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Working with water

Review of surface water flood management

Fulbourn

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1. Introduction

The overall objective of this work was to define the extent of surface water flooding, and determine the efficacy of the outline flood management measures for a proposed development site located in the village of Fulbourn located to the east of the city of Cambridge in Cambridgeshire. The Environment Agency's surface water flood map, shown in Figure 1.1, indicates that the site will be affected by surface water flooding during periods of extreme rainfall.

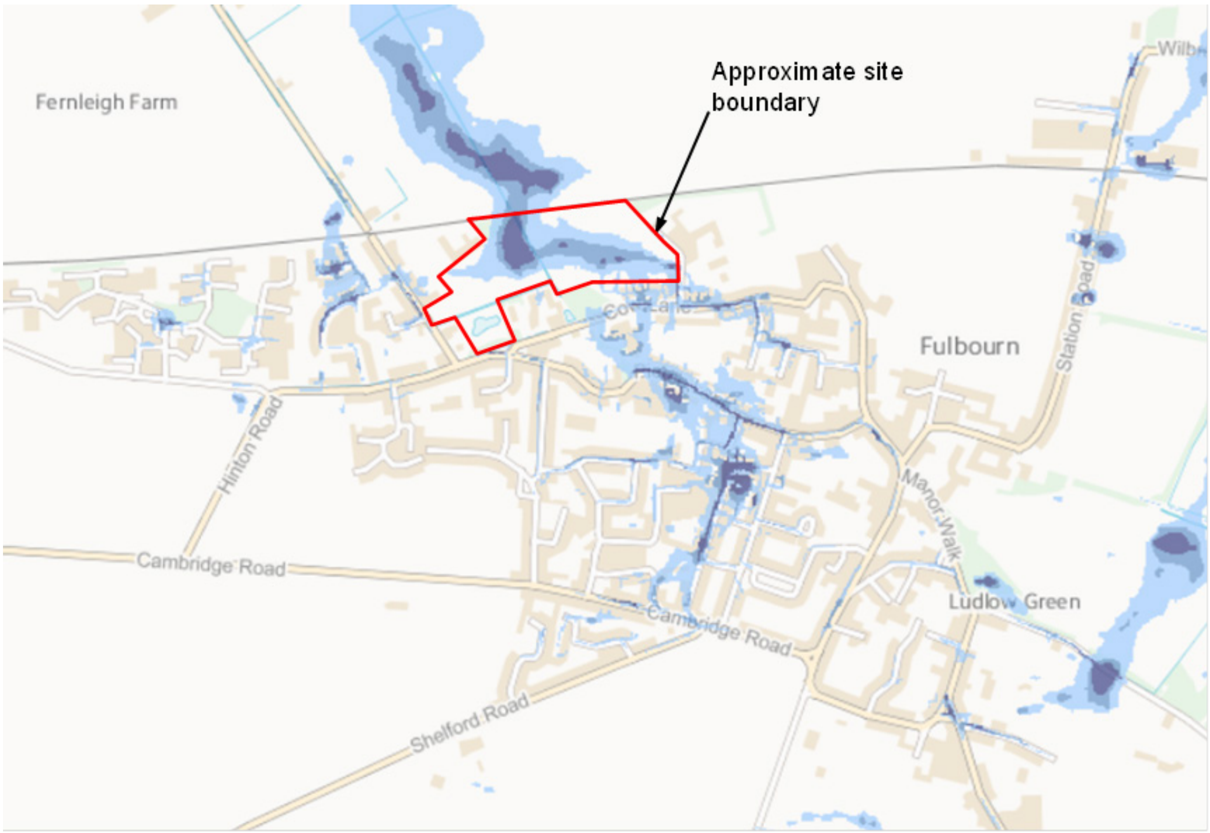

Figure 1.1: Environment Agency surface water flood map

Source: Environment Agency, 2015

As part of the study it will be necessary to estimate the 1 in 30 year (3.33% annual probability), 1 in 100 year (1% annual probability), 1 in 100 year climate change flows (i.e. +40%) and 1 in 1,000 year (0.1% annual probability) return period flood depths and extents associated with surface water flooding on the site, as well as assessing flood management measures to protect the proposed development from inundation by surface water floodwater, whilst also helping to avoid an increase in downstream flood risk.

We undertook a visit to the site on 28 April 2016. The objective of this site visit was to gain a better understanding of the hydrology of the catchment and the hydraulics of the watercourse including the downstream culvert that carries the drainage ditch under the railway to the north of the site.

2. Hydrology

2.1. Background to the catchment

The ungauged catchment draining to the site covers an area of some 1 km^2. The underlying geology is free draining chalk, although the catchment is quite heavily urbanised. This makes estimating flood flow hydrographs for the catchment challenging. Our approach is detailed below.

The catchment boundary in the Flood Estimation Handbook (FEH) draining to the site was found to be undersized when checked against a higher resolution LiDAR Digital Terrain Model (DTM). The catchment area derived from the LiDAR data was found to be 1.06 km^2 compared with 0.5 km^2 from the FEH. A comparison of the FEH and LiDAR-derived catchment boundaries is shown in Figure 2.1.

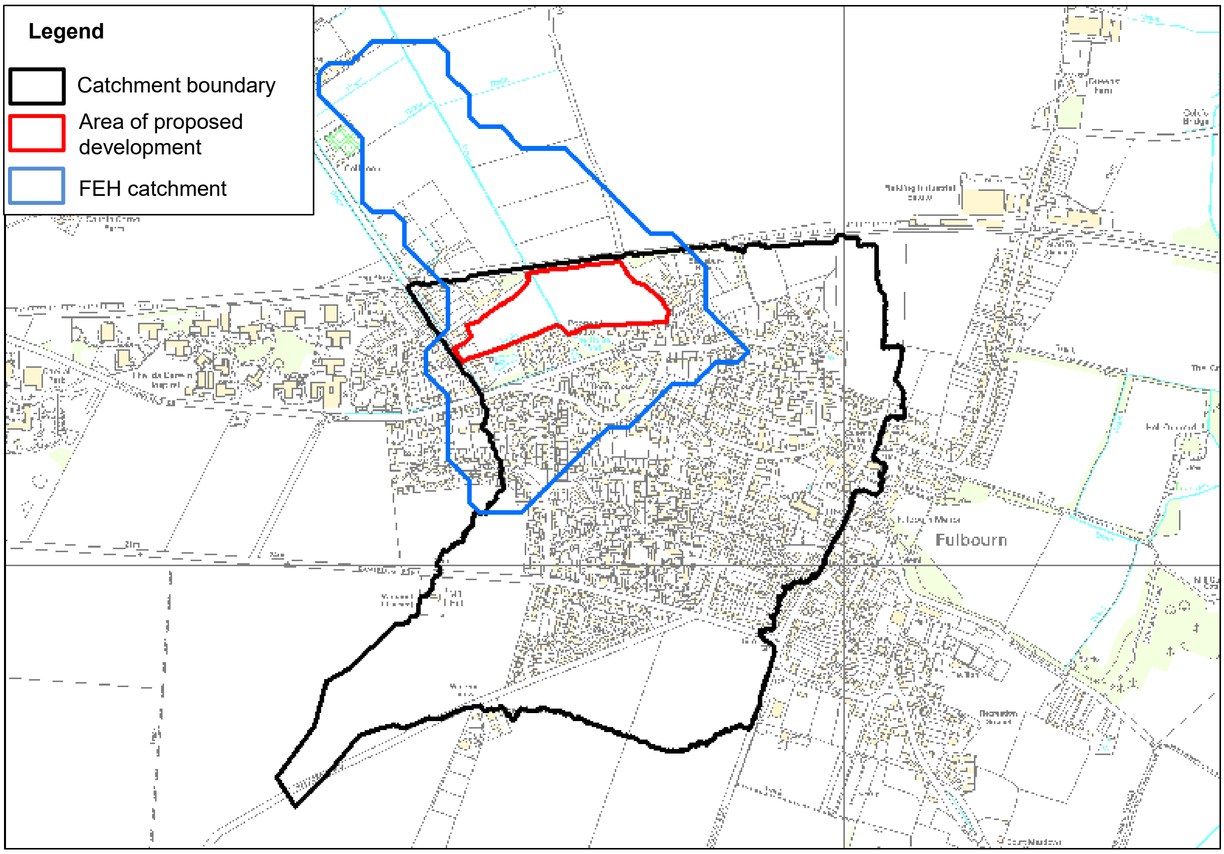

Figure 2.1: Catchment boundary from FEH and LiDAR

The UK soils map was used to check the Standard Percentage Runoff (SPR) for the catchment. This shows that the predominant soils class in the catchment is very permeable (511e with Host class of 1) and that using a FEH-derived SPR of 4.81 from catchment descriptors is appropriate.

2.1.1. Hydrological approaches to estimating flood flows

There are a number of hydrological approaches that can be used to estimate flood flows for the site including:

- **Direct rainfall approach** using a two dimensional (2D) model of the entire catchment to simulate the surface flow paths towards the drainage channel that runs through the site.
- **The FEH Revitalised Flood Hydrograph model (ReFH2**) rainfall runoff method – It is acceptable to use this method because the catchment is small, highly permeable and has a large proportion of urban area. ReFH2 has improvements for modelling the urban component of runoff compared to previous versions of the FEH rainfall-runoff methods.
- **The FEH statistical method** – This method is unlikely to be suitable for a catchment of this nature given the extent of the urban area, the high permeability of the soil and its small area.

We have thus undertaken ReFH2 and a direct rainfall approach to the hydrology.

2.1.2. Adjustment of catchment descriptors

The catchment descriptors from the FEH were adjusted to account for the catchment area because this is twice the value that is given in the FEH. The parameters that are most likely to be influenced by the change in catchment area are:

- DPLBAR – Average drainage path length
- DPSBAR – Average catchment slope
- URBEXT2000 – Urban extent.

The DPLBAR for the revised catchment area has been estimated using the equation in FEH1999 volume 1

$DPLBAR = AREA^{0.548}$

Assuming a catchment area of 1.06 km^2 gives a revised DPLBAR for the catchment of 1.032 km.

DPSBAR has been checked for the revised catchment area and found to be similar to that in the FEH catchment descriptors.

The urban area within the catchment was measured using the Ordnance Survey (OS) OS50K map as described in the ReFH2 Technical Report. The urban area within the revised catchment is 0.604 km^2 and the impermeable extent of the urban has been measured from the OS10K maps as 0.14 km^2 (These are shown in Figure 2.2). This is 29% of the urban area and is very similar to the default of 30% assumed in the ReFH2 Technical Report. The default value has been used in the calculations because this will result in slightly higher flows.

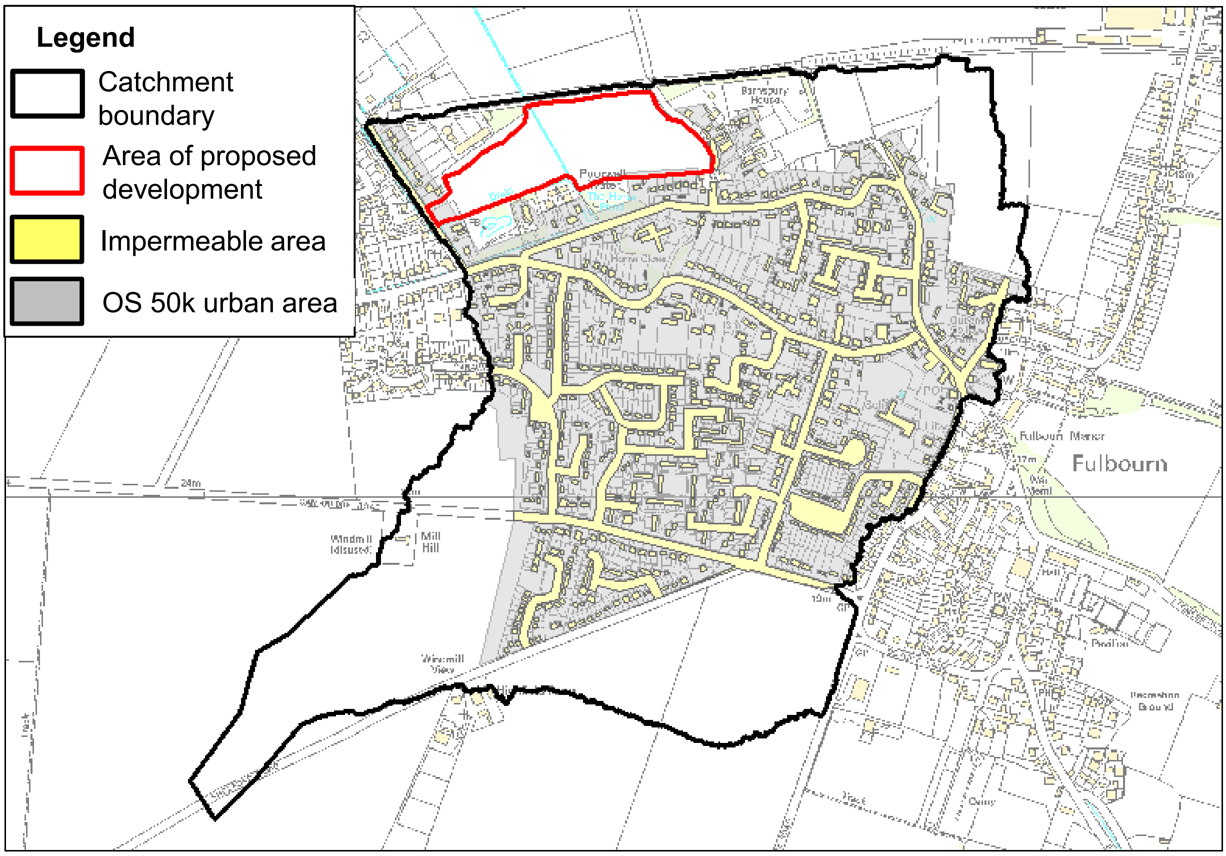

Figure 2.2: Urban area and the impermeable area within the catchment

2.2. Revitalised Flood Hydrograph model (ReFH2)

The revised catchment descriptors were entered into the FEH ReFH2 version 2.1 software and hydrographs were simulated for the following range of storm durations:

- 1.25 hour
- 3.25 hours
- 5.5 hours
- 9 hours.

The summer rainfall profile produced a higher peak flow than the winter storm profile for the rainfall depth-duration-frequency (DDF) information for the catchments derived from the new FEH rainfall model (FEH, 2013). This is because it is more "peaky" than the winter profile, owing to the prevalence of intense convective storms during the summer. This means the intensity is greater in the middle of the storm, thus the summer profile is more likely to be critical for surface water flooding in a small urbanised catchment such as that of Fulbourn. The resulting hydrographs, shown in Figure 2.3, show that the 3.25 hour storm duration is critical in terms of peak flow.

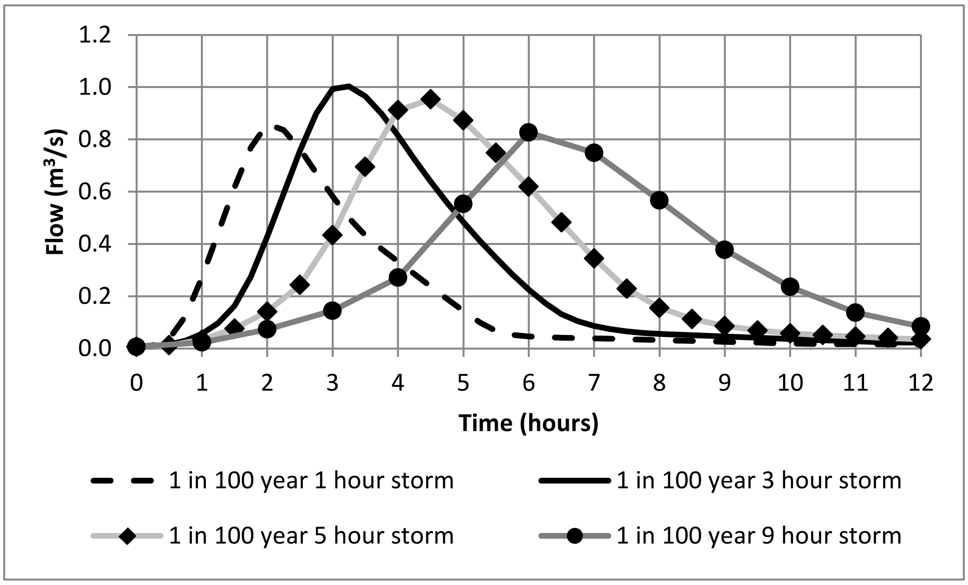

Figure 2.3: ReFH2 flood flow hydrographs

2.3. Direct runoff

The new FEH rainfall (FEH, 2013) was applied directly to a two dimensional (2D) hydrodynamic model mesh of the whole catchment. The ground elevations of the 2D mesh are based on LiDAR topographic data with a (0.5 m horizontal resolution). The average triangular mesh element area is 16 m^2. The model does not include the drainage ditches or channels that run through the site or along-side roads. The main drainage ditch crossing the site has been included as a one dimensional (1D) hydraulic model. A base flow of 0.1 m^3/s has been included in this ditch.

The percentage runoff applied was based on that from ReFH2 model. The rural areas use the percentage runoff of 6.1% calculated from a 'rural' ReFH2 run for the 3.25 hour 1 in 100 year return period summer storm. The urban areas follow the ReFH2 Technical Report where the area is split by the impermeable area, which is given a percentage runoff of 70% and the permeable area which has the same percentage runoff as the rural areas of the catchment. These values were combined to give an overall percentage runoff of 25.3% for the urban50K area.

Urban drainage systems vary in nature and their effectiveness in different storm events is linked to very local characteristics such as the arrangement and capacity of road gullies and whether drainage is via combined or separate sewerage systems. The Environment Agency has found that the calculated range of sewer capacities, in terms of rainfall, is in the range of 5 mm/hour to 54 mm/hour; with a typical drainage removal rate of 12 mm/hour across catchments in England and Wales. Anglian Water sewer plans do not indicate any surface water sewers within the identified catchment. We have therefore not accounted for drainage removal of rainfall in the model.

The advantage of the direct rainfall approach is that it is similar to the method that was used to produce the Environment Agency's surface water maps and it shows the flow paths of surface water flowing onto the site. This is shown in Figure 2.4, the main flow path is through the depression at the south of the site (Poorwell

Water), where the drainage channel starts. A second flow path is across the site from the east towards the drainage channel in the centre of the site. Approximately 70% of the total flow across the site follows the drainage path from the south and 20% follows the drainage path from the east and 10% from the south-west.

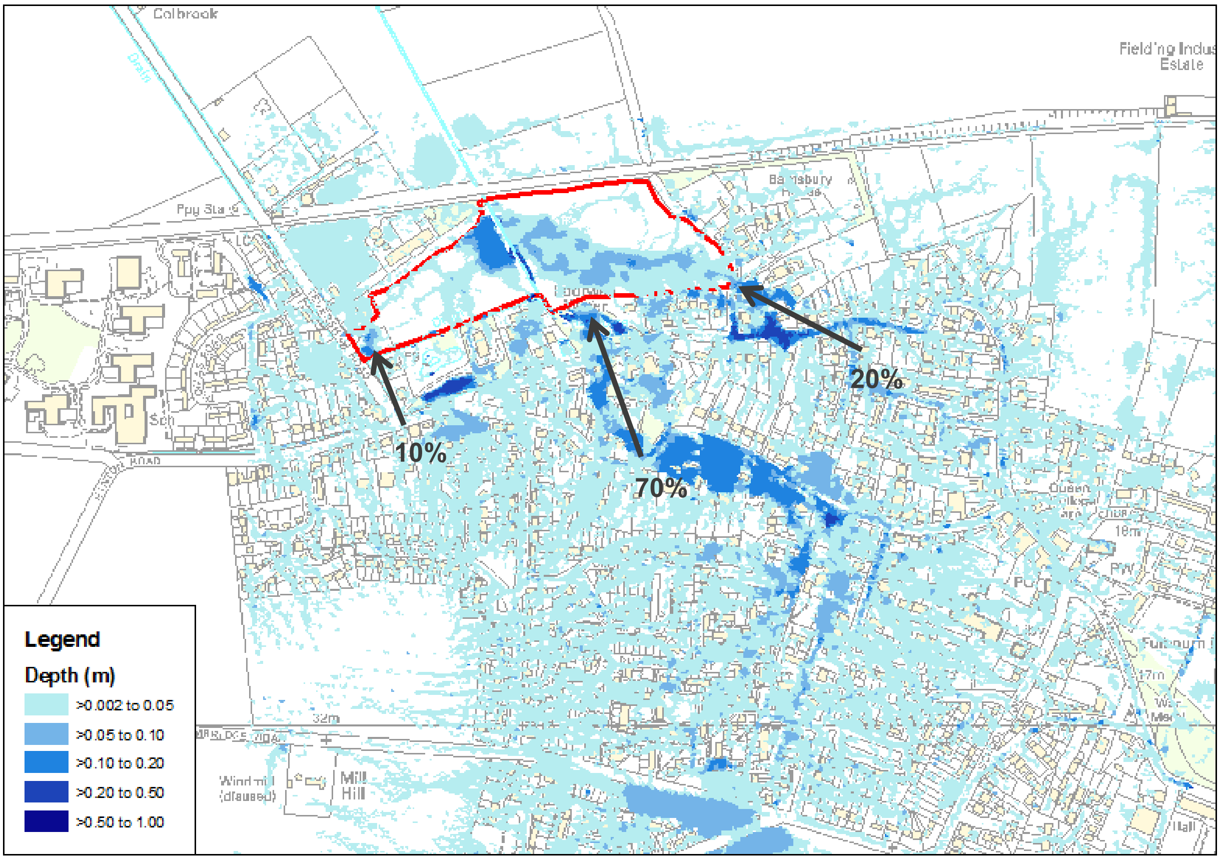

Figure 2.4: Surface water flow paths on the site

2.4. Comparison of flows

A comparison of the hydrographs generated using the ReFH2 and direct runoff methods is shown in Figure 2.5.

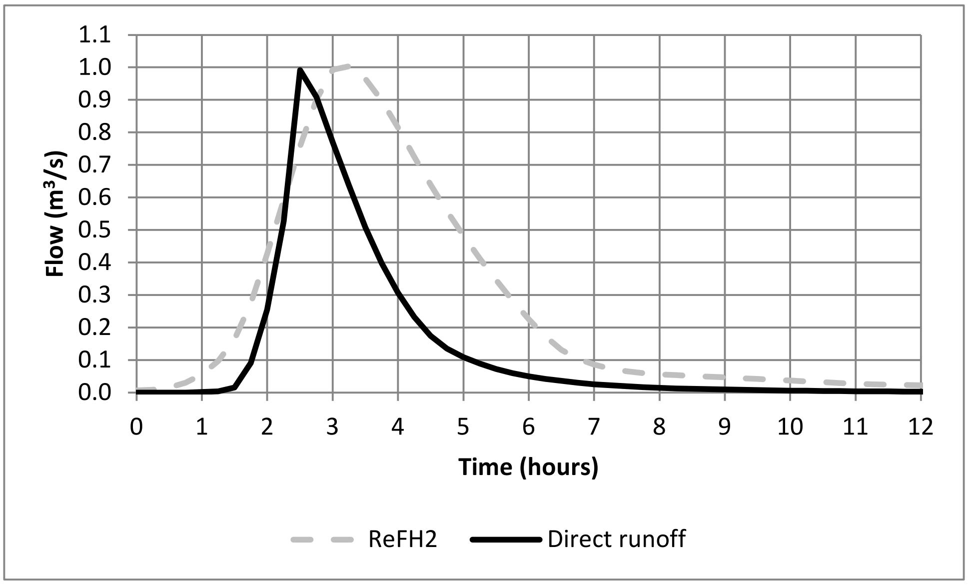

Figure 2.5: Flow hydrographs from ReFH and the Direct Rainfall method for the 3.25 hour 100 year storm

The main difference between the direct runoff approach and the ReFH2 is that not all of the catchment area defined by the DTM contributes flow along defined flow routes or even through the site because of the flat land at the base of the hill. Some of the difference between the hydrographs is also because ReFH2 includes the baseflow component, although this is very low approximately 0.02 m^3/s.

2.5. Final method

Owing to the complexity of the catchment geology and its high degree of urbanisation we carried out two dimensional (2D) hydraulic modelling of the entire 1 km^2 catchment using the InfoWorks ICM software with an appropriate terrain sensitive triangular grid. This size of the grid used in the model was more detailed where the changes in slope are largest and also areas of particular interest such as the site itself.

3. Integrated Catchment Model (ICM) hydraulic of the Fulbourn catchment

3.1. Hydrological components

The catchment has been divided up into permeability zones, depending on the land use, as described in Section 2.3.

3.2. Representation of the site

The 2D model hydraulic model described in Section 2.3 was revised to include high resolution mesh cells on and around the development site and to include the local drainage network through the site. The drainage network through the site was represented with 1D river sections and culverts in the ICM modelling software.

A base flow of 0.1 m^3/s was assumed for the drainage channels. The open channels are dynamically linked to the 2D mesh of the site and the surrounding catchment. At the time of the site visit there was dense vegetation on the banks of the channel with the channel bed relatively clear of vegetation. The Manning's 'n' roughness was therefore set to 0.03 on the channel bed and 0.05 to 0.075 on the sides of the channel, depending on the location. A typical view of the drainage channel through the site is shown in Photograph 3.1.

Photograph 3.1: Typical view of the drainage channel through the site

The culvert through the railway embankment was modelled with an arch culvert with a radius of 0.8 m and an invert level of 8.51 m AD. The Manning's n on the base was set to 0.03 and 0.018 on the arch. The 520 mm diameter circular culverts that link open drainage channels on the site was modelled with a Manning's n of 0.012.

The 2D mesh on the site was formed of a triangular mesh with the size of the triangles varying between 4 m^2 and 9 m^2. The ground levels have been taken from the local site topographic survey provided to us. The existing vegetation on the site is typically rough grass for which a Manning's n roughness of 0.04 is appropriate. Photograph 3.2 and 3.3 show typical views of the eastern and western parts of the site.

Photograph 3.2: Eastern area of the site, looking to the east

Photograph 3.3: Western areas of the site, looking towards the centre of the site

3.3. Representation of the post development site

Post development ground levels were provided by Cannon Consulting Engineers. The ground levels show three raised development platforms that are to be raised by a few hundred millimetres above the original ground level. The boundary of each platform indicated below includes the surface water (runoff) attenuation facilities for each platform. A revised hydraulic model of the site was setup with the proposed development platforms, a lowered landscaped area/wide based channel to convey flows from the south-eastern corner of the site, and five 150 mm diameter pipes beneath a footpath that joins the two platforms in the eastern part of the site. These are shown in Figure 3.1. The invert levels of the culverts are 9.50 m AOD. A wide box culvert under a road in the centre of the eastern platform allows flows to move westward. This culvert is 2m wide and 0.1 m high with an invert of 9.6 m AOD.

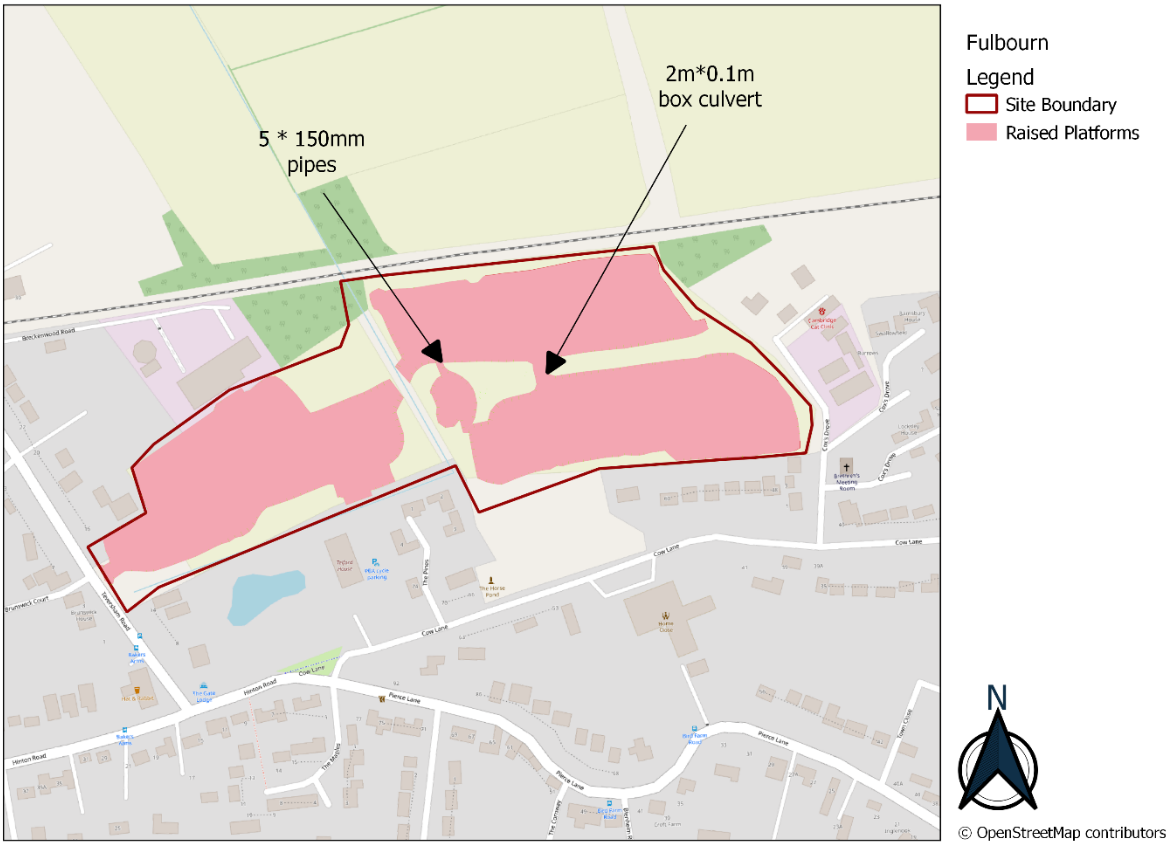

Figure 3.1: Development scheme showing the areas of land which are proposed to be raised

4. Results

4.1. Existing conditions

The InfoWorks ICM hydraulic model for existing conditions was run using FEH 2013 design rainfall profiles for the following return periods:

- 1 in 30 years
- 1 in 100 years
- 1 in 100 years plus 40% (Upper climate change scenario from the Environment Agency (2020))
- 1 in 1,000 years.

Flood extents and depths owing to surface water flooding on the site are shown in Figure 4.1 to Figure 4.4. The source of the water that causes the surface water flooding to the site is mainly from the adjacent housing and the site itself. Figure 4.1 to Figure 4.4 show that for the 1 in 30 year and 1 in 100 year annual probability return period rainfall events there is relatively shallow flow (i.e. < 10cm) across the site from the east towards the central channel. For the 1 in 1,000 year annual probability return period rainfall event this water is slightly deeper in places (i.e. up to 50 cm). The results of the modelling indicated that on the western part of the site there is an area of ponding next to the central channel in all rainfall events, where the bank level is higher than the surrounding land preventing the water draining into the channel. The depth of water in this area increases as the rainfall depth increases.

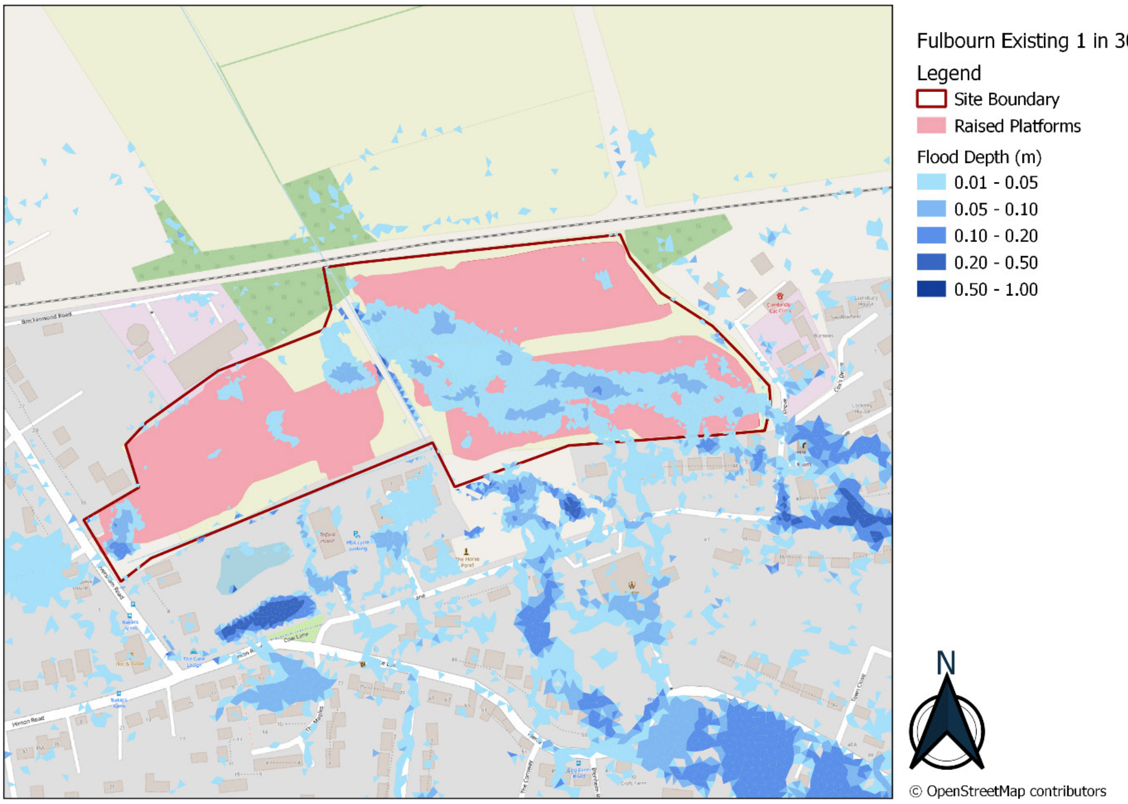

Figure 4.1: Surface water flood depths for the 1 in 30 year rainfall

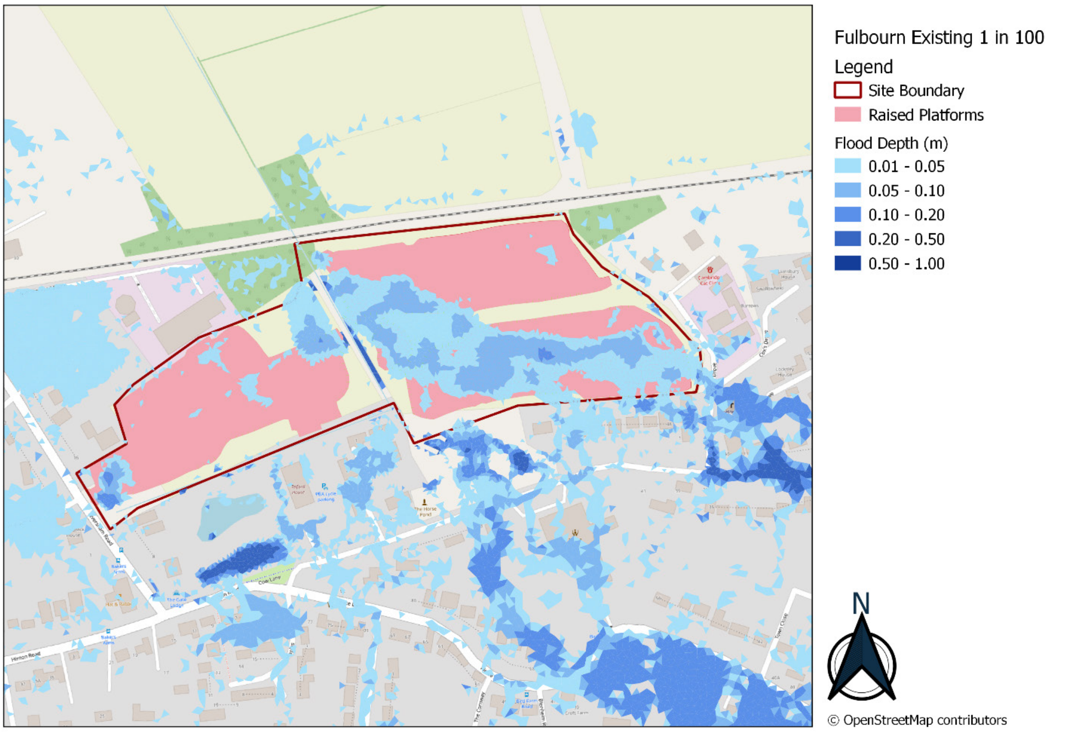

Figure 4.2: Surface water flood depths for the 1 in 100 year rainfall

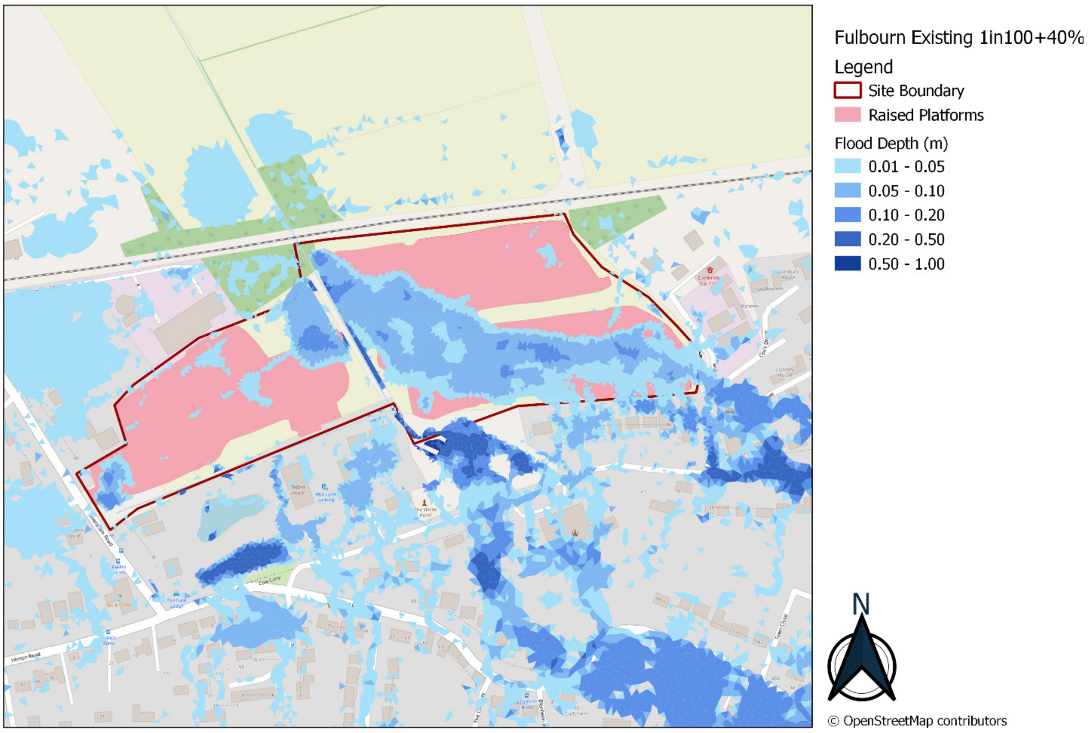

Figure 4.3: Surface water flood depths for the 1 in 100 year rainfall plus 40% climate change

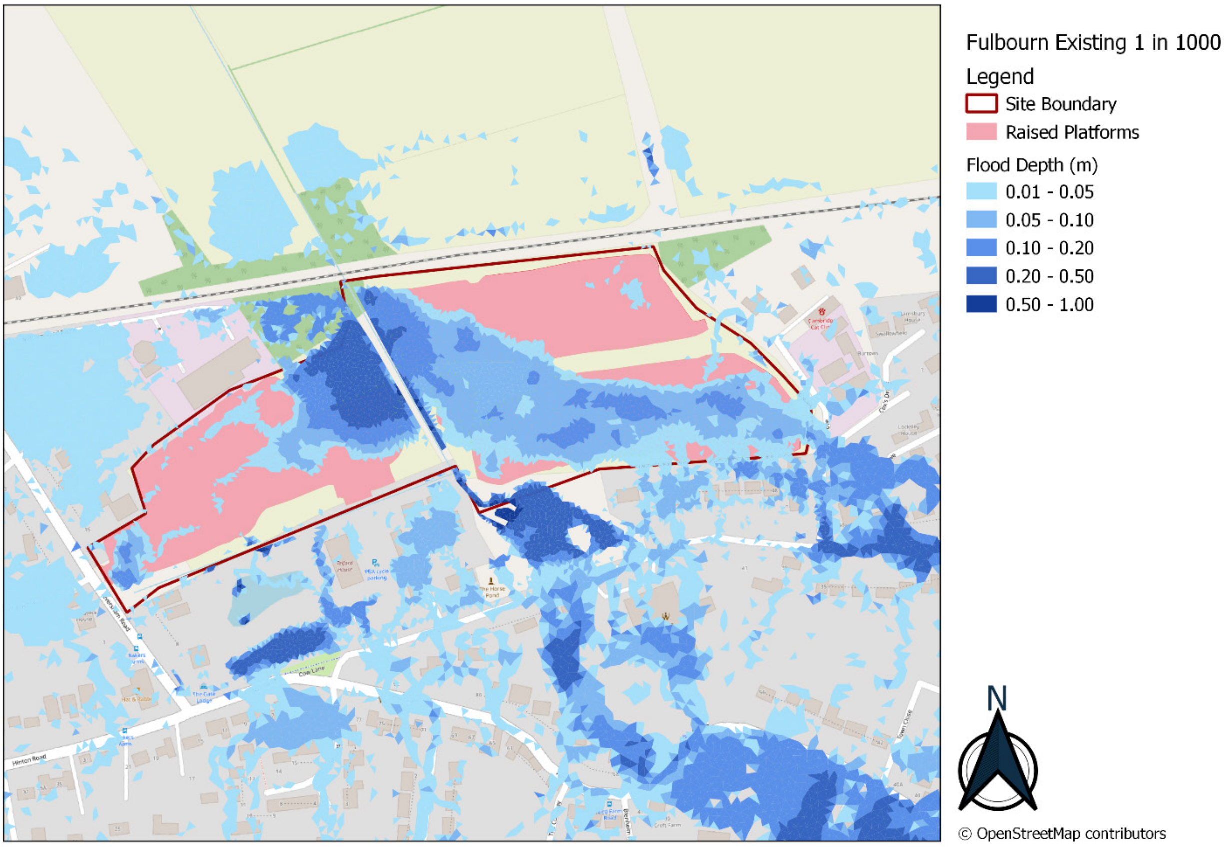

Figure 4.4: Surface water flood depths for the 1 in 1,000 year rainfall

4.2. Post development flood modelling

The InfoWorks ICM hydraulic model for the post development conditions (i.e. with the areas to be developed raised out of the surface floodwater) was run using the FEH 2013 design rainfall profiles for the following return periods:

- 1 in 30 years
- 1 in 100 years
- 1 in 100 years plus 40% (Upper climate change scenario from the Environment Agency (2020))
- 1 in 1,000 years.

Flood extents and depths owing to surface water flooding on the site are shown in Figure 4.5 to Figure 4.8.

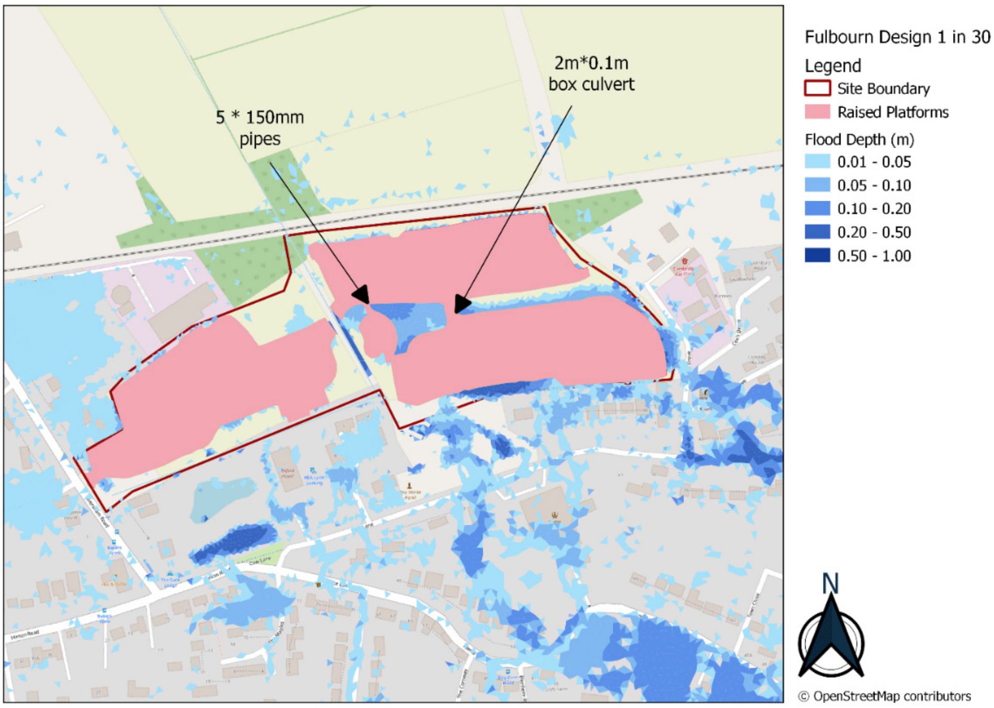

Figure 4.5: Surface water flood depths for the 1 in 30 year rainfall with the development in place

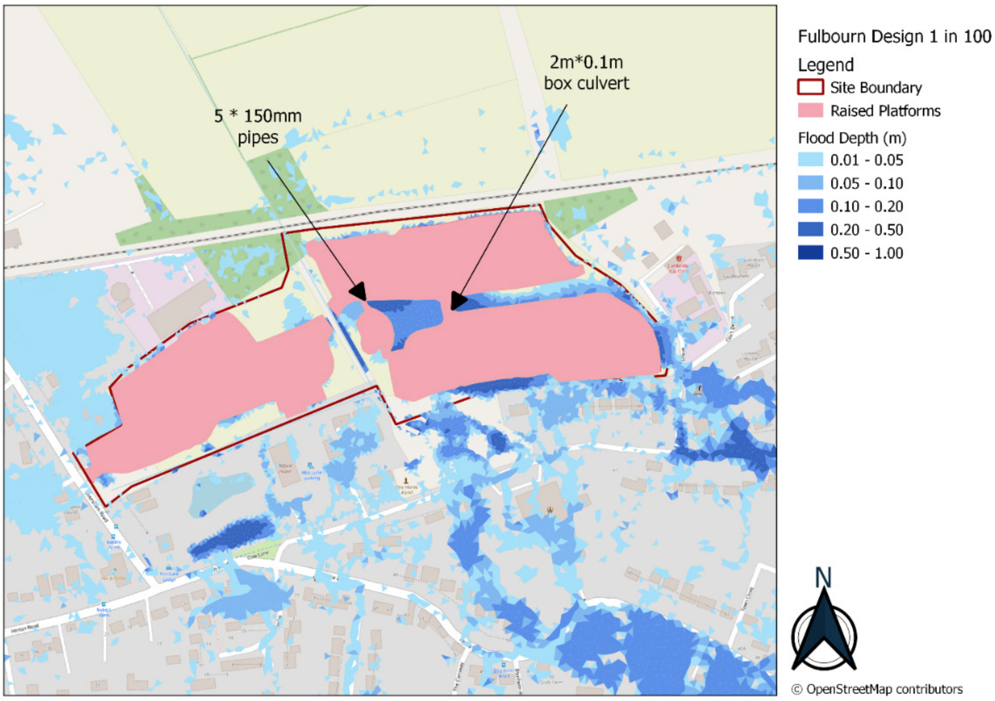

Figure 4.6: Surface water flood depths for the 1 in 100 year rainfall with development in place

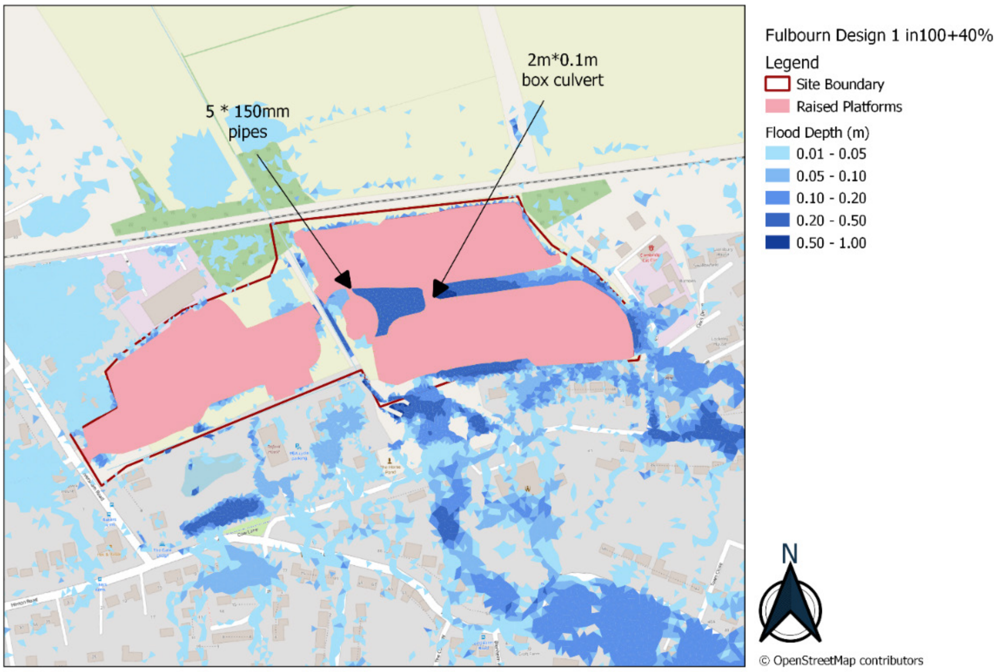

Figure 4.7: Surface water flood depths for the 1 in 100 year climate change rainfall with development in place

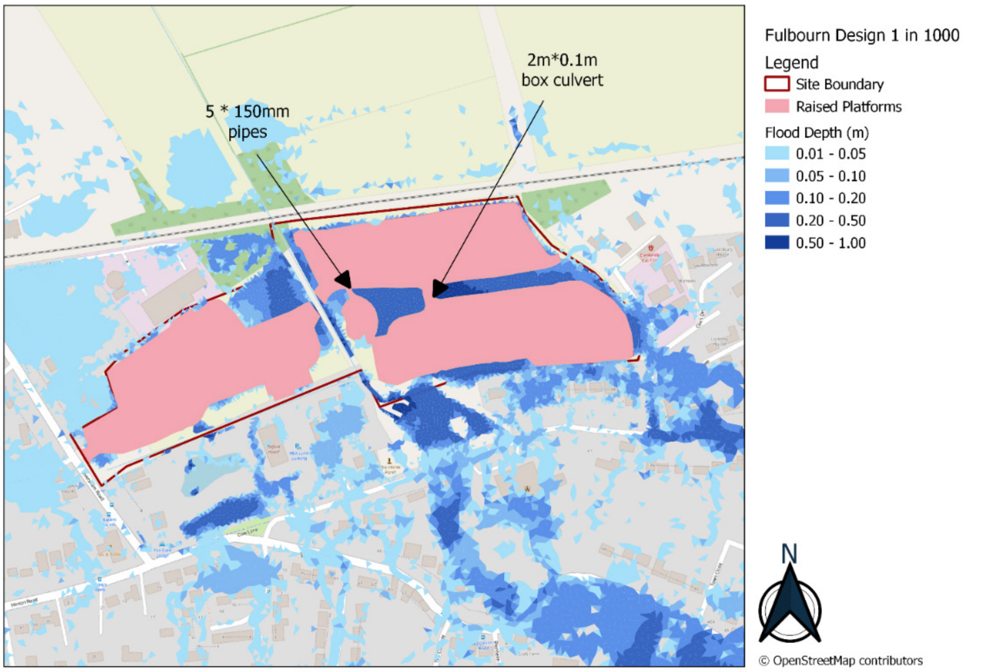

Figure 4.8: Surface water flood depths for the 1 in 1,000 year climate change rainfall with development in place

The peak flows through the railway embankment with the proposed development in place have been compared to existing conditions(see Table 4.1). The comparison shows that the configuration of the proposed development platforms leads to a slight decrease in peak flows downstream of the site.

Table 4.1: Change in peak flow downstream of the site

Return period (years)	Peak flow in existing conditions (m^3/s)	Change in peak flow with the development in place at the culvert passing under the railway embankment at the downstream end of the site (%)
1 in 30 year	0.68	-3.22
1 in 100 year	1.12	-5.12
1 in 100 year plus 40% climate change	1.58	-5.63
1 in 1,000 year	1.66	-0.12

5. Conclusions

Design flows through the site have been assessed with a direct rainfall approach and the ReFH2, both methods give similar magnitude of peak flow at the culvert through the railway embankment at the downstream end of the site.

An integrated 1D-2D hydraulic model of the catchment has been used to simulate the surface water flood extents and depths on the proposed development site for existing conditions. The model includes the detail of the drainage channel system through the site and under the railway embankment. The resulting 1 in 100 year flood extent for the existing situation is larger than that shown on the Environment Agency's surface water flood map. It is possible to raise the development so that it is unaffected by surface water flooding. The hydraulic modelling of design floods shows that post-development there would be a slight reduction in peak flow downstream of the site for all return periods. This reduction in downstream flow may allow for an increased discharge rate from the proposed surface water attenuation facilities.

6. References

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