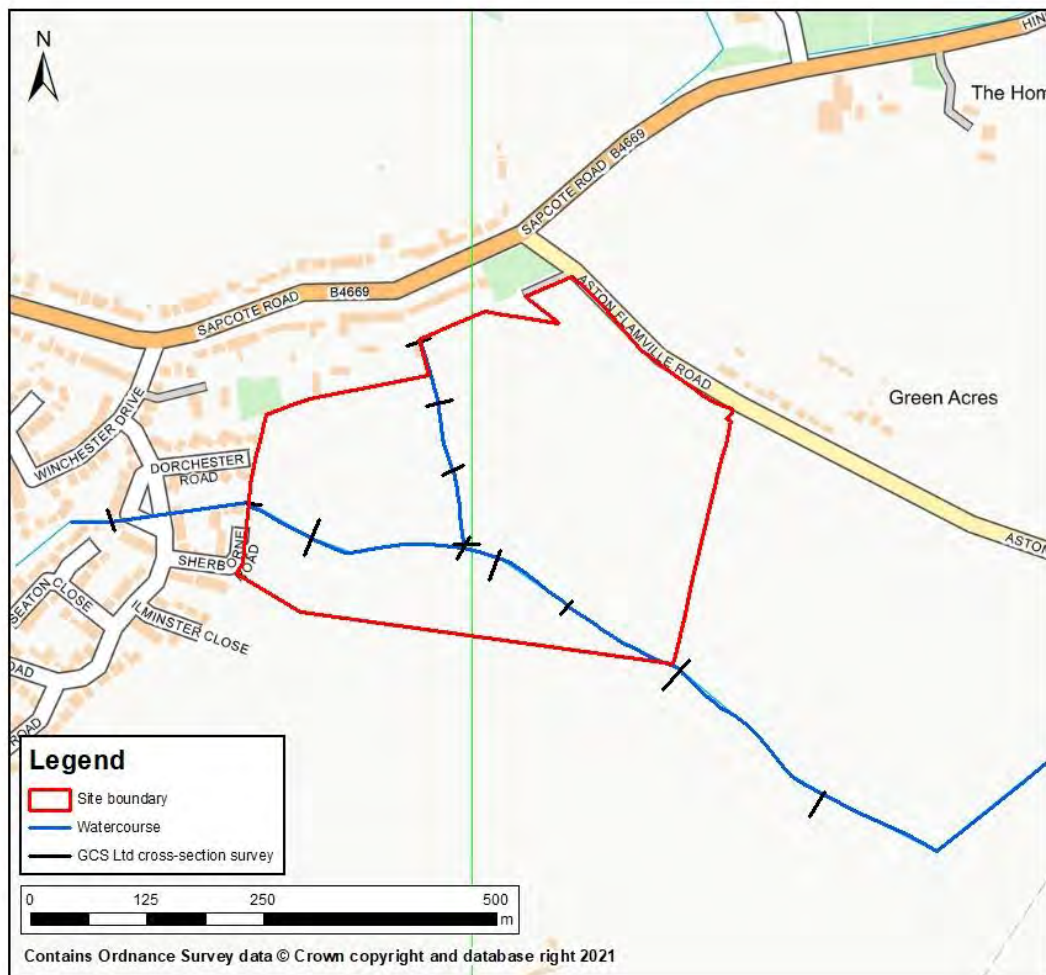


Figure 2-1 Channel survey locations

The existing floodplain topography was represented by combining a site-specific topographic survey provided by the client with LiDAR DTM data obtained from the Open Data website. The LiDAR DTM had a grid resolution of 1m and was flown in 2017. The topographic survey was captured by Phoenix Survey Services Ltd in July 2020 and can be found in Appendix B.

#### 2.1.2 Model extent and build

The hydraulic model represents the ordinary watercourse flowing approximately west to east in the southern part of the site and the tributary passing through the centre of the site. The extent of the model in the 1D and 2D domains is represented in Figure 2-2.

The watercourse and the associated structures were represented as a set of 1D features using Flood Modeller based on channel survey data collected in July 2020 by GCS Ltd. An additional cross section was derived at the upstream extent of the main watercourse to allow the representation of open channel flow before the watercourse enters the culvert present at the first surveyed cross section. This surveyed cross section was copied, and bed levels at the additional cross section were increased based on average channel gradient calculated from LiDAR elevations in GIS. Approximately 0.92 km of the ordinary watercourse through the site is modelled, beginning approximately 190m upstream of the site and extending to a point approximately 220m downstream of the site. The length of the modelled tributary passing through the site is approximately 225m. Figure 2-2 shows the location of this additional cross section (XS8u\_4815) node along with the location of surveyed cross sections. Where hydraulic structures are present, the surveyed section usually represents the upstream face.

The cross section and structure data were trimmed to the top of bank to allow linkage to the 2D TUFLOW domain representing the floodplain. The 2D domain has an area of 0.458km<sup>2</sup> with a 2m grid resolution.

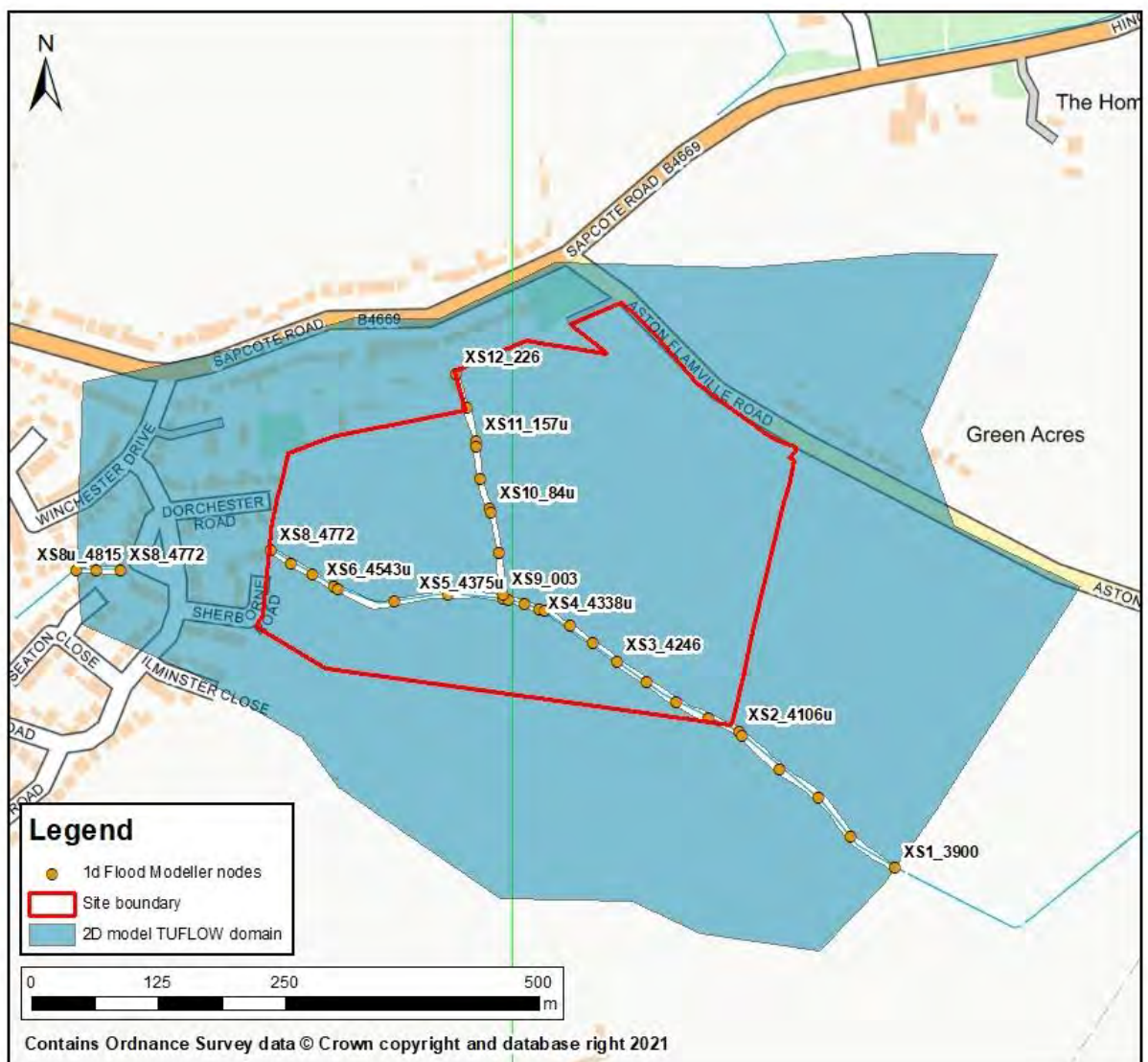


Figure 2-2 Model extent

### 2.1.3 Model roughness parameters

Manning's 'n' coefficients were used to represent roughness of the channel and floodplain.

The values for channel roughness were based on photographs gathered by GCS in July 2020.

Floodplain roughness values were based on land use from OS OpenData. Table 2-1 gives the range of Manning's 'n' values used in the 1D and 2D domains.

Table 2-1 Manning's 'n' values for roughness used in model

| Feature           | Manning's 'n' value |
|-------------------|---------------------|
| 1D channel        | 0.040-0.050         |
| 1D culverts       | 0.020               |
| 1D banks          | 0.060               |
| General Surface   | 0.050               |
| Buildings         | 0.300               |
| Roads             | 0.020               |
| Water             | 0.035               |
| Vegetation        | 0.070               |
| Stability patches | 0.300               |

#### 2.1.4 Model structures

All key hydraulic structures located along the modelled watercourse including culverts and bridges were represented in the 1D Flood Modeller domain. Full details of any assumptions when modelling these structures can be found in Appendix D.

### 2.2 Model Boundary conditions

#### 2.2.1 Model inflows

Hydrographs were applied at the upstream extent of the ordinary watercourse and the tributary channels. A hydrological assessment was carried out in order to derive flow-time hydrographs for the 20-year (5% AEP), 100-year (1% AEP) and 1,000-year (0.1% AEP) events. The 100-year plus climate change events were also calculated, with allowances of 30% (higher central) and 50% (upper end) applied in line with the Environment Agency allowances for climate change (for the Humber river basin district). The hydrological assessment is documented in Appendix E.

#### 2.2.2 Downstream boundary conditions

The downstream boundaries of both the 1D and 2D model domains are represented by a normal slope calculated using the change in elevation with LiDAR around the downstream area of the model.

### 2.3 Model Runs

The following baseline scenarios were simulated using the hydraulic model:

- [Baseline scenario] 2-year flood event
- [Baseline scenario] 20-year flood event
- [Baseline scenario] 100-year flood event
- [Baseline scenario] 100-year with (30%) climate change flood event
- [Baseline scenario] 100-year with (50%) climate change flood event
- [Baseline scenario] 1,000-year

The following sensitivity scenarios were also simulated to test the impact of changes to key model parameters:

- [Sensitivity scenario] 100-year flood event (+20% Manning's 'n')

- [Sensitivity scenario] 100-year flood event (+20% Flow)
- [Sensitivity scenario] 100-year flood event (+250mm DSBDY)

The following post-development optioneering scenarios were also simulated to investigate options to mitigate flood risk across the site and downstream:

- [Post-development scenario – Option 1] 100-year with (30%) climate change flood event
- [Post-development scenario – Option 2] 100-year with (30%) climate change flood event
- [Post-development scenario – Option 3] 100-year with (30%) climate change flood event
- [Post-development scenario – Option 4] 100-year with (30%) climate change flood event

### 3 Hydraulic modelling results

#### 3.1 Flood Extents

Figure 3-1 shows the baseline flood extents for the 20-year, 100-year and the 1,000-year fluvial flood events. Flood extents for the 100-year plus 30% and 50% climate change are shown in Figure 3-2, in comparison with the 100-year event.

LiDAR data indicates that there is a narrow, shallow, unmodelled drainage ditch mid-way down the small tributary, crossing from approximately west to east in the centre of the site. The modelled flood extents suggest that this drainage ditch overtops its banks approximately 130m to the southwest of where it splits from the modelled tributary in the 20-year event, contributing to a flow path through the site on the northern bank of the modelled ordinary watercourse. This flow path is more extensive in the 100-year and 1000-year modelled events, with the unmodelled drainage ditch overtopping in additional locations to add to this.

As the catchment area of the modelled watercourse is less than 3km<sup>2</sup>, flood risk from the watercourse is not represented in the Environment Agency (EA) Flood map for Planning. As a result, a direct comparison between the modelled 1,000-year and 100-year flood outlines with the EAs' Zone 2 and 3 extents was not possible.

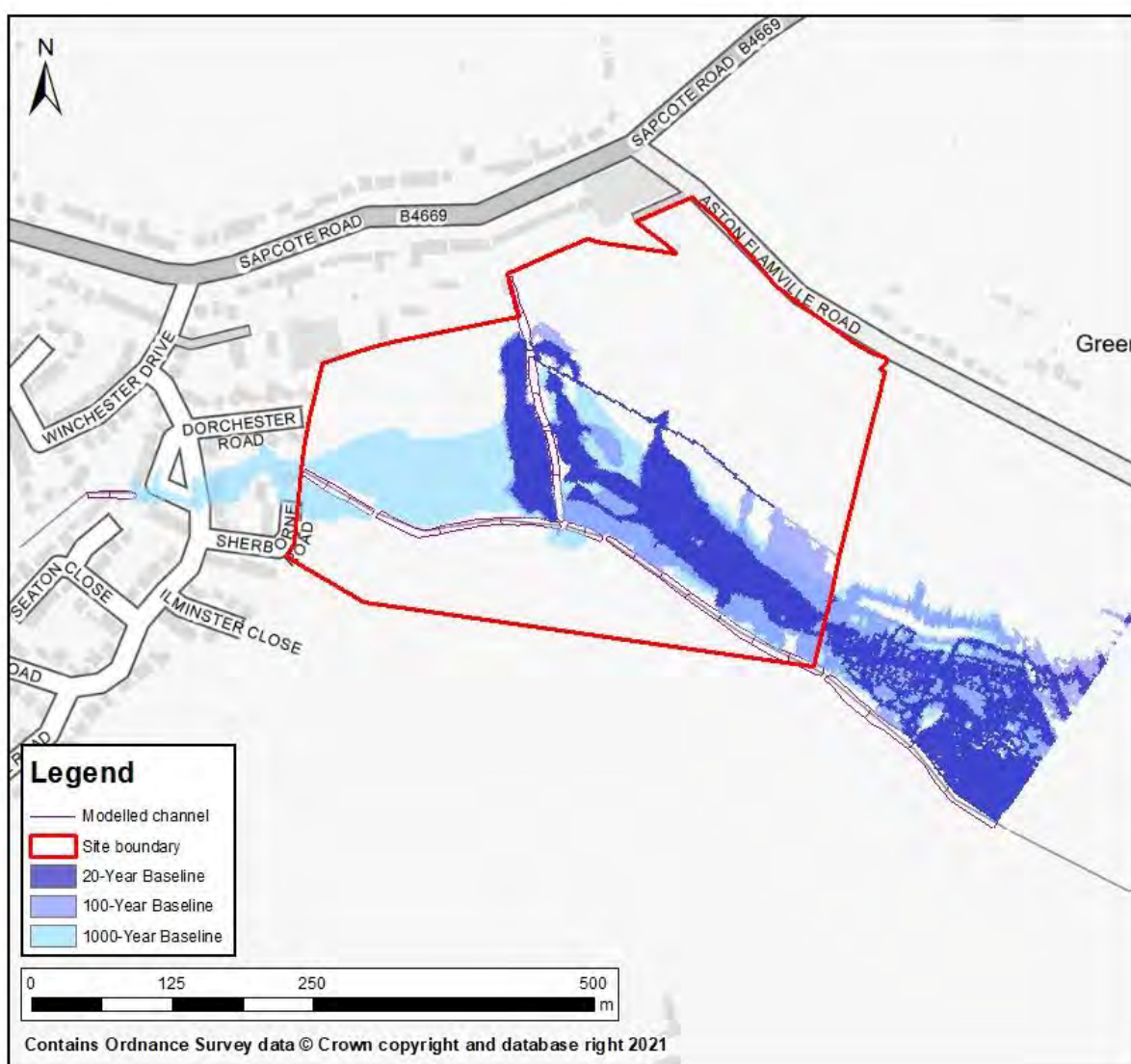


Figure 3-1: 20-year, 100-year and 1,000-year Baseline Flood Extents

Figure 3-1 shows that, for all modelled baseline scenarios, flooding would predominantly occur in the southeast of the site. Water also spills out of the channel along the banks of the modelled tributary that flows in a southerly direction through the site. The 1000-year flood extent also extends across the western area of the site. Flooding generally remains to the north of the main modelled ordinary watercourse. In general, in all modelled scenarios flooding occurs due to the lack of capacity of the channel and the presence of hydraulic structures such as culverts. For example, water spills out of the channel upstream of a culvert at XS11\_157u or at XS4\_4338u.

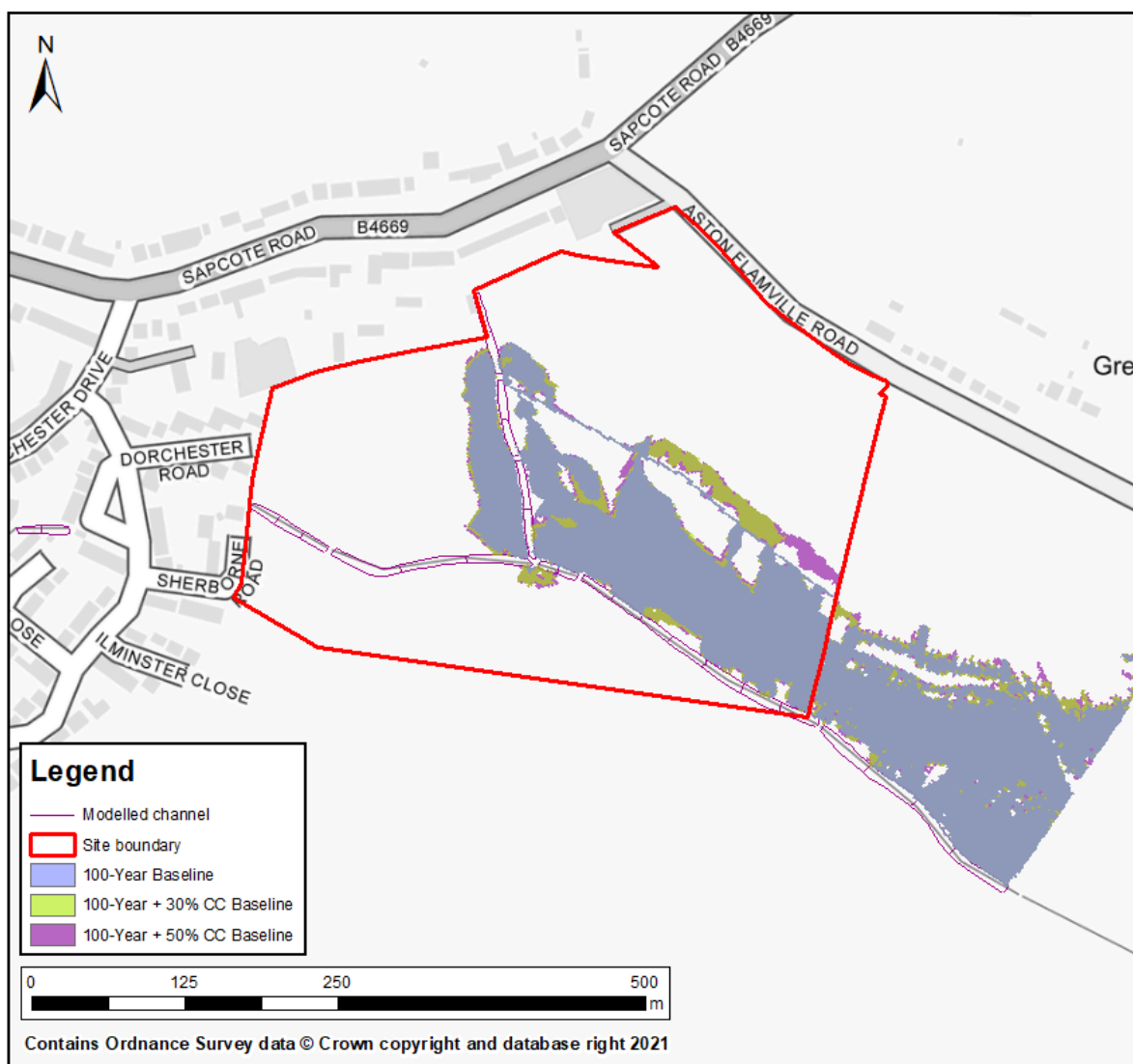


Figure 3-2: 100-year, 100-year (+30 %) CC and 100-year (+50 %) CC baseline flood extents

Figure 3-2 shows that, within the site, the extent of flooding does not significantly increase when applying the 30% and 50% climate change allowances to the 100-year event. This suggests that flooding to the site is mainly driven by the local topography.

### 3.2 Peak Flood Depths

Peak flood depths for the 100-year plus climate change (+30% and +50%) baseline flood events are shown in Figure 3-3 and Figure 3-4.

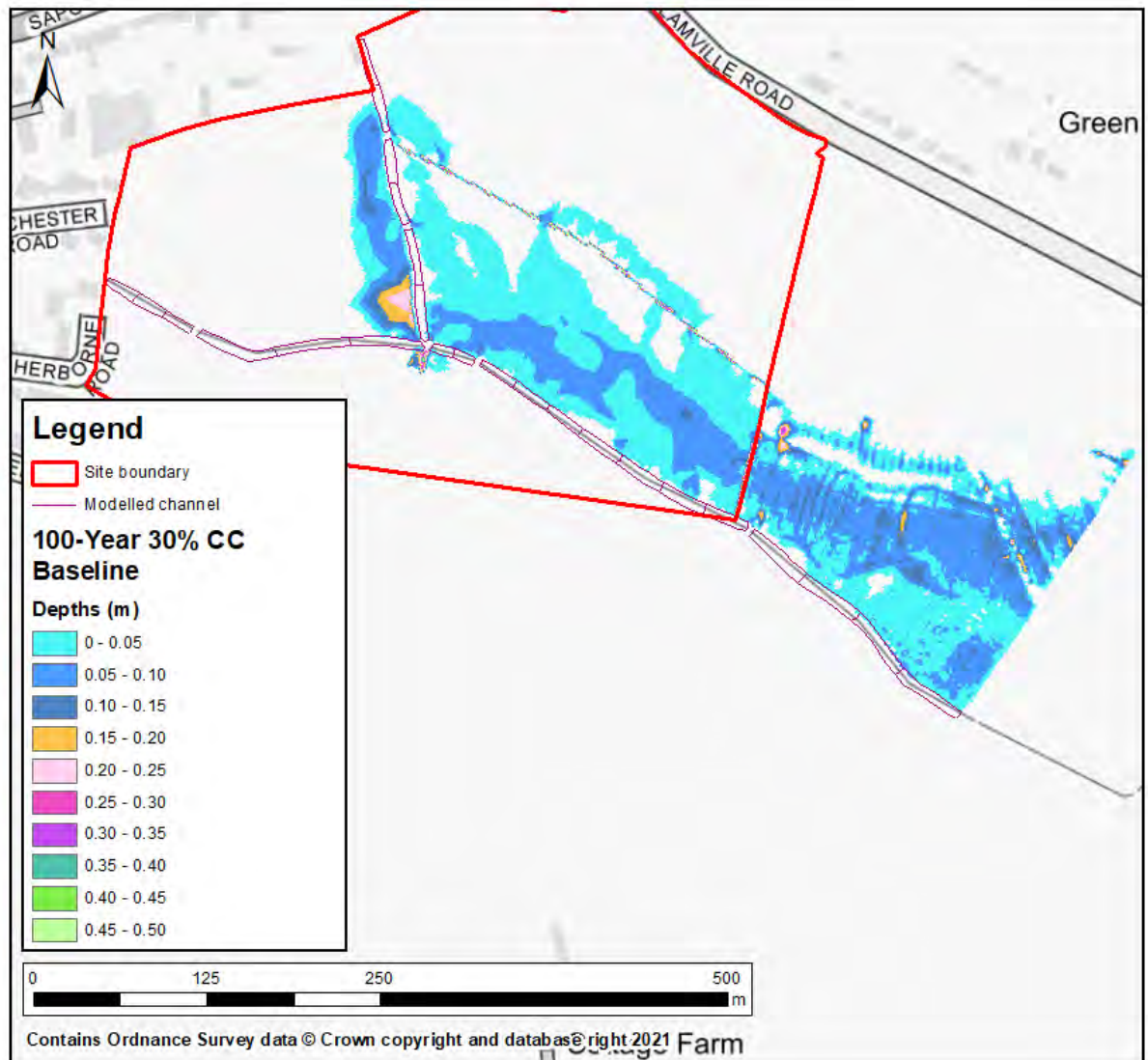


Figure 3-3 Peak flood depths modelled for the 100-year +30% CC baseline scenario

The maximum flood depth within the site during the 100-year with 30% climate change scenario is approximately 0.28m (at the confluence within the site) and generally 0.30m within the small drainage ditch crossing the site and running parallel to the unnamed watercourse. Overall, flood depths across the site are relatively shallow.

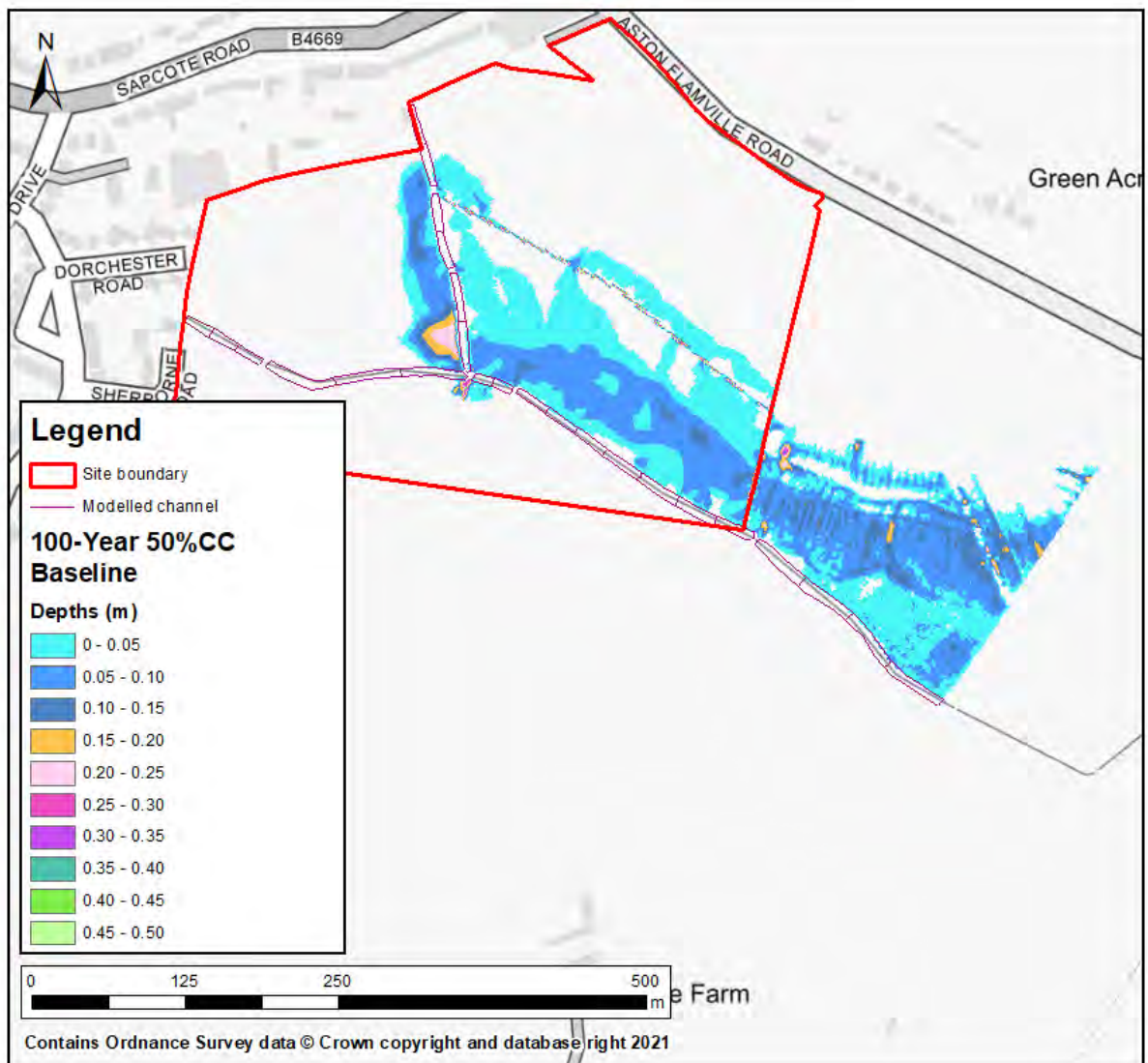


Figure 3-4 Peak flood depths modelled for the 100-year +50 % CC baseline scenario

The peak flood depths during the 100-year with 50% climate change scenario are approximately 0.29 m at the confluence within the site, and 0.30 m at the small channel picked up from LiDAR in the hydraulic modelling.

### 3.3 Peak Water Levels

Peak water levels for the 100-year with climate change scenarios (30% and 50%) are shown in Figure 3-5 and Figure 3-6.

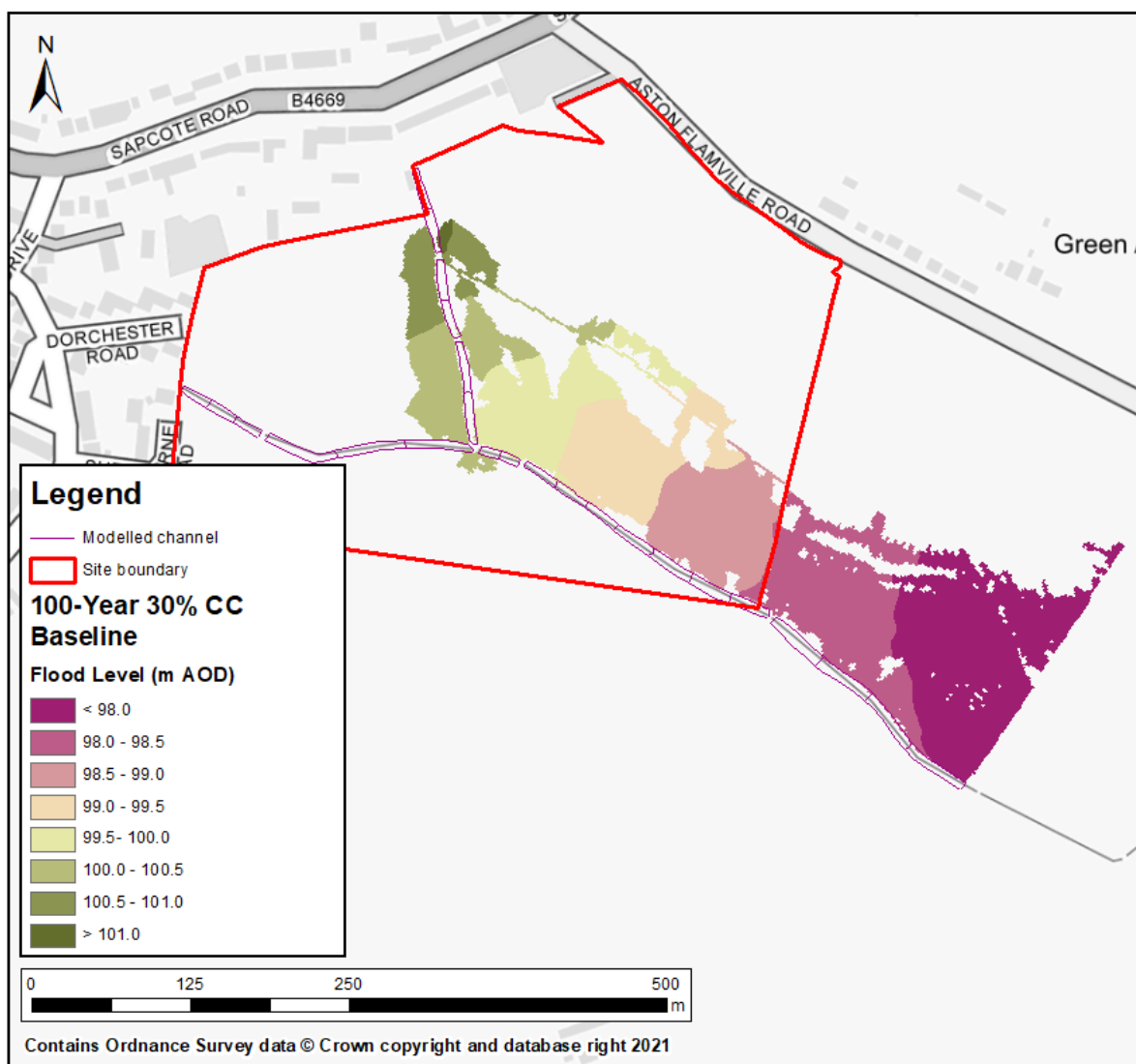


Figure 3-5 Modelled flood levels for the 100-year with 30 % climate change baseline scenario

Figure 3-5 shows the 100-year with (+30%) climate change peak flood levels vary between 101.02m AOD and 98.40m AOD.

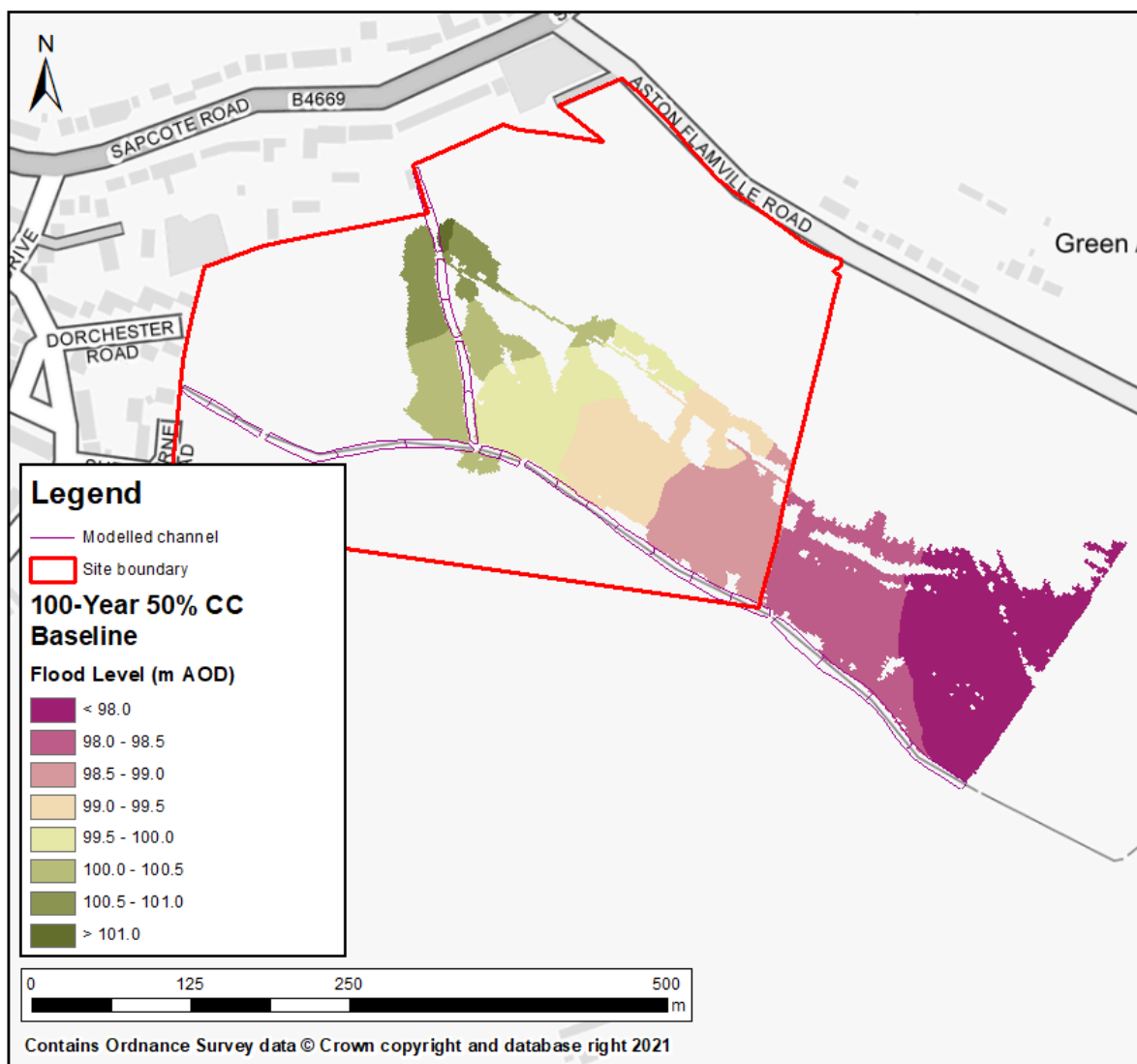


Figure 3-6 Modelled peak flood levels for the 100-year with 50 % climate change baseline scenario

Figure 3-6 shows that the highest and lowest water levels within the site are 101.05m AOD and 98.44m AOD, respectively.

Table 3-1 shows the peak water level recorded within the channel for the baseline scenarios. Locations of model nodes can be seen in Figure 2-2.

Table 3-1 Peak water levels (mAOD) at model nodes in baseline scenarios

| Model node | Peak water levels (m AOD) |          |                      |                      |            |
|------------|---------------------------|----------|----------------------|----------------------|------------|
|            | 20-year                   | 100-year | 100-year plus 30% CC | 100-year plus 50% CC | 1,000-year |
| XS8u_4815  | 106.17                    | 106.28   | 106.32               | 106.39               | 106.41     |
| XS8_4772   | 105.04                    | 105.23   | 105.36               | 105.47               | 105.59     |
| XS7_4620   | 101.97                    | 102.10   | 102.19               | 102.29               | 102.34     |
| XS6_4543u  | 100.85                    | 100.96   | 101.06               | 101.25               | 101.45     |
| XS6_4543d  | 100.82                    | 100.91   | 100.99               | 101.04               | 101.12     |
| XS5_4375u  | 99.84                     | 100.05   | 100.09               | 100.11               | 100.13     |
| XS5_4375d  | 99.76                     | 99.89    | 99.91                | 99.93                | 99.94      |
| XS4_4338u  | 99.71                     | 99.84    | 99.86                | 99.88                | 99.88      |
| XS4_4338d  | 99.62                     | 99.71    | 99.71                | 99.72                | 99.73      |
| XS3_4246   | 99.18                     | 99.26    | 99.26                | 99.27                | 99.27      |
| XS2_4106u  | 98.40                     | 98.49    | 98.49                | 98.50                | 98.51      |
| XS2_4106d  | 98.33                     | 98.39    | 98.39                | 98.40                | 98.41      |
| XS1_3900   | 97.95                     | 97.95    | 97.95                | 97.96                | 97.96      |
| XS12_226   | 101.10                    | 101.17   | 101.24               | 101.28               | 101.36     |
| XS11_157u  | 101.02                    | 101.04   | 101.05               | 101.06               | 101.06     |
| XS11_157d  | 100.58                    | 100.61   | 100.64               | 100.65               | 100.67     |
| XS10_84u   | 100.33                    | 100.35   | 100.36               | 100.37               | 100.38     |
| XS10_84d   | 99.99                     | 100.12   | 100.15               | 100.17               | 100.189    |
| XS9_003    | 99.85                     | 100.05   | 100.09               | 100.11               | 100.13     |
| XS9_003d   | 99.84                     | 100.05   | 100.09               | 100.11               | 100.13     |

### 3.4 Hazard to People Classifications

The fluvial hazard-to-people rating during a 100-year with 30% climate change flood scenario has been mapped using the formula as suggested in Defra's FD2321/TR2 "Flood Risk to People". The different hazard categories are shown in Table 3-2 and the hazard classification to the site during the 100-year with (30%) climate change scenario is shown in Figure 3-7.

Table 3-2 Defra's FD2321/TR2 "Flood Risks to People" classifications

| Flood hazard rating depth x (velocity+0.5) + DF | Level of Flood Hazard Description | Description                                                                             |
|-------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------|
| <0.75                                           | Low                               | Caution "Flood zone with shallow flowing water or deep standing water"                  |
| 0.75 - 1.25                                     | Moderate                          | Dangerous for some (i.e. Children) "Danger: flood zone with deep or fast flowing water" |
| 1.25 - 2.0                                      | Significant                       | Dangerous for most "Danger: flood zone with deep fast flowing water"                    |
| >2.0                                            | Extreme                           | Dangerous for all "Extreme danger: flood zone with deep fast flowing water"             |

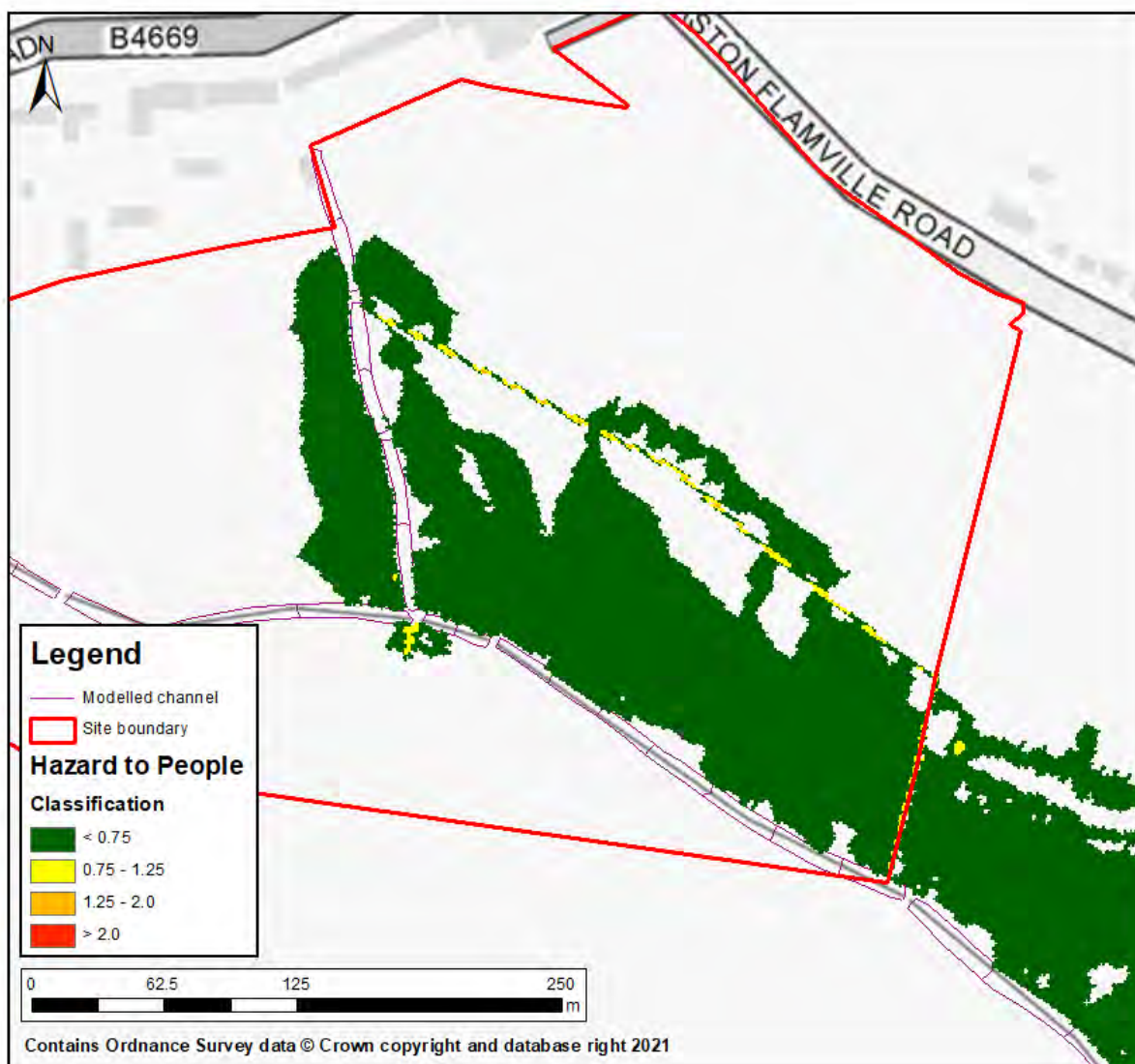


Figure 3-7 Hazard to People Classification

Figure 3-7 shows that the Hazard to People rating for the majority of the site falls within the very low or low hazard category within the site. The only area within the site to reach the significant hazard category is along the small drainage ditch and within the channel of the unnamed watercourses. There are no areas within the site which fall into the 'Extreme' category, meaning access to the site for Emergency Services should be available throughout the event.

### 3.5 Sensitivity Analysis

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

The results of the sensitivity analysis indicate that the model results at the site are a) relatively insensitive to changes in flow and roughness values and b) not sensitive to changes in downstream boundary conditions. This is characteristic of development sites with a steep topography.

## 4 Optioneering phase

### 4.1 Option descriptions

As the shallow flood depths on site are generated by conveyance issues within the channel, flood mitigation options were tested to reduce flood risk to the site without increasing flood risk elsewhere.

The following options were modelled:

- Option 1: Two culverts were removed at XS11\_157u and XS10\_84u along the channel (see Figure 4-1).
- Option 2: In addition to the removal of the culverts considered as part of Option 1, bank heights were increased by 300mm along the length of the tributary channel. Between XS5\_4375u and XS3\_4246 a 1m increase in channel width was modelled with bank heights increased by 300mm (see Figure 4-1).

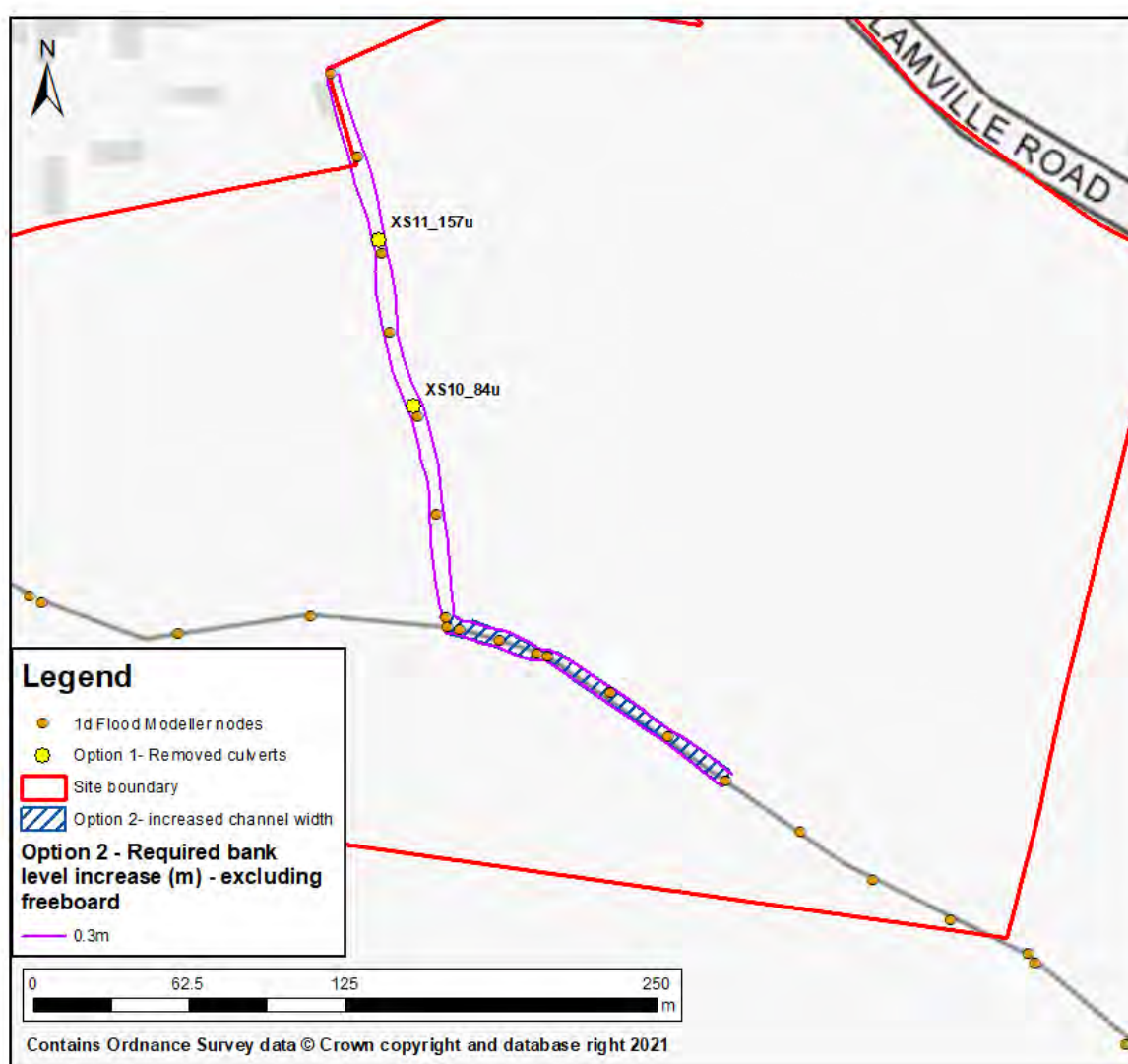


Figure 4-1 Model schematic showing changes required for Option 1 and Option 2

- Option 3: The culverts along the tributary channel were removed, as per Option 1. The existing orifice structure at XS4\_4338u was reduced in diameter from 1.10m to 0.48m in order to maintain the flow leaving the site to its pre-development value. Directly upstream of this throttled culvert, the channel was widened by 5 times and the height of the banks were increased in order to

contain the throttled flow within the channel. Additionally, bank heights along the modelled tributary channel (flowing from north to south through the site) and along parts of the main watercourse were increased by heights of up to 2.93m in order to contain flood water within the channel. In areas where an increase in bank height is required, a low flow channel has been maintained. The key features characterising Option 3 are represented in Figure 4-2. Figure 4-3 shows an example of a modelled low flow channel cross-section which was proposed to allow space for wetlands and ecological benefits.

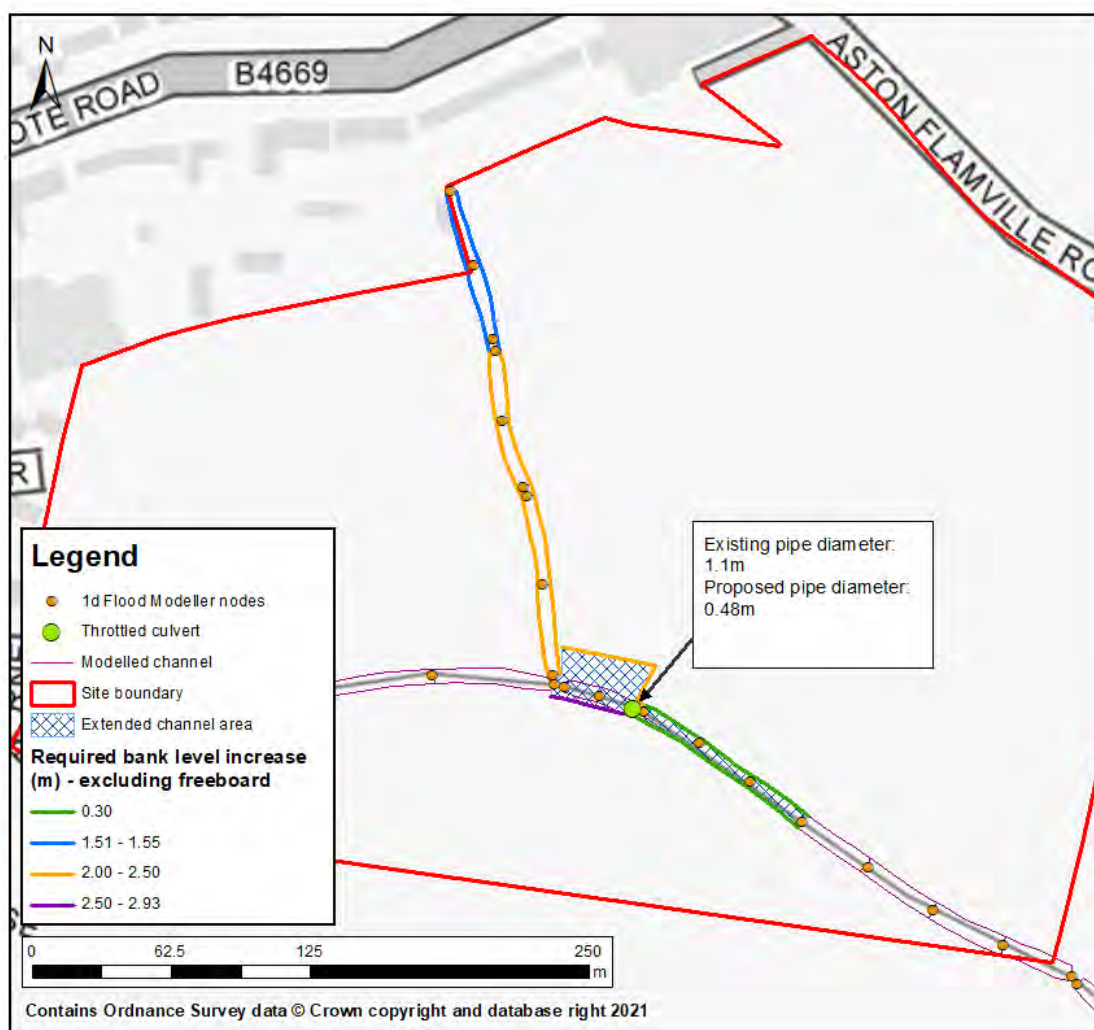


Figure 4-2 Model schematic for Option 3

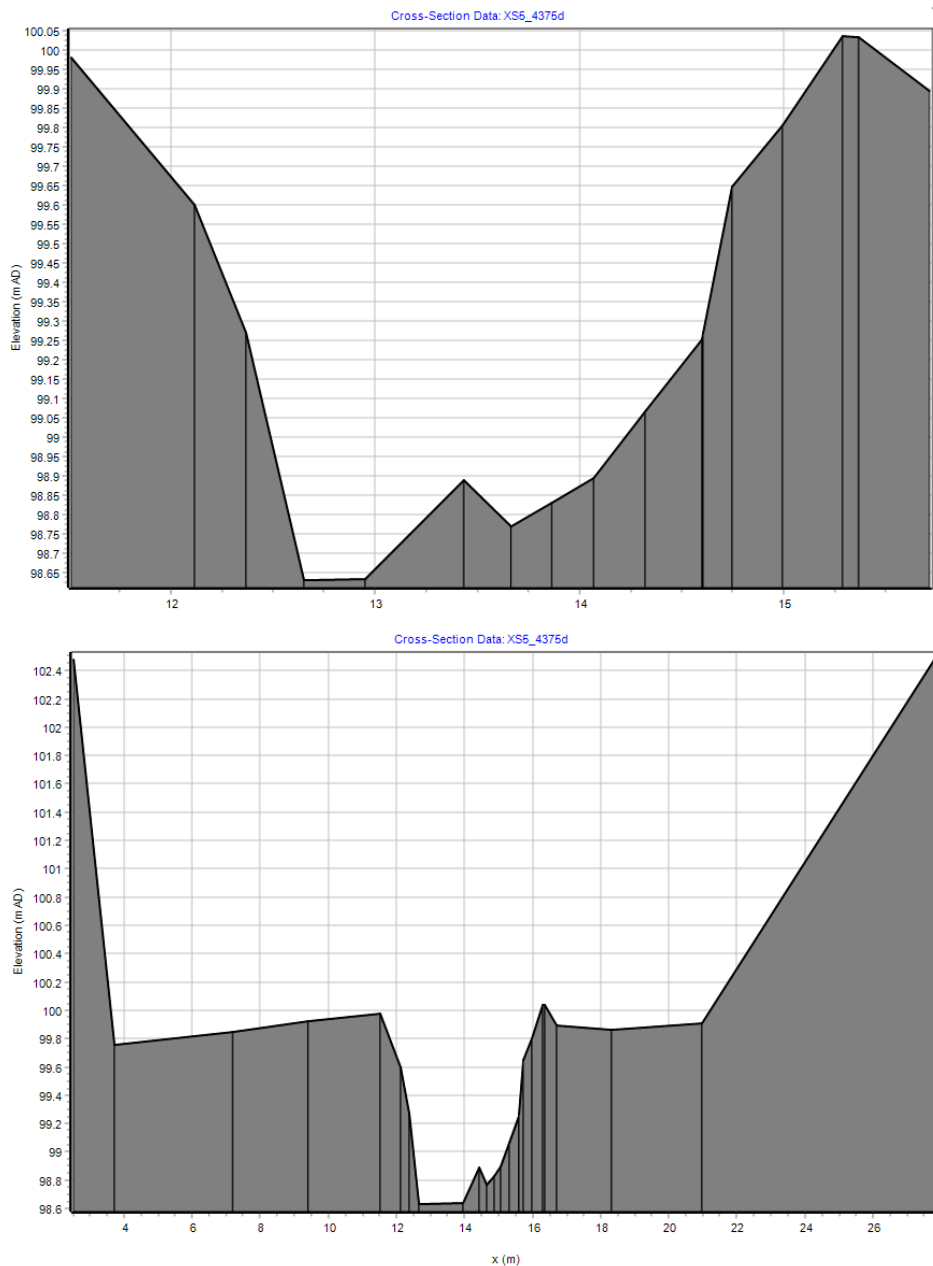


Figure 4-3 XS5\_4375u: An example of the original channel cross section modelled in the baseline scenario compared to the extended channel width, including a low-flow channel, modelled in Option 3.

- Option 4: A Flood Storage Area (FSA) was introduced in the model in order to:
  - o Attenuate the flows at the approach of the flow control structure, and thus increase the diameter of the flow control structure required (which will ultimately reduce the risk of a blockage)
  - o Spread the flood water volumes upstream of the flow control structure over a wider area, and thus reduce the bank heights required to contain flood flows in the channel.

Option 4 comprises the following changes:

- The removal of three undersized culverts
- Raising of the banks of the two modelled watercourses
- The creation of a flood storage area with flow control structure at the southern end of the site

- A 1m deep low flow channel running alongside the FSA with a lowered left-hand bank to allow excess water to spill directly into the FSA.

An orifice structure was added at the downstream end of the FSA at model node XS3\_4246i4 with a pipe diameter of 700mm. In the channel reach running alongside the FSA, from XS3\_4246 to XS2\_4106u, the left-hand bank (over which water spills directly into the FSA) was lowered to a height 1m above the surveyed bed level at these locations. This change in bank height facilitated a 1m deep low flow channel in this reach which can fill to capacity before water begins to interact with the FSA.

The key features characterising Option 4 are represented in Figure 4-4.

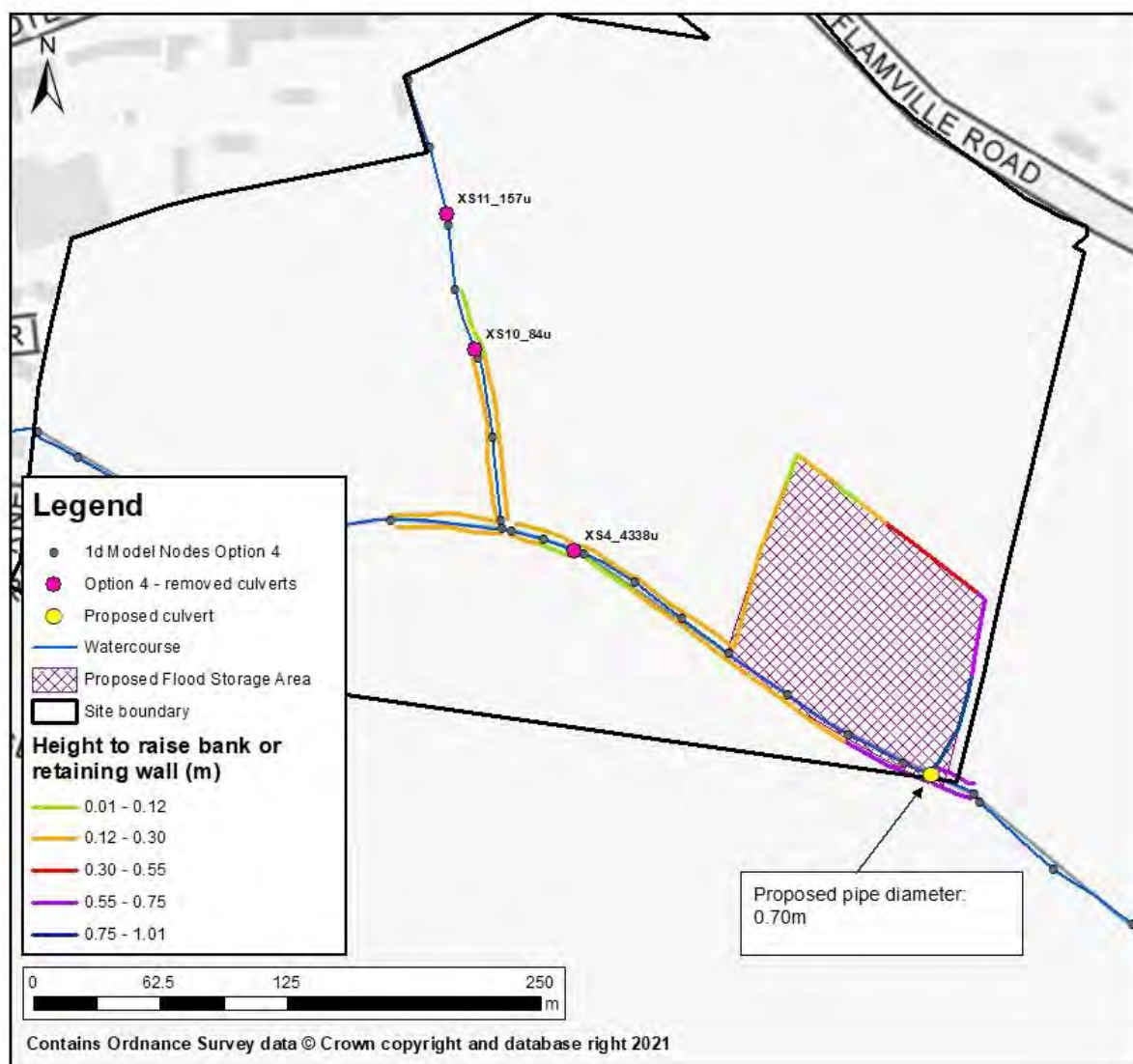


Figure 4-4 Model schematic for Option 4

## 4.2 Modelling results

### 4.2.1 Options 1 and 2

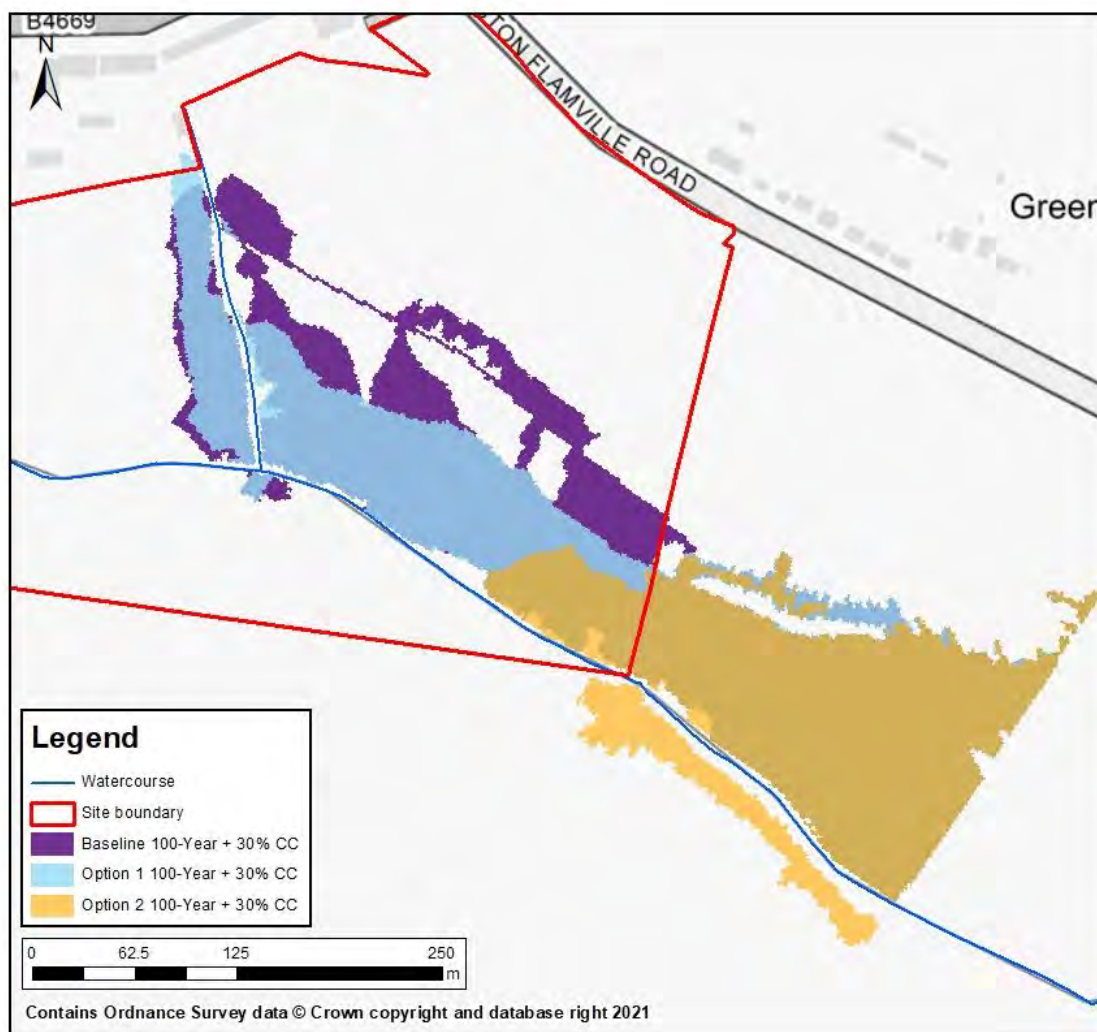


Figure 4-5 shows the impact of Option 1 and Option 2 on the 100-year with 30% climate change flood extents.

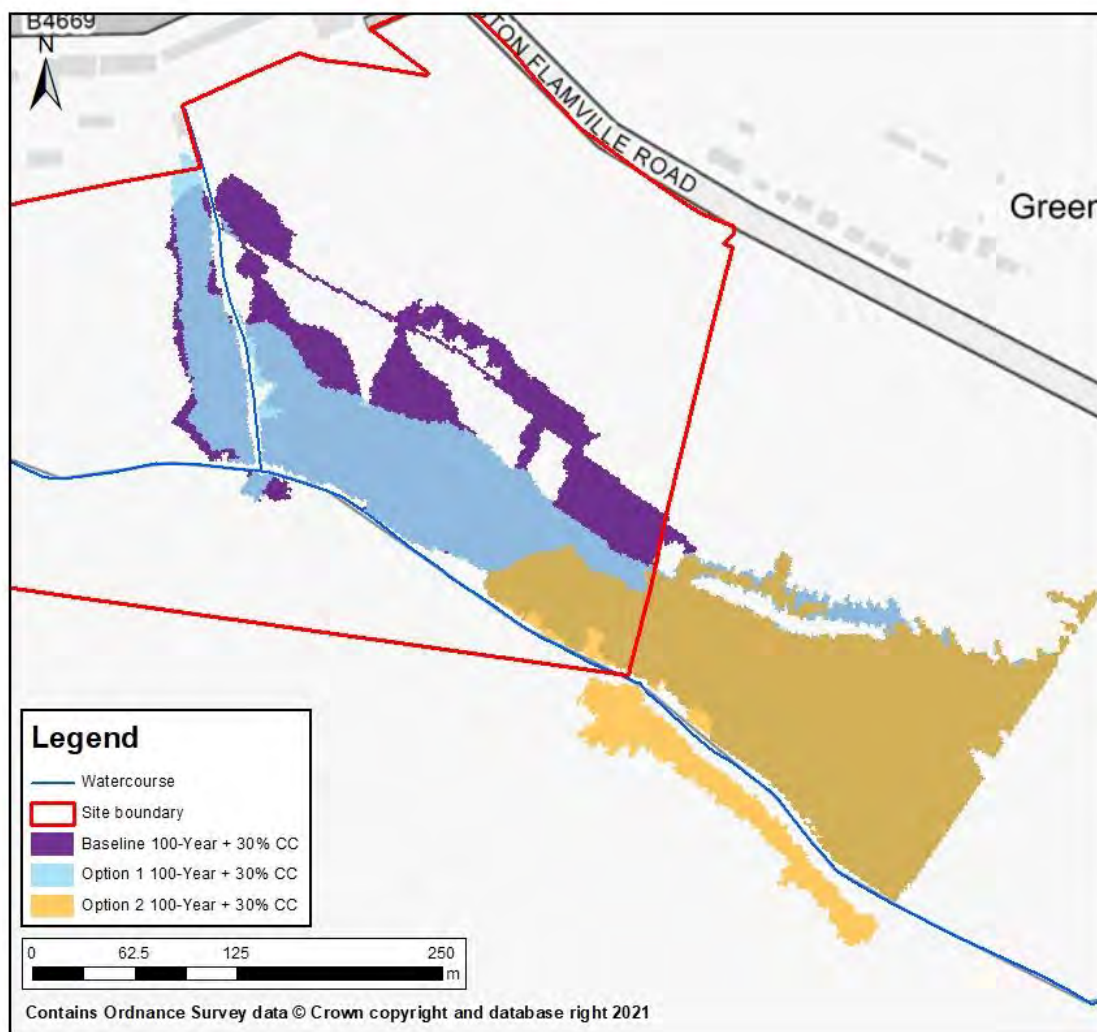


Figure 4-5: 100-year + 30 % climate change flood extents - Option 1 and Option 2

Figure 4-5 shows that both Option 1 and Option 2 will be able to reduce flood risk to the site although they will generate an increase in flood extent downstream. As a result, both these options were deemed unviable.

#### 4.2.2 Option 3

Modelling results from Option 3 indicate that water is retained within the channel through the site and onto third party land in the study area downstream with no water overtopping onto the floodplain.

Figure 4-6 compares the peak flow leaving the site at XS2\_4106u in the baseline scenario and Option 3.

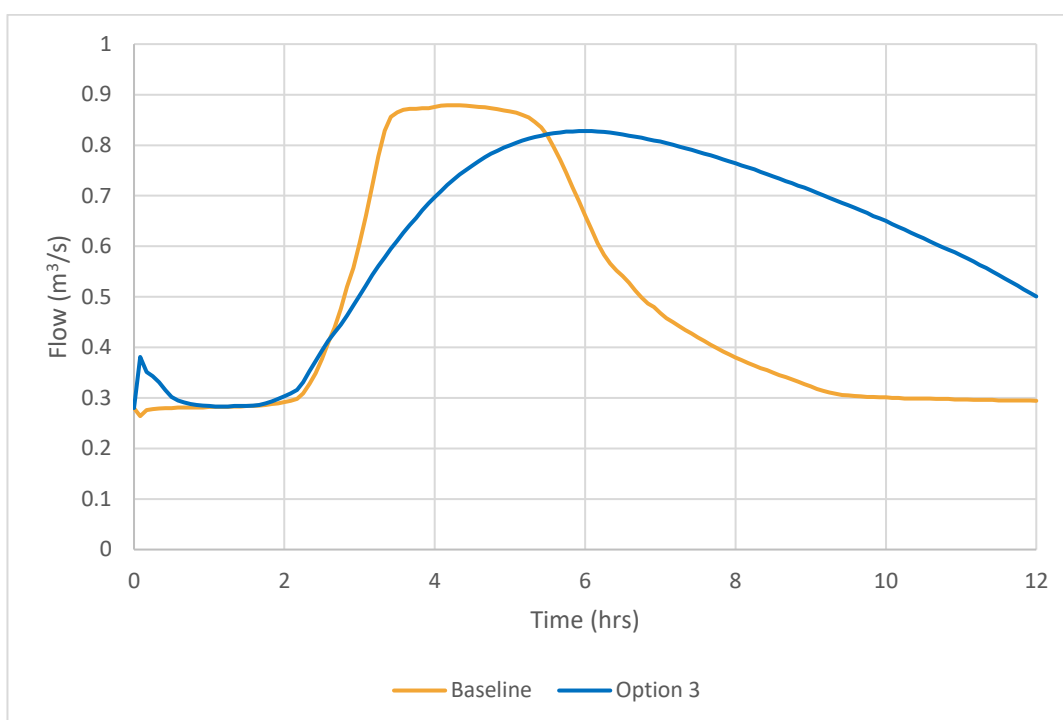


Figure 4-6 Modelled peak flow leaving the site at in the 100-year +30 % CC event – Option 3

This option manages to maintain the peak flow leaving the site, and even reduces it below its pre-development value. Additionally, flood waters are retained within the channel throughout the model. However, the viability of this option was questioned as a) widening the channel would generate environmental issues and b) the increase in bank heights required upstream is too significant.

#### 4.2.3 Option 4

Figure 4-7 shows the impact of Option 4 on the 100-year with 30% climate change flood extent.

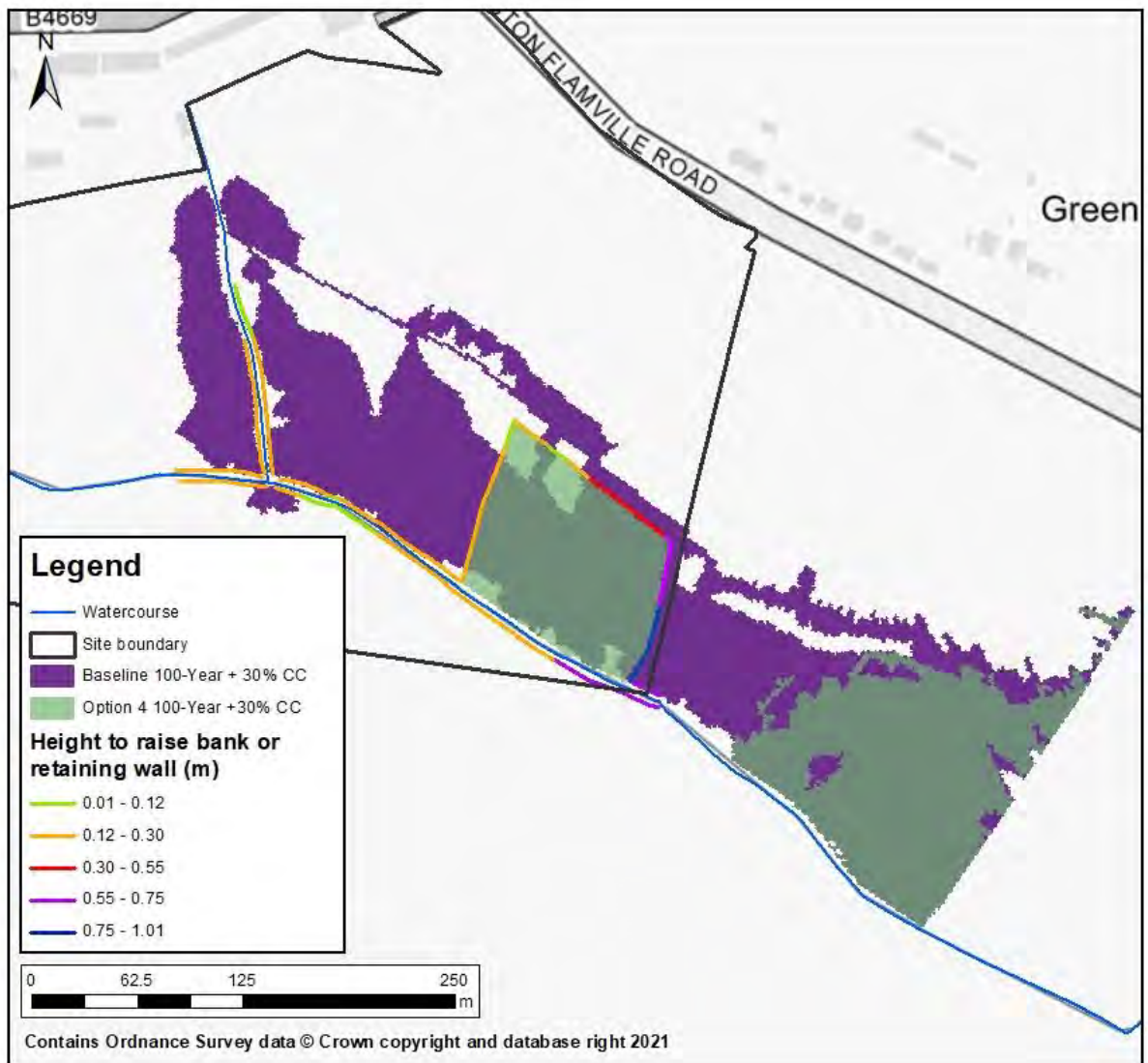


Figure 4-7 Modelled flood extents for Option 4 in the 100-year with 30 % climate change

This shows that flood waters are contained within the channel through the development site until they are allowed to spill into the proposed FSA in the southern part of the site. There is a reduced flood extent downstream of the site.

Figure 4-8 shows the peak flow leaving the site at node XS2\_4106u.

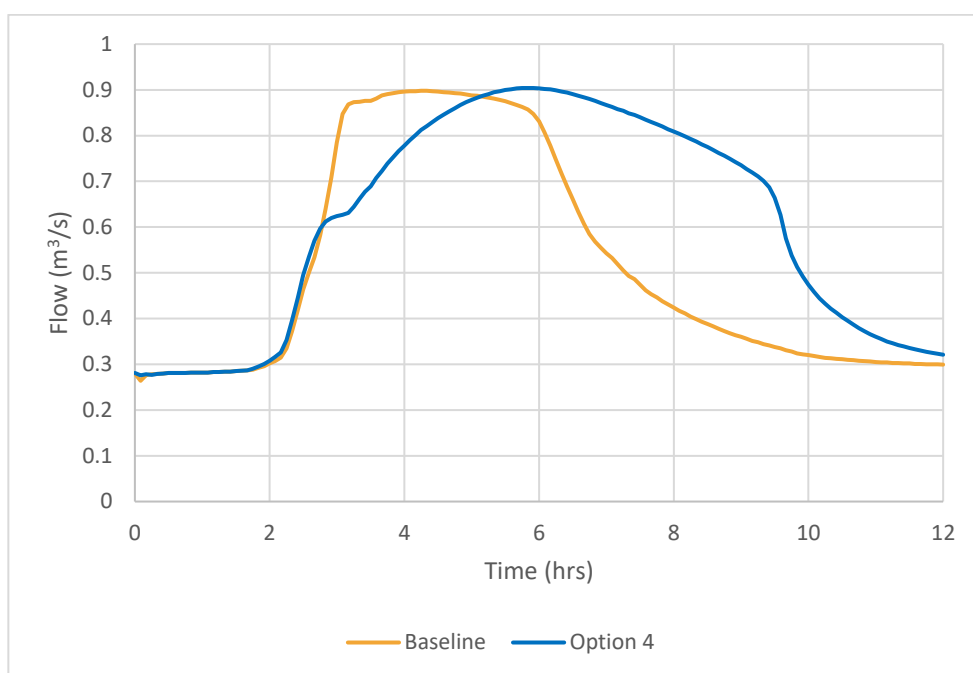


Figure 4-8 Modelled peak flow leaving the site in the 100-year +30 % CC event – Option 4

This shows that the peak flow leaving the site will not increase as a result of implementing Option 4.

Figure 4-9 shows the impacts of implementing Option 4 on flood depths through the model compared to the baseline scenario.

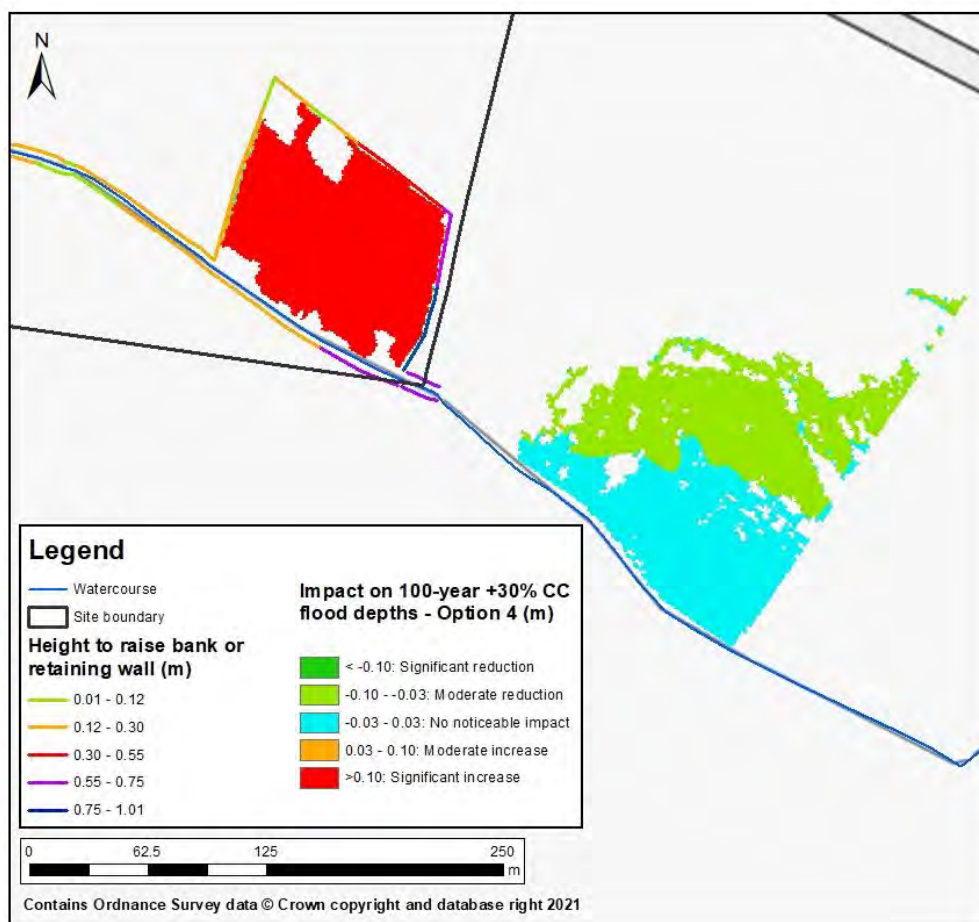


Figure 4-9 Impact on 100-year +30 % climate change flood depths - Option 4

Figure 4-9 shows that Option 4 will not generate any detrimental impacts across third-party land. As a result, Option 4 was selected as the preferred option.

## 5 Conclusions and Recommendations

The hydraulic model was run for the 20-year, 100-year, 100-year plus climate change (+30% and +50%) and for the 1,000-year fluvial flood scenarios. The model was also tested for its sensitivity to changes in Manning's roughness, downstream boundary and increase in flow.

Results from the baseline hydraulic modelling results show that:

- Flooding occurs in all modelled events due to the lack of capacity of the channel and undersized culverts which act to constrict flow and hinder the conveyance of flood water downstream
- Exceedance flows generate widespread flooding across the floodplain. Flood depths along these overland flow routes are very shallow due to the steep topography of the site.
- The peak flood depth across the site is located near the confluence between the tributary and unnamed watercourse and is estimated as 0.28m and 0.29m for the 100-year with 30% and 50% climate change scenarios, respectively.
- Water levels at the site are generally not sensitive to changes in flow, roughness value or downstream boundary conditions.

A number of post-development options were tested to reduce flood risk to the site without increasing flood risk elsewhere. Option 4 was chosen as the preferred option at this development site (Figure 4-4).

This option includes:

- The removal of three undersized culverts
- Raising of the banks of the two modelled watercourses
- The creation of a flood storage area with flow control structure at the southern end of the site
- A 1m deep low flow channel running alongside the FSA with a lowered left-hand bank to allow excess water to spill directly into the FSA.

The above combination of flood mitigation features will prevent flood water from overtopping the river channel (and thus prevent wide-spread flooding across the site) without increasing flood risk elsewhere.

## Appendices

### A Channel Survey



Whilst every effort has been made to identify all above ground details, it should be noted that some items may have been obscured at time of survey.

Below ground drainage information as been visually inspected from the surface and should therefore be treated as approximate only.

Where this survey has been carried out for the purpose of enabling trackside drainage design, the position of any running rail has been surveyed in line with a general topographic survey and should not be used for the purpose of track design.

All dimensions to be checked on site prior to design and construction.

| Control Table |             |          |           |        |
|---------------|-------------|----------|-----------|--------|
| Station       | Description | Eastings | Northings | Height |
|               |             |          |           |        |

Title: WATERCOURSE SURVEY AT  
Sherbourne Road XS, Burbage  
(Key Plan)

 **Grantham Coates  
Surveys Ltd**

Land - Engineering - Building Surveyors

2 Arden Court, Arden Road, Alcester  
Warwickshire, B49 6HN

Tel: 01789 764420

E-Mail: [info@gcsurveys.co.uk](mailto:info@gcsurveys.co.uk)  
Web Site: [www.gcsurveys.co.uk](http://www.gcsurveys.co.uk)

 THE SURVEY  
ASSOCIATION  
FULL MEMBER

 chartered  
ICES

| Date: | Notes: | Name: | Rev: |
|-------|--------|-------|------|
|       |        |       |      |
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|                              |                 |                   |                   |
|------------------------------|-----------------|-------------------|-------------------|
| Drawn:<br>MS                 | Checked:<br>JMG | Scale:<br>1:1250  | Date:<br>20/07/20 |
| File Name:<br>GCS-JBA-0877-1 |                 | Sheet size:<br>A1 | Sheet:<br>1 of 6  |



This survey should only be relied upon for its original purpose. Grantham Coates Surveys Limited accepts no responsibility for use of this plan outside of the original remit, or by use of any party other than the original client.

Whilst every effort has been made to identify all above ground details, it should be noted that some items may have been obscured at time of survey.

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All dimensions to be checked on site prior to design and construction.

|                              |     |                      |                                                                                     |
|------------------------------|-----|----------------------|-------------------------------------------------------------------------------------|
| ARN VALVE                    | AV  | WATER TAP            | TAP                                                                                 |
| BAND                         | BD  | TEMPORARY BENCH MARK | TBM                                                                                 |
| BORE HOLE                    | BH  | TELEPHONE CANY       | TEL                                                                                 |
| BUS STOP                     | BS  | TELEPHONE POST       | TEL                                                                                 |
| CABLE TELEVISION COVER       | CTV | THRESHOLD LEVEL      | THL                                                                                 |
| BT BOX                       | BTB | TRAFFIC LIGHT        | TL                                                                                  |
| CABLE TV INSPECTION COVER    | CTV | TOP OF WALL          | TOW                                                                                 |
| CEILING                      | CL  | TELEPHONE POLE       | TP                                                                                  |
| DOWN PIPE                    | DP  | UNABLE TO LIFT       | U/L                                                                                 |
| EXPOSED KERB                 | EK  | NEW CURB             | NP                                                                                  |
| ELECTRICITY CONTROL BOX      | ECB | RAIL WELD            | WE                                                                                  |
| EAVES HEIGHT                 | EH  | WATER METER          | WM                                                                                  |
| ELECTRICITY MANHOLE          | EM  | WASHOUT              | WO                                                                                  |
| ELECTRICITY POLE             | EP  |                      |                                                                                     |
| EXPOSED FLOOR                | ER  |                      |                                                                                     |
| FINISHED FLOOR LEVEL         | FFL |                      |                                                                                     |
| FIRE HYDRANT                 | FP  | SURVEY STATION       | GCS1                                                                                |
| FOUL WATER                   | FW  |                      |                                                                                     |
| GULLY                        | GU  |                      |                                                                                     |
| GATE POST                    | GP  | BUSHES               |  |
| GAS VALVE                    | GV  |                      |                                                                                     |
| INSULATED JOINT              | IJ  |                      |                                                                                     |
| INSPECTION COVER             | IC  | HEDGES               |  |
| INVERT LEVEL                 | IL  |                      |                                                                                     |
| KERB OUTLET                  | KO  | TREES                |  |
| LAMPPOST                     | LP  |                      | Height Spreads to scale)                                                            |
| LITTER BIN                   | LB  |                      |                                                                                     |
| MARKER POST                  | MP  |                      |                                                                                     |
| MANHOLE                      | MO  |                      |                                                                                     |
| RODDING EYE                  | RE  | GATE                 |  |
| RODDE HEIGHT                 | RH  |                      |                                                                                     |
| ROAD NAMEPLATE               | RN  |                      |                                                                                     |
| ROAD SIGN                    | RS  | SECURITY FENCE       |  |
| SEWER                        | SE  | FENCE                |  |
| SOFFIT LEVEL                 | SL  | OVERHEAD CABLES      |  |
| SIGNAL POST                  | SP  | FOUL WATER           |  |
| RAIL SLEEPER                 | SL  | GAS MAIN             |  |
| SIGNALS AND TELECOMS BOX     | STB | UG POWER LINE        |  |
| SIGNALS AND TELECOMS CABINET | STC | NEW CURB             |  |
| SIGNALS AND TELECOMS POST    | STP | UG TELEPHONE         |  |
| STOP SIGN                    | SN  | WATER MAIN           |  |
| STOP SIGN                    | ST  |                      |                                                                                     |
| STOP VALVE                   | SV  |                      |                                                                                     |
| STAY                         | SW  |                      |                                                                                     |
| STORM WATER                  | SW  |                      |                                                                                     |

| Station | Description | Eastings | Northings | Height |
|---------|-------------|----------|-----------|--------|
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**Grid:** OS *National Grid* **Datum:** *Ordnance Datum Newlyn*  
 Survey related to Ordnance Survey National Grid (OSGB36) via GPS and the OS Active Network.  
 A National Grid (OSGB36) coordinate has been established on site via Transformation OSTN15 and Geoid Model OSGM15, a further OS coordinate was used to orientate the survey to Ordnance Grid.  
 No scale factor has been applied to the survey

Title: WATERCOURSE SURVEY AT  
Sherbourne Road XS, Burbage  
(Cross Sections)

Client: **JBA CONSULTING**  
The Library  
St. Philip's Courtyard  
Coleshill  
Warwickshire B46 3AD



Land - Engineering - Building Surveyors

2 Arden Court, Arden Road, Alcester  
Warwickshire, B49 6HN

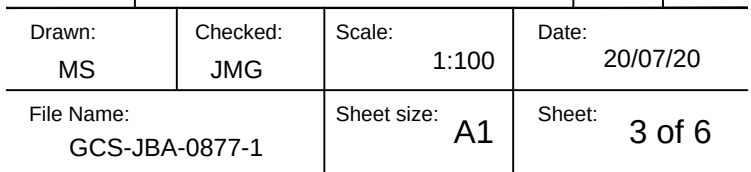


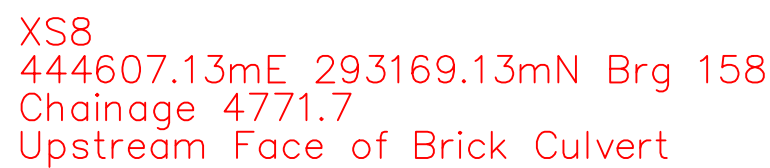
THE SURVEY  
ASSOCIATION  
FULL MEMBER

E-Mail: [info@gcsurveys.co.uk](mailto:info@gcsurveys.co.uk)  
Web Site: [www.gcsurveys.co.uk](http://www.gcsurveys.co.uk)



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This survey should only be relied upon for its original purpose. Grantham Coates Surveys Limited accepts no responsibility for use of this plan outside of the original remit, or by use of any party other than the original client.

Whilst every effort has been made to identify all above ground details, it should be noted that some items may have been obscured at time of survey.

Below ground drainage information has been visually inspected from the surface and should therefore be treated as approximate only.

Where this survey has been carried out for the purpose of enabling trackside drainage design, The position of any running rail has been surveyed in line with a general topographic survey and should not be used for the purpose of track design.

All dimensions to be checked on site prior to design and construction.

|                            |      |                      |     |
|----------------------------|------|----------------------|-----|
| AR VALVE                   | AV   | WATER TAP            | TAP |
| BOLLARD                    | BH   | TEMPORARY BENCH MARK | TBM |
| BUS STOP                   | BS   | TELEPHONE CALL BOX   | TCS |
| BUS STOP TELEPHONE COVER   | BT   | TELEPHONE POST       | TEL |
| BT BOX                     | BTB  | THRESHOLD LEVEL      | TL  |
| CABLE TV INSPECTION COVER  | CTV  | TRAFFIC LIGHT        | TOL |
| CABLE TV                   | CTV  | TOP OF WALL          | TOW |
| DOWN PIPE                  | DP   | TELEGRAPHIC POLE     | TP  |
| DOWN INSPECTION KERB       | DI   | UNABLE TO LEVEL      | U/L |
| ELECTRICITY CONTROL BOX    | ECB  | UP                   | UP  |
| EAVES HIGHT                | ECH  | RAIL WELD            | WE  |
| ELECTRICITY MANHOLE        | EM   | WATER METER          | WM  |
| ELECTRICITY POLE           | EP   | WASHCUP              | WU  |
| FAIR ROAD                  | ER   |                      |     |
| FINISHED FLOOR LEVEL       | FFL  |                      |     |
| FIRE HYDRANT               | FW   |                      |     |
| FLY                        | FLY  |                      |     |
| GULLY                      | G    |                      |     |
| GATE POST                  | GP   |                      |     |
| GAZ VALVE                  | GV   |                      |     |
| INSULATED JOINT            | IJ   |                      |     |
| INSPECTION COVER           | IC   |                      |     |
| INVERT LEVEL               | IL   |                      |     |
| KERB OUTLET                | KO   |                      |     |
| LAMPPOST                   | LP   |                      |     |
| LITTER BIN                 | LB   |                      |     |
| MARKER POST                | MP   |                      |     |
| MALE POST                  | MK   |                      |     |
| PO                         | PO   |                      |     |
| RODDING EYE                | RE   |                      |     |
| RODDE HIGHT                | RH   |                      |     |
| ROAD NAMEPLATE             | RN   |                      |     |
| ROAD SIGN                  | RS   |                      |     |
| SE                         | SE   |                      |     |
| SOFFIT LEVEL               | SF   |                      |     |
| SIGNAL POST                | SP   |                      |     |
| SIGNALS AND TELECOMS BOX   | STB  |                      |     |
| SIGNALS AND TELECOMS       | STG  |                      |     |
| SIGNALS AND TELECOMS CABLE | STC  |                      |     |
| SIGNALS AND TELECOMS STOP  | STN  |                      |     |
| SIGNAL STOP                | STP  |                      |     |
| STOP VALVE                 | SV   |                      |     |
| STAY                       | STAY |                      |     |
| STORM WATER                | SW   |                      |     |

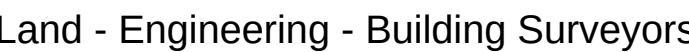
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**Grid:** *OS National Grid* **Datum:** *Ordnance Datum Newlyn*  
Survey related to Ordnance Survey National Grid (OSGB36) via GPS and the OS Active Network.  
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No scale factor has been applied to the survey

Title: WATERCOURSE SURVEY AT  
Sherbourne Road XS, Burbage  
(Cross Sections)

Client:

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The Library  
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Warwickshire B46 3AD



2 Arden Court, Arden Road, Alcester  
Warwickshire, B49 6HN

Tel: 01789 764420

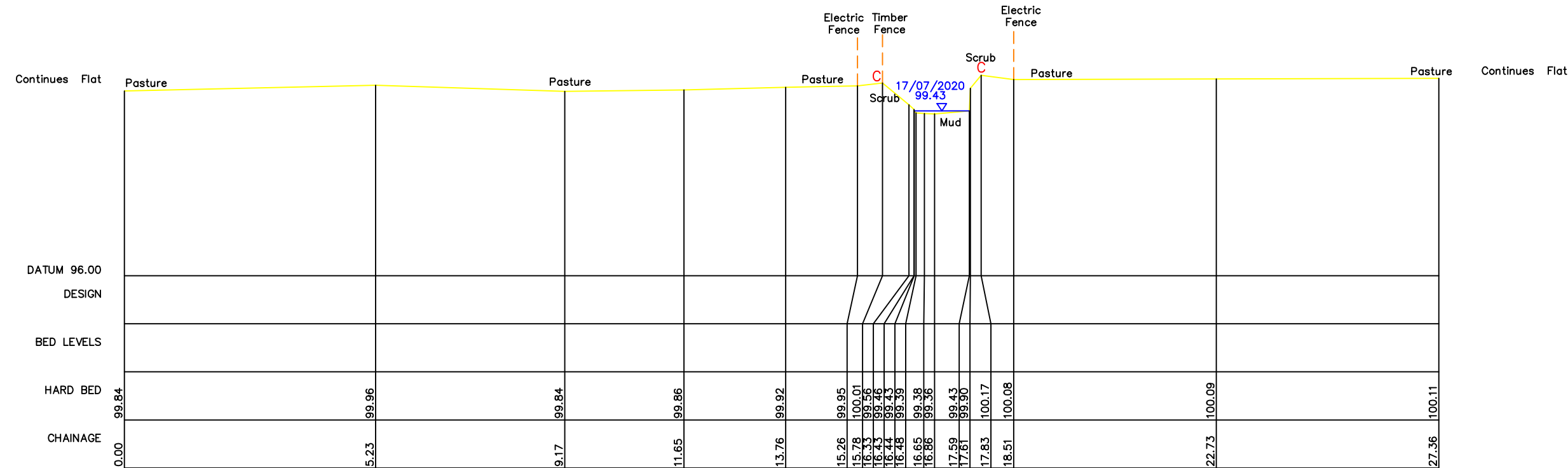
**THE SURVEY ASSOCIATION**  
FULL MEMBER

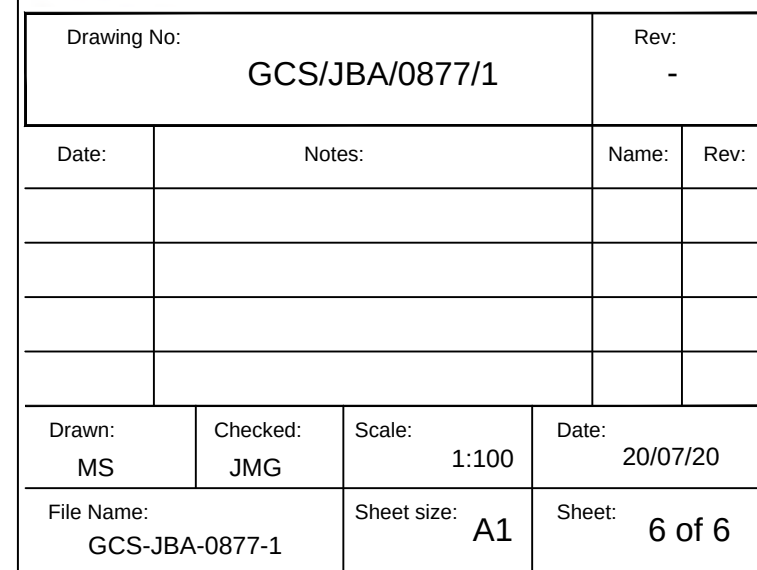
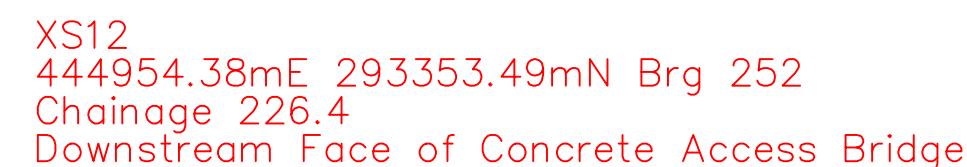
E-Mail: [info@gcsurveys.co.uk](mailto:info@gcsurveys.co.uk)  
Web Site: [www.gcsurveys.co.uk](http://www.gcsurveys.co.uk)



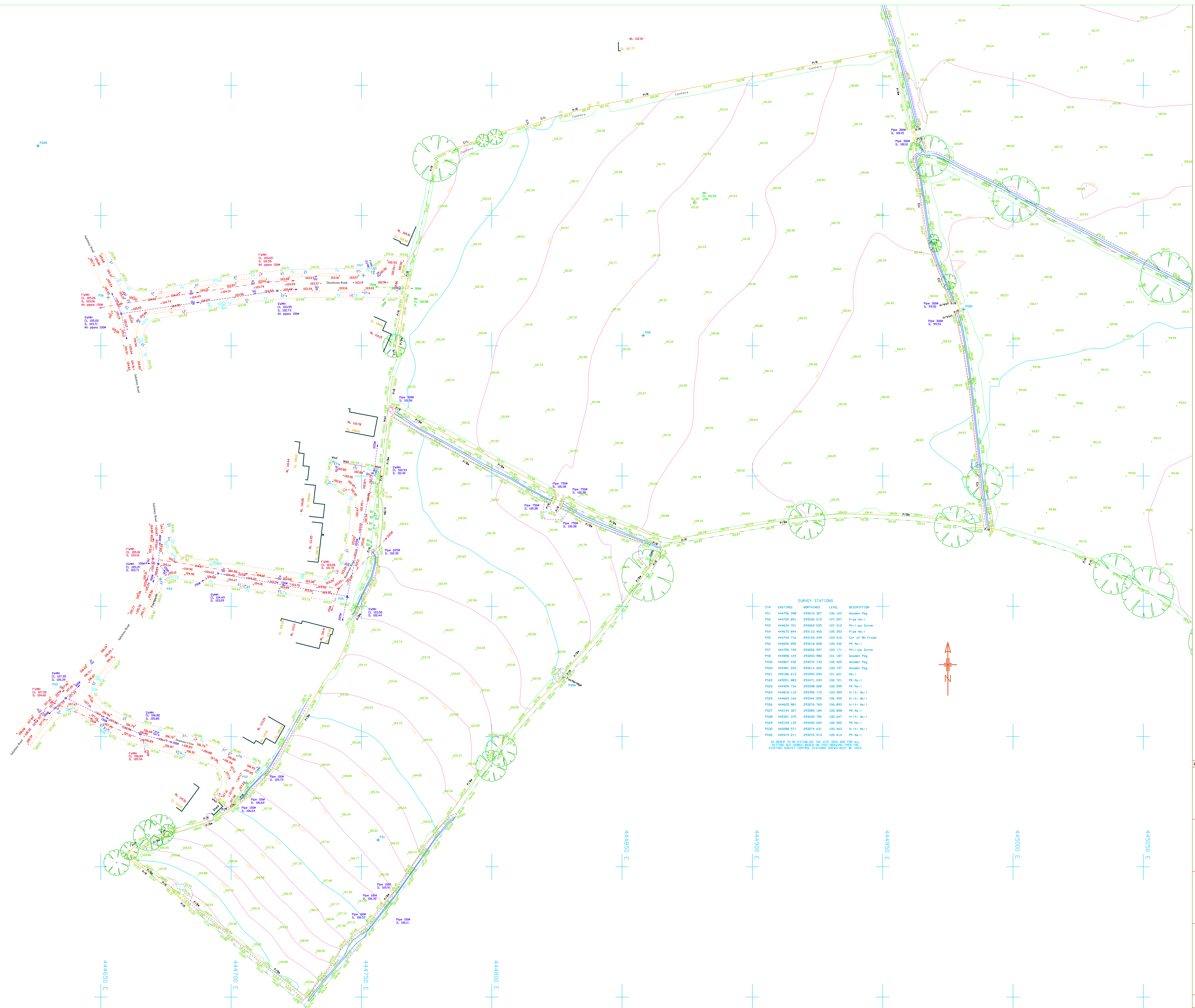
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| GCS-JBA-0877-1 |  |          |  | A1             |  | 4 of 6   |  |      |  |

REACH 2





## B Topographic survey



## SURVEY NOTES

1. THE SURVEY GRID (OSGB36) WAS ESTABLISHED WITH GPS AND THEN A ONE POINT SITE CENTRED TRANSFORMATION CARRIED OUT TO ELIMINATE SCALE FACTOR. IN ORDER TO RE-ESTABLISH THE SITE GRID THEN THE EXISTING SURVEY CONTROL STATIONS MUST BE USED

[illegible]

## STREET FURNITURE

[illegible]

INFORMATION SHOWN ON THIS DRAWING  
IS SURVEYED TO THE ACCURACY OF THE BASE

MAN ENTRY TO SEWERS HAS NOT BEEN UNDERTAKEN. DEPTHS, PIPE SIZES ARE MEASURED/ESTIMATED FROM THE GROUND. ALL SEWER DETAILS TO BE CHECKED WITH LOCAL AUTHORITY RECORDS OR ON SITE PRIOR TO COMMENCEMENT OF WORKS.

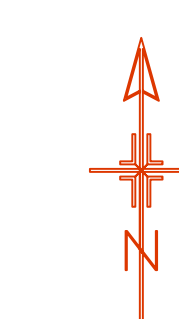
BOUNDARIES SHOWN ARE PHYSICAL  
FEATURES AND MAY NOT REPRESENT LEGALLY

ALL TREE HEIGHTS AND SPREADS ARE APPROXIMATE.  
TREE TYPES WHICH HAVE BEEN IDENTIFIED SHOULD  
BE CHECKED BY A TREE SPECIALIST.

WHERE ADJACENT BUILDINGS HAVE BEEN SURVEYED  
REMOVEDLY NOT ALL EXTERNAL WALLS MAYBE  
SHOWN DUE TO OBSTRUCTIONS ALONG LINE OF  
SIGHT

| SURVEY STATIONS |            |            |         |                |
|-----------------|------------|------------|---------|----------------|
| STN             | EASTINGS   | NORTHINGS  | LEVEL   | DESCRIPTION    |
| P51             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P52             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P53             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P54             | 444634.701 | 931013.429 | 107.132 | Water in Scree |
| P55             | 444674.844 | 931013.429 | 105.353 | Pipe Nail      |
| P56             | 444744.716 | 931013.449 | 103.512 | Gr of Mt. Hira |
| P57             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P58             | 444730.745 | 930828.997 | 103.171 | Water in Scree |
| P59             | 444658.124 | 931026.991 | 101.187 | Wooden Peg     |
| P60             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P61             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P62             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P63             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P64             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P65             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P66             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P67             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P68             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P69             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P70             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P71             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P72             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P73             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P74             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P75             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P76             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P77             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P78             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P79             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P80             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P81             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P82             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P83             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P84             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P85             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P86             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P87             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P88             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P89             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P90             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P91             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P92             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P93             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P94             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P95             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P96             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P97             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P98             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P99             | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |
| P100            | 444675.298 | 930900.337 | 106.163 | Wooden Peg     |

IN ORDER TO RE-ESTABLISH THE SITE GRID AND FOR ALL  
SETTING OUT WORKS BASED ON THIS DRAWING THEN THE  
EXISTING SURVEY CONTROL STATIONS SHOWN MUST BE USED



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| A   | 28/07/20 | FIELDS TO THE EAST ADDED | GRA | AL |
| REV | DATE     | DESCRIPTION              | BY  | AP |



Client



Project Title

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| Date: 04/04/2013  | Scale: 1/500 | Sheet Size: A0 |
| Dep. No. S3396-01 |              | Rev. A         |

## SURVEY NOTES

1. THE SURVEY GRID (COSG036) WAS ESTABLISHED WITH GPS AND THEN A ONE POINT SITE CENTRED TRANSFORMATION CARRIED OUT TO ELIMINATE SCALE FACTOR. IN ORDER TO RE-ESTABLISH THE SITE GRID THEN THE EXISTING SURVEY CONTROL STATIONS SHOWN MUST BE USED.

[illegible]

## STREET FURNITURE

|                  |      |                              |
|------------------|------|------------------------------|
| Alene Bore       | BB   | Marker Post                  |
| Alene Bore       | BB   | Mark Post                    |
| Alene Bore       | BB   | Pillar Box                   |
| Auto Stop        | BS   | Pipe                         |
| Auto Stop        | BS   | Pipe                         |
| Electric Pole    | EP   | Pumping Water                |
| Electric Pole    | EP   | Post                         |
| Flood Light      | FL   | Rodding Eye                  |
| Flood Light      | FL   | Refraction Post              |
| Gate Post        | GP   | Road Sign                    |
| Gully            | GU   | Stack Lock                   |
| Gully            | GU   | Stop Sign                    |
| Inspection Cover | IC   | Sign                         |
| Litter Bin       | LB   | Slump                        |
| Lane Post        | LP   | Stop Valve                   |
| Traffic Light    | TL   | Telegraph Pole               |
| Manhole          | MH   | Vent Pipe                    |
| Manhole          | MH   | Telecommunication            |
| Fire Hydrant     | PH   | Water Tap                    |
| Wash Out         | WO   | Ward Outlet                  |
| Water Meter      | WM   | Water Valve                  |
| Cable Television | TV   | Tell Coil Box                |
| Earth Rod        | ER   | Trial Pin                    |
| Earth Rod        | ER   | Dissect Circuit Test         |
| Central Light    | Ca/L | Multi Utility Pole (EP/LATP) |

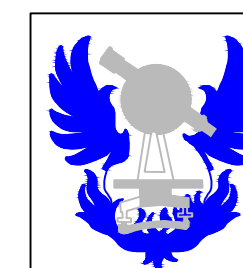
MAN ENTRY TO SEWERS HAS NOT BEEN UNDERTAKEN. DEPTHS, PIPE SIZES ARE MEASURED/ESTIMATED FROM THE GROUND. ALL SEWER DETAILS TO BE CHECKED WITH LOCAL AUTHORITY RECORDS OR ON SITE PRIOR TO COMMENCEMENT OF

BOUNDARIES SHOWN ARE PHYSICAL  
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CONVEYED OWNERSHIP

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REMOVEDLY NOT ALL EXTERNAL WALLS MAYBE  
SHOWN DUE TO OBSTRUCTIONS ALONG LINE OF  
SIGHT

| REV | DATE | DESCRIPTION | BY |
|-----|------|-------------|----|
|-----|------|-------------|----|



**Phoenix Survey  
Services Ltd.**  
49 William Road, Long Buckby, Northampton  
NN6 7YS  
Tel 07768 996511 or 07810 752133  
or 07876 658389 Fax 01327 843294  
Email info@phoenixsurveysservices.co.uk

Client



Project Title

Dorchester Road  
Burbage

Drawing Title

Topographical Survey  
Sheet 2 of 3

|                        |                |                  |
|------------------------|----------------|------------------|
| Drawn<br>GRA           | Checked<br>ALB | Approved<br>GRA  |
| Date<br>28/07/2020     | Scale<br>1/500 | Sheet Size<br>A0 |
| Desig. No.<br>S3396-02 |                | Rev              |



## C Model 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:

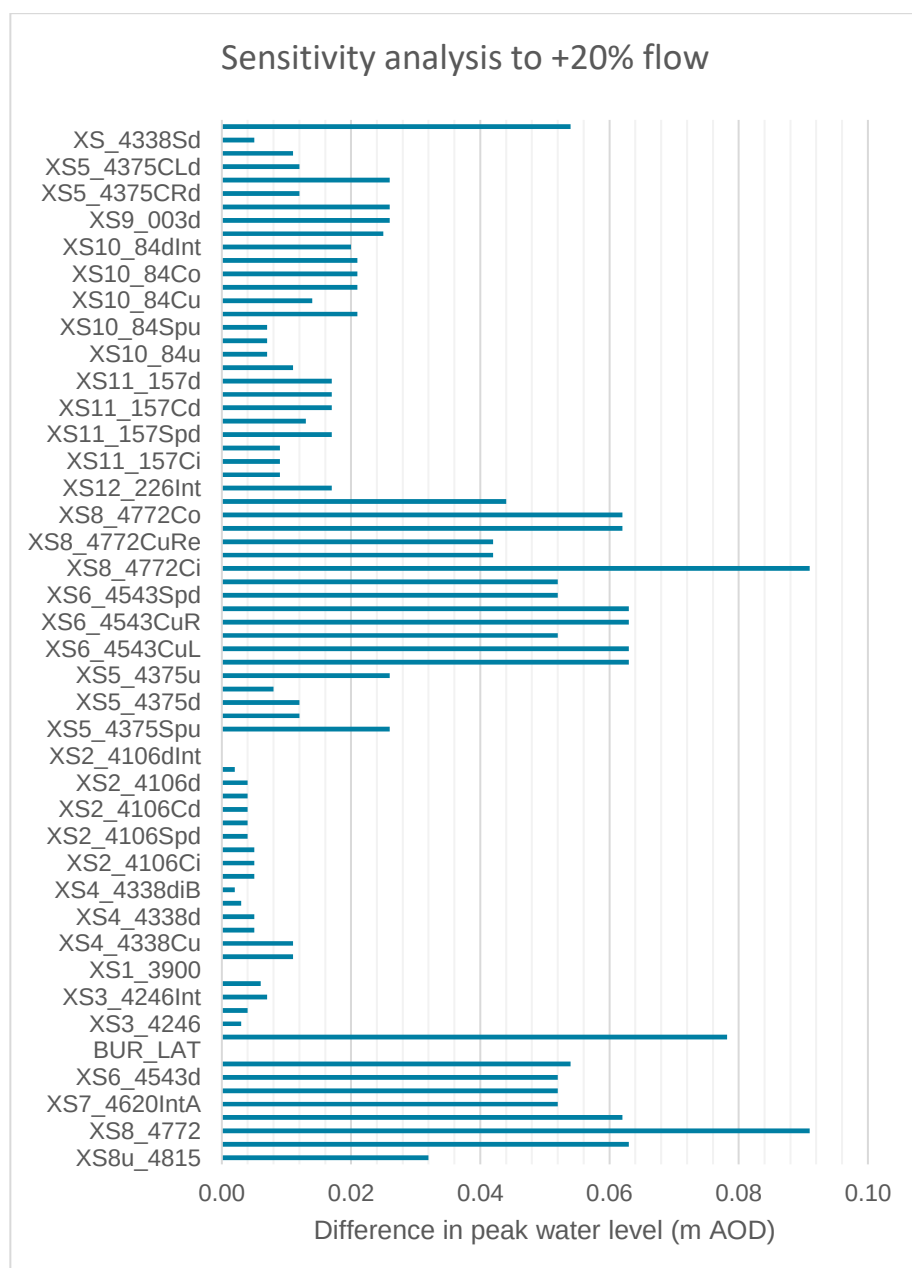
- Changing flows by + 20%;
- Changing the Manning's n values by + 20%. This was applied both in the 1D ESTRY and in the 2D TUFLOW domain, and;
- Altering the downstream boundary by + 250mm in the 1D domain.

### C.1 Sensitivity to flow

Figure B-5-1 shows the changes in peak water level compared to the baseline 100-year event when an increase of 20% is applied to all inflows respectively. The average change in peak water levels at model nodes due to a 20% increase in flow is 0.02 m.

The node which has the greatest sensitivity to an increase of 20% flow is XS8\_4772 with an increase of 0.09 m.

Figure B-5-1 Sensitivity to changes in increase in flow

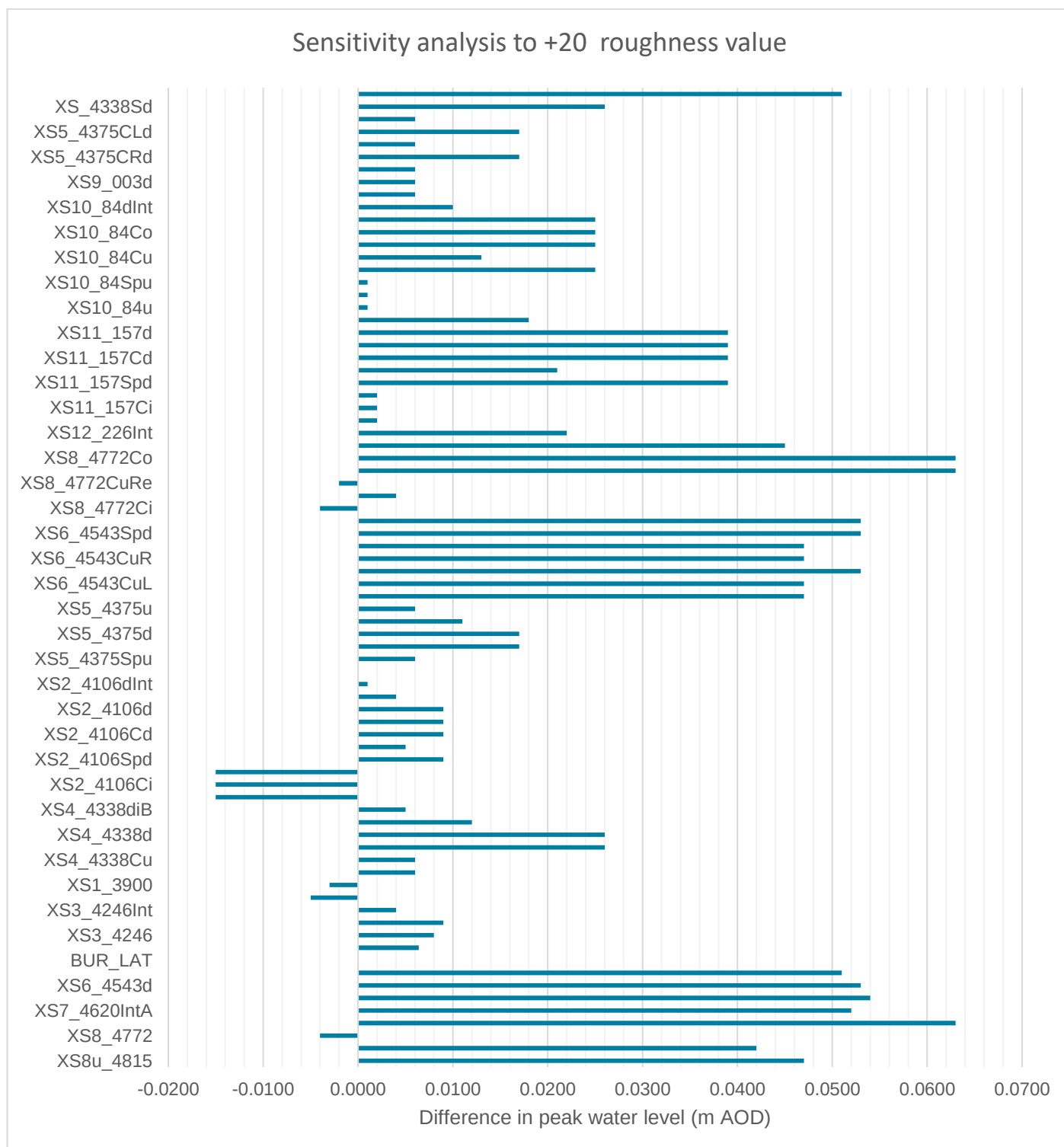


## C.2 Sensitivity to roughness

Figure B-5-2 shows the changes in peak water level compared to the baseline 100-year event when a change of + 20% is applied to Manning's 'n' in both the 1D and 2D domains.

The node in the model which is most sensitive to a change in the roughness values is XS8\_4772, which had the maximum change for the increase of 20% sensitivity of 0.063m. The average change across all model nodes in peak water level due to a 20% increase in roughness is 0.02m.

Figure B-5-2 Sensitivity to changes in increase in roughness

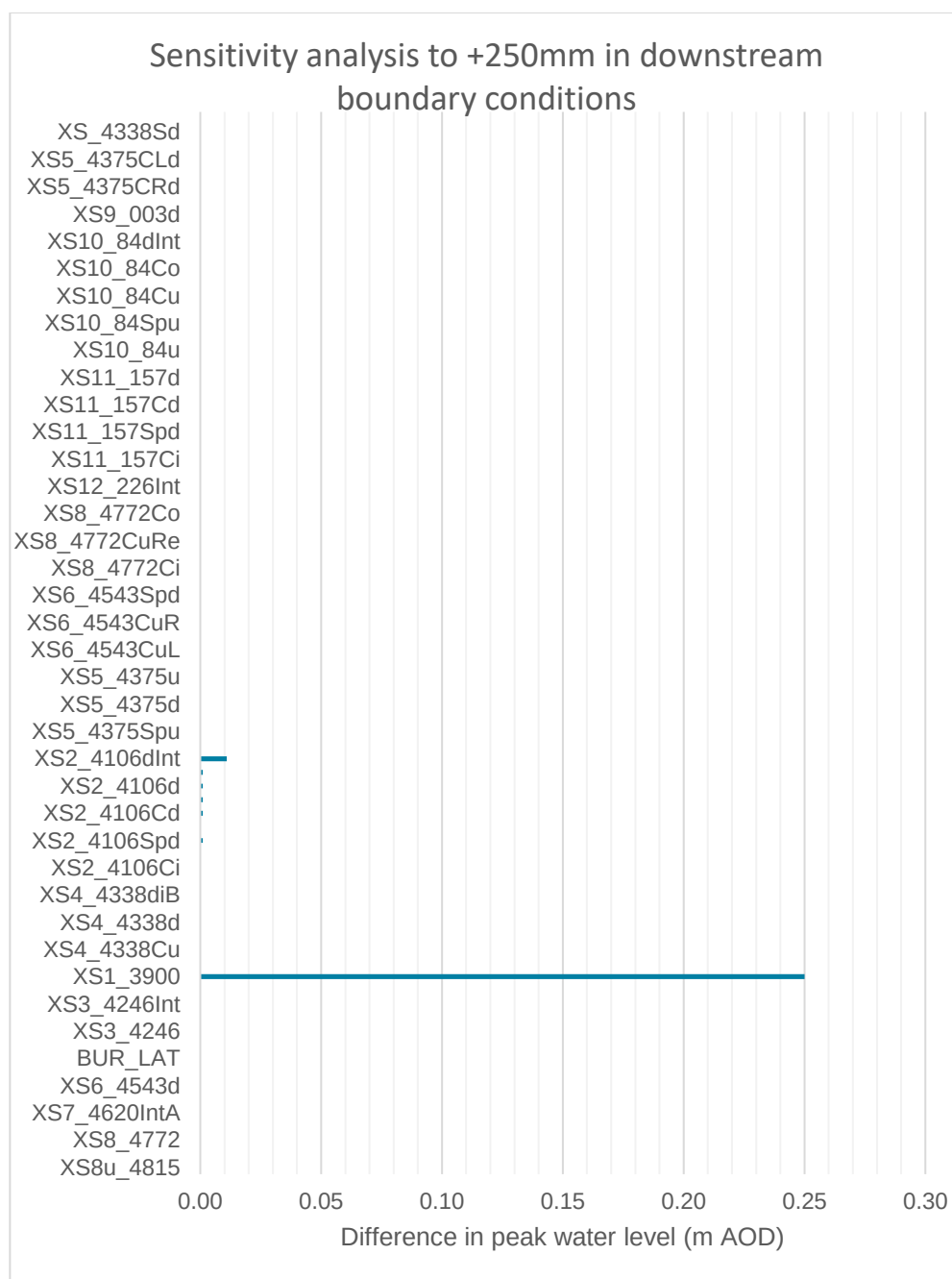


### C.3 Sensitivity to Downstream boundary

Changes in peak water level compared to the baseline 100-year event when a change of + 250mm was applied to the downstream 'head-flow' model boundary condition.

The maximum change in the downstream boundary change sensitivity is seen within the node connected to the downstream (XS1\_3900). Here the change seen is +/- 0.25m respectively. The changes in peak water levels due to a change in the downstream boundary level do not extend upstream to model nodes within the site boundary. The results of this test show that the model is not sensitive to changes in the downstream boundary conditions.

Figure B-5-3 Sensitivity to changes in increase in downstream boundary conditions



## D Key Hydraulic Structures

### D.1 Concrete Culvert – XS 8 (main channel)

|                                  |                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS8 – upstream face                                                                                                                                                                                                                                                                                                                                                          |
| Included in model?               | Yes. Open channel cross section added upstream.                                                                                                                                                                                                                                                                                                                              |
| Model label                      | XS8_4772 to XS7_4620                                                                                                                                                                                                                                                                                                                                                         |
| Type                             | Concrete pipe<br>152m long<br>0.680m diameter                                                                                                                                                                                                                                                                                                                                |
| How has structure been modelled? | Represented in Flood Modeller using circular conduit units. A replicate unit was modelled at the mid-point of the culvert due to the culvert length. The drop in bed level at this unit was calculated using an average gradient along the length of the culvert.<br><br>Overtopping of the structure was represented within the 2D domain due to the length of the culvert. |
| Photographs                      | <p>Upstream face of culvert (XS8)</p>  <p>Downstream face of culvert (XS7)</p>                                                                                                                        |

## D.2 Concrete culvert – XS 6 (main channel)

|                                  |                                                                                                                                                                                                                     |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS6 – downstream face                                                                                                                                                                                               |
| Included in model?               | Yes                                                                                                                                                                                                                 |
| Model label                      | XS6_4543u to XS6_4543d                                                                                                                                                                                              |
| Type                             | Concrete pipe culverts with an access crossing above<br>0.700 m diameter<br>4.7 m long                                                                                                                              |
| How has structure been modelled? | Two concrete culvert pipes were surveyed by GCS. Both were represented using orifice units.<br>Overtopping of the structure was represented in the 1D domain using a spill unit.                                    |
| Photographs                      | <p>Access bridge</p>  <p>Concrete pipes</p>  |

## D.3 Concrete culvert – XS 5 (main channel)

|                        |                                                      |
|------------------------|------------------------------------------------------|
| Surveyed Cross Section | XS5 – upstream face                                  |
| Included in model?     | Yes                                                  |
| Model label            | XS5_4375u to XS5_4375d                               |
| Type                   | Concrete pipe culverts with an access crossing above |

|                                  |                                                                                                                                                                                                              |
|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  | 0.700 m diameter<br>5 m long                                                                                                                                                                                 |
| How has structure been modelled? | Two concrete culvert pipes were surveyed by GCS. Both were represented in Flood Modeller using circular conduit units.<br>Overtopping of the structures was represented in the 1D domain using a spill unit. |
| Photographs                      | Concrete pipes cross beneath the access bridge<br>                                                                        |

#### D.4 Concrete culvert – XS 4 (main channel)

|                                  |                                                                                                                                                            |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS4 – upstream face                                                                                                                                        |
| Included in model?               | Yes                                                                                                                                                        |
| Model label                      | XS4_4338u to XS4_4338d                                                                                                                                     |
| Type                             | Concrete pipe culvert with an access crossing above<br>1 m diameter<br>4.2 m long                                                                          |
| How has structure been modelled? | Culvert represented in Flood Modeller using a circular conduit unit.<br>Overtopping of the structures was represented in the 1D domain using a spill unit. |
| Photographs                      | Culvert passing beneath access bridge<br>                              |

#### D.5 Concrete culvert – XS 2 (main channel)

|                                  |                                                                                                                                                         |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS2 – upstream face                                                                                                                                     |
| Included in model?               | Yes                                                                                                                                                     |
| Model label                      | XS2_4106u to XS2_4106d                                                                                                                                  |
| Type                             | Concrete pipe culvert with an access crossing above<br>1 m diameter, 4.4 m long                                                                         |
| How has structure been modelled? | Culvert represented in Flood Modeller using a circular conduit unit. Overtopping of the structures was represented in the 1D domain using a spill unit. |
| Photographs                      | <p>Culvert opening beneath access bridge</p>                         |

#### D.6 Culvert – XS 11 (tributary channel)

|                                  |                                                                                                                                                         |
|----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS11 – upstream face                                                                                                                                    |
| Included in model?               | Yes                                                                                                                                                     |
| Model label                      | XS11_157u to XS11_157d                                                                                                                                  |
| Type                             | Culvert with an access crossing above<br>0.300 m diameter, 5.5 m long                                                                                   |
| How has structure been modelled? | Culvert represented in Flood Modeller using a circular conduit unit. Overtopping of the structures was represented in the 1D domain using a spill unit. |
| Photographs                      | <p>Culvert beneath access track, brick headwall</p>                 |

#### D.7 Culvert – XS 10 (tributary channel)

|                                  |                                                                                                                                                                                                                                                  |
|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Surveyed Cross Section           | XS10 – downstream face                                                                                                                                                                                                                           |
| Included in model?               | Yes                                                                                                                                                                                                                                              |
| Model label                      | XS10_84u to XS10_84d                                                                                                                                                                                                                             |
| Type                             | Culvert with an access crossing above<br>0.300 m diameter<br>5.6 m long                                                                                                                                                                          |
| How has structure been modelled? | Culvert represented in Flood Modeller using a circular conduit unit.<br>Overtopping of the structures was represented in the 1D domain using a spill unit.                                                                                       |
| Photographs                      | <p>Access track which culvert passes beneath</p>  <p>Culvert opening</p>  |

## E Hydrological Assessment

# Flood estimation report: Sherborne Road, Burbage

## Introduction

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

## Contents

|   |                                               |    |
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## Approval

|                               | Name and qualifications                     | Date       |
|-------------------------------|---------------------------------------------|------------|
| Method statement prepared by: | Bryony McLeod BSc MSc                       | 22/07/2020 |
| Method statement reviewed by: | Eva Kordomenidi BSc MSc MCIWEM<br>CWEM CSci | 22/07/2020 |
| Calculations prepared by:     | Bryony McLeod BSc MSc                       | 22/07/2020 |
| Calculations reviewed by:     | Eva Kordomenidi BSc MSc MCIWEM<br>CWEM CSci | 22/07/2020 |

## Revision History

| Revision reference | Date issued | Amendments | Issued to |
|--------------------|-------------|------------|-----------|
|                    |             |            |           |
|                    |             |            |           |
|                    |             |            |           |

## Abbreviations

|                  |                                                                       |
|------------------|-----------------------------------------------------------------------|
| AM.....          | Annual Maximum                                                        |
| AREA .....       | Catchment area (km <sup>2</sup> )                                     |
| 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

|                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Overview</b></p> <ul style="list-style-type: none"> <li>• Purpose of study</li> <li>• Peak flows or hydrographs?</li> <li>• Range of return periods and locations</li> </ul> | <p>A flood risk assessment is to be undertaken for a site by Sherborne Road, Burbage. There is an existing 2013 model developed for the site, since this FEH methods have been updated, prompting a requirement to update inflows for the model. The previous approach used a mix of the ReFH method for rural areas and modified rational for impermeable locations.</p> <p>The watercourse is at the upstream end of a tributary to Soar Brook, itself a tributary to the River Soar. Three inflow points are required, with much of the catchment urbanised.</p> |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

## 1.2 The catchment

|                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Map</p>                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p><b>Legend</b></p> <ul style="list-style-type: none"> <li>• Flow estimation points</li> <li>□ FEH Catchment boundary</li> </ul>                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p>Contains OS data © Crown copyright and database right 2020</p>                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <p><b>Description</b></p> <p>Include topography, climate, geology, soils, land use and any unusual features that may affect the flood hydrology.</p> | <p>This is a small urbanised catchment, with the main site of interest on agricultural land. The downstream flow estimation point is located on the Soar Brook at the smallest FEH catchment boundary. Upstream of this point the watercourse is in small ditches through the rural location. The development site is mostly flat, the Burbage village to the west is on a slope towards the site.</p> <p>The catchment geology consists of mudstone, which is slow-draining and so tends to have a higher run-off rate.</p> |

### 1.3 Source of flood peak data

|        |                                                                                                           |
|--------|-----------------------------------------------------------------------------------------------------------|
| Source | NRFA peak flows dataset, Version 8, released September 2019. This contains data up to water year 2017-18. |
|--------|-----------------------------------------------------------------------------------------------------------|

### 1.4 Hydrological understanding of catchment

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Outline the conceptual model, addressing questions such as:</p> <ul style="list-style-type: none"> <li>Where are the main sites of interest?</li> <li>What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...)</li> <li>Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?</li> <li>Is there a need to consider temporary debris dams that could collapse?</li> </ul>                                                                                                                   | <p>Three upstream FEPs are required which are located on small drains and the catchments are too small for the FEH web service. The downstream FEP is only located on Soar Brook</p> <p>The upstream FEPs are located at the urban/rural boundary and for A &amp; C at the onset of the watercourse.</p> |
| <p>Any unusual catchment features to take into account?</p> <p>e.g.</p> <ul style="list-style-type: none"> <li>highly permeable – avoid ReFH if BFIHOST&gt;0.65, consider permeable catchment adjustment for statistical method if SPRHOST&lt;20%</li> <li>highly urbanised – seek local flow data; consider method that can account for differing sewer and topographic catchments</li> <li>pumped watercourse – consider lowland catchment version of rainfall-runoff method</li> <li>major reservoir influence (FARL&lt;0.90) – consider flood routing, extensive floodplain storage – consider choice of method carefully</li> </ul> | <p>Highly urbanised requires the use of ReFH2 method which accounts for runoff over paved surfaces. The sub-catchments have very small areas. It is recommended that flows are scaled based on relative catchment size from the FEH catchment than calculated for the FEH Statistical method.</p>        |

### 1.5 Initial choice of approach

|                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                          |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Is FEH appropriate? (it may not be for extremely heavily urbanised or complex catchments) If not, describe other methods to be used.</p>                                | <p>Catchment, and area of interest, are heavily urbanised. Due to a lack of gauged flow measurements in the catchment, the FEH statistical method is unlikely to be suitable but will be considered for comparison purposes. As such ReFH2 will be used, which accounts for paved surfaces within the catchment.</p>                                                                     |
| <p>Initial choice of method(s) and reasons</p> <p>How will hydrograph shapes be derived if needed?</p> <p>Will the catchment be split into sub-catchments? If so, how?</p> | <p>ReFH2 will be the main choice of method for calculating the growth curve and hydrograph shapes for the upstream and downstream flow estimation points.</p> <p>The sub-catchment inflows will be calculated by applying the FEH methods to the SR_DS catchment, and then being scaled based on the ratio of catchment areas as recommended for catchments below 0.5km<sup>2</sup>.</p> |

|                                            |                                                                           |
|--------------------------------------------|---------------------------------------------------------------------------|
| Software to be used (with version numbers) | FEH Web Service <sup>1</sup> / WINFAP-FEH v3.0.003 <sup>2</sup> / ReFH2.3 |
|--------------------------------------------|---------------------------------------------------------------------------|

## 1.6 Gauging stations (flow or level)

There is a gauging station downstream of the subject site on the River Soar. It is unlikely to be representative of the subject site.

| Water-course | Station name | Gauging authority number | NRFA number (used in FEH) | Grid reference | Catchment area (km <sup>2</sup> ) | Type (rated / ultrasonic / level...) | Start and end of flow record |
|--------------|--------------|--------------------------|---------------------------|----------------|-----------------------------------|--------------------------------------|------------------------------|
| River Soar   | Littlethorpe | 4082                     | 28082                     | 374350, 406850 | 183.9                             | Electro-magnetic and rated           | 08/1971 -present             |

## 1.7 Available flood history data

The Environment Agencies recorded flood outlines showed no flood history in the model study area. A search of flood history indicates Burbage and Hinckley are at risk of flooding from the River Anker; this does not include the site of interest.

<sup>1</sup> CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, Oxon, UK.

<sup>2</sup> WINFAP-FEH v3 © Wallingford HydroSolutions Limited and NERC (CEH) 2009.  
JBA FEH calculation record\_Sherborne Rd.docx

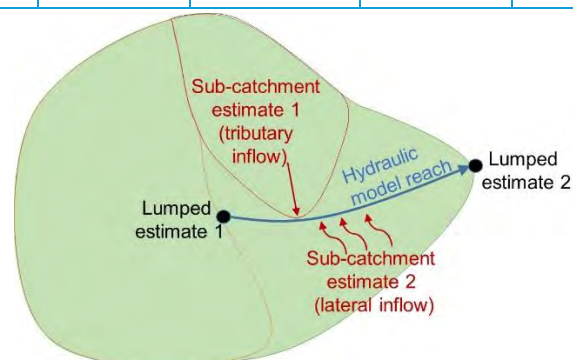
## 2 Locations where flood estimates required

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<br>L: lumped catchment<br>S: Sub-catchment | Watercourse          | Name or description of site                               | Easting | Northing | AREA on FEH CD-ROM (km <sup>2</sup> ) | Revised AREA if altered |
|-----------|-------------------------------------------------------------|----------------------|-----------------------------------------------------------|---------|----------|---------------------------------------|-------------------------|
| SR_DS     | L                                                           | Soar Brook           | Downstream extent of model, and location of FEH catchment | 445000  | 293150   | 0.55                                  | 0.74                    |
| A         | S                                                           | Soar Brook tributary | One of the upstream model extents for flow estimate       | 444954  | 293312   | N/A                                   | 0.27                    |
| B         | S                                                           | Soar Brook tributary | One of the upstream model extents for flow estimate       | 444761  | 293177   | N/A                                   | 0.29                    |
| C         | S                                                           | Soar Brook tributary | One of the upstream model extents for flow estimate       | 444730  | 292945   | N/A                                   | 0.06                    |

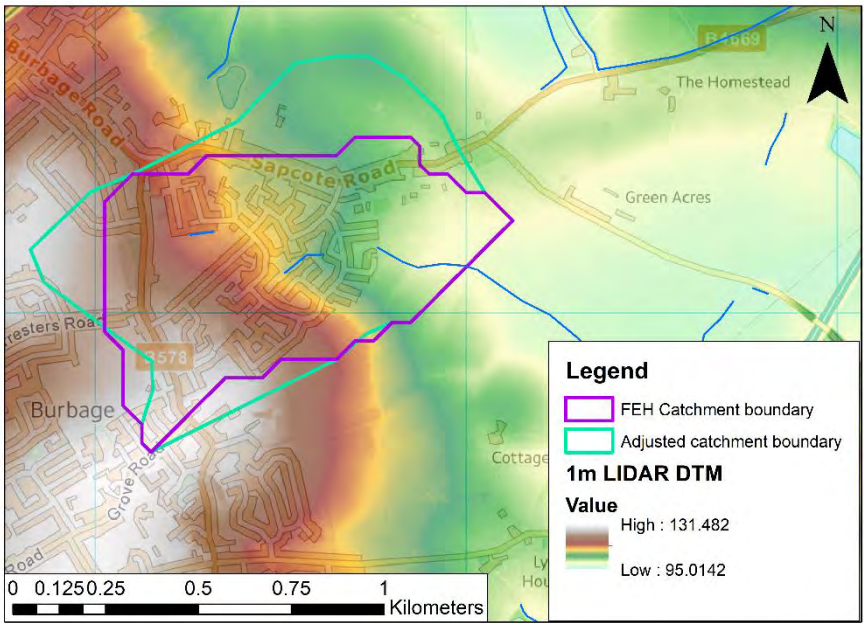
Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required. Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, 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)

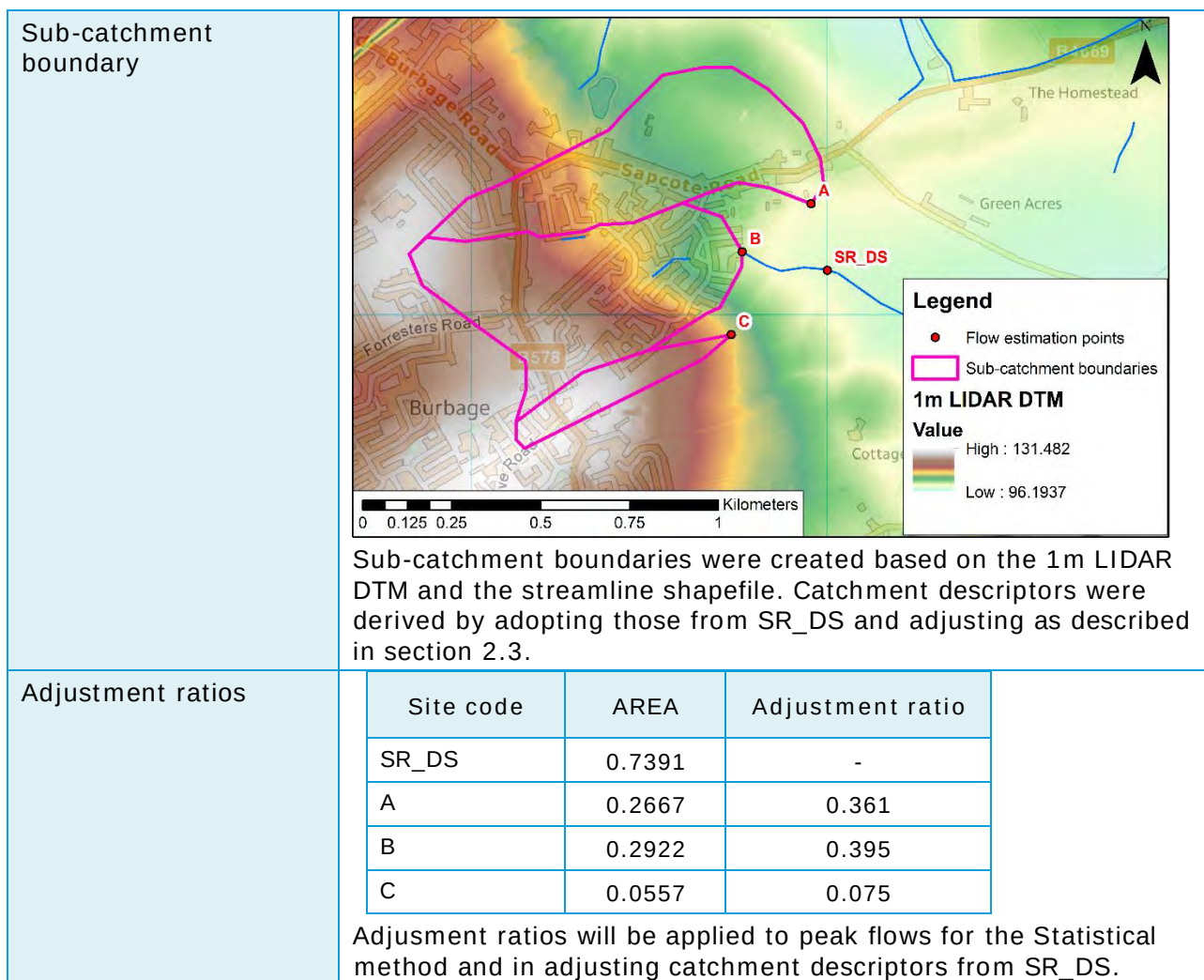
| Site code | FARL  | PROPWET | BFIHOST | DPLBAR (km) | DPSBAR (m / km) | SAAR (mm) | URBEXT 2000 | FPEXT |
|-----------|-------|---------|---------|-------------|-----------------|-----------|-------------|-------|
| SR_DS     | 1.000 | 0.30    | 0.447   | 0.96        | 31.5            | 649       | 0.3536      | 0.091 |
| A         | 1.000 | 0.30    | 0.447   | 0.35        | 31.5            | 649       | 0.3496      | 0.091 |
| B         | 1.000 | 0.30    | 0.447   | 0.38        | 31.5            | 649       | 0.5005      | 0.091 |
| C         | 1.000 | 0.30    | 0.447   | 0.07        | 31.5            | 649       | 0.2459      | 0.091 |

## 2.3 Checking catchment descriptors

|                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Record how catchment boundary was checked and describe any changes (add maps if needed)</p> | <p>The catchment boundary was checked against the 1m Lidar DTM. It was altered to the north to include an area that appeared it would drain into the catchment. Slight alterations were made elsewhere based on the DTM.</p>  <p>LIDAR data © Environment Agency copyright and/or database right 2020. All rights reserved.</p> |
| <p>Record how other catchment descriptors were checked and describe any changes.</p>           | <p>BFIHOST, and FARL appeared to be reasonable based on an overview of local mapping for the sites, so were not changed. The DPLBAR was amended in line with the percentage change of catchment area. URBEXT2000 was recalculated based on the OS 50k mapping of the area. The remaining descriptors were based on the DS catchment descriptors.</p>                                                               |
| <p>Source of URBEXT</p>                                                                        | <p>URBEXT2000</p>                                                                                                                                                                                                                                                                                                                                                                                                  |
| <p>Method for updating of URBEXT</p>                                                           | <p>CPRE formula from FEH Volume 4</p>                                                                                                                                                                                                                                                                                                                                                                              |

## 2.4 Determining sub-catchments

The sub-catchments are too small for the FEH web service to include. The catchment descriptors have been area-weighted as detailed in FEH Volume 5 using the downstream catchment. The sub-catchment inflows will be calculated by applying the FEH methods to the SR\_DS downstream catchment, and then scaled based on the ratio of catchment areas as recommended for catchments below 0.5km<sup>2</sup>.



## 3 Statistical method

### 3.1 Overview of estimation of QMED at each subject site

| Site code                                                                                                                                                                                                                                                                                                          | Initial QMED rural (m <sup>3</sup> /s) (from catchment descriptors) | Final method | Data transfer                                                |                                                 |                                                      |                        | Urban adjustment factor (UAF) | Final QMED estimate (m <sup>3</sup> /s) |                          |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------|--------------|--------------------------------------------------------------|-------------------------------------------------|------------------------------------------------------|------------------------|-------------------------------|-----------------------------------------|--------------------------|
|                                                                                                                                                                                                                                                                                                                    |                                                                     |              | NRFA numbers for donor sites used (see 3.3)                  | Distance between centroids d <sub>ij</sub> (km) | Moderated QMED adjustment factor, (A/B) <sup>a</sup> | If more than one donor |                               |                                         |                          |
|                                                                                                                                                                                                                                                                                                                    |                                                                     |              |                                                              |                                                 |                                                      | Weight                 |                               |                                         | Weighted ave. adjustment |
| SR_DS                                                                                                                                                                                                                                                                                                              | 0.28                                                                | CD           | 54102                                                        | 22.781                                          | 0.979                                                | 0.25                   | 1.08                          | 1.435                                   | 0.30                     |
|                                                                                                                                                                                                                                                                                                                    |                                                                     |              | 32029                                                        | 37.851                                          | 1.071                                                | 0.25                   |                               |                                         |                          |
|                                                                                                                                                                                                                                                                                                                    |                                                                     |              | 31010                                                        | 44.236                                          | 1.073                                                | 0.25                   |                               |                                         |                          |
|                                                                                                                                                                                                                                                                                                                    |                                                                     |              | 31026                                                        | 45.635                                          | 1.222                                                | 0.25                   |                               |                                         |                          |
| Are the values of QMED spatially consistent?                                                                                                                                                                                                                                                                       |                                                                     |              |                                                              |                                                 | Yes                                                  |                        |                               |                                         |                          |
| Method used for urban adjustment for subject and donor sites                                                                                                                                                                                                                                                       |                                                                     |              |                                                              |                                                 | WINFAP v4 <sup>3</sup>                               |                        |                               |                                         |                          |
| Parameters used for WINFAP v4 urban adjustment if applicable                                                                                                                                                                                                                                                       |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |
| Impervious fraction for built-up areas, IF                                                                                                                                                                                                                                                                         |                                                                     |              | Percentage runoff for impervious surfaces, PR <sub>imp</sub> |                                                 | Method for calculating fractional urban cover, URBAN |                        |                               |                                         |                          |
| 0.3                                                                                                                                                                                                                                                                                                                |                                                                     |              | 70%                                                          |                                                 | From updated URBEXT2000                              |                        |                               |                                         |                          |
| Notes                                                                                                                                                                                                                                                                                                              |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |
| Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).                                       |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |
| The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is: (A/B) <sup>a</sup> x QMED <sub>initial</sub> x UAF |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |
| Important note on urban adjustment                                                                                                                                                                                                                                                                                 |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |
| The method used to adjust QMED for urbanisation published in Kjeldsen (2010) <sup>4</sup> in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable.                                             |                                                                     |              |                                                              |                                                 |                                                      |                        |                               |                                         |                          |

<sup>3</sup> Wallingford HydroSolutions (2016). WINFAP 4 Urban adjustment procedures.

<sup>4</sup> Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

### 3.2 Search for donor sites for QMED

|                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Comment on potential donor sites</b><br/>Include a map if necessary. Note that donor catchments should usually be rural.</p> | <p>There are no high-flow gauging stations or level only gauges on the reach of the Soar Brook being modelled in this study. There are high-flow gauges on surrounding watercourses, however, these are located between 20 and 50km from the SR_DS catchment centroid.</p> <p>The following gauges on the NRFA database were considered:</p> <ul style="list-style-type: none"> <li>• 54105: Avon @ Lilbourne</li> <li>• 32029: Flore @ Experimental Catchment</li> <li>• 31025: Gwash South Arm @ Manton</li> <li>• 39026: Cherwell @ Banbury</li> <li>• 31010: Charter @ Fosters Bridge</li> <li>• 31026: Egleton Brook @ Egleton</li> </ul> <p>The first catchment was chosen based on smallest distance from SR_DS. The further 3 catchments were chosen based on similarity of catchment descriptors and low level of urbanisation. The donor sites chosen are 54102, 32029, 31010 and 31026, it was decided to use evenly weighted adjustment using the donor sites in this case.</p> |
|------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### 3.3 Donor sites chosen and QMED adjustment factors

| NRFA no. | Reasons for choosing                                     | Method (AM or POT) | Adjustment for climatic variation ? | QMED from flow data (A) | QMED from catchment descriptors (B) | Adjustment ratio (A/B) |
|----------|----------------------------------------------------------|--------------------|-------------------------------------|-------------------------|-------------------------------------|------------------------|
| 54102    | Proximity to catchment centroid                          | AM                 | No                                  | 12.4                    | 13.24                               | 0.931                  |
| 32029    | Similarity of catchment descriptors and low urbanisation | AM                 | No                                  | 1.94                    | 1.42                                | 1.371                  |
| 31010    | Similarity of catchment descriptors and low urbanisation | AM                 | No                                  | 9.95                    | 6.84                                | 1.446                  |
| 31026    | Similarity of catchment descriptors and low urbanisation | AM                 | No                                  | 1.14                    | 0.39                                | 2.958                  |

### 3.4 Derivation of pooling groups

Several subject sites may use the same pooling group.

| Name of group                                                                               | Site code from whose descriptor s group was derived | Subject site treated as gauged? (enhanced single site analysis) | Changes made to default pooling group, with reasons                                                                                                                                                         | Weighted average L-moments, L-CV and L-skew, (before urban adjustment) |
|---------------------------------------------------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| SR_DS_pool                                                                                  | SR_DS                                               | No                                                              | 49005: Bolingey Stream @ Bolingey Cocks Bridge<br>Removed from the default pooling group as record length was only 8 years; the groups record length remained over 500 years once this station was removed. | 0.223, 0.245                                                           |
| Note: Pooling groups were derived using the procedures from Science Report SC050050 (2008). |                                                     |                                                                 |                                                                                                                                                                                                             |                                                                        |

### 3.5 Derivation of flood growth curves at subject sites

| Site code                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Method (SS, P, ESS, J) | If P, ESS or J, name of pooling group (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 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------|--------------------------------------------------------------------------|------------------------------------------|
| SR_DS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | P                      | SR_DS_pool                                                                 | Gen. logistic is the only distribution suitable for this pooling group | Urban adjustments applied                         | 1.000, 0.167, -0.313                                                     | 2.715                                    |
| <b>Notes</b><br>Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis<br>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 method of Kjeldsen (2010).<br>Growth curves were derived using the procedures from Science Report SC050050 (2008). |                        |                                                                            |                                                                        |                                                   |                                                                          |                                          |

### 3.6 Flood estimates from the statistical method

Sub-catchment flood estimates calculated based on the area ratio with SR\_DS as is recommended for small catchments.

| Site code | Flood peak (m <sup>3</sup> /s) for the following return periods (in years) |      |      |      |      |      |      |
|-----------|----------------------------------------------------------------------------|------|------|------|------|------|------|
|           | 2                                                                          | 10   | 20   | 50   | 100  | 200  | 1000 |
| SR_DS     | 0.30                                                                       | 0.46 | 0.54 | 0.68 | 0.82 | 0.98 | 1.53 |
| A         | 0.11                                                                       | 0.17 | 0.20 | 0.25 | 0.29 | 0.35 | 0.55 |
| B         | 0.12                                                                       | 0.18 | 0.21 | 0.27 | 0.32 | 0.39 | 0.60 |
| C         | 0.02                                                                       | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.12 |

## 4 Revitalised flood hydrograph 2 (ReFH2) method

### 4.1 Catchment sub-divisions for ReFH2 model

| Site code                                         | Area (km <sup>2</sup> )                                                                              |       |                                                                                             |                                                                         |
|---------------------------------------------------|------------------------------------------------------------------------------------------------------|-------|---------------------------------------------------------------------------------------------|-------------------------------------------------------------------------|
|                                                   | Rural or un-developed                                                                                | Paved | Only relevant if significant transfers of water via sewers crossing catchment boundaries... |                                                                         |
|                                                   |                                                                                                      |       | Paved with sewers draining out of topographic catchment                                     | Paved outside topographic catchment with sewers draining into catchment |
| SR_DS                                             | 0.33                                                                                                 | 0.41  | 0                                                                                           | 0                                                                       |
| A                                                 | 0.12                                                                                                 | 0.15  | 0                                                                                           | 0                                                                       |
| B                                                 | 0.06                                                                                                 | 0.23  | 0                                                                                           | 0                                                                       |
| Sources of information for creating sub-divisions | The urbanised area in the ReFH2 software was estimated based on the URBEXT2000 catchment descriptor. |       | Sewer capacity (return period / rainfall intensity / flow rate) and source of information   | 5-year return period rainfall <sup>†</sup>                              |

<sup>†</sup> In the absence of detailed information about sewer drainage in the catchment, a conservative assumption was applied with a 5-year return period set as the sewer capacity. It is also assumed no sewers drain out of the catchment as this is the more conservative assumption when no sewer mapping is provided.

### 4.2 Parameters for ReFH2 model

ReFH2.3 software has been used to calculate the inflows. Site A was calculated using plot scale equations due to the lack of watercourse within the sub-catchment. Site C was calculated based on scaling the SR-DS hydrograph by area scaling factor.

| Site code                                                                                                               | Method                    | T <sub>p</sub> <sub>rural</sub><br>(hours) | T <sub>p</sub> <sub>urban</sub><br>(hours) | C <sub>max</sub><br>(mm)                                                     | PR <sub>imp</sub><br>% runoff for<br>impermeable<br>surfaces | BL<br>(hours) | BR    | Sewer<br>capacity<br>(m <sup>3</sup> /s) |
|-------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------------------------------|--------------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------|---------------|-------|------------------------------------------|
| SR_DS                                                                                                                   | CD                        | 2.47                                       | 1.85                                       | 358.9                                                                        | 70                                                           | 32.4          | 2.862 | 0.730                                    |
| A                                                                                                                       | CD                        | 1.91                                       | 1.43                                       | 358.9                                                                        | 70                                                           | 36.4          | 2.972 | 0.262                                    |
| B                                                                                                                       | CD                        | 1.45                                       | 1.09                                       | 358.9                                                                        | 70                                                           | 26.5          | 2.860 | 0.411                                    |
| C                                                                                                                       | Area<br>scaling<br>factor | -                                          | -                                          | -                                                                            | -                                                            | -             | -     | -                                        |
| Brief description of any flood event analysis carried out (further details should be given in the annex)                |                           |                                            |                                            | The catchment is ungauged hence no flood event analysis was undertaken here. |                                                              |               |       |                                          |
| Methods: OPT: Optimisation, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details) |                           |                                            |                                            |                                                                              |                                                              |               |       |                                          |

### 4.3 Design events for ReFH2 method

| Site code                                                                                                                   | Season of design event | Storm duration (hours) | Storm area for ARF (if not catchment area)                                                                                |
|-----------------------------------------------------------------------------------------------------------------------------|------------------------|------------------------|---------------------------------------------------------------------------------------------------------------------------|
| SR_DS                                                                                                                       | Summer                 | 4.5                    | -                                                                                                                         |
| A                                                                                                                           | Summer                 | 4.5                    | -                                                                                                                         |
| B                                                                                                                           | Summer                 | 4.5                    | -                                                                                                                         |
| Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model? |                        |                        | Storm duration may be tested within the hydraulic model, so half and double durations have also been derived using ReFH2. |

### 4.4 Flood estimates from the ReFH2 method

| Site code | Flood peak (m <sup>3</sup> /s) for the following return periods (in years) |      |      |      |      |      |      |
|-----------|----------------------------------------------------------------------------|------|------|------|------|------|------|
|           | 2                                                                          | 10   | 20   | 50   | 100  | 200  | 1000 |
| SR_DS     | 0.42                                                                       | 0.69 | 0.82 | 1.03 | 1.25 | 1.52 | 2.33 |
| A         | 0.18                                                                       | 0.30 | 0.35 | 0.44 | 0.53 | 0.65 | 0.99 |
| B         | 0.27                                                                       | 0.44 | 0.53 | 0.66 | 0.79 | 0.96 | 1.46 |
| C         | 0.03                                                                       | 0.05 | 0.06 | 0.08 | 0.09 | 0.11 | 0.18 |

## 6 Discussion and summary of results

### 6.1 Comparison of results from different methods

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

| Site code | Ratio of peak flow to FEH Statistical peak |                         |
|-----------|--------------------------------------------|-------------------------|
|           | Return period 2 years                      | Return period 100 years |
|           | ReFH                                       | ReFH                    |
| SR_DS     | 1.40                                       | 1.53                    |
| A         | 1.65                                       | 1.81                    |
| B         | 2.27                                       | 2.46                    |
| C         | 1.40                                       | 1.53                    |

### 6.2 Final choice of method

|                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|---------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p><b>Choice of method and reasons</b></p> <p>Include reference to type of study, nature of catchment and type of data available.</p> | <p>ReFH2 urban hydrographs.</p> <p>This method is suitable for highly urbanised catchments.</p> <p>The use of donor data has improved the FEH statistical flow estimates, but still carries considerable uncertainty given the high urbanisation of the catchment in this study (QMED donor transfer across neighbouring catchments with different levels of urbanisation carries additional uncertainties compared to rural-only catchments).</p> <p>This is a small, ungauged catchment and as such, all estimated design flows carry appreciable uncertainty.</p> <p>Research on small catchments: Guidance on choice of method for flood estimation on small catchments was developed in Science Project SC090031: Estimating flood peaks and hydrographs for small catchments. In accordance with the report on Phase 1 (Faulkner and others, 2012) we recommend that the flood estimates on small catchments are derived from FEH methods (Statistical or ReFH2) and not from older methods. In addition, Phase 2 of the small catchments research, SC090031 (Stewart and others, 2019) found that on average the ReFH2 method gave a slightly reduced bias and lower factorial standard error than FEH Statistical when estimating QMED on small catchments.</p> <p>Consideration of Urbanisation: This catchment includes a degree of urbanisation therefore the ReFH2 is considered the most suitable approach as it includes an urban component that introduces three extra parameters to account for the effect of urbanisation to the runoff and time-to-Peak.</p> <p>For the above reasons the preferred method is the ReFH2 (using FEH 13 Rainfall). This method is based on latest guidance and is believed to be providing the most reliable estimates for the catchment.</p> |
| <p><b>How will the flows be applied to a hydraulic model?</b></p>                                                                     | <p>The upstream sites (A, B and C) will apply the flows using a flow-time boundary, inputting the ReFH2 hydrographs. The model will be used to route the inflows.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

## 6.3 Assumptions, limitations and uncertainty

| List the main assumptions made (specific to this study)                                                                                         | <ul style="list-style-type: none"><li>Urban area for ReFH2 method taken from URBEXT2000 which is based on the OS 50k mapping, rather than based on detailed mapping (e.g. OS MasterMap).</li></ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                  |             |             |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
|-------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------|-------------|-------------|------------|--|-----|-----|-----|-----|--------|-------------|-------------|-------------|-------------|--------|-------------|-------------|-------------|-------------|----------|-------------|-------------|------------|-------------|
| Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed. | The lack of gauged flow records forces a greater reliance on catchment descriptor methods in this study. Even a level only record on the catchment would greatly aid calibration of hydrological parameters, such as TP in the Urban ReFH method for example.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                  |             |             |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| Give what information you can on uncertainty in the results, e.g. confidence limits from Kjeldsen (2014).                                       | <p>There are no published methods for quantifying uncertainty for the Urban ReFH2 method, apart from carrying out sensitivity tests on key model parameters.</p> <p>Using QMED donor information from a neighbouring catchment, research from the FEH Local project suggests confidence bands (as a factor of the final peak flow) as follows:</p> <table><tr><th rowspan="2">Confidence level</th><th colspan="2">One donor</th><th colspan="2">Six donors</th></tr><tr><th>68%</th><th>95%</th><th>68%</th><th>95%</th></tr><tr><td>5% AEP</td><td>0.60 – 1.66</td><td>0.36 – 2.76</td><td>0.60 – 1.66</td><td>0.36 - 2.75</td></tr><tr><td>1% AEP</td><td>0.58 – 1.72</td><td>0.34 – 2.94</td><td>0.59 – 1.71</td><td>0.34 – 2.91</td></tr><tr><td>0.1% AEP</td><td>0.54 – 1.86</td><td>0.29 – 3.45</td><td>.54 – 1.84</td><td>0.30 – 3.38</td></tr></table> <p>These are for moderately urbanised catchments (<math>0.03 \leq \text{URBEXT} &lt; 0.15</math>), so the confidence intervals for these highly urbanised catchments is likely to be slightly wider.</p> | Confidence level | One donor   |             | Six donors |  | 68% | 95% | 68% | 95% | 5% AEP | 0.60 – 1.66 | 0.36 – 2.76 | 0.60 – 1.66 | 0.36 - 2.75 | 1% AEP | 0.58 – 1.72 | 0.34 – 2.94 | 0.59 – 1.71 | 0.34 – 2.91 | 0.1% AEP | 0.54 – 1.86 | 0.29 – 3.45 | .54 – 1.84 | 0.30 – 3.38 |
| Confidence level                                                                                                                                | One donor                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |                  | Six donors  |             |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
|                                                                                                                                                 | 68%                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 95%              | 68%         | 95%         |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| 5% AEP                                                                                                                                          | 0.60 – 1.66                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.36 – 2.76      | 0.60 – 1.66 | 0.36 - 2.75 |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| 1% AEP                                                                                                                                          | 0.58 – 1.72                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.34 – 2.94      | 0.59 – 1.71 | 0.34 – 2.91 |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| 0.1% AEP                                                                                                                                        | 0.54 – 1.86                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 0.29 – 3.45      | .54 – 1.84  | 0.30 – 3.38 |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.                               | Flows would only be suitable for future studies if the proposed development in this flood risk assessment is not implemented, otherwise the URBEXT value would need to be updated for the downstream estimate. It would also be pertinent to check for any new methodologies suitable for very small or highly urban catchments.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                  |             |             |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |
| Give any other comments on the study, e.g. suggestions for additional work.                                                                     | Installation of flow / river level telemetry on this stream would greatly aid at accuracy of hydrological calculations.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                  |             |             |            |  |     |     |     |     |        |             |             |             |             |        |             |             |             |             |          |             |             |            |             |

## 6.4 Checks

|                                                                                                                                 |                                                                                                                                                                                                                                                             |
|---------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Are the results consistent, for example at confluences?                                                                         | Yes, flows increase moving downstream and increase with catchment size.<br>The sub-catchments peak slightly before the downstream hydrograph which is as expected.                                                                                          |
| What do the results imply regarding the return periods of floods during the period of record?                                   | The site is ungauged so there is no period of record.                                                                                                                                                                                                       |
| What is the range of 100-year growth factors? Is this realistic?                                                                | The 100-year growth factor is 2.96. The typical range is 2.1 to 4.0 therefore the growth factor is within the typical range.                                                                                                                                |
| If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?                        | 1.84 – 1.86                                                                                                                                                                                                                                                 |
| How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred. | The previous study derived flows using a mixture of ReFH and the modified rational method. The updated flows are significantly larger than the previous flows. The updated flows use the ReFH2 method which is suited to the urban nature of the catchment. |
| Are the results compatible with the longer-term flood history?                                                                  | There is no longer term flood history provided.                                                                                                                                                                                                             |
| Describe any other checks on the results                                                                                        |                                                                                                                                                                                                                                                             |

## 6.5 Final results

| Site code | Flood peak (m <sup>3</sup> /s) for the following return periods (in years) |      |      |      |      |      |      |
|-----------|----------------------------------------------------------------------------|------|------|------|------|------|------|
|           | 2                                                                          | 10   | 20   | 50   | 100  | 200  | 1000 |
| SR_DS     | 0.42                                                                       | 0.69 | 0.82 | 1.03 | 1.25 | 1.52 | 2.33 |
| A         | 0.18                                                                       | 0.30 | 0.35 | 0.44 | 0.53 | 0.65 | 0.99 |
| B         | 0.27                                                                       | 0.44 | 0.53 | 0.66 | 0.79 | 0.96 | 1.46 |
| C         | 0.03                                                                       | 0.05 | 0.06 | 0.08 | 0.09 | 0.11 | 0.18 |

|                                                                                                                                                                             |  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below) |  |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|

## 7 Annex

## 7.1 Pooling Group

| Station                                  | Distance<br>SDM | Years<br>of<br>data | QMED<br>AM | L-CV  | L-SKEW | Discordancy | AREA  | SAAR | FPEXT | FARL  | URBEXT<br>2000 |
|------------------------------------------|-----------------|---------------------|------------|-------|--------|-------------|-------|------|-------|-------|----------------|
| 76011 (Coal Burn @ Coalburn)             | 1.503           | 41                  | 1.840      | 0.165 | 0.315  | 0.720       | 1.63  | 1096 | 0.074 | 1     | 0              |
| 45815 (Haddeo @ Upton)                   | 3.44            | 25                  | 3.456      | 0.306 | 0.399  | 0.948       | 6.81  | 1210 | 0.011 | 1     | 0.005          |
| 27051 (Crimple @ Burn Bridge)            | 3.508           | 46                  | 4.539      | 0.219 | 0.148  | 0.388       | 8.17  | 855  | 0.013 | 1     | 0.006          |
| 28033 (Dove @ Hollinsclough)             | 3.714           | 43                  | 4.205      | 0.231 | 0.369  | 0.635       | 7.92  | 1346 | 0.007 | 1     | 0              |
| 27073 (Brompton Beck @ Snainton Ings)    | 3.721           | 37                  | 0.820      | 0.200 | 0.047  | 1.342       | 8.06  | 721  | 0.237 | 1     | 0.008          |
| 91802 (Allt Leachdach @ Intake)          | 4.136           | 34                  | 6.350      | 0.153 | 0.257  | 0.878       | 6.54  | 2554 | 0.003 | 0.992 | 0              |
| 25019 (Leven @ Easby)                    | 4.315           | 40                  | 5.384      | 0.343 | 0.378  | 1.733       | 15.09 | 830  | 0.020 | 1     | 0.004          |
| 71003 (Croasdale Beck @ Croasdale Flume) | 4.335           | 37                  | 10.900     | 0.212 | 0.323  | 0.240       | 10.71 | 1882 | 0.016 | 1     | 0              |
| 26802 (Gypsey Race @ Kirby Grindalythe)  | 4.346           | 19                  | 0.109      | 0.309 | 0.183  | 1.003       | 15.85 | 757  | 0.030 | 1     | 0              |
| 25011 (Langdon Beck @ Langdon)           | 4.365           | 32                  | 15.533     | 0.235 | 0.334  | 1.409       | 12.79 | 1463 | 0.012 | 1     | 0.001          |
| 25003 (Trout Beck @ Moor House)          | 4.377           | 45                  | 15.120     | 0.167 | 0.302  | 0.587       | 11.40 | 1905 | 0.041 | 1     | 0              |
| 47022 (Tory Brook @ Newnham Park)        | 4.393           | 25                  | 6.180      | 0.273 | 0.149  | 0.963       | 13.43 | 1403 | 0.023 | 0.942 | 0.014          |
| 54022 (Severn @ Plynlimon Flume)         | 4.395           | 38                  | 14.988     | 0.156 | 0.171  | 1.034       | 8.750 | 2481 | 0.010 | 1     | 0              |
| 206006 (Annalong @ Recorder)             | 4.609           | 48                  | 15.330     | 0.189 | 0.052  | 2.119       | 14.44 | 1704 | 0.023 | 0.981 | 0              |

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