28 JUNE, 2024

# Hydraulic Modelling Report

## Begbroke Innovation District

Prepared for:

Buro Happold
230, Lower Bristol Road,
Bath
BA2 3DQ

EdenvaleYoung

Edenvale Young Associates Ltd.
30, Queen Charlotte Street,
Bristol
BS1 4HJ
United Kingdom

# Document Control

| | |
|---|---|
| **Report Title** | Hydraulic Modelling Report |
| **Project Name** | Begbroke Innovation District |
| **Project Number** | EVY1077 |
| **Report Revision** | E |
| **Client** | Buro Happold |

| | | |
|---|---|---|
| Written by | Sally Hatton | 28 June, 2024 |
| Checked by | Maria Jarquin | 28 June, 2024 |
| Approved by | Maria Jarquin | 28 June, 2024 |

| Revision | Issued to | Date |
|---|---|---|
| A | Buro Happold | April 12, 2023 |
| B | Buro Happold | May 22, 2023 |
| C | Buro Happold | July 17, 2023 |
| D | Buro Happold | March 27, 2024 |
| E | Buro Happold | June 28, 2024 |

# Contents

# List of Figures

# List of Tables

INTRODUCTION

# 1. Project Overview

## 1.1 Project Requirements

Edenvale Young Associates have been commissioned by Buro Happold to undertake hydraulic modelling at a site west of Kidlington, Oxfordshire. The results of this hydraulic modelling will be used to inform a Flood Risk Assessment (FRA) for the proposed Begbroke Innovation District—a mixed use development incorporating the existing Begbroke Science Park. The site boundary is shown in figure 1.1, along with a summary of watercourse locations. The watercourses have been subdivided into a series of reaches for the purposes of this report and the naming used for these reaches is also shown in this figure.

The purpose of the study is to define the flood extents and map the flood depths associated with a set of key design events required for the planning process, specifically the 3.33%, 1% and 0.1% AEP present day events and the 1% AEP event with climate change allowances to the 2080s from Gloucestershire and the Vale Management Catchment. These events are shown in table 1.1.

| AEP | Epoch | Estimate | Uplift |
|---|---|---|---|
| 3.33% | Present | | 0% |
| 1% | Present | | 0% |
| 1% | 2080s | Central | 26% |
| 1% | 2080s | Higher | 41% |
| 0.1% | Present | | 0% |

Table 1.1: *Fluvial events to be simulated*

## 1.2 Purpose of this Report

This report seeks to

- provide an overview of the site and the local watercourses that could impact on the site's flood risk;
- describe the peak flow hydrological analysis undertaken for the site and how those inflows are distributed across the site;
- describe the hydraulic modelling methodology and how particular key features of the site and its local watercourses have been simulated;
- present the results of the baseline modelling exercise and sensitivity tests;
- present modelling of proposed mitigation options;
- outline key assumptions associated with the model build and results.

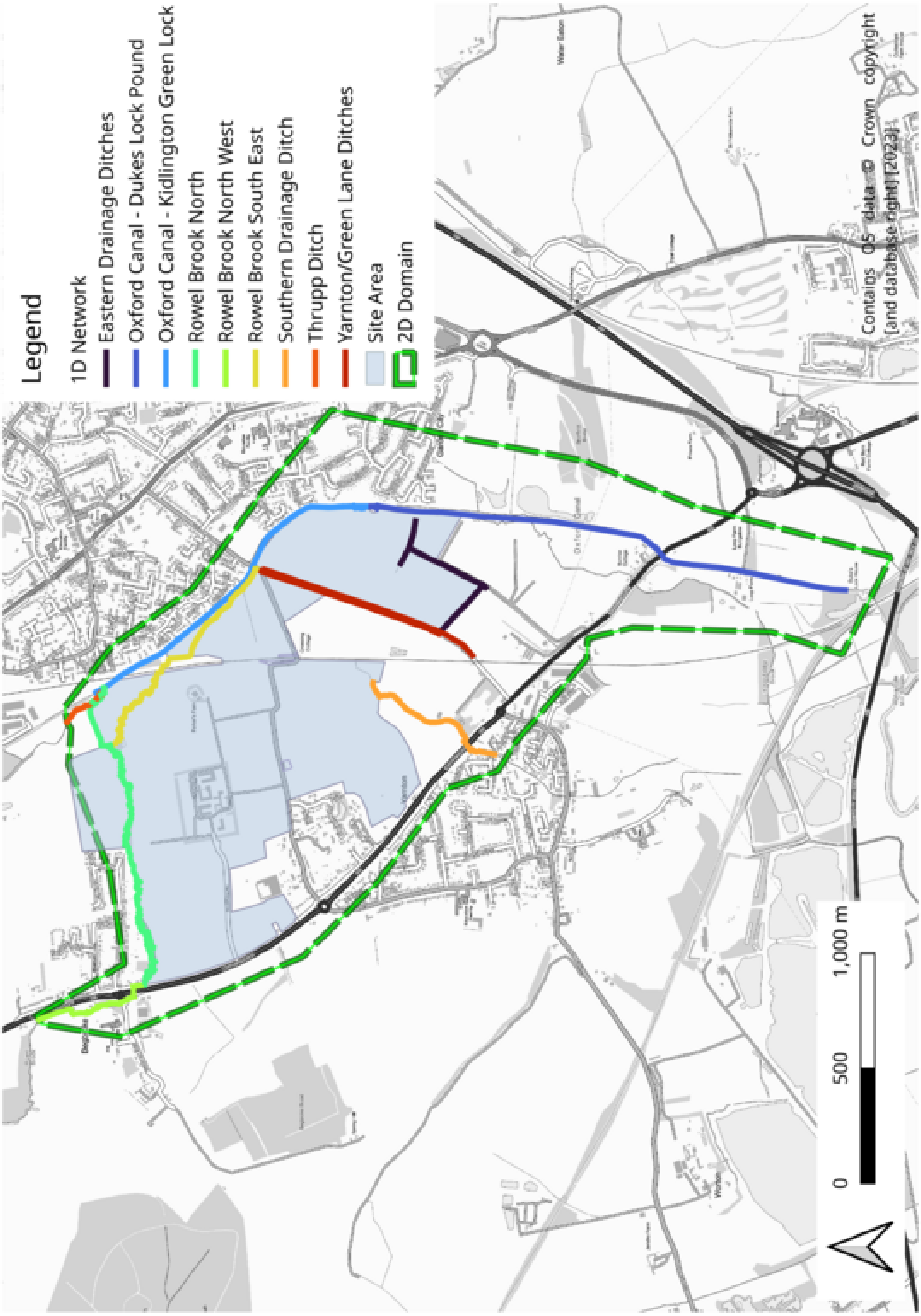


Figure 1.1: *Site boundary and nearby watercourses*

OVERVIEW

# 2. Description of the Site

## 2.1 Overview

There are a number of watercourses on and adjacent to the site. These include the Rowel Brook, the Thrupp ditch, the Southern Drainage Ditch, the Eastern Drainage Ditches as well as other field ditches. The location of these watercourses is shown in figure 1.1. To the east, the site is bounded by the Oxford Canal.

This section of the report sets out the key characteristics of each watercourse. This has been informed by two site visits, which were undertaken in October 2022 and March 2023 to help better understand the connectivity of the channels and inform the model build. Flow conditions within the watercourses were notably different on each occasion; in October, many of the channels were dry whilst in March, flow was evident in the majority of channels.

## 2.2 Rowel Brook: North West and North

The Rowel Brook originates west of Oxford Airport and drains east to the A44, Woodstock Road, before turning south towards Begbroke village. Once at Begbroke, the Rowel Brook is culverted under the road and flows east across the northern boundary and through the north western corner of the proposed development site. Within this reach the channel is comparatively sinuous. These reaches are referred to in this report as the Rowel Brook North West and Rowel Brook North.

This watercourse appears to be ephemeral, having no flow or standing water at the time of the initial site visit, but with a visible flow when the second site visit was undertaken. The watercourse bifurcates in a small wooded area to the north of the proposed development. The ground levels in this wooded area are variable and there was no obvious low-flow connection to the Rowel Brook South East. Similarly, a number of ponds in this location did contain water behind a weir that would seemingly discharge into the Rowel Brook South East, but there was no obvious connection from these ponds to the Rowel Brook North.

A topographic survey has been undertaken in this area to better understand likely flow paths and surface water connections during high flow conditions. The Rowel Brook North flows north east from the copse and appears to discharge into the Oxford Canal via a culvert shortly after its confluence with the Thrupp Ditch. This branch contained standing water during the initial site visit, but visible flow during the second site visit.

## 2.3 Rowel Brook, South East and Yarnton/Green Lane Ditches

The Rowel Brook South East branch flows in a south easterly direction through the site and, after passing through a culvert under the railway line, along the site's eastern edge. After crossing under

Sandy Lane it flows along the western side of Yarnton/Green Lane. Observations on site, along with the topographic survey, indicated that flow from the Rowel Brook is only routed along the western side.

The ditches along Yarnton/Green Lane appeared poorly maintained and the connectivity between the ditches was not always clear. A culvert close to the confluence with the Eastern Drainage Ditches appears to convey water from west to east below Yarnton/Green Lane, but water in either ditch was limited during the site visits and therefore this hypothesis is unconfirmed. This culvert is shown in figure 2.1 and was modelled based on an approximate measurement undertaken on the site visit. Section 4.8 outlines the assumptions made for these ditches.

Figure 2.1: *Culvert assumed to convey water from the western to eastern ditch along Yarnton/Green Lane*

## 2.4 Eastern Drainage Ditches

The watercourse is finally routed from Yarnton/Green Lane into field drainage ditches, which are referred to here as the Eastern Drainage Ditches. This flow route is assumed as the confluence between the Yarnton/Green Lane and the Eastern Drainage Ditch was dry during both site visits, but the morphology of the channels suggested that the dominant flow route during high flows would be into the eastern ditch system. During the second site visit, flow was evident in ditches closer to the canal and it was clear that this flow was eventually routed back towards the A44, south of the site. It was not possible to access this area for detailed survey. Figure 2.2 shows flow within the ditch system looking downstream.

Prior to the acquisition of topographic survey there was some uncertainty associated with the connectivity of the ditches either side of Yarnton/Green Lane. Some uncertainty remains, but it is now considered that:

- only the western channel along Yarnton Lane is connected to Rowel Brook at the upstream extent.
- flow along along both sides of Yarnton Lane is not continuous, with significant vegetation growth and debris blockages.
- the channels are connected to each other at their southern end via a culvert as shown in the watercourse map.
- the Eastern Drainage Ditches are eventually connected to the return crossing under the A44 via field drains to the east
- the Eastern Drainage Ditches are not directly connected into the Oxford Canal.

Figure 2.2: *Eastern Drainage Ditch system looking downstream in a south-westerly direction. The solar farm is visible on the left bank.*

## 2.5 Thrupp Ditch

The Thrupp Ditch drains a catchment north of the site and flows south through an industrial estate, east of Oxford Airport. It runs just west of the Oxford Canal, flowing south, before entering a culvert under a footpath and joins with the Rowel Brook North and, shortly downstream, the Oxford Canal.

## 2.6 Oxford Canal

Figure 2.3: *Side spill at Kidlington Green Lock*

The Oxford Canal runs in a southerly direction from the northeast of the site, down the eastern edge of the site boundary. There are two pounds that affect the site. The most significant runs from Roundham Lock - just upstream of the confluence with the Rowel Brook and Thrupp Ditch - along the eastern boundary of the site to Kidlington Green Lock. The second pound starts here and runs south for a considerable distance, ending a short way upstream of the A40 at Dukes Lock.

Kidlington Green Lock has a substantial upstream side-spill weir, shown in Figure 2.3, to maintain the upper pound level. This discharges into a parallel channel around the lock on the western side and returns to the canal downstream. It should be noted that, whilst a field drainage ditch runs perpendicular to this offtake, it did not appear to be connected to the bypass channel. A similar structure can be observed at Dukes Lock in aerial photography, but no detailed survey was available.

## 2.7 Southern Drainage Ditch

The Southern Drainage Ditch originates to the west of the railway within the site boundary and flows southwest, beneath the A44 Woodstock Road and through Yarnton village, with no connections upstream.

# 3. Peak Flow Estimation

## 3.1 Overview

A full hydrological analysis has been undertaken in order to derive design flow hydrographs to be implemented as boundaries to the hydraulic model for the required events. Full details of the hydrological analysis are provided in the Flood Estimation Report (appendix A) included with this report. The analysis has been carried out in accordance to the requirements set out by current Environment Agency guidelines[1] and the FEH (Flood Estimation Handbook). Therefore, both the FEH Statistical and ReFH2 rainfall-runoff approaches have been applied for the purposes of the hydrological analysis. However, this has also been aided by the implementation of a Direct Rainfall Model (DRM) of the area of study.

The Flood Estimation Report covers the conceptual model and selection of estimated locations for the main watercourses, namely the Rowel Brook, Thrupp ditch and Southern Drainage ditch. Details of the FEH analysis at the locations selected for the purposes of flood estimation on these watercourses are also provided in the appendix. The intervening area at the downstream boundary of the model has been split into sub-catchments, according to the DRM results. Details of the DRM built to refine the FEH analysis and a summary of its outputs are provided in section 3.2. A summary of the FEH analysis outputs is provided in section 3.3.

## 3.2 Direct Rainfall Model

Due to limitations associated with the resolution at which the FEH catchments can be defined and to the characteristics of the topography of the area, it was necessary to refine the delineation of the overall runoff contributing area to the site of interest and to gain a better understanding of the surface flow routes which might affect the estimation of flood risk at the site. For this purpose, a broad scale 2D Direct Rainfall Model (DRM) has been built in TUFLOW version 2020-10-AC using LiDAR DTM data. Minor modifications were made to the topography based on-site observations and the topographic survey in order to ensure that a representative flow path was identified. Variations to 2D roughness values were applied to reflect different surface coverage within the model domain.

The model has been run with the 0.1% Annual Exceedance Probability design rainfall and evaluated in terms of unit flow and velocity modelled outputs within the 2D model domain. This process has allowed the refinement of the FEH catchment boundaries and the delineation of on- and off-site sub-catchments to be taken into account for the purposes of the hydraulic modelling.

The final contributing areas for the Rowel Brook, Thrupp ditch and Southern Drainage ditch, delineated as a result of the refinement of the FEH boundaries on the basis of the DRM results, are shown in

[1] LIT11832 Environment Agency Flood Estimation Guidelines, published 23/12/2022

figure 3.1. The overall contributing catchment downstream of the site of interest (at Kingsbridge, KB01) is also shown in figure 3.1.

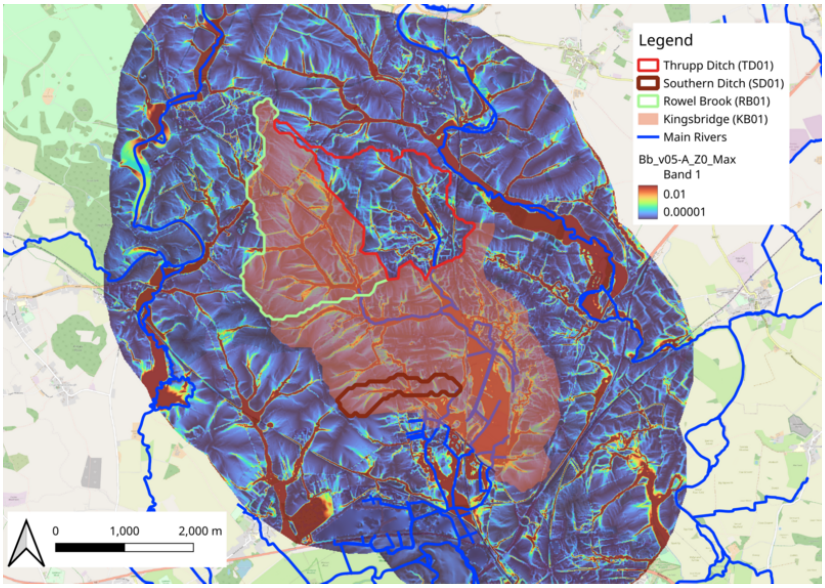


Figure 3.1: *Final contributing catchments at the locations selected for FEH analysis and the Direct Rainfall Model unit flow results*

Figure 3.2 shows the sub-catchments delineated as a result of the DRM outputs analysis. It should be noted that, according to the results of the DRM, the sub-catchment S08 has been identified as providing the most accurate representation of the runoff contributing to the Southern Drainage ditch.

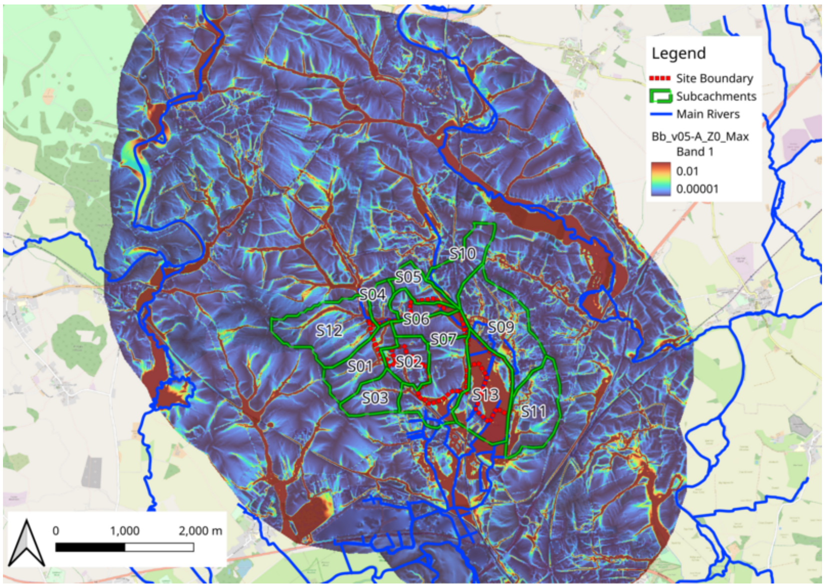


Figure 3.2: *Sub-catchments delineated using the DRM results for which lumped or distributed inflows are being incorporated in the hydraulic model.*

A summary of the final contributing areas for the estimation of the main inflows on the Rowel Brook (RB01), Thrupp ditch (TD01) and Southern Drainage ditch (SD01) is provided in table 3.1. The areas of all sub-catchments and the total contributing area at KB01 are also detailed in table 3.1. It should be noted that the sum of all contributing areas at the main estimate locations and for all sub-catchments accounts for about 90% of the total contributing area at KB01.

| Node ID | Area ($km^2$) |
|---|---|
| KB01 | 14.056 |
| RB01 | 3.55 |
| TD01 | 2.67 |
| SD01 (=S08) | 0.811 |
| S01 | 0.546 |
| S02 | 0.382 |
| S03 | 0.369 |
| S04 | 0.189 |
| S05 | 0.265 |
| S06 | 0.221 |
| S07 | 0.351 |
| S09 | 1.076 |
| S10 | 0.464 |
| S11 | 0.757 |
| S12 | 0.963 |
| S13 | 0.894 |
| Total | 12.614 |

Table 3.1: *Contributing areas at main estimate locations and for all sub-catchments*

## 3.3 FEH analysis outputs

### Q peak estimates

Final Q peak estimates at RB01, TD01, and SD01 are the statistical estimates. QMED has been estimated from catchment descriptors and adjusted by donor transfer and for urbanisation. Q peaks for events with AEP < 50% have been estimated by applying growth factors derived from pooled analysis at KB01. It should be noted that the peak estimates for all sub-catchments have been obtained from Qpeaks estimated at KB01, scaled by the ratio of catchment areas. A summary of Qpeaks for all AEPs(%) is provided in table 3.2.

| % AEP | Return Period | KB01 | RB01 | TD01 | SD01 | S01 | S02 | S03 | S04 | S05 | S06 | S07 | S09 | S10 | S11 | S12 | S13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 2 | 0.891 | 0.180 | 0.176 | 0.120 | 0.035 | 0.024 | 0.023 | 0.012 | 0.017 | 0.014 | 0.022 | 0.068 | 0.029 | 0.048 | 0.061 | 0.057 |
| 20 | 5 | 1.306 | 0.263 | 0.258 | 0.177 | 0.051 | 0.035 | 0.034 | 0.018 | 0.025 | 0.021 | 0.033 | 0.100 | 0.043 | 0.070 | 0.089 | 0.083 |
| 10 | 10 | 1.615 | 0.326 | 0.319 | 0.218 | 0.063 | 0.044 | 0.042 | 0.022 | 0.030 | 0.025 | 0.040 | 0.124 | 0.053 | 0.087 | 0.111 | 0.103 |
| 3.33 | 30 | 2.171 | 0.438 | 0.429 | 0.294 | 0.084 | 0.059 | 0.057 | 0.029 | 0.041 | 0.034 | 0.054 | 0.166 | 0.072 | 0.117 | 0.149 | 0.138 |
| 2 | 50 | 2.471 | 0.498 | 0.488 | 0.334 | 0.096 | 0.067 | 0.065 | 0.033 | 0.047 | 0.039 | 0.062 | 0.189 | 0.082 | 0.133 | 0.169 | 0.157 |
| 1 | 100 | 2.932 | 0.591 | 0.579 | 0.396 | 0.114 | 0.080 | 0.077 | 0.039 | 0.055 | 0.046 | 0.073 | 0.224 | 0.097 | 0.158 | 0.201 | 0.186 |
| 0.5 | 200 | 3.466 | 0.699 | 0.684 | 0.469 | 0.135 | 0.094 | 0.091 | 0.047 | 0.065 | 0.054 | 0.087 | 0.265 | 0.114 | 0.187 | 0.237 | 0.220 |
| 0.2 | 500 | 4.308 | 0.869 | 0.851 | 0.583 | 0.167 | 0.117 | 0.113 | 0.058 | 0.081 | 0.068 | 0.108 | 0.330 | 0.142 | 0.232 | 0.295 | 0.274 |
| 0.1 | 1000 | 5.068 | 1.022 | 1.001 | 0.685 | 0.197 | 0.138 | 0.133 | 0.068 | 0.096 | 0.080 | 0.127 | 0.388 | 0.167 | 0.273 | 0.347 | 0.322 |
| QBAR | | 0.953 | 0.193 | 0.188 | 0.128 | 0.037 | 0.026 | 0.025 | 0.013 | 0.018 | 0.015 | 0.024 | 0.073 | 0.031 | 0.051 | 0.065 | 0.061 |

Table 3.2: *Qpeak estimates ($m^3/s$) at main estimate locations and sub-catchments*

### Design Hydrographs

Design hydrographs have been derived as ReFH2 hydrographs scaled to match the statistical peaks. For this purpose, two storms applied consistently across the area of interest to the analysis have been selected, and these are detailed in table 3.3. The storms have been estimated from ReFH2 analysis as representative of the critical storm conditions for fast response hydrological features at the site location (SD=3.5hrs) and for the wider watershed including the site (SD=11hrs).

| Storm Duration (hr) | DDF Model | Storm Area ($km^2$) | Areal Reduction Factor (ARF) |
|---|---|---|---|
| 3.5 | DDF13 | 0.811 | 0.977 |
| 11 | DDF13 | 14.056 | 0.96 |

Table 3.3: *Summary of design storms*

# 4. Hydraulic Modelling

## 4.1 General Modelling Approach

The hydraulic model was constructed using ESTRY-TUFLOW. ESTRY was selected for the 1D component of the model due to the meandering, shallow gradient and ephemeral nature of the Rowel Brook and other watercourses. The model has been run using TUFLOW version 2023-03-AC-iDP-w64 and the HPC solver. Due to the comparatively small peak flows derived by the hydrological analysis, the model has been run using double precision.

## 4.2 Model Extent

The model domain is shown in figure 4.1, bounded by the green line. This extent fully covers the site of interest and extends upstream on the Rowel Brook and its tributaries as well as downstream as far as is practical. This image also shows the extent of the 1D network and the small number of channels have been represented in 2D.

The majority of the Digital Terrain Model (DTM) uses 2020 2m Composite LiDAR data downloaded from the DeFRA website. Where available, this has been superseded using detailed topographic survey. The model uses a 2m cell size throughout.

## 4.3 Representation of Channels

The mid-point approach for ESTRY cross section representation has been used. This approach reduces the amount of interpolation of data performed by the ESTRY solver and provides a representation of the channels that is closer to the surveyed data. This approach has also allows a high level of detail to be include in respect to variation in the modelled bed level between cross-sections.

Structures have been modelled using the appropriate channel type based on the supplied topographic survey. Figure 4.2 shows the extent of the 1D ESTRY network included within the model and the use of different channel types. Where loss coefficients are applied for culverts, these values are based on the values recommended in the TUFLOW manual.

## 4.4 Topographic Survey

Detailed topographic survey of the site, including cross-sectional survey of channels and structures, was undertaken in early 2023 and this has been incorporated into the model build.

The river centreline was surveyed at a 2m spacing along each channel (coarser along the Oxford Canal) which has allowed critical high and low points in each channel to be identified and included in the modelling even where full cross-sections are not available at those locations.

Wider topographic survey of the site has also been undertaken. A Triangulated Irregular Network (TIN) based on this information

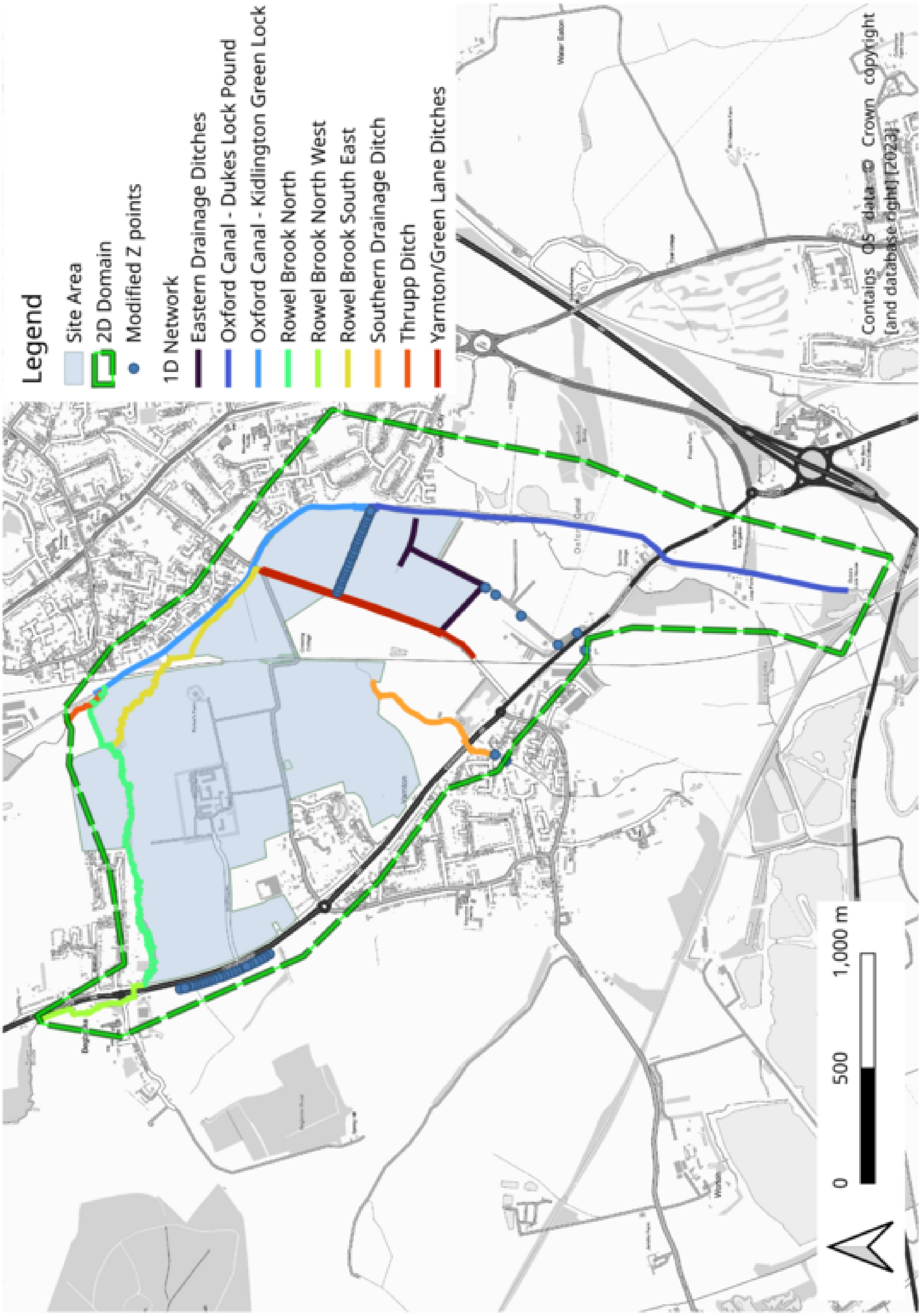


*Figure 4.1: Model domain and 1D/2D channels*

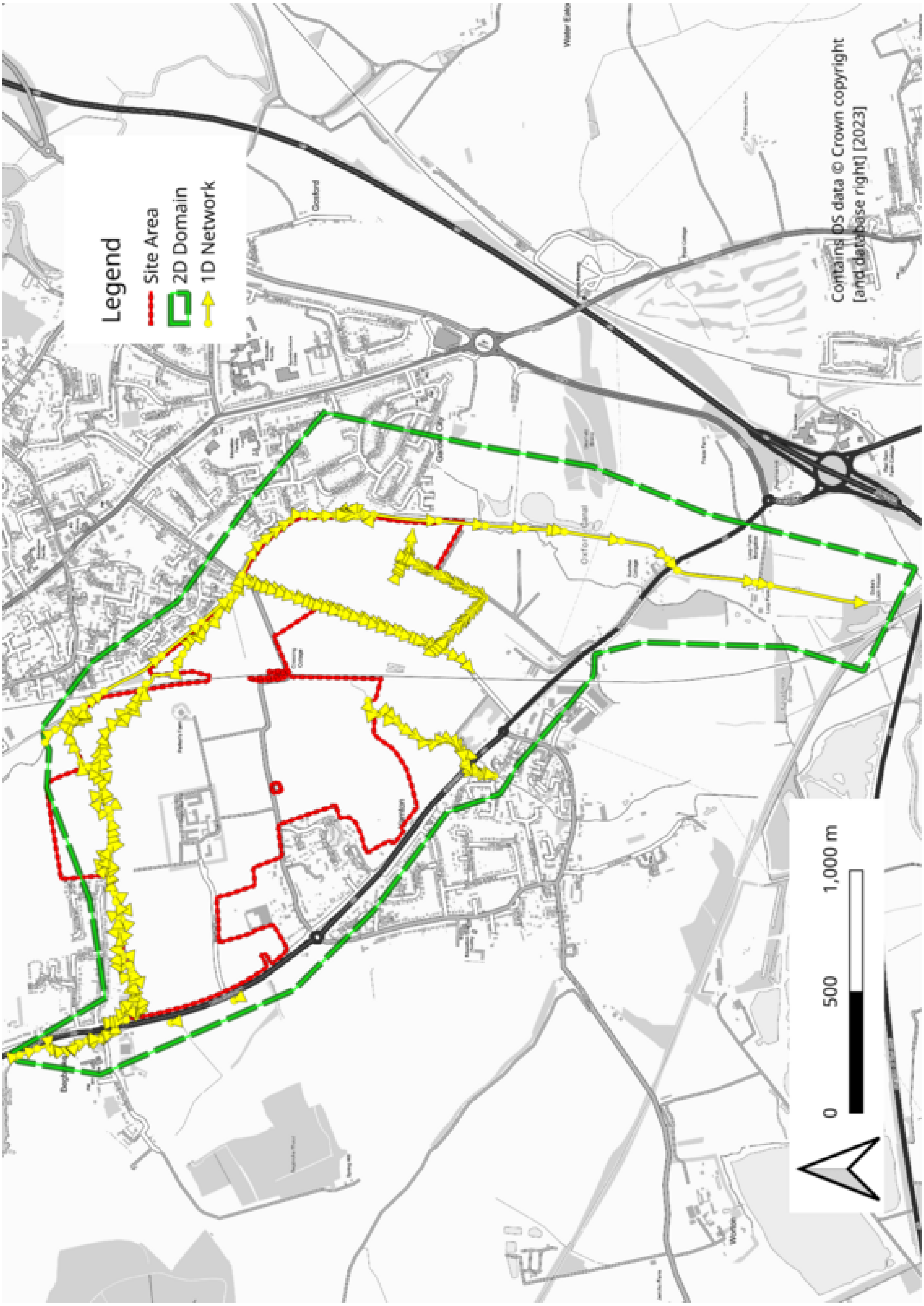


*Figure 4.2: Model domain and 1D channels*

has been applied where available; bespoke Topographic survey is usually used in preference to LiDAR as it is considered more accurate.

It should be noted that the topographic survey was limited in some instances. For example, there was incomplete bank top survey of the Southern Drainage Ditch and along the Oxford Canal. Access restrictions also resulted in incomplete coverage in some locations, including the uppermost reach of the Rowel Brook. This meant that assumptions had to be made in terms of channel geometry and connectivity.

The homogeneity of the channel means that a large number of cross-sections were not required to fully understand channel conveyance. In some locations, however, there was no data to confirm the invert or bank levels and these therefore needed to be inferred from the information that was available. Additionally, the survey of existing structures was not very detailed and required interpretation as part of the model build.

## 4.5 Other Topographic Modifications

Banklines have been applied along most watercourses, based on a combination of cross-sectional and bank top survey, to ensure that the onset of flooding from these channels is accurately represented. This ensures that water will spill from the 1D domain into the 2D domain at an appropriate elevation.

Topographic survey of channel banks was available for much, but not all, of the modelled extent. This means that there is some variation in whether the bank heights used to inform the banklines/boundary cells originate from the channel cross-section or the, separate, bank top survey. In general, it was deemed more appropriate to use the bank top survey elevations as these contained a greater number of elevation points.

As shown in figure 4.1, a number of drainage ditches were identified on-site but detailed cross-sectional survey was not available in all locations. In these instances, channels have been represented in the 2D model based on an approximate channel width. Bed elevations have been set using channel bed survey where available.

## 4.6 Hydraulic Roughness Values

Hydraulic roughness coefficients have been applied based on representative reaches of the channel observed during the site visit. Table 4.1 sets out the 1D roughness values for the modelled reaches within the model.

To account for the very high sinuosity of the Rowel Brook as it runs across the northern edge of the site, Cowan's method was used to determine an appropriate roughness coefficient. Cowan's method breaks down the estimation of roughness into six factors, one of which is sinuosity, and was therefore considered appropriate in the estimation of roughness at this location.

| Material | $d_1$ | $n_1$ | $d_2$ | $n_2$ |
|---|---|---|---|---|
| General | 0.1 | 0.5 | 0.2 | 0.05 |
| Roads | – | 0.02 | – | – |
| Trees/ Wooded | 0.1 | 1.0 | 0.2 | 0.1 |
| Buildings | – | 1.0 | – | – |
| Water-course | – | 0.035 | – | – |
| Ditches | – | 0.065 | – | – |

Table 4.2: *2D Model roughness values*

| Watercourse | Roughness | Commentary |
|---|---|---|
| Rowel Brook, North West | 0.04 - 0.07 | Particularly overgrown at upstream extent, see Figure 4.4 |
| Rowel Brook, North | 0.0805 | Based on Cowan's method |
| Rowel Brook South East | 0.07 - 0.0805 | |
| Thrupp Ditch | 0.07 | |
| Oxford Canal | 0.03 | |
| Southern Drainage Ditch | 0.05 - 0.07 | Limited photographic evidence available. Consistent with other ditches on site |
| Green/Yarnton Lane Ditches | 0.07 | pBlockage attribute also utilised |
| Eastern Drainage Ditches | 0.04 - 0.07 | Recent vegetation clearance evident on some reaches |

Table 4.1: *1D Model roughness values*

Table 4.2 sets out the roughness parameter values in the 2D domain. These are based on Edenvale Young's standard TUFLOW modelling template, giving consistency with a large number of existing models in the UK, many of them well-calibrated to observed data.

## 4.7 Model Boundaries

Figure 4.3 shows the location of the key model inflows. These have been selected with reference to the direct rainfall model to best simulate how water from each of the subcatchments is expected to reach the channels. The majority of the subcatchment inflows are applied as point inflows to the 1D domain. In some cases the results of the direct rainfall modelling suggested that it would be more appropriate to distribute the flow across a reach of channel. This is the case for inflow S06 along the Rowel Brook North. Two inflows (S01 and S07) are applied directly to the 2D domain. In both instances, there was some uncertainty relating to the direction of flow from both Begbroke Hill and within the wooded copse. It was therefore deemed appropriate to apply the inflows in 2D and allow the model to route flow based on the topography rather than via assumptions made by the modeller.

## 4.8 Watercourse Specific Considerations

### Rowel Brook, North West

The upstream modelled extent on the Rowel Brook is located adjacent to Woodstock Road, upstream of Begbroke village, as shown in figure 1.1. This location was determined by the upstream extent of the detailed topographic survey and the reach incorporates a number of structures and features which are expected to provide a flow control upstream of the site. The culverts under the A44 at

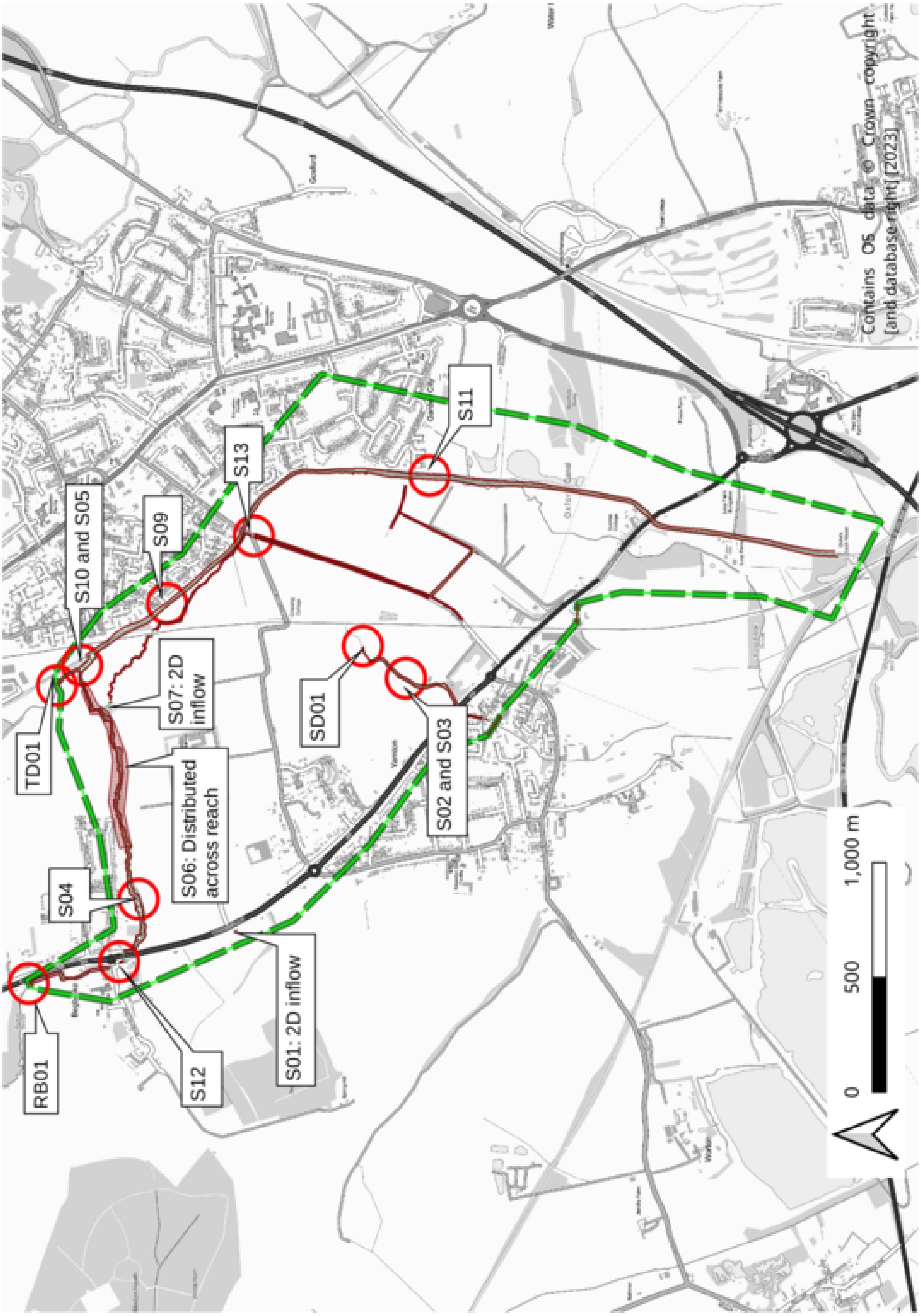


Figure 4.3: *Location of model inflows*

the north western corner of the site have been explicitly modelled in the 1D network, connecting the Rowel Brook North West reach to the Rowel Brook North.

It was noted that the uppermost reach of the watercourse, to the west of Woodstock Road, was particularly overgrown. This reach has been applied a higher roughness value than the majority of the Rowel Brook North West. An example of this is shown in Figure 4.4.

### Rowel Brook, North

The Rowel Brook meanders along the northern boundary of the site and south of Fernhill Road. The channel is notably sinuous in this location. Modelling individual meander bends in quick succession can result in stability issues as water rapidly passes between 1D and 2D components of the model. To avoid this, the sinuosity of this channel has been represented using Manning's "n" roughness values. An appropriate Mannings "n" value was determined using the estimation method described in Cowan (1956)[1], which considers channel sinuosity as well as other factors. A roughness value of 0.0805 is applied to the channels of the Rowel Brook North, based on the application of Cowan's method.

Figures 4.5 and 4.6 show examples of the Rowel Brook in this area.


Figure 4.5: *Example of Rowel Brook North upstream extent*

The flow split between the north eastern and south eastern branches of the Rowel Brook occurs in a small wooded area within the site boundary, close to its northern edge. The connectivity of channels in this location was uncertain, although direct connectivity during normal flow conditions was not observed on either site visit. A surface DTM was supplied for incorporation into the model in this area and has been integrated into the model, superseding the LiDAR and setting the elevation of the boundary cells on the right bank of the Rowel Brook. This means that the direction of flow within the copse during high flows events is determined hydraulically rather than by assumptions made during the model build.

An Initial Water Level (IWL) consistent with the downstream weir crest has been applied to the pond in the copse area. The pond and weir are shown in figure 4.7. This is considered conservative and means that the 2D inflow located within the pond will immediately initiate overtopping of the weir.

The Rowel Brook North is connected to the Thrupp Ditch immediately upstream of Oxford Canal in the far north east corner of the site. Prior to their confluence, the two watercourses run either side of a footpath, which has been modelled in 1D using a weir channel rather than in 2D. This footpath is shown in Figure 4.8The Rowel Brook North eventually connects to the Oxford Canal.

### Thrupp Ditch

The upstream extent of the Thrupp Ditch is located approximately 180m upstream of its confluence with the Rowel Brook and the site's red line boundary.

[1]Cowan, W.L. Systematic Method for Estimation Roughness Coefficients. Agricultural Engineering. 1956


Figure 4.6: *Example of culvert on Rowel Brook North*

Figure 4.7: *Pond and weir crest within copse*

The hydrological inflow point is located downstream (south) of the industrial estate and the inflow hydrograph therefore does not explicitly include any attenuation associated with flood risk measures, flow constrictions or flooding in the industrial estate or upstream. This is a conservative assumption.

The model domain is trimmed adjacent to the upstream extent of the Thrupp Ditch. This results in very minor glasswalling in this location, but given the lack of upstream survey and that the model must terminate somewhere, this is deemed appropriate.

### Rowel Brook, South East

This reach of the Rowel Brook has been modelled consistently with the North and North West reaches. The culvert under the railway line has been modelled as open channel, but results were checked to ensure that the soffit height of the culvert was not exceeded during modelled flood conditions. The reach downstream of the railway was considerably overgrown and has been modelled with a comparatively high roughness value. Figure 4.9 provides a representative image of the Rowel Brook South East upstream of the railway crossing. Figure 4.10 shows a representative image of the Rowel Brook South East downstream of the railway crossing, which is particularly overgrown.

Figure 4.8: *Footpath separating the Rowel Brook and Thrupp Ditch*

Figure 4.9: *Example of Rowel Brook South East, upstream of railway crossing*

### Yarnton/Green Lane

The parallel ditches running either side of Yarnton/Green Lane have been modelled as separate 1D model elements; the road itself is modelled in 2D.

As noted previously, the channels either side of Yarnton/Green Lane are poorly maintained and have therefore been modelled with a roughness value of 0.07. Observations made during the site visit also indicated that the flow path along the ditches may not be continuous, although it was not possible to assess all instances of channel blockage on the site visit. To provide some representation of this, the pBlockage attribute has been included in some network lines along both the western and eastern ditches, applying intermittent 50% blockages to the channels. An example of the condition of the ditches is shown in figure 4.11.

The southern extremities of both ditches - beyond the confluence with the Eastern Drainage Ditch System - terminate where the cross-sectional survey ends. No water was visible here on either site visit.

The topographic survey included measured water levels along the ditches. Early iterations of the model included these levels as an initial condition but the level did not appear realistic. Later versions of the model reduced these levels based on available LiDAR data and engineering judgement. It should be noted that in the design event the choice of initial water level does not impact the peak of the hydrograph.

Figure 4.10: *Example of Rowel Brook South East, downstream of railway crossing*

Figure 4.11: *Example of the condition of the ditches running parallel to Yarnton/Green Lane*

### Eastern Drainage Ditches

The Eastern Drainage Ditch system connects to the Yarnton/Lane Ditches at the confluence shown on figure 1.1 via the 1D network in this location. Some stretches of the ditch system appear to have been recently cleared, as shown in Figure 4.12 and a lower roughness value of 0.04 has been applied here compared to other ditches within the model. The reach of the Eastern Drainage Ditch which connects to Yarnton/Green Lane was poorly maintained and was therefore assigned a roughness value of 0.07. An example of this is shown in Figure 4.11.

The downstream extent of the Eastern Drainage Ditches—which may be considered as a continuation of the Rowel Brook South East—was not surveyed due to access constraints. The culvert shown in figure 4.13 has been included as part of the 1D network but subsequently discharges into the 2D domain via an SX boundary. The channel downstream of this location has been represented in the 2D domain to ensure a continuous flow path but bed elevations have been estimated from LiDAR. Any structures which may be present have not been included due to lack of survey. The structure which conveys the ditch beneath the A44 Woodstock Road has been modelled as open channel as it assumed that the road crossing does not represent a constriction. On this basis, model results in this location should be viewed with caution, but this should not affect the conclusions of this report as the area lies outside the site boundary.

The downstream boundary of the Eastern Drainage Ditches has been modelled with a HQ boundary in 2D. A slope of 0.01 has been applied.

| Lock Name | Pound Level (mAOD) | IWL (mAOD) |
|---|---|---|
| Kidlington Green Lock | 61.618 | 61.618 |
| Duke's Lock | 60.149 | 60.25 |

Table 4.3: *Canal pound levels and modelled initial water levels*

Figure 4.12: *Example of apparent recent vegetation clearance along the Eastern Drainage Ditch system*

Figure 4.13: *End of 1D network along Eastern Drainage Ditch*

### Oxford Canal

Two pounds of the canal have been modelled, from Roundham Lock just north east of the site to Duke's Lock approximately 900m downstream of the A44. These pounds are shown on Figure 1.1. Cross sectional survey of the canal was specified to be sparse as the geometry is largely consistent throughout the modelled reach. Where constrictions were observed on aerial photography and had not been surveyed, estimates of the width of the canal were made from aerial photography with a simple rectangular channel profile created to represent these locations.

The canal survey included bed elevations, but when comparing these to the surveyed water levels the canal appeared unrealistically shallow: in some cases only 0.5m. The bed level of the canal in the supplied cross-sections has therefore been manually adjusted to reflect an assumed water depth of 1.5 metres, based on engineering judgement. The initial water levels (IWLs) in the pounds were based on information from the Canal and Rivers Trust and set out in table 4.3.

#### Kidlington Green Lock

Kidlington Green Lock is located midway along the Oxford Canal and adjacent to the site. A significant side-spill weir at Kidlington Green Lock has been modelled explicitly, which helps understand whether flood flows entering the canal via the Rowel Brook further upstream are able to leave the canal and flood the site from this location. This was previously shown in Figure 2.3. The side spill has been modelled as multiple 1D WW channel, whereby the combined width of all WW channels is equal to the length of the side spill. The side spill is linked to the bypass channel via an SX link, with the bypass channel itself modelled in 2D based on surveyed channel bed levels. Reconnection to the canal downstream of the lock is included as another 1D element. Topographic modifications around the bypass channel have been explicitly applied based on the top of bank elevations identified on the topographic survey.

#### Duke's Lock

Aerial photograph indicates that a similar offtake structure exists at Duke's Lock. No topographic survey was available Duke's Lock to model this in detail. Instead, an IWL 0.1m higher than the maintained pound level was included as a HT boundary. This increase above the maintained pound level will allow for some superelevation of the downstream water levels due to flood flows.

## Oxford Canal - Further Comments

The modelling shows flooding along the left bank of the canal, downstream of Kidlington Green Lock. It should be noted that detailed topographic survey was limited along the left bank of the canal and therefore information on bank heights in this location is sparse. Whilst banklines set the elevation of boundary cells along the left bank of the canal, the model does not represent local variation in elevation and therefore the flood extents on the eastern side of the canal should be viewed with caution. The area to the east of the canal is outside of the site boundary.

The canal is assumed not to be carrying unusually high flows originating from catchments not discussed in this analysis during the design flood events. In general canals are not designed or intended to convey flood flows and it is considered to be beyond the scope of this work to identify other catchments upstream or downstream that might discharge into the canal, raising its water levels significantly beyond the maintained pound levels. The canal has been represented using 1D modelling, allowing backwater effects from significant discharges into the canal originating from the Rowel Brook and Thrupp Ditch catchments to be modelled.

## Southern Drainage Ditch

It was not possible to access most of the Southern Drainage Ditch and therefore on-site observations could not be used to inform the application roughness values. Mannings 'n' roughness values have been estimated based on the limited number of photographs available and with consideration of the maintenance of other ditches on-site. The downstream boundary has been modelled using a HQ boundary in the 2D domain with a gradient of 0.01. This is approximately consistent with the gradient of the final surveyed sections; this schematisation is simply intended to convey water out of the model and is beyond the site boundary.

## Road and Other Ditches

Overland flow from Begbroke Hill, to the west of the site, is a plausible flood mechanism that may result in overland flow reaching the site. A number of drainage ditches run along the west of Woodstock Road which may intercept overland flow originating on Begbroke Hill. Whilst detailed cross-sectional survey was unavailable, the elevations for the bottom and top of bank were supplied for these ditches; this has been used to model the ditch in the 2D domain. On-site observations suggested that the ditch was approximately 0.6m wide. An image of the ditch is shown in 4.14 Given the 2m cell size, a cell width factor (CWF) of 0.3 was applied to limit the flow width to 30% of the cell size. Figure 4.1, highlights the location of the road ditches explicitly included within the model. It should be noted that, given the available information, there is some uncertainty associated with the capacity of this ditch.

Figure 4.14: *Photograph of culvert adjacent to Woodstock Road.*


Figure 4.4: *Example of Rowel Brook North West, upstream extent*

RESULTS

# 5. Hydraulic Model Results

## 5.1 Baseline Model Results

Figures 5.1–5.5 show the maximum depth results from each of the modelled design events with the longer, 11-hour storm duration.

The messages layer associated with the baseline model has been reviewed and the warnings/checking are not considered to be of concern. The majority of these are GIS related or due to the interpolation of channel geometry. Messages referring to structure invert levels and dangling Z Lines are deemed reasonable.

The majority of out of bank flooding is located towards the eastern portion of the site, close to Oxford Canal. This is not unexpected, as the Eastern Drainage Ditches, where much of the water from the site is routed, do not appear to be designed with extreme flood risk in mind. The flood extents in this area should be viewed with some caution as much of the channel that would drain this area was not surveyed due to access constraints, and it is therefore possible that, if this channel was particularly well-maintained, the flood extents in this area would reduce. There is also shown to be flooding in the fields outside of the site boundary.

The model shows significant flooding to Kidlington from the east bank of the Oxford Canal, outside of the site boundary. This is predominantly driven by the flows from the Rowel Brook and Thrupp Ditch which discharge into the canal and cause a backwater from Kidlington Green Lock—a structure which was likely not designed to handle such high flows. As noted previously, detailed topographic survey was limited along the left bank of the canal. The model does not represent local variation in elevation and therefore the flood extents in this area should be viewed with caution

Flooding associated with the Rowel Brook North is typically confined to a narrow corridor either side of the channel. In the largest events, a shallow flow route fed by run-off from Begbroke Hill overtops Woodstock Road from the west and crosses the north west corner of the site. During the 0.1% AEP event this flow route reconnects with the Rowel Brook.

The Southern Drainage Ditch is shown to cause out-of-bank flooding in adjacent fields, particularly on the right bank. Water ponds upstream of the Woodstock Road although the road is not shown to overtop.

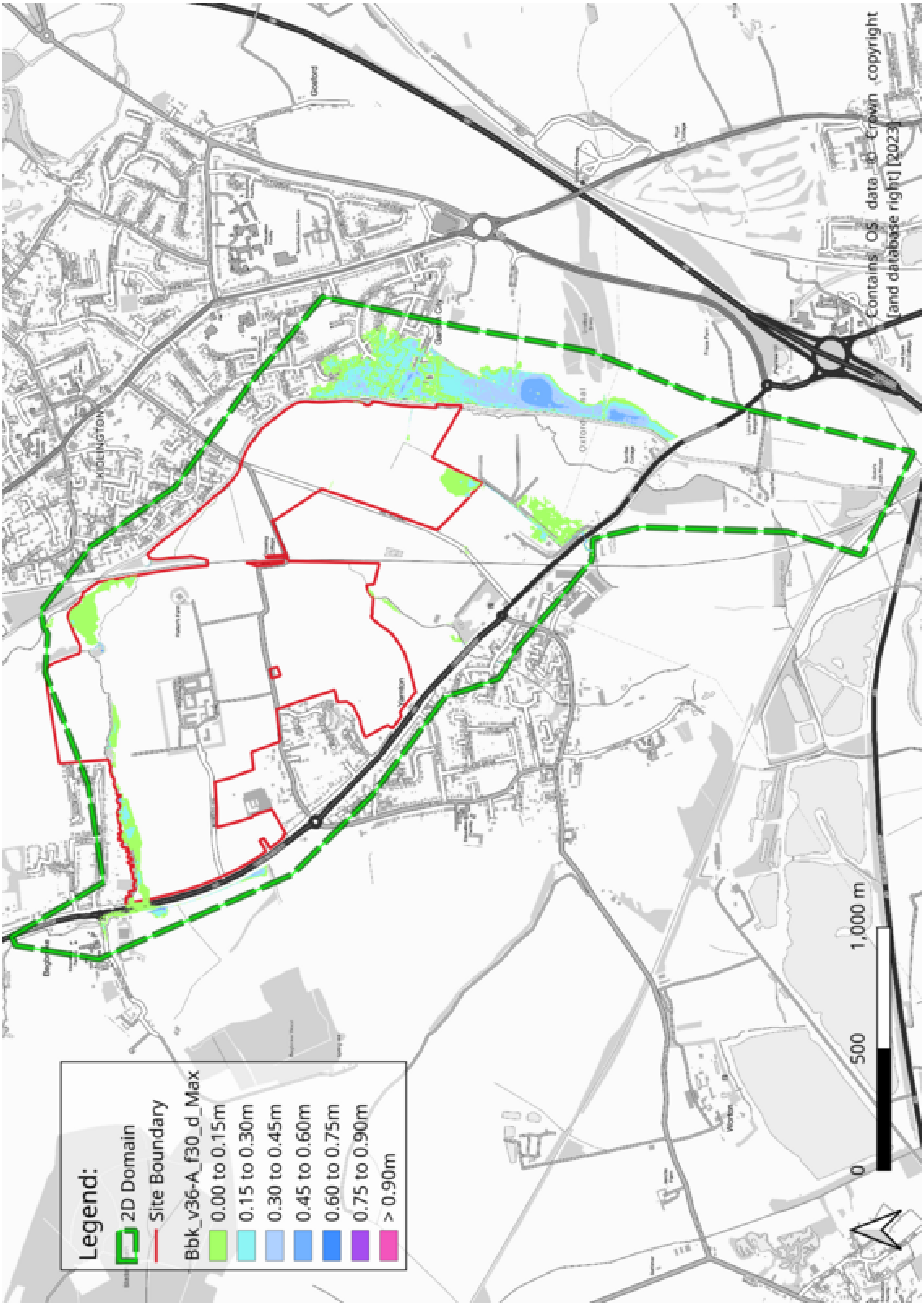


Figure 5.1: *Maximum modelled depth in the 3.33% AEP event, 11 hour storm duration*

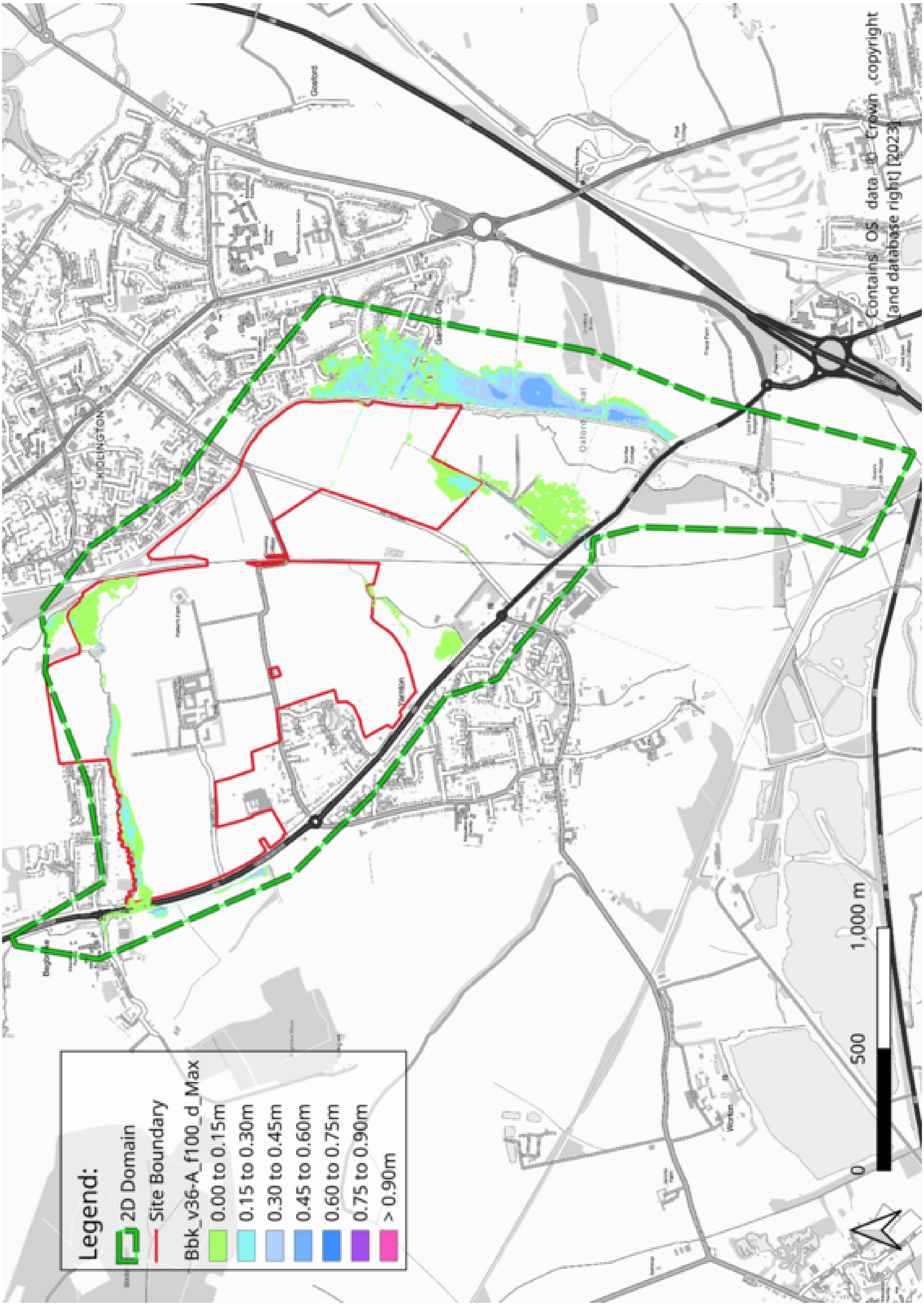


Figure 5.2: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration*

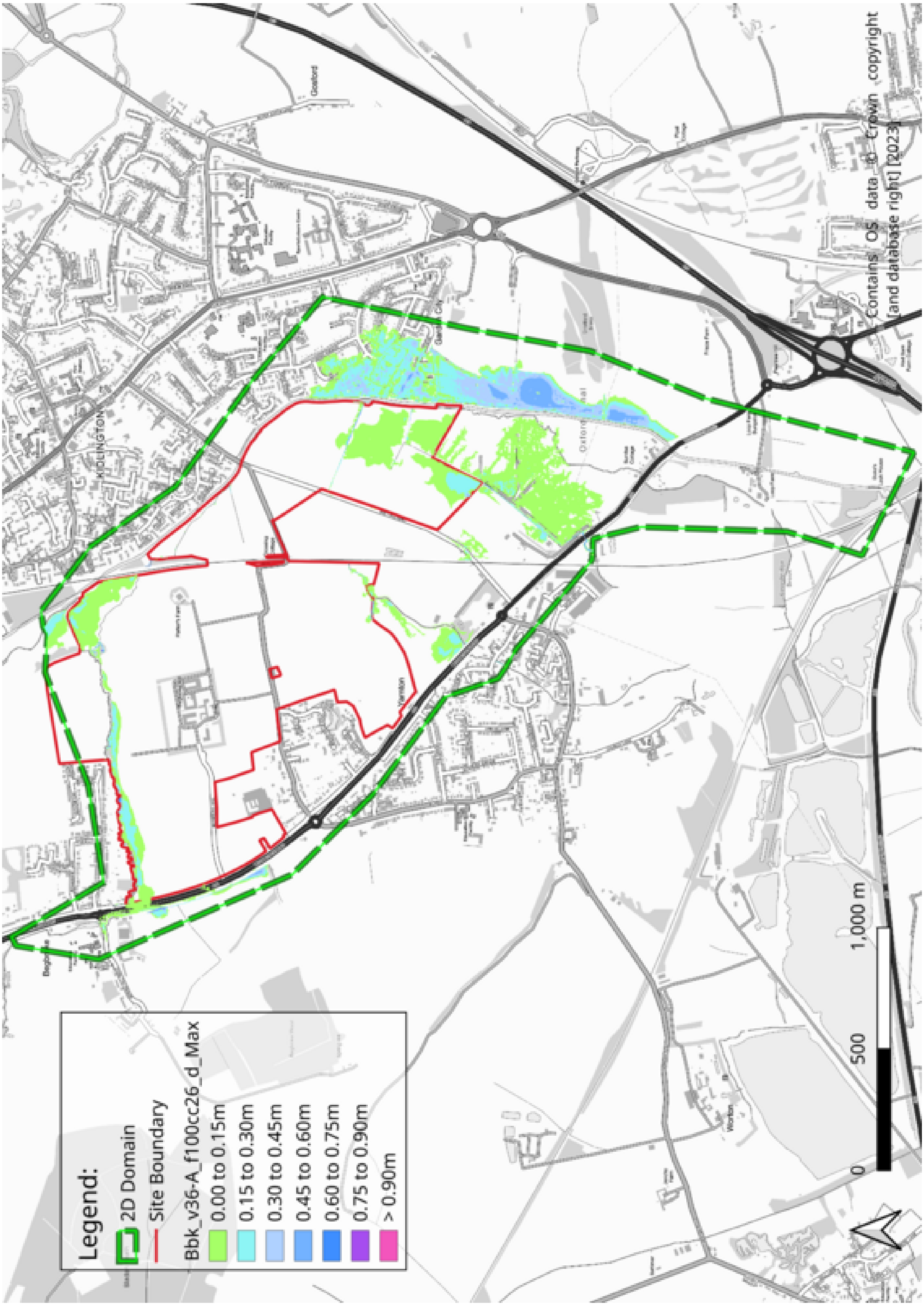


Figure 5.3: *Maximum modelled depth in the 1% AEP event plus 26% allowance for climate change, 11 hour storm duration*

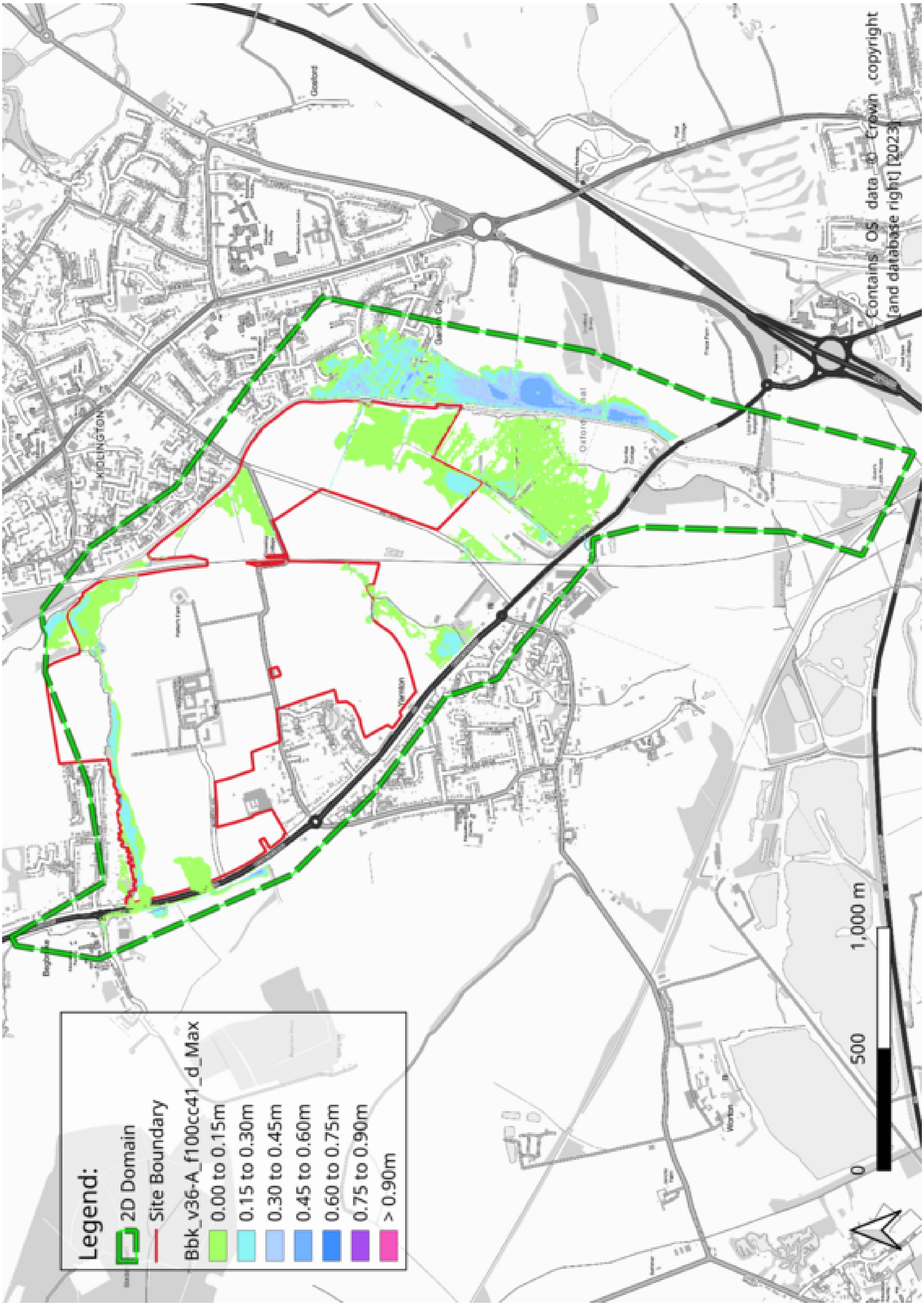


*Figure 5.4: Maximum modelled depth in the 1% AEP event plus 41% allowance for climate change, 11 hour storm duration*

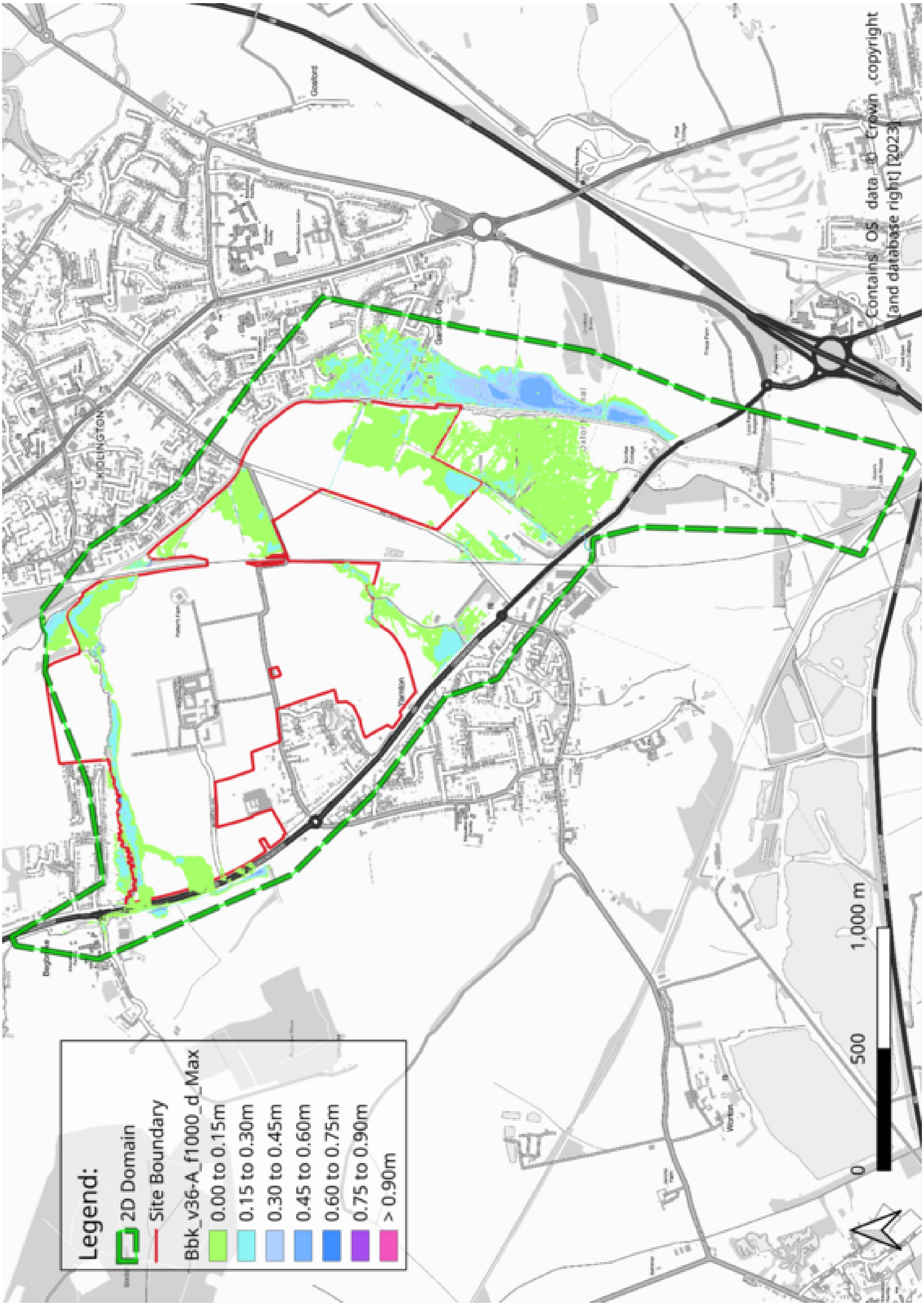


Figure 5.5: *Maximum modelled depth in the 0.1% AEP event, 11 hour storm duration*

## 5.2 Model Verification

Verification of the flows used in the model has been carried out by comparing the hydrological sub catchments peak flows and the peak flows of the 1D watercourses in the model. Figure 5.6 shows the location of two watercourses represented in 1D. These watercourses together convey the flow (in some cases fully and in some cases partially) from the sub-catchments SD01, SD04, SD05, SD06, SD07, SD10, SD12, TD01 and RB01.

The added peak flows at these two locations are shown in Table 5.1 and compared against the contributing sub catchments. It is expected that the out-of-bank flows, the timing between peak flows at the catchments, hydraulic structure controls and diversion of flow routes might explain the differences between the hydrological and the hydraulic estimates. The first two columns in Table5.1 shows the peak flows if the sub-catchments, SD01, SD04, SD05, SD06, SD07, SD10, SD12, TD01 and RB01 contribute to these watercourses entirely. The comparison shows a variation in peak flows between 26% and 28%. However, SD01 and S12 seem to only contribute partially, since Woodstock Road controls the flow route and seems to push some of the flow to the South, instead of allowing the flow back into the Rowel Brook. The fifth column in Table 5.1 shows the sum of all peak flows of the sub catchments except for S01 and S12. In this case, the variation in peak flows varies between 1.4% and 3.6%.

Given the uncertainties outlined above, the comparison between the hydrological sub catchments and the hydraulic model seems to agree sufficiently well. It should be noted that the distributions of inflows via multiple subcatchments, along with the complexity of the model schematisation, means that it is challenging to select locations at which such a comparison can be undertaken. For this reason, only two locations were selected for this exercise.


Figure 5.6: *1D watercourses used for verification (in yellow)*

| Return Period (% AEP) | Peak flows combined model reaches CH0093 and CH0084 (m3/s) | All catchments peak flows combined (m3/s) | Difference (%) | Catchments peak flows combined without S01 and S12 (m3/s) | Difference (%) |
|---|---|---|---|---|---|
| 3.3 | 1.113 | 1.54 | 28 | 1.097 | 1.4 |
| 1 | 1.535 | 2.077 | 26 | 1.48 | 3.6 |
| 0.1 | 2.657 | 3.593 | 26 | 2.561 | 3.6 |

Table 5.1: *Peak flow comparisons*

## 5.3 Sensitivity Analysis

Four sensitivity tests have been undertaken.

A. Increase and decrease the roughness of the channel and land surfaces by 20%. The sensitivity test helps to quantify the impact of the uncertainty in the selection of roughness values on model results.

B. The downstream boundary conditions on the Eastern Drainage Ditches and the Southern Drainage Ditch have been sensitivity tested by doubling and halving the slope in these boundaries. They are currently modelled using HQ boundaries in the 2D domain on the basis they are located sufficiently downstream of the site to simply remove flow from the model without impacting results within the area of interest. These sensitivity tests quantify whether this assumption is reasonable.

C. The pound level upstream of Duke's Lock has been reduced by 0.1m. In the baseline case, the pound level has been modelled 0.1m higher than the maintained pound level due to a lack of information about the offtake structure at Duke's Lock. This sensitivity test reduces the pound level.

D. A sensitivity test on flow has been undertaken whereby all model inflows have been increased or decreased by 20%. This has been applied with the use of a scaling factor and has been run in the baseline case and the 1% AEP event with a Central 26% allowance for climate change.

All, except for the flow sensitivity tests, have been undertaken using the 1% AEP design event without an allowance for climate change.

### Increase or Decrease in Model Roughness

The results of changing the model's hydraulic roughness coefficients are shown in figures 5.7 and 5.8. The model is relatively insensitive to changes in roughness. Reducing roughness values results in a limited reduction reduction in flood extent, whilst increasing roughness values results in a general increase in flood extents. This is to be expected.

The greatest variation in flood extent occurs in area surrounding the Eastern Drainage Ditches and near to the solar farm, some of which falls outside of the site boundary. As ground levels are relatively flat, it is expected that the small changes in water level would result in extension or contraction of the extent.

There is limited change to the flood extent around the Rowel Brook North.

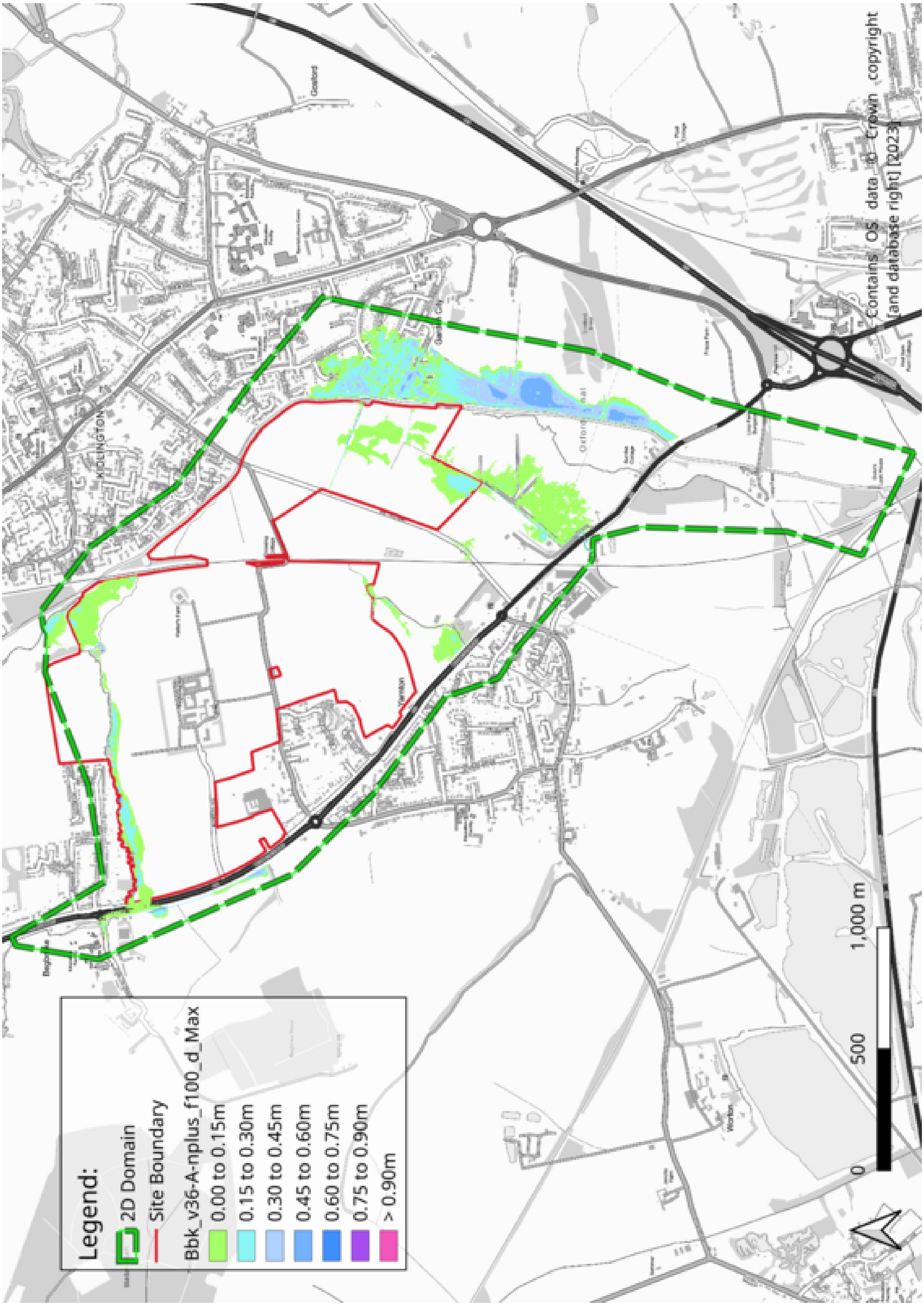


Figure 5.7: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration, 20% increase in roughness*

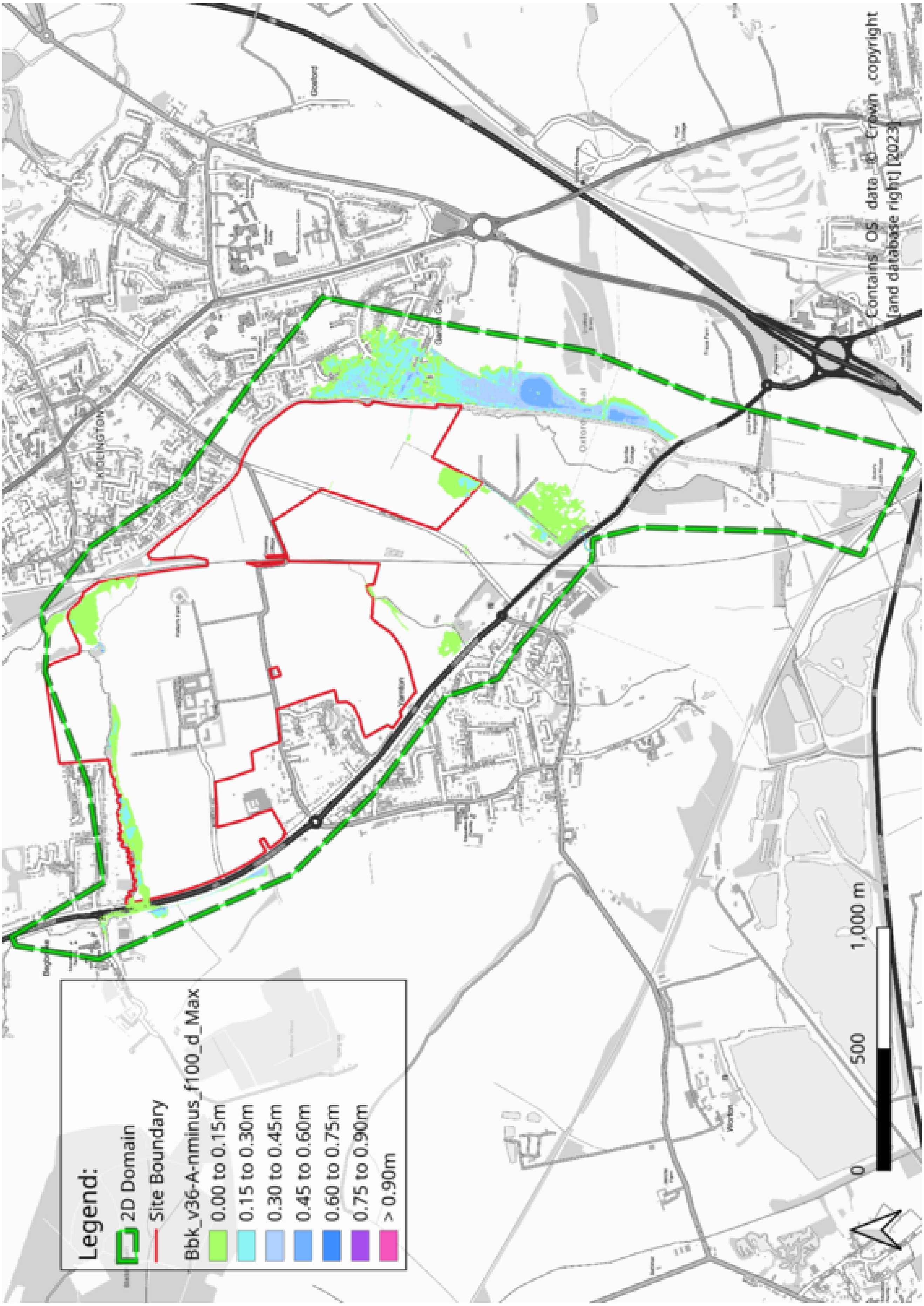


Figure 5.8: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration, 20% reduction in roughness*

### Downstream Boundary Variation

The results of changing the assumed downstream boundary slopes of the eastern and southern drainage ditches are shown in figures 5.9 and 5.10. Variation in the slope of the HQ boundaries demonstrates that they are sufficiently far downstream to have no impact on-site.

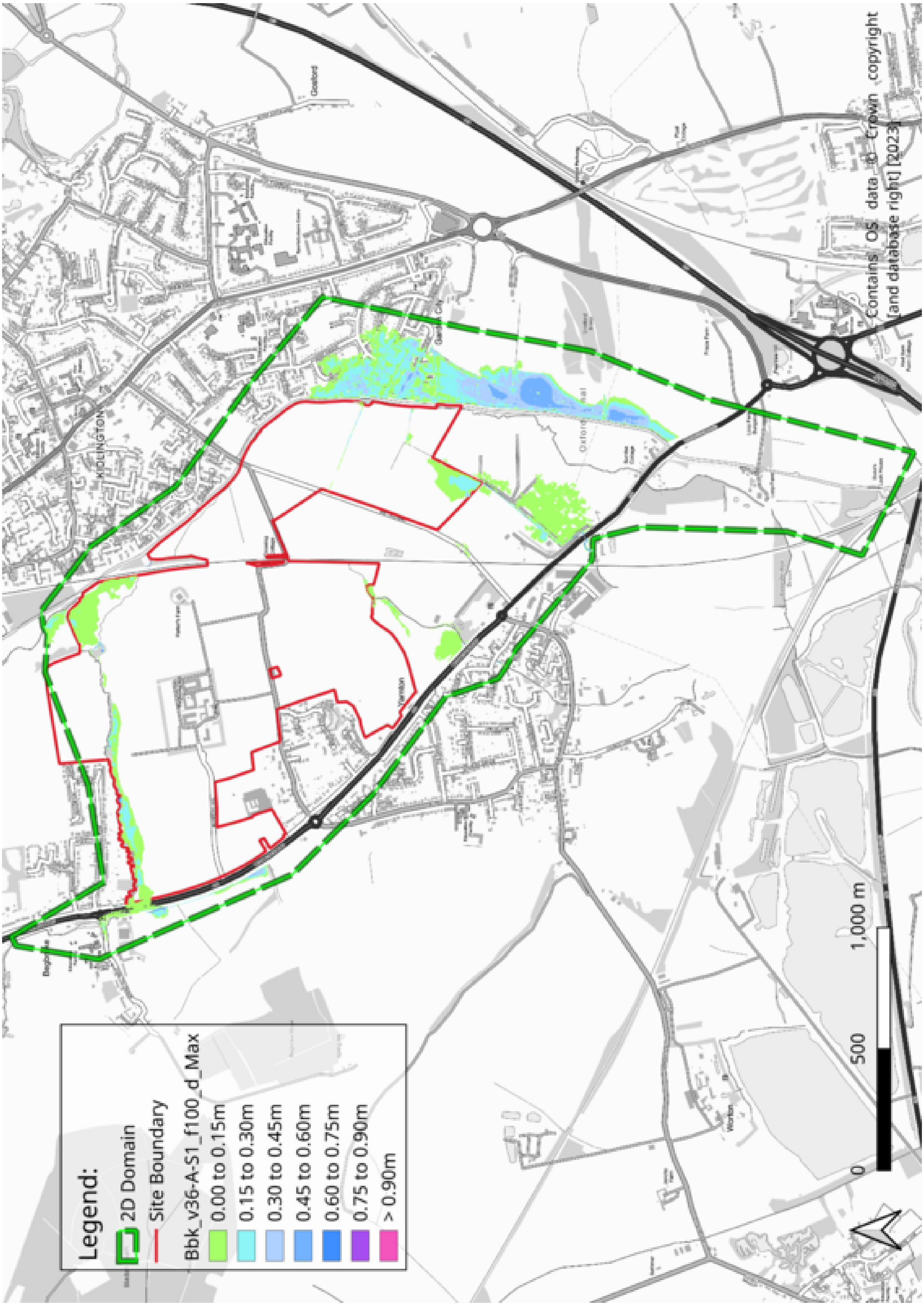


Figure 5.9: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration, HQ boundary gradient doubled to 0.02*

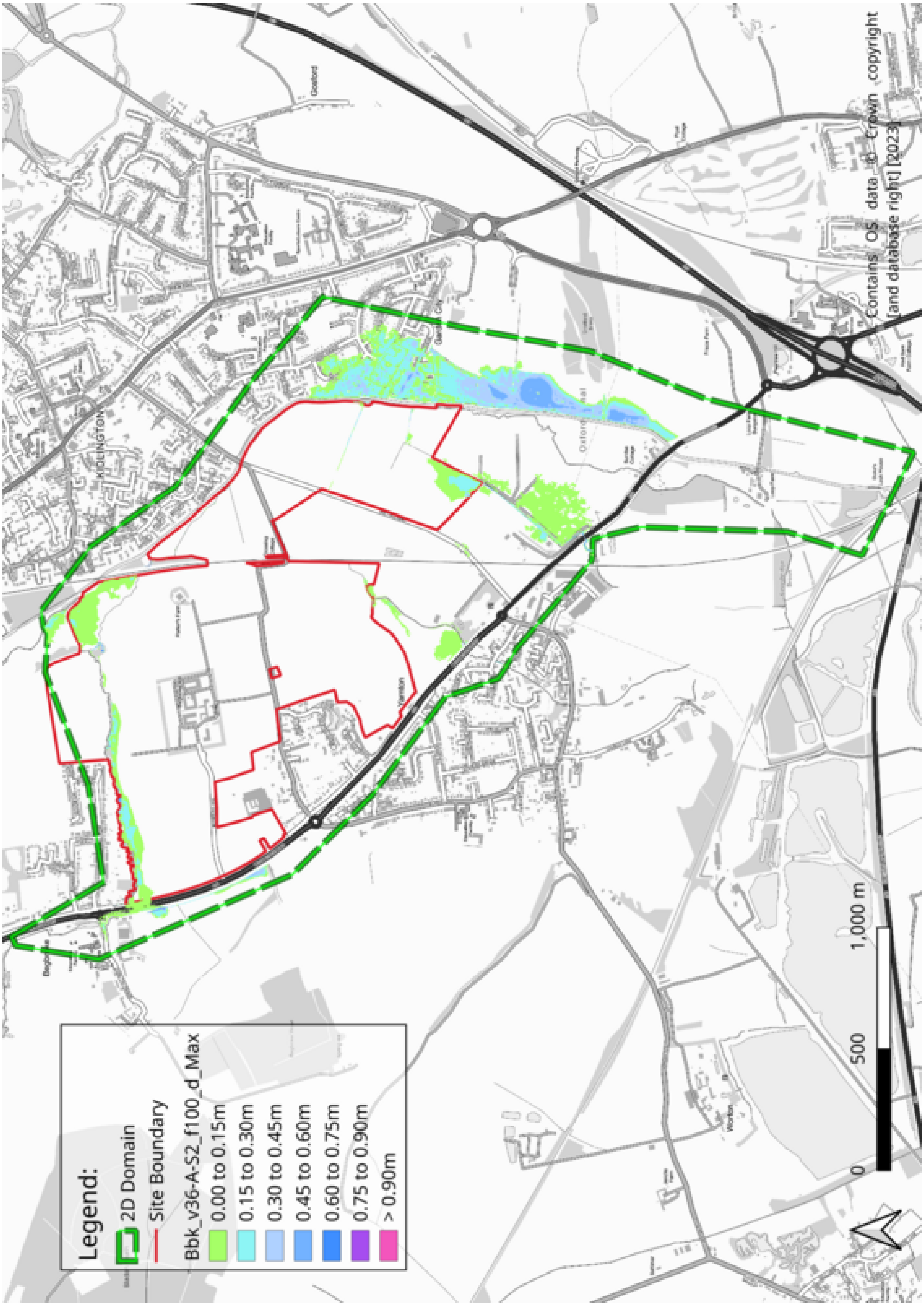


Figure 5.10: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration, HQ boundary gradient halved to 0.005*

### Canal Pound Level Variation

The result of changing the assumption made about the down-stream pound level at Dukes Lock on the Oxford canal is shown in figure 5.11. Variation in the canal pound level is shown to have negligible impact on-site. within the bypass channel at Kidlington Green Lock, but this is extremely localised and has no impact on flood extent.

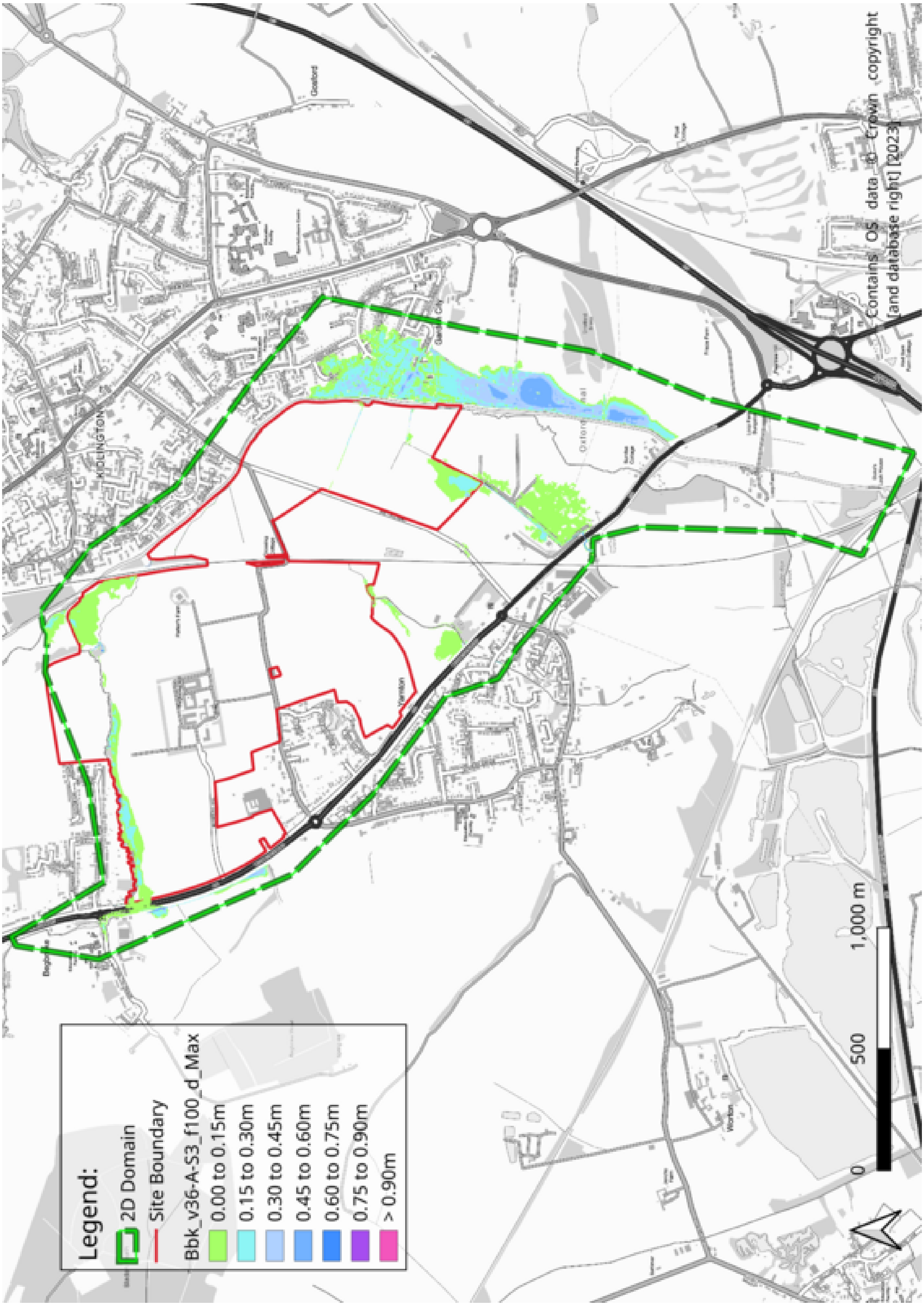


Figure 5.11: *Maximum modelled depth in the 1% AEP event, 11 hour storm duration*

## Increase and Decrease in Model Flow

In response to the EA review, a sensitivity test on flow has been undertaken whereby all model inflows have been increased or decreased by 20%. This has been applied with the use of a scaling factor in the bc_dbase file and has been run in the baseline case and the 1% AEP event with a Central 26% allowance for climate change. Other sensitivity tests have been already been undertaken using the 1% AEP event without an allowance for climate change, but in this instance the event with the Central allowance was selected based on the list of typical sensitivity tests highlighted in the EA review spreadsheet.

It should be noted that the resultant peak inflows are higher than those when the higher central climate change allowance is applied but lower than the 0.1% AEP event.

Figure 5.12 shows an example of the the inflow at SD01 from the 1d_bc_tables check file for the baseline model run alongside the equivalent inflows used in these sensitivity tests.

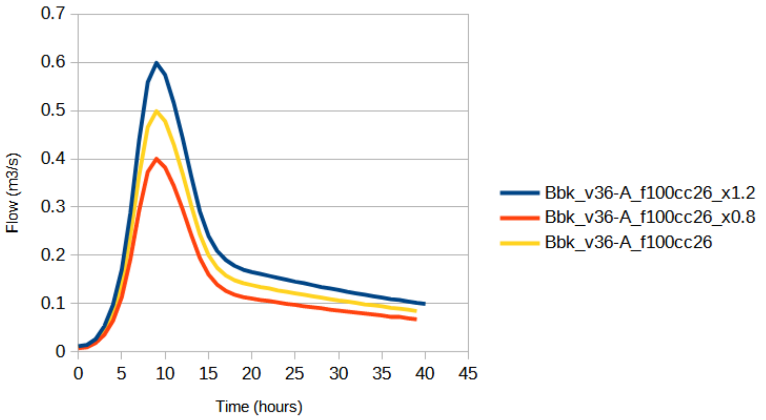


Figure 5.12: *Example inflow variation at SD01 with +/- 20% flow*

As expected, decreasing the flow results in a reduction in out of bank flooding. This is most noticeable in the vicinity of the Eastern Drainage Ditches where the flood extents contract and is unsurprising given that ground levels in this location are relatively flat and a small variation in water level will result in a large change in the flood extents. See figure 5.13. Much of this area is outside of the site boundary.

When inflows are increased, the flood extents also increase. Again, the relatively flat topography adjacent to the eastern drainage ditches means that variation is clearly visible in this area. Elsewhere, the most notable areas of change are to the north of Yarnton Road and east of the railway line where the model now shows an area of out of bank flooding. Depths in this area are generally less than 100mm. See figure 5.14.

Along the Rowel Brook North a small stretch of the left bank is now overtopped, resulting in a confined area of flooding between the watercourse and Fernhill Road. The flow route across Woodstock Road also becomes active, with water flowing across the site and draining into the Rowel Brook North.

The results of this sensitivity test are not unexpected and are consistent with the results of the other return period events and climate change scenarios which have already been run as part of this project.

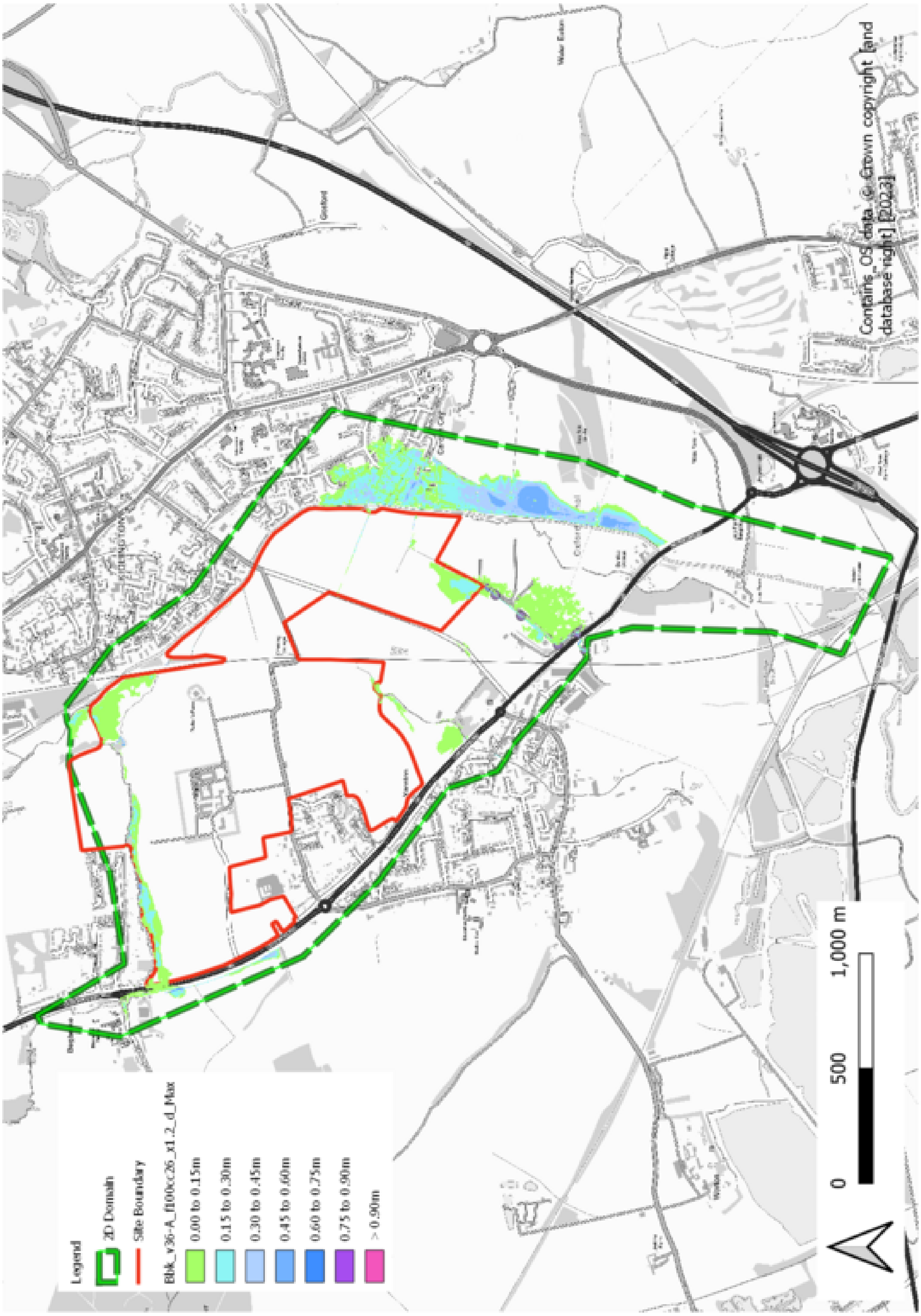


Figure 5.13: *Maximum modelled depths for the 1% AEP event with 26% climate change allowance., 20% decrease in flow*

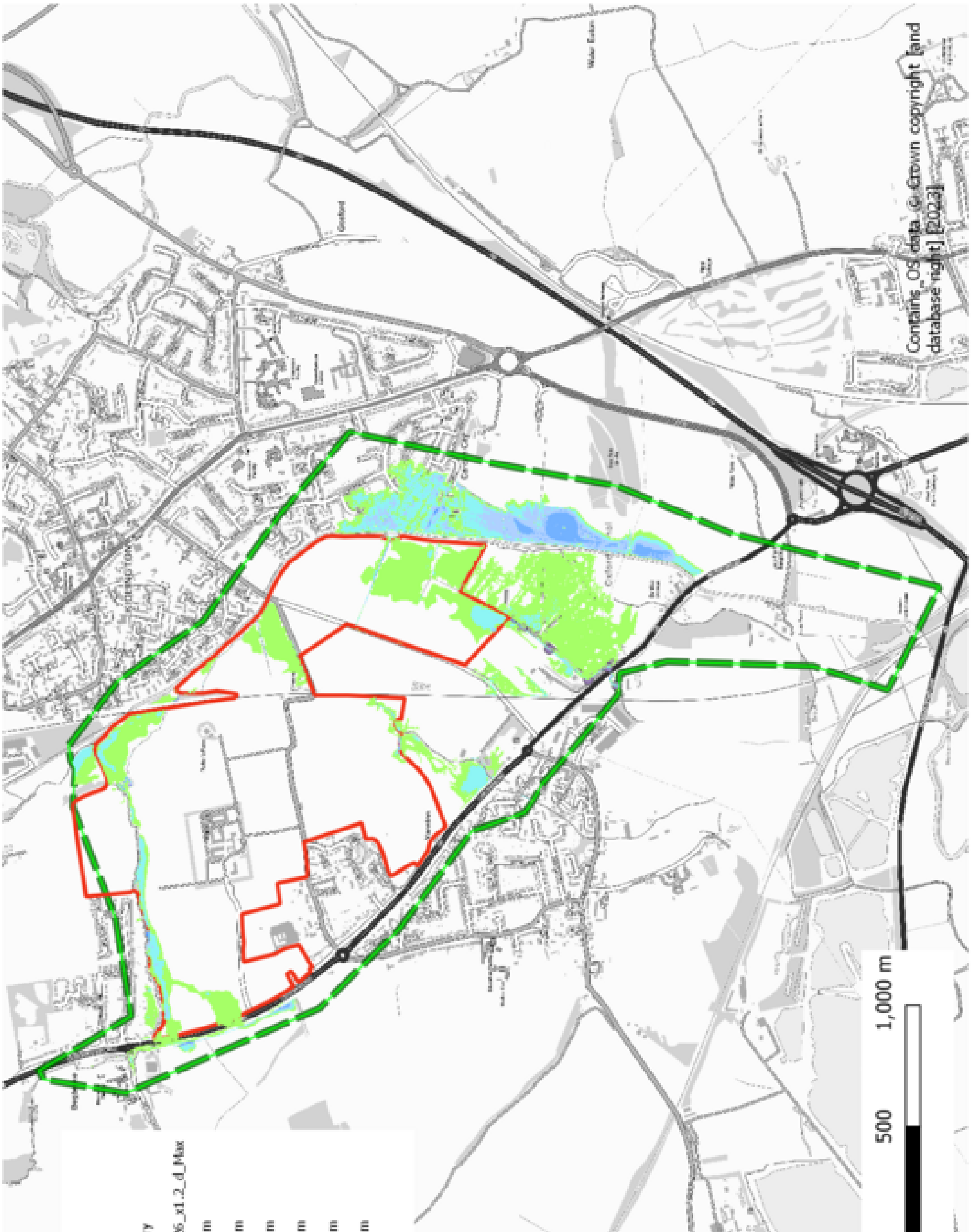


*Figure 5.14: Maximum modelled depths for the 1% AEP event with 26% climate change allowance., 20% increase in flow*

## 5.4 Model Accuracy

The accuracy of a model is dependent on the reliability of its sources. Key elements that need to be considered are topography, roughness, inflows and boundary conditions, all of which have limitations and their own accuracy tolerances. Model inaccuracies can be compounded due to the interpretation of these elements and simplifications caused as part of the mathematical schematisation of the physical processes being represented.

In order to optimise the accuracy of the model, Best Practice Modelling Guidelines have been followed to ensure that the most appropriate model build is undertaken with the available data. These Guidelines consider the schematisation of the 1D channels, the choice of grid sizes, the spatial distribution of roughness, the location of boundaries in the 1D and 2D domains, the choice of software and the general stability of the hydraulic model.

Given there are intrinsic uncertainties, it is advised that a conservative approach be used when carrying out a modelling exercise and making decisions based on the results. In order to try to quantify the precision of the model, the results obtained from the sensitivity analysis carried out for this study have been sampled in different locations and are presented in the table below. The results are all extracted from the 1% AEP Baseline event. All sensitivity tests have been described in more detail in the preceding sections of this report. The location of these checks are shown in Figure 5.15.

The largest differences in water levels in the reported locations result from the changes in the roughness coefficients. For this reason, special attention has been given to the choice of the roughness coefficients for the entire model as per Best Practice Guidelines.


Figure 5.15: *Location of result comparison points*

| Location | CAN05 | | CH0055 | | DD_0009 | | GLE_0009 | | SDD_0016 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Invert level (mAOD) | 60.08 | | 63.96 | | 59.45 | | 59.84 | | 59.80 | |
| | Max Depth (m) | Diff (%) | Max Depth (m) | Diff (%) | Max Depth (m) | Diff (%) | Max Depth (m) | Diff (%) | Max Depth (m) | Diff (%) |
| Baseline (1%AEP) | 1.654 | | 0.964 | | 0.804 | | 0.608 | | 0.626 | |
| DS Bdy increase | 1.654 | 0.0% | 0.964 | 0.0% | 0.804 | 0.0% | 0.608 | 0.0% | 0.626 | 0.0% |
| DS Bdy decrease | 1.654 | 0.0% | 0.964 | 0.0% | 0.804 | 0.0% | 0.608 | 0.0% | 0.626 | 0.0% |
| Lock Level | 1.654 | 0.0% | 0.964 | 0.0% | 0.804 | 0.0% | 0.608 | 0.0% | 0.626 | 0.0% |
| n minus 20% | 1.648 | -0.4% | 0.899 | -6.8% | 0.767 | -4.5% | 0.560 | -7.9% | 0.580 | -7.3% |
| n plus 20% | 1.659 | 0.3% | 0.999 | 3.6% | 0.828 | 3.0% | 0.663 | 9.0% | 0.661 | 5.6% |
| Baseline (1%AEP+26%CC) | 1.662 | | 1.026 | | 0.844 | | 0.700 | | 0.674 | |
| Flow minus 20% | 1.654 | -0.5% | 0.967 | -6.1% | 0.805 | -4.8% | 0.700 | 0.0% | 0.628 | -7.3% |
| Flow plus 20% | 1.671 | 0.5% | 1.050 | 2.3% | 0.857 | 1.5% | 0.765 | 8.4% | 0.728 | 7.5% |

Table 5.2: *Comparison of peak flood depths at various locations for the 1% AEP plus 26% Climate Change Allowance event for the flow sensitivities and 1% AEP event for the rest of the sensitivity conditions*

PROPOSED MITIGATION

# 6. Proposed Swale

## 6.1 Overview

The latest baseline modelling continues to show flooding across Woodstock Road, towards the Rowel Brook, in the largest events including the 0.1% AEP event. The water comes from the Begbroke Hill area, west of Woodstock Road, flowing across the road into the site area where buildings are proposed (figures 5.4 and 5.5). During the 0.1% AEP event this flooding drains into Rowel Brook North.

Mitigation will be required to ensure that the new development does not flood during these events. The mitigation strategy recommended in this report is to construct a swale to the west of the site area at risk, running parallel to the road.

## 6.2 Scenario Configuration

The swale has been modelled in the 1D, utilising the same techniques as described in section 4.3. It's location is illustrated in figure 6.1.

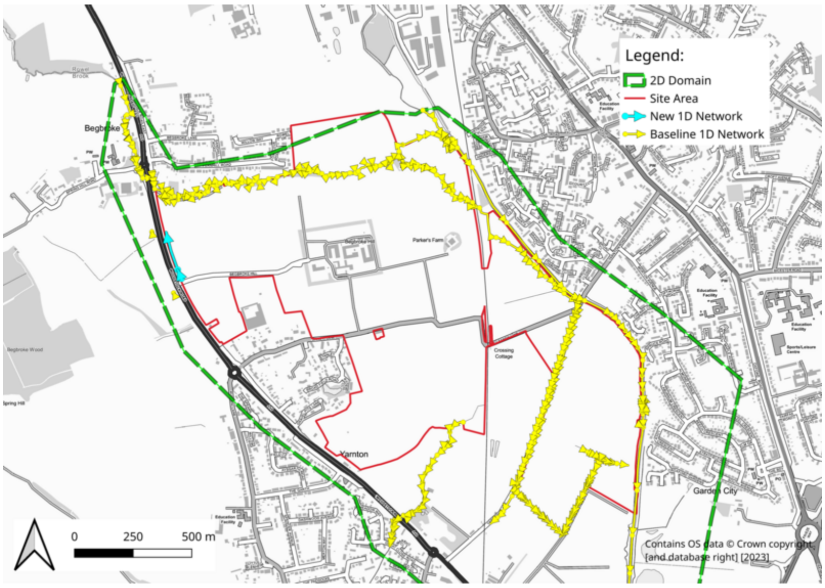


Figure 6.1: *Location of Swale in the North-west of the site*

The geometry of the swale has a base width of 5 m, a top width of 7 m, and is 0.5 m deep. This forms a shallow channel with 1:2 sides, extending for 207.7 m. The channel geometry is deliberately large so that the swale acts in part as flood storage as well as conveying the flow around the site.

The topography around the swale's east and north banks has been altered to form a 'wall', shown in figure 6.2. This ensures that all of the flow across the Woodstock Road is captured by the swale in all of the design flood events where the swale operates. In practice, this structure does not need to be implemented as a wall and could be a low embankment or any other structure impervious to flood water east of the swale to an average height of approximately 0.3 m.

The swale has been designed to attenuate the flood water as well as convey it to the north. This ensures that the travel time for water moving through the swale is similar to that of water that does not cross the Woodstock Road and that flood risk is therefore not increased in the Rowel Brook due to providing a more direct flow path.

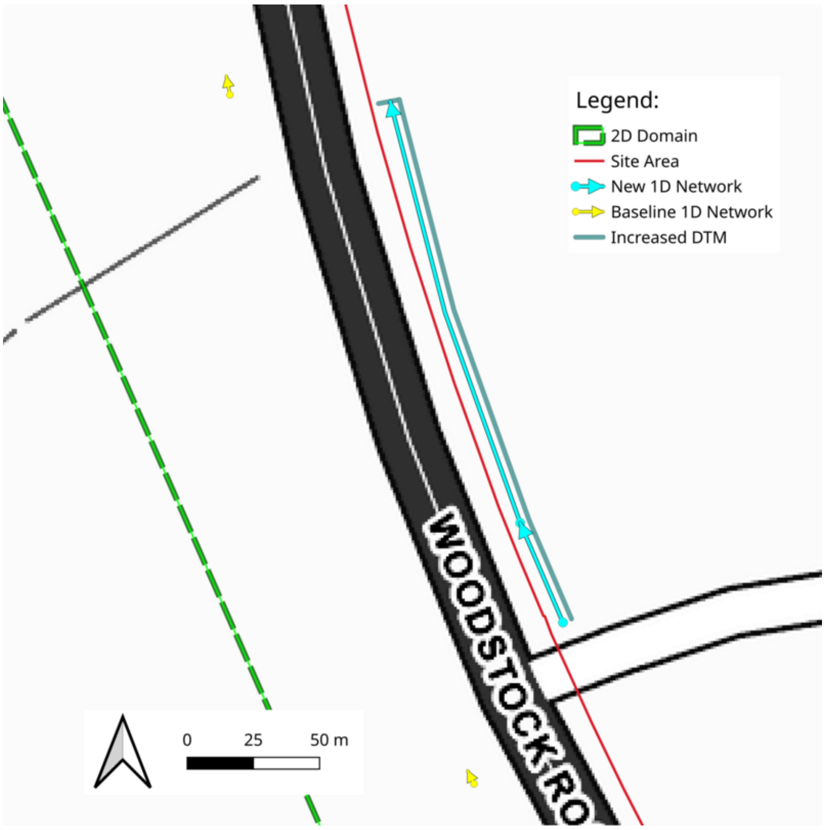


Figure 6.2: *Location of where the DTM has been increased to form a natural wall*

## 6.3 Results

### Maximum Depth

Figures 6.3 and 6.4 show the maximum depth results when the swale is included for the 1% AEP event with 41% allowance for climate change and the 0.1% AEP event, 11-hour storm duration.

The maximum flood depth results illustrate that flooding is situated around the northern edge of the field, in the Rowel Brook North's floodplain. The maps show there is still water build-up on Woodstock Road but it is not spilling over into the development area, demonstrating that the swale is a functional flood mitigation option.

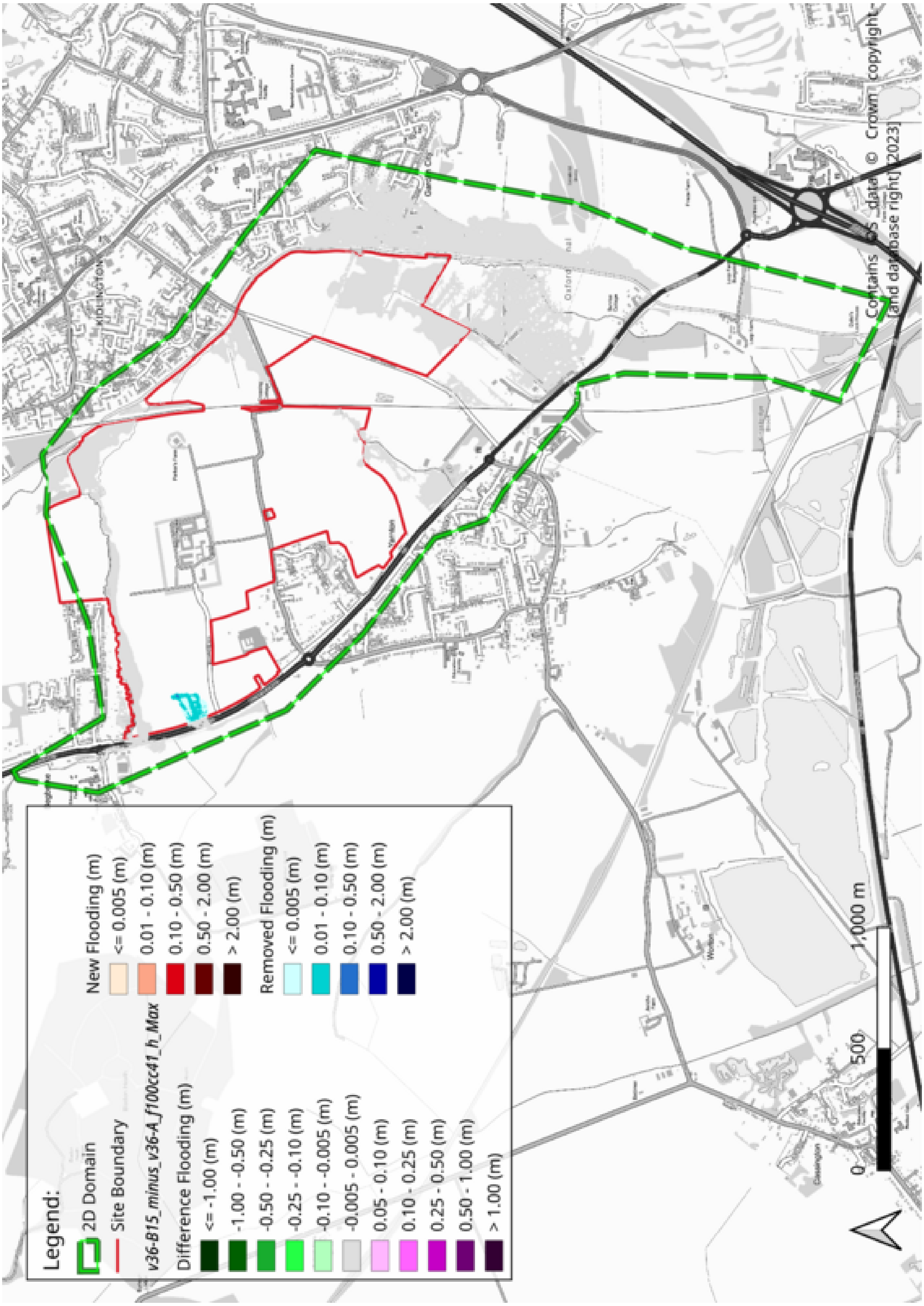


Figure 6.3: Maximum modelled depth with mitigation in the North-west of the site in the 1% AEP event plus 41% allowance for climate change, 11 hour storm duration

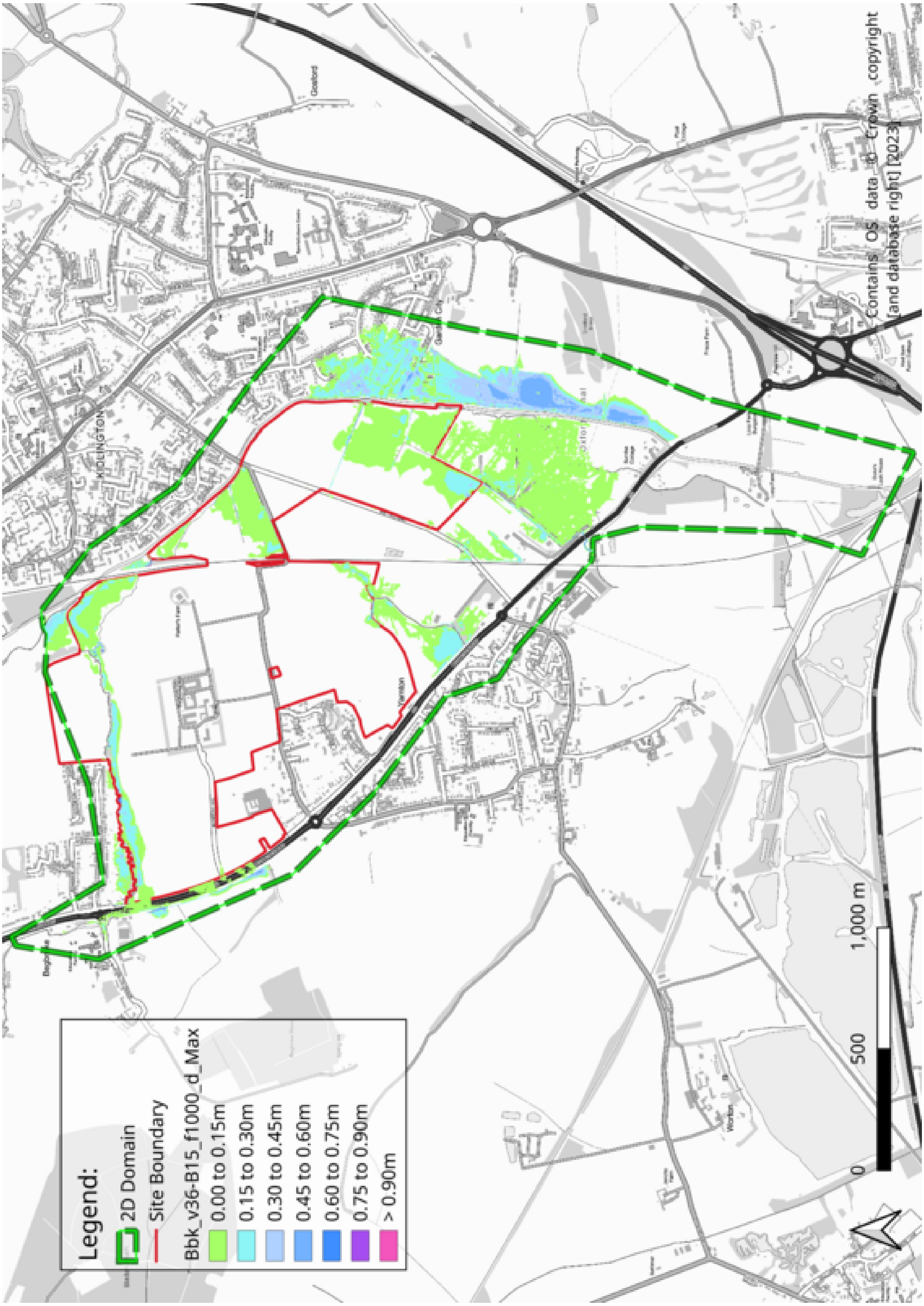


*Figure 6.4: Maximum modelled depth with mitigation in the North-west of the site in the 0.1% AEP event, 11 hour storm duration*

### Flood Level Differences

Figures 6.5 and 6.6 show the difference in maximum flood level between the mitigated swale scenario and the baseline model, for the 1% AEP event plus 41% allowance for climate change and the 0.1% AEP event, 11 hour storm duration. Where there is zero or negligible (<5 mm) change in the maximum flood level, the results are shown as grey. For an increase in maximum flood level the results are shades of green and where there has been a decrease the results are shown in purple. New flooding as a result of the proposal is highlighted in red and flooding removed as a result of the proposal is shown in blue.

Both figures demonstrate that the construction of the swale prevents the proposed development from flooding and causes no increased flood risk elsewhere. Water is intercepted by the swale rather than flowing across the north western corner of the site as shown by the blue extent on the mapping.

For the 1% AEP plus 41% climate change allowance event.

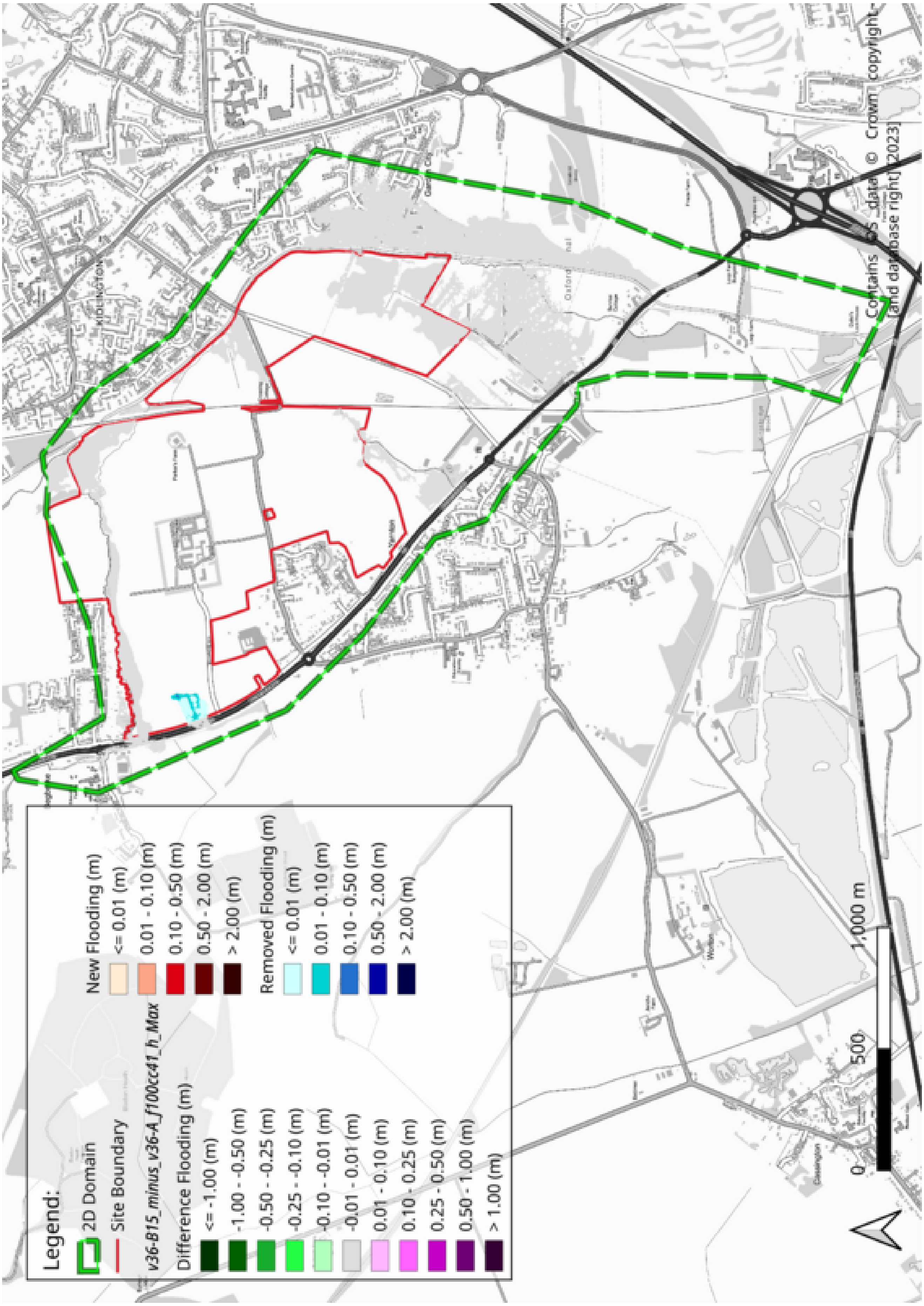


Figure 6.5: Difference in flood level between the baseline model and the North-west mitigation scenario in the 1% AEP event plus 41% allowance for climate change, 11 hour storm duration

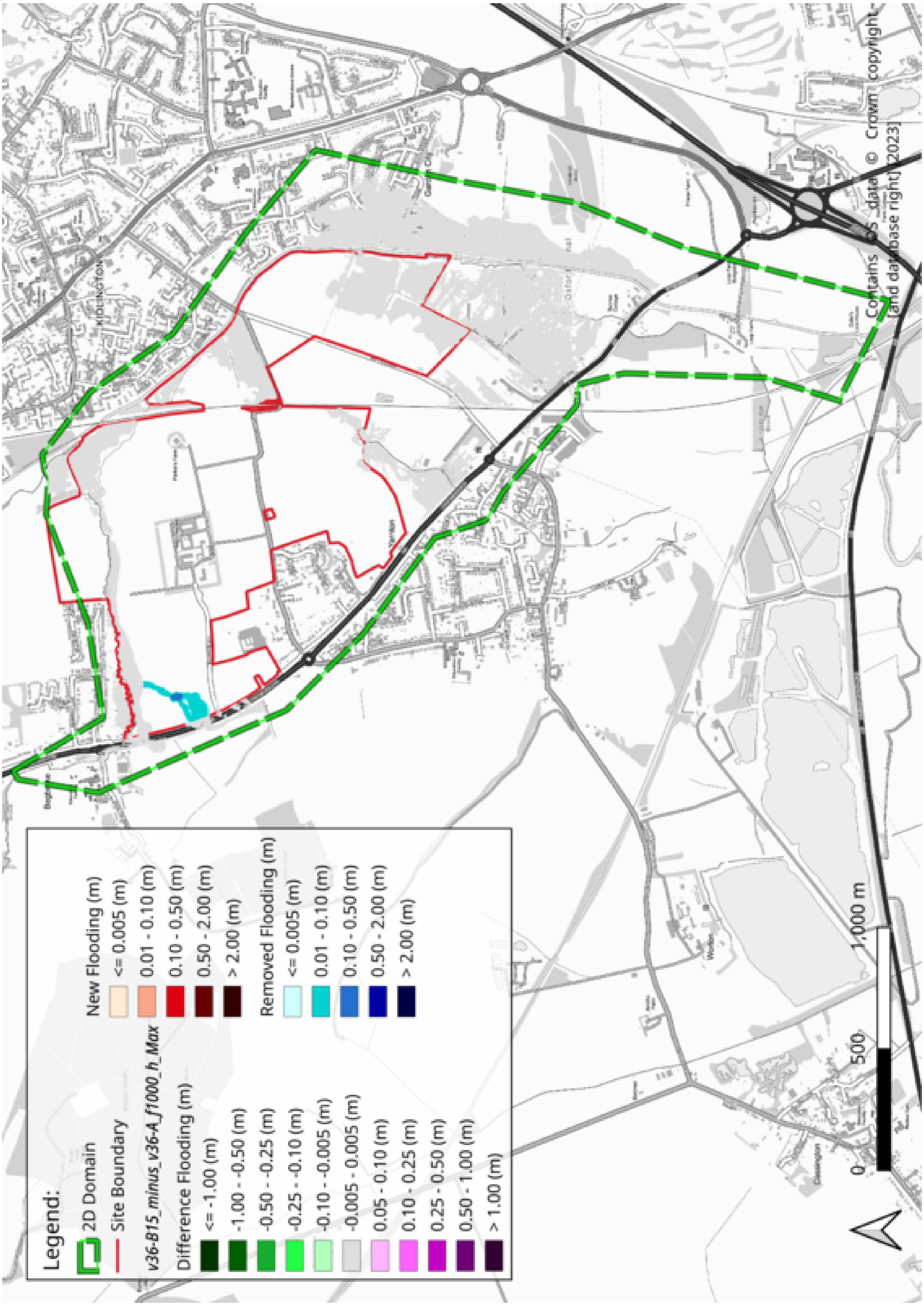


Figure 6.6: *Difference in flood level between the baseline model and the North-west mitigation scenario in the 0.1% AEP event, 11 hour storm duration*

# 7. Proposed School Site

## 7.1 Overview

The Begbroke Innovation District incorporates a proposed school site and it is a project requirement that this school site be free of flooding in the design flood events. Accordingly it is proposed to re-grade the land within the school site so that flood risk from outside that land is eliminated and to manage the rainfall incident on the site via surface water drainage. The location of the school site is shown in figure 7.1.

The effect of the re-grading has been modelled for three design events: two 1% AEP events with 26% and 41% allowance for climate change (the "Central" and "Higher" estimates for the 2080s epoch, respectively); and the 0.1% AEP "present day" event. An 11-hour storm duration has been used in each case. These model runs use the Baseline model as a starting point and therefore the swale configuration outlined in 6 is not included within this scenario.

## 7.2 Scenario Configuration

It is proposed to re-grade the school site by raising the ground levels sufficiently to prevent flood water backing up onto the site from the Southern Drainage Ditch. In the model, the school site has been raised to a level above the highest modelled flood levels and the hydrological inflow location for the southern drainage ditch has been moved downstream to the edge of the school site. These model changes are representative of the proposed works under the following assumptions:

- The proposed grading of the school site does not significantly alter the drainage directions of ground and surface water, which continues to drain from the existing catchments to the southern drainage ditch.
- The reaches of the southern drainage ditch currently crossing the school site are backfilled as part of the re-grading process.
- Excess rainfall on the school site is handled by the surface water drainage system and drains to the southern drainage ditch at approximately green-field run-off rates.

The proposed land-raising across the school site would necessitate the filling-in of an existing tributary reach of the Southern Drainage Ditch across the southwest corner of the site. This would severely limit connectivity with this area and is likely to cause significant downstream disbenefit. Accordingly, a replacement channel is proposed along the boundary of the school site to maintain the connectivity of the southern drainage ditch. The route of this channel is shown in Figure 7.2. This has been simulated through land-lowering in the 2D model. It should be noted that, as the existing ditch falls within the school site, it is assumed to be backfilled and the replacement channel will follow the boundary of the site, to the southwest.

## 7.3 Results

### Maximum Depth

Figures 7.3 - 7.5show the maximum depth results in the proposed condition for each of the three design events. It can be seen that the school site is flood free in all of the events and the peak water level results from this model may therefore be used to inform the required levels for re-grading the site.

### Flood Level Differences

Figures 7.6 - 7.8 show the differences in maximum flood level and extent between the proposed school re-grading scenario and the baseline model. It can be seen that a substantial amount of floodwater has been displaced from the school site and that mitigation will be required.

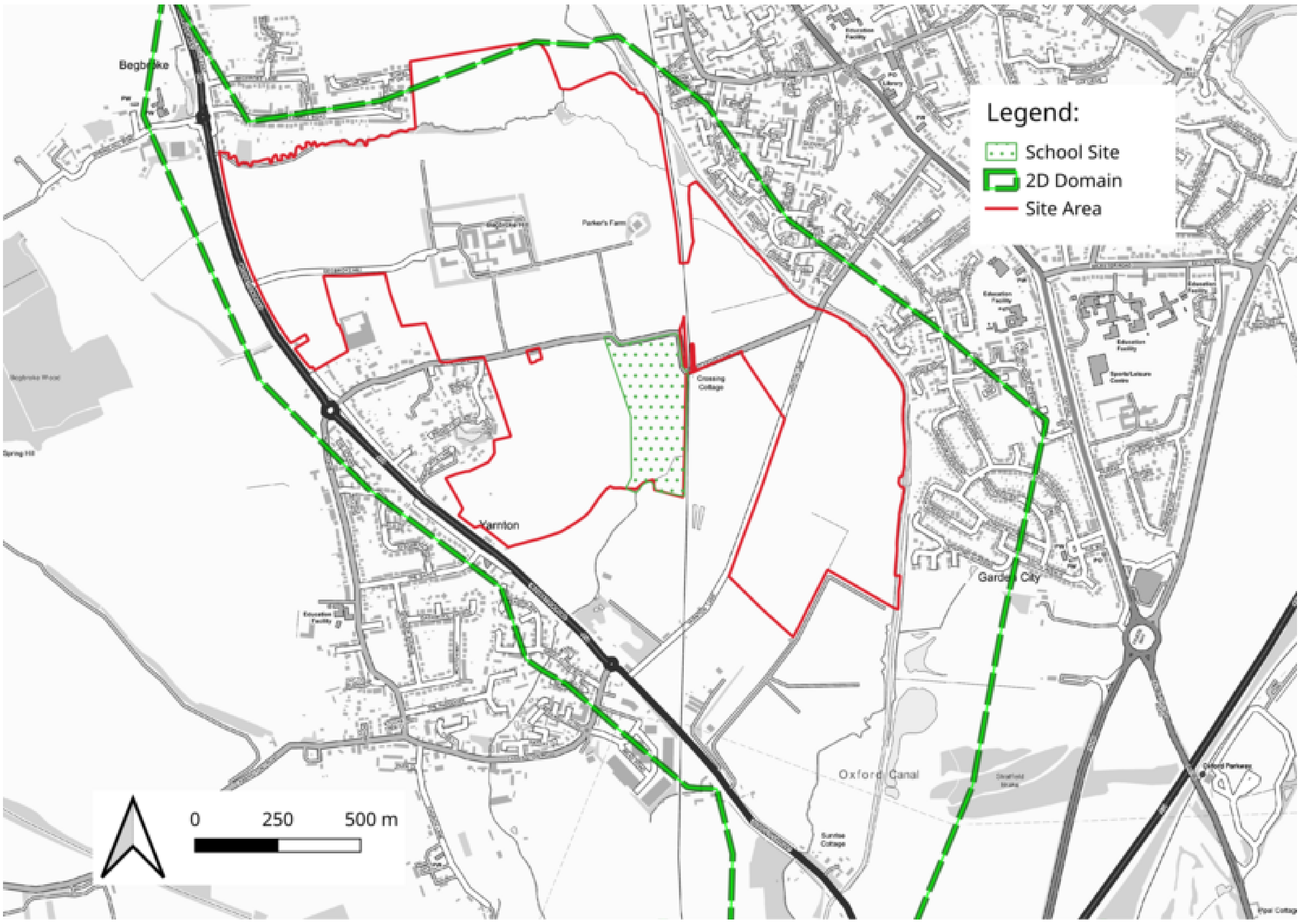


Figure 7.1: *School site location within the wider Begbroke Innvoation District red line.*

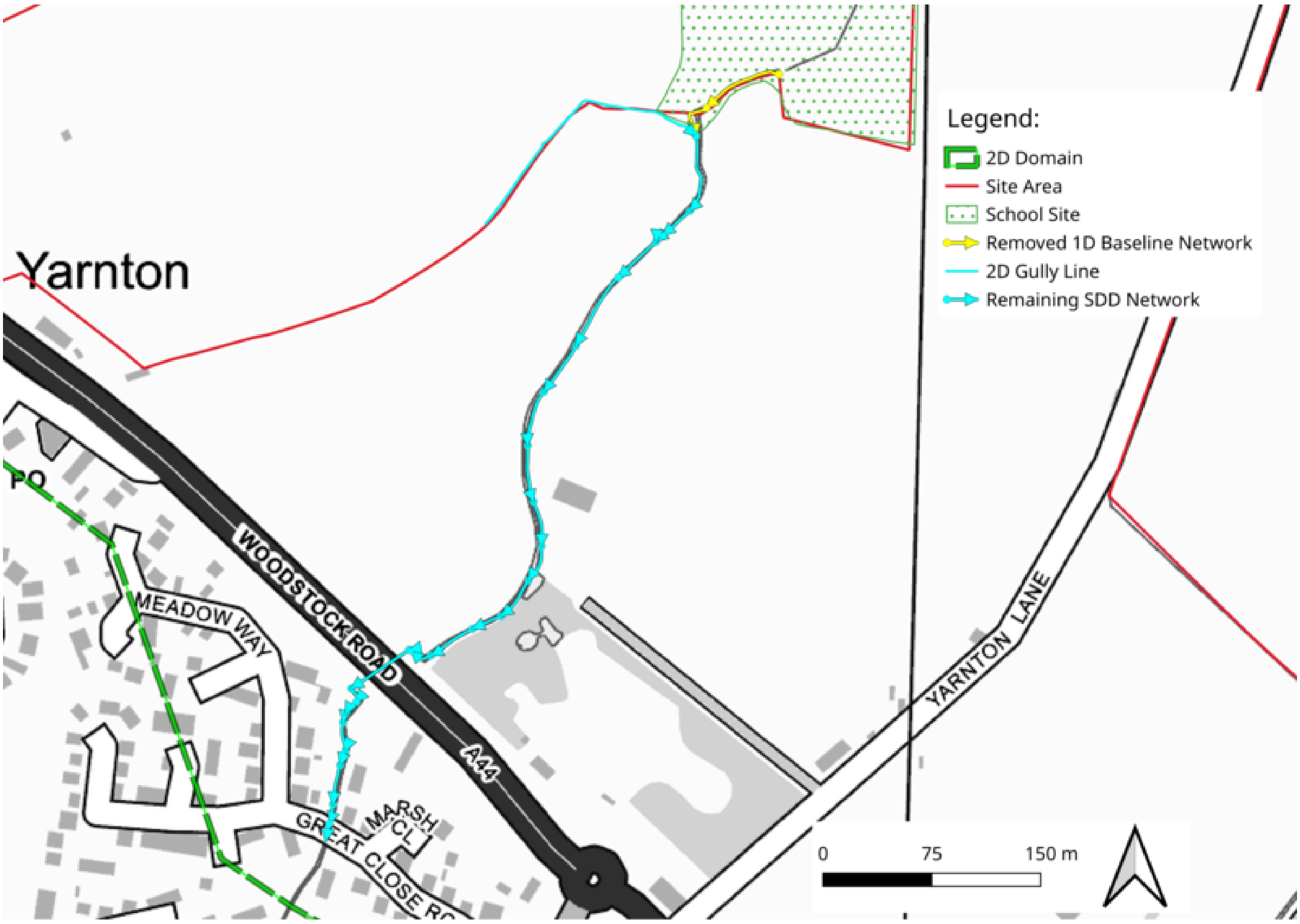


Figure 7.2: *Plan showing changes between the baseline channel schematisation and the proposed condition.*

EdenvaleYoung

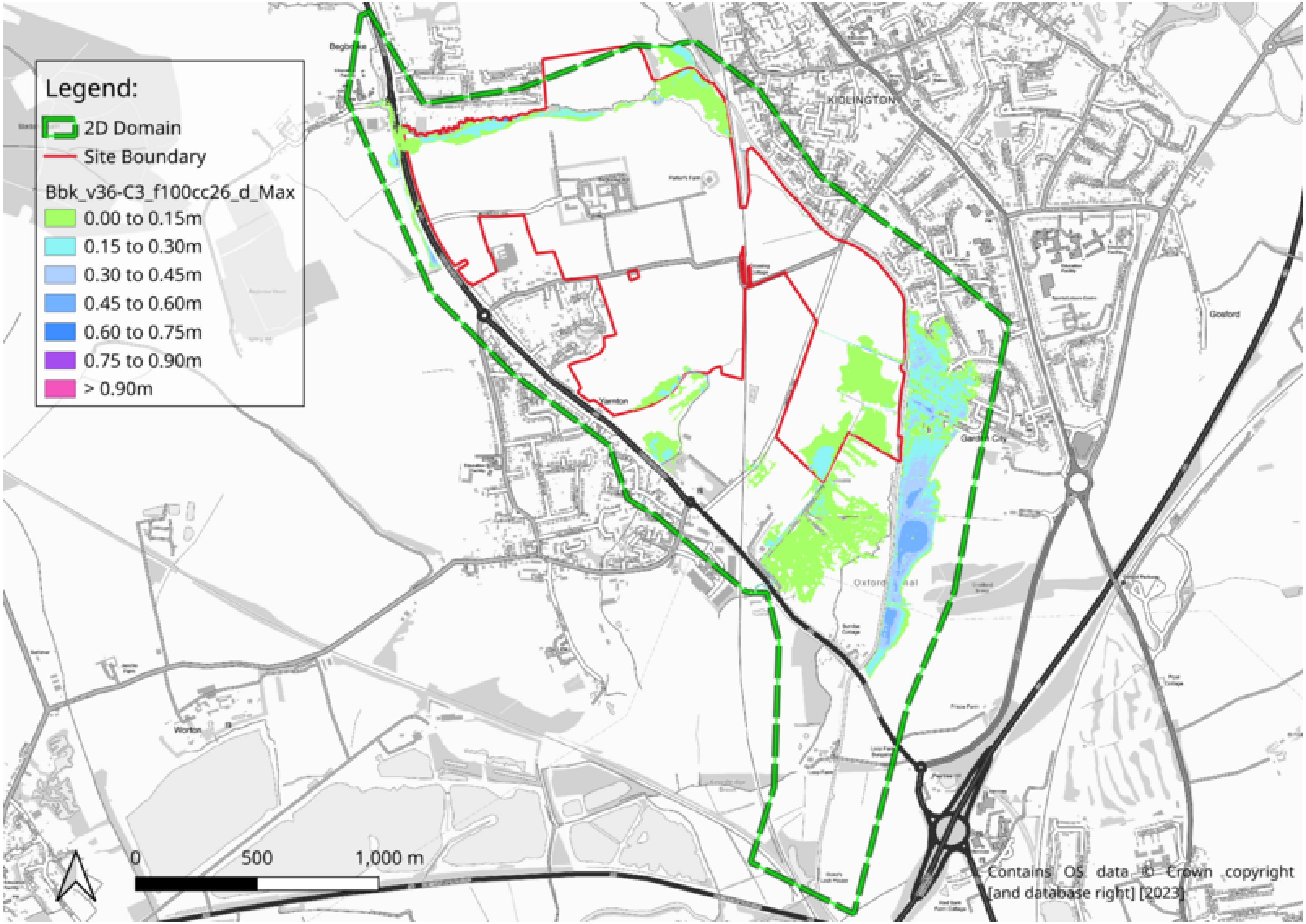


Figure 7.3: *Maximum modelled depths for the 1% AEP event with 26% climate change allowance.*

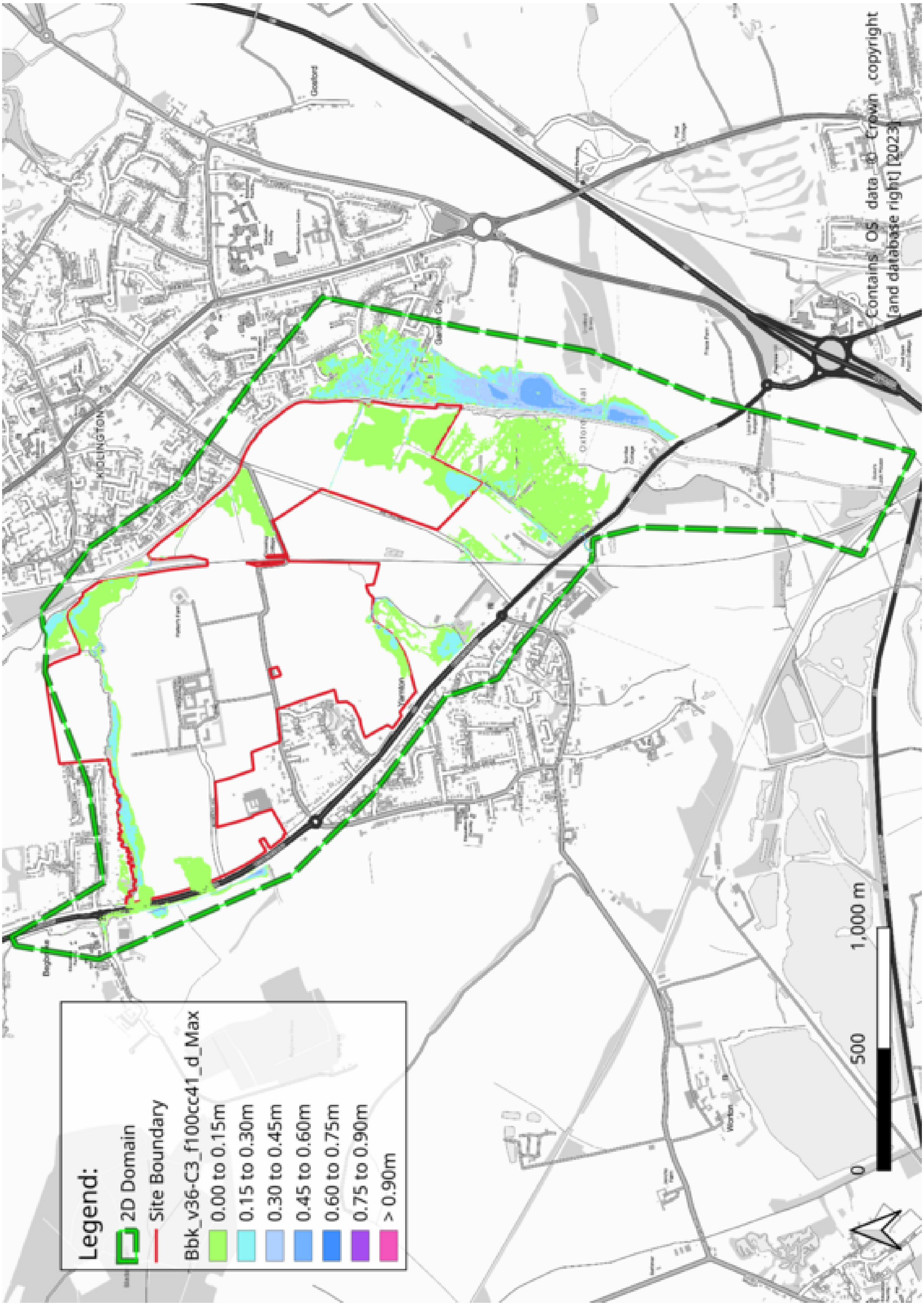


*Figure 7.4: Maximum modelled depths for the 1% AEP event with 41% climate change allowance.*

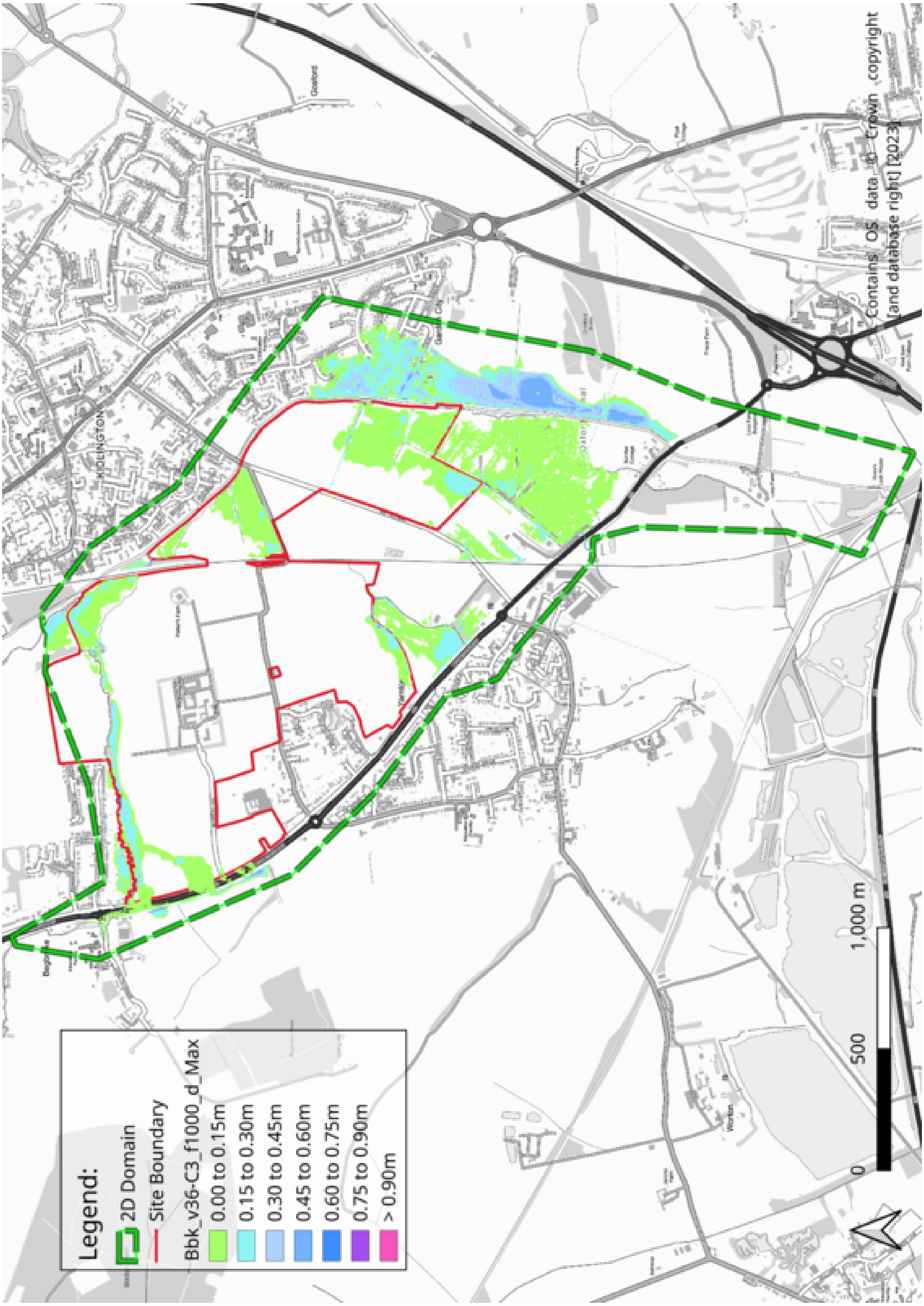


*Figure 7.5: Maximum modelled depths for the 0.1% AEP present-day event.*

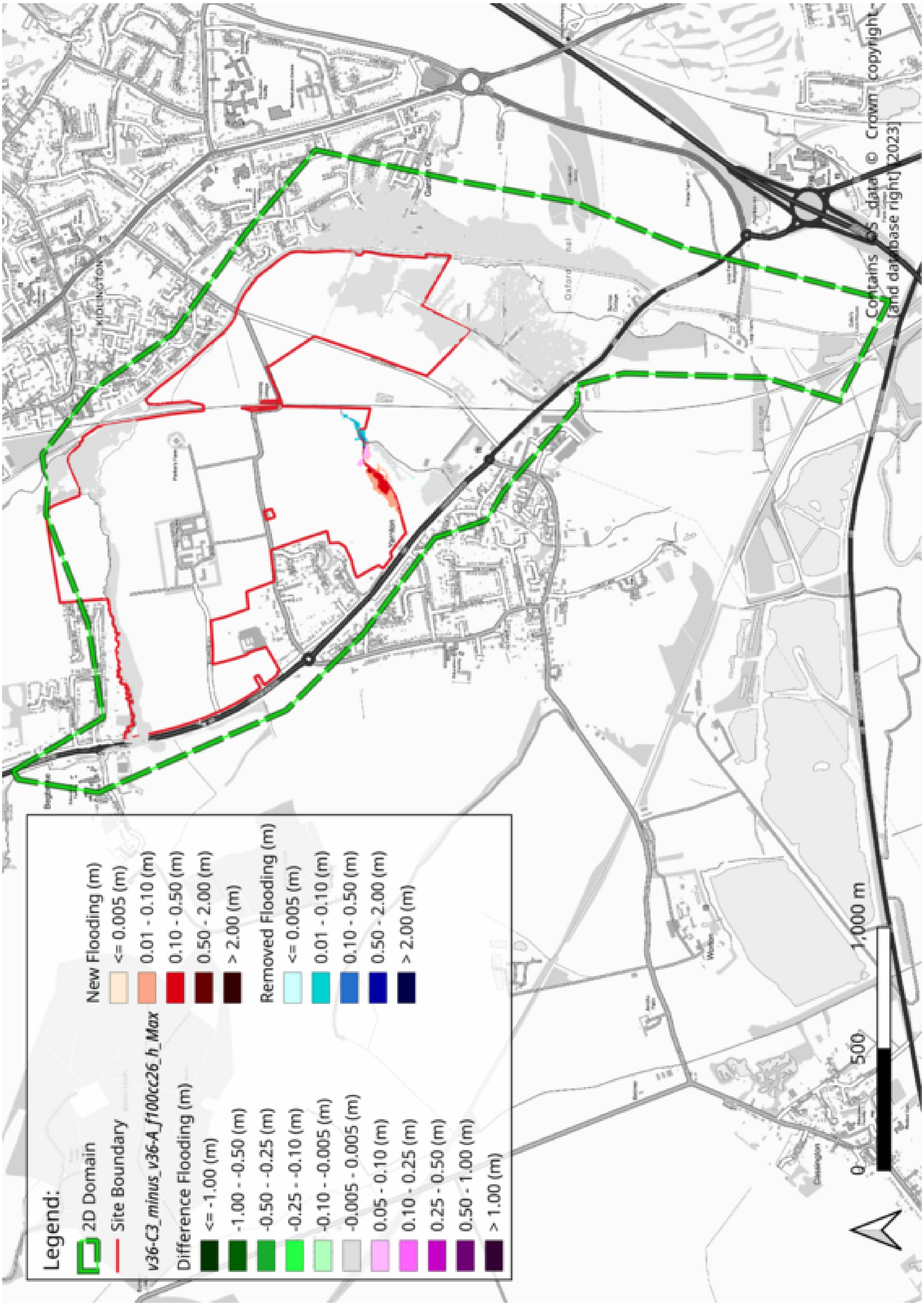


Figure 7.6: Peak water level differences between the proposed and baseline conditions for the 1% AEP event with 26% climate change allowance.

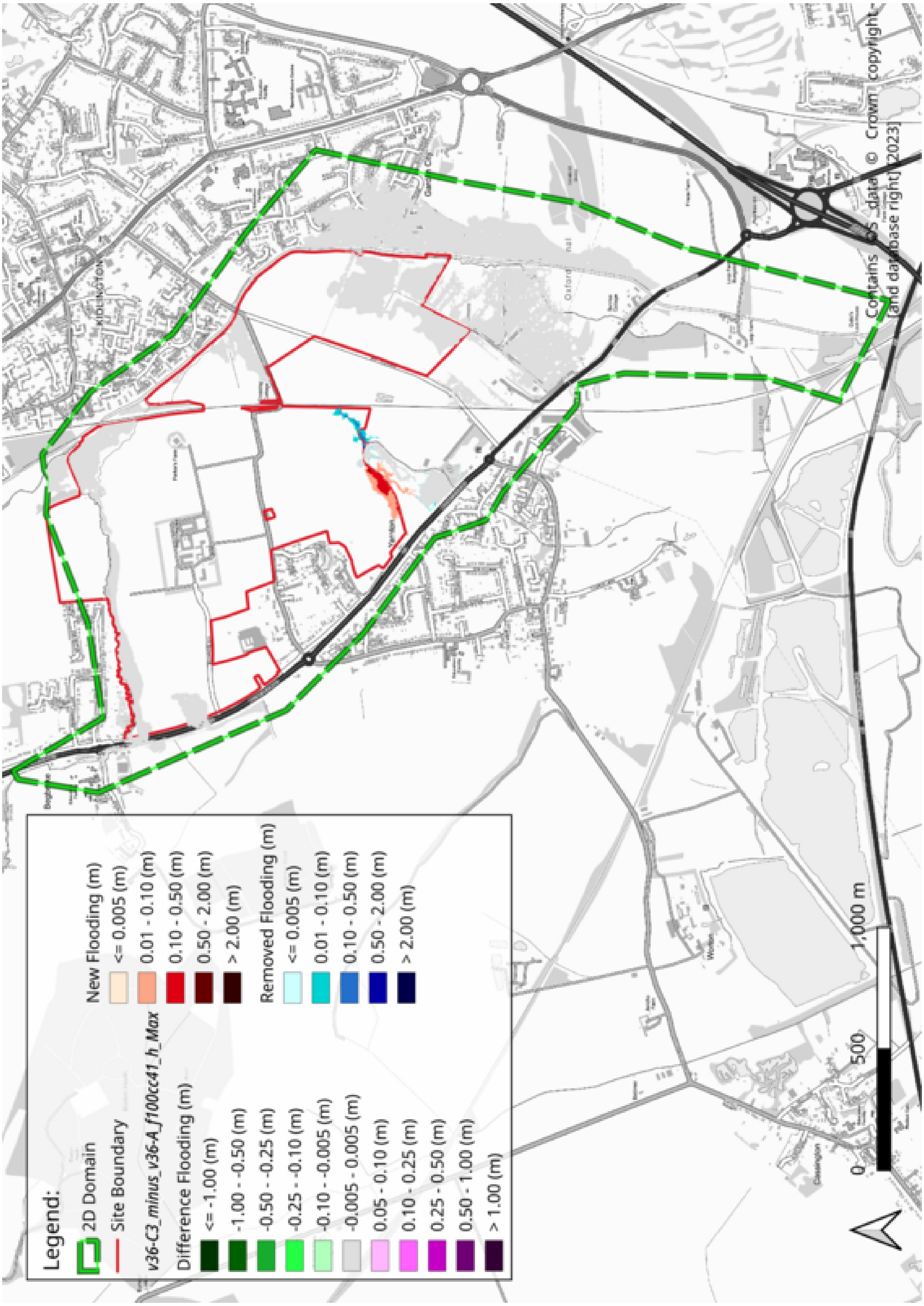


*Figure 7.7: Peak water level differences between the proposed and baseline conditions for the 1% AEP event with 41% climate change allowance.*

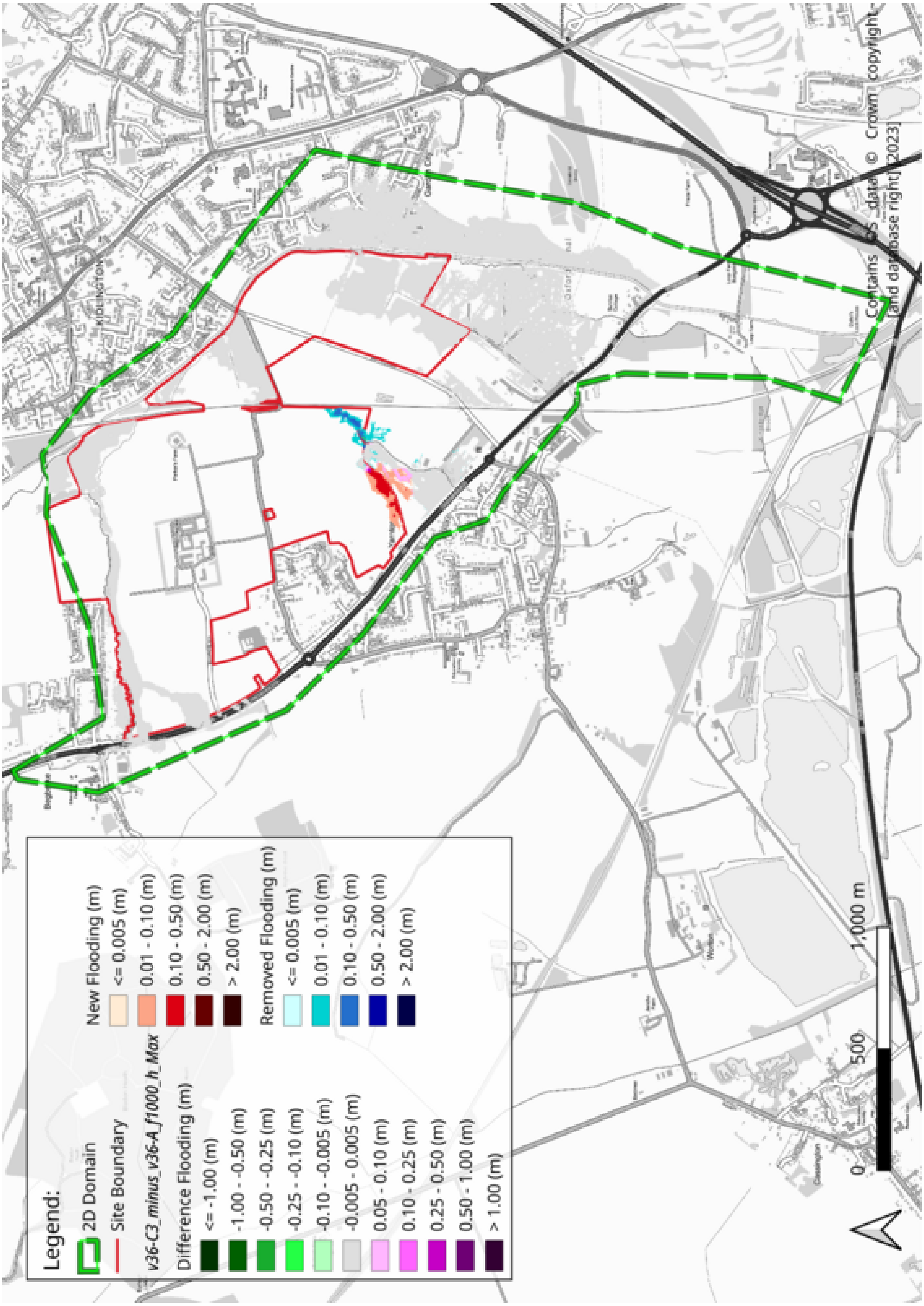


*Figure 7.8: Peak water level differences between the proposed and baseline conditions for the 0.1% AEP present-day event.*

# 8. Conclusions

Edenvale Young Associates were commissioned to undertake hydraulic modelling adjacent to the existing Begbroke Science Park, Oxfordshire. The following tasks have been undertaken:

- A baseline ESTRY-TUFLOW model has been constructed using detailed topographic survey and a bespoke hydrological analysis has been undertaken.
- The model has been run for a range of design events
- Sensitivity testing has been undertaken to assess the impact of key assumptions on the results

The results show flooding to the site of interest, with the majority of out of bank flooding occurring on the eastern side of the site close to the Oxford Canal and Eastern Drainage Ditches. Where proposed development would intersect with the flood extents of the 1% AEP events with climate change allowance it is recommended that such development is relocated, or mitigation work is undertaken to ensure that the development is not at risk and no third-party impacts are caused.

A small area of flood risk to the proposed development in the 1% AEP with 41% climate change allowance and 0.1% AEP flood events has been identified in the northwest corner of the site. The modelling has been used to inform the outline design of a swale which has been shown to be an effective flood mitigation measure for these events that does not cause any third-party impact.

## 8.1 Assumptions

Limitations and assumptions associated with the model build have been set out in the relevant sections above. The following list reiterates these points.

- the connectivity of the Rowel Brook North and Rowel Brook South East within the wooded copse is uncertain. This area has been modelled in 2D using detailed topographic survey to allow the topography to control flow routing rather than requiring assumptions by the modeller.
- detailed topographic survey of the road ditches adjacent Woodstock Road was not available, meaning that there is some uncertainty associated with their geometry; assumptions have been made based on on-site observations. Similarly, the direction of flow from Begbroke Hill is uncertain.
- whilst topographic survey was available for much of the site, coverage was incomplete. The downstream extent of the Eastern Drainage Ditches and the northern portion of the Rowel Brook has not been surveyed due to access restrictions, for example, which has resulted in the need for modelling assumptions in these locations.

- it was also the case that topographic survey of structures was limited, again necessitating modelling assumptions in the representation of these structures based on available data.
- there are multiple locations within the model domain where connectivity of channel and ditches is uncertain. In particular, the connectivity between the Rowel Brook and the Yarnton/Green Lane ditches, as well as along the Yarnton/Green Lane ditches themselves.
- the depth of the canal has been estimated as the bed levels in the supplied topographic survey was deemed uncertain. As the canal is full this should not impact model results.
- the canal is assumed not to be carrying unusually high flows.
- the hydrological inflow point is located downstream (south) of the industrial estate and the inflow hydrograph therefore does not explicitly include any attenuation associated with flood risk measures, flow constrictions or flooding in the industrial estate or upstream. This is a conservative assumption.
- any structures beyond the 1D portions of the Eastern Drainage Ditch have not been included due to lack of survey. The structure which conveys the ditch beneath the A44 Woodstock Road has been modelled as open channel as it assumed that the road crossing does not represent a constriction. Model results in this location should therefore be viewed with caution, but this should not affect the conclusions of this report as the area lies outside the site boundary.
- much of the Southern Drainage Ditch could not be accessed on the site visit. It has been assumed that the condition of the ditch is similar to other ditches on-site and roughness values have been selected accordingly.
- on-site observations indicated that the Yarnton/Green Lane ditches were poorly maintained with limited connectivity in places. A representative blockage factor of 50% has been applied to multiple network lines along these channels as it was not possible or proportionate to attempt to replicate every variation along these channel.
- limitations associated with the hydrological analysis are outlined in the Flood Estimation Report.

APPENDIX

# A. 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 | Sara Liguori | | | 01/03/2024 |
| 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:**

Begbroke, including Rowel Brook, Thrupp ditch and Southern Drainage ditch, Oxfordshire

**Purpose of study and complexity:**

Routine hydrological assessment to estimate design hydrographs needed as input to the 1D-2D hydraulic model of the watercourses in the area of study.

**Key catchment features:**

The site of interest is rural but the hydrological catchments of interest for the estimation of runoff to and from the site are more variously characterised. The overall contributing catchment downstream of the site, at the downstream hydraulic model extent, is moderately urbanised. All hydrological catchments of interest are classified as small.

**Flooding mechanisms:**

Fluvial and pluvial.

**Gauged / ungauged:**

Ungauged

**Final choice of method:**

Statistical peak flow estimates; hydrograph shapes from ReFH2

**Key limitations / uncertainties in results:**

Lack of data to inform analysis and verify results.

## 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:**

This document details the hydrological analysis undertaken to derive design peak flows and hydrographs for use in a 1D-2D hydraulic model of the Rowel Brook, Thrupp ditch and Southern drainage ditch at a site near Begbroke, Oxfordshire. The results of the hydraulic modelling will be used for the purpose of informing a flood risk assessment for a proposed development.

Design peak flow estimates and hydrographs will be derived for the following AEP (%) events: 3.33, 1, and 0.1. In addition, the following AEP (%) events have been considered for the purposes of this assessment: 50, 20, 10, 2, 0.5, and 0.2. The impact of climate change on flood risk will be assessed by applying climate change allowances to the 1%AEP flow estimates. The central (26%) and higher (41%) allowances for the 2080s epoch, as defined by current climate change guidance[1] for the Gloucestershire and Vale Management Catchment, will be considered for the purposes of the hydraulic modelling.

Design estimates will be derived as lumped inflows for the Rowel Brook, Thrupp ditch, and Southern drainage ditch at the site. The contribution of the intervening area at the d/s extent of the hydraulic model will be estimated from the overall catchment at this location. A map of the approximate site boundaries and contributing catchments as defined on the FEH Web is shown in Figure 1.

It is anticipated that the FEH catchments boundaries and contributing areas will be refined on the basis of the results of a Direct Rainfall Model (DRM) built for the area of interest. The DRM will provide information about surface flow paths in the area, according to the LiDAR DTM and known local features impacting on the topography and the hydrological connectivity in the area. It is also anticipated that the distribution of runoff estimated for the intervening area will be made in accordance with the indication of relevant flow paths as shown by the results of the direct rainfall model. The DRM results might also indicate that a significant runoff contribution to the Oxford Canal is to be taken into account for the purposes of the hydraulic. It should be noted that details on the DRM model build and analysis of DRM results are covered within the main report.

## 2.2 The Catchment

**Maps:**

[1] Environment Agency. Flood risk assessments: climate change allowances. Last Updated May 2022 https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow

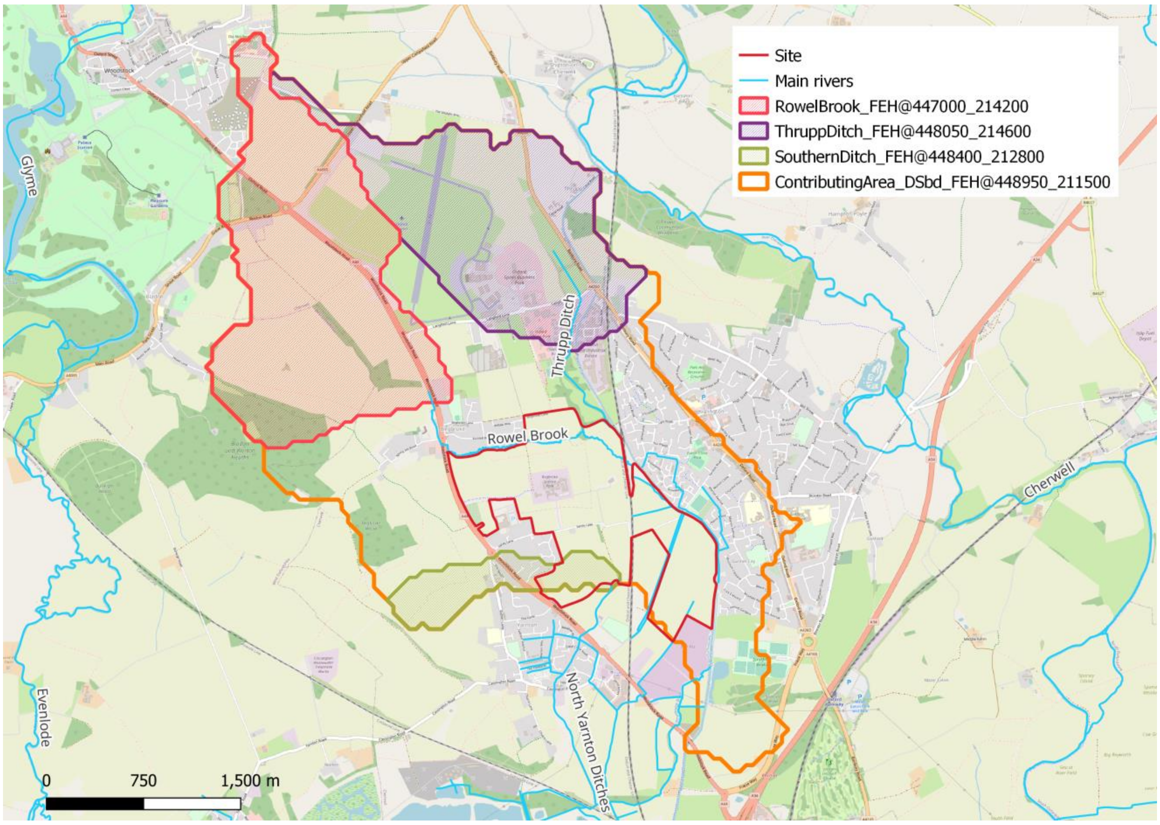


*Figure 1 FEH catchments and site boundaries*

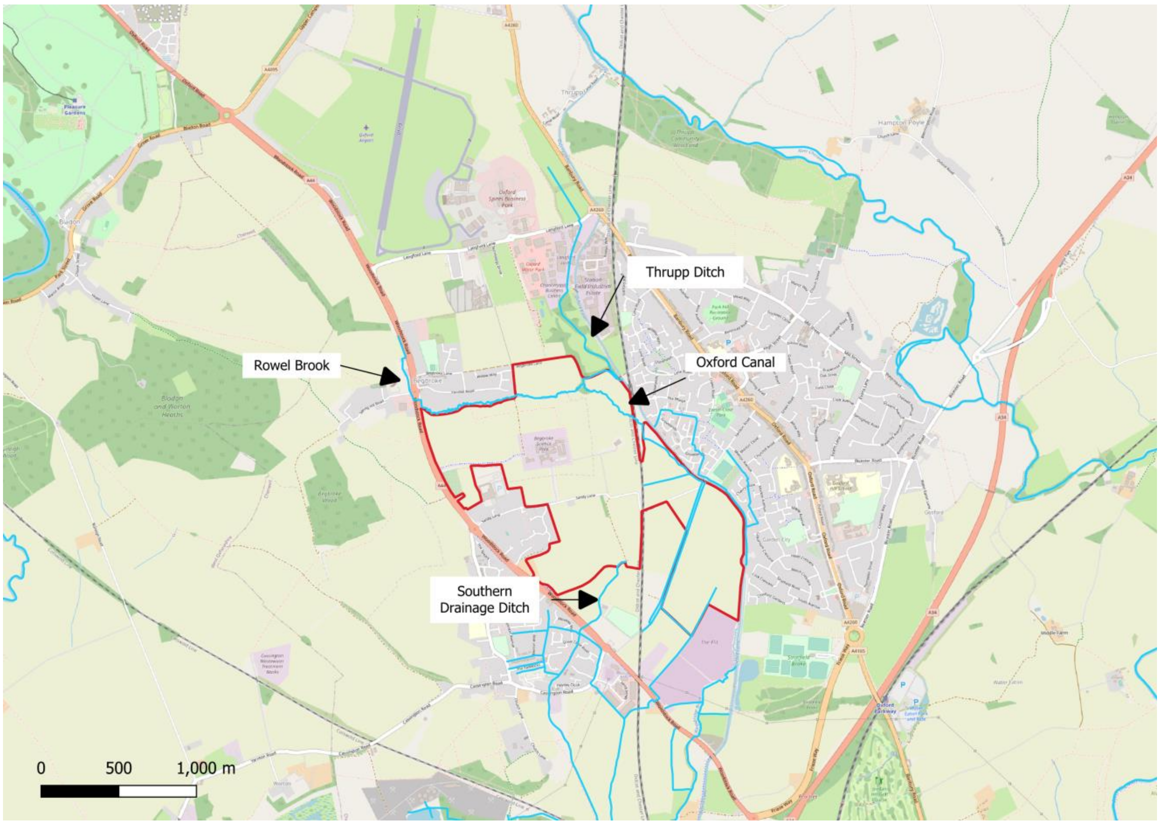


*Figure 2 Watercourses in the area of interest*

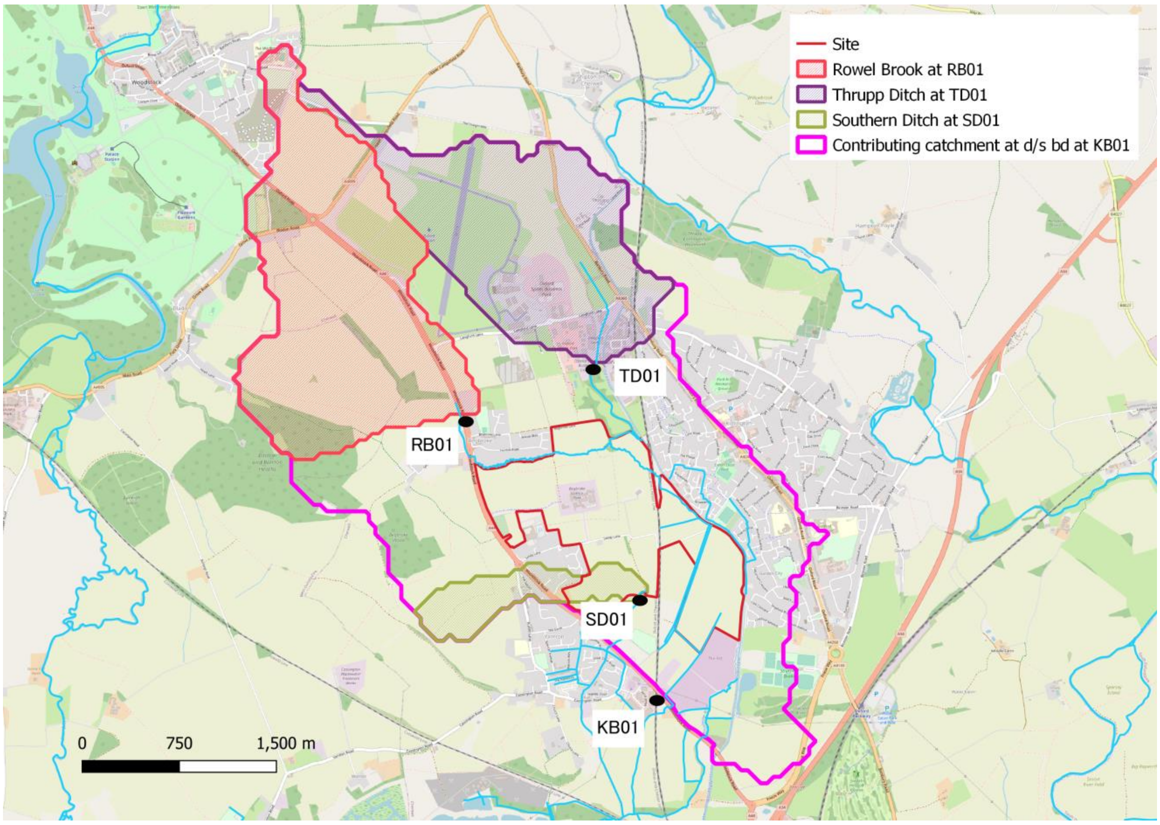


*Figure 3 Locations selected for the purposes of the FEH analysis*

**Catchment Description:**

The main watercourses and ditches near and on the site of interest are shown in Figure 2. The Rowel Brook originates west of Oxford Airport and drains east the A44. It then turns south towards Begbroke, where is culverted and flows east across the northern boundary of the proposed development site. It then bifurcates, with the north eastern branch from the bifurcation flowing north and then east. This branch joins with the Thrupp Ditch and discharges into the Oxford Canal. The south eastern branch of the Rowel Brook flows through the site, it passes through a culvert under the railway line and then flows along the eastern edge of the site. It then flows in a pair of ditches along either side of Yarnton Lane and is routed through field drainage and under the A44 south of the site.

The Thrupp ditch drains a catchment north of the site. It flows south, east of Oxford Airport and west of the Oxford Canal. It joins with the Rowel Brook and Oxford Canal on the north eastern boundary of the site.

The Southern drainage ditch originates to the west of the railway within the site boundary and flows southwest through Yarnton.

The area lies on a Limestone and mudstone sedimentary bedrock formation. The hydrological catchments include a variety of soils, mostly base-rich loamy and clayey. A map showing bedrock and superficial deposits in the area of interest extracted from the BGS GeoIndex web interface is provided in Figure 4.

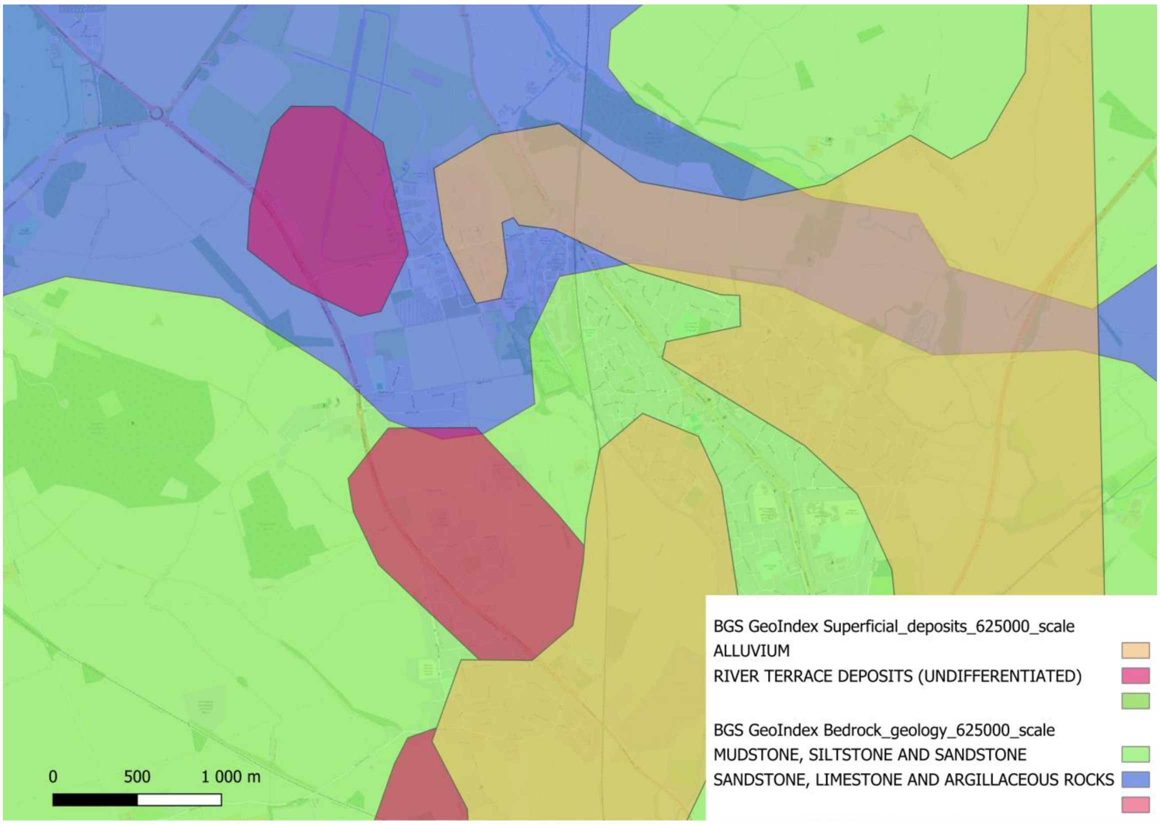


*Figure 4 British Geological Survey GeoIndex Superficial deposits and Bedrock geology*

---

## 2.3 Hydrometric Data

**Source of flood peak data:**

NRFA v11, released September 2022, contains data up to the end of September 2021.

**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 |
|---|---|---|---|---|---|---|
| River Thames | Days Weir | | 39002 | 3444.7 | Miscellaneous | 1938 - 2018 |

**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 |
|---|---|---|---|---|---|---|---|---|
| Days Weir | 1938 - 2018 | AMAX | 1938 - 2018 | Outside scope | Yes | Yes | Outside scope | Calculated flows within 5% of measured flows, increasing to 10% at flows over 100m3/s. |

**Updates or revisions to flood peak data:**

Outside scope

**Data quality checks carried out:**

Outside scope

**Rating Equations:**

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

**Rating reviews:**

**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 | NA | No | NA | NA |

| Type of data | Data relevant to this study? | Data available? | Source of data | Details |
|---|---|---|---|---|
| Historical flood data | Yes | Yes | EA Historic flood map and recorded flood outlines dataset. | Site is shown and there are some areas to the east of the site that have flooded in the past. |
| Flow or river level data for events | NA | No | NA | NA |
| Rainfall data for events | NA | No | NA | NA |
| Potential evaporation data | NA | No | NA | NA |
| Results from previous studies | NA | No | NA | NA |
| Other data or information | NA | No | NA | NA |

**Conclusions of hydrometric data review:**

| Station name | Rating suitability | Suitability for flood estimation calculations | Non-stationary analysis requirements |
|---|---|---|---|
| Thames@Days Weir | Rating formulae based upon gaugings - tailwater calibration applies for flows > 70 cumecs | Gauge is suitable as QMED donor for the purposes of this study | Not required |

---

## 2.4 Hydrological understanding of the catchment

**Plots of flood peak data and interpretation:**

NA

**Plots of flow data and interpretation:**

NA

**Plots of stage data and interpretation:**

NA

**Conceptual model:**

The site of interest comprises the fields surrounding Oxford Science Park, as shown in Figure 1. Flooding is likely to be caused by the capacity of the Rowel Brook and nearby channels being exceeded, resulting in overland flow. Peak flows are of primary importance as finished floor levels for the proposed development will be informed by the hydraulic modelling driven by design flows estimated for this study. Only the potential sources of fluvial flooding are covered within this assessment.

The hydrological connectivity within the area of study is affected by the presence of numerous field drains and ditches and by the interaction of the main watercourses near the site of interest with the Oxford canal. Therefore, the implementation of standard FEH approaches has been aided by the implementation of a direct rainfall model to gain a more comprehensive understanding of hydrological connectivity and flow paths in the area of interest.

**Unusual catchment features:**

All FEH catchments in Figure 1 are classified as small. With respect to urbanisation levels, the following applies:

- Rowel Brook is classified as essentially rural;
- Thrupp ditch is classified as heavily urbanised;
- Southern drainage ditch and overall FEH catchment at d/s hydraulic model extent are both classified as moderately urbanised.

According to their BFIHOST19 values, all FEH catchments in Figure 1 except the Southern Drainage ditch catchment are classified as groundwater dominated, according to current FEH guidelines[2].

---

## 2.5 Initial choice of approach

**Are FEH methods appropriate?**

FEH methods are appropriate according to current FEH guidelines[2]. In line with the guidelines on the implementation of the Statistical method on small catchments, QMED should be adjusted by using one single donor and the small catchments method should be implemented in the pooling group selection process. The latest advice from the EA is, however, to assess the small

---

2 LIT11832 Environment Agency Flood Estimation Guidelines, published 23/12/2022

catchments SDM approach against the standard SDM approach when deriving pooling groups using NRFAv11[3].

Current guidance on the implementation of ReFH2 on heavily urbanised catchments is to use:

- a Tp scaling factor of 1;
- a summer storm if the catchment is highly permeable (BFIHOST19 is > 0.65).

The indication is also for heavily urbanised catchments to treat the catchment as rural, as the small catchments research found that this approach would lead to more accurate flood frequency estimates, according to FEH guidelines[2]. The guidelines also suggest that the statistical method should be used in preference to the rainfall-runoff approach when estimating peak flows on groundwater dominated catchments.

**Initial choice of method(s) and reasons:**

The Statistical method and ReFH2 model are going to be applied to derive and compare peak flow estimates at the main inflow locations, namely RB01, TD01, and SD01 in Figure 3. The same standard FEH approaches are going to provide estimates for the FEH catchment at the d/s location KB01, also shown in Figure 3. It is anticipated that, given the characteristics of the study catchments, statistical estimates are going to be preferred. Hydrograph shapes are going to be derived from ReFH2, with one or more appropriate storms selected to be applied across all subcatchments in order to represent the conditions maximizing flood risk at relevant locations.

**How will hydrograph shapes be derived if needed?**

ReFH2

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

The intervening area at KB01 is to be split into sub-catchments defined according to the DRM results.

**Software to be used:**

WINFAP5

ReFH2 version3.3

---

3 Environment Agency, Flood estimation impacts of updating from NRFA v10 to v11 Evidence & Risk – National Flood Hydrology Team Published: 22/12/2022

# 3. Locations where flood estimates are required

## 3.1 Summary of subject sites

| 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) ($km^2$) |
|---|---|---|---|---|---|---|---|
| RB01 | L | Rowel Brook | Upstream inflow | 446041 | 215112 | 3.24 | 3.55 |
| TD01 | L | Thrupp ditch | Upstream inflow | 447477 | 215536 | 2.49 | 2.67 |
| SD01 | L | Southern drainage ditch | Upstream inflow | 447443 | 212772 | 0.505 | 0.811 |
| KB01 | L | Kingsbridge Brook | Downstream estimation point | 447376 | 214287 | 12.66 | 14.056 |
| IC01 | S | Kingsbridge Brook | Intervening catchment | 447376 | 214287 | NA | 7.025 |

## 3.2 Catchment Descriptors

**Final catchment descriptors at each subject site:**

| Site code | FARL | PROPWET | BFIHOST19 | DPLBAR (km) | DPSBAR (m/km) | SAAR (mm) | URBEXT 2000 | FPEXT |
|---|---|---|---|---|---|---|---|---|
| RB01 | 1 | 0.32 | 0.807 | 1.85 | 16.2 | 628 | 0.0167 | 0.1381 |
| TD01 | 1 | 0.32 | 0.87 | 1.53 | 14.9 | 618 | 0.216 | 0.2098 |
| SD01 | 1 | 0.32 | 0.637 | 1.02 | 24.4 | 619 | 0.088 | 0.1584 |
| KB01 | 1 | 0.32 | 0.759 | 4.12 | 15.4 | 620 | 0.143 | 0.2049 |

**Catchment boundary checks and revisions:**

Catchment boundaries at KB01 were revised according to the results of the DRM. The revised catchment boundaries and the DRM results are shown in Figure 5.

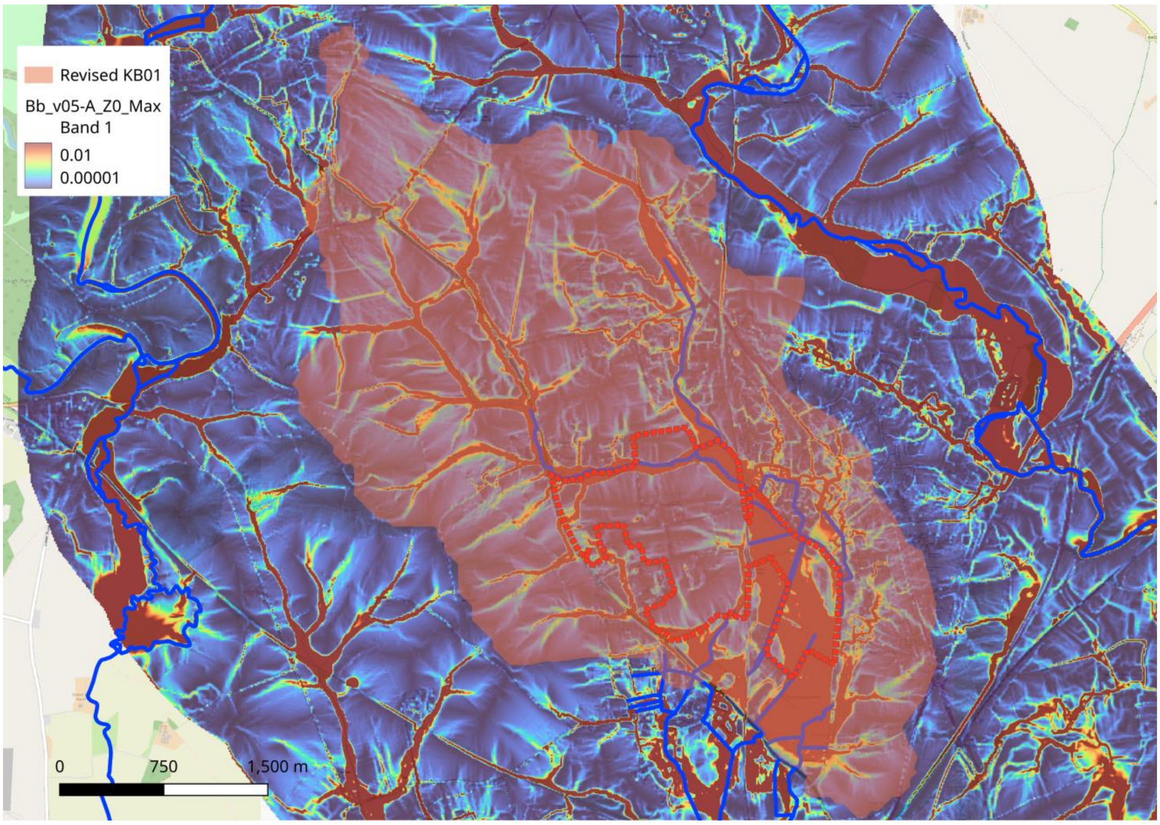


*Figure 5 Revised contributing catchment at KB01 and Direct Rainfall Model (DRM) unit flow ($m^2/s$) results.*

The DRM model has provided information about the flow paths which has also being used to refine catchment boundaries at the main inflow locations RB01 and TD01 and the distribution of inflows from off and on site subcatchments to the main watercourses on site. Revised catchment boundaries at RB01 and TD01 are shown in Figure 6, while the subcatchments delineated using the DRM results are shown in Figure 7. It should be noted that, according to on site investigation and the results of the DRM model, the contributing runoff area at SD01 has been deemed to be misrepresented on the FEH Web service. The contributing area at SD01 has been effectively replaced by subcatchment S08 in Figure 7 for the purposes of the hydrological analysis. It should also be noted that, according to the DRM results two runoff contributing areas to the Oxford Canal will be taken into account for the purposes of the hydraulic modelling.

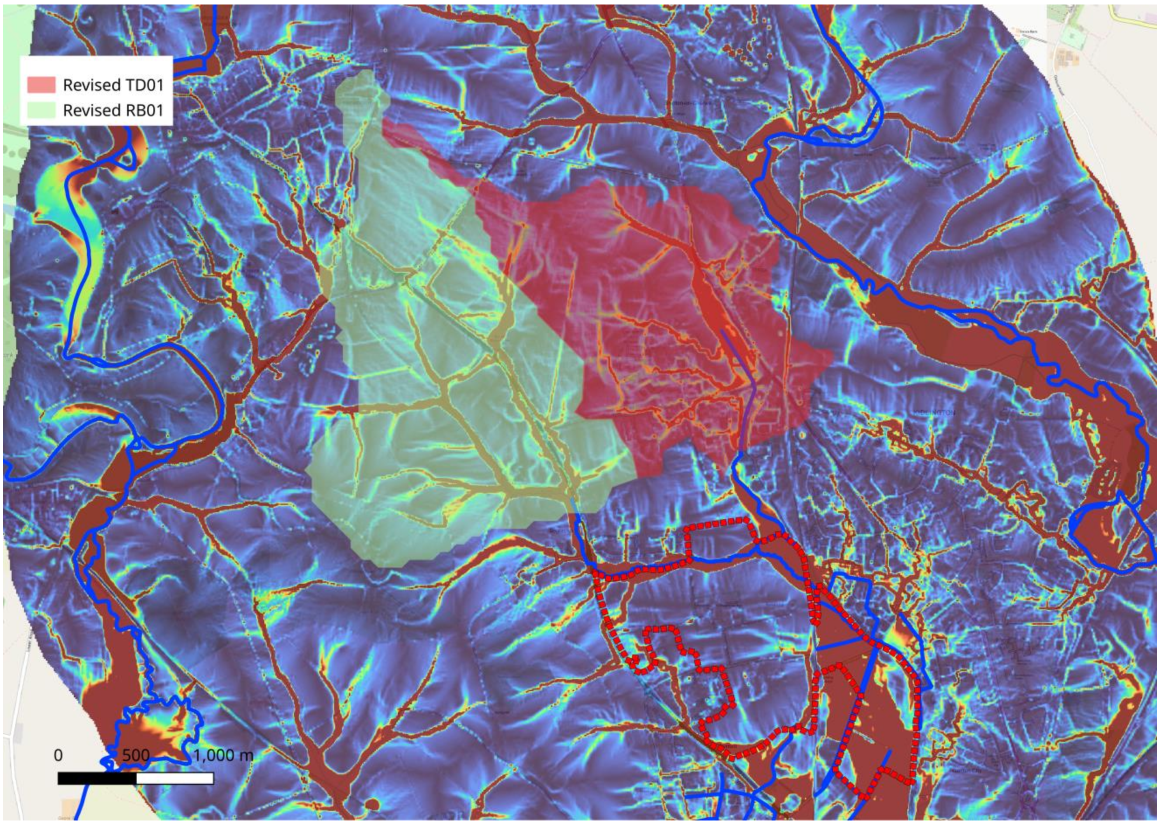


*Figure 6 Revised contributing catchments at RB01 and TD01 according to the DRM results.*

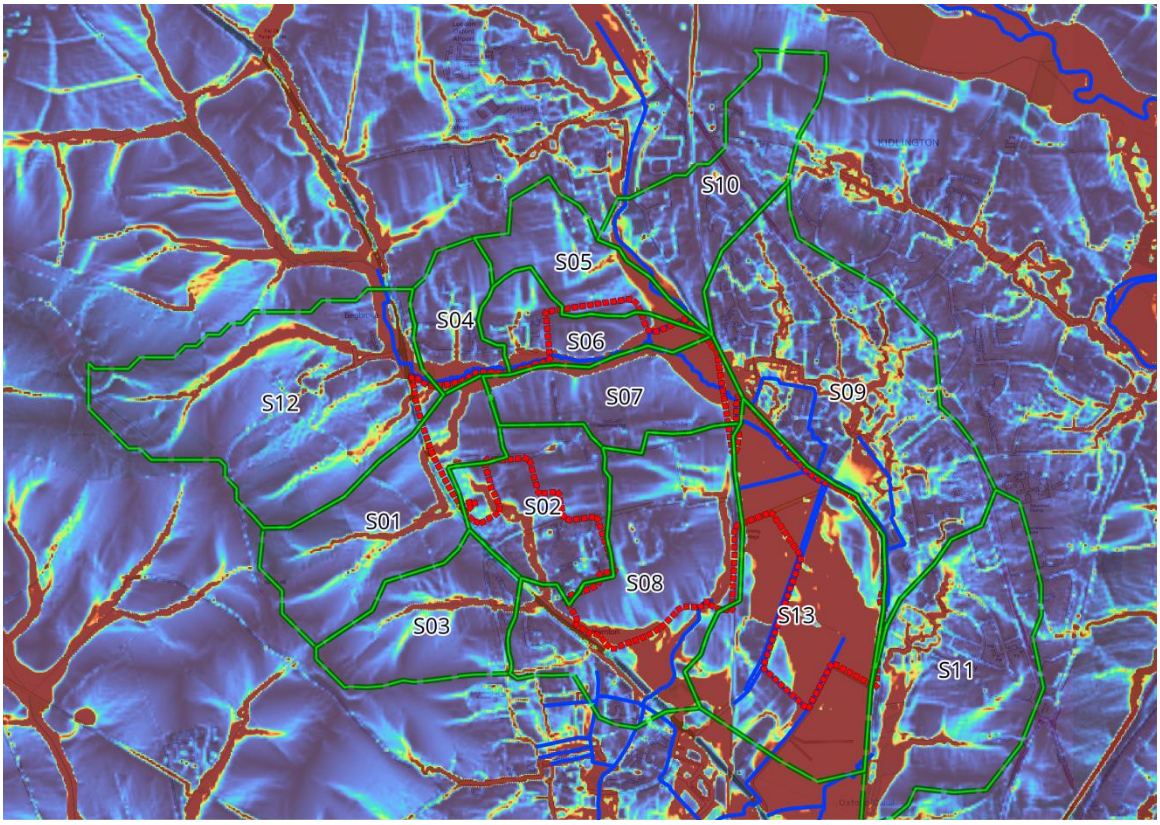


*Figure 7 On and off site subcatchments delineated using the DRM results for which lumped or distributed inflows are being incorporated in the hydraulic model. Subcatchment S08 has replaced the lumped contributing area at SD01 (Southern Drainage Ditch) in the final revision of the hydrological analysis.*

Revised Areas in 3.1 are the results of adjustments made according to the results of the DRM.

**URBEXT source and method for updating:**

Default URBEXT2000 updated according to UEF (Section 2.3 FEH guidelines[2]) to present day at main inflow locations RB01, RD01 and SD01. At KB01 URBEXT2000 estimated in WINFAP5 from the extent of the URBAN area as defined on the basis of OS mapping (Section 2.3 FEH guidelines[2]).

**BFIHOST source, checks and updates:**

BFIHOST19 values are consistent with soils and geology maps (see Figure 4).

**Checks and revisions to other catchment descriptors:**

FARL was checked against OS mapping and found to be appropriate.

# 4. Stationary statistical methods

## 4.1 Method overview

**What is the purpose of applying these methods?**

Peak flow estimation at all required inflow locations and in addition at downstream location KB01.

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

| Site code | Methods used for QMED | Methods used for growth curves |
|---|---|---|
| RB01 | DT | |
| TD01 | DT | |
| SD01 | DT | |
| KB01 | DT | Pooling, small catchment method (compared with standard SDM method) |

---

## 4.2 Estimating QMED

**QMED at gauged subject sites:**

| 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 ($m^3/s$) |
|---|---|---|---|---|---|---|---|---|
| RB01 | DT | 0.154 | 39002 | 15.28 | | 1.020 | 1.045 | 0.164 |
| TD01 | DT | 0.085 | 39002 | 16.76 | | 1.015 | 1.901 | 0.164 |
| SD01 | DT | 0.065 | 39002 | 16.52 | | 1.022 | 1.142 | 0.075 |
| KB01 | DT | 0.651 | 39002 | 16.51 | | 1.019 | 1.342 | 0.891 |
| NOTE | QMED at RB01, TD01, and SD01 was derived for the FEH catchment areas in 3.1 during the initial stage of analysis. QMED at KB01 was recalculated for the revised catchment area and descriptors as detailed in 3.1 and 3.2. | | | | | | | |

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

**Urban adjustment of QMED:**

Urban adjustment procedures applied in WINFAP5

**Search for donor sites:**

The search for potential suitable donors to all subject sites has mainly focused on evaluating the suitability of the closest gauge. This is also in line with current guidance on peak flow estimation on small catchments. The closest NRFA gauge to all subject sites except TD01 is 39002 (Thames@DaysWeir). The guage is approximately 15-16km away from all subject sites. Despite being characterised by a catchment area substiantially larger than all subject sites, 39002 has been selected as QMED donor, as it is a suitable donor and also provides conservative estimates of QMED at all subject sites. With respect to TD01, gauge 39002 is the second nearest suitable gauge to the subject site, the closest gauge being NRFA 39034 (Evenlode@Cassington). However, 39002 provides a more conservative estimate and has also been selected to ensure consistency in the donor adjustment factors calculated across the area of study. It should be noted that all potential donors located within 30km from the subject sites are characterised by catchment areas substantially larger than the subject sites (with the smallest area being approximately 230km$^2$).

**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) |
|---|---|---|---|---|---|---|
| 39002 | AM | No | 148.014 | 141.243 | 133.189 | 1.060 |

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 |
|---|---|---|---|---|---|---|
| KB01 | P | KB01 | GL, best fit | Urban | 1<br>0.287<br>-0.221 | 3.291 |

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? |
|---|---|---|---|---|---|
| KB01 | KB01 | No | 0.03 | Yes | Yes |

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 |
|---|---|---|
| PG01 | According to EA recommendation[3], gauge 26017 Ings Beck@South Newbald was removed from the default pooling group. This was found to be heterogeneous. A review of the pooling group was undertaken based on the distribution of L-moments. Therefore, the NRFA gauges 27073, 25019, 27051, 39033, 33054, 7011 were all further investigated. The review of information available on the NRFA did not provide justification for the removal of theses gauges from the default pooling group. No other gauge has been | 0.305<br>0.197 |

| Name of group | Changes made to default pooling group, with reasons | Weighted average L-moments |
|---|---|---|
| | added to the pooling group. | |

## 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 |
|---|---|---|
| RB01 | Urban/donor adjusted QMED; best estimate based on available data. | KB01 GC selected for this site; selected as appropriate due to the extent of area of study |
| TD01 | Urban/donor adjusted QMED; best estimate based on available data. | Same as for RB01 |
| SD01 | Urban/donor adjusted QMED; best estimate based on available data. | Same as for RB01 |
| KB01 | Urban/donor adjusted QMED; best estimate based on available data. | Pooled growth curve based on GL distribution, small catchments pooling method. Best fit. The small catchments pooling method results have been compared with the standard pooling results (not reported here) and found to be more conservative. |
| NOTE | It should be noted that the *final* QMED estimates at RB01, TD01, and SD01 in 4.2 were derived for the FEH catchment areas during the initial stage of analysis. The final QMED estimates at RB01, TD01, and SD01 in the table below are equlivalent to the QMED estimates in 4.2 adjusted by the ratios of catchment area, i.e. Revised Area/FEH Area as detailed in table 3.1. | |

**Final flood estimates from stationary statistical methods:**

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.180 | 0.263 | 0.326 | 0.438 | 0.498 | 0.591 | 0.699 | 0.869 | 1.022 |
| TD01 | 0.176 | 0.258 | 0.319 | 0.429 | 0.488 | 0.579 | 0.684 | 0.851 | 1.001 |
| SD01 | 0.120 | 0.177 | 0.218 | 0.294 | 0.334 | 0.396 | 0.469 | 0.583 | 0.685 |
| KB01 | 0.891 | 1.306 | 1.615 | 2.171 | 2.471 | 2.932 | 3.466 | 4.308 | 5.068 |

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

# 5. Non-stationary statistical methods

## 5.1 Method Overview

**What is the purpose of applying these methods?**

**What methods will be used?**

| Site code | If ungauged, which gauging station is being used? | Methods used to test for trends and change points | Methods used for non-stationary frequency analysis |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

## 5.2 Testing for trends and change points

**Non-parametric trend tests:**

**Step change tests:**

**Split sample tests:**

**Interpretation and conclusions:**

## 5.3 Non-stationary frequency analysis

**Selection of covariates:**

**Fitting non-stationary models:**

**Interpretation and conclusions:**

**Final flood estimates from non-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% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

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

# 6. Revitalised flood hydrograph (ReFH1) method

## 6.1 Method Overview

**What is the purpose of applying this method?**

**Rural and urban catchment sub-divisions:**

## 6.2 Model Parameters

**Summary of model parameters:**

| Site code | Method | Tp (hours) rural | Tp (hours) urban | Cmax (mm) | BL (hours) | BR | $PR_{imp}$ % |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

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:**

## 6.3 Model inputs for design events

**Design events for lumped catchments:**

| Site code | Rainfall DDF model | Urban or rural | Season of design event | Storm duration (hrs) | Initial soil moisture Cini | Initial baseflow BFO |
|---|---|---|---|---|---|---|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

**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:**

---

## 6.4 Final choice of ReFH1 flow estimates

**Method choice and reasons:**

| Site code | Final choice of design inputs and model parameters |
|---|---|
| | |
| | |
| | |
| | |

**Final flood estimates from ReFH1 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% |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |

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

---

# 7. Revitalised flood hydrograph 2 (ReFH2) method

## 7.1 Method Overview

**What is the purpose of applying this method?**

To derive peak flow estimates to compare with the Statistical estimates. To derive a hydrograph shape for two representative storm durations.

**Rural and urban catchment sub-divisions:**

Based on standard ReFH2 equations

**Version of ReFH2 applied:**

ReFH2 3.3 with DDF13

## 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 |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | CD | 4.311 | 918.421 | 53.316 | 0.093 | 0.75 | 0.4 | 0.7 | 0.5 |
| TD01 | CD | 4.047 | 1081.717 | 53.928 | 0.904 | 1 | 0.4 | 0.7 | 0.5 |
| SD01 | CD | 2.385 | 590.556 | 38.734 | 0.112 | 0.75 | 0.4 | 0.7 | 0.5 |
| KB01 | CD | 6.748 | 810.759 | 60.568 | 3.144 | 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:**

Model parameters derived from catchment descriptors. No further analysis carried out.

## 7.3 Model inputs for design events

**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 |
|---|---|---|---|---|---|---|---|
| RB01 | DDF13 | Rural | Yes | Winter | 7.5 | 60.746 | 0 |
| TD01 | DDF13 | Rural | Yes | Summer | 6.5 | 27.742 | 0 |
| SD01 | DDF13 | Rural | No | Winter | 3.5 | 79.134 | 0.006 |
| KB01 | DDF13 | Rural | Yes | Winter | 11 | 65.455 | 0 |

**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 |
|---|---|---|---|---|---|---|
| SD01 | DDF13 | Winter | 3.5 | 0.811 | 0.977 | Representative of critical storm for fast response hydrological features at the site location |
| KB01 | DDF13 | Winter | 11 | 14.056 | 0.96 | Representative of the overall critical storm conditions for the wider watershed including the site |

**Storm duration testing:**

Both 3.5hr and 11 hr storm durations tested in the hydraulic modelling at all events.

## 7.4 Final choice of ReFH2 flow estimates

**Method choice and reasons:**

| Site code | Final choice of design inputs and model parameters |
|---|---|
| RB01 | Model parameters from catchment descriptors. Recommended storm duration for lumped estimates and design storms at SD01 and KB01 for distributed modelling. |
| TD01 | Model parameters from catchment descriptors. Recommended storm duration for lumped estimates and design storms at SD01 and KB01 for distributed modelling |
| SD01 | Model parameters from catchment descriptors. Recommended storm duration for lumped estimates and design storms at SD01 and KB01 for distributed modelling |
| KB01 | Model parameters from catchment descriptors. Recommended storm duration for lumped estimates and derivation of design hydrographs for subcatchments. Additional design storm at SD01 for the purpose of deriving the subcatchments design hydrogaphs. |

**Final flood estimates from ReFH2 method:**

| Site code | 2<br>50% | 5<br>20% | 10<br>10% | 30<br>3.3% | 50<br>2% | 100<br>1% | 200<br>0.5% | 500<br>0.2% | 1000<br>0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.18 | 0.27 | 0.33 | 0.44 | 0.50 | 0.60 | 0.72 | 0.91 | 1.08 |
| TD01 | 0.10 | 0.16 | 0.21 | 0.30 | 0.35 | 0.43 | 0.54 | 0.72 | 0.88 |
| SD01 | 0.11 | 0.16 | 0.20 | 0.26 | 0.29 | 0.35 | 0.41 | 0.51 | 0.59 |
| KB01 | 0.65 | 0.93 | 1.14 | 1.52 | 1.74 | 2.08 | 2.49 | 3.13 | 3.68 |

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

## 8.2 FSR-FEH Rainfall-Runoff Method

## 8.3 Direct Rainfall Modelling

The Direct Rainfall Model developed as part of this study has been implemented solely for the purpose of assessing surface flow paths, refining FEH catchments and delineating subcatchments within the area of study. The DRM model has not being implemented to derive hydrological estimates and details on the DRM model built are provided in the main report.

# 9. Discussion and summary of results

## 9.1 Comparison of results from different methods

| Site code | *Ratio of ReFH2 to stationary statistical peak, 50% AEP* | *Ratio of ReFH2 to stationary statistical peak, 1% AEP* |
|---|---|---|
| RB01 | 1 | 1.015 |
| TD01 | 0.568 | 0.743 |
| SD01 | 0.917 | 0.884 |
| KB01 | 0.730 | 0.709 |

## 9.2 Final choice of method

**Choice of method and reasons:**

The statistical estimates, with:

- QMED from catchment descriptors and adjusted by donor transfer and for urbanisation;
- Growth factors for AEPs <50% from pooled analysis at KB01, applying the small catchments method and selecting the GL distribution

have been selected as final. A comparison between statistical and ReFH2 estimates has highlighted that the rainfall-runoff approach provides lower estimates compared to the statistical method. For all sites but SD01, current FEH guidelines would recommend the statistical method in preference to ReFH2, given the characteristics of the subject sites. Therefore, the statistical method has been selected to derive the final peak estimates at all sites for consistency. Hydrograph shapes are from ReFH2 and design hydrographs are derived from ReFH2 hydrographs scaled to match the statistical peaks. Design flows for the subcatchments as detailed in Figure 7 are derived from design hydrographs at KB01 scaled down by the ratio of catchment areas.

**How will the 0.1% AEP flows be estimated?**

Peak flows from Statistical method

**How will the flows be applied to a hydraulic model?**

Lumped inflows at RB01, TD01, and SD01. Design flows for the subcatchments are going to be applied as lumped or distributed inflows in the hydraulic model. Details of peak flow estimates for subcatchments and the application of subcatchments design hydrographs in the hydraulic model are included in the main report.

## 9.3 Final results

| Site code | 2<br>50% | 5<br>20% | 10<br>10% | 30<br>3.3% | 50<br>2% | 100<br>1% | 200<br>0.5% | 500<br>0.2% | 1000<br>0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.180 | 0.263 | 0.326 | 0.438 | 0.498 | 0.591 | 0.699 | 0.869 | 1.022 |
| TD01 | 0.176 | 0.258 | 0.319 | 0.429 | 0.488 | 0.579 | 0.684 | 0.851 | 1.001 |
| SD01 | 0.120 | 0.177 | 0.218 | 0.294 | 0.334 | 0.396 | 0.469 | 0.583 | 0.685 |
| KB01 | 0.891 | 1.306 | 1.615 | 2.171 | 2.471 | 2.932 | 3.466 | 4.308 | 5.068 |

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 |
|---|---|---|---|---|---|
| SD01 | Winter | 3.5 | 0.811 | 3.33%AEP<br>1%AEP<br>1%AEP+26%climate change<br>1%AEP+41%climate change<br>0.1%AEP | Representative of critical storm for fast response hydrological features at the site location |
| KB01 | Winter | 11 | 14.056 | 3.33%AEP<br>1%AEP<br>1%AEP+26%climate change<br>1%AEP+41%climate change<br>0.1%AEP | Representative of the overall critical storm conditions for the wider watershed including the site |

**Climate change allowances:**

Central (26%) and higher (41%) peak flow allowances for the 2080s epoch (Gloucestershire and Vale Management Catchment [4]).

[4] Environment Agency. Flood risk assessments: climate change allowances. Last Updated May 2022 https://environment.data.gov.uk/hydrology/climate-change-allowances/river-flow

## 9.4 Checks

**Growth factor checks:**

| Site code | 1% AEP growth factor | 0.1% AEP / 1% AEP ratio |
|---|---|---|
| KB01 | 3.291 | 1.729 |

**Specific discharge: NA**

| Site code | 2 50% | 5 20% | 10 10% | 30 3.3% | 50 2% | 100 1% | 200 0.5% | 500 0.2% | 1000 0.1% |
|---|---|---|---|---|---|---|---|---|---|
| RB01 | 0.506 | 0.742 | 0.918 | 1.234 | 1.404 | 1.666 | 1.970 | 2.448 | 2.880 |
| TD01 | 0.659 | 0.966 | 1.194 | 1.605 | 1.827 | 2.168 | 2.563 | 3.186 | 3.748 |
| SD01 | 1.485 | 2.177 | 2.693 | 3.619 | 4.120 | 4.888 | 5.779 | 7.184 | 8.450 |
| KB01 | 0.634 | 0.929 | 1.149 | 1.545 | 1.758 | 2.086 | 2.466 | 3.065 | 3.606 |

Flood peak in l/s/ha for the return periods in years or AEP (%) events.

**Spatial consistency of results:**

Given the characteristics and extent of the area of study, the spatial consistency of results has not been assessd.

**Return periods for notable historic floods:**

NA

**Compatibility with longer-term flood history:**

NA

**Comparisons with previous studies:**

NA

**Checks on hydraulic model results:**

Sensitivity testing on hydraulic model results are reported on in the main report

---

## 9.5 Assumptions, limitations, and uncertainty

**Assumptions (specific to this study):**

- QMED and pooling suitability assessed on the basis of information available on the NRFA; no local gauge available
- Adjustment to catchment boundaries and distribution of contributing runoff to local watercourses is made in accordance to the topography of the area

and the results of a direct rainfall model. Thus, it is assumed that surface runoff processes are most likely to inform a correct representation of the subcatchments contributions across the study area.

**Limitations:**

- Statistical method applied outside AEPs range of applicability;
- Hydrological catchments of interest are all ungauged. Hydrological response is highly affected by local topographical features and alterations to hydrological connectivity due to artificial drainage. While a better understanding of flow paths within the area of interest has been achieved through direct rainfall modelling, the lack of local hydrometric data remains a key limitation in the results.

**Uncertainty:**

| Site code | 50% AEP Lower 95% | 50% AEP Upper 95% | 5% AEP Lower 95% | 5% AEP Upper 95% | 1% AEP Lower 95% | 1% AEP Upper 95% | 0.1% AEP Lower 95% | 0.1% AEP Upper 95% |
|---|---|---|---|---|---|---|---|---|
| RB01 | 0.090 | 0.363 | Na | Na | 0.278 | 1.254 | 0.460 | 2.280 |
| SD01 | 0.048 | 0.302 | Na | Na | 0.135 | 1.165 | 0.199 | 2.364 |
| KB01 | 0.356 | 2.236 | Na | Na | 0.997 | 8.620 | 1.470 | 17.485 |

Upper and lower 95% confidence bounds for the flood peak in $m^3/s$ for the AEP (%) events. Note: Confidence bounds at TB01 are not provided because the catchment is heavily urbanised.

**Suitability of results for future studies:**

Assessment of flood risk specific to the area of interest of current project.

**Recommendations for future work:**

A higher degree of confidence in the results might be achieved by incorporating local hydrometric data in the analysis.

# 10. Appendix

## 10.1 Digital files

**Input data:**

**Project or calculation files:**

**Output data:**

## 10.2 Other Supporting Information

*Table 1 Pooling group at KB01*

| | Station | Distance (SDM) | Years of data | QMED AM | L-CV Observed | L-CV Deurbanised | L-SKEW Observed | L-SKEW Deurbanised | Discordancy |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 36010 (Bumpstead Brook @ Bro | 0.555 | 54 | 7.545 | 0.372 | **0.374** | 0.168 | **0.167** | 1.183 |
| 2 | 26016 (Gypsey Race @ Kirby Gr | 0.580 | 24 | 0.103 | 0.304 | **0.304** | 0.240 | **0.240** | 0.088 |
| 3 | 27073 (Brompton Beck @ Snain | 0.617 | 41 | 0.820 | 0.212 | **0.213** | 0.006 | **0.005** | 0.838 |
| 4 | 26014 (Water Forlornes @ Driffie | 0.790 | 23 | 0.437 | 0.315 | **0.316** | 0.164 | **0.163** | 0.350 |
| 5 | 25019 (Leven @ Easby) | 0.838 | 43 | 5.677 | 0.334 | **0.335** | 0.373 | **0.372** | 0.747 |
| 6 | 39033 (Winterbourne Stream @ | 1.015 | 59 | 0.403 | 0.338 | **0.338** | 0.375 | **0.375** | 1.178 |
| 7 | 27051 (Crimple @ Burn Bridge) | 1.016 | 49 | 4.564 | 0.217 | **0.218** | 0.143 | **0.142** | 0.785 |
| 8 | 36004 (Chad Brook @ Long Mel | 1.020 | 54 | 4.873 | 0.301 | **0.302** | 0.170 | **0.169** | 0.458 |
| 9 | 33054 (Babingley @ Castle Risir | 1.022 | 45 | 1.136 | 0.229 | **0.229** | 0.183 | **0.182** | 1.109 |
| 10 | 7011 (Black Burn @ Pluscarden | 1.069 | 9 | 5.205 | 0.491 | **0.491** | 0.521 | **0.521** | 2.431 |
| 11 | 26013 (Driffield Trout Stream @ | 1.099 | 11 | 2.700 | 0.281 | **0.282** | 0.196 | **0.195** | 2.597 |
| 12 | 36003 (Box @ Polstead) | 1.134 | 61 | 3.900 | 0.311 | **0.313** | 0.082 | **0.080** | 1.001 |
| 13 | 33032 (Heacham @ Heacham) | 1.136 | 53 | 0.449 | 0.297 | **0.298** | 0.129 | **0.128** | 0.234 |
| 14 | | | | | | | | | |
| 15 | Rejected Stations | | | | | | | | |
| 16 | 26017 (Ings Beck @ South New | 0.364 | 22 | 0.502 | 0.215 | 0.216 | 0.060 | 0.059 | |
| 17 | | | | | | | | | |
| 18 | | | | | | | | | |