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# Update to surface water flood management

Fulbourn



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# Contents

1	Introduction.....	5
2	Hydrology .....	5
2.1	Background to the catchment .....	5
2.1.1	Hydrological approaches to estimating flood flows.....	6
2.1.2	Adjustment of catchment descriptors.....	7
2.2	Revitalised Flood Hydrograph model (ReFH2).....	8
2.3	Direct runoff.....	8
2.4	Comparison of flows.....	10
2.5	Final method .....	10
3	Integrated Catchment Model (ICM) hydraulic of the Fulbourn catchment .....	10
3.1	Hydrological components.....	10
3.2	Representation of the site .....	11
3.3	Representation of the post development site.....	13
4	Results .....	13
4.1	Existing conditions (i.e. pre development).....	13
4.2	Post development flood modelling .....	16
4.3	Changes in peak flood depths and extents pre and post development of the site .....	19
4.4	Flow downstream of the site .....	21
5	Conclusions.....	22
6	References .....	22

## Tables

Table 4.1:	Peak flow downstream of the site .....	21
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## Figures

Figure 1.1:	Environment Agency surface water flood map for the site .....	5
Figure 2.1:	Comparison of the catchment boundary defined using the FEH and LiDAR topographic data.....	6
Figure 2.2:	Urban and the impermeable areas within the catchment .....	7
Figure 2.3:	ReFH2 flood flow hydrographs .....	8
Figure 2.4:	Existing surface water flow paths on the site.....	9
Figure 2.5:	Flow hydrographs from ReFH and the Direct Rainfall method for the 3.25 hour 1 in 100 year storm.....	10
Figure 3.1:	Development scheme showing the areas of land which are proposed to be raised .....	13
Figure 4.1:	Surface water flood depths for the existing site conditions for the 1 in 30 year rainfall.....	14
Figure 4.2:	Surface water flood depths for the existing site conditions for the 1 in 100 year rainfall.....	15
Figure 4.3:	Surface water flood depths for the existing site conditions for the 1 in 100 year climate change rainfall .....	15
Figure 4.4:	Surface water flood depths for the existing site conditions for the 1 in 1,000 year rainfall..	16
Figure 4.5:	Surface water flood depths for the 1 in 30 year rainfall with the development in place.....	17
Figure 4.6:	Surface water flood depths for the 1 in 100 year rainfall with development in place.....	17

Figure 4.7: Surface water flood depths for the 1 in 100 year climate change rainfall with development in place ..... 18

Figure 4.8: Surface water flood depths for the 1 in 1,000 year rainfall with development in place..... 18

Figure 4.9: Change in surface water flood depths for the 1 in 30 year rainfall post development compared to the existing situation..... 19

Figure 4.10: Change in surface water flood depths for the 1 in 100 year rainfall post development compared to the existing situation..... 19

Figure 4.11: Change in surface water flood depths for the 1 in 100 year climate change rainfall post development compared to the existing situation ..... 20

Figure 4.12: Change in surface water flood depths for the 1 in 1,000 year rainfall post development compared to the existing situation..... 20

Figure 4.13: Flow hydrographs through the railway culvert downstream of the site for the 1 in 100 year plus climate change rainfall ..... 21

## Photographs

Photograph 3.1: Typical view of the drainage channel through the site ..... 11

Photograph 3.2: Eastern area of the site, looking towards the east ..... 12

Photograph 3.3: Western areas of the site, looking towards the centre of the site..... 12

# 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. This report provides an update to work carried out in 2020 and described in a report entitled “Review of surface water management – Fulbourn - August 2020”. 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.

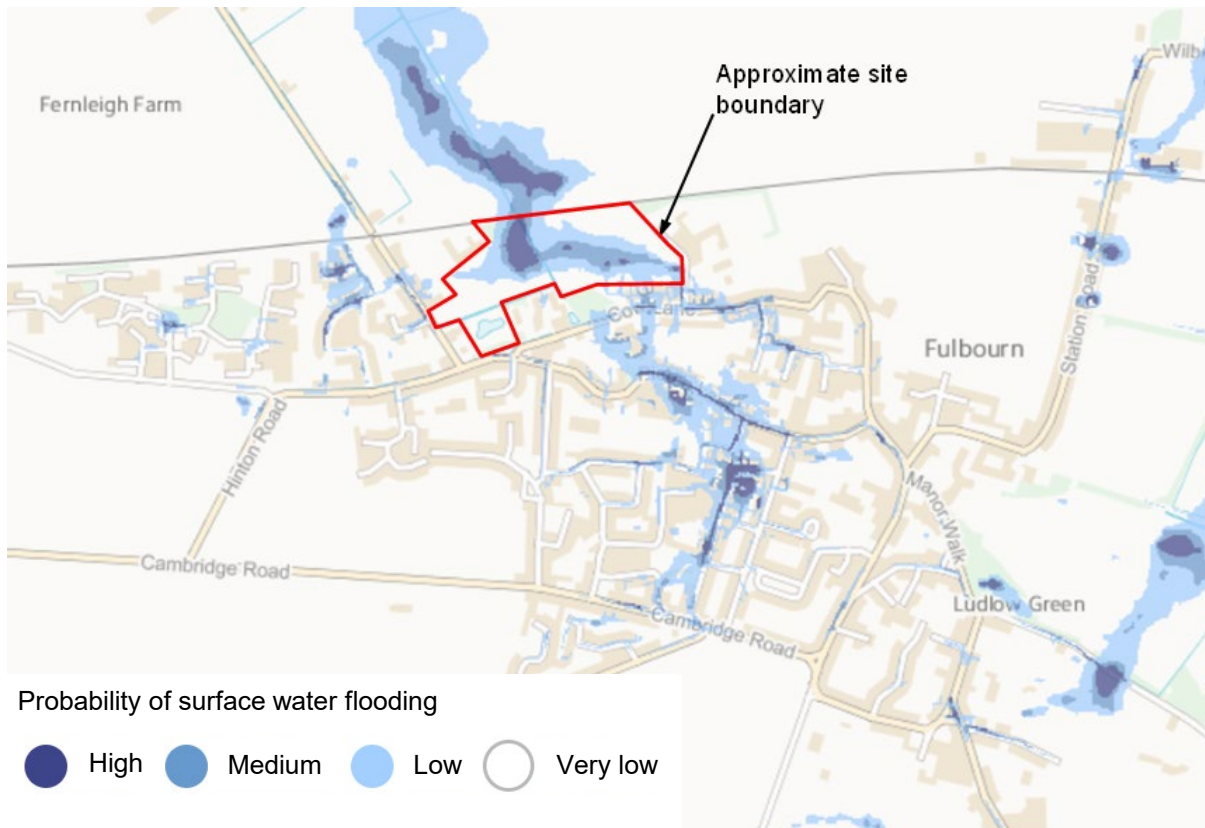


Figure 1.1: Environment Agency surface water flood map for the site

Source: Environment Agency, 2022

As part of the study it was necessary to estimate the 1 in 30 year (3.33% annual probability), 1 in 100 year (1% annual exceedance probability), 1 in 100 year climate change flows (i.e. +40%) and 1 in 1,000 year (0.1% annual exceedance 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 from surface water floods, whilst also helping to avoid an increase in downstream flood risk.

## 2 Hydrology

### 2.1 Background to the catchment

The ungauged catchment draining to the site covers an area of some 1 km<sup>2</sup>. 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<sup>2</sup> compared with 0.5 km<sup>2</sup> from the FEH. A comparison of the FEH and LiDAR-derived catchment boundaries is shown in Figure 2.1.

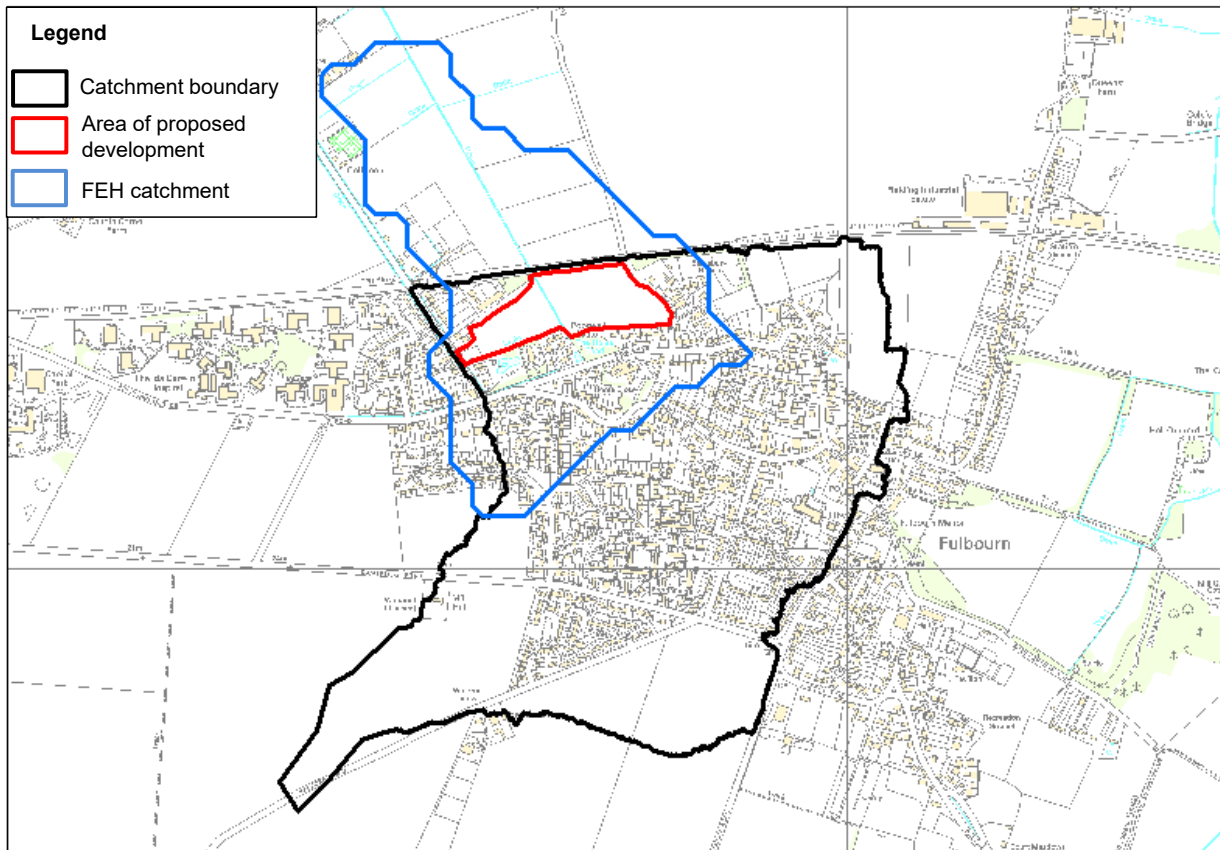


Figure 2.1: Comparison of the catchment boundary defined using the FEH and LiDAR topographic data

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:

$$\text{DPLBAR} = \text{AREA}^{0.548}$$

Assuming a catchment area of 1.06 km<sup>2</sup> 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<sup>2</sup> and the impermeable extent of the urban has been measured from the OS10K maps as 0.14 km<sup>2</sup> (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.

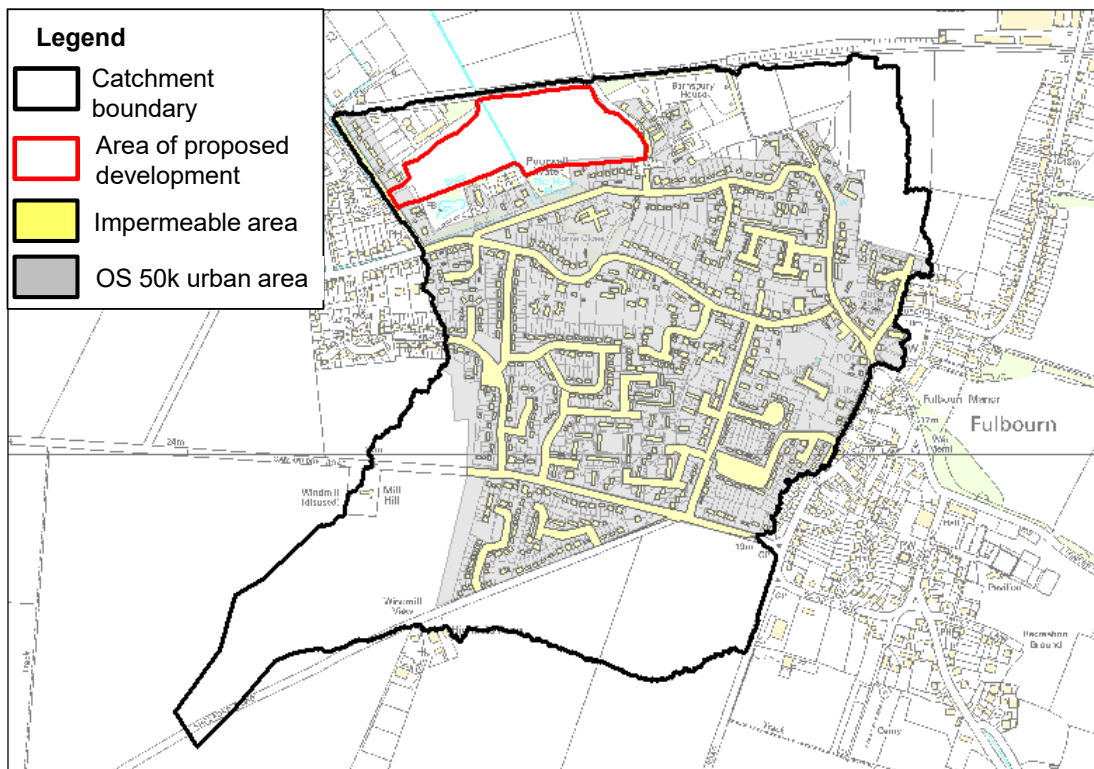


Figure 2.2: Urban and the impermeable areas within the catchment

## 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.

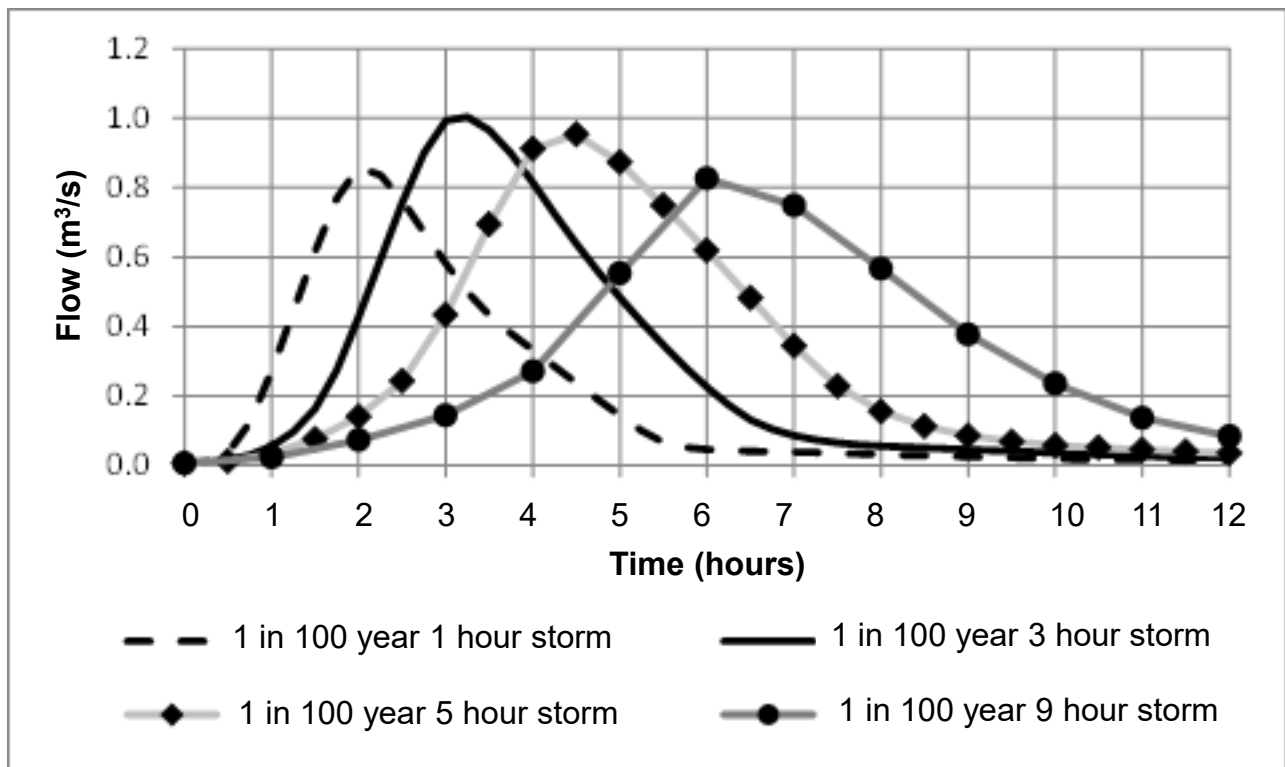


Figure 2.3: ReFH2 flood flow hydrographs

## 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 were based on LiDAR topographic data with a (0.5 m horizontal resolution). The average triangular mesh element area used was 16 m<sup>2</sup>. 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<sup>3</sup>/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 reducing the gross rainfall input to the 2D hydraulic model as a result of any form of drainage systems.

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.

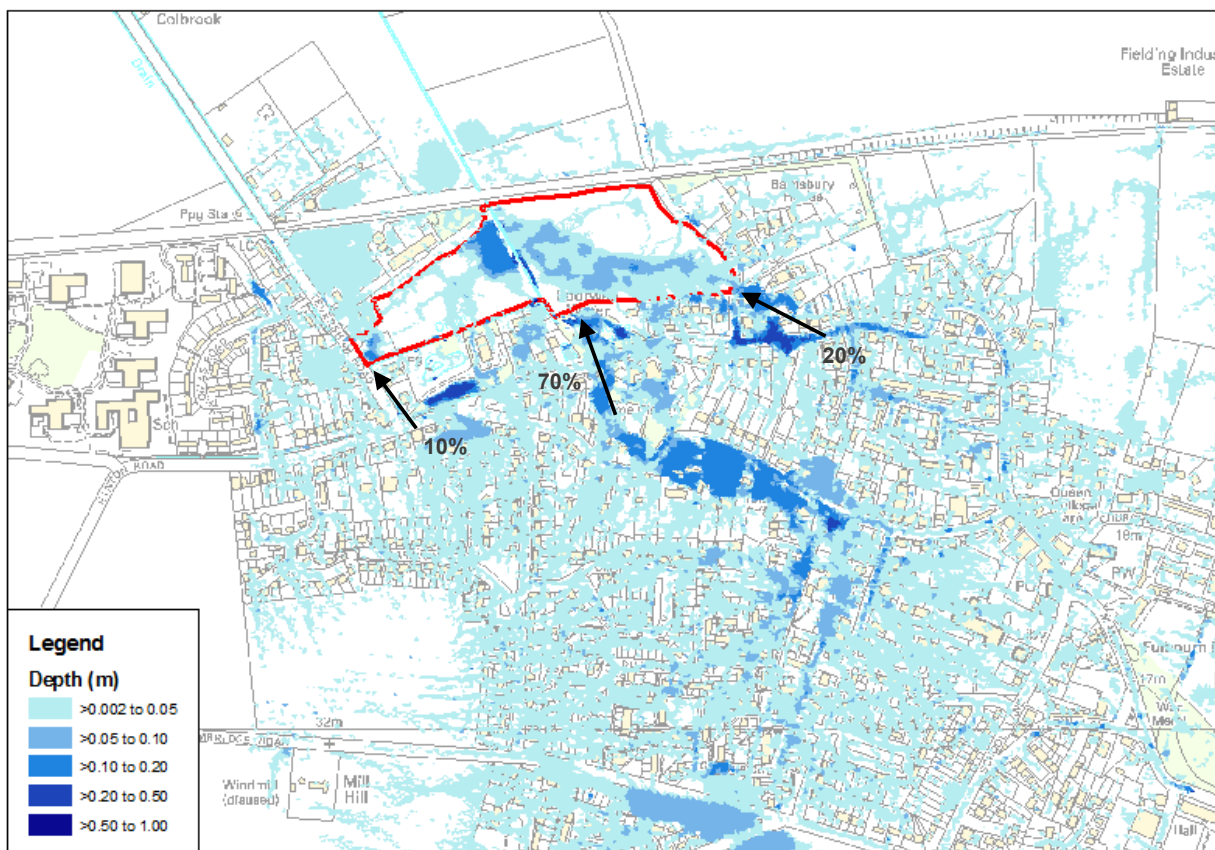


Figure 2.4: Existing surface water flow paths on the site

## 2.4 Comparison of flows

A comparison of the hydrographs generated using the ReFH2 and direct runoff methods is shown in Figure 2.5. 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<sup>3</sup>/s.

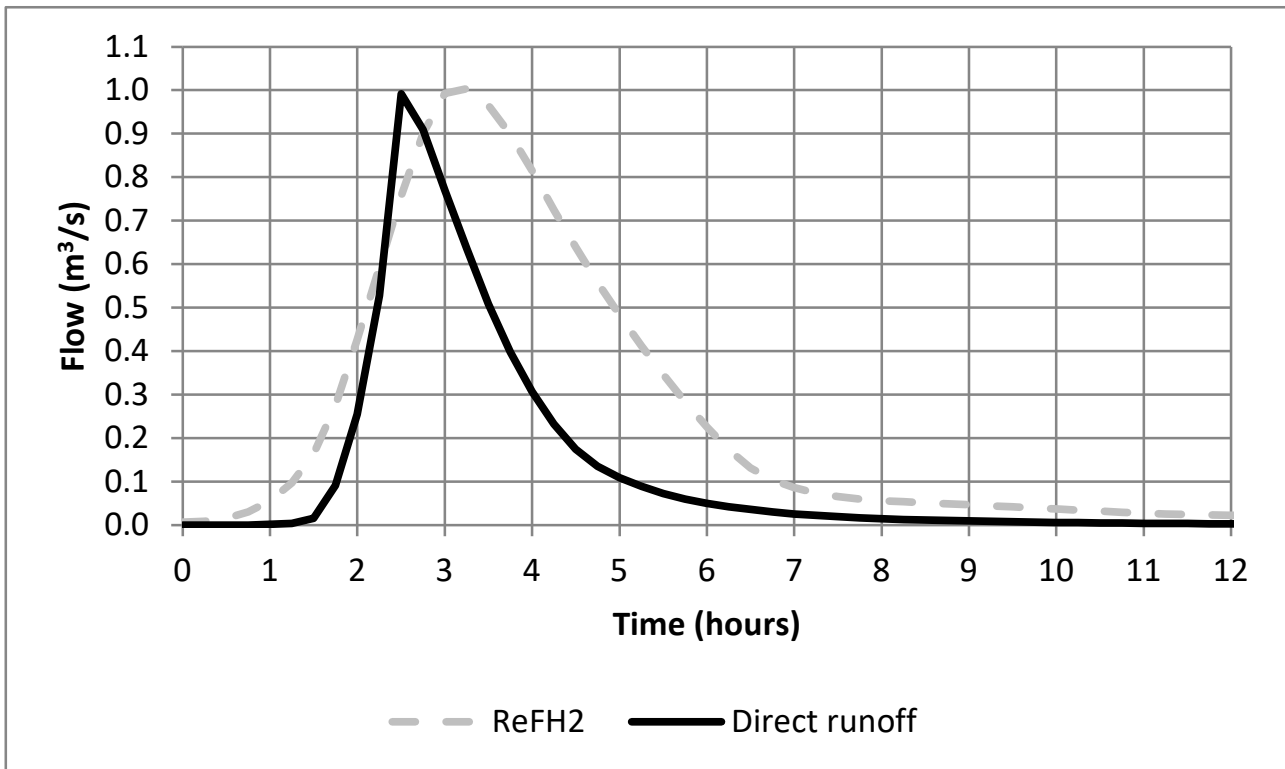


Figure 2.5: Flow hydrographs from ReFH and the Direct Rainfall method for the 3.25 hour 1 in 100 year storm

## 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<sup>2</sup> 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  $0.1 \text{ m}^3/\text{s}$  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  $4 \text{ m}^2$  and  $9 \text{ m}^2$ . 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 towards 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. In the hydraulic modelling the ground levels of the three development platforms were raised above the highest flood level i.e. so that could not be inundated during any of the design flood events that were considered. The layout of the design platforms was provided to us by Cannon Consulting Engineers. The area covered by the development platforms is smaller than the areas previously considered in 2020. 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 2 m wide and 0.1 m high with an invert of 9.6 m AOD. There is also a 1 m x 0.25 m culvert running from south to north to improve the conveyance of water, as well as 1.5 m x 0.25 m box culvert under the access road on the edge of the south-eastern platform.

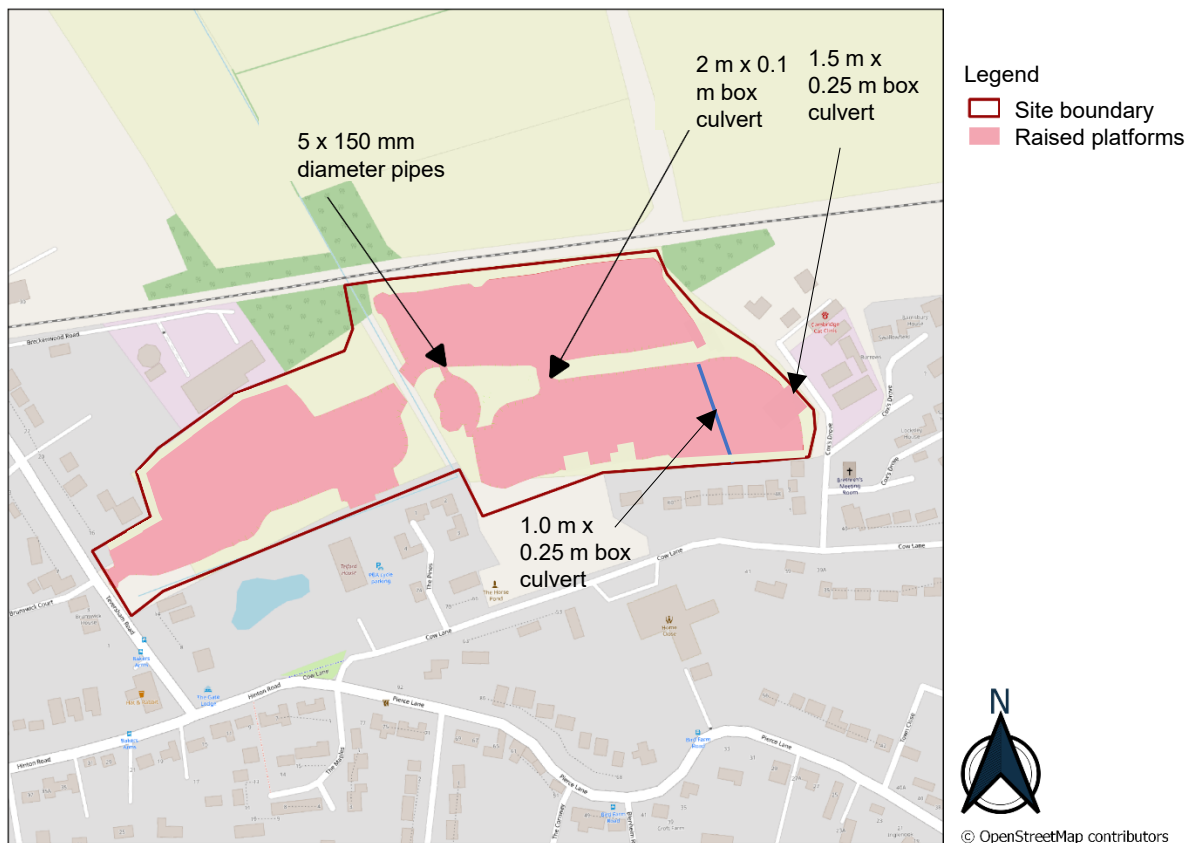


Figure 3.1: Development scheme showing the areas of land which are proposed to be raised

## 4 Results

### 4.1 Existing conditions (i.e. pre development)

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 (2022));
- 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. < 10 cm) 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.

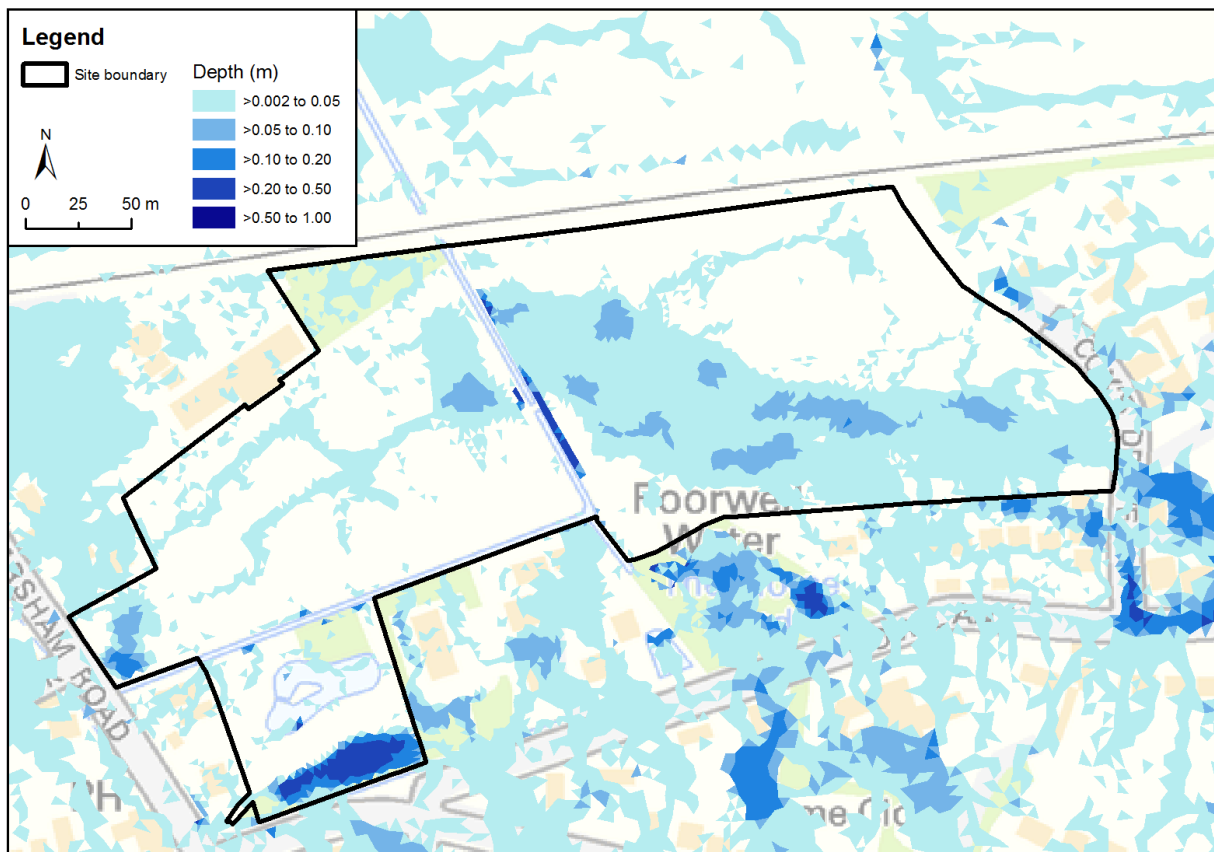


Figure 4.1: Surface water flood depths for the existing site conditions for the 1 in 30 year rainfall

Source: Contains OS data © Crown Copyright (2022)

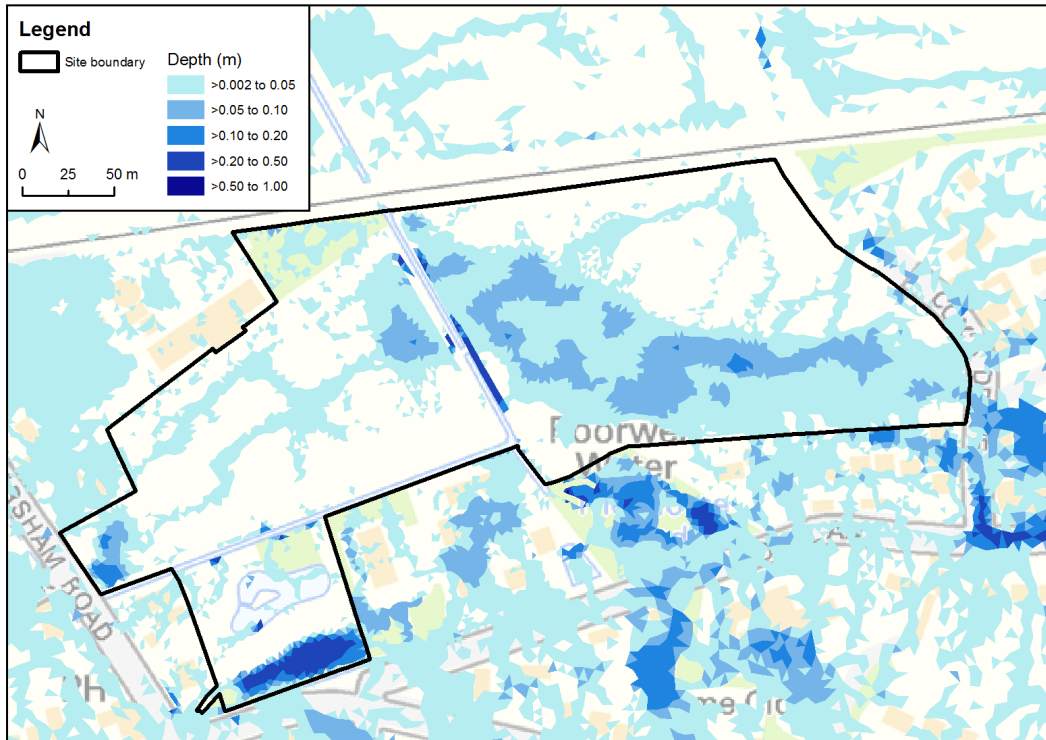


Figure 4.2: Surface water flood depths for the existing site conditions for the 1 in 100 year rainfall

Source: Contains OS data © Crown Copyright (2022)

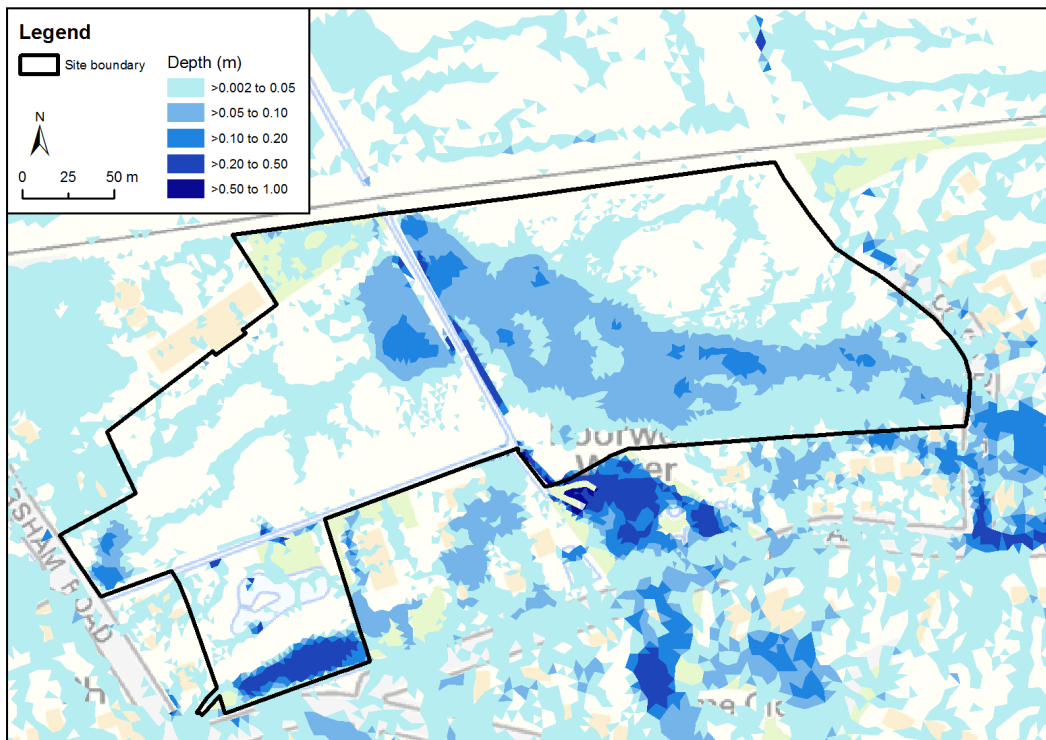


Figure 4.3: Surface water flood depths for the existing site conditions for the 1 in 100 year climate change rainfall

Source: Contains OS data © Crown Copyright (2022)

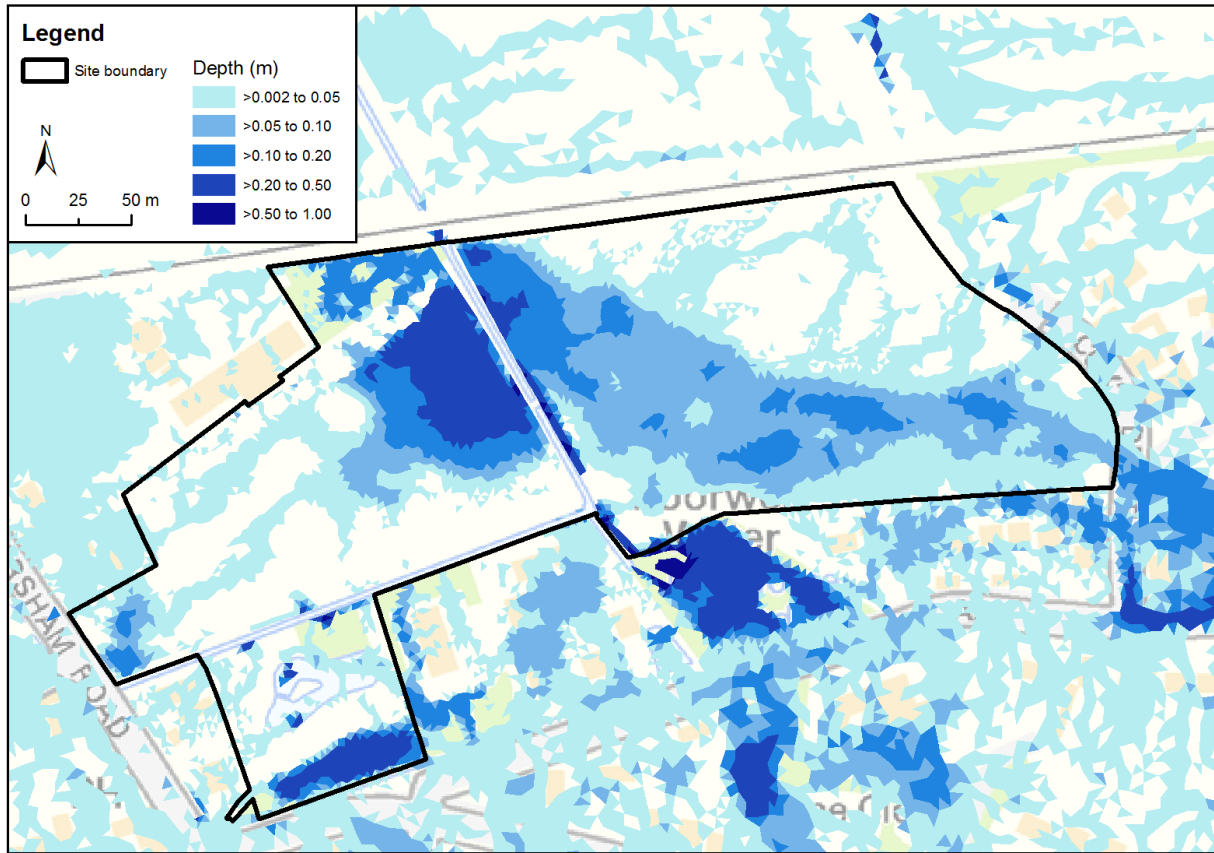


Figure 4.4: Surface water flood depths for the existing site conditions for the 1 in 1,000 year rainfall

Source: Contains OS data © Crown Copyright (2022)

## 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 for the above return periods owing to surface water flooding on the site are shown in Figures 4.5 to 4.8.



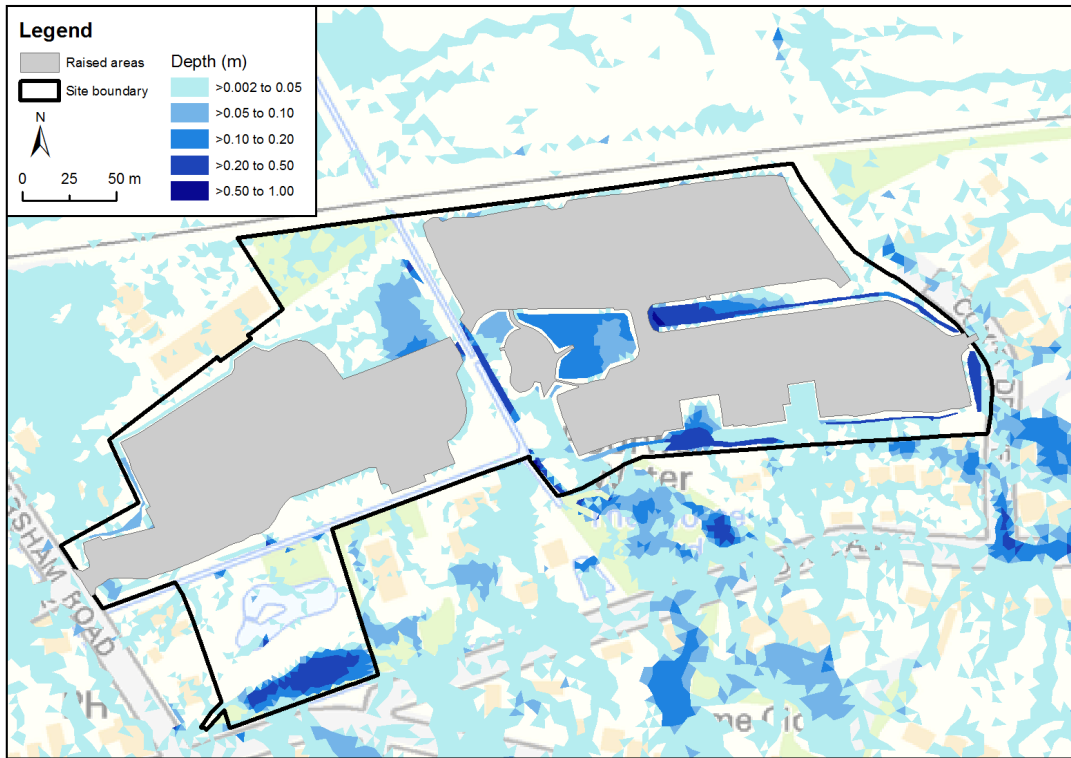


Figure 4.5: Surface water flood depths for the 1 in 30 year rainfall with the development in place

Source: Contains OS data © Crown Copyright (2022)

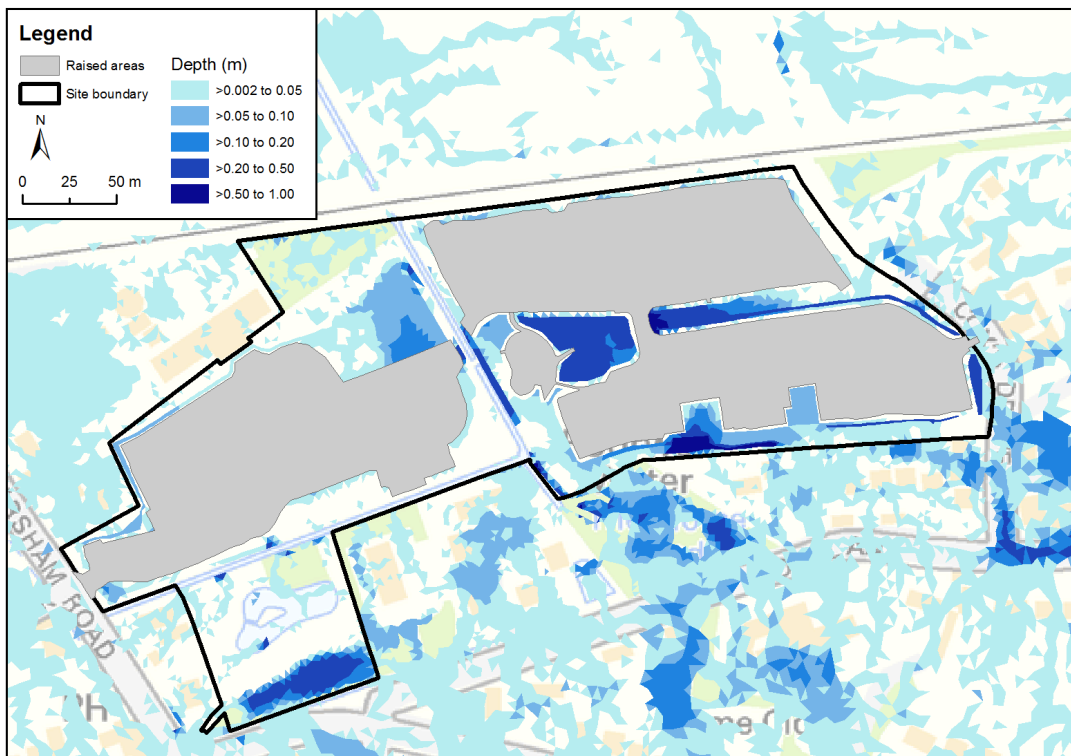


Figure 4.6: Surface water flood depths for the 1 in 100 year rainfall with development in place

Source: Contains OS data © Crown Copyright (2022)

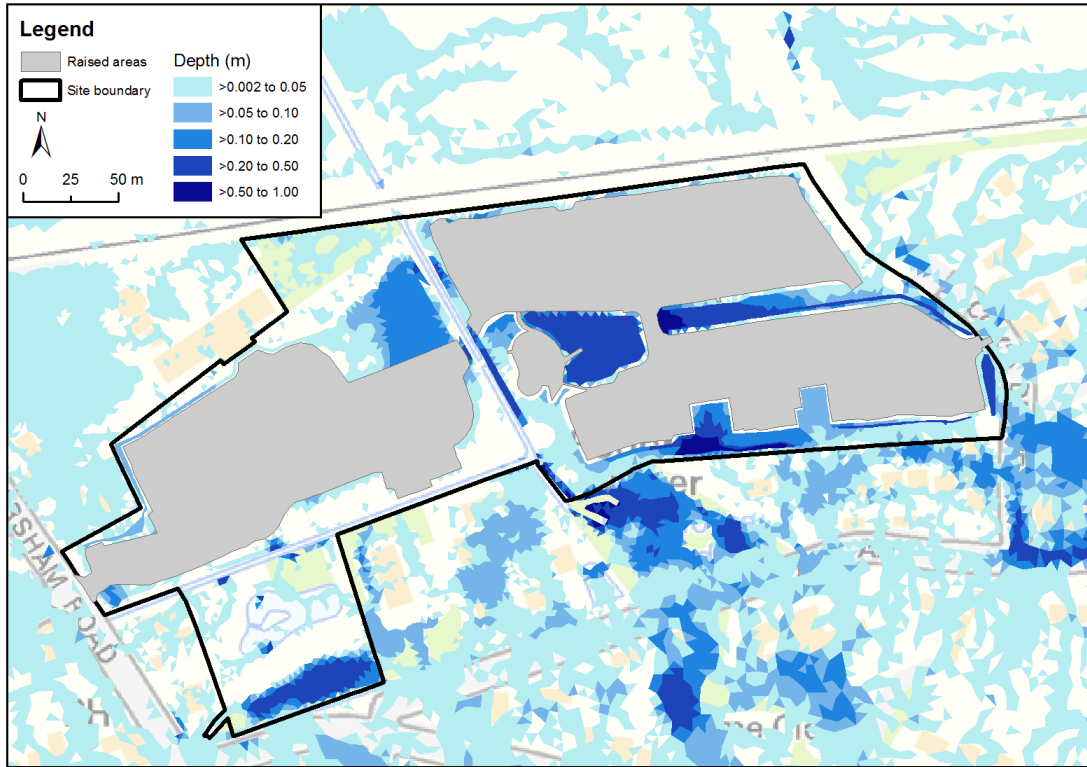


Figure 4.7: Surface water flood depths for the 1 in 100 year climate change rainfall with development in place  
Source: Contains OS data © Crown Copyright (2022)

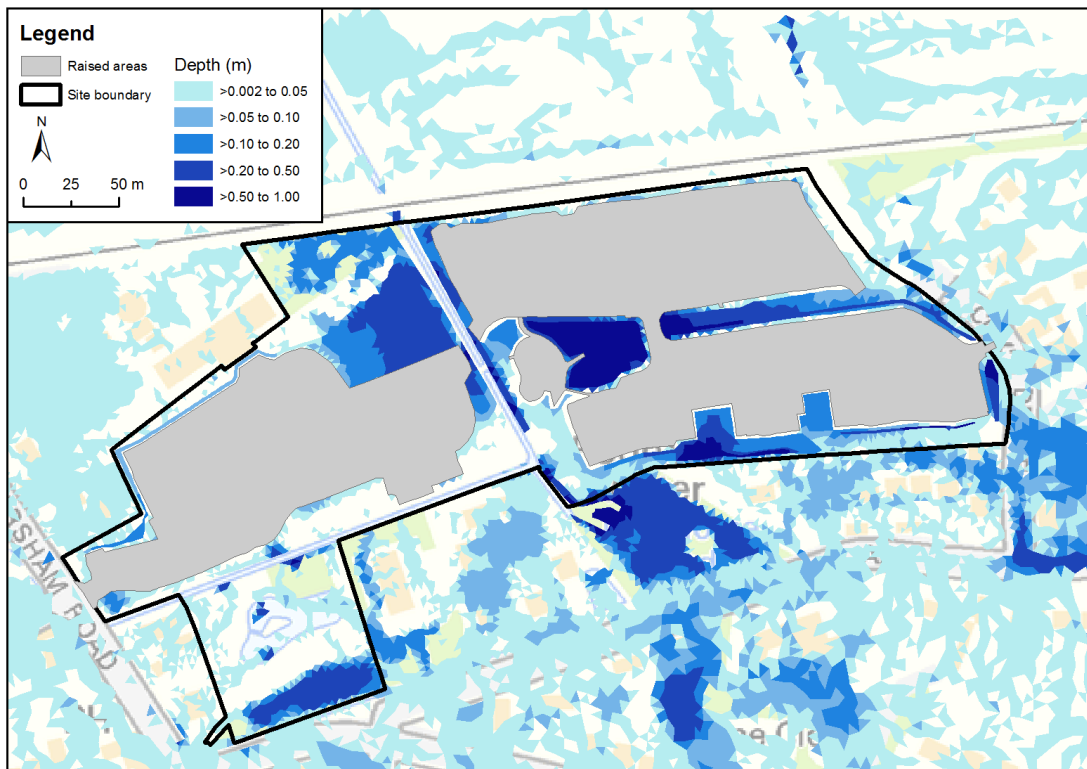


Figure 4.8: Surface water flood depths for the 1 in 1,000 year rainfall with development in place  
Source: Contains OS data © Crown Copyright (2022)

### 4.3 Changes in peak flood depths and extents pre and post development of the site

Figures 4.9 to 4.12 show the changes in peak flood depths between the pre and post development of the site.

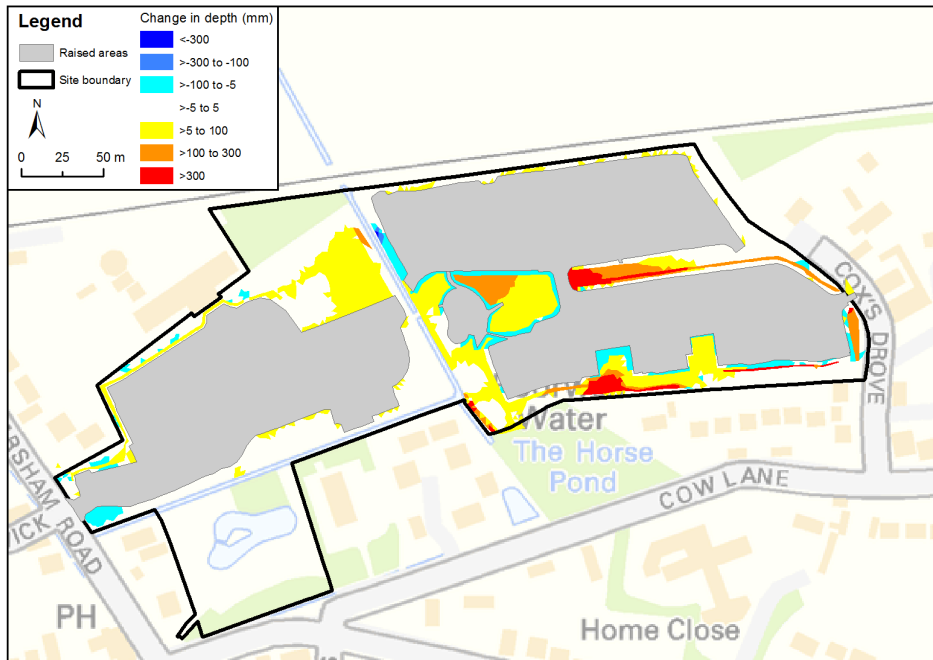


Figure 4.9: Change in surface water flood depths for the 1 in 30 year rainfall post development compared to the existing situation

Source: Contains OS data © Crown Copyright (2022)

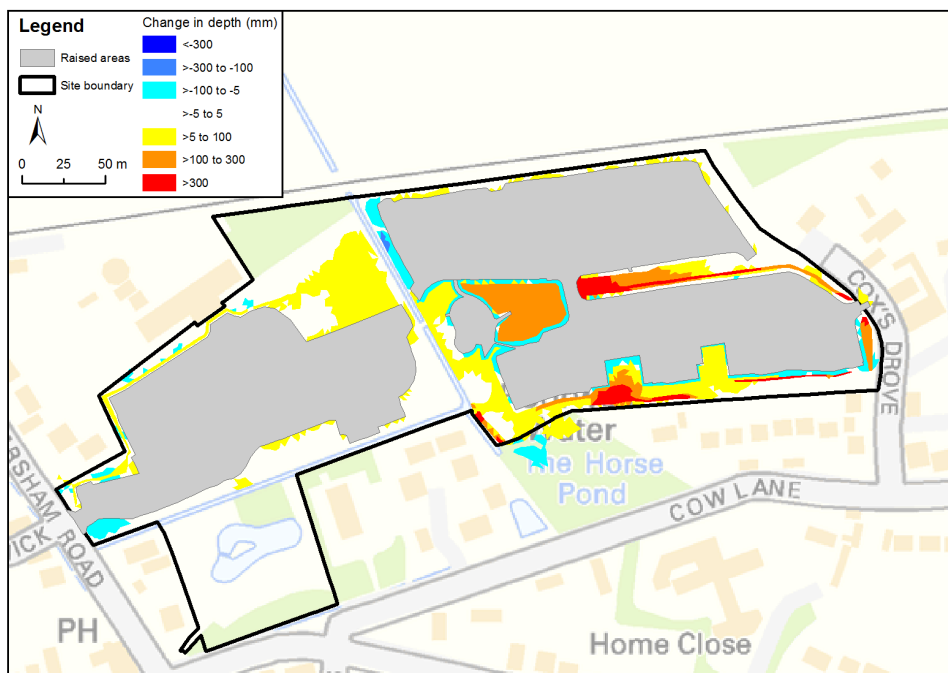


Figure 4.10: Change in surface water flood depths for the 1 in 100 year rainfall post development compared to the existing situation

Source: Contains OS data © Crown Copyright (2022)

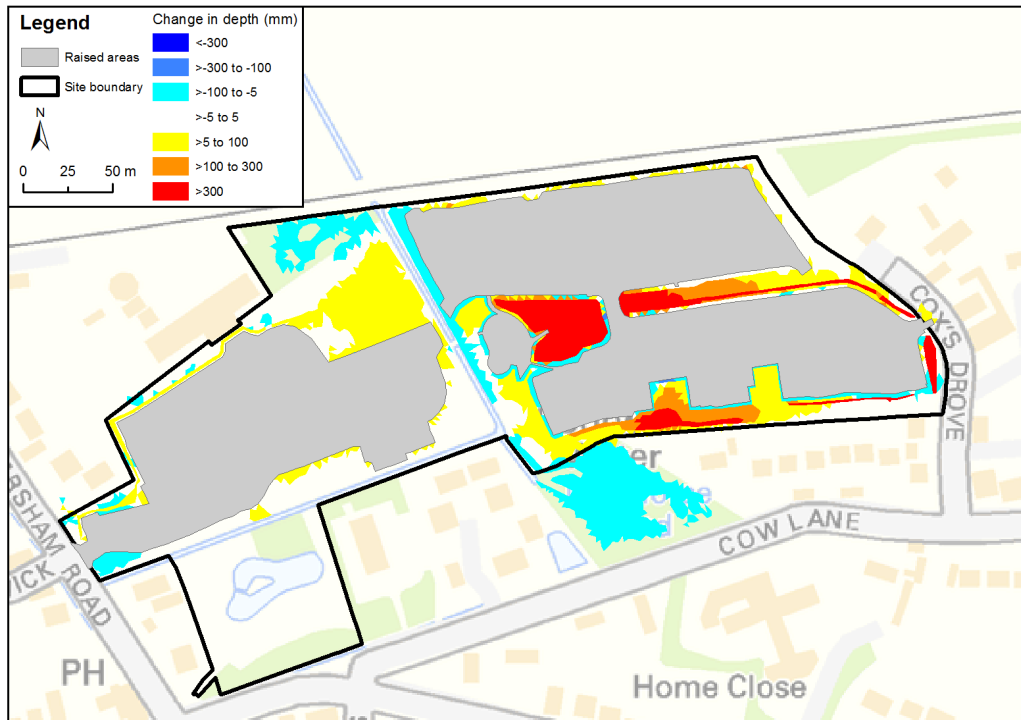


Figure 4.11: Change in surface water flood depths for the 1 in 100 year climate change rainfall post development compared to the existing situation

Source: Contains OS data © Crown Copyright (2022)

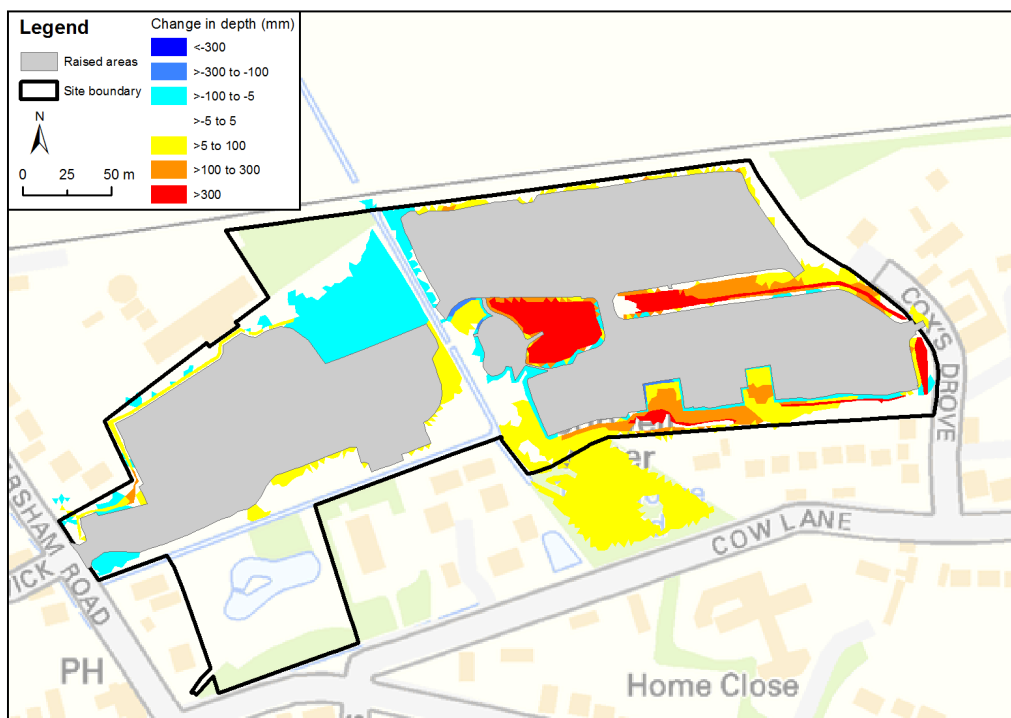


Figure 4.12: Change in surface water flood depths for the 1 in 1,000 year rainfall post development compared to the existing situation

Source: Contains OS data © Crown Copyright (2022)

Figures 4.9 to 4.12 show that the development does not lead to an increase in flood risk i.e. an increase in flood depth where there are properties at risk. In addition, the peak flows through the railway embankment with the proposed development in place have been compared to existing conditions.

## 4.4 Flow downstream of the site

The comparison of the flows through the railway culvert downstream of the site shows that the proposed development platforms do not lead to an increase in peak flows downstream of the site. The peak flows in each flood event are given in Table 4.1 and the flow hydrographs for the 1 in 100 year plus climate change rainfall event are shown in Figure 4.13.

Table 4.1: Peak flow downstream of the site

Flood event	Peak flow (m <sup>3</sup> /s)	
	Existing conditions	Post development
1 in 30 year	0.68	0.62
1 in 100 year	1.12	1.02
1 in 100 year plus climate change	1.58	1.52
1 in 1,000 year	1.67	1.67

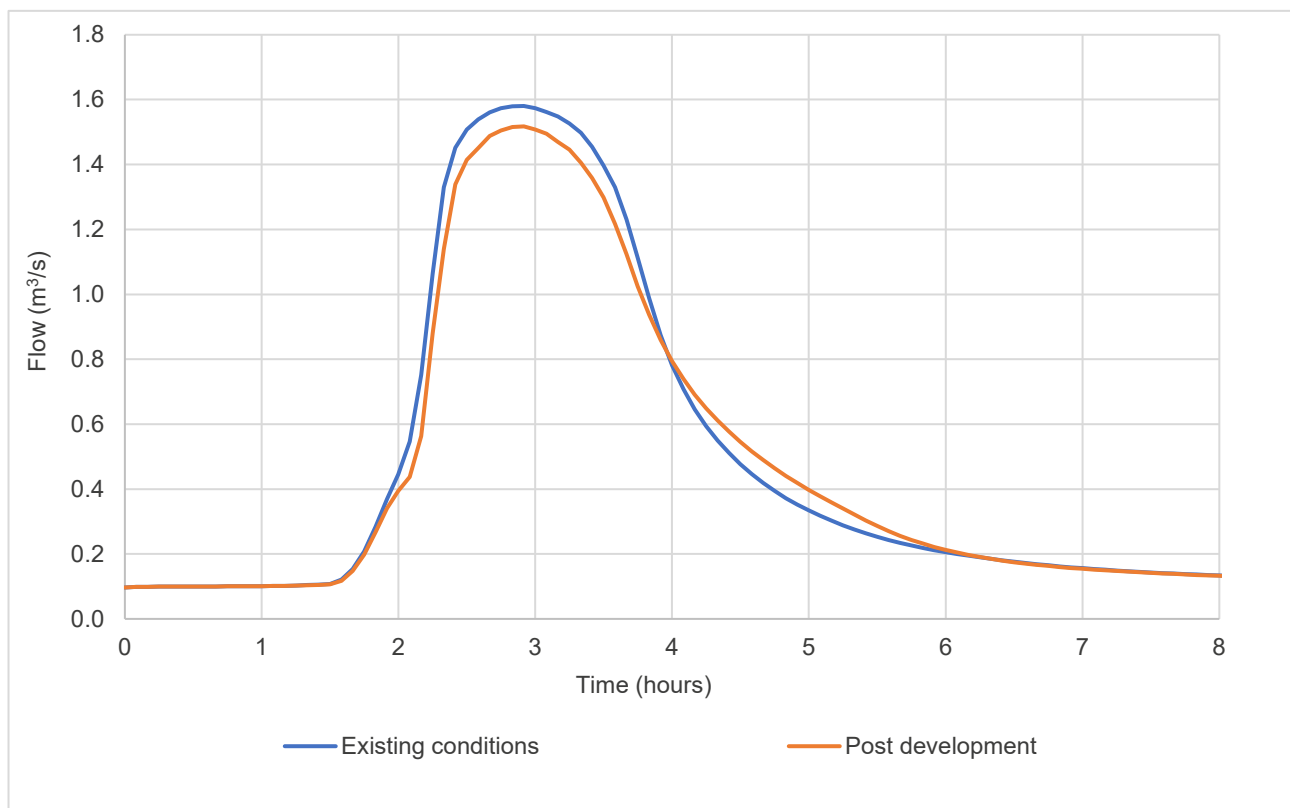


Figure 4.13: Flow hydrographs through the railway culvert downstream of the site for the 1 in 100 year plus climate change rainfall

## 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 for the pre and post development conditions. The hydraulic model includes the detail of the drainage channel system through the site and under the railway embankment. The hydraulic modelling has shown that the proposed development layout means that would be unaffected by surface water flooding for the 1 in 100 and 1 in 1,000 year events. In addition, the proposed development would not increase the flood risk to properties located outside the boundary of the site.

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