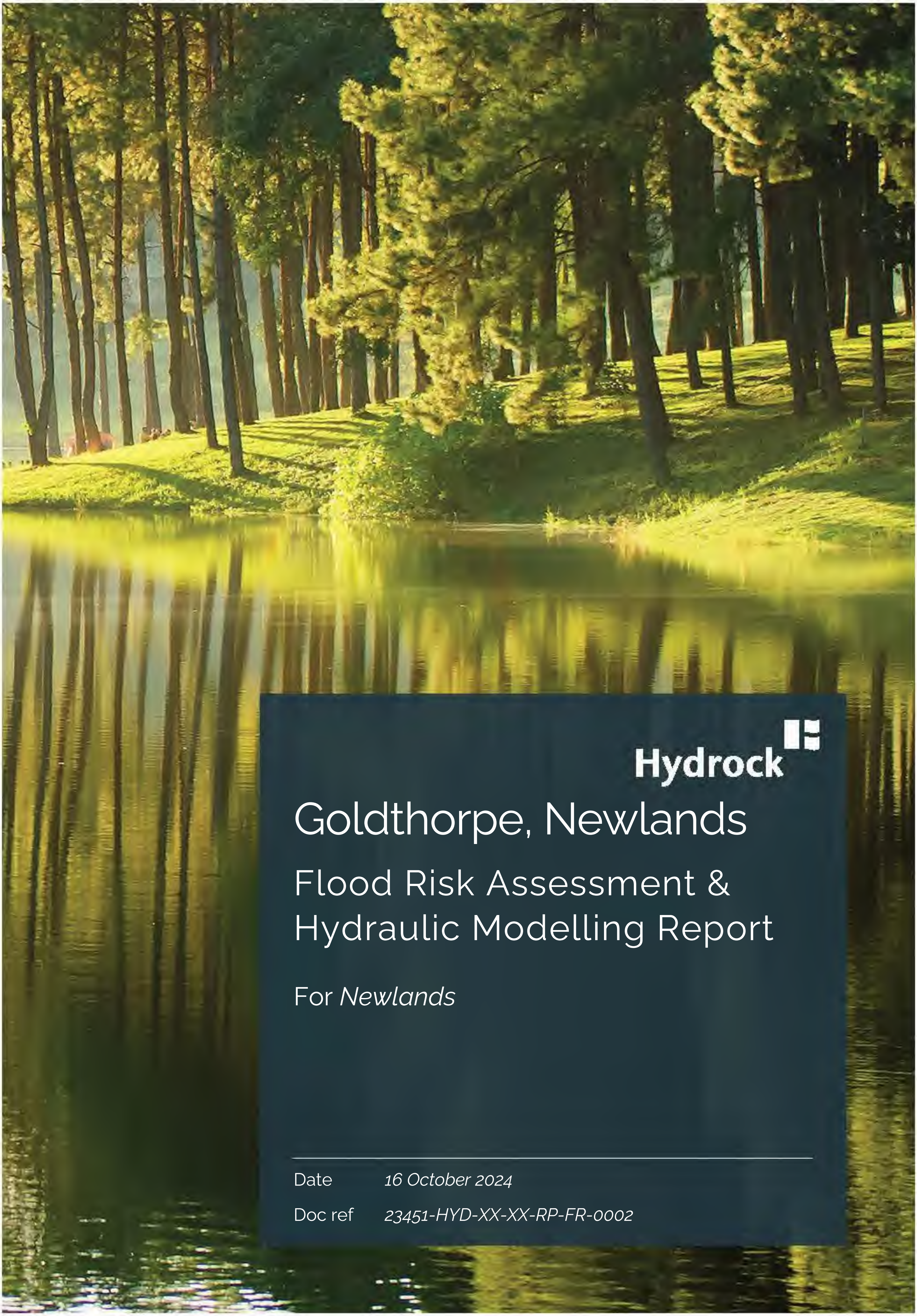

Hydrock

Goldthorpe, Newlands

Flood Risk Assessment & Hydraulic Modelling Report

For *Newlands*

Date *16 October 2024*

Doc ref *23451-HYD-XX-XX-RP-FR-0002*

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1. INTRODUCTION

This report has been prepared by Hydrock Consultants Limited (Hydrock) on behalf of our client Newlands in support of a planning application for a proposed industrial use development with associated parking and access.

Owing to the identified level of risk to the site, through the Environment Agency (EA) Flood Map for Planning and Long-Term Flood Risk Services, it was concluded that detailed hydraulic modelling for the site was needed to confirm both existing risk and ensure the safety of the development, with regards to flood risk, across its design life. The methodology and proposed mitigation were discussed with the Yorkshire & Humber Internal Drainage Board (IDB) at a meeting (14/10/2022) and agreed in principle.

As such, this report provides detail with regards to the methodology and results of the hydrological and hydraulic modelling undertaken by Hydrock.

Local Planning Authorities are advised by the Government's National Planning Policy Framework (NPPF) to consult the EA on development proposals in areas at risk of flooding and / or for sites greater than 1 hectare in area. The EA requires a Flood Risk Assessment (FRA) to be submitted in support of the planning application for the proposed development.

The report has been prepared to consider the requirements of NPPF through:

- Assessing whether the proposed development is likely to be affected by flooding;
- Assessing whether the proposed development is appropriate in the suggested location; and
- Detailing measures necessary to mitigate any flood risk identified, to ensure that the proposed development and occupants would be safe, and that flood risk would not be increased elsewhere.

The report considers the requirements for undertaking an FRA as stipulated in NPPF Technical Guidance. Only those requirements that are appropriate to a development of this nature have been considered in the compilation of this report.

This report has been prepared in accordance with current EA policy.

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2. SITE INFORMATION

2.1 Location

The Site is located on greenfield (undeveloped) land comprised of agricultural fields, west of Goldthorpe, Barnsley, South Yorkshire, England.

The Site is bound:

» To the north by the A635 Barnsley Road beyond which lies Billingley Green Lane and further agricultural fields;

» To the east by both industrial and residential developments, including an Aldi Distribution Centre;

» To the south by Carr Head Lane beyond which lies further agricultural fields; and

» To the west by agricultural fields.

The Site is split into four proposed development zones across three key land parcels (Shown in Figure 1), taken from the Parameters Plan (22081_P0520E). The nearest watercourse is the Ings Carr Dike (Carr Dike), a land drain under the jurisdiction of Yorkshire & Humber IDB, which runs through the central extents of the site in a south-westerly direction. A tributary of the Carr Dike, the Highgate Lane Dike, flows in a general westerly direction from the eastern boundary of the Site. Other watercourses in the area include the River Dearne (a Main River under the jurisdiction of the EA) which is located to the west of the Site and flows in a southerly direction, before flowing generally east to the south of the Site (approximately 700m south of the Site at its closest point), Several surface water ponds / features which make up Dearne Valley Nature Reserve, also lies south of the site.

Access is provided from the A635 Barnsley Road to the north and Carr Head Lane to the south.

The Site address and Ordnance Survey Grid Reference is provided in Table 1 below, with site boundaries and locations shown in Figure 1.

Table 1: Site Referencing Information

Site Referencing Information	
Site Address	Land South of Dearne Valley Parkway, Goldthorpe S72 0JE
Grid Reference	444222, 403580 SE442035

Figure 1. Site Location and Red Line Boundary

2.2 Topography

A site-specific topographic survey has been undertaken and included within Appendix A. The survey indicates levels fall towards the Carr Dike, from both northern, southern and eastern boundaries, running through the centre of the site.

The area to the north of the Carr Dike, north west of Zone 1, indicates a high point of approximately 28.79m AOD along the northern boundary with levels dropping off in a southerly direction towards the Carr Dike and a bed level of approximately 20.00m AOD. Within Zone 1 boundary, the survey identifies a raised area reaching a high point of approximately 25.47m AOD. Around the northern boundary of Zone 1, a low point is identified within the survey at a level of 22.40m AOD.

To the area east of the Carr Dike, around Zone 2, levels are identified to reach a maximum 37.00m AOD on the north eastern boundary of the Site and fall towards the Carr Dike to the west.

The area south of the Carr Dike, around Zone 3 and 4, the Site is shown to have a much steeper gradient with maximum levels of 46.37m AOD along the southern boundary and falling over 20m in a northerly direction towards the Carr Dike.

Additional survey of the watercourses in the site has also been undertaken and included within Appendix A. Bed levels of the Carr Dike are identified to have a general fall through the site from a high point of approximately 21.7m AOD at the top of the site (northern boundary) to a low of approximately 19.8m AOD at the eastern boundary.

2.3 Current Site Use

The site is currently used for agricultural purposes and at present is fields laid to grass and is entirely undeveloped.

2.4 Proposed Site Use

The proposed development is for the construction of multiple new warehouses with associated offices, HGV loading bays, car parking and associated infrastructure and access road. The proposed Illustrative Masterplan is included within Appendix B.

3. SOURCES OF FLOOD RISK

3.1 Tidal / Fluvial Flood Risk

According to the current EA Flood Zones shown in Figure 2, the majority of the Site is within Flood Zone 1 (Low Risk) however, mapping identifies some encroachment of Flood Zones 2 (Medium Risk) and 3 (High Risk), extending within the site originating from Carr Dike.

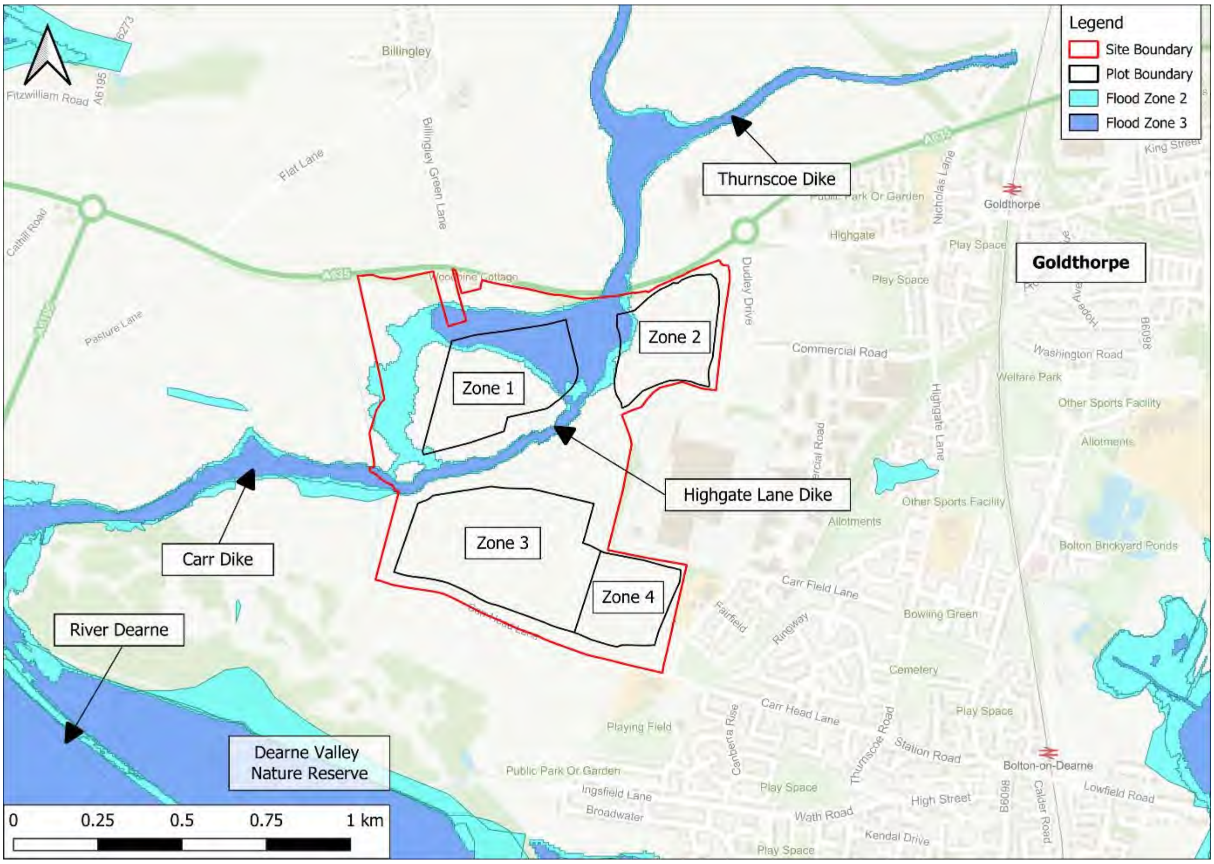

Figure 2. EA Flood Zone Mapping
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The Environment Agency Flood Zones are defined within Paragraph 078 of the NPPG for Flood Risk and Coastal Change as:

- Flood Zone 1 (Low Risk) comprises land assessed as having a ≤0.1% AEP of fluvial or tidal flooding in any given year, equivalent to the ≥1,000yr return period flood event.
- Flood Zone 2 (Medium Risk) comprises land assessed as having a 0.1-1% AEP of fluvial flooding or 0.1-0.5% AEP of tidal flooding in any given year, equivalent to the 1,000-100yr return period flood event.
- Flood Zone 3a (High Risk) comprises land assessed as having a ≥1% AEP of fluvial flooding or ≥0.5% AEP tidal flooding in any given year, equivalent to the ≤100yr return period flood event.
- Flood Zone 3b (The Functional Floodplain) comprises land where water from rivers or the sea has to flow or be stored in times of flood. The identification of functional floodplain should take account of local circumstances and not be defined solely on rigid probability parameters. Functional floodplain will normally comprise:
    - Land having a 3.3% or greater annual probability of flooding, with any existing flood risk management infrastructure operating effectively; or

- Land that is designed to flood (such as a flood attenuation scheme), even if it would only flood in more extreme events (such as 0.1% annual probability of flooding).

3.1.1 Historical Flooding

According to the 'Recorded Flood Outlines' dataset provided by the EA, the site is shown to be partially within the extents of a historical flood event shown in Figure 3 below, which occurred in 2007 due to channel capacity exceedance (no raised defences) from Carr Dike. The historical flood extents only encroach into the site marginally, if at all, and therefore this is not considered to have had an impact on the site.

Figure 3. EA Recorded Flood Outlines
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3.1.2 Fluvial Modelling

Following a Freedom of Information request to the EA, it was confirmed that no detailed modelling for the Carr Dike and its tributaries existed. A copy of the strategic model for the River Dearne was supplied however, the Site and associated watercourses were shown to lie outside the maximum extents of the strategic models' subject areas. The EA have confirmed Flood Zones along the Carr Dike to be from JFLOW and is therefore considered to be coarse data and not suitable to confirm flood risk and/or provide flood levels to enable safe design of the proposed development

Therefore, given the lack of detailed modelling and confirmation from the EA that the current JFLOW mapping is not suitable for site-specific use, Hydrock undertook a modelling exercise. The detailed assessment of the watercourses would confirm risk and provide detailed flood information to ensure the proposed development would be safe across its design life, providing mitigation measures where necessary i.e., flood compensation storage. Full details of the hydrological and hydraulic modelling study, including proposed mitigations can be found in Sections 4 and 5.

3.2 Tidal Flooding

It should be noted that neither the EA Flood Zone Mapping nor the Barnsley Strategic Flood Risk Assessment (JBA, 2010) distinguish between fluvial and tidal flood risk. Owing to the raised elevation of the sites (>19m AOD), inland geographical location, and the distance from any tidally influenced waterbodies, the risk of tidal flooding at the site is concluded to be 'low'.

3.3 Surface Water Flooding

Surface water flooding occurs as the result of an inability of intense rainfall to infiltrate the ground. This often happens when the maximum soil infiltration rate or storage capacity is reached. Flows generated by such events either enter existing land drainage features or follow the general topography which can concentrate flows and lead to localised ponding/flooding.

Current EA Surface Water Flood Risk Mapping (Figure 4) indicates large portions of the site to be at 'Very Low' risk however, the mapping also indicates areas of increased risk, up to 'High' around the existing watercourses and extending into the site. The mapping also identifies some localised areas of increased risk which show limited to no connectivity to the wider predicted flood extents.

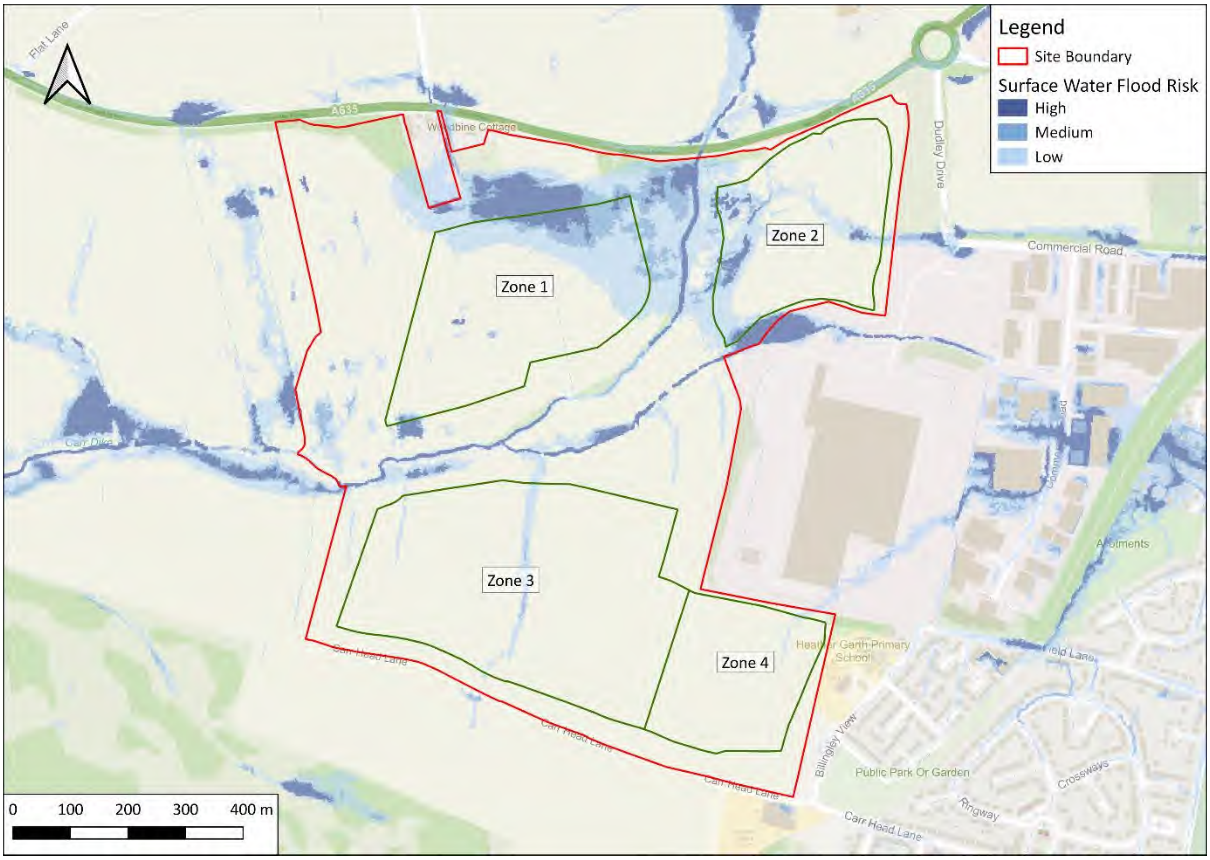

Figure 4. EA Surface Water Flood Risk Map
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For reference, the EA Surface Water Flood Risk mapping are banded into four levels of flood risk, these are:

- High - each year, the area has a chance of flooding of greater than 1 in 30 (3.3%)
- Medium - each year, the area has a chance of flooding of between 1 in 100 (1%) and 1 in 30 (3.3%)
- Low - each year, the area has a chance of flooding of between 1 in 1000 (0.1%) and 1 in 100 (1%)

» Very low - each year, the area has a chance of flooding of less than 1 in 1000 (0.1%)

According to the EA's Online Long-Term Flood Risk Service, the predicted flooding is indicated to have a range of flood depths across the different scenarios. During the High risk scenario, the areas of flood risk appear to largely remain within the watercourses present within the Site with some identified isolated areas of predicted flooding, likely an indication of localised low spots in the natural topography where depths can increase prior to connectivity to flow routes off site. However, during the Medium risk scenario the extents appear to exceed the channel and flow westwards across the northern extents of the site, parallel to the A635 (Barnsley Road) to the north with depths predicted to be between 300-900mm. During the Low-risk scenario (worst-case scenario), these extents become more severe and a large section of the area of risk is modelled at depths exceeding 900mm.

In the absence of detailed modelling, surface water flooding extents can often be used to detail the worst-case extents of flooding from watercourse i.e. fluvial flooding as the peak flows within the Carr Dike and Highgate Lane Dike are likely from surface water runoff.

The extents of flooding shown in the EA Surface Water Flood Risk maps show a similar extent to the modelled fluvial extents, undertaken by Hydrock. As such, the majority of the large flood extents shown by the EA mapping in the north of the Site is be deemed to be from fluvial sources and as such is described in Section 3.1 with mitigation provided in Section 6.2.

The remaining predicted flooding on site i.e. to the west of Zone 1 is indicated to be isolated areas of flooding. These small patches of predicted increased risk show no connectivity to the watercourse or each other and as such are more likely to be an indication of localised low-spots in the topography.

The SFRA does not identify the site or the surrounding area to be an area with persistent surface water flooding problems. Therefore, as the majority of the predicted flood extents is attributed to fluvial flooding from the existing watercourses on site the site is concluded to be at 'low' risk of surface water flooding with areas of increased risk as a result of locally lower lying areas and as such recommended mitigation is provided in Section 6.2.

3.4 Groundwater Flood Risk

British Geological Survey (BGS) Mapping indicates the majority of the northern portions of the Site to be underlain by bedrock geology of the Pennine Middle Coal Measures Formation (mudstone, siltstone and sandstone) with the southern portion of the Site to be underlain by bedrock geology of the Mexborough Rock (sandstone). Overlying the bedrock geologies are superficial deposits of Alluvium (clay, silt, sand and gravel) which follows the reaches of the Carr Dike and Highgate Lane Dike through the centre of the Site.

According to Soilscapes[1] mapping, the site is located within 'slowly permeable seasonally wet acid loamy and clayey soils' with impeded drainage. BGS identifies both the bedrock and superficial deposits to be classified as Secondary A aquifers described as "*…permeable layers that can support local water supplied, and may form an important source of base flow to rivers.*" As such, there is potential for groundwater flow within the bedrock geology and superficial deposits.

Given the presence of the Carr Dike and Highgate Lane Dike within the site, these watercourses are likely to act as a natural drawdown point for any groundwater flows and as such groundwater is likely to be in hydraulic connectivity with normal channel water levels. As such, any groundwater

[1] *https://www.landis.org.uk/soilscapes/*

flooding is likely to only occur when fluvial flooding is already present and high fluvial flows have caused out of bank flooding.

The Barnsley SFRA does not indicate the site to be in an area with potential for groundwater re-emergence and as such the site is concluded to be at low risk of flooding from groundwater sources.

3.5 Infrastructure Flooding

There are no recorded canals in close proximity to this site. Due to this, it is unlikely that any infrastructure failure related to canals would result in a flood event affecting the site.

The EA Reservoir Failure Extent mapping (EA, 2022)[2] shows the site to lie outside of the extents of potential reservoir flooding. The EA state that reservoir flooding is extremely unlikely to happen. All large reservoirs must be inspected and supervised by reservoir panel engineers. As the enforcement authority for the Reservoirs Act 1975 in England, the EA ensure that reservoirs are inspected regularly, and essential safety work is carried out.

The 2011 PFRA provides recorded incidents of sewer flooding as recorded by Yorkshire Water. The mapping is based on the DG5 register and suggests that the site has not experienced any historic sewer flooding. Due to the greenfield (undeveloped) nature of the site, it is considered highly unlikely that sewer flooding has occurred at the site since the release of the 2011 PFRA.

Given that there is no known risk of flooding from canals or any other artificial sources at the site, it can be concluded that the risk of flooding from infrastructure failure is 'low'.

[2] *EA Long Term Flood Risk Maps - https://flood-warning-information.service.gov.uk/long-term-flood-risk/map*

4. Hydrological Modelling

4.1 Introduction

A hydrological assessment was undertaken for the Carr Dike and its tributaries, Thurnscoe Dike and Highgate Lane Dike.

Full details of the hydrological assessment methodology and application can be found in the Flood Estimation report in Appendix C. A short summary of the hydrological assessment is presented below.

4.2 Catchment Description

There are three watercourses of interest which impact the flood extents through the subject site. The main watercourse is the Carr Dike which flows in a general south westerly direction into the Ings Dike and is a tributary of the River Dearne, approximately 3km downstream of the subject site.

The Thurnscoe Dike is a tributary of the Carr Dike, which is sourced from Thurnscoe to the north east of the subject site. The watercourse flows in a general south westerly direction to its confluence with the Carr Dike, located approximately 500m north of the A635 and subject site

The Highgate Dike is also a tributary of the Carr Dike which flows from a commercial / industrial use development to the east of the subject site in a westerly direction meeting the Carr Dike in the centre of the subject area.

The National River Flow Archive (NRFA) and Hydrology Data Explorer indicate that there are no gauging stations along the Carr Dike, Thurnscoe Dike or Highgate Dike and as such the catchments are therefore ungauged. Thus, all calculations have been based upon catchment descriptors derived from the Flood Estimation Handbook (FEH) Web Service.

The FEH catchment descriptors indicate that overall, the catchments are not highly permeable. The catchments are predominantly rural but include Thurnscoe village. The Highgate Dike includes majority of commercial / industrial use developments and as such is considered to be very heavily urbanised. The selected methods will account for the mix of urban and rural catchments. There are no known significant factors or unusual features that could impact flows within the catchments.

4.3 Methodology

The ReFH2 method was selected due to its ability to represent flows in ungauged catchments. The ReFH2.2 model, using FEH22 rainfall, was used to produce peak flow estimates and hydrographs for the hydraulic model.

The catchment is ungauged and the FEH Statistical method resulted in a pooling group that was considered to be heterogeneous with a review being desirable. As such, confidence in the pooling group being considered representative of the subject catchment was not high, and this method was not selected.

Peak flow estimates were derived for the following locations: (1) the downstream extent of the Carr Dike (CA_DS); (2) upstream Carr Dike catchment from its confluence with the Thurnscoe Dike (CA_US); (3) upstream Thurnscoe Dike catchment from its confluence with the Carr Dike; (4) sub-catchment of Highgate Dike from its confluence with the Carr Dike - see Figure 5.

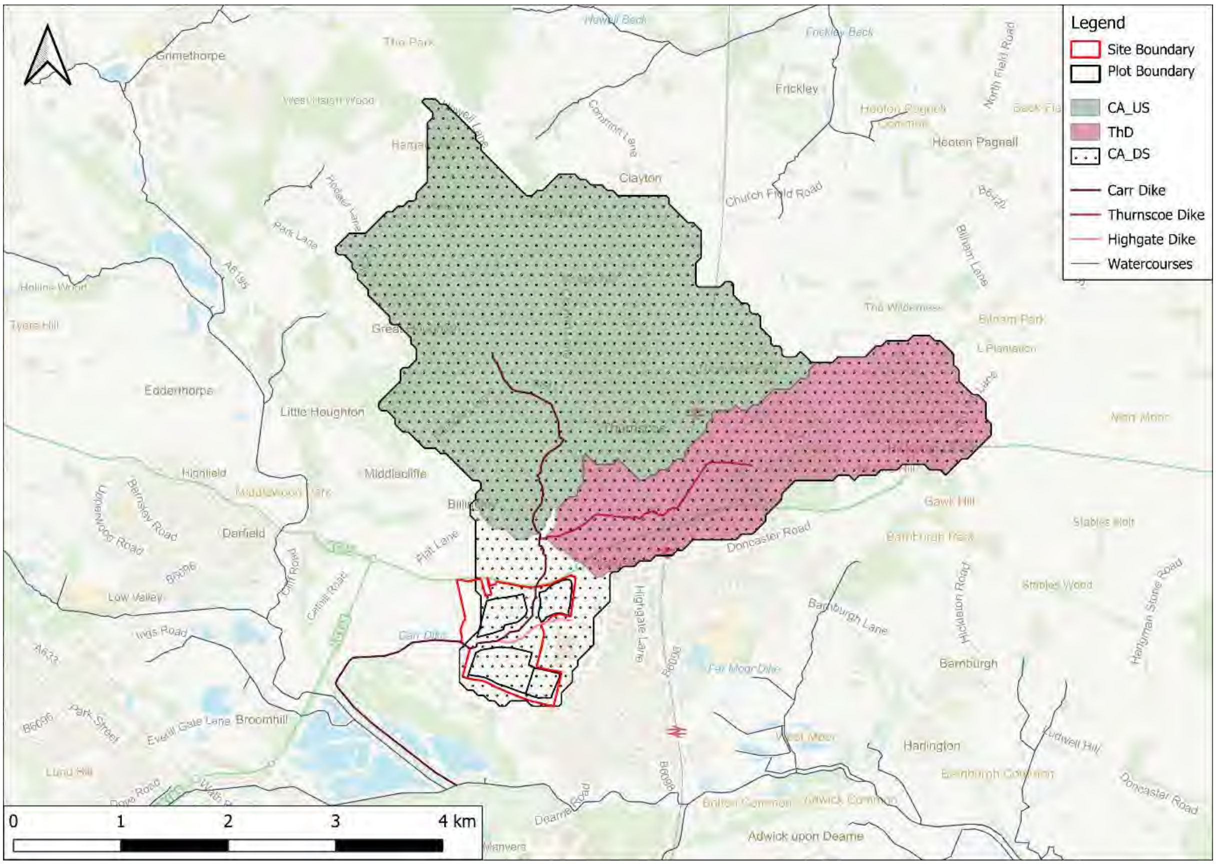


Figure 5: Catchment Plan

4.4 Summary of Results

The final hydrological inflows were derived from the ReFH2 method due to its ability to represent flows in small, ungauged catchments. ReFH2 version 2.3 was used as it is the most up to date methodology and makes use of the FEH22 rainfall data, which is the latest data available.

For the purpose of generating hydrographs from the ReFH2.3 model, it is proposed that the catchments CA_DS, CA_US and ThD are treated as rural due to the extent of urbanisation within the catchments (URBEXT2000 < 0.3 for all catchments) and a winter storm profile has been used in results extracted.

HiG is very heavily urbanised, as such a summer storm and urban results have been extracted for this catchment. The use of both winter and summer storm profiles is a conservative approach to estimating flows for this study, given the urban nature of HiG.

Final peak flow estimates are provided in Table 2 below, with full details of the assessment included in the Flood Estimation report in Appendix C.

Table 2: Final Peak Flow Estimation

Flow Node	Flood Peak (m3/s) for the following return period (in years)			
	2	30	100	1000
	Flood Peak (m3/s) for the following AEP (%) events			
	50	3.33	1	0.1
CA_DS	2.7	5.4	7.1	12.3
CA_US	1.1	2.4	3.1	5.5
ThD	1.52	3.1	4.0	6.9
HiG	0.44	0.99	1.30	2.29

4.5 Climate Change

The impacts of climate change will be modelled based on the latest available guidance. The site is located within the 'Don and Rother' Management Catchment, peak river flow allowances of +28% (central) and +38% (higher central) allowances are applicable to this study for the 2080s epoch (2070-2115).

5. Hydraulic Modelling

5.1 Introduction

The following section details the methodology and details of the hydraulic model build for the Carr Dike, Highgate Lane Dike and Thurnscoe Dike centred around the Site. Following a baseline assessment of the existing conditions, a post-development scenario has been modelled to include the proposed levels for the plots and road layouts and any mitigation measures necessary i.e., Flood Compensation Areas to ensure no increase in flood risk to third party land and no loss of floodplain storage in order to meet National Planning Policy Framework.

5.1.1 Model Summary

For the model build, an ESTRY-TUFLOW model was chose to be the most suitable and stable for this build. The version of the software that was used is:

- TUFLOW - 2023-03-AE

The baseline scenario uses a combination of topographical survey and LiDAR to represent the geometry of the channel using cross sections along the reach of the watercourse through the site. The modelling focused on the following reach lengths:

- An approximate 2740m length of the Carr Dike extending from a point approximately 750m upstream of the A635 and the Site's northern boundary and ending approximately 780m downstream of the western Site boundary.
- An approximate 500m length of the Thurnscoe Dike extending upstream from its confluence with the Carr Dike approximately 500m upstream of the A635 and the Site's northern boundary.
- An approximate 950m length of the Highgate Lane Dike extending from a point approximately 400m upstream of the Site's eastern boundary to its confluence with the Carr Dike in the centre of the Site.

The list of files for the final baseline scenario are:

- TCF – GOLD_BL_009.tcf
- TRD – GOLD_BL_009.trd
- ECF – GOLD_BL_009.ecf
- TEF – GOLD_BL_001.tef
- TBC & TGC – GOLD_BL_005
- Shapefiles – all referenced within the ECF, TBC and TGC

5.1.2 Events & Scenarios

Baseline models have been run for each of the four events listed in Table 2, with the addition of the 1 in 100 year plus climate change event. Further sensitivity / residual risk tests were then undertaken in line with standard practise:

- A sensitivity test on the baseline scenario model to assess the impact of a 20% increase and a 20% decrease in the 1D and 2D roughness parameters.
- A sensitivity test on the baseline scenario model to assess the impact of a 20% increase and a 20% decrease in the downstream boundary gradient.
- Residual risk tests were undertaken in the post-development scenario model to assess the impact of a blockage of five of the proposed structures.

5.1.3 Channel, Structures and Topographical Survey

Multiple sources of data were used to construct the model:

- A channel survey was used for culvert invert levels, structure dimensions and for channel cross section profiles along the Carr Dike, Thurnscoe Brook and Highgate Lane Dike.
- Site-specific topographical survey was used for the main site DTM to accurately convey ground levels and for the channel geometry and structure dimensions.
- Environment Agency LiDAR 1m DTM data was used as a baseline DTM where site-specific topographical survey didn't cover i.e., outside of the site boundary.

Table 3 outlines the model nodes, associated CSV files, and corresponding channel survey names. Where channel surveys were unavailable, areas that exhibited significant changes in channel geometry or were located far from surveyed regions relied on topographical surveys. In cases where topographical surveys were not available, LiDAR data was used as a substitute.

Table 3: Model Node and Corresponding Channel Survey and CSV file.

Node	Channel Survey Name	Model CSV
CARR_001	Section 16	CARR_XS_003.csv
CARR_002	Section 15	CARR_XS_003.csv
CARR_002D	Section 14	CARR_XS_003.csv
CARR_003	Section 13	CARR_XS_003.csv
THURN_001	Section 28	TRIBS_XS_003.csv
THURN_002	Taken from LiDAR	TRIBS_XS_003.csv
THURN_003	Section 27	TRIBS_XS_003.csv
CARR_004	Section 12	CARR_XS_003.csv
CARR_005	Taken from LiDAR	CARR_XS_003.csv
CARR_006	Section 11	CARR_XS_003.csv
CARR_007	Section 10	CARR_XS_003.csv
CARR_008	Section 9	CARR_XS_003.csv
CARR_010	Section 8	CARR_XS_003.csv
CARR_013	Section 7	CARR_XS_003.csv
CARR_015	Section 6	CARR_XS_003.csv
CARR_016	Section 5	CARR_XS_003.csv
TRIB_001	Section 26	TRIBS_XS_004.csv
TRIB_002	Section 25	TRIBS_XS_004.csv
TRIB_003	Section 24	TRIBS_XS_004.csv

TRIB_004	Section 23	TRIBS_XS_004.csv
TRIB_005	Section 22	TRIBS_XS_004.csv
TRIB_006	Taken from LiDAR	TRIBS_XS_004.csv
TRIB_007	Section 21	TRIBS_XS_004.csv
TRIB_008	Section 20	TRIBS_XS_004.csv
TRIB_011	Section 19	TRIBS_XS_004.csv
TRIB_012	Section 18	TRIBS_XS_004.csv
TRIB_015	Section 17	TRIBS_XS_004.csv
CARR_018	Section 4	CARR_XS_003.csv
CARR_023	Section 3	CARR_XS_003.csv
CARR_024	Section 2	CARR_XS_003.csv
CARR_026	Section 1	CARR_XS_003.csv
CARR_027	Taken from LiDAR	CARR_XS_003.csv
CARR_028	Taken from LiDAR	CARR_XS_003.csv
CARR_029	Taken from LiDAR	CARR_XS_003.csv
CARR_030	Taken from LiDAR	CARR_XS_003.csv

5.2 Baseline Model Build

5.2.1 1D Model Build

A model schematic for the 1D ESTRY elements are shown in Figure 6.

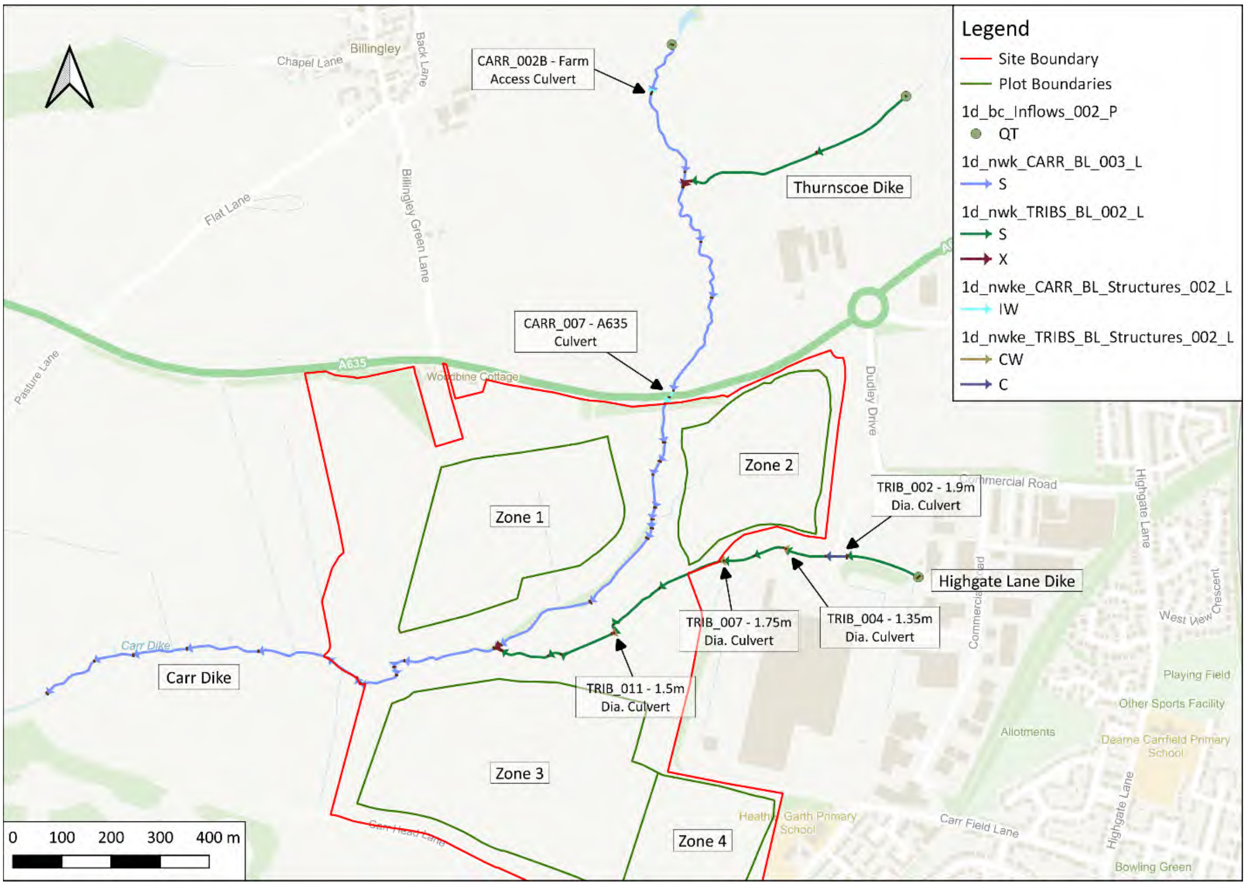


Figure 6. 1D Model Schematic

A summary of the 1D cross sections included in the model is as follows:

- Carr Dike
  - Upstream Cross Section - CARR_001
  - Downstream Cross Section - CARR_028
  - Total Cross Sections - 32
- Thurnscoe Dike
  - Upstream Cross Section - THURN_001
  - Downstream Cross Section - THURN_003
  - Total Cross Sections - 3
- Highgate Lane Dike
  - Upstream Cross Section - TRIB_001
  - Downstream Cross Section - THURN_015
  - Total Cross Sections - 15

The 1D network has been built using the 1d_nwk, 1d_nwke and 1d_xs shapefiles linking to individual cross section csv's which define the channel geometry and Manning's n roughness values. Open channels have been defined using the 'S' attribute within the 1d_nwk shapefiles. Figure 7 and Figure 8 show the long profiles of the Carr Dike and the Highgate Lane Dike, the two watercourses that pose the greatest potential risk to the Site.

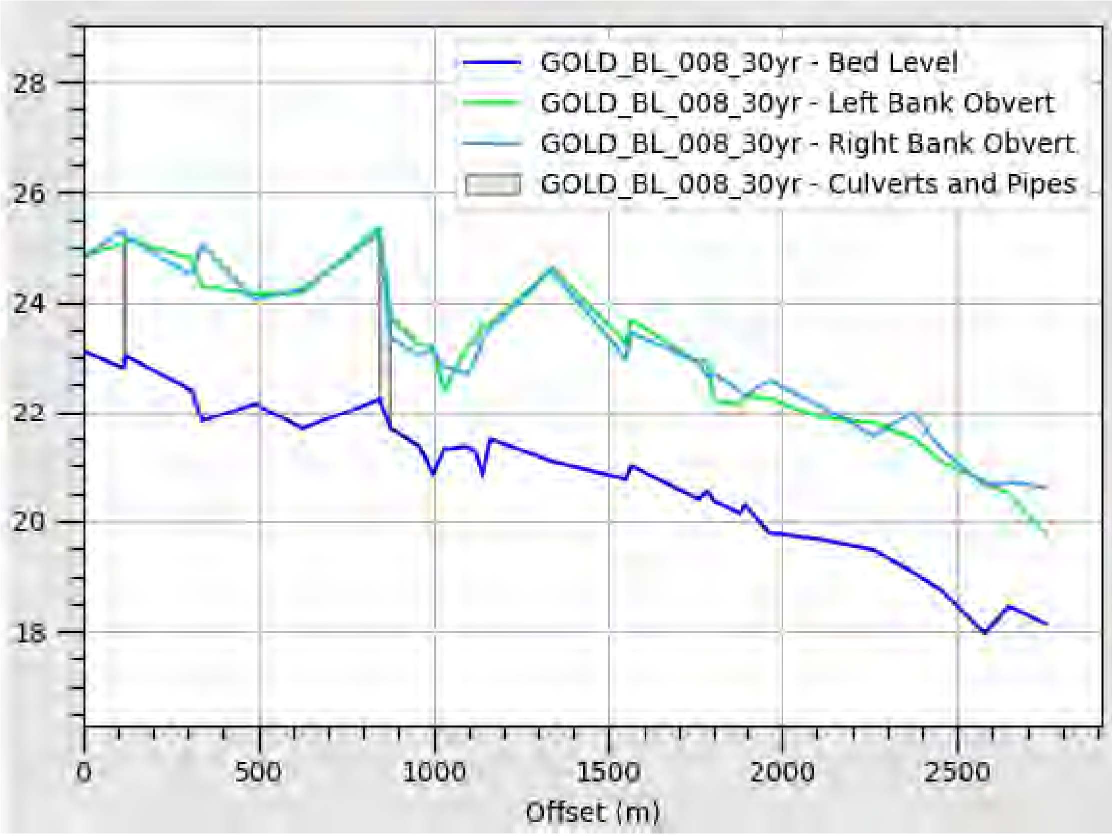


Figure 7. Carr Dike Modelled Long Section

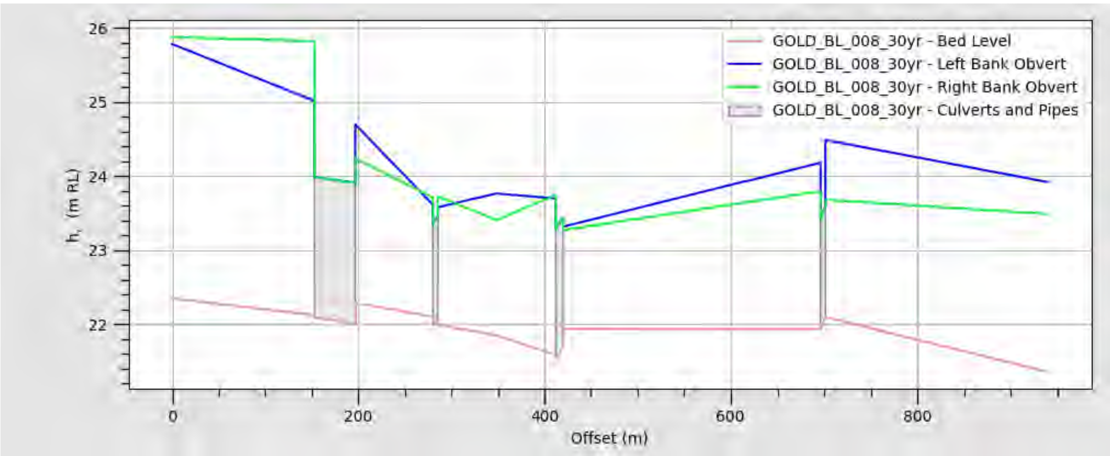


Figure 8. Highgate Lane Dike Modelled Long Section

Manning's n roughness values were assigned using the approach adopted by Chow[3]. Values used in the model were based on photographs of the channel, banks and culvert and information obtained during the site walkover survey and are therefore considered appropriate. These photographs and corresponding values are found in Table 4.

Table 4: Manning's N Roughness used at each model node and justification.

Node	Photograph	Roughness and Justification
CARR_001		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.

[3] Manning's n for Channels (Chow, 1959) - http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

CARR_002		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_002D		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_003		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
THURN_001		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
THURN_002	Taken from LiDAR, used the upstream and downstream cross section to set the roughness. This was corroborated using satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

THURN_003		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_004		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_005	Taken from LiDAR. Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_006		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_007		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_008		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_009	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_010		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_011	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_011.2	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_012	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_013		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_014	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_015		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_016	No picture available so the roughness was kept the same as the upstream section. This was corroborated by satellite imagery	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
TRIB_001		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.

TRIB_002		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.
TRIB_003		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.

TRIB_004		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.
TRIB_005		Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.
TRIB_006	Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.03. Representing a clean, straight channel.

TRIB_007		Banks: 0.06. Representing light brush and trees. Channel: 0.05. Representing a clean, straight channel with some stones and weeds.
TRIB_008		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
TRIB_009	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel.

TRIB_010	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel.
TRIB_011		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

TRIB_012		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
TRIB_013	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
TRIB_014	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

TRIB_015		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_017	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_018		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_019	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_020	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_021	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_022	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_023		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_024		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_025	Taken from Topographical Survey, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

CARR_026		Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_027	Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_028	Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_029	Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.
CARR_030	Taken from LiDAR, the roughness was kept the same as the upstream section. This was corroborated by satellite imagery.	Banks: 0.06. Representing light brush and trees. Channel: 0.04. Representing a clean, straight channel with some stones and weeds.

5.2.1.1 1D Boundary Conditions

For the upstream boundaries a QT type 1d_bc nodes were applied for the Carr Dike, Thurnscoe Dike and Highgate Lane Dike linking to the bc database referenced in the .tcf file. Events were defined within the batch files and linked via a .tef file and would subsequently define the event hydrographs within the .csv. The hydrographs were scaled to the peak flows in Table 2, with models run for 30 hours. The timestep for the 1D (0.5s) was set at half the 2D timestep (1s) as is standard modelling practice

For the 1D downstream boundary a 1d_bc boundary has been snapped to the downstream end of the 1d_nwk with the slope taken from the last two nodes.

5.2.1.2 1D Structures

In total six (6) structures were identified along the modelled reach, two along the Carr Dike and four along the Highgate Lane Dike in the existing scenario (Figures 9-14). Of the modelled structures only one (1) lies within the site boundary however, the remaining five (5) have been included as they have potential to restrict flows entering the site. Structure geometries and invert levels have been taken from the channel survey.

Carr Dike Structures

CARR_002 - Section 15 on channel survey

The first structure on the Carr Dike (CARR_002) is a small farm access culvert located 750m upstream of the site boundary. The culvert was identified to be a tall arch and as such has been modelled as type 'IW' in the 1d_nwke shapefile. The culvert's opening geometry has been defined using a type 'HW' midpoint cross section (1d_xs) with measurements taken from the channel survey. The 'IW' type has also been used to take advantage of the automatic weir functionality available from TUFLOW. All measurements for the weir attributes within the 1d_nwke layer have been taken from the supplied topographical survey.

Figure 9. CARR_002 upstream inlet - Farm Access Culvert

CARR_007 - Section 10 on channel survey

The second structure along the Carr Dike (CARR_007) is the culvert under the A635 immediately upstream of the Sites northern boundary. The culvert has a general oval shape and as such has also been modelled as an 'IW' type culvert within the 1d_nwke shapefile. Whilst the attributes for the automatic weir feature have been defined, the size of the culvert and height of the road level above suggest it is unlikely that surcharging flows would be able to overtop the road embankment. The culvert's opening geometry has been defined using a type 'HW' midpoint cross section (1d_xs) with measurements taken from the channel survey.

Figure 10. CARR_007 upstream inlet - A635 Culvert

Highgate Lane Structures

TRIB_002 - Section 25 on channel survey

The first structure along the modelled reach of the Highgate Lane Dike (TRIB_002) is a 1.9m diameter culvert, located approximately 230m east of the Site boundary. This has been modelled as a 'C' type culvert within the 1d_nwke layer. Dimensions and invert levels have been taken from the channel survey. Given the reach of this structure, approximately 43m, 2d_bc lines with 'HX' type have been digitised around the null channels to allow any surcharging flows to overtop and escape into the 2D domain.

Figure 11. TRIB_002 upstream inlet- 1.9m diameter culvert

TRIB_004 - Section 23 on channel survey

The second structure along the Highgate Lane Dike (TRIB_004), located approximately 130m east of the Site boundary is another culvert measured to be 1.35m diameter. This culvert has been identified to have a short reach and as such has been modelled as a type 'CW' culvert to utilise the automatic weir functionality of the 1d_nwke feature.

Figure 12. TRIB_004 upstream inlet- 1.35m diameter culvert

TRIB_007 - Section 21 on channel survey

The third structure along the Highgate Lane Dike (TRIB_007), located along the eastern Site boundary is another culvert measured to be 1.75m diameter. This culvert has been identified to have a short reach and as such has been modelled as a type 'CW' culvert to utilise the automatic weir functionality of the 1d_nwke feature.

Figure 13. TRIB_007 downstream outlet - 1.75m diameter culvert

TRIB_011 - Section 19 on channel survey.

The final structure along the Highgate Lane Dike (TRIB_011), located within the Site boundary is another culvert measured to be 1. 5m diameter. This culvert has been identified to have a short reach and as such has been modelled as a type 'CW' culvert to utilise the automatic weir functionality of the 1d_nwke feature.

Figure 14. TRIB_011 upstream inlet - 1.55m diameter culvert

5.2.2 2D Model Build

A model schematic for the 2D TUFLOW element is shown in Figure 15.

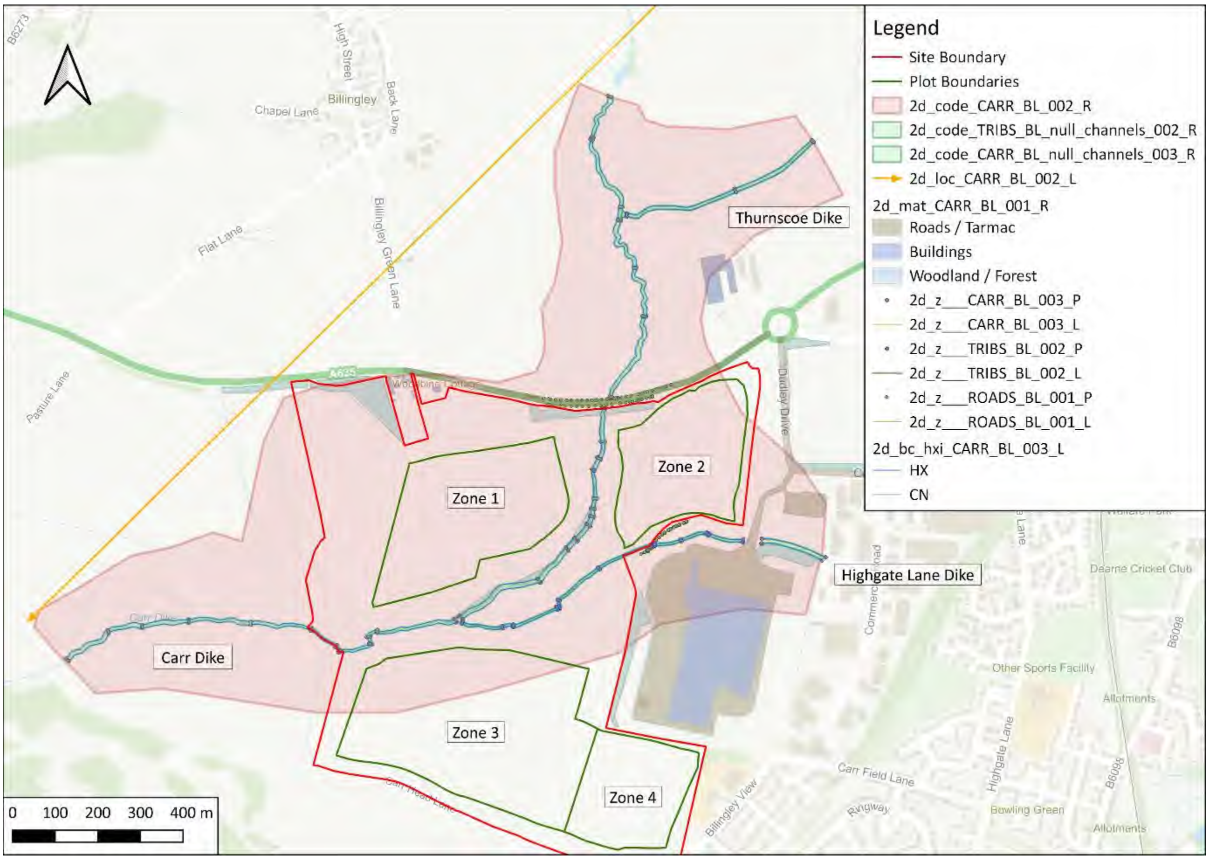


Figure 15. 2D Model Schematic

The 2D model domain covered a total area of area of approximately 1.35km^2, measuring approximately 1.3km wide and 2.2km long, being centred around the Site of interest.

The 2D model was predominantly based on LiDAR data at a 1m resolution obtained from the EA Data library. This LiDAR data was the most recent information available at the time of modelling. Within the Site boundary, a site-specific topographical survey has been provided, and given this information is generally considered more accurate than available LiDAR data, the data has been converted to create a DTM grid (topo_survey.asc) to overlay the existing LiDAR.

LiDAR and EA Flood Zones around the Site were used to identify areas of higher ground (ultimately watersheds) which were then used to help determine the required 2D domain extent. The domain chosen followed the line of high ground around the watercourses and Site boundary. It is noted that the 2d_code layer does not cover the entire Site, with areas in the south shown to be outside of the modelled area. EA Flood Zones indicated this area to be well outside the predicted flood extents and LiDAR identified these portions of the Site to be at a higher elevation than the areas to the north and as such it was deemed that it was not necessary to include within the modelled areas.

The model was a linked 1D-2D (ESTRY-TUFLOW) model with coupling via the use of HX and CN lines. A check of each cross-section width was undertaken to ensure that the 1D domain width (i.e., area coded out) matched the surveyed width of the channel. All cross-section widths within the 2D model were within 10% of the surveyed channel width as is standard modelling practice.

5.2.2.1 2D Boundary Conditions

A Stage-Discharge boundary was applied along the downstream edge of the TUFLOW domain to prevent any over-estimation of flood levels within the Site due to 'backing up' at the downstream model limit, and this was represented as a HQ boundary within the 2d_hxe file with gradients calculated from LiDAR across the boundary. The gradients found on the left bank were 0.011, 0.011 and 0.012, therefore the average gradient of 0.011 was used. The gradients found on the right bank were 0.01, 0.015 and 0.012, therefore the average gradient of 0.012 was used.

5.2.2.2 2D Roughness

The baseline 2D roughness values were represented within a 2d_mat file with all buildings, highways, and areas of woodland being represented. The location of all of the features included within the materials file was taken initially from OS Open Map Local data. The major roadways within the modelled domain were created using a 6m buffer from the Roads OS layer and cross checked against aerial imagery as is standard modelling practice. Any areas deemed to have a significant change in roughness value that were not included within the OS Open Map Local Data) were added in manually using aerial imagery as a reference, i.e., large areas of car parking / tarmac around the industrial developments to the east of the Site.

Within the materials file each land use was represented through a reference number (2 for highways, 3 for dwellings, etc) with these being linked to a separate spreadsheet file (materials.csv) which referenced the Manning's values adopting the Chow methodology.

5.2.2.3 2D structures

No structures were identified as being required within the 2D domain. However, additional Z lines and Z points have been applied to the A635 and small access road along the eastern boundary to reinforce the levels included within the Site' topographical survey.

5.2.2.4 Model Run Parameters

The 2D timesteps were run at half the model grid resolution (2m). The model has been run using TUFLOW HPC.

5.2.3 Baseline Model Results

The maximum flood levels and depths of the baseline modelling are shown in Table 5 with the maximum extents in the present day and climate change results shown in Figure 16 - Figure 19 respectively.

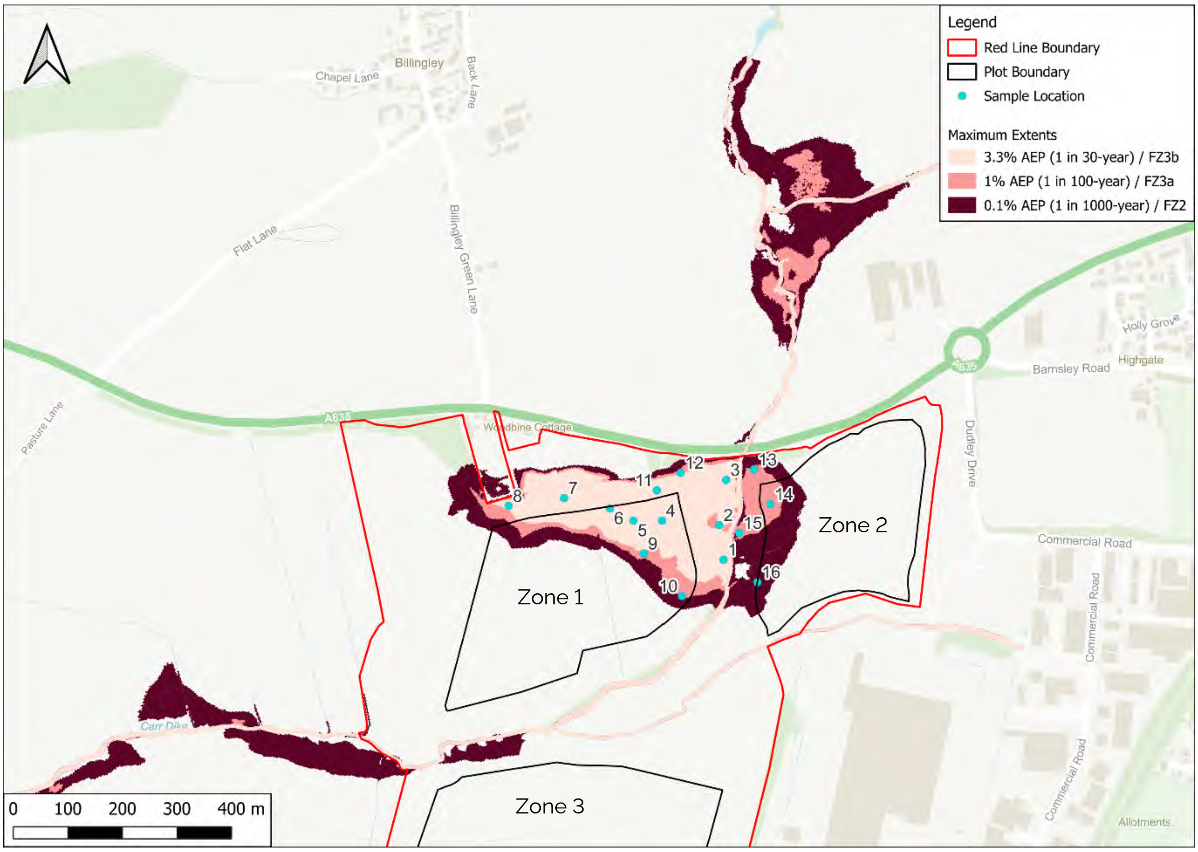


Figure 16. Baseline Full Extents - Present Day

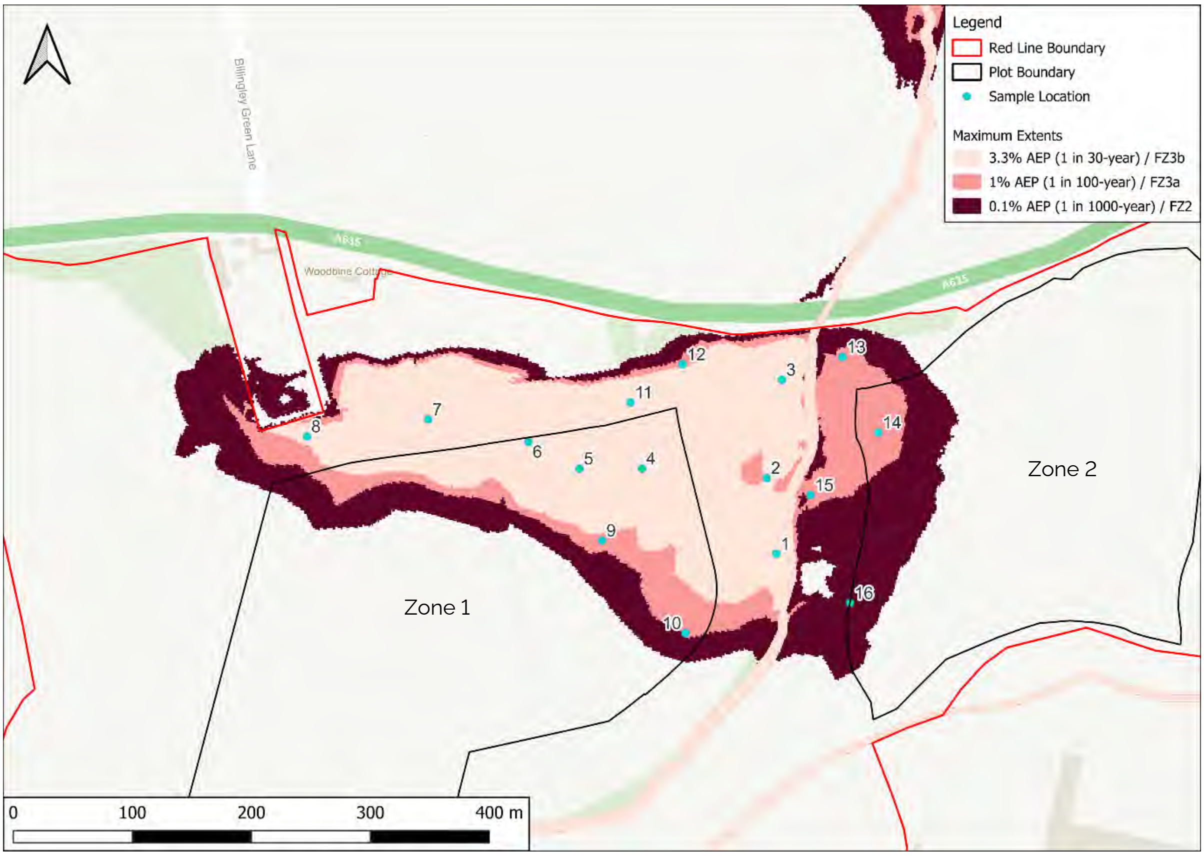


Figure 17. Baseline Extents (Zoomed In) - Present Day

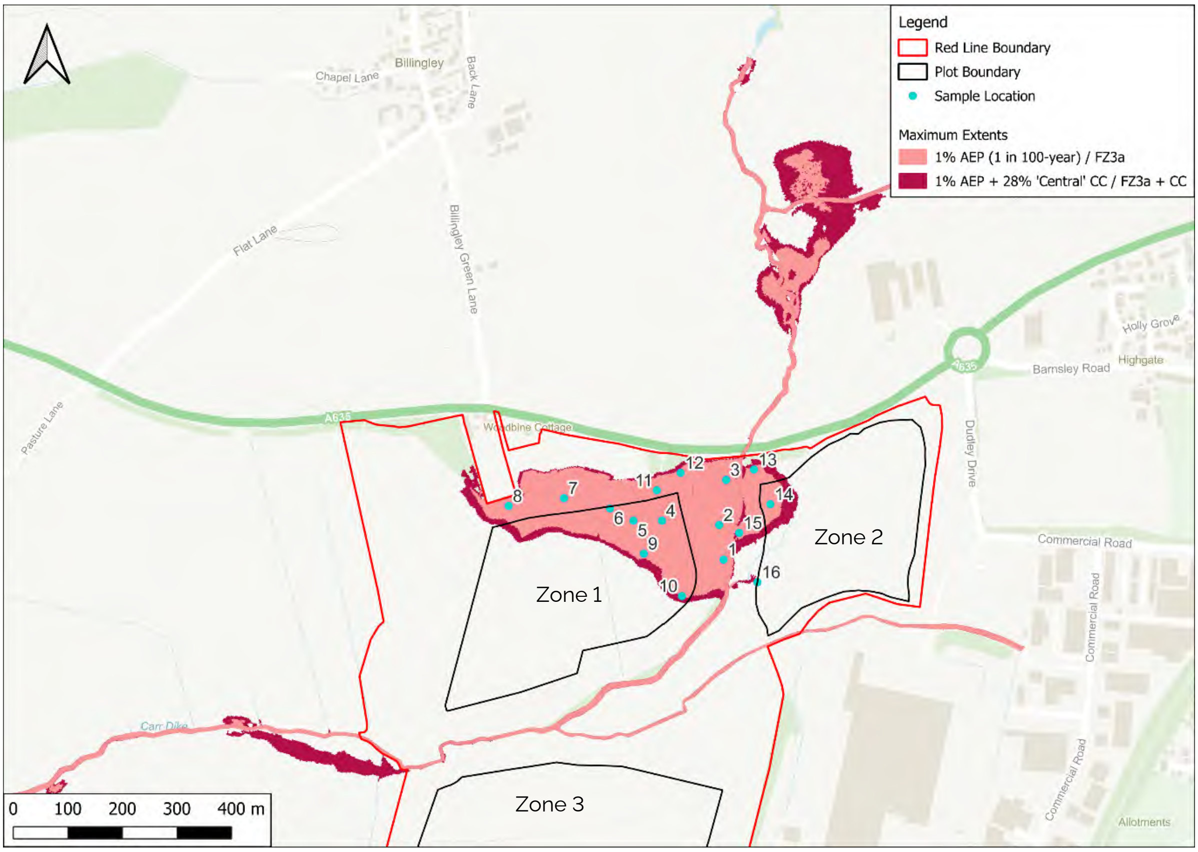


Figure 18. Baseline Full Extents - Climate Change

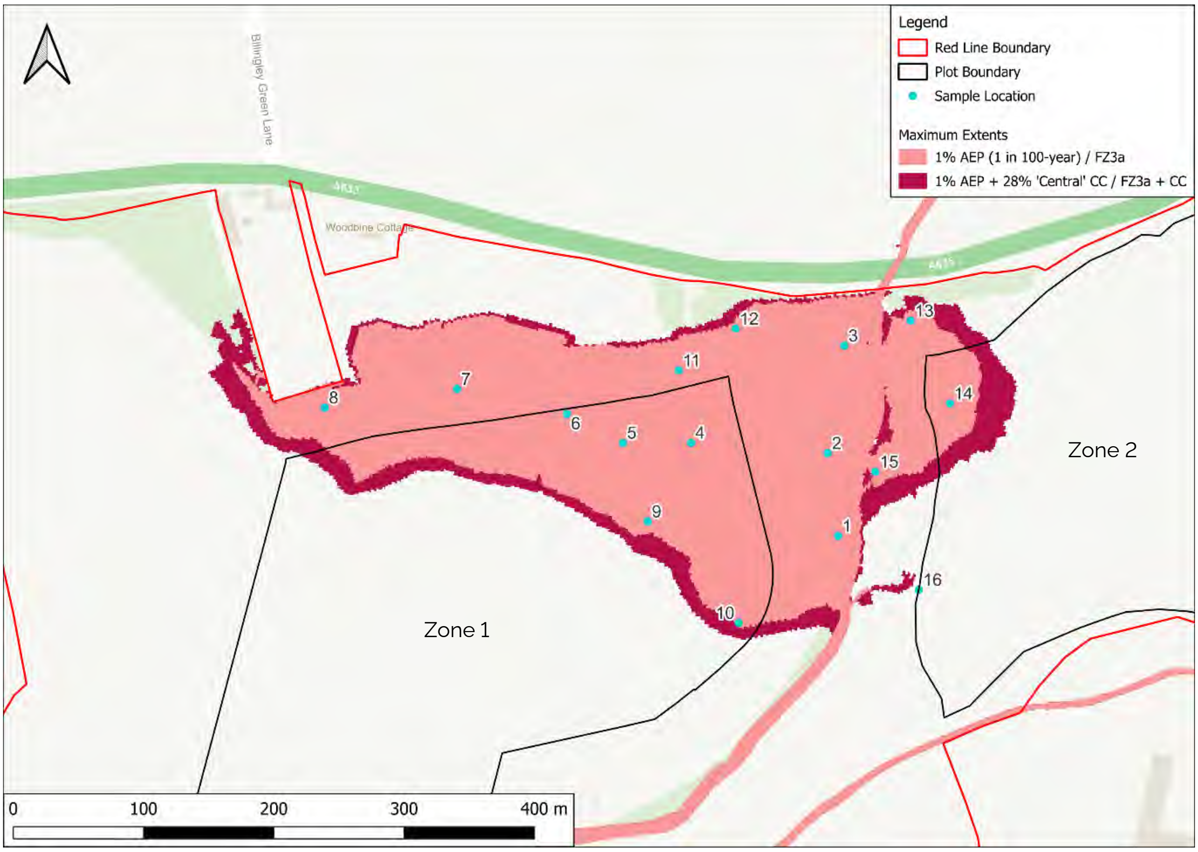


Figure 19. Baseline Extents (Zoomed In) - Climate Change

Table 5. Maximum Flood Levels and Depths for the Baseline Model.

Sample Points	3.3% AEP		1% AEP		1% + Central CC		0.1% AEP	
	Level (m AOD)	Depth (m)	Level (m AOD)	Depth (m)	Level (m AOD)	Depth (m)	Level (m AOD)	Depth (m)
1	23.01	0.12	23.22	0.33	23.42	0.53	23.68	0.79
2	23.05	0.05	23.23	0.23	23.43	0.42	23.68	0.68
3	23.05	0.39	23.24	0.55	23.44	0.74	23.69	0.99
4	23.04	0.2	23.24	0.4	23.43	0.59	23.68	0.85
5	23.04	0.27	23.24	0.46	23.43	0.66	23.68	0.91
6	23.04	0.45	23.24	0.65	23.43	0.84	23.68	1.09
7	23.04	0.61	23.24	0.8	23.43	0.99	23.68	1.25
8	23.04	0.05	23.24	0.26	23.43	0.45	23.68	0.7
9	-	-	23.24	0.11	23.43	0.31	23.68	0.55
10	-	-	23.23	0.01	23.43	0.22	23.68	0.48
11	23.04	0.26	23.24	0.45	23.43	0.64	23.68	0.9
12		-	23.24	0.19	23.43	0.3	23.68	0.59
13	-	-	23.24	0.07	23.44	0.27	23.69	0.52
14	-	-	23.24	0.15	23.43	0.34	23.69	0.6
15	-	-	23.24	0.08	23.43	0.27	23.68	0.51
16	-	-	-	-	-	-	23.68	0.21

The results of the baseline scenario confirm that in all events modelled (both present day and with climate change), fluvial flooding is predicted to come out of bank along the Carr Dike extending into the Site impacting the proposed development Zone 1. Figure 20 below shows the flood mechanism from the Carr Dike during the baseline scenario. Flooding is first predicted to come out of the Carr Dike along the western (right) bank (around sample point 3), due to the lower elevated bank top levels along this reach. From here, flooding is shown to extend west into the Site following the local topography and meet a second flow route from a downstream reach of the Carr Dike. Flood waters proceed to fill the natural low areas within the Site with a maximum extent stretching across the northern portions of the Site and impacting Zone 1. In the design event, 1% AEP (1 in 100-year) plus 'Central' Climate Change allowance, maximum flood levels and depths across this area are predicted to be 23.44m AOD and 0.99m, respectively. Deeper flooding is shown to the north of sample point seven (7) however this is attributed to a local drainage feature and therefore not representative of flooding on the land parcels.

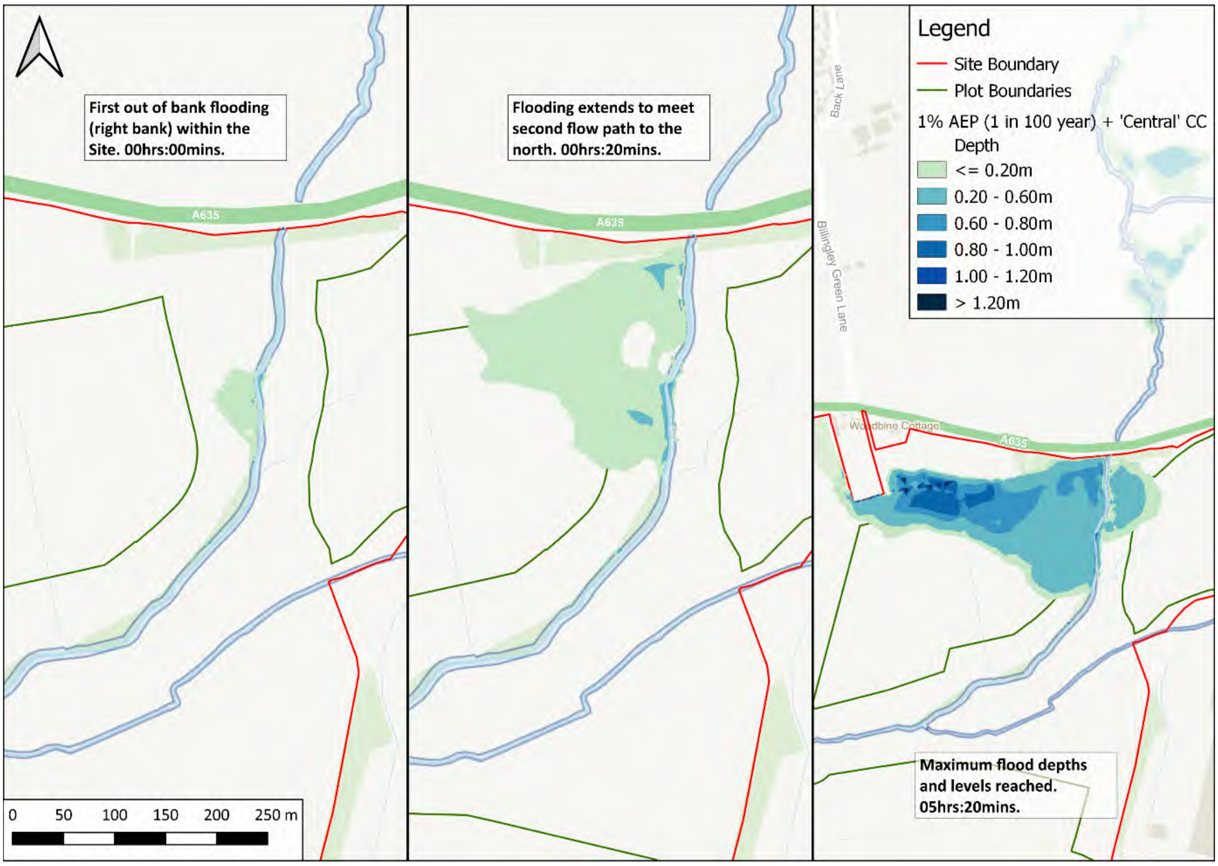


Figure 20. Flood Mechanism in the Baseline Scenario for the Carr Dike – 1% AEP plus 'Central' Climate Change

In events larger than 1% AEP, flooding is also experienced on the eastern (left) bank, extending into development Zone 2 with flood levels shown to range between 23.24m AOD and 23.69m AOD and depths up to 0.6m in the largest 0.1% AEP flood event.

EA Flood Zone mapping suggests Flood Zone 2 i.e., 0.1% AEP event, has a flow path extending from the Carr Dike across the northern portions of the site before flowing south and re-joining the watercourse to the south east of development Zone 1. However, the detailed modelling undertaken (which includes site-specific topographical survey data) confirms that this flow path does not occur and instead flooding is predicted to be limited to the northern portions of the site and development Zone 1 and 2.

The modelling also confirms the site to be at risk of flooding in the 3.3% AEP event (1 in 30-year) which is defined by the EA to be the functional floodplain (Flood Zone 3b). Similarly, to the larger events, flooding is also predicted to extend from the Carr Dike and impact development Zone 1 and the northern portion of the Site. Maximum flood levels and depths for this event are indicated to be 23.05m AOD and 0.61m respectively. Figure 21 to Figure 23 show the maximum depths for the present-day Flood Zones 2, 3a and 3b.

The Highgate Lane Dike, from the eastern boundary, is not identified to have any additional flooding from its channel with all events shown to be contained within the channel capacity.

Outside of the Site boundary, flooding is identified to occur north of the A635 in all events, around the confluence between the Carr Dike and the Thurnscoe Dike approximately 500m north of the Site boundary.

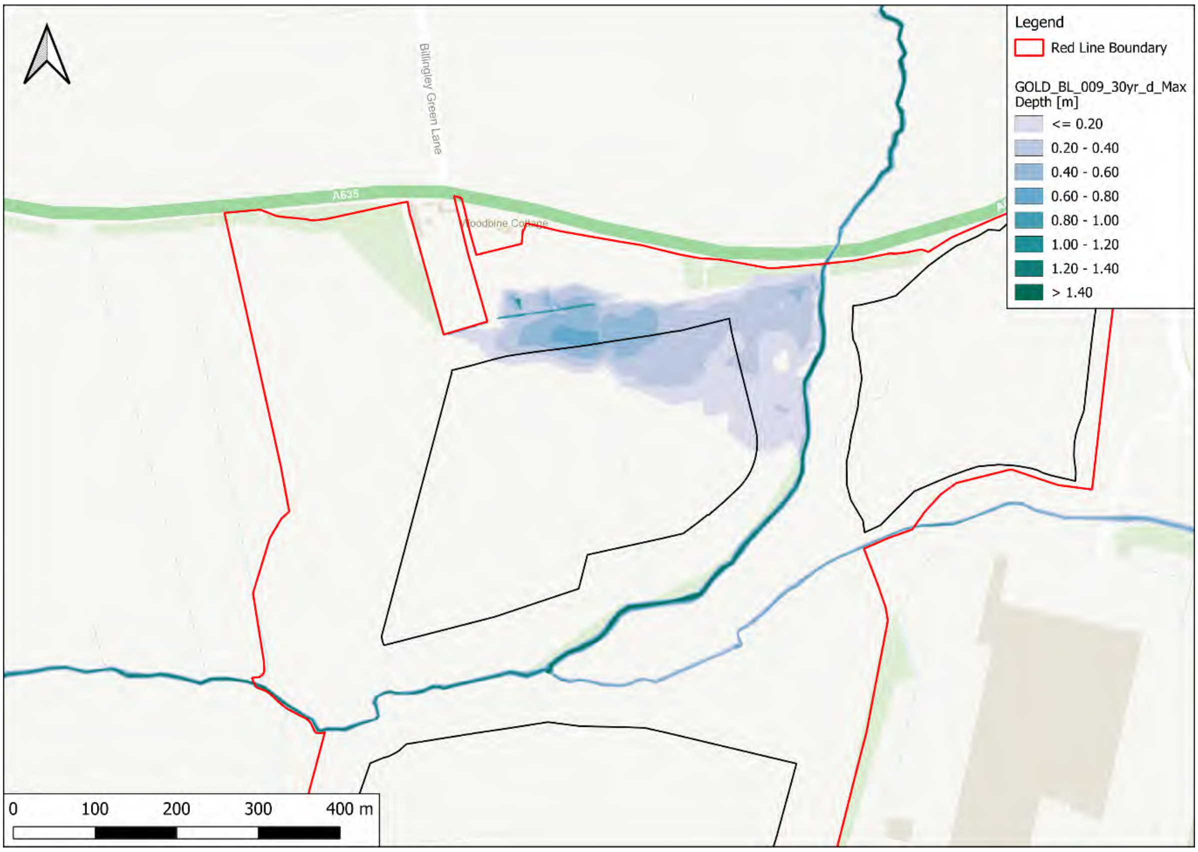


Figure 21. 3.3% AEP (1 in 30 year) / Flood Zone 3b - Max Depths

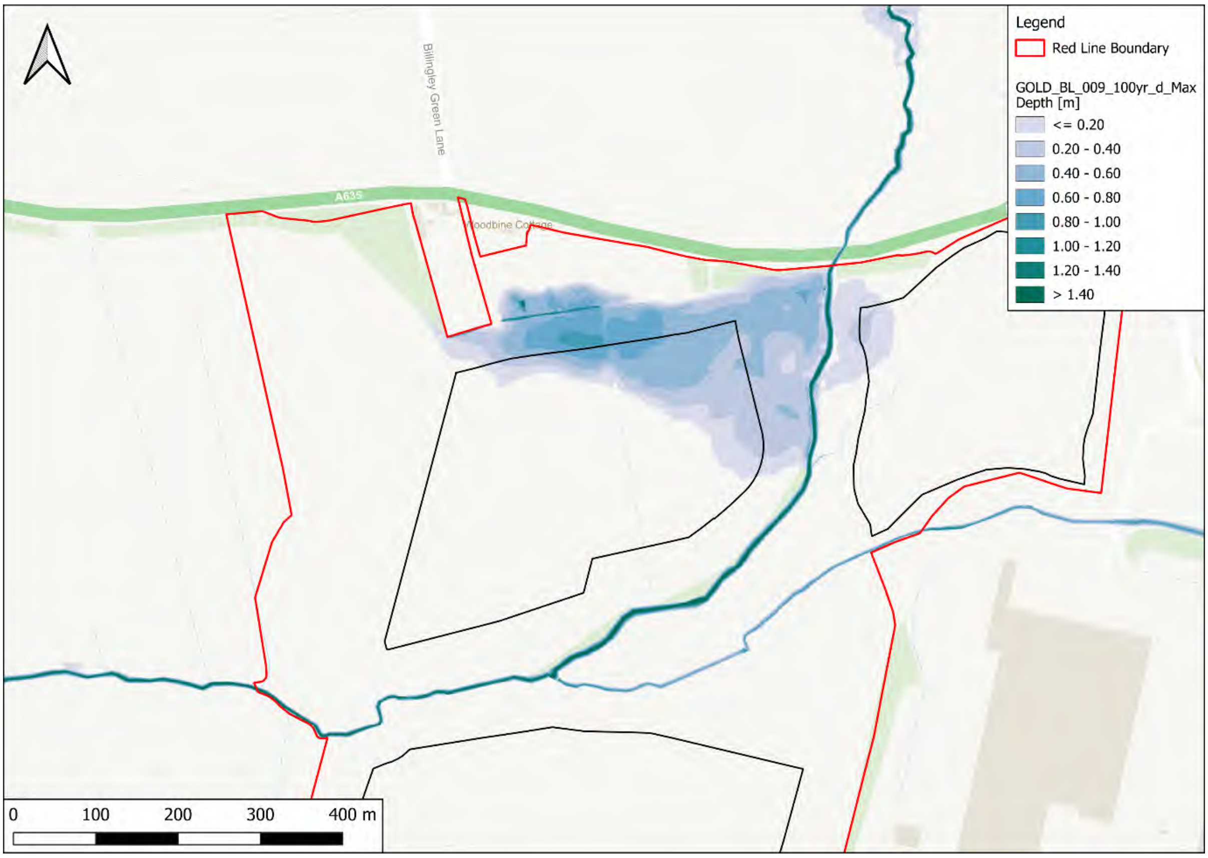


Figure 22. 1% AEP (1 in 100 year) / Flood Zone 3a - Max Depths

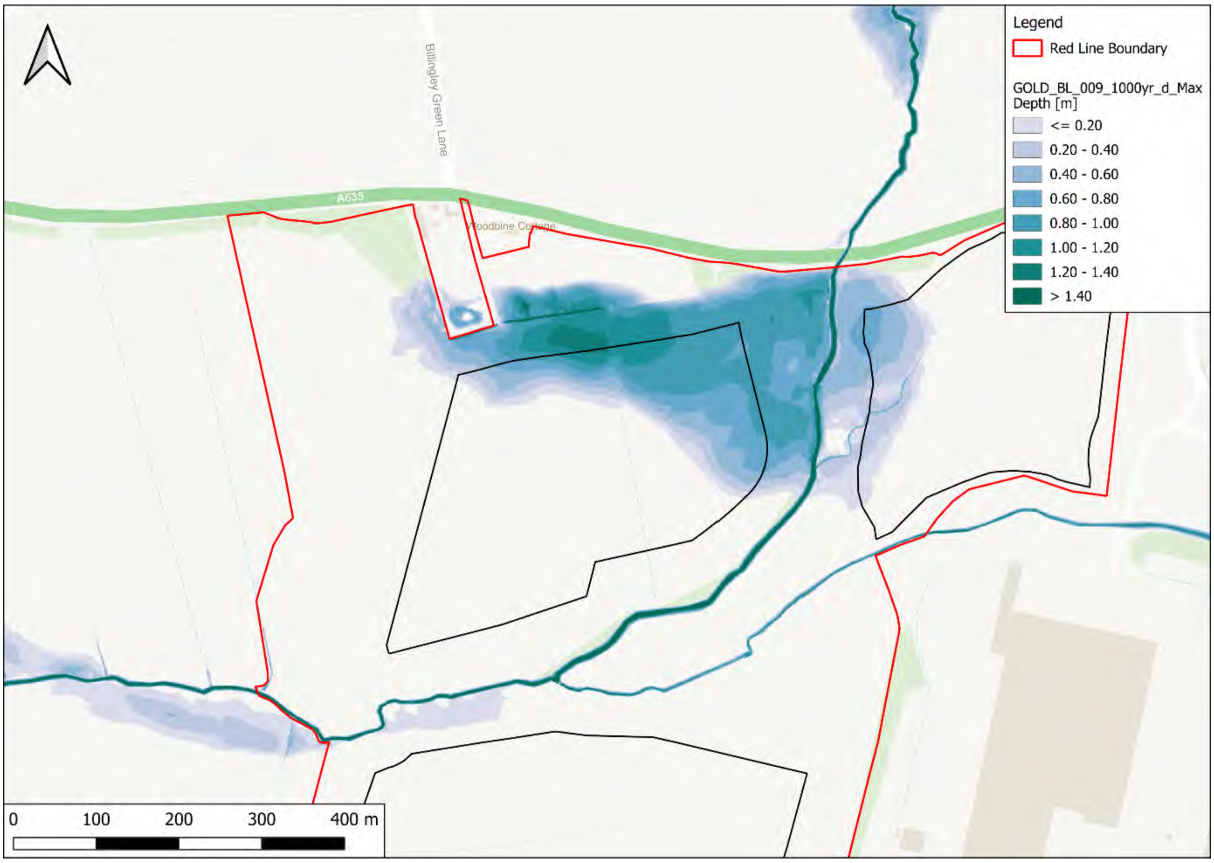


Figure 23. 0.1% AEP (1 in 1000 year) / Flood Zone 2 - Max Depths

5.2.4 Model Warning and Stability

5.2.4.1 Warning and Check Messages

WARNING 2218 – Manning's n Value of 1. For Materia 99 is unusually low or high

This manning's value has been applied within the 'Material.csv' for any stability patches required within the modelling. No stability patches have been necessary this time and as such the warning is not applicable.

Warning 2583 - Material ID XX has a manning's n value greater than Wu n limit - n value will be limited in Wu formulation

This applied to the manning's n values of 0.3 and 1 relating to buildings and the stability patch respectively. The manning's n value of 0.3 for buildings is an industry standard approach. In addition, No stability patches have been necessary this time and as such the warning is not applicable.

Warning 2330 - XF file has incorrect location and/or dimensions

This has no effect on the model results. No action necessary

WARNING 2073 – Object ignored. Only Points, Lines, Polylines, Regions & Region Centres used.

Caused by null geometries within the shapefiles. All have been ignored and do not cause an impact to the model.

WARNING 1100 – Structure XX crest/invert is below bed of primary upstream channel XX

Six of these warnings were present within the model. All invert and crest levels of structures and channel bed mentioned in the warnings have been taken from surveyed data and as such are correct.

WARNING 2550 – XX instability timestep corrections recorded at cell [XX,XX]

Repeated timestep corrections were investigated and two were found to be at 7hrs:35 mins of model simulation time. This occurs when the river starts to come out of bank. No further repeated timesteps occurred during the simulation or across the peak of the hydrographs. No negative depths occurred through the simulation and the results seem sensible with no extreme spikes in levels across the area of interest.

CHECK 1152 – For channel XX, using centre cross section and ignoring end cross sections.

This message was due to the midpoint cross sections around the irregular type culverts CARR_002B and CARR_007. No further action needed.

Check 1037 - Channel interpolated from XS and XS.

These occur where the channel has been interpolated as intended where the cross section survey is limited.

CHECK 2370 - Ignoring coincident point found in ORIGINAL layer.

No action necessary.

5.2.4.2 1D Mass Error

The cumulative 1D mass error for the baseline scenario, 1% AEP (1 in 100 year) plus 28% Central (2080s) Climate Change allowance shows that after initial spikes reaching a maximum of 0.3%, the model settles with no further spikes after the 4 hour mark (Figure 24). The model is concluded to be well within the ±1% tolerance and the model is therefore demonstrated to be stable in the 1D.

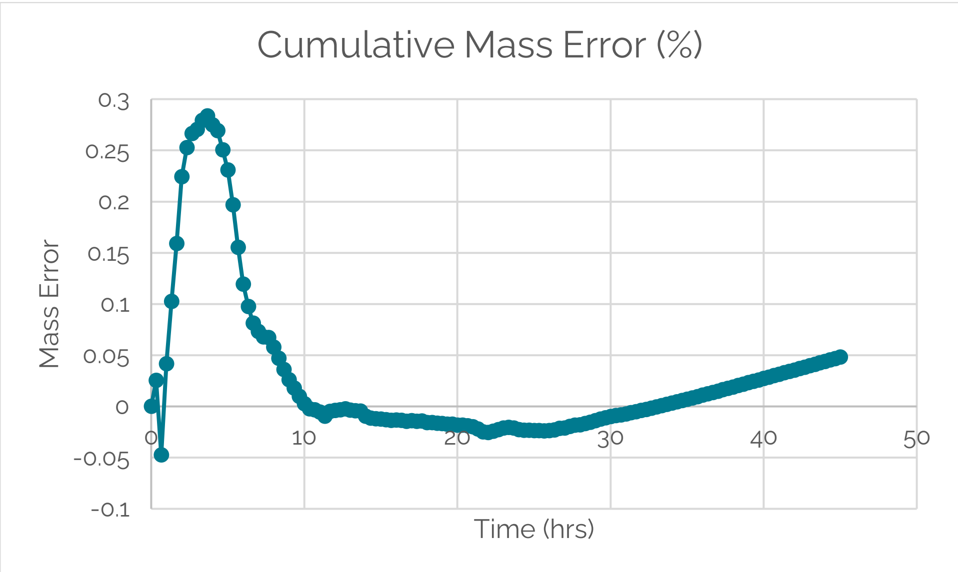


Figure 24. Cumulative 1D Mass Error (Baseline Scenario, 1% AEP + Central CC Event)

5.2.4.3 2D Mass Error

The HPC solver uses an adaptive timestep to solve the equation to find a balance between model stability and run time. A timestep that is required to drop below 1/10th of the model grid size (in this instance 0.2s) would be indicative of poor model stability.

Figure 25 shows that the timestep remained steady over the whole duration of the simulation, which is indicative of good model stability. Nu, Nc and Nd values were also checked and shown to remain in the appropriate range. Flow and stage time series were checked throughout the model to ensure continuity of flow and smooth hydrographs, with no issues observed that would compromise results at the site.

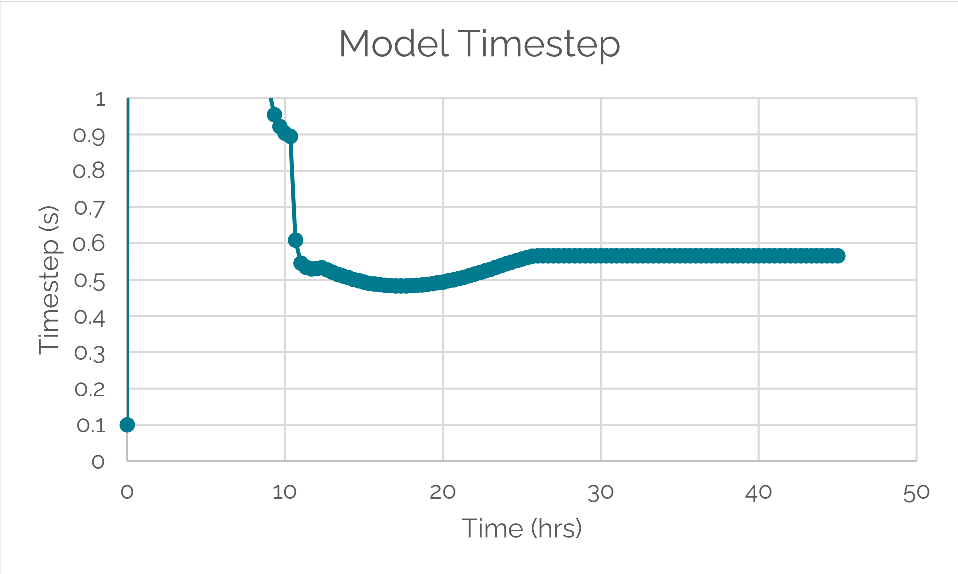


Figure 25. Cumulative 2D Mass Error (Baseline Scenario, 1% AEP + Central CC Event)

5.2.4.4 Operations under different flow conditions

In all the modelled scenarios, the model consistently demonstrates stability across both one-dimensional (1D) and two-dimensional (2D) frameworks, ensuring its robustness and reliability. This stability persists under a wide range of flow conditions, confirming that the model remains accurate and dependable regardless of the variability of the flow environment.

5.2.5 Sensitivity Testing

Four sensitivity tests were undertaken for the baseline model, using the 1 in 100 year (1% AEP) + 28% Central Climate Change allowance design event, to confirm the suitability of the results. These are considered below.

5.2.5.1 Baseline Scenario - Sensitivity Test 1 - Manning's Roughness +20%

A 20% increase to the 1D Channel and 2D Floodplain values was applied to consider the sensitivity of this parameter. The results of this test cause the maximum flooded extents within the model to show a maximum increase of 67m in floodplain width on site with a maximum increase of 127mm in flood depth. However, the proposed mitigation and post-development modelling confirms the development and associated infrastructure to sit well above (>2m) the predicted the maximum flood extents even with the increased roughness.

5.2.5.2 Baseline Scenario - Sensitivity Test 2 - Manning's Roughness -20%

A 20% decrease to the 1D Channel and 2D Floodplain values was applied to consider the sensitivity of this parameter. The results of this test cause the maximum flooded extents within the model to show a slight decrease with onsite flood levels predicted to decrease by approximately 162mm and a maximum decrease in floodplain width of 24m.

Whilst the model has shown to be sensitive to changes to Manning's Roughness values, the design of the road and development will ensure it is safe against the worst-case levels of the 20% increase in Manning's Roughness.

5.2.5.3 Baseline Scenario - Sensitivity Test 3 - Downstream Boundary Gradient +20%

A 20% increase to the downstream boundary gradient in the 1D channel and 2D floodplain was applied to consider sensitivity to this parameter. The results show negligible differences in the majority of the 2D domain with a slight decrease in extent at the downstream boundary. Within the 1D domain, there is a maximum decrease of 49mm in flood levels up to node CARR_027.

5.2.5.4 Baseline Scenario - Sensitivity Test 4 - Downstream Boundary Gradient -20%

A 20% decrease to the downstream boundary gradient in the 2D floodplain was applied to consider sensitivity to this parameter. The results show an increase in levels within the watercourse around the last three nodes (CARR_027 to CARR_030). In the 2D floodplain the extent is greatly increased at the downstream boundary. In the 1D channel the flood levels are increased by a maximum of 39mm. Negligible impact occurs above node CARR_027 which lies downstream of the site.

On this basis the wider model is not considered sensitive to a change in the downstream boundary gradients.

5.3 Post-Development Modelling

5.3.1 Model Build

A schematic of the proposed development and mitigation measures implemented within the post-development model is shown below in Figure 26. It should be noted that no changes have been made between the baseline scenario and the post-development scenario unless stated below.

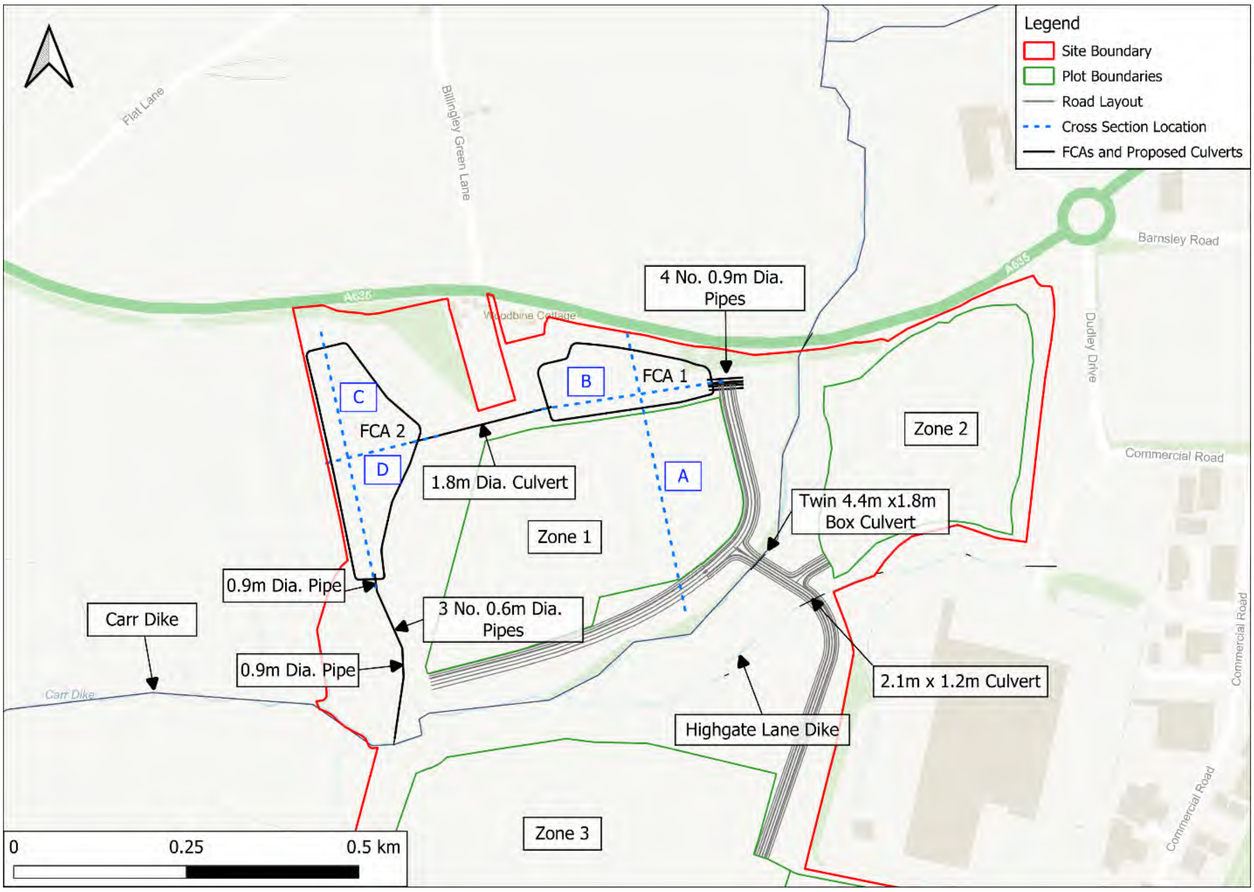


Figure 26. Proposed Development and Mitigation

The list of files for the final post development scenario are:

- TCF – GOLD_PD_018.tcf
- TRD – GOLD_PD_018.trd
- ECF – GOLD_PD_018.ecf
- TEF – GOLD_BL_001.tef
- TBC – GOLD_PD_016
- TGC – GOLD_PD_018
- Shapefiles – all referenced within the ECF, TBC and TGC

5.3.1.1 Flood Compensation Areas

Due to the developments proposed location within the baseline flood extents, mitigation is required to ensure the development is safe across its design life whilst also ensuring no increase in flood risk to third-party land as a result of the development.

The proposed plots / development zones and road network have been designed to be raised above and therefore out of the flood extents to ensure the development is safe and dry across its design life. As this ground raising occurs within the baseline floodplain, a series of two flood compensation areas (FCAs) have been designed and modelled to ensure no detrimental impact and provide the compensatory storage required. Rather than a single large / deep FCA, two FCAs have been connected with a series of pipes and culverts to allow flooding to follow its natural flow path, extending west across the development Site, as occurs in the baseline scenario. The secondary FCA allows flows to fill the area with a gradient south leading to a further network of culverts, allowing flows to re-enter the Carr Dike at the western boundary of the Site. The network of pipes and culverts therefore act as a bypass and temporary storage for the predicted flood flows with modelling undertaken to prove its effectiveness in mitigating onsite flooding and ensuring no detrimental impact to third-party land. The FCAs and proposed culvert networks have been designed using the design flood, 1% AEP plus 'Central' Climate Change as is standard modelling practice.

To model the FCAs, plots, road networks and associated infrastructure (drainage attenuation ponds etc.) a 3D model has been prepared in conjunction with the proposed drainage strategy (23451-HYD-XX-XX-RP-D-0003 – Drainage Strategy). To ensure the hydraulic model aligned with the designed levels, this 3D model was converted to an .asc format (Goldthorpe_Proposed_Levels_P6.asc) and read into the post development.tgc. Figure 26 shows the locations of example cross sections (see Figure 27 to Figure 30) within the hydraulic model. FCA1 has a maximum bed level of 21.20m AOD in the east, falling to a low point of 21.10m AOD in the west. FCA2 has been designed to have a maximum bed level of 21.00m AOD in the north, with a fall towards the outlet in the south at a low point of 20.90m AOD. Where the culvert from FCA1 outfalls to FCA2, the bed level is 20.95m AOD.

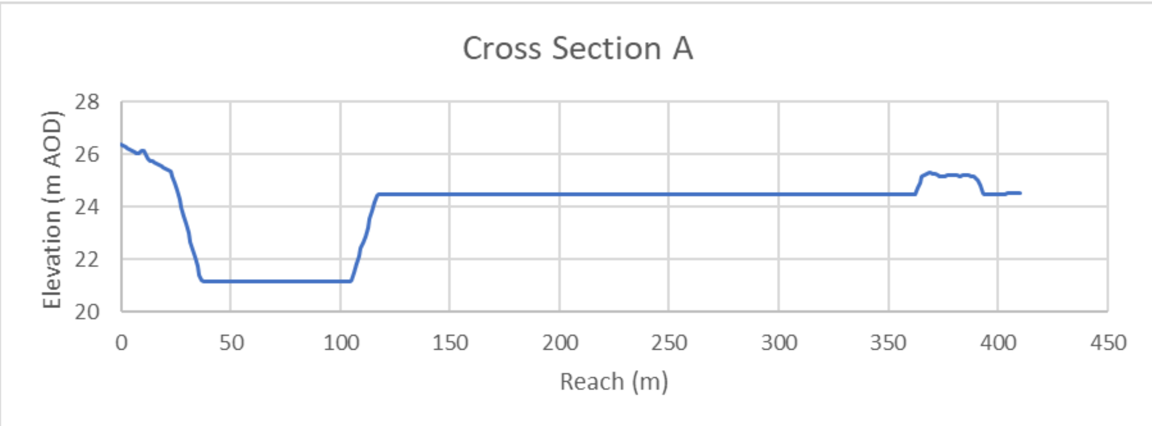


Figure 27. Cross Section A - FCA1 and Zone 1 Plot Level

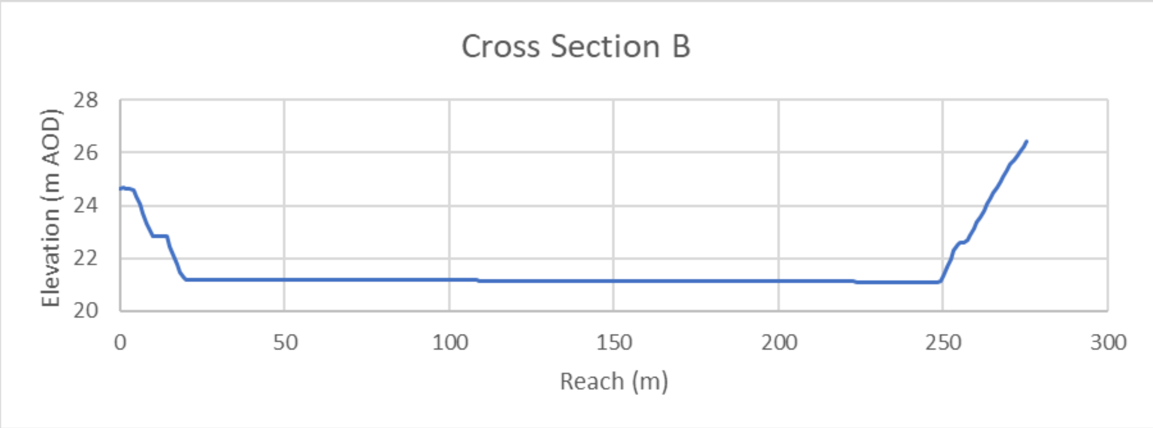


Figure 28. Cross Section B - FCA1 East to West

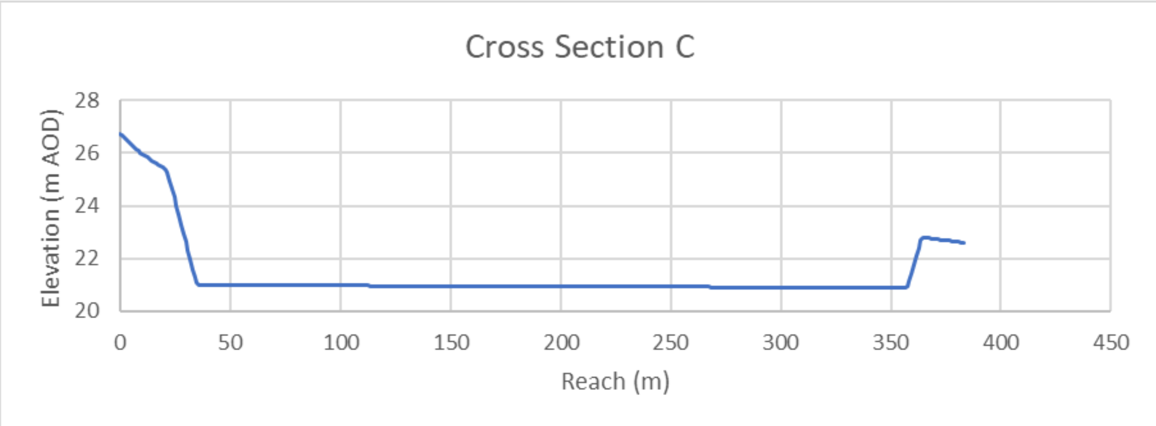


Figure 29. Cross Section C - FCA2 North to South

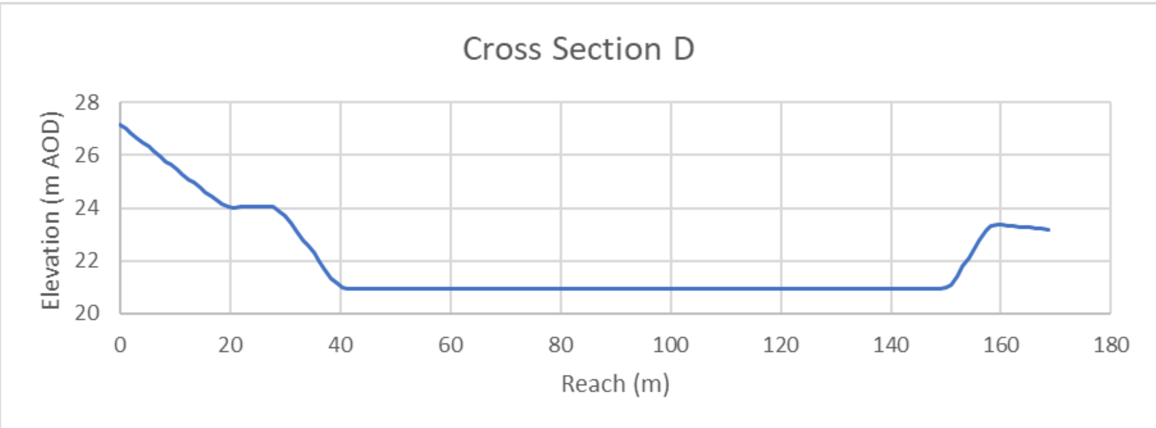


Figure 30. Cross Section D - FCA2 East to West

A series of culverts connects the FCAs with the flood plains and ultimately discharging into the Carr Dike. These have been represented as a 1d network lines (1d_nwke_CARR_PD_Structures_013_L.shp) with 2d_bc points or lines with 'SX' type snapped to the upstream and downstream of the network lines to allow for interaction between the 1d and 2d. From FCA2 into the Carr Dike, the series of culverts have been connected to the 1d network of the Carr Dike with a type 'X' connector.

The first culverts, from the floodplain into FCA1 have been designed and modelled as 4 no. 0.9m diameter pipes (Type C with 4 no. Barrels) with an upstream invert level maintained at ground level of the floodplain (22.73m AOD). The culvert between FCA1 and FCA2 has been designed and modelled as a single 1.8m diameter pipe (Type C) with upstream and downstream invert levels kept at bed level of the FCAs. The final network of pipes from FCA2 discharging back into the Carr Dike have been designed as a series of single 0.9m pipes (Type CU) with a fall towards the Carr Dike. For the second reach within the series of culverts, due to the drainage strategy, the 0.9m pipe is replaced with 3 no. 0.6m pipes to ensure sufficient cover is achieved. The culverts have been modelled as type CU to ensure a uni-directional flow down into the Carr Dike and simulate a non-return valve on the outfall with the watercourse.

5.3.1.2 Proposed Roads and Watercourse Crossings

The proposed layout for the Site included two watercourse crossings, one across the Carr Dike and a second over the Highgate Lane Dike. Road design and levels have been included within the wider 3D model which also includes the FCAs, as stated above.

The proposed culvert in the Carr Dike has been modelled as a twin 4.4m wide x 1.8m high box culverts (Type R) to ensure limited flow restriction occurs and ensure no additional flooding on land to the north of the Site and A635. The proposed culvert for the Highgate Lane Dike a single rectangular 2.1 wide x 1.2m high diameter culvert (Type R). All null channels, 2d_bc hxi lines, 2d_zsh and 1d_nwk shapefiles have been updated accordingly.

To ensure access to the Carr Dike is still possible, to allow for management and maintenance of the watercourse, ramps have been included within the design of the proposed development and the 3D model. The proposed access points and requirements have been discussed and agreed in principle with the IDB at the meeting (14/10/2022).

5.3.2 Post-Development Results

The results of the post-development model confirm the development to be safe and free from flooding in all events. Developments and roads are raised with significant freeboard above the flood level and are shown to remain dry in all events modelled.

Maximum flood levels and depths in the design event in the two FCAs are shown in Table 6 with maximum flood extents and depths shown in Figure 31.

Table 6. Maximum Flood Levels and Depths for the Flood Compensation Areas.

	Maximum Level (m AOD)	Maximum Depth (m)
FCA1	22.55	1.45
FCA2	22.53	1.65

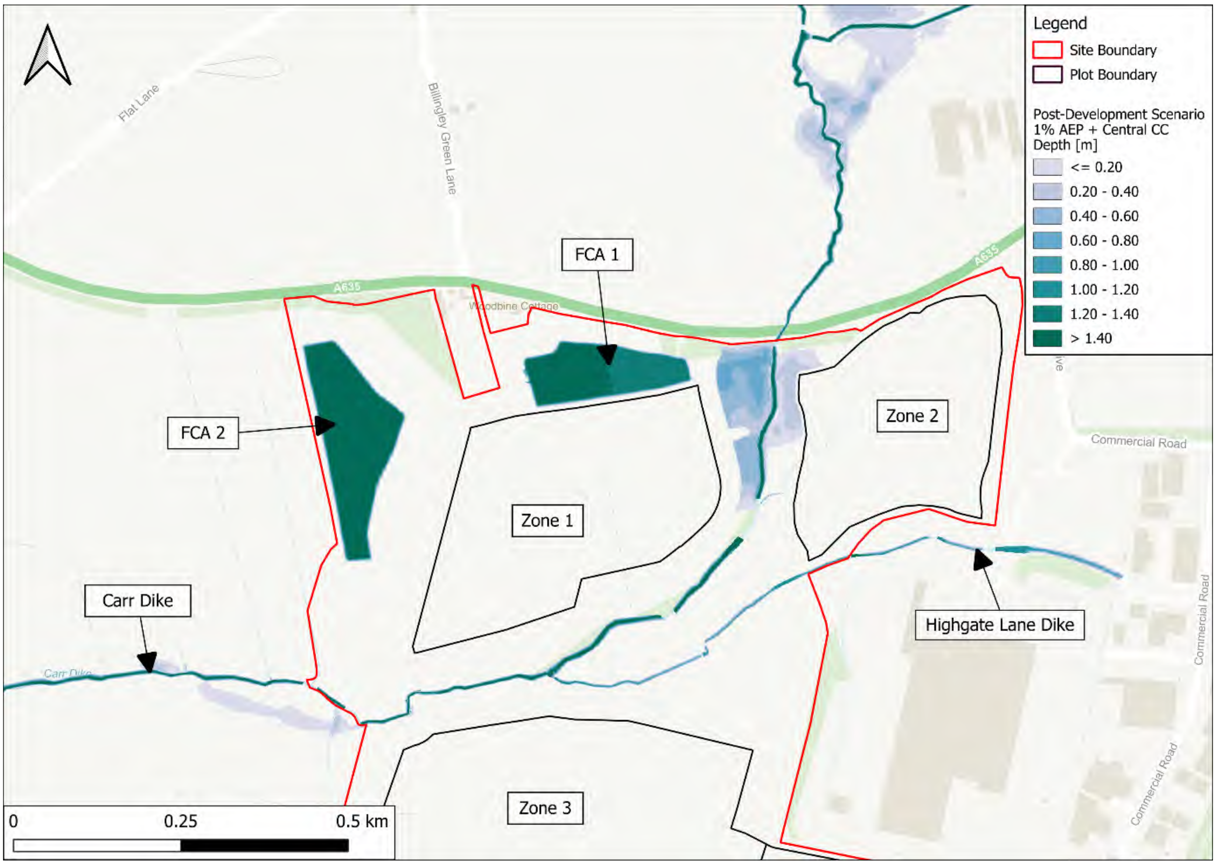


Figure 31: Maximum Extent and Flood Depth for the Post-Development Scenario – 1% AEP plus 'Central' Climate Change

Flood levels within the FCAs are shown to be flat, however, flood depths show a degree of variance. Across FCA1, the greatest flood depths are located at the outlet to FCA2 with flood depths at the inlet approximately 100mm shallower. For FCA2, maximum depths are also found at the outlet to the Carr Dike with depths in the north of the compensation area indicated to be approximately 100mm shallower.

The proposed sequence of FCA's and culverts are shown to successfully act as a bypass route for the predicted out of bank flooding along the Carr Dike, with flows able to enter the FCA1 and follow the designed gradient eventually out falling back into the Carr Dike at the western boundary of the Site. The maximum flood levels within the FCA are approximately 3m below the design finished floor level of Plot 1 (25.5m AOD) and therefore provides a significant freeboard. The FCAs have been designed using the 1 in 100 year + central climate change allowance flood event, however for the 0.1% AEP (1 in 1,000 year) event, a small area of flooding is predicted to overtop the southern bank of FCA2 and flood a small area (~1.59 hectares) within the Site boundary. Similarly, an extremely small area of flooding is predicted to overtop the southwestern bank of FCA1. The predicted areas of flooding are limited to small areas of locally lower lying topography and are not shown to impact the proposed developments and as such are considered to be acceptable. It is noted that the FCA2 exceedance flow is predicted to extend onto ~1.8 hectares of third-party land, however, this occurs in the extreme 1 in 1000 year event only and is not present during the design flood event (the 1 in 100 year + climate change event).

A comparison exercise has been undertaken between the post-development scenario and the baseline scenario design events to confirm no detrimental impacts as a result of the proposed development to third party land during the design event, shown in Figure 32. The results of the comparison show the development does not cause additional flooding outside of the Site boundary during the 1% AEP plus 'Central' Climate Change, and the FCAs reduce flood levels experienced within the Site, around the Carr Dike corridor. The proposed road crossings and additional culverts are also not predicted to cause any additional flooding upstream of the structures. In-channel water levels through the site are increased in some reaches, and reduced in others. However, where in-channel depths are increased, flows still remain confined to the channels.

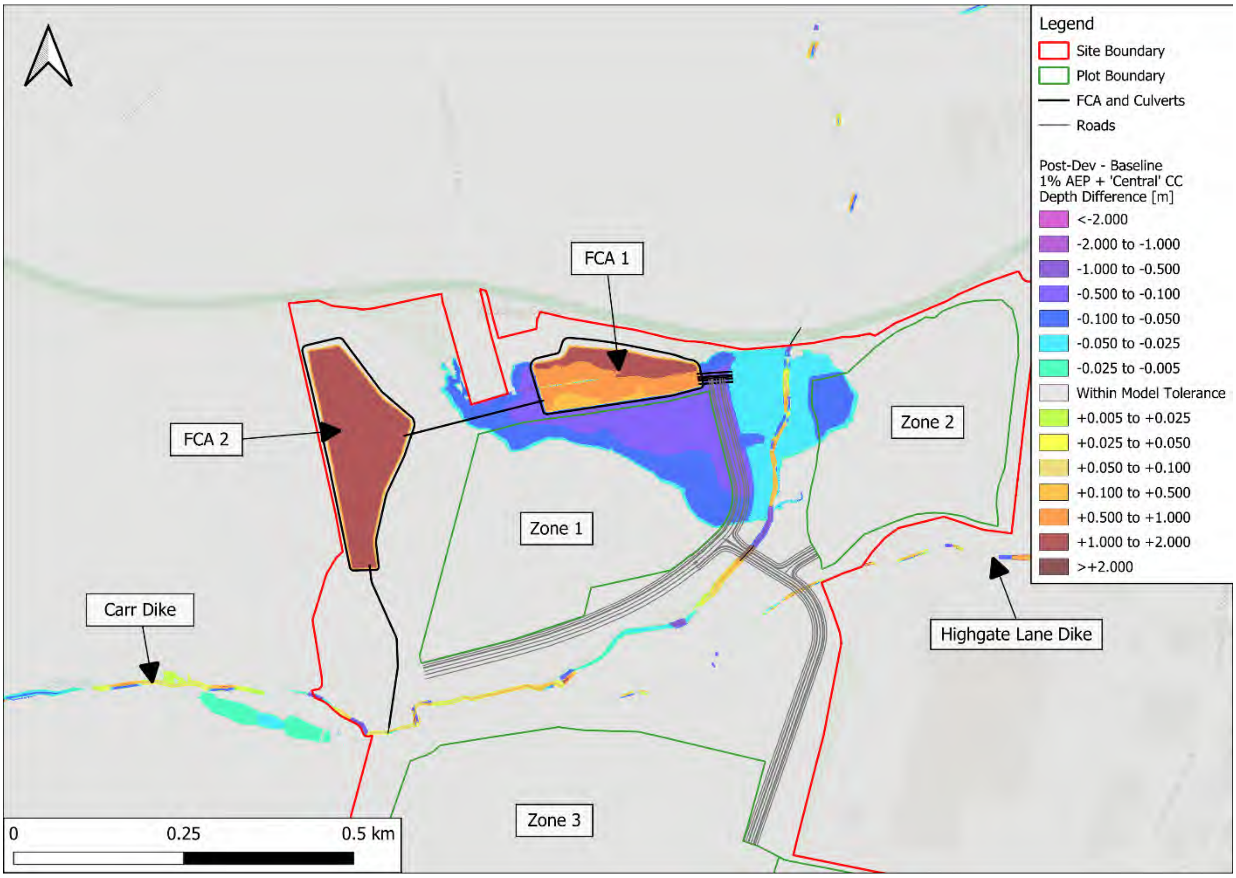


Figure 32. Level Comparison between Post Development & Baseline Scenario - 1% AEP plus 'Central' Climate Change

5.3.3 Residual Blockage Scenarios

Five blockage scenarios have been simulated within the post-development model and compared with both the baseline scenario and the post-development scenario with no blockages. The blockage scenarios have been assessed to investigate the effect of blockage of the new culverts on the attenuation basin function, the internal road network, to third-party land, and relative to the existing site. The five culverts have been selected for the blockage assessment on the basis that these have the greatest potential impact on flooding on Site and to third-party land. All blockages have been run with the design event, 1% AEP plus 'Central' Climate Change event. In line with standard modelling practise, culverts with a bore area under 1m^2 have been applied with a 90% blockage and culverts with a bore area over 1m^2 a 50% blockage has been applied. Blockages have been applied using the pBlockage attribute in the nwke file.

5.3.3.1 R1 – Carr Dike Culvert

A 50% blockage has been applied to CARR_014B, the twin barrel 4.4m wide x 1.8m high culvert along the Carr Dike. A comparison with the baseline 1% AEP plus 'Central' climate change scenario with the R1 post-development 50% Carr Dike Culvert blockage scenario shows a reduction in flood level upstream of the Carr Dike Culvert between 53-89mm. Flood levels are also reduced by 864mm in FCA1. Downstream of the Carr Dike Culvert, south of development Zone 1, flood levels are increased relative to the baseline scenario, however, flows associated with this increased flood level remain in-channel. To the west of the site boundary, on third-party land, flood levels are generally reduced, with the exception of a small area west of the site, where levels are increased, but flows remain confined to the Carr Dike channel.

Comparing the post-development 1% AEP plus 'Central' climate change scenario with the R1 post-development 50% Carr Dike Culvert blockage scenario shows an increase in flood levels upstream of the culvert. Specifically, FCAs 1 and 2 experience a 17mm increase in flood level, while along the Carr Dike Watercourse between development Zones 1 and 2 flood levels are shown to increase.

Even with the slight increase in flood levels, development plots are still designed with a significant freeboard above this and as such, the Site is concluded to not be at an increased risk of flooding by a 50% blockage to the Carr Dike Culvert.

5.3.3.2 R2 – Highgate Lane Dike Culvert

A 50% blockage has been applied to TRIB_009B, the single 1.2m diameter pipe along the Highgate Lane Dike. A comparison with the baseline 1% AEP plus 'Central' climate change scenario with the R2 post-development 50% Highgate Lane Dike Culvert blockage scenario shows an increase in flood level upstream of the Highgate Lane Dike Culvert within the far east of site, and on third-party land, east of the site. However, this increased flood level remains confined to Highgate Lane Dike channel.

Comparing the post-development 1% AEP plus 'Central' climate change scenario with the R2 post-development 50% Highgate Lane Dike Culvert blockage scenario shows an increase in flood levels upstream of the culvert, however, all increased flood levels remain in-channel.

As all increased flows remain in-channel, a 50% blockage to the Highgate Lane Dike Culvert is concluded to not cause additional flood risk to the Site or third-party land.

5.3.3.3 R3 – FCA1 4no. Culverts

A 50% blockage has been applied to the first set of culverts into FCA1, 4 no. 0.9m diameter pipes. Whilst the individual pipes have a bore area less than 1m^2, the total bore area of the pipes is well above the 1m^2 hence why a 50% blockage has been applied. A comparison with the baseline 1% AEP plus 'Central' climate change scenario with the R3 post-development 50% FCA1 4no. Culvert blockage scenario shows a reduction in flood level within FCA1 by 1050mm. The comparison also shows a reduction in flood level along the Carr Dike between development Zones 1 and 2, and further downstream along the Carr Dike. Increases in flood level are observed even further downstream of Carr Dike, south of development Zone 1, and along Highgate Lane Dike. Outside of the site boundary, to the west of the site, in-channel flood levels are shown to increase, with some minor out-of-bank flooding, with an associated increased level of 49mm. Generally, flood flows remain confined to the Carr Dike.

Comparing the post-development 1% AEP plus 'Central' climate change scenario with the R3 post-development 50% FCA1 4no. Culvert blockage scenario shows an increase in flood levels east of the culvert entrance. These increased levels propagate downstream along the Carr Dike. However, the increased levels within the Carr Dike remain confined to the channel. Under the 50% FCA1 post-development blockage scenario, flood levels in FCA1 and FCA2 are reduced by up to 168mm.

Although identifying a slight increase in on-site flood levels within the Carr and Highgate Lane Dikes, development plots are still designed with a significant freeboard above this and as such, the Site is concluded to not be at an increased risk of flooding by a 50% blockage to the FCA1 4no. culverts.

5.3.3.4 R4 – FCA1 to FCA2 Culvert

A 50% blockage has been applied to the culvert between FCA1 and FCA2, the single 1.8m diameter pipe. A comparison with the baseline 1% AEP plus 'Central' climate change scenario with the R4 post-development 50% FCA1 to FCA2 Culvert blockage scenario shows reduced flood levels within

FCA1 by up to 697mm, and reduced flood levels west of FCA1 Culvert inlet along the Carr Dike channel. Reduced flood levels continue along the Carr Dike, until the south west of development Zone 1, however, this increased flooding remains contained within the Carr Dike channel.

Comparing the post-development 1% AEP plus 'Central' climate change scenario with the R4 post-development 50% FCA1 to FCA2 Culvert blockage scenario shows an increase in flood level within FCA1 by up to 184mm. The capacity of FCA1 is shown to be sufficient to support these increased flood levels. Flood levels are not shown to increase or decrease anywhere else on- or off- site.

Results of the blockage to the culvert between FCAs shows FCA1 to increase by up to 184mm but water remains within the FCA. Considering the above information, a 50% blockage to the culvert between FCA1 and FCA2 is concluded to not cause additional flood risk to the Site or third-party land.

5.3.3.5 R5 – FCA2 Outlet Culvert

A 90% blockage has been applied to the culvert at the outlet of FCA2, the single 0.6m diameter pipe leading into the Carr Dike. A comparison with the baseline 1% AEP plus 'Central' climate change scenario with the R5 post-development 90% FCA2 Outlet Culvert blockage scenario shows reduced flood levels within FCA1 by up to 745mm, and reduced flood levels west of FCA1 Culvert inlet along the Carr Dike channel. Reduced flood levels continue along the Carr Dike, until the south west of development Zone 1. To the west of the site boundary, flood levels alternate between increased and decreased, relative to the baseline scenario, but flooding remains confined to the channel at increased levels.

Comparing the post-development 1% AEP plus 'Central' climate change scenario with the R5 post-development 90% FCA2 Outlet Culvert blockage scenario shows increased flood levels in both FCAs by 136-146mm. However, these increased flood levels remain contained within the FCAs.

Even with an increase in flood levels, the development plots are still designed with a significant freeboard above this and as such, the Site is concluded to not be at an increased risk of flooding by a 90% blockage to the FCA2 culvert outlet.

5.4 Summary

The results of the modelling confirm the Site to be at risk of fluvial flooding, in all modelled events, in the existing scenario. Flooding is predicted to come out of bank along the Carr Dike, within the Site boundary, and extend across the western (right bank) land parcels covering a large area in the north of the Site and impacting a portion of development Zone 1. In events larger than the 1 in 100-year flood, the flooding is predicted to come out of bank and extend to the east (left bank) impacting parts of development Zone 2. The results of the modelling therefore confirm the Site to lie within Flood Zone 1, 2, 3a and 3b.

Due to the predicted flooding within the Site boundary, mitigation has been modelled as a post-development scenario. A proposed combination of ground raising, flood compensation areas and a series of culverts have been modelled to ensure the development is safe for its lifetime and causes no additional risk to third-party land.

Results of the post-development model confirms the ground raising of the plots and road network to be sufficient in providing significant freeboard above the maximum flood levels in all modelled events. The series of flood compensation areas and network of culverts provide a bypass route for the predicted flooding, allowing flood waters to be temporarily stored and diverted around the development and eventually discharge positively into the Carr Dike along the western boundary of the Site. Blockage scenarios for five of the new structures confirm the FCAs and culverts to be adequately sized so as a 50/90% blockage does not cause additional flood risk on Site or to third-party land.

Upon implementation of the proposed mitigation strategy, a robust management and maintenance plan will be put in place to ensure that the FCAs and culverts are maintained in order to minimise any risk of blockages which may impact the efficiency of these features. The proposed mitigation strategy is designed to be dry except in times of flood and is a free-flowing system rather than relying on 'backing up' then 'draining down'. As such, it is not considered that there are any issues with siltation and the potential risks associated with blockages will be mitigated.

Modelling also confirms the proposed road crossings and over the Carr Dike and Highgate Lane and proposed culverts to be adequately sized to ensure no additional flooding as a result.

On the basis of the above, whilst the Site is confirmed to be at predicted risk in the baseline scenario, provided mitigation measures ensures the development will be safe across its design life without causing additional flood risk to third-party land.

6. NATIONAL PLANNING POLICY FRAMEWORK

6.1 Sequential & Exception Tests

This assessment has demonstrated that the majority of the Site is located within Flood Zone 1 (Low Risk) however, modelling has confirmed an extent of Flood Zone 2, 3a and 3b (Medium Risk, High Risk and Functional Floodplain) within the northern portion of the Site. The Site is at low or negligible risk of flooding from all other assessed sources.

Paragraph 023 of the Flood Risk and Coastal Change National Planning Practice Guidance (NPPG) states that the Sequential approach 'is designed to ensure that areas at little or no risk of flooding from any source are developed in preference to areas at higher risk. This means avoiding, so far as possible, development in current and future medium and high flood risk areas considering all sources of flooding including areas at risk of surface water flooding.'

The site makes up the area allocated within the Goldthorpe Masterplan Framework (ES10)[4], adopted by the Full Council (30/09/2021). The framework document states the following with regard to flood risk and drainage:

"*The majority of the site falls within Flood Zone 1 and is therefore at low risk from flooding. However, the north of the site falls within Flood Zones 2 and 3 and is therefore considered to be high risk of flooding from fluvial sources (rivers and streams). All planning applications over one hectare will require a Flood Risk Assessment which will be assessed by Barnsley Council and the Environment Agency. The Environment Agency may also require hydraulic modelling of the site, therefore early engagement is advised. Built development should be avoided within the areas identified as sitting in Flood Zone 2 and 3, however it may be appropriate to include such areas as parking areas or service areas.*

Flood compensation areas may be required. In accordance with NPPF, SuDS should be a key feature within the development to manage surface water sustainably. Attenuation can be provided in a variety of forms and the incorporation of certain forms at this stage does not prevent the use of additional SuDS during the development of the design. The incorporation of additional SuDS within the plots such as green roofs, rainwater harvesting and bio-retention areas will reduce the size of attenuation features located downstream."

Furthermore, the Barnsley Local Plan (adopted January 2019) includes the following policy with regards to flood risk:

<u>Policy CC3 Flood Risk</u>

'The extent and impact of flooding will be reduced by:

- *Not permitting new development where it would be at an unacceptable risk of flooding from any sources of flooding, or would give rise to flooding elsewhere;*
- *Ensuring that in the Functional Floodplain (Flood Zone 3b), only water compatible development or essential infrastructure (subject to the flood risk exception test) will be allowed. In either case it must be demonstrated that there would not be a harmful effect on the ability of this land to store floodwater;*
- *Requiring developers with proposals in Flood Zones 2 and 3 to provide evidence of the sequential test and exception test where appropriate;*

[4] *https://www.barnsley.gov.uk/media/19799/goldthorpemasterplanframework.pdf*

» *Requiring site-specific Flood Risk Assessments (FRAs) for proposals over 1 hectare in Flood Zone 1 and all proposals in Flood Zones 2 and 3;*

» *Expecting proposals over 1000 m2 floor space or 0.4 hectares in Flood Zone 1 to demonstrate how the proposal will make a positive contribution to reducing or managing flood risk; and*

» *Expecting all development proposals on brownfield sites to reduce surface water run-off by at least 30% and development on greenfield sites to maintain or reduce existing run-off rates requiring development proposals to use Sustainable Drainage Systems (SuDS) in accordance with policy CC4; and*

» *Using flood resilient design in areas of high flood risk.'*

Whilst the Site has been allocated and therefore does not require the application of the Sequential Test in this instance, as stated within the report, hydraulic modelling has been undertaken to confirm appropriate mitigation measures to ensure the development will be safe across its design life whilst causing no detrimental impact to third-party land. As part of these mitigation measures, a combination of ground raising and lowering (flood compensation areas) has been confirmed to provide significant protection to the development and as such the Site would be located within Flood Zone 1 (Low Risk) with the areas of highest risk i.e., Flood Zone 2, 3a and 3b identified to bypass the proposed development utilising the flood compensation areas. Therefore, the Site is adopting a Sequential approach to developments.

Industrial type development such as that being proposed on this Site is classified within the NPPF Annex 3: Flood risk vulnerability classification as 'Less Vulnerable'. The NPPG Flood Risk Vulnerability and Flood Zone Compatibility matrix (Table 2 of the NPPG), Table 7, indicates 'less vulnerable' developments are "appropriate" in Flood Zone 1, 2 and 3a without application of the Exception Test but is not appropriate within Flood Zone 3b

Table 7: Flood Risk Vulnerability and Flood Zone 'incompatibility'

	Essential Infrastructure	Highly Vulnerable	More Vulnerable	Less Vulnerable	Water Compatible
Zone 1	✓	✓	✓	✓	✓
Zone 2	✓	Exception Test Required	✓	✓	✓
Zone 3a	Exception Test Required	X	Exception Test Required	✓	✓
Zone 3b	Exception Test Required	X	X	X	✓

Hydraulic modelling undertaken within this report confirms the proposed development would sit outside of the predicted areas of flooding with the implementation of the proposed mitigation measures and as such the Exception Test is deemed to not be necessary in this instance.

6.2 Mitigation Measures

Whilst an Exception Test is not explicitly required under the NPPG, the following section details any measures recommended to mitigate any 'residual' flood risks and to ensure that the proposed development will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, akin to the requirements of section 'b' of the Exception Test as outlined in the NPPG.

6.2.1 Flood Compensation and Finished Floor Levels

Following the confirmation of existing risk, a post-development scenario was also developed to ensure the proposed development would be safe from flooding both in the present day and across its design life, 75 years for a non-residential development in accordance with Paragraph 006 of the NPPG.

As part of the proposed mitigation works, development finished floor levels (FFLs) have been raised with a significant freeboard above the design flood level, shown in Table 8, in line with the proposed drainage strategy (23451-HYD-XX-XX-RP-D-0003).

Table 8. Development Zones and Proposed Finished Floor Levels

Development Zone / Plot Number	Proposed Finished Floor Level (m AOD)
Zone 1 / Plot 1	25.5
Zone 2 / Plot 2	26.0
Zone 3 / Plot 3	34.7
Zone 4 / Plot 4	34.7

Paragraph 049 of the NPPG states *"Where flood storage from any source of flooding is to be lost as a result of development, on-site level-for-level compensatory storage, accounting for the predicted impacts of climate change over the lifetime of the development, should be provided".*

Modelling has confirmed that the provision of two flood compensation areas (FCAs), connected with a series of culverts, provides the necessary storage required to mitigate against off-site increases to third-party land.

The two FCA's have been designed so as to allow flood waters overtopping the Carr Dike to follow the natural topography, entering the FCAs through a series of pipes and culverts and allowing flood waters to discharge positively back into the watercourse downstream of the Site. This mechanism acts as a bypass and temporary storage for the flood waters rather than causing a build-up of flooding creating a larger hydraulic head and forcing more water back into the channel and causing additional out of bank flooding to the south of the Site.

Due to the mechanism of flooding indicated in the baseline scenario i.e., flood waters initially spilling out of bank downstream of Barnsley Road (A635), it was concluded that allowing the flood waters to follow the natural topography and its preferential flow route using the bypass system would be the most effective way to mitigate additional flooding. The proposed mitigation was discussed and the principle agreed in a meeting with the Yorkshire and Humber IDB (14/10/2022).

The results of the post-development scenario (See Section 5.3.2) confirm all development zones would be free from flooding in all scenarios with the proposed network of FCA's successfully managing the predicted flooding allowing flow to bypass the Site and re-join the Carr Dike along the western boundary. A comparison exercise done with the modelling also confirms the development would not cause additional flooding to third-party land during the design flood event and the FCAs provides sufficient compensation storage to mitigate against the proposed ground raising.

6.2.2 Safe Access and Egress

The Site is proposed to be accessed via a new vehicular entrance off the A635 along the northern boundary of the Site. Hydraulic modelling has confirmed the proposed road network and existing

A635 to be free from fluvial flooding in all events modelled. The A635 is also shown to be at low or negligible risk from all other assessed sources and as such safe access and egress is concluded to be possible.

6.2.3 Surface Water Drainage Strategy

It should be noted that, post-development, any rainfall and surface water flood risk within the Site will be managed through an engineered surface water drainage strategy (23451-HYD-XX-XX-RP-D-0003), prepared separately to this document, which will further reduce/mitigate the risk of surface water flooding within the Site.

7. SUMMARY

This report has been prepared by Hydrock Consultants Limited (Hydrock) on behalf of our client Newlands in support of a planning application for a proposed development at Land South of Dearne Valley Parkway, S72 0JE.

A detailed assessment of flood risk has identified that, based on current EA Flood Zone Mapping, the majority of the Site is located within Flood Zone 1 (Low Risk) but there are extents of Flood Zone 2 and 3 (Medium and High Risk) within the northern portions of the Site. The Site is concluded to be at 'low' or 'negligible' risk of flooding from all other assessed sources.

Detailed hydraulic modelling for the Site has confirmed that, subject to confirmation from the EA, the Site is primarily located within Flood Zone 1 but is at risk of fluvial flooding (Flood Zones 2, 3a and 3b) with extents of flooding predicted to extend across the site from the Carr Dike.

Post-development scenario modelling has confirmed the proposed mitigation measures, ground raising and flood compensation areas, to successfully mitigate onsite flooding across the developments design life. The proposed sequence of FCAs and culverts allow out of bank flows to bypass the Site and re-join the Carr Dike along the western boundary, ensuring no detrimental impacts to third-party land. The modelling also confirms the proposed crossings over the Carr Dike and Highgate Lane Dike do not cause additional flooding.

The Site is allocated within the adopted Barnsley Council Local Plan as part of the Goldthorpe Masterplan Framework (ES10) and as such the Sequential and Exception Test are not deemed to be necessary in this instance.

Finished floor levels have been raised significantly above the maximum flood level (>2m) ensuring the developments are safe across its design life.

It should be noted that, post-development, any rainfall and surface water flood risk within the Site will be managed through an engineered surface water drainage strategy which will further reduce/mitigate the risk of surface water flooding within the site.

It has also been demonstrated that a means of safe access and egress is possible to and from the Site via the proposed entrance off A635 and that the proposed development is also not considered to increase flood risk within the catchment through a loss of floodplain storage.

This report therefore demonstrates that, in respect to flood risk, the proposed development:

» Is suitable in the location proposed if mitigation measures are considered;
» Will be adequately flood resistant and resilient;
» Will not place additional persons at risk of flooding, and will offer a safe means of access and egress; and
» Will not increase flood risk elsewhere as a result of the proposed development through the loss of floodplain storage or impedance of flood flows; and
» Will put in place measures to ensure surface water is appropriately managed.

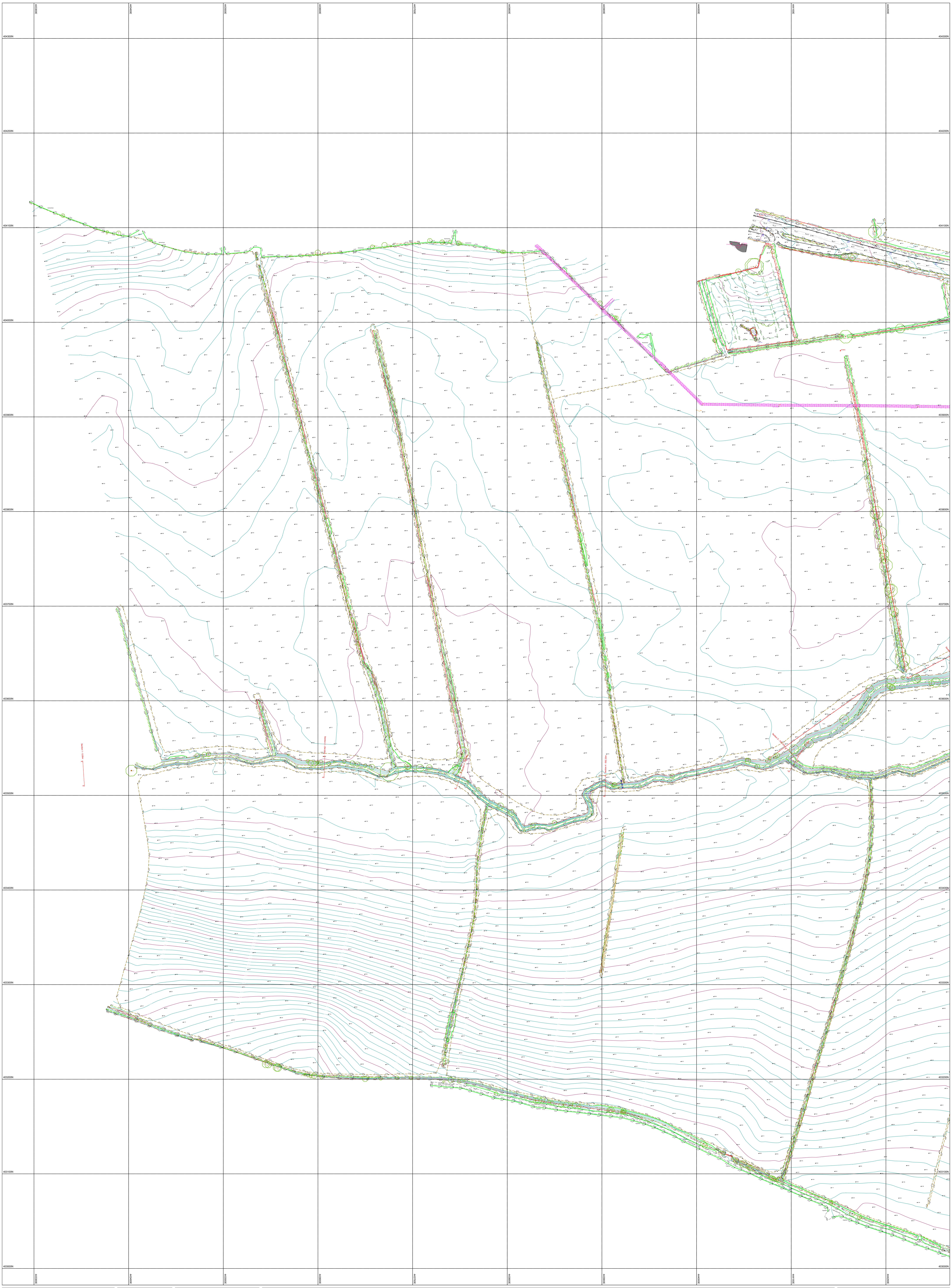
Hydrock Consultants Ltd

8. REFERENCES

Author	Date	Description
Barnsley Metropolitan Borough Council	Jul 2011	Preliminary Flood Risk Assessment (https://www.barnsley.gov.uk/media/16269/barnsley-pfra-report.pdf)
JBA Consulting	Sep 2010	Barnsley Strategic Flood Risk Assessment Level 1 (https://www.barnsley.gov.uk/media/18125/barnsley-strategic-flood-risk-assessment-level-1-report-sept-2010.pdf)
Barnsley Metropolitan Borough Council	Sep 2017	Local Flood Risk Management Strategy (https://www.barnsley.gov.uk/media/17940/flood-risk-management-strategy.pdf)
Barnsley Metropolitan Borough Council	Jan 2019	Barnsley Local Plan – Adopted January 2019 (https://www.barnsley.gov.uk/media/17249/local-plan-adopted.pdf)
Barnsley Metropolitan Borough Council	Sep 2021	Goldthorpe Masterplan Framework (https://www.barnsley.gov.uk/media/19799/goldthorpe masterplanframework.pdf)

Appendix A

Site-Specific Topographical Survey



SITE	SCALE	CLIENT
A635 Barnsley Road Goldthorpe	1:1250 @ A0	newlands developments
	DATE	
	02/09/2022	
PROJECT	DRAWING No.	
Topographical Survey	12506	

NOTES

Boundaries surveyed are physical features and may not necessarily represent the legally conveyed ownership.

Tree Spreads, Girths and Heights are approximate, any tree species identified should not be relied upon and checked by a specialist if critical

Underground drainage depths, pipe sizes and runs have been recorded from the surface and may have been estimated or assumed

Features surveyed off site such as buildings and trees may have been recorded remotely and may not be shown in full detail due to access / sighting restrictions

CO-ORDINATES & DATUM DERRIVED USING GEOID MODEL OSGM15(GB) & HORIZONTAL TRANSFORMATION OSTN15

THIS SURVEY IS ORIENTATED TO ORDNANCE SURVEY GRID NORTH WITH A TRUE OSGM15 CO-ORDINATE NEAR THE CENTRE OF THE SURVEY.

THE SURVEY IS PLOTTED TO A FLAT PLANE GRID. HORIZONTAL MEASUREMENTS TAKEN FROM THIS SURVEY WILL BE TRUE DISTANCES

REFER TO SURVEY CONTROL STATION LISTING FOR RE-ESTABLISHING CONTROL ON SITE

SURVEY STATIONS

Name	Easting	Northing	Height
STNA	444758.935	404161.559	33.274
STNB	444558.726	404066.137	27.078
STNC	444419.715	404053.500	25.053
STND	444310.088	404054.883	25.302
STNE	444172.903	404084.074	27.875
STNF	444066.407	404113.499	27.572
STNFA	444540.558	403974.198	23.485
STNFB	444551.288	403903.619	23.886
STNFC	444282.698	403884.393	22.938
STNFD	444151.895	403969.943	22.545
STNG	444604.836	402914.118	44.733
STNH	444484.653	402945.090	44.656
STNI	444378.405	402971.357	44.332
STNJ	444644.105	402918.347	44.229
STNRA	444625.250	404089.202	28.343

stafsurv LAND SURVEYORS

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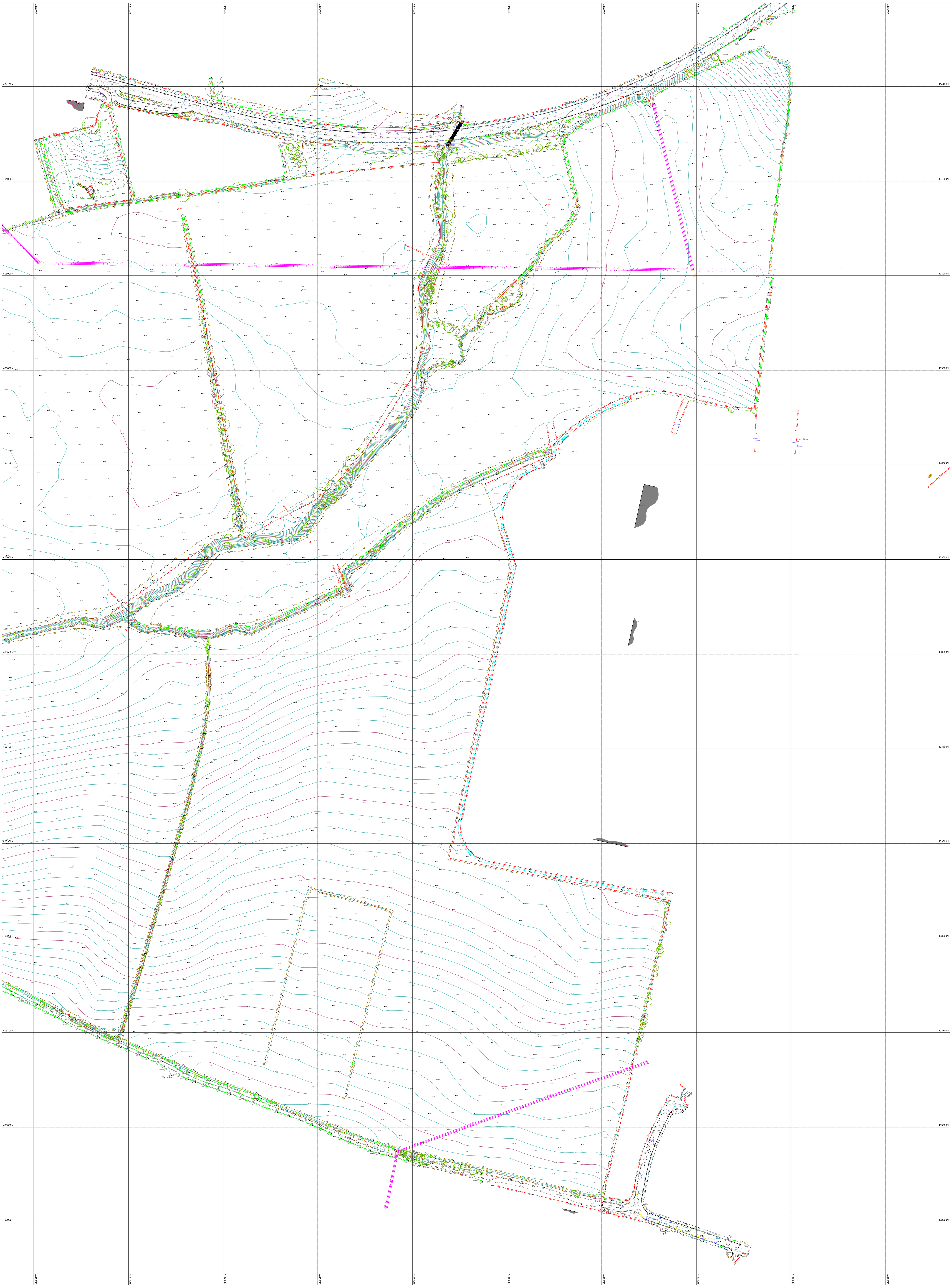

SITE

A635 Barnsley Road
Goldthorpe

SCALE

1:1250 @ A0

DATE

02/09/2022

PROJECT

Topographical Survey

DRAWING No.

12506

CLIENT

newlands developments

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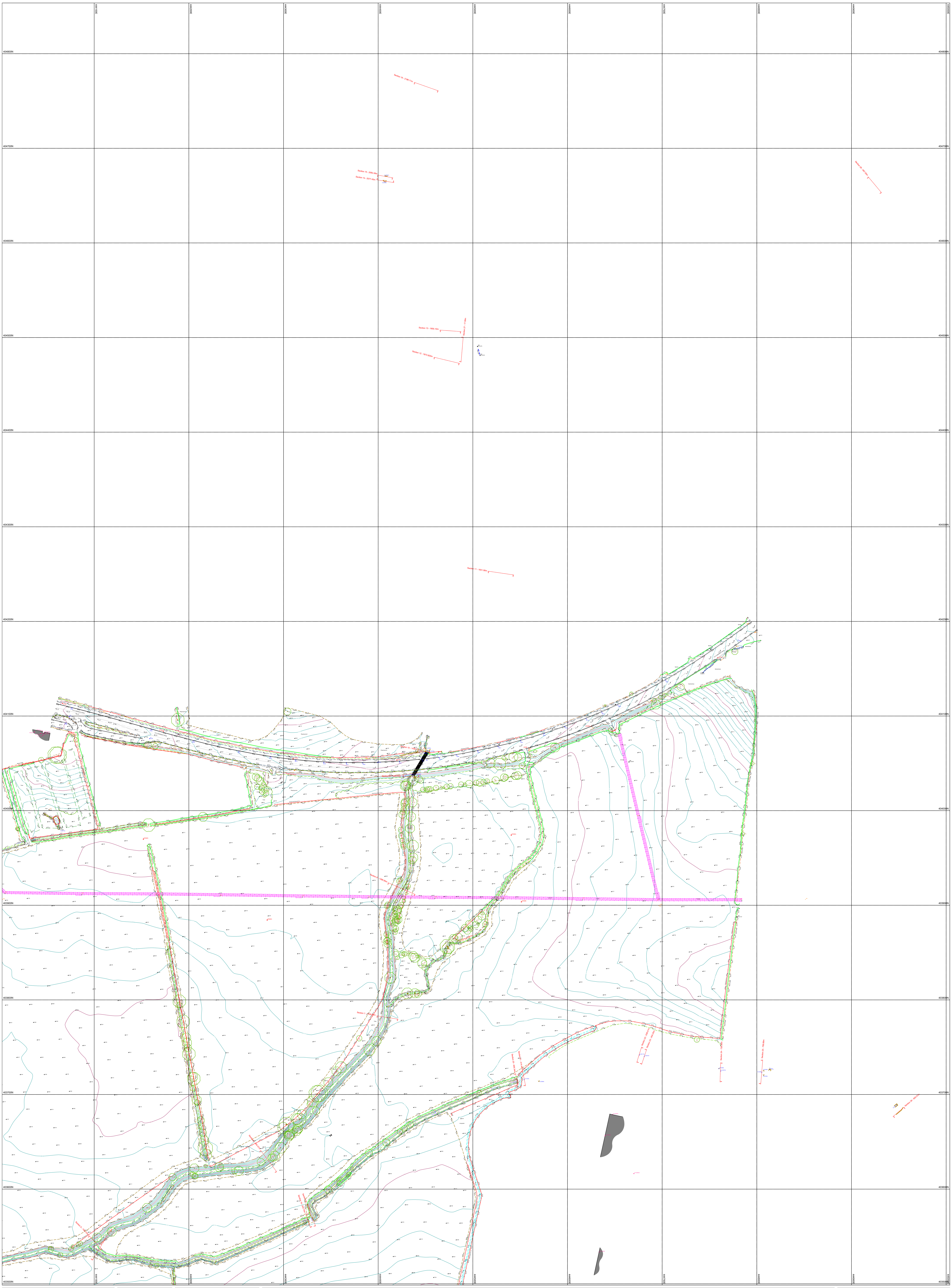

SITE	SCALE	CLIENT
A635 Barnsley Road Goldthorpe	1:1250 @ A0	newlands developments
	DATE	
	02/09/2022	
PROJECT	DRAWING No.	
Topographical Survey	12506	

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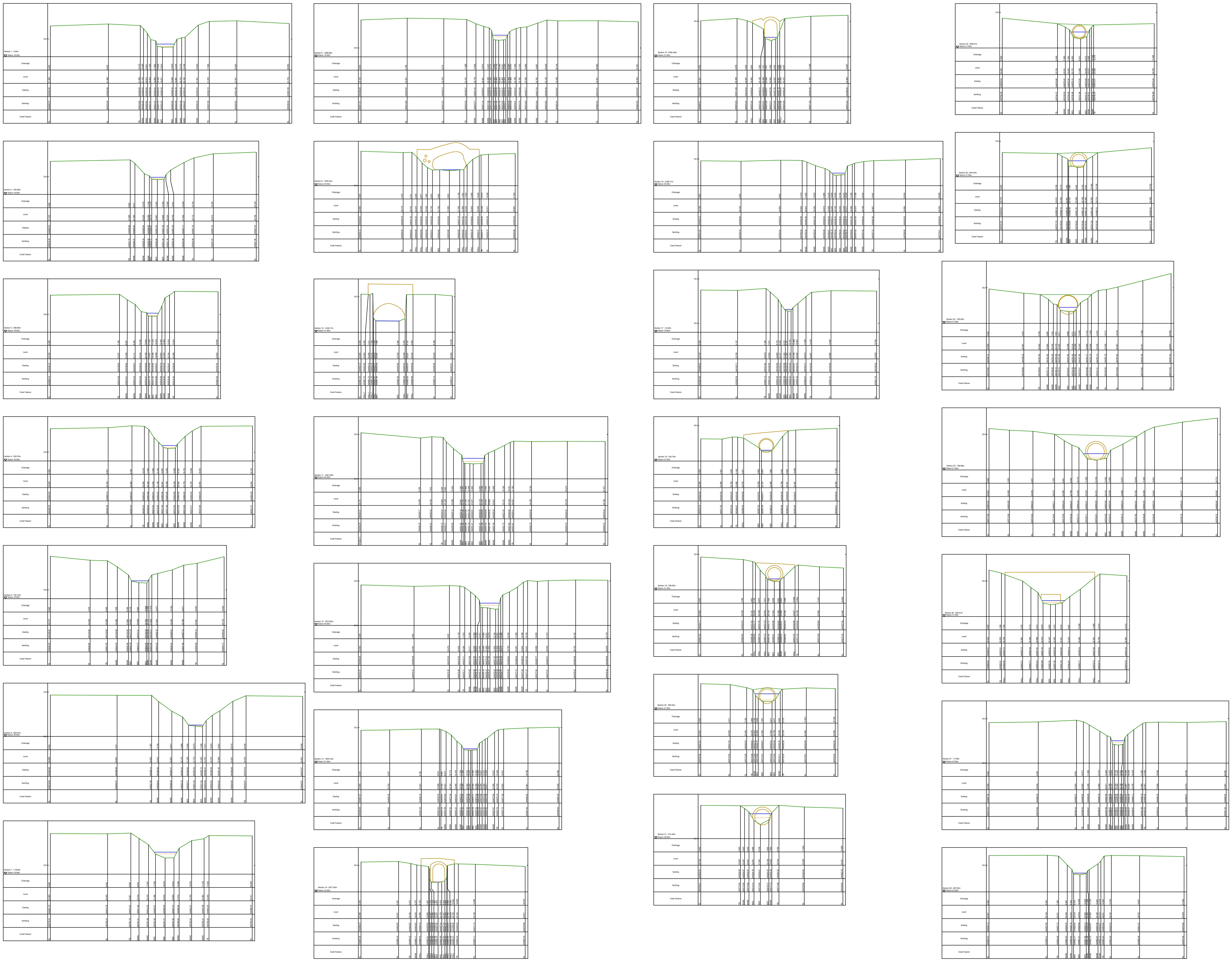
Watercourse Survey



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CLIENT

SITE

A635 Barnsley Road
Goldthorpe

PROJECT

Watercourse
Sections

SCALE	DATE
1:200 @ A1	02/09/202

DRAWING No.

12506

Appendix B

Proposed Illustrative Masterplan

- Dimensions are in millimeters, unless stated otherwise.
- Scaling of this drawing is not recommended.
- It is the recipients responsibility to print this document to the correct scale.
- All relevant drawings and specifications should be read in conjunction with this drawing.

Indicative Schedule of Accommodation

Unit 1	sq m	sq ft
Warehouse	49,564	533,500
2-Storey Mezzanine Office	2,323	25,000
2-Storey Pod Office	465	5,000
2-Storey Pod Office	465	5,000
Gatehouse	28	300
Total	**52,843**	**568,800**

Unit 2	sq m	sq ft
Warehouse	32,214	346,750
2-Storey Mezzanine Office	1,695	18,250
2-Storey Pod Office	465	5,000
Gatehouse	28	300
Total	**34,402**	**370,300**

Unit 3	sq m	sq ft
Warehouse	74,787	805,000
2-Storey Mezzanine Office	2,323	25,000
2-Storey Pod Office A	465	5,000
2-Storey Pod Office A	465	5,000
Gatehouse	28	300
Total	**78,066**	**840,300**

Unit 4	sq m	sq ft
Warehouse	30,008	323,000
2-Storey Mezzanine Office	1,579	17,000
2-Storey Pod Office	465	5,000
Gatehouse	28	300
Total	**32,080**	**345,300**
Development Total	**197,390**	**2,124,700**

NOTE:
All areas specified are Gross Internal Areas [GIA]

For the avoidance of doubt, the information shown within the development plots is indicative only, and will be subject to subsequent Reserved Matters Applications

Illustrative Plan Only

PLANNING
THIS DRAWING IS FOR PLANNING CONSIDERATION ONLY AND SHOULD NOT BE USED FOR ANY OTHER PURPOSE

rev	amendments	by	ckd	date

Barnsley Road,
Goldthorpe

Illustrative Masterplan

newlands developments

umc architects

Newark Beacon, Cafferata Way, Newark, Nottinghamshire NG24 2TN
o. +44 (0)1636 653027 e. info@umcarchitects.com

Drawing Status:	Planning
Drawn / Checked:	SS / SM
Date:	07/11/2023
Scale:	1:2500 A1
Drawing no:	Revision:
22081 P0601	G

Appendix C

Flood Estimation Report

Flood Estimation Report Template

Template: LIT 65087 Published: 29/12/2022

Audience: Environment Agency

Description: This report template is a supporting document to the Environment Agency's Flood Estimation Guidelines (LIT 11832). It provides a record of the hydrological context, the method statement, the calculations, the decisions made, and the results of flood estimation. This document can be used for one site or multiple sites.

Guidance notes to help you complete this template are available separately.

Contents

Approval

Revision stage	Analyst:	Approved by:	Amendments	Date
Method statement	L Whalley/ K Thistlethwaite	N Maxworthy		03/10/2024
Calculations - Revision 1				
Calculations - Revision 2				

Abbreviations

Abbreviation	Short for
AEP	annual exceedance probability
AMAX	Annual Maximum
AREA	Catchment area (km2)
BFI	Base Flow Index
BFIHOST19	Base Flow Index derived using the HOST soil classification, revised in 2019
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
GEV	Generalised Extreme Value
GLO	Generalised Logistic
HOST	Hydrology of Soil Types
IF	Impervious Fraction
IRF	Impervious Runoff Factor
LF	Low flow statistics (flow duration curve)
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
Tp	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	Windows Frequency Analysis Package (software that can be used for FEH statistical method)

1. Summary of assessment

1.1 Summary

Catchment location:

There are three watercourses of interest which impact the flood extents through the subject site. The main watercourse is the Carr Dike which flows in a general south westerly direction into the Ings Dike and is a tributary of the River Dearne, approximately 3km downstream of the subject site (443702.7E, 402195.2N).

The Thurnscoe Dike is a tributary of the Carr Dike, which is sourced from Thurnscoe to the north east of the subject site. The watercourse flows in a general south westerly direction to its confluence with the Carr Dike, located approximately 500m north of the A635 and subject site (444473.8E, 404480.5N).

The Highgate Dike is also a tributary of the Carr Dike which flows from a commercial / industrial use development to the east of the subject site in a westerly direction meeting the Carr Dike in the centre of the subject area (444089.77E, 403537.01N).

Purpose of study and complexity:

The aim of this study is to derive peak flow estimates and hydrographs for the watercourses named above to inform inflows for hydraulic modelling. A hydraulic model of the Carr Dike has been developed to support the design and development of an industrial use development on land to the west of Goldthorpe, Barnsley. The site is split by the Carr Dike, which runs north to south through the site, and the Highgate Dike, which runs east to west through the site.

Key catchment features:

The catchments are predominantly rural but include Thurnscoe village. The Highgate Dike includes majority of commercial / industrial use developments and as such is considered to be urban. The selected methods will account for the mix of urban and rural catchments. There are no reservoirs within the catchments and are not known to be pumped or mined.

Flooding mechanisms:

The key flooding mechanism being considered is the fluvial response and be related to peak flows exceeding the channel capacity.

Gauged / ungauged:

The National River Flow Archive (NRFA) and Hydrology Data Explorer indicate that there are no gauging stations along the Carr Dike, Thurnscoe Dike or Highgate Dike and as such the catchments are therefore ungauged.

Final choice of method:

The ReFH2 method is used to derive peak flows values and hydrographs.

Key limitations / uncertainties in results:

The catchment is ungauged, which is the largest source of uncertainty.

1.2 Flood frequencies

- The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.
- Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval.
- Results tables in this document contain both return period and AEP titles; both rows can be retained, or the relevant row can be retained and the other removed, depending on the requirement of the study.
- The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.013	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

2. Method Statement

2.1 Requirements for flood estimates

Overview and Project Scope:

The aim of the study is to derive peak flow estimates and hydrographs for the Carr, Thurnscoe and Highgate Dikes located to the west of Goldthorpe, Barnsley to inform hydraulic modelling of the watercourses. A hydraulic model of the three watercourses has been developed to support the design and development of an industrial use development on land to the west of Goldthorpe, Barnsley which is split by the Carr and Highgate Dike.

Peak flow estimates and hydrographs will be derived for the 1 in 2, 5, 10, 20, 30, 50, 75, 100, 200 and 1000 year events.

The impacts of climate change will be modelled based on the latest available guidance[1]. The site is located within the ‘Don and Rother' Management Catchment, peak river flow allowances of +28% (central) and +38% (higher central) allowances are applicable to this study for the 2080s epoch (2070-2115).

The study derives peak flow estimates at key locations within each catchment, and for inflow locations to suit the extent of the hydraulic model.

The purpose of this document is to detail the methods followed, the outcomes and results, and the decision-making process and justification of final accepted flows. Note that it does not include any additional analysis completed using the hydraulic modelling, which is reported and provided separately.

The hydrological assessment makes use of the NRFA v13 dataset within WINFAP5. ReFH2.4 with FEH22 rainfall data will be applied as a second suitable method to derive peak flow estimates and to define hydrograph shapes. The catchment is ungauged and therefore hydrograph shapes will be defined using the latest available rainfall-runoff method.

This report should be read in conjunction with the hydraulic modelling report

1 EA, 2022, Flood Risk Assessments: Climate Change Allowances

2.2 The Catchment

Maps:

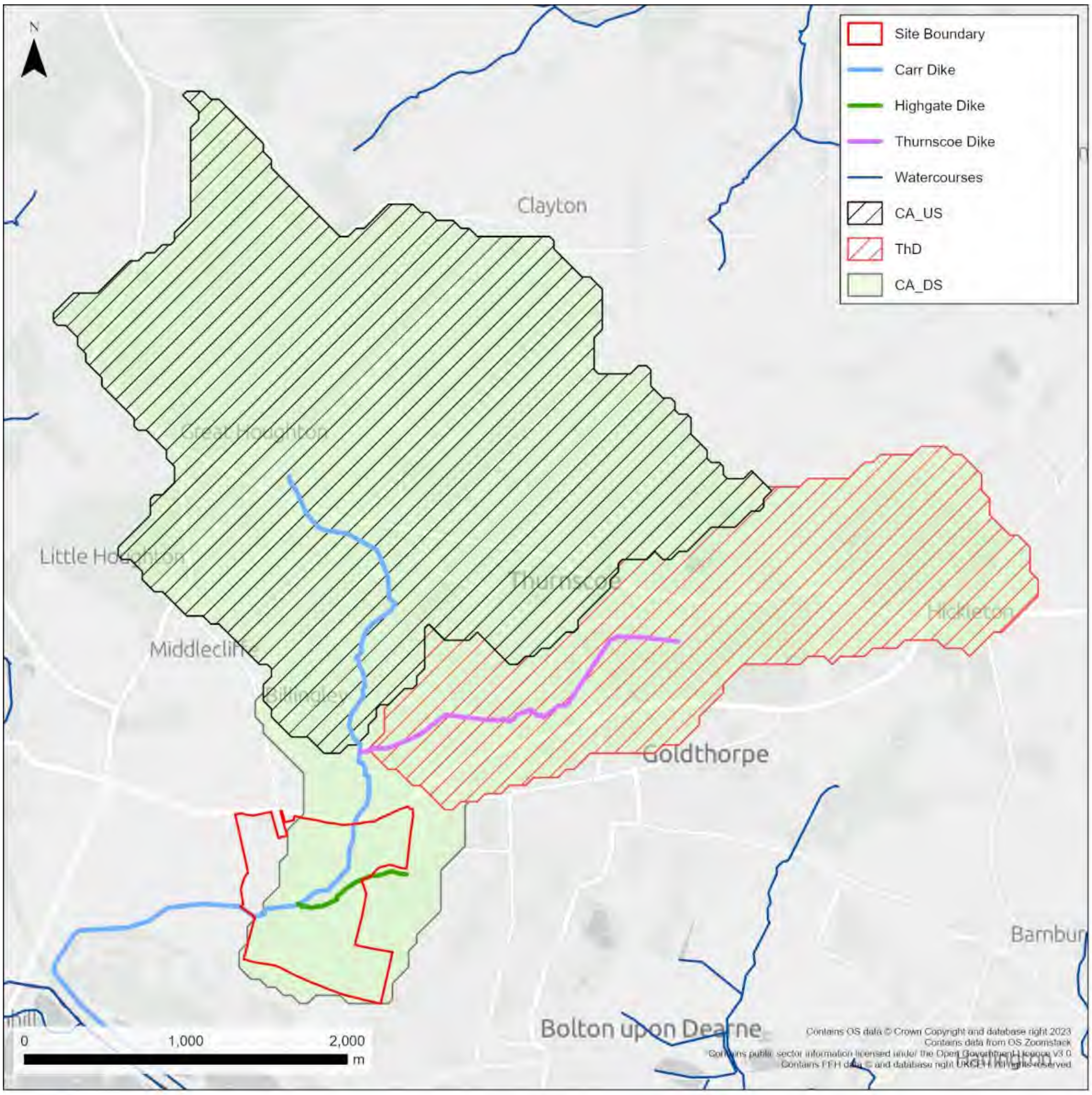


Figure 1 – Overview of Catchment Areas and Site

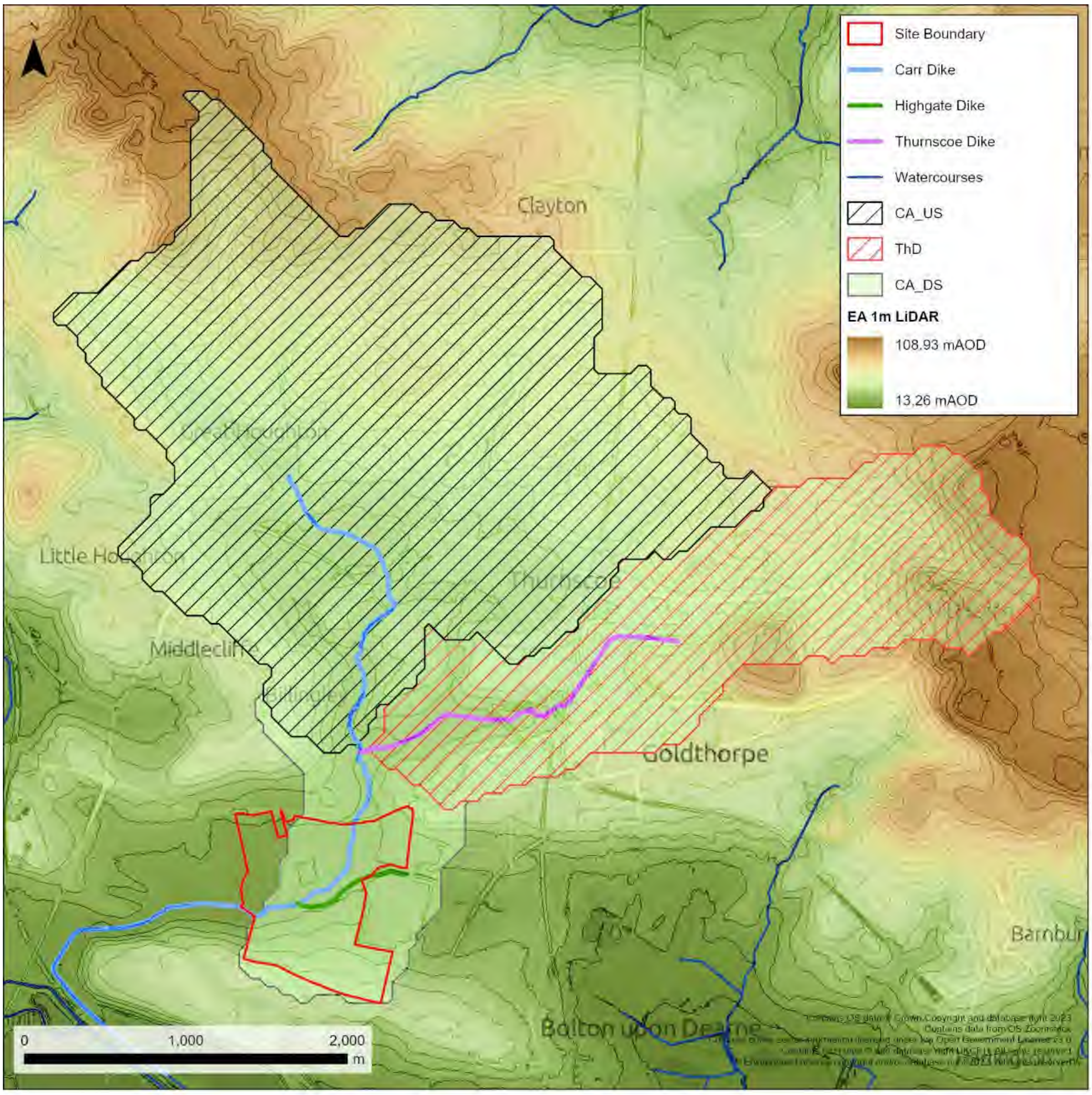


Figure 2 – Overview of Topography using EA LiDAR

Catchment Description:

There are three distinct watercourses which impact flows within the study area and have been included within this assessment: Carr Dike (CA_US), Thurnscoe Dike (ThD) and Highgate Dike (HiG). The characteristics for each catchment are described below. All three catchments are also contained within the wider Carr Dike catchment (CA_DS).

The Carr Dikes total catchment area from the downstream outlet (443850,403450) of the subject site is 14.54km^2. The wider catchment area contains Thurnscoe and western portions of Goldthorpe and is considered heavily urbanised (FEH URBEXT2000 value of 0.141). The Carr Dike flows in a general southerly direction through the catchment where it is joined by the Thurnscoe Dike just north of A365. The Carr Dike continues south through the road embankment and into the subject site where it changes direction to the west and is met by the Highgate Dike entering from the east of the catchment.

The topography of the total catchment falls from approximately 113mAOD at the north eastern extent of the catchment, to approximately 21mAOD at the south western outlet.

The Carr Dike upper catchment area from its confluence with the Thurnscoe Dike is 9.04km^2. It covers mostly rural areas but also a portion of Thurnscoe village in the east and is considered moderately urbanised (FEH URBEXT2000 value of 0.1193). This upper sub catchment is relatively steep with the topography indicated to fall from approximately 106mAOD in the north to 24mAOD at its confluence with the Thurnscoe Dike.

The Thurnscoe Dike catchment area from its confluence with the Carr Dike is 3.98km^2. It includes sub urban developments of Thurnscoe and Goldthorpe and is considered heavily urbanised (FEH URBEXT2000 value of 0.2247). The sub catchment topography falls from 113mAOD in the east to approximately 24mAOD at the confluence with the Carr Dike.

The Highgate Dike catchment area to its confluence with the Carr Dike in the subject area is 0.78km^2. This smaller sub-catchment coverts predominantly urban developments in the west of Goldthorpe consisting of commercial and industrial use developments and the catchment is considered urban. The topography of the catchment falls from 45mAOD in the south to a low of approximately 24mAOD at its confluence with the Carr Dike.

The British Geological Survey (BGS) indicates the catchments are underlain by multiple geologies included Pennine Middle Coal Measures Formation, Pennine Upper Coal Measures Formation, Ackworth Rock and Mexborough Rock consisting of sandstones, mudstones and siltstones. Around the watercourse corridors, the BGS mapping indicates superficial deposits of Alluvium consisting of clay, silt, sand and gravel.

Soilcapes mapping indicates the majority of the catchments are underlain by slowly permeable seasonally wet acid loamy and clayey soils (Soilscapes classification 8). In the upper reaches of the catchment (CA_US) mapping indicates areas of freely draining slightly acid loamy soils (Soilscapes classification 6).

The catchment is not known to be pumped or mined.

The NFRA and Hydrology Data Explorer indicate that there are no gauging stations along the Carr Dike or Thurnscoe Dike.

2.3 Hydrometric Data

Source of flood peak data:

NFRA peak flows dataset, Version 13, released August 2024. This contains data up to September 2023 and includes FEH22 Depth Duration Frequency (DDF) rainfall descriptors.

Gauging stations (flow and level):

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of record and end if station closed
N/A	N/A	N/A	N/A	N/A	N/A	N/A

Data available at each flow gauging station:

Station name	Data source	Data type	Start and end of flood peak record	Update for this study?	OK for QMED?	OK for pooling ?	Data quality check needed?	Station and flow data quality summary
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Updates or revisions to flood peak data:

N/A

Data quality checks carried out:

N/A

Rating Equations:

Station name	Type of rating e.g., theoretical, empirical; degree of extrapolation	Rating review needed?	Comments and link to any rating reviews
N/A	N/A	N/A	N/A

Rating reviews:

N/A

Other data available and how it has been obtained:

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings	-	No	-	No spot flow gauging available.
Historical flood data	Yes	Yes	Environment Agency	OpenData – DEFRA Data Services Platform, 'Recorded Flood Outlines' - No recorded flood outlines within the catchment
Flow or river level data for events	-	No	-	No flow or river level gauging available.
Rainfall data for events	-	No	-	
Potential evaporation data	No	-	-	
Results from previous studies	-	No	-	No previous studies carried out.
Other data or information	-	No	-	

Conclusions of hydrometric data review:

Station name	Rating suitability	Suitability for flood estimation calculations	Non-stationary analysis requirements
Burage	N/A	Not suitable for use in defining peak flows directly for subject watercourses within this study.	Not required

2.4 Hydrological understanding of the catchment

Plots of flood peak data and interpretation:

N/A – catchment is ungauged.

Plots of flow data and interpretation:

N/A – catchment is ungauged.

Plots of stage data and interpretation:

N/A – catchment is ungauged.

Conceptual model:

The main site of interest is the area of land located to the east of Goldthorpe, Barnsley, shown in Figure 1, which is proposed for industrial use developments. The Carr Dike and Highgate Dike flows through the proposed development site. A hydraulic model of the watercourse systems has been developed to support the design and development of the Goldthorpe site.

The likely cause of flooding along the majority of the watercourse is flood flows exceeding channel capacity. Where the watercourse is culverted under intersecting roads, this is likely to cause backing up within the floodplain when flood flows exceed culvert capacity.

Unusual catchment features:

The Carr Dike and Thurnscoe Dike catchment are considered rural (<0.3 URBEXT2000) are not considered to be groundwater driven. The Highgate Dike, flows from an industrial and commercial use area to the east of the proposed development site and as such the catchment is considered to be heavily urban.

The catchments are not known to be pumped or mined.

2.5 Initial choice of approach

Are FEH methods appropriate?

The FEH methods are considered to be suitable for application.

Initial choice of method(s) and reasons:

The FEH Statistical method will be used to derive QMED values and peak flow estimates at the flow estimation locations. A pooling group will be derived for the catchment based on the downstream catchment extent as a full catchment response.

The ReFH2 method will also be applied to derive peak flow estimates at the flow estimation locations. The ReFH2 method will be applied using the latest available version of the software.

How will hydrograph shapes be derived if needed?

Full hydrographs will be derived from the ReFH2 software.

Will the catchment be split into sub-catchments? If so, how?

Peak flow estimates will be derived for lumped and sub-catchments at appropriate flow estimation points (see **Figure 3**).

The areas from the downloaded FEH catchments will be checked and verified using LiDAR data.

The flow estimates will be distributed in the hydraulic model as appropriate.

Software to be used:

FEH Web Service[2] / WINFAP 5[3] / ReFH2.3[4] / Flood Modeller Pro Version 7

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

3 WINFAP 5 © Wallingford HydroSolutions Limited 2022.

4 ReFH2.3 © Wallingford HydroSolutions Limited 2023.

3. Locations where flood estimates are required

3.1 Summary of subject sites

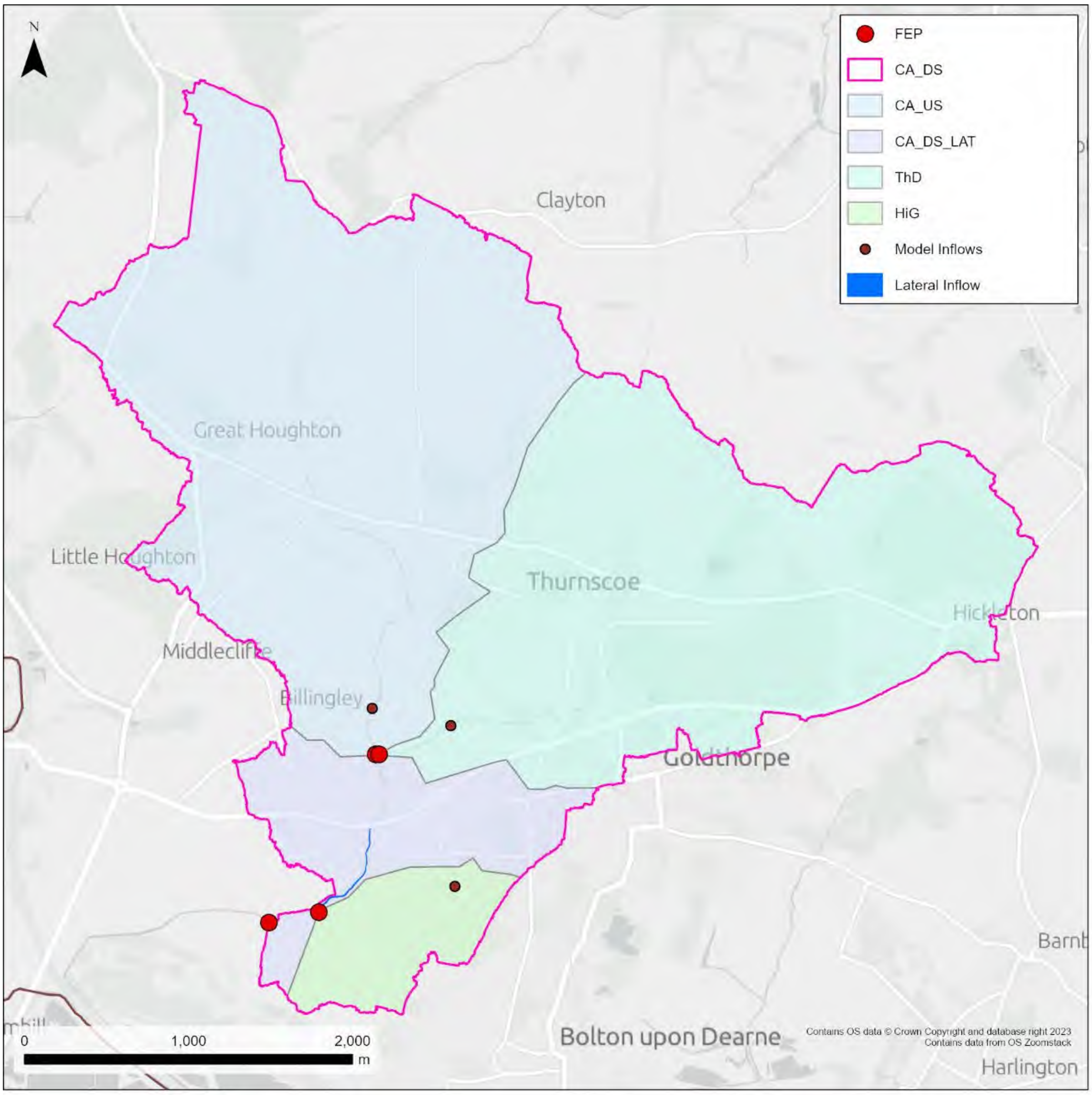


Figure 3 - Catchments & Flow Estimation Points

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space. Flow estimation points and hydraulic model inflows are shown in **Figure 3.**

Site code	Type of estimate: lumped (L) or sub-catchment (S)	Water-course	Site name / descrip-tion	Easting	Northing	AREA on FEH Web Service (km^2)	Revised AREA (if altered) (km^2)
CA_DS	L	Carr Dike	Total catchment to downstream extent of the subject site.	443850	403450	14.535	14.94
CA_US	S	Carr Dike	Upstream Carr Dike catchment from its confluence with the Thurnscoe Dike	444450	404550	9.04	6.91
ThD	S	Thurnscoe Dike	Upstream Thurnscoe Dike catchment from its confluence with the Carr Dike	444550	404500	3.9775	5.87
HiG	S	Highgate Dike	Sub-catchment of Highgate Dike from its confluence with the Carr Dike	443850	403450	14.535	0.78

3.2 Catchment Descriptors

Final catchment descriptors at each subject site:

Site code	FARL	PROPWET	BFIHOST19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990	URBEXT 2000	FPEXT
CA_DS	0.996	0.32	0.508 (0.513)	4.40 (4.02)	35.20	611	0.136 (0.125)	0.147 (0.141)	0.088
CA_US	1.000	0.32	0.561 (0.524)	2.88 (2.76)	35.00	613	0.130 (0.1193)	0.123 (0.1173)	0.078
ThD	0.987	0.32	0.450 (0.504)	2.64 (2.86)	39.70	614	0.194 (0.1785)	0.235 (0.2247)	0.081
HiG	1.000	0.32	0.456 (0.513)	0.87 (4.02)	35.20	611	0.321 (0.125)	0.321 (0.141)	0.088

Catchment boundary checks and revisions:

The overall catchment boundary for the Carr Dike catchment (CA_DS) were reviewed using available LiDAR data (1m resolution) – see **Figure 4**. The watershed tool on GIS was used to review the catchment delineations and discrepancies were found and therefore updates were made to the FEH catchment where necessary. Rural areas in the north and east of the catchment are shown to have been excluded from the updated catchment boundary however more significantly, additional urban areas of Goldthorpe along the eastern boundary have now been included. The catchment area for CA_DS was amended accordingly and resulted in an overall increase to 14.94km^2.

For the Carr Dike upstream (CA_US) (**Figure 5**) and Thurnscoe Dike (ThD) (**Figure 6**) catchments, the streamlines output from the watershed delineation tool were used to review the boundary between the adjacent catchments. It showed that much of Thurnscoe developments, included in the CA_US catchment, drained towards the Thurnscoe Dike instead. As such, the boundary between these two catchments was adjusted and the catchment areas amended. The change in boundary resulted in an overall increase in catchment area for the Thurnscoe Dike (ThD) to 5.87km^2 and a decrease in catchment area for the Carr Dike upstream (CA_US) to 6.91km^2.

The Highgate Dike (HiG) (**Figure 7**) is a sub-catchment of the Carr Dike (CA_DS). This catchment includes the commercial and industrial developments in the south east of the wider catchment. The catchment area for this has been updated to 0.78km^2.

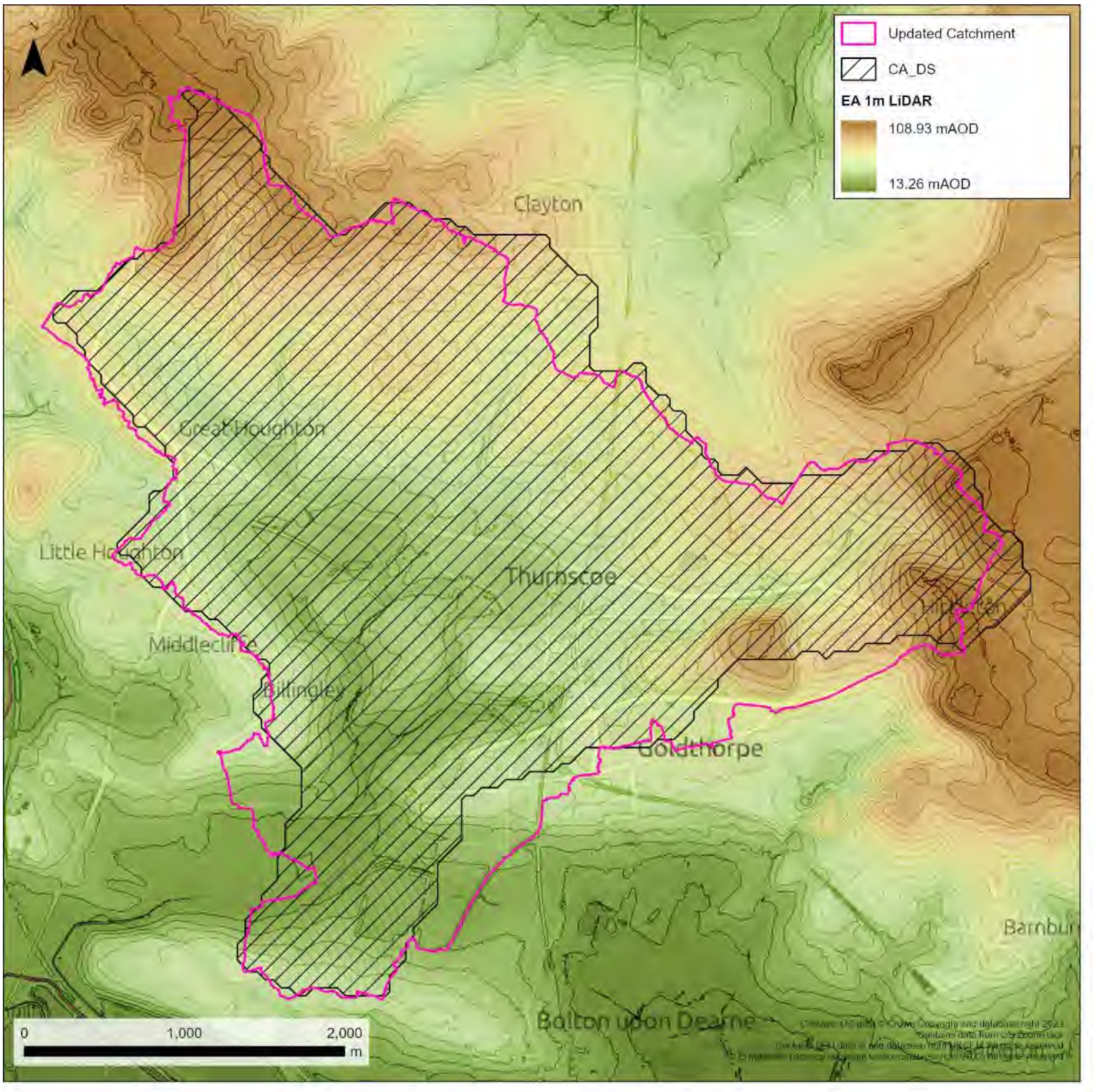


Figure 4 - CA_DS Catchment Area

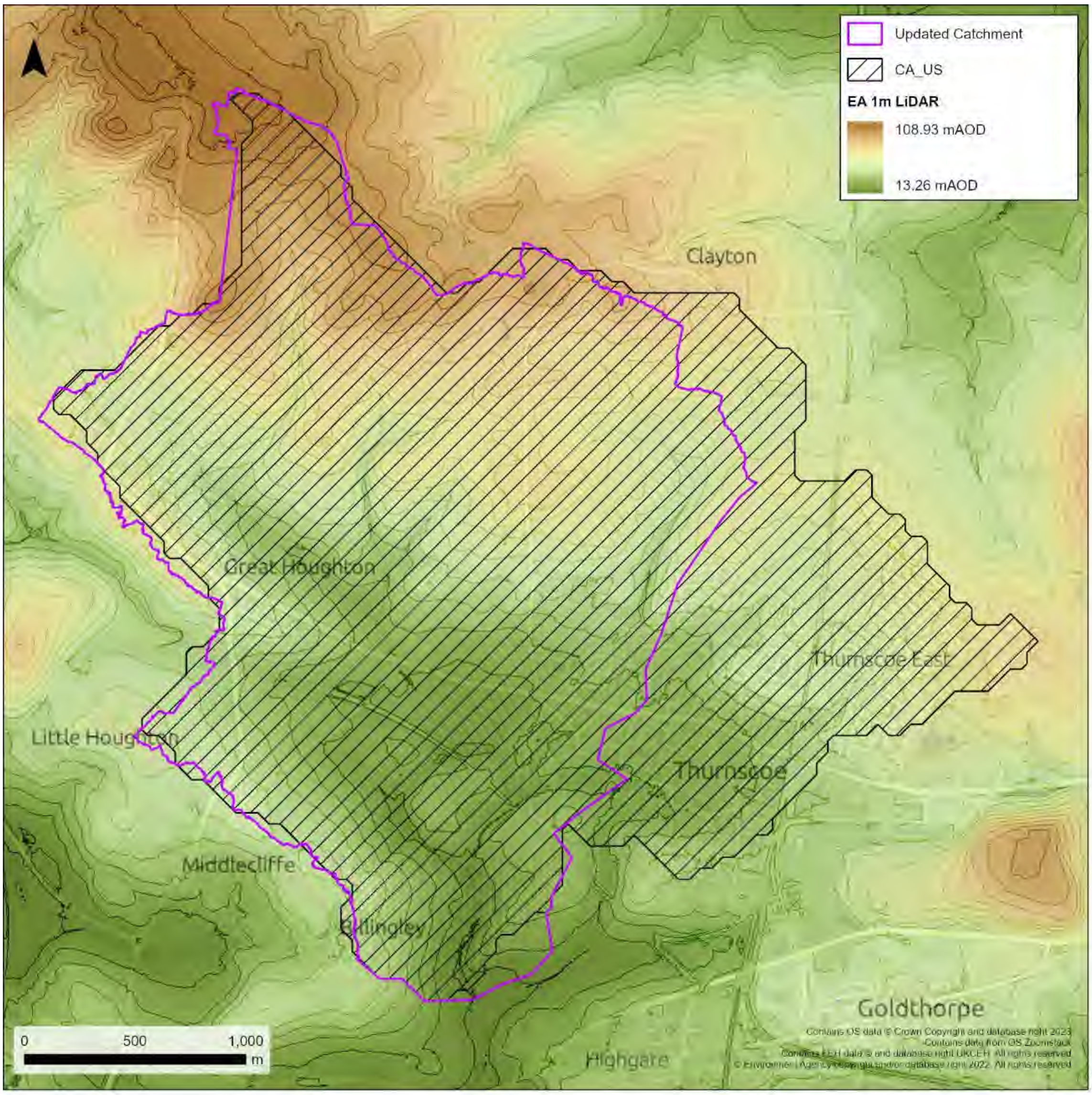


Figure 5 - CA_US Catchment Area

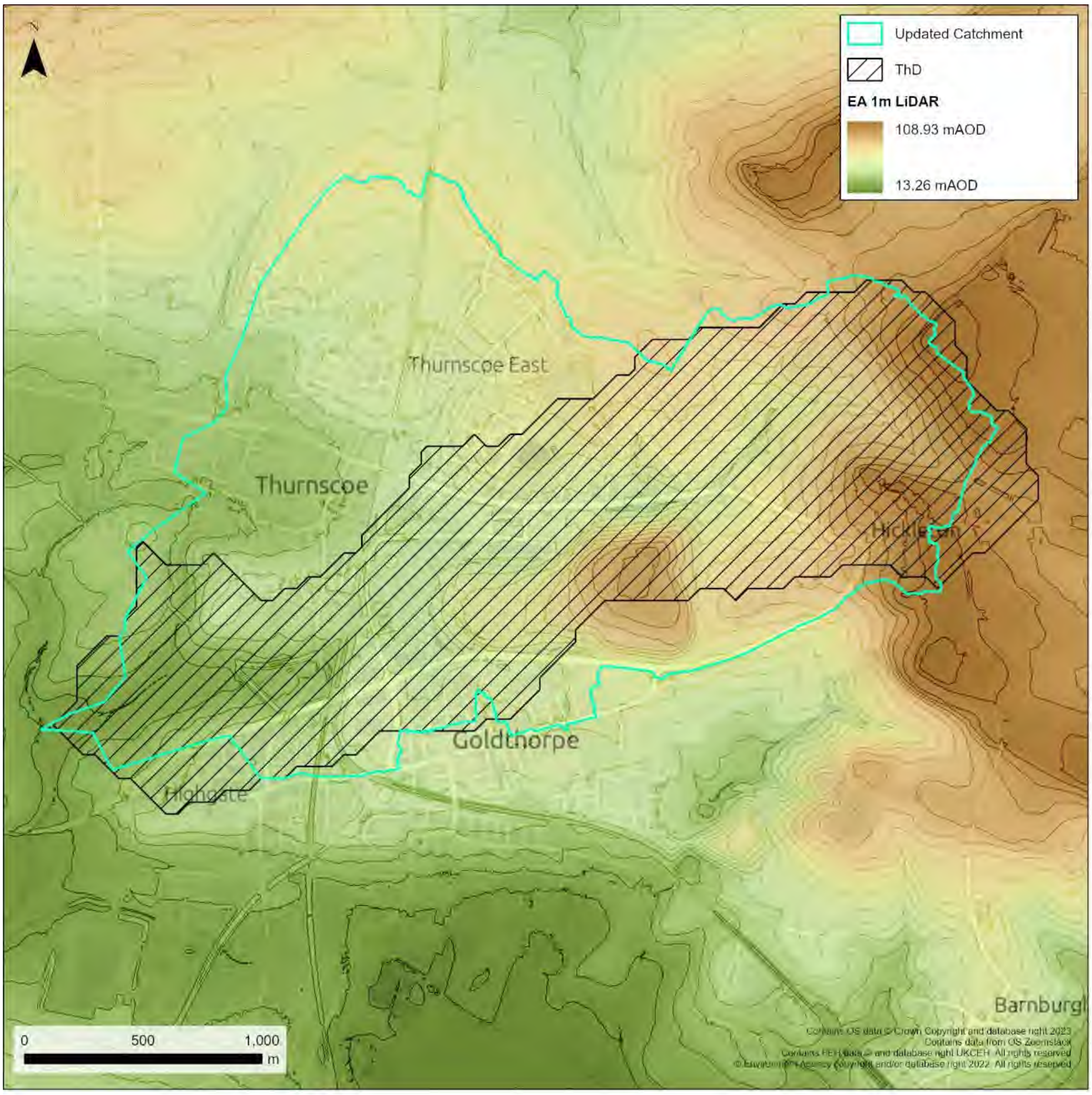


Figure 6 - ThD Catchment Area

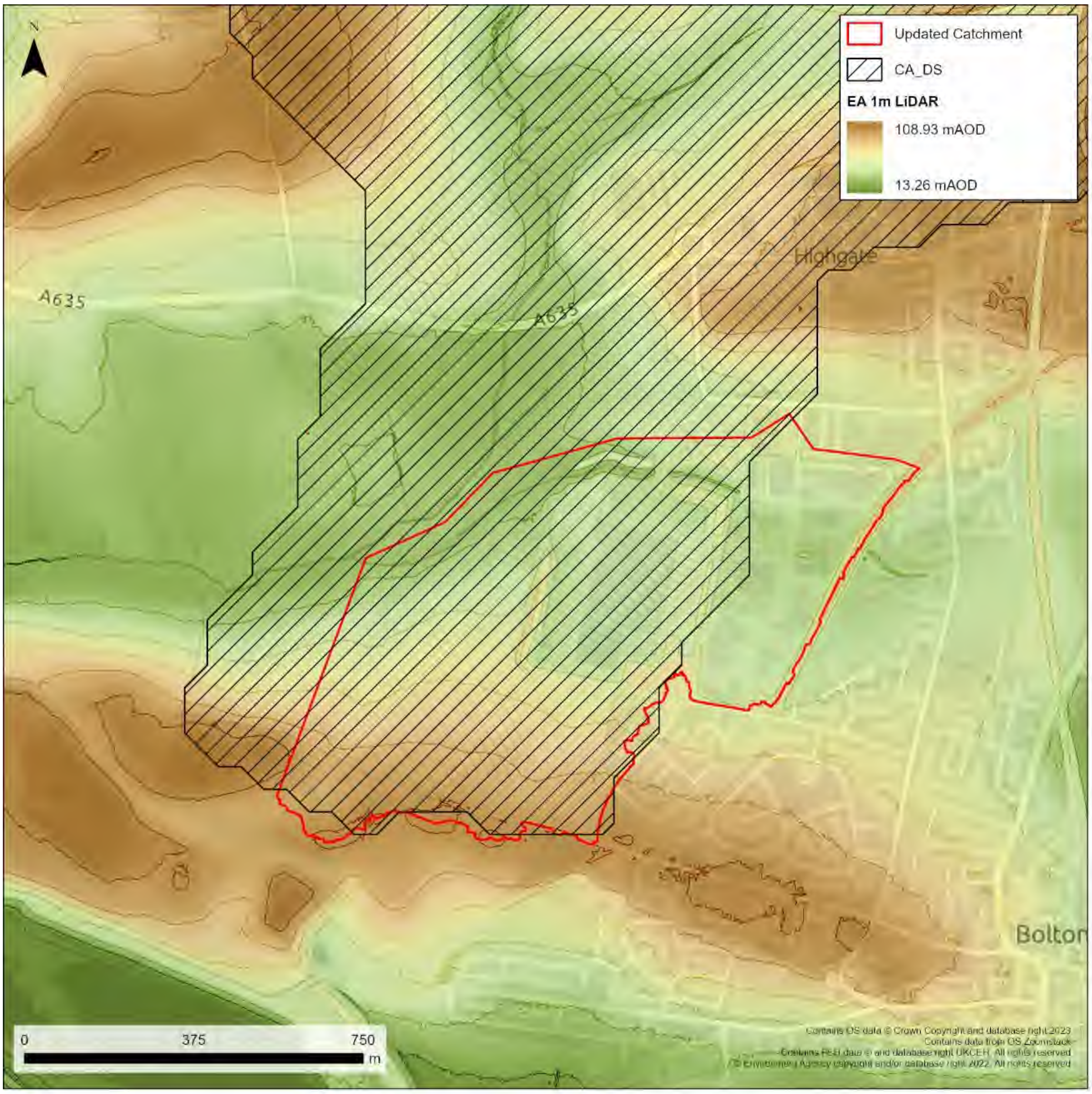


Figure 7 - HiG Catchment Area

URBEXT source and method for updating:

The URBEXT values were provided by the FEH Web Service and were checked using OS mapping and information provided by the FEH Web Service. Generally for the CA_DS, CA_US and ThD catchments, FEH represented the urban / sub-urban developments within the catchments well and as such the FEH values for these three catchments have been maintained with the Urban Expansion Factors of 1.09 and 1.05 applied to the URBEXT1990 and URBEXT2000 values respectively.

The Highgate Dike catchment (HiG) is a sub catchment of the Carr Dike downstream catchment. However as mentioned this catchment contains a significant area of urban development in the east of the catchment, associated with industrial and commercial developments. As such, URBEXT values have been amended to reflect the area of urban developments within this catchment. An URBEXT value of 0.3205 has been calculated.

BFIHOST source, checks and updates:

The BFIHOST, BFIHOST19 and SPRHOST values were checked using the 1:250,0000 Soil Survey for England and Wales map, in accordance with the IoH126 method. As the areas of all the catchments had ben altered, the manually calculated soil values were adopted.

Checks and revisions to other catchment descriptors:

The catchment descriptors for Carr Dike downstream (CA_DS) was used as a donor for Highgate Dike (HiG), with descriptors being manually calculated where possible as discussed above.

DPLBAR values were adjusted to account for changes in the catchment areas, using the ratio between the original area and the updated area, with the resultant ratio applied to the FEH DPLBAR value. The calculated values were accepted over the original FEH values.

SAAR is consistent with the geographical location of the catchments.

FARL was checked using OS mapping and satellite imagery. There are little to no reservoirs or lakes observed within the catchments; therefore, the FEH FARL values have been accepted. For HiG a FARL value of 1 has been used.

4. Stationary statistical methods

4.1 Method overview

What is the purpose of applying these methods?

The FEH Statistical method will be used to derive QMED values and peak flow estimates at the flow estimation locations. A pooling group will be derived for the entire lumped catchment of Carr Dike (CA_DS).

What methods will be used to estimate QMED and growth curves?

Site code	Methods used for QMED	Methods used for growth curves
CA_DS	Donor adjusted	Pooled

4.2 Estimating QMED

QMED at gauged subject sites:

No observed flow data available to inform QMED.

Site code	Method (AM/ POT/LF)	Initial QMED (m^3/s)	Number of water years of data used	Adjustment for climatic variation?	Final QMED (m^3/s)
-	-	-	-	-	-

Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

QMED at ungauged subject sites:

Site code	Method (CD/ DT/BCW)	Initial QMED (rural) from CDs (m^3/s)	Donors used (NRFA numbers)	Donor distances from subject centroid (km)	Individual donor weights	Combined and weighted donor adjustment factor	Urban adjustment factor	Final QMED (m^3/s)
CA_DS	DA	1.75	28070	30.32	-	-	1.181	2.01

Methods: CD - Catchment descriptors alone; DT - catchment descriptors with donor transfer; BCW - catchment descriptors with bankfull channel width.

Urban adjustment of QMED:

WINFAP5 was used for urban adjustment of QMED.

Parameters used for the urban adjustment:

- Impervious fraction for built-up areas, IF: 0.3
- Percentage runoff for impervious surfaces, PRimp: 70%
- Method for calculating fractional urban cover, URBAN: updated URBEXT 2000

Search for donor sites:

A donor search was completed within WINFAP5 for all catchments.

The 28070 Burbage Brook @ Burbage was recommended by WINFAP5 as the closest station to the catchment (30.32km from subject catchment). This station had the most similar key catchment descriptors to the subject catchments. As such, it was used to inform QMED.

The remainder of the potential donors identified were not considered to be hydrologically similar due to significant differences in either their catchment areas, SAAR, FARL, BFIHOST and SPRHOST values.

Donor sites chosen and QMED adjustment factors:

NRFA no.	Method (AM/ POT/LF)	Adjustment for climatic variation?	QMED from flow data (m^3/s)	De-urbanised QMED from flow data (m^3/s) (A)	QMED from catchment descriptors (m^3/s) (B)	Adjustment ratio (A/B)
28070	AM	No	2.010	1.703	1.749	0.97

Methods: AM – Annual maxima; POT – Peaks over threshold; LF – Low flow (flow duration curve) statistics.

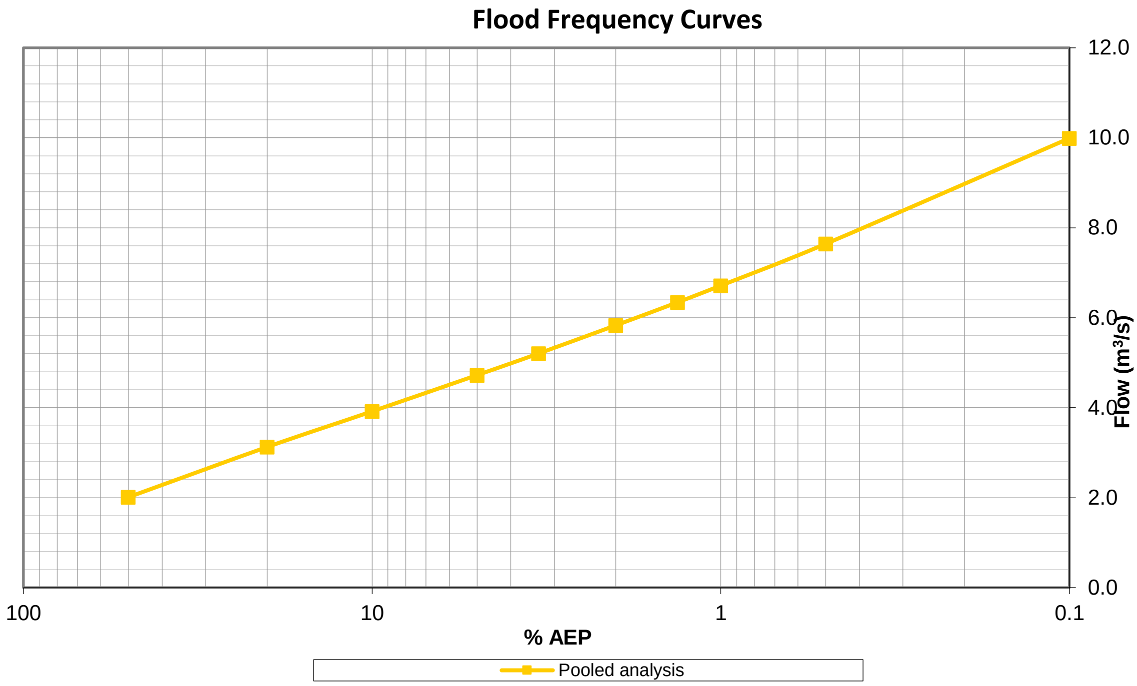
4.3 Estimating growth curves

Derivation of growth curves at subject sites:

Site code	Method (SS, P, ESS, H.)	If P or ESS, name of pooling group	Distribution used and reason for choice	Any urban or non-flood years adjustments	Parameters of distribution (location, scale and shape after adjustments)	Growth factor for 100-year return period
CA_DS	P	CA_DS	Gen. Ex. Value	Urban QMED applied.	Location: 0.831, Scale: 0.456, Shape: -0.076	3.34

Methods: SS - Single Site; P - Pooled; ESS - Enhanced Single Site; H - Historical. Pooled and ESS growth curves were derived using the procedures from Science Report SC050050 (2008). Urban adjustments are carried out using the method of Kjeldsen (2010).

Flood frequency curve plots:



Derivation of pooling groups:

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (ESS)	URBEXT2000 threshold applied to pooling group selection?	L-moments deurbanised (including subject site for ESS)?	Small catchment pooling procedure applied?
CA_DS_Final	CA_DS	No	0.030	L-CV: 0.301 L-SKEW: 0.220	No

Methods: Unless otherwise stated, pooling groups were derived using the procedures from Science Report SC050050 (2008). The small catchment pooling procedure is given in the report on Phase 2 of project SC090031 (2021) and implemented in WINFAP v5.

Pooling group composition:

Name of group	Changes made to default pooling group, with reasons	Weighted average L-moments
CA_DS_Final	Removed - 26016 (Gypsey Race @ Kirby Grindalythe): Highly permeable - 27073 (Brompton Beck @ Snainton Ings): Highly permeable - 26014 (Water Forlornes @ Driffield): Highly permeable - 33054 (Babingley @ Castle Rising): Low FARL and Highly permeable - 39033 (Winterbourne Stream @ Bagnor): Highly permeable - 26015 (Driffield Canal @ Wansford Bridge): Highly permeable - 26013 (Driffield Trout Stream @ Driffield): Highly permeable Station added as catchment descriptors suggest the station is hydrologically similar: - 36007 (Belchamp Brook @ Barfield Bridge)	L-CV: 0.301 L-SKEW: 0.220

Name of group	Changes made to default pooling group, with reasons	Weighted average L-moments
	- 20006 (Beil Water @ Belton House) - 53017 (Boyd @ Biton) - 9006 (Deskford Burn @ Cullen) - 34005 (Tud @ Costessey Park)	

Significant adjustments were required to the pooling group, therefore reducing confidence as a result.

4.4 Final choice of QMED and growth curves

Method choice and reasons:

Site code	Final choice of QMED and reasons	Final choice of flood growth curve method and reasons
CA_DS	Catchment descriptors with donor adjustment using WINFAP 5 - the catchment is ungauged, therefore the default method is to use Catchment Descriptors. Local data from the Burbage Brook @ Burbage is advantageous to inform QMED. Other local donors had differing geology and therefore were not appropriate to use.	Gen Ex. Value – Best fit

Final flood estimates from stationary statistical methods:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
CA_DS	2.010	3.126	3.918	4.723	5.205	5.831	6.342	6.714	7.642	9.989

Flood peak in m^3/s for the return periods in years or AEP (%) events.

5. Non-stationary statistical methods

Not Required

6. Revitalised flood hydrograph (ReFH1) method

Not completed

7. Revitalised flood hydrograph 2 (ReFH2) method

7.1 Method Overview

What is the purpose of applying this method?

The ReFH2.4 method will be used to derive peak flow estimates at the flow estimation locations. The ReFH2.4 method will be applied using the latest available version of the software. ReFH2.4 will define the hydrograph shapes for the hydraulic model inflows.

The ReFH2.4 unadjusted methods were applied. The unadjusted method is where the results are purely based upon catchment descriptors. No gauged flow or level data is available for any of the watercourses of interest.

Rural and urban catchment sub-divisions:

The ReFH2.4 method was applied with peak flow estimates being derived for lumped catchments to understand how the peak flows change throughout the watercourse.

HiG as mentioned this catchment contains a significant area of urban development in the east of the catchment, associated with industrial and commercial developments, and considered very heavily urbanised.

Version of ReFH2 applied:

ReFH2.4

7.2 Model Parameters

Summary of model parameters:

Site code	Method	Tp (hours) rural	Cmax (mm)	BL (hours)	Area modelled as urban (km2)	TP urban scaling factor	IF	IRF	DS
CA_DS	CD	5.291	416.958	47.543	3.44	0.75	0.4	0.7	0.5
CA_US	CD	4.162	472.326	45.82	1.33	0.75	0.4	0.7	0.5
ThD	CD	3.8	363.33	39.746	2.16	0.75	0.4	0.7	0.5

Site code	Method	Tp (hours) rural	Cmax (mm)	BL (hours)	Area modelled as urban (km2)	TP urban scaling factor	IF	IRF	DS
HiG	CD	2.097	369.038	31.48	0.39	0.75	0.4	0.7	0.5

Methods: OPT: Optimisation from event analysis, BR: Baseflow recession fitting, LAG: TP from lag analysis, CD: Catchment descriptors, DT: Data transfer, CAL: model calibration.

Analysis undertaken to derive model parameters:

Due to the lack of available flow data to validate the simulated events it is not considered appropriate to alter any model parameters away from default values.

7.3 Model inputs for design events

For the purpose of generating hydrographs from the ReFH2.3 model, it is proposed that the catchments CA_DS, CA_US and ThD are treated as rural due to the extent of urbanisation within the catchments (URBEXT2000 < 0.3 for all catchments) and a winter storm profile has been used in results extracted.

HiG is very heavily urbanised, as such a summer storm and urban results have been extracted for this catchment.

The storm duration for each catchment was optimised through trial and error.

The storm durations are calculated for each catchment individually and will be updated to a consistent storm duration for all catchments if ReFH2 is chosen as the final method.

Design events for lumped catchments:

Site code	Rainfall DDF model	Urban or rural	Highly permeable?	Season of design event	Storm duration (hrs)	Initial soil moisture Cini	Initial baseflow BFO
CA_DS	FEH22	Rural	No	Winter	16.5	99.023	0.298
CA_US	FEH22	Rural	No	Winter	12.5	91.27	0.105
ThD	FEH22	Rural	No	Winter	10.5	108.35	0.153
HiG	FEH22	Urban	No	Summer	5.5	66.475	0.01

Design events for subcatchments and intervening areas:

Site code(s)	Rainfall DDF model	Season of design event	Storm duration (hrs)	Storm area for ARF	Areal reduction factor ARF	Reason for selecting storm
-	-	-	-	-	-	-

Storm duration testing:

The storm duration for each catchment was optimised through trial and error.

The storm durations are calculated for each catchment individually and will be updated to a consistent storm duration for all catchments if ReFH2 is chosen as the final method.

7.4 Final choice of ReFH2 flow estimates

Method choice and reasons:

Site code	Final choice of design inputs and model parameters
CA_DS CA_US ThD	Model parameters derived from catchment descriptors. Critical storm durations are calculated for each catchment individually. A winter storm profile is adopted based on URBEXT2000.
HiG	Same critical storm duration adopted. A summer storm profile is adopted based on URBEXT2000 >0.3.

The use of both winter and summer storm profiles is a conservative approach to estimating flows for this study, given the urban nature of HiG.

Final flood estimates from ReFH2 method:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
CA_DS	2.70	3.59	4.25	4.96	5.43	6.09	6.68	7.14	8.43	12.28
CA_uS	1.11	1.49	1.77	2.09	2.29	2.58	2.84	3.05	3.63	5.40
ThD	1.47	1.95	2.31	2.69	2.94	3.29	3.61	3.86	4.55	6.62
HiG	0.39	0.53	0.63	0.82	0.82	0.92	1.02	1.09	1.30	1.93

Flood peak in m^3/s for the return periods in years or AEP (%) events.

8. Other Rainfall-Runoff or Hydrograph Methods

8.1 Averaged Hydrograph Shapes

Not completed

8.2 FSR-FEH Rainfall-Runoff Method

Not completed

8.3 Direct Rainfall Modelling

Not completed

9. Discussion and summary of results

9.1 Comparison of results from different methods

Site code	*e.g., Ratio of ReFH2 to stationary statistical peak, 50% AEP*	*e.g., Ratio of ReFH2 to stationary statistical peak, 1% AEP*
CA_DS	1.34	1.06

9.2 Final choice of method

Choice of method and reasons:

The ReFH2 method was selected due to its ability to represent flows in ungauged catchments. ReFH2 version 2.3 was used as it is the most up to date methodology and makes use of FEH22 rainfall data, which is the latest available dataset.

The catchment is ungauged and the FEH Statistical method resulted in a pooling group that was considered to be heterogeneous with a review being desirable. As such, confidence in the pooling group being considered representative of the subject catchment was not high and this method was not selected.

How will the 0.1% AEP flows be estimated?

The 0.1% AEP flows will be estimated using ReFH2.

How will the flows be applied to a hydraulic model?

CA_US will be applied as the upstream inflow to the hydraulic model to the Carr Dike channel.

ThD will applied as an upstream inflow to the hydraulic model to the Thurnscoe Dike.

HiG will be applied as an upstream inflow to the hydraulic model to the Highgate Dike.

CA_DS will be aerially weighted and applied as a lateral input at an appropriate location for the intervening catchment between the upstream and downstream extent of the model.

9.3 Final results

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
CA_DS	2.7	3.6	4.3	5.0	5.4	6.1	6.7	7.1	8.4	12.3
CA_US	1.1	1.5	1.8	2.2	2.4	2.7	2.9	3.1	3.7	5.5
ThD	1.52	2.0	2.4	2.8	3.1	3.5	3.8	4.0	4.7	6.9
HiG	0.44	0.62	0.76	0.9	0.99	1.11	1.22	1.30	1.53	2.29

Flood peak in m^3/s for the return periods in years or AEP (%) events.

Design storms applied in the hydraulic model:

Site code(s)	Season of design event	Storm duration (hrs)	Storm area for ARF (km2)	Return period(s)	Reason for selecting storm
CA_DS	Winter	16.5	0.965	30yr, 100yr, 100yr plus appropriate climate change allowances and 1000yr	URBEXT2000<0.3 for all.
CA_US					
ThD					
HiG	Summer				URBEXT2000>0.3

Appropriate storm profile is adopted as based on URBEXT2000.

The hydrograph shape will be derived using ReFH2.3. A consistent storm duration is adopted based on the critical storm duration of the total catchment, CA_DS 16.5hrs.

Where appropriate, a consistent areal reduction factor (ARF) was selected based on the ARF calculated for each total catchment;

Climate change allowances:

The impacts of climate change will be modelled based on the latest available guidance[5]. The site is located within the ‘Don and Rother' Management Catchment, peak river flow allowances of +28% (central) and +38% (higher central) allowances are applicable to this study for the 2080s epoch (2070-2115).

5 EA, 2022, Flood Risk Assessments: Climate Change Allowances

9.4 Checks

Growth factor checks:

Site code	1% AEP growth factor	0.1% AEP / 1% AEP ratio
CA_DS	3.34	1.72
CA_US	-	1.78
ThD	-	1.72
HiG	-	1.76

Specific discharge:

Site code	2 50%	5 20%	10 10%	20 5%	30 3.3%	50 2%	75 1.3%	100 1%	200 0.5%	1000 0.1%
CA_DS	0.243	0.324	0.387	0.45	0.486	0.549	0.603	0.639	0.756	1.107
CA_US	1.1	1.5	1.8	2.2	2.4	2.7	2.9	3.1	3.7	5.5
ThD	1.52	2.0	2.4	2.8	3.1	3.5	3.8	4.0	4.7	6.9
HiG	0.44	0.62	0.76	0.9	0.99	1.11	1.22	1.30	1.53	2.29

Flood peak in m^3/s for the return periods in years or AEP (%) events.

Spatial consistency of results:

Peak flow estimates increase downstream at confluences and through lumped catchments.

Return periods for notable historic floods:

N/A – no observed flow data.

Compatibility with longer-term flood history:

There is limited flood history information available for the site and therefore compatibility cannot be inferred.

Comparisons with previous studies:

No previous studies

Checks on hydraulic model results:

Modelled levels and extents will be sense checked to confirm that flow inputs result in realistic results. This will be reporting within the hydraulic modelling report.

9.5 Assumptions, limitations, and uncertainty

Assumptions (specific to this study):

The catchment delineations are sufficiently representative of the topographic areas draining to the watercourses.

It is assumed that any potential exports and imports via sewers within the catchment roughly balance.

The pooling group is representative of the hydrological response of the catchments.

The QMED values are representative of the catchments.

The ReFH2.4 hydrograph shapes are representative of the responses of the catchments to rainfall.

Limitations:

The ungauged nature of flows within the catchment is the most significant limitation.

Uncertainty:

The ReFH2 method does not have a recognised method of estimating uncertainty in flows.

Suitability of results for future studies:

The peak flow estimates were derived for the purposes of this study. Therefore, should further studies be completed within the catchment it would be advised that a review of the hydrology be completed as a minimum.

Recommendations for future work:

The main limitation of this study is the lack of gauged flow data. If a flow monitoring station were installed upon the watercourses, the observed data could be used to refine the peak flow estimates derived. This was outside the scope of this study.

10. Appendix

10.1 Digital files

Catchment Descriptors:

- CA_DS_editied.xml
- CA_US_edited.xml
- ThD_edited.xml
- HiG.xml

FEH Statistical

- CA_DS.wxml

ReFH2

- CA_DS_16.5_0.5.rxml
- CA_US_12.5_0.5.rxml
- CA_US_16.5_0.5.rxml
- HiG_5.5_0.5_Summer.rxml
- HiG_16.5_0.5.rxml
- ThD_10.5_0.5.rxml
- ThD_16.5_0.5.rxml

10.2 Other Supporting Information

CA_DS Pooling Group

Station	Distance	Years of Data	QMED AM
36010 (Bumpstead Brook @ Broad Green)	0.496	56	7.855
26016 (Gypsey Race @ Kirby Grindalythe)	0.616	26	0.1
27073 (Brompton Beck @ Snainton Ings)	0.681	43	0.812
26014 (Water Forlornes @ Driffield)	0.775	25	0.424

25019 (Leven @ Easby)	0.878	45	5.09
7009 (Mosset Burn @ Wardend Bridge)	0.932	25	7.053
36004 (Chad Brook @ Long Melford)	0.967	56	4.799
33054 (Babingley @ Castle Rising)	0.989	47	1.129
39033 (Winterbourne Stream @ Bagnor)	0.99	61	0.399
26015 (Driffield Canal @ Wansford Bridge)	1.022	13	2.49
26013 (Driffield Trout Stream @ Driffield)	1.065	13	2.7
7011 (Black Burn @ Pluscarden Abbey)	1.066	11	4.298
27051 (Crimple @ Burn Bridge)	1.075	51	4.564
36003 (Box @ Polstead)	1.078	63	3.85

CA_DS_Final Pooling Group

Station	Distance	Years of Data	QMED AM
36010 (Bumpstead Brook @ Broad Green)	0.496	56	7.855
25019 (Leven @ Easby)	0.878	45	5.09
7009 (Mosset Burn @ Wardend Bridge)	0.932	25	7.053
36004 (Chad Brook @ Long Melford)	0.967	56	4.799
7011 (Black Burn @ Pluscarden Abbey)	1.066	11	4.298
27051 (Crimple @ Burn Bridge)	1.075	51	4.564
36003 (Box @ Polstead)	1.078	63	3.85
36007 (Belchamp Brook @ Bardfield Bridge)	1.104	58	4.63
20006 (Biel Water @ Belton House)	1.203	28	11.748
53017 (Boyd @ Bitton)	1.215	50	13.908
9006 (Deskford Burn @ Cullen)	1.247	13	17.671
34005 (Tud @ Costessey Park)	1.257	61	3.11