Technical Note

KRS Environmental

November 2022

Oxford North Hydraulic Modelling

Project	Oxford North Hydraulic Modelling
Project Number	WHS1869
Title	**Oxford North Hydraulic Modelling Technical Note**
Description	This technical note details the updates made to the baseline model of the Wendlebury Brook and Gagle Brook. It quantifies the impact on flood risk of a proposed development on a greenfield site, using hydraulic modelling.
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Date	30th November 2022
Version	1.4

1 Introduction

1.1 Background

Wallingford Hydrosolutions Ltd has been commissioned by KRS Environmental to update the existing Wendlebury Brook and Gagle Brook model in support of a Flood Risk Assessment (FRA) for a commercial development on a greenfield site approximately 31 ha in size. The site lies to the immediate east of junction 9 on the M40, Wendlebury, Oxfordshire (NGR: SP 55368 19504) as shown in Figure 1. This document contains the technical method undertaken for the modelling and presents the results. The note should be read in conjunction with the original model report[1], and FRA which will be submitted separately by KRS Environmental.

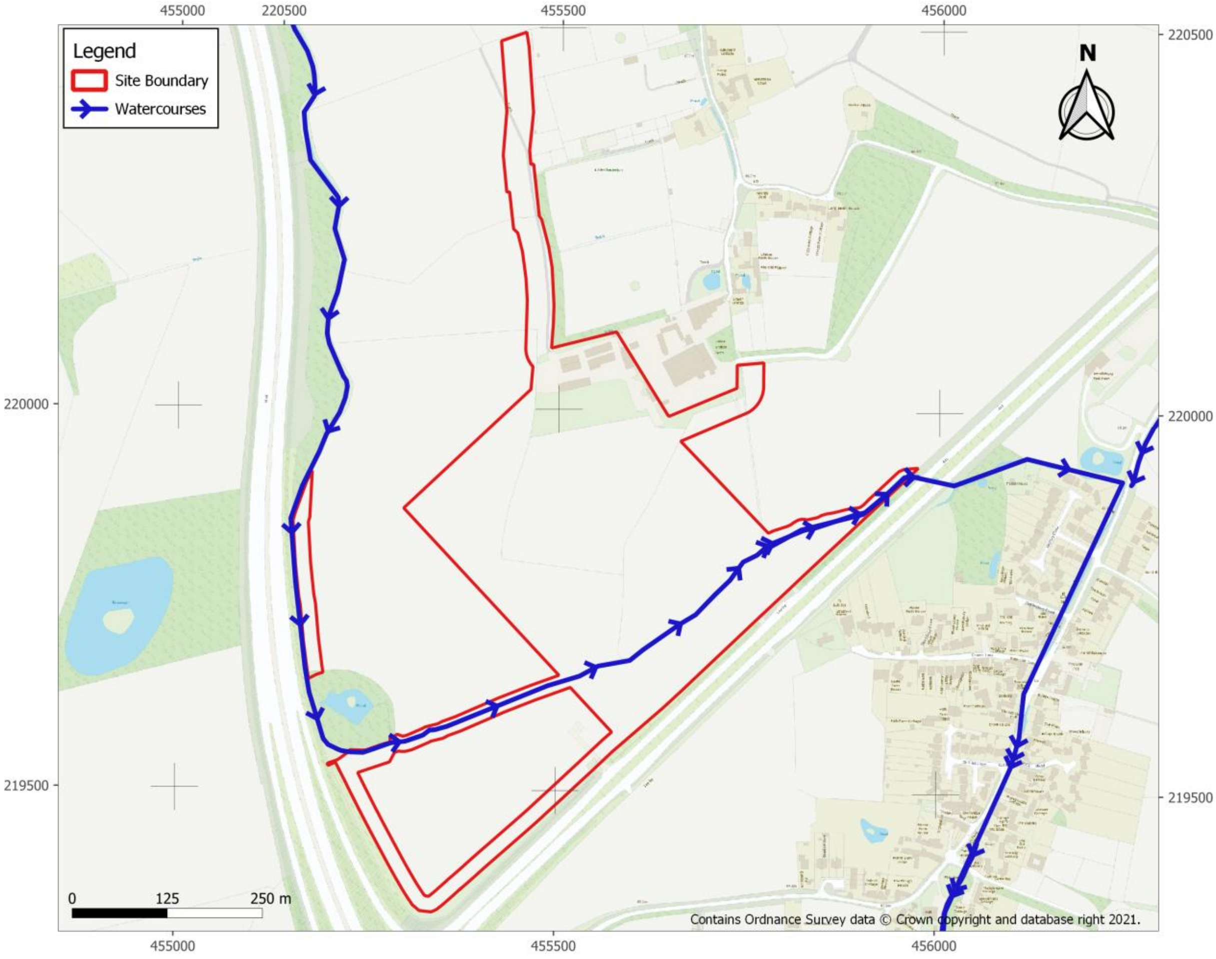


Figure 1 - Site Location

[1] Wendlebury Brook Flood Risk Mapping Study Final Report, IMSE500106, JBA Consulting on behalf of the EA, 2014

1.2 Scope

The site is situated partially in flood zone 2, with the principal flood risk mechanism being a fluvial event from the Wendlebury Brook which runs through the site. The proposed development is to realign the Wendlebury Brook with cut and fill earthworks to reprofile ground levels. This hydraulic modelling study is required to quantify the risk to the proposed development and assess the impacts of realigning the Wendlebury Brook.

In summary, this technical note includes the following information:

- Local review of the existing Environment Agency (EA) model.
- Updates made to the baseline model.
- Results of baseline modelling.
- Approach to modelling the channel realignment.
- Impacts of the proposed development on flood risk.

1.3 Approach

This study utilises a hydraulic model of the Wendlebury Brook and Gagle Brook[2] supplied by the Environment Agency (EA) to assess the flood risk to the site. The baseline model has been updated to use the latest software version and climate change allowances to be suitable for use in this study.

The development proposals are then incorporated into the model and the post-development results are compared to the baseline to quantify impacts on flood risk.

[2] Wendlebury Brook Flood Risk Mapping Study, IMSE500106, JBA Consulting on behalf of the EA, 2014

2 Wendlebury Brook and Gagle Brook Model (2014)

2.1 Baseline Updates

In total three key updates were made to the baseline model;

- Updated software version,
- Updated climate change allowances,
- Updated 1D panel markers.

Both the 1D and 2D software versions were updated to use the best available software for the estimation of flood levels at the site. These are summarised in Table 1.

Table 1 - Software Version Updates

Software	Previous Version	Updated Version
Flood Modeller (1D)	ISIS V6.6	Flood Modeller 5.0
TuFLOW (2D)	2013-12-AA	2020-10-AD

The previous approach for climate change has also been superseded in 2021 by the new national climate change guidance, dependant on which management catchment the target catchment falls in. The Cherwell and Ray management catchment is within the Thames River basin district. The Central climate change allowance applicable to “less vulnerable” development for this catchment is +15%, replacing the +20% value used in the 2014 model.

This allowance was applied to the 1.0% AEP event. The hydrographs for this event were created by increasing the ‘fit to peak of value’ in the Flood Modeller ReFH boundaries for the 1.0% AEP event by 15%. For the WB03_IA hydrograph, the ‘by a factor of’ method was used instead of the to ‘fit to peak of’ method, with a factor of 1.15 applied. The peak flow values used for the 1.0% AEP and 1.0% AEP + 15CC events can be seen in Table 2.

Table 2 - Climate Change Peak Flow Updates

Hydrograph Node Label	1.0% AEP Peak Flow	1.0% AEP + 15CC Peak Flow
WB01a	0.380	0.437
WB02a	0.830	0.955
TRIB01	0.610	0.702
WB03_IA	2.000*	2.300*
GB01	2.190	2.519

**Scale factor used instead of peak flow fit.*

It was identified that some 1D Flood Modeller nodes had decreasing conveyance at bank level, as such the panel marks for these nodes were updated, to ensure conveyance increased with river stage.

In addition to the updates specified above, the model timestep was increased from 0.5s to 1.0s in Flood Modeller. This was done to improve the stability of the model. Some minor updates were also made to baseline model TuFLOW files, a description of the updates made to the baseline model are specified in Table 3 below.

Table 3 - Summary of baseline model updates

Updated Files	Description	Descriptions of Updates
WBs_~s1~_~s2~_e1~_003.tcf		
Global Settings	GIS Format	GIS format updated to use shapefiles.
	Simulation management	TCF updated to use event and scenarios functionality, so all model runs read the same TCF file.
	File locations	Check, Result and Log files location updated to use simulation scenario and event name in the folder structure.
	Output intervals	Map Output interval updated from 900s to 300s. Time Series Output interval updated from 120s to 900s Screen Displace interval updated from 10s to 30s.
	Map Output Data Types	MB1D, MB, MB2D and z9 outputs removed. MB1 output added.
Projection.shp	Shapefile setting the projection system to British National Grid (OSGB 1936).	Projection is now set from shapefile instead of MIF file projection.
1D_ND_ISIS_08.shp	1D FMP Node Locations	File updated from MIF to SHP format.
1d_x1d_ISIS_nwk_WB_04.shp	1D FMP Network	File updated from MIF to SHP format.
1d_WLL_03.shp	1D FMP Water Level Lines	File updated from MIF to SHP format.
2d_po_WB.shp	PO line	File updated from MIF to SHP format.
WB_21_SLext_with_SP_002.tgc		
2d_loc_WB.shp	2D grid location and orientation	File updated from MIF to SHP format.
2d_code_WB_01.shp	2D active cells, Wendlebury Brook	File updated from MIF to SHP format.
2d_code_GB_extended_2.shp	2D active cells, Gagle Brook	File updated from MIF to SHP format.
2d_code_WB_1d_05.shp	2D de-active cells, Wendlebury Brook	File updated from MIF to SHP format.
2d_code_GB_1d_02.shp	2D de-active cells, Gagle Brook	File updated from MIF to SHP format.
2d_zln_bank_levels_03_L.shp | 2d_zln_bank_levels_03_P.shp	Wendlebury Brook bank levels from topographic survey	File updated from MIF to SHP format.

2d_zsh_WB_Road_banks_02_R.shp | 2d_zsh_WB_Road_banks_02_P.shp	Road bank levels from topographic survey	File updated from MIF to SHP format.
2d_zln_GB_Topbanks_survey_L.shp | 2d_zln_GB_Topbanks_survey_P.shp	Gagle Brook bank levels from topographic survey	File updated from MIF to SHP format.
2d_zln_Ch2_top_of_bank_L.shp | 2d_Ch2_top_of_bank_P.shp	Channel 2 bank levels from topographic survey	File updated from MIF to SHP format.
2d_zsh_Topo_Check_Points_R.shp | 2d_zsh_Topo_Check_Points_P.shp	Topographic survey check points behind houses at Rectory Close	File updated from MIF to SHP format.
2d_zln_bank_levels_North_Rectory_Close_03_L.shp | 2d_zln_bank_levels_North_Rectory_Close_03_P.shp	Wendlebury Brook bank levels north of Rectory Close, from topographic survey	File updated from MIF to SHP format.
2d_zln_Channel_Bed_behind_Rectory_Close_L.shp | 2d_zln_Channel_Bed_behind_Rectory_Close_P.shp	Channel bed levels along drains behind Rectory Close	File updated from MIF to SHP format.
2d_zln_Road_Level_L.shp | 2d_zln_Road_Level_P.shp	Road levels	File updated from MIF to SHP format.
2d_zln_Gagle_Brook_Channel_Lower_Points_L.shp | 2d_zln_Gagle_Brook_Channel_Lower_Points_P.shp	Not surveyed Gagle Brook channel (2D domain) low point taken from LiDAR	File updated from MIF to SHP format.
2d_zln_bank_levels_Upstream_A41_L.shp | 2d_zln_bank_levels_Upstream_A41_P.shp	Wendlebury Brook bank levels upstream of A41 from topographic survey	File updated from MIF to SHP format.
2d_mat_WB_01.shp	2D materials codes	File updated from MIF to SHP format
2d_mat_stability_patch_03.shp	2D materials stability patch	File updated from MIF to SHP format
WB_16SLext.tbc		
2d_bc_hxi_GB_04.shp	1D 2D link from Gagle Brook and Channel 1	File updated from MIF to SHP format
2d_bc_GB_1d_01.shp	Downstream end of 1D Gagle Brook spilling in the 2D	File updated from MIF to SHP format

2d_bc_GB_downstream_01.shp	Downstream 2D boundary of Gagle Brook	File updated from MIF to SHP format
2d_bc_Railway_boundary.shp	Downstream 2D boundary at the railway line	File updated from MIF to SHP format
2d_bc_hxi_wb_07_L.shp | 2d_bc_hxi_07_P.shp	1D 2D link for the Wendlebury Brook	File updated from MIF to SHP format
Wbs_Events_001.tef		
-	Defines model events.	File added to runs folder and read in by TCF
WB_33.dat/WB_34.dat		
WB_35a.dat/WB_35b.dat	FMP Network	Panel markers updated to improve conveyance curves

2.2 Review of 1D Spills

A high-level review of the existing model was undertaken, in this review it was identified that a number of structures did not have spills associated with them. The two culverts under the A41 WB_1878 and WB_1854 are not overtopped during any of the modelled events and as such spill units are not required for these structures. The remaining structures without spill levels are located sufficiently downstream of the site (a minimum of 340m) to not affect the modelled flood levels around the vicinity of the site.

2.3 Review of Manning's Roughness

1D Manning's Roughness

The existing model has been reviewed and the in-bank Manning's number has been identified as being 0.040, which is considered to be an appropriate value for channel reaches of this nature (see Table 4 for photograph and further description).

In addition to this, Manning's values used to represent the in-channel roughness for the extended reaches of the model have also been assigned an in-bank Manning's value of 0.040, as shown in Table 5. This selected value is based on engineering judgement and published guideline values[3].

Table 4 - Example of 1D Manning's Values in Existing Reach

Location:	Wendlebury Brook - downstream of A41 crossing	Manning's:	0.040

Description
Main channel, clean, straight, full stage, no rifts or deep pools with more stones and weeds.

[3] Chow, V T (1959). *Open-channel Hydraulics.* McGraw-Hill.

Table 5 - Example of 1D Manning's Values in New Reach

Location:	Extended Reach of the Wendlebury Brook (Node-WB_3434)	Manning's:	0.040

Description

Main channel, clean, straight, full stage, no rifts or deep pools with more stones and weeds.

2D Manning's Roughness

The Manning's values used to represent the surface roughness within the 2D domain of the existing model have been defined using OS Master Map data. The selected values for each type of surface have been reviewed and are considered appropriate for continued use. All of the Manning's values used in the 2D domain are summarised in Table 6.

Table 6 – Summary of 2D Manning's values

Material Code	Description	Master Map Code	Manning's n
1	Structure	10185	0.3
2	Pylon	10193	0.035
3	Upper Level of Communication	10187	0.03
4	Overhead Construction	10185	0.035
5	Building	10021	0.3
6	Archway	10021	0.07
7	Glasshouse	10062	0.2
8	Inland Water	10089	0.035
9	Tidal Water	10203	0.035
10	Path	10123	0.03
11	Road Or Track	10172	0.015
12	Step	10054	0.017
13	Roadside	10183	0.025
14	Rail	10167	0.02

Material Code	Description	Master Map Code	Manning's n
15	Multi Surface	10053	0.03
16	General Surface (Manmade)	10056	0.02
17	General Surface (Natural)	10056	0.04
18	Slope	10096	0.04
19	General Surface (Unknown)	10056	0.025
20	Unclassified	10217	0.04
21	Boulders	10111	0.045
23	Coniferous Trees	10111	0.1
24	Coniferous Trees (Scattered)	10111	0.06
25	Coppice Or Osiers	10111	0.07
26	Heath	10111	0.07
27	Marsh Reeds Or Saltmarsh	10111	0.048
28	Non coniferous Trees	10111	0.07
29	Non coniferous Trees (Scattered)	10111	0.04
30	Orchard	10111	0.065
31	Rock	10111	0.05
32	Rough Grassland	10111	0.04
33	Scrub	10111	0.05
99	Roughness used within stability patches	n/a	0.1
100	default roughness	n/a	0.035

2.4 Impact of Baseline Updates.

The modelled flood extents during the 1.0% AEP event can be seen in Figure 2 and Figure 3.The updates made to the baseline model specified above, resulted in some minor changes in the flood extents observed in Wendlebury, with some larger changes seen downstream of Wendlebury and along the Gagle Brook. It is worth noting that the improved conveyance curves resulted in better conveyance for multiple 1D nodes.

For the 0.1% AEP runs, two structures continue to be missing, as per the received EA model, this has been reviewed and given their location with respect to the proposed works, their omittance is acceptable and is retained for stability reasons.

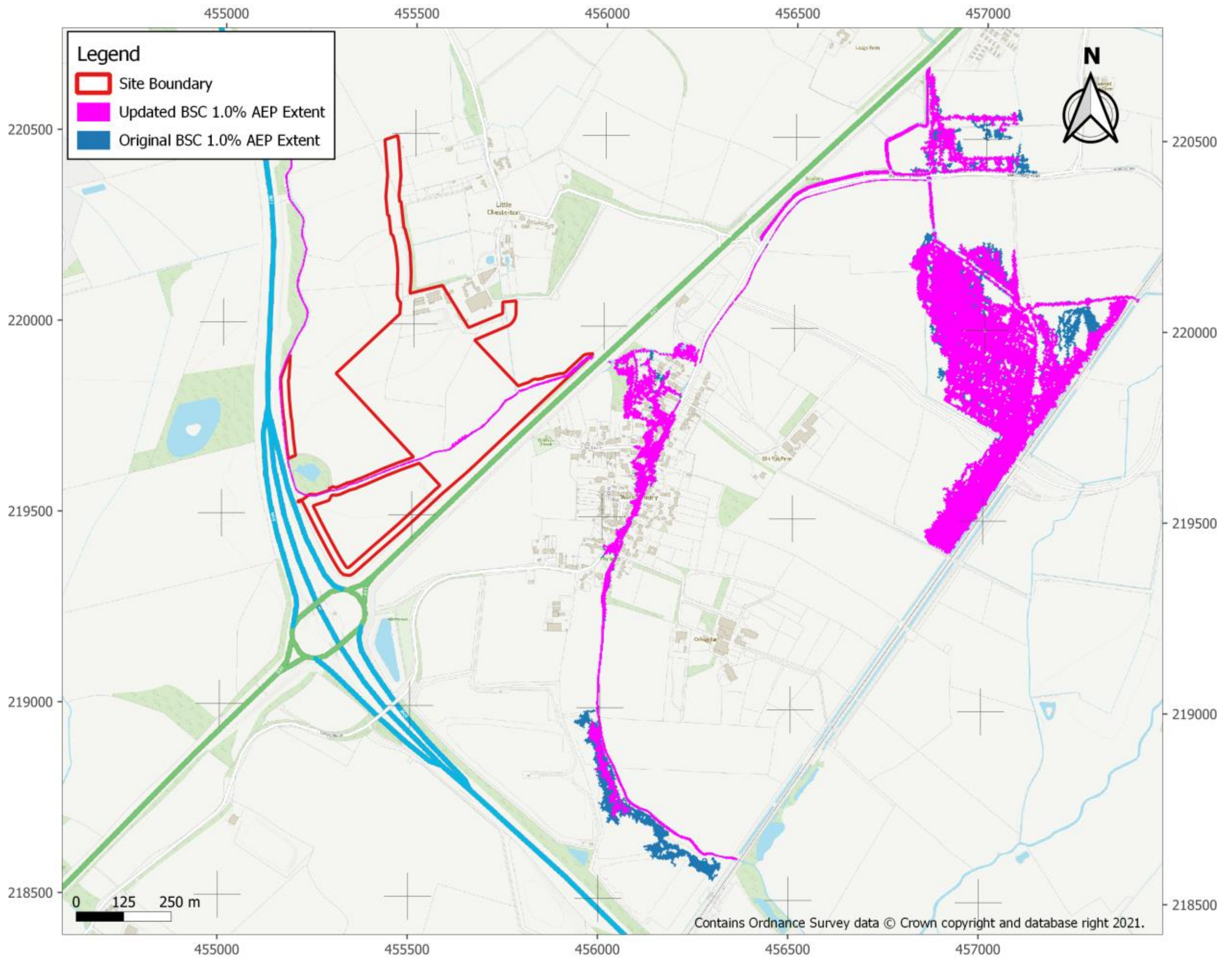


Figure 2 - Original and Updated Baseline Model 1.0% AEP Flood Extents

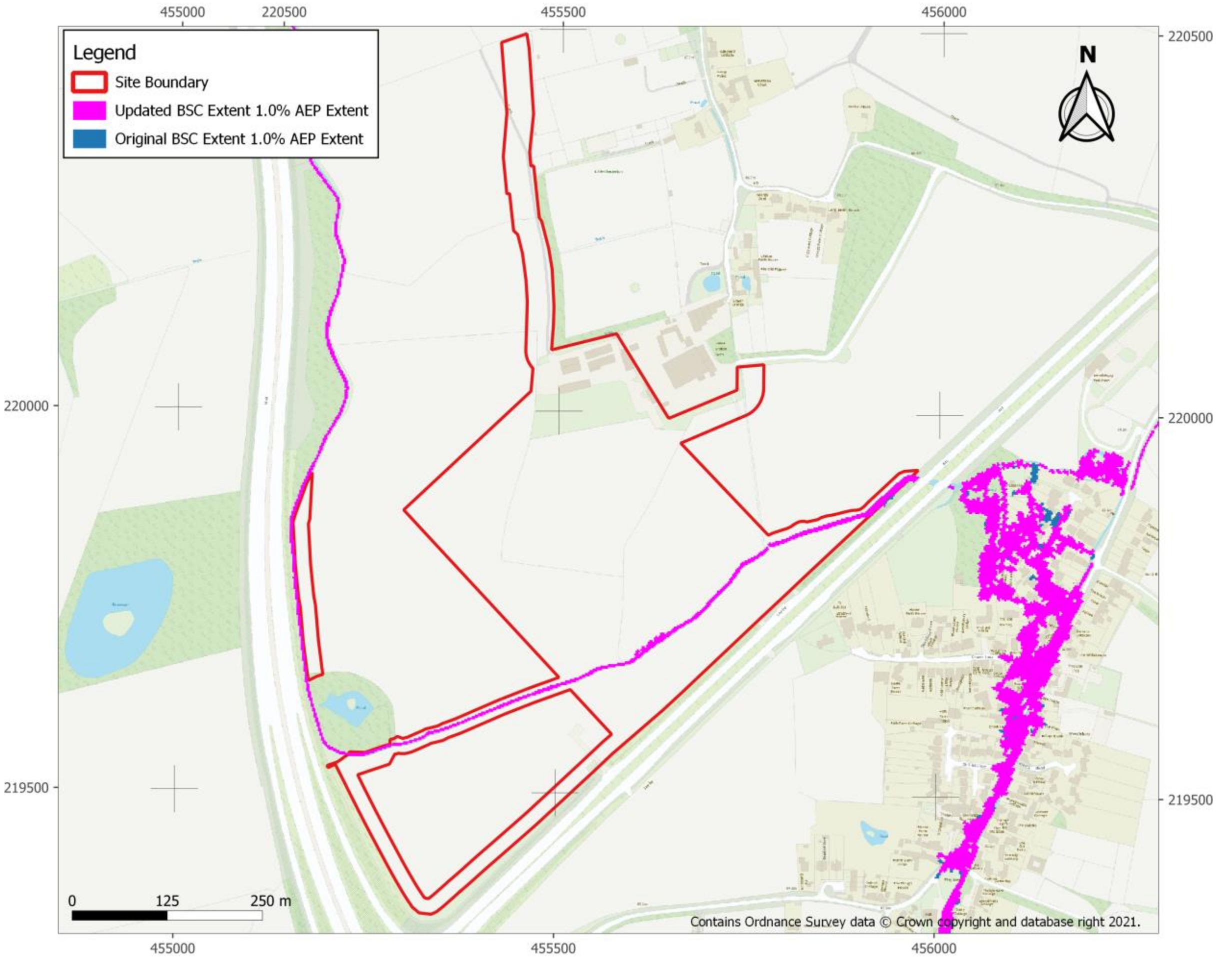


Figure 3 – Original vs Baseline Model 1.0% AEP Extent for the Proposed development site and Wendlebury

2.5 Summary of Runtime Warnings

1D Runtime Warnings

There are 101 unique Warning messages in the 1D domain during the 'WBS_34_Q1000_RC_SLEXT SP_002' model simulation.

Of these warning messages, 22 are located upstream of the A41 and as such, these have been reviewed to confirm if they will have an impact on the modelled results, (see Table 7).

In summary, all of the warnings located upstream of the A41 will have no impact on the modelled flood levels. It is noted, however, that several warnings have no associated warning message and because of this, these have not been reviewed.

Table 7 – Summary of 1D Warnings

No	Code	Node	Comment
1	W2311	WB01a	No warning message available, unable to review
3	W2309	WB01a	No warning message available, unable to review
5	W2305	WB01a	No warning message available, unable to review
7	W2306	WB01a	No warning message available, unable to review
9	W2532	WB01a	Warning model does not start at 0hrs - No impact on results
11	W2311	WB02a	No warning message available, unable to review
13	W2309	WB02a	No warning message available, unable to review
15	W2306	WB02a	No warning message available, unable to review
17	W2532	WB02a	Warning model does not start at 0hrs - No impact on results
19	W2311	TRIB01	No warning message available, unable to review
21	W2309	TRIB01	No warning message available, unable to review
23	W2532	TRIB01	Warning model does not start at 0hrs - No impact on results
25	W2311	WB03_IA	No warning message available, unable to review
27	W2309	WB03_IA	No warning message available, unable to review
29	W2532	WB03_IA	Warning model does not start at 0hrs - No impact on results
31	W2311	GB01	No warning message available, unable to review
33	W2309	GB01	No warning message available, unable to review
35	W2305	GB01	No warning message available, unable to review
37	W2306	GB01	No warning message available, unable to review
39	W2532	GB01	Warning model does not start at 0hrs - No impact on results
41	W2229	WB_1878ci	Warning related to trash screen height being set to 0 - but no trash screen at culvert inlet - No impact on results
43	W2229	WB_1854ci	Warning related to trash screen height being set to 0 - but no trash screen at culvert inlet - No impact on results

2D Runtime Warnings

There are three unique Warning and Check messages in the 2D domain during the 'WBs BSC 1000 2021 003' model simulation (see Table 8).

From these, two warning messages 2118 are located downstream of the A41 and as such, will not have any impact on the proposed development site. The check message 2370 has been reviewed and it is concluded that it will also have no impact on the modelled flood levels at the proposed development site.

Table 8 – Summary of 2D Warnings and Checks

Warning and Check Messages	Comment
CHECK 2370 - Ignoring coincident point found in ORIGINAL layer.	This check will not impact the modelled results
WARNING 2118 - Lowered SX ZC Zpt by 0.36m to 1D node bed level.	Located d/s of the A41 and will not impact the modelled results at the proposed development location.
WARNING 2118 - Lowered SX ZC Zpt by 0.99m to 1D node bed level.	Located d/s of the A41 and will not impact the modelled results at the proposed development location.

3 Baseline Model Results

3.1 1.0% AEP Event

As can be seen in Figure 4, during the 1.0% AEP event there are no significant out of bank flows for the Wendlebury Brook upstream of the A41. As such the site is not at risk of fluvial flooding during the 1.0% AEP baseline event.

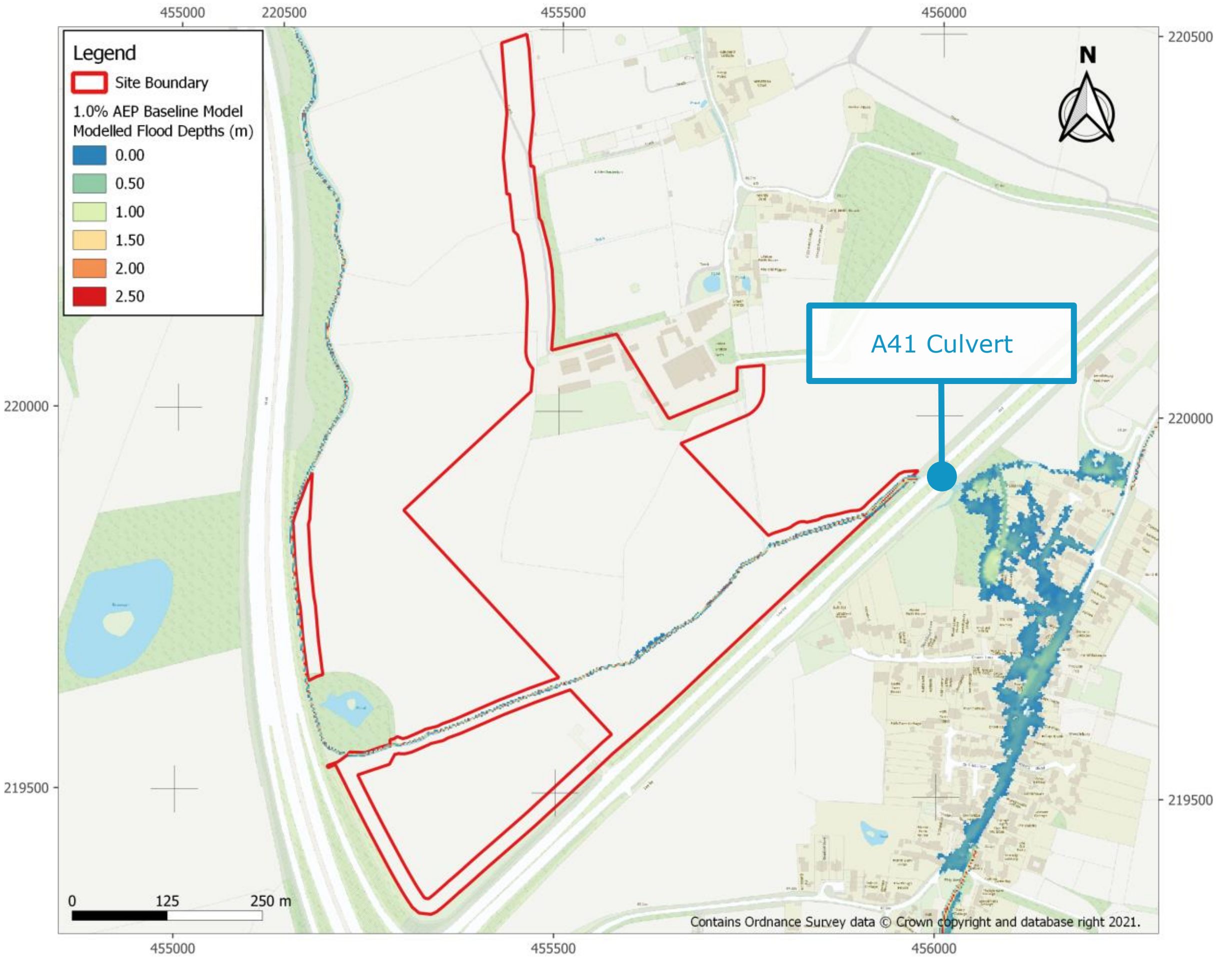


Figure 4 - Baseline 1.0% AEP Modelled Flood Depths

3.2 1.0% AEP + 15% Climate Change (Central) Event

As can be seen in Figure 5, during the 1.0% AEP + 15% climate change event there are also no significant out of bank flows within the development site. As such the site is not at risk of fluvial flooding during the 1.0% AEP + 15% climate change event.

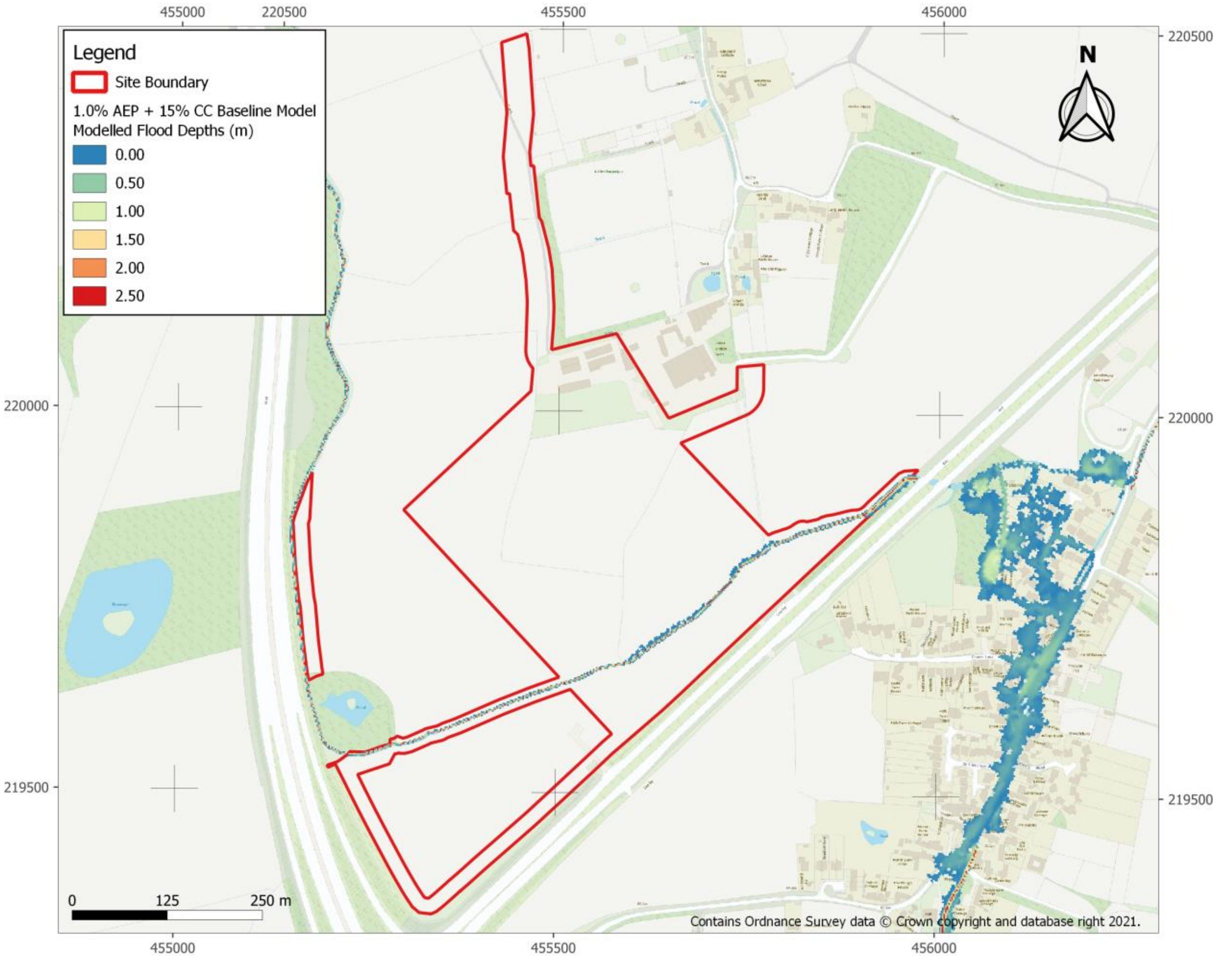


Figure 5 - Baseline 1.0% AEP + 15% Climate Change Modelled Flood Depths

3.3 0.1% AEP Event

As can be seen in Figure 6, during the more extreme 0.1% AEP event some fluvial flooding can be seen within the eastern area of the site. As such some of the site is at risk of fluvial flooding during the 0.1% AEP baseline event.

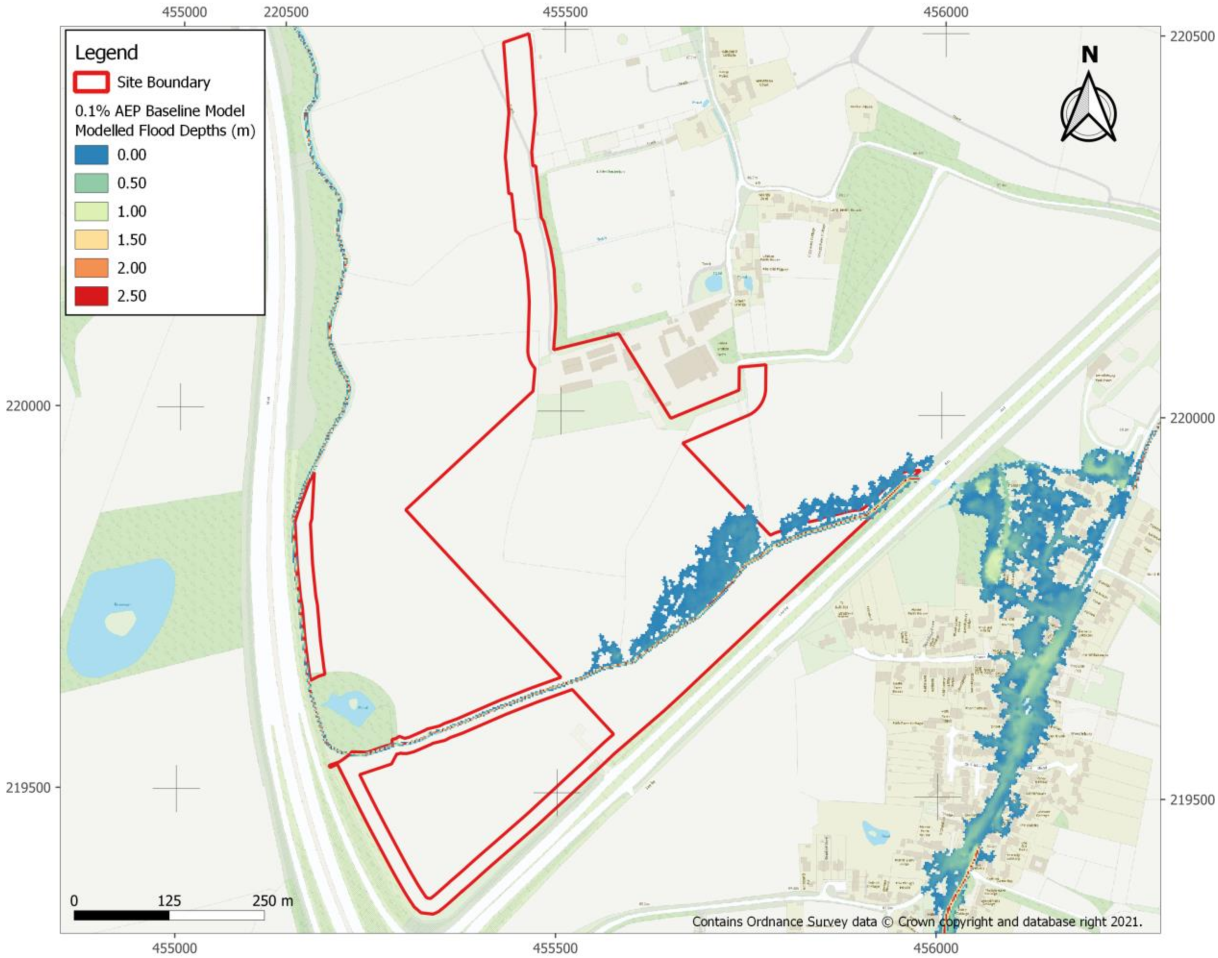


Figure 6 - Baseline 0.1% AEP Modelled Flood Depths

4 Proposed Development

The following sections detail the updates made to the baseline model to create the post-development model. These consisted off:

- Updated 1D river section nodes along the realigned channel
- Updated 1D/2D linkage along the realigned channel
- Updated 2D digital terrain model along the realigned channel
- Updated 2D active and de-active domains along the realigned channel

4.1 FMP Updates

For the development site, it is proposed that an approximate 768m stretch of the Wendlebury Brook, be realigned to the southern boundary of the site. This stretch of the Wendlebury Brook is between model node WB_2733 and WB_1965. The long section of this in the baseline model can be seen in Figure 7 and the georeferenced node locations can be seen in Figure 8.

In the post-development model, the 9 river sections nodes from the 768m stretch of the baseline model between WB_2733 and WB_1965 were replaced with 8 new river section nodes, and 1 interpolate section node. In addition to the new river sections, the chainage for WB_2733 was updated to be 33.315m from 133.421m in the baseline model. The updated chainage for the realigned channel is approximately 987m.

A junction node is used between WB_A-A and WB_A-Ad to connect the inflow from an unnamed tributary. This tributary connects to the Wendlebury Brook within the development site. The realigned channel sections were represented by triangular sections, with the bank and bed levels obtained from the proposed development drawings. The CAD for the proposed development which shows the realignment in more detail can be found in Appendix 1.

The long section of the realigned channel can be seen in Figure 9, and a typical river cross-section for the realigned channel can be seen in Figure 10, with Table 9 showing the updated river section data.

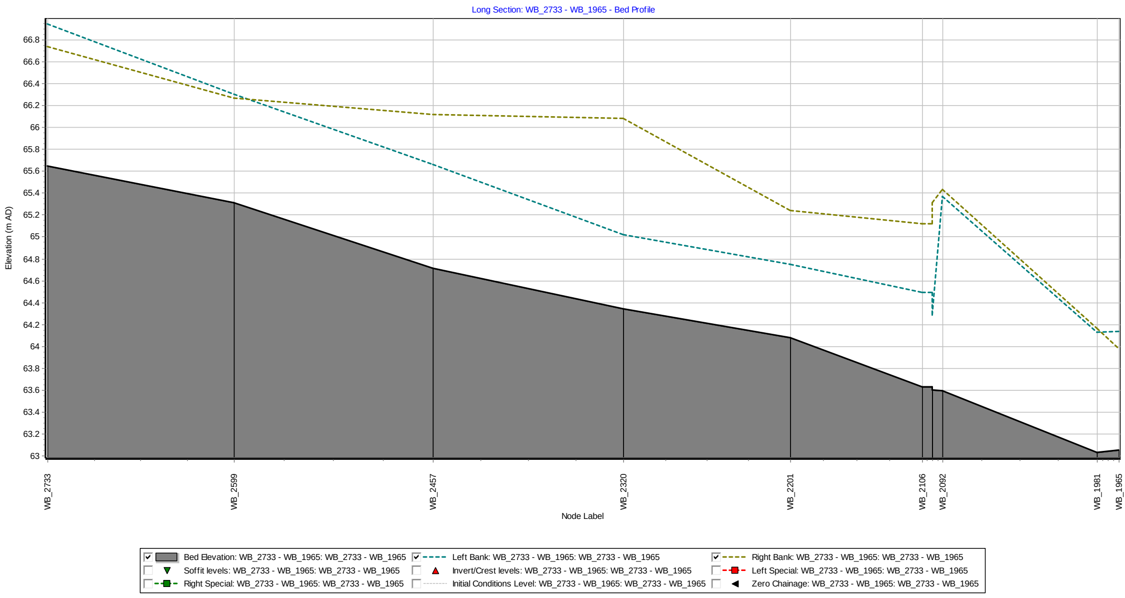


Figure 7 - Baseline Model WB_2733 to WB_1965 Long Section

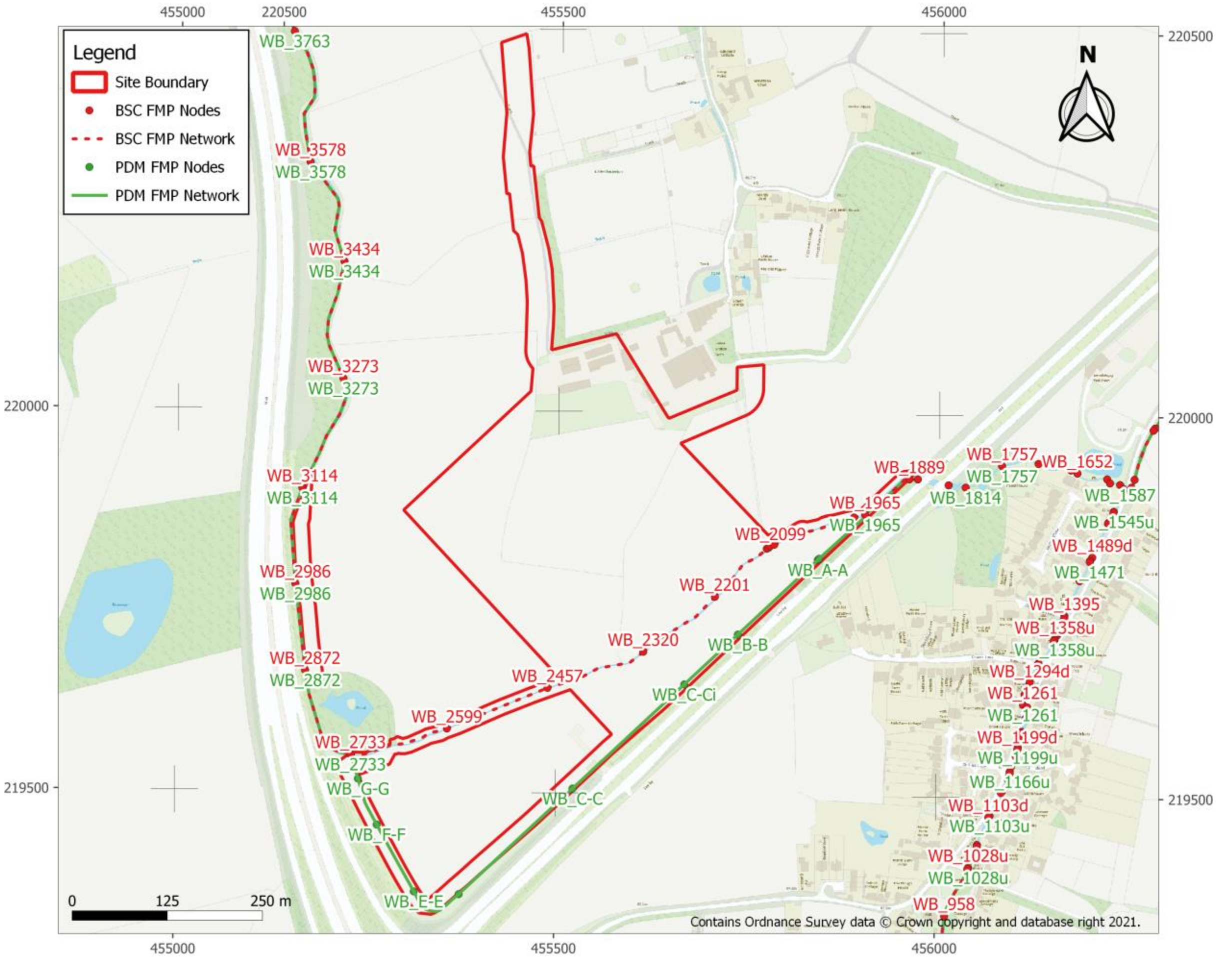


Figure 8 - Baseline and Post Development models 1D Network and Nodes

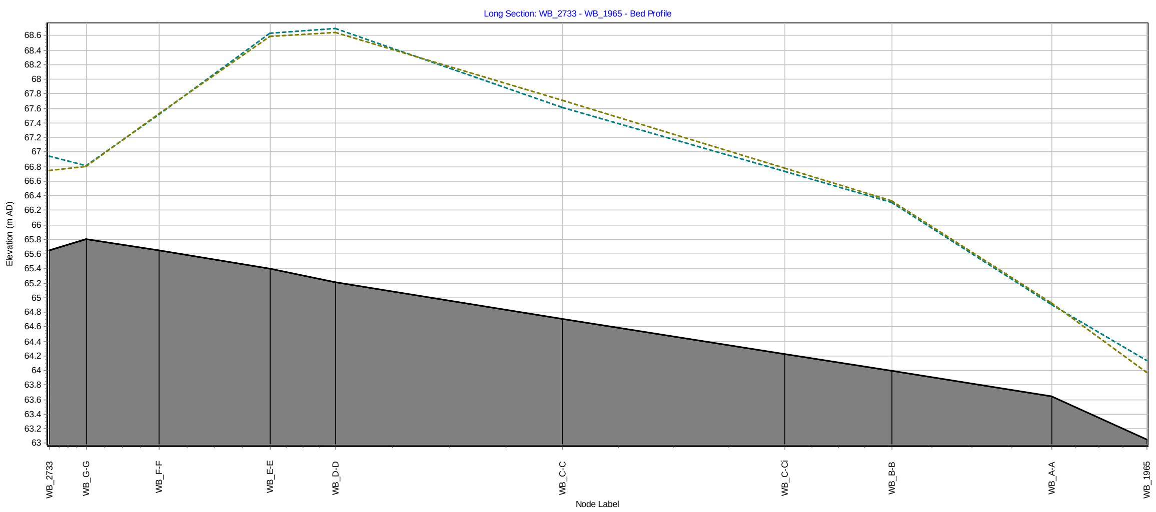


Figure 9 - Post Development Model WB_2733 to WB_1965 Long-section

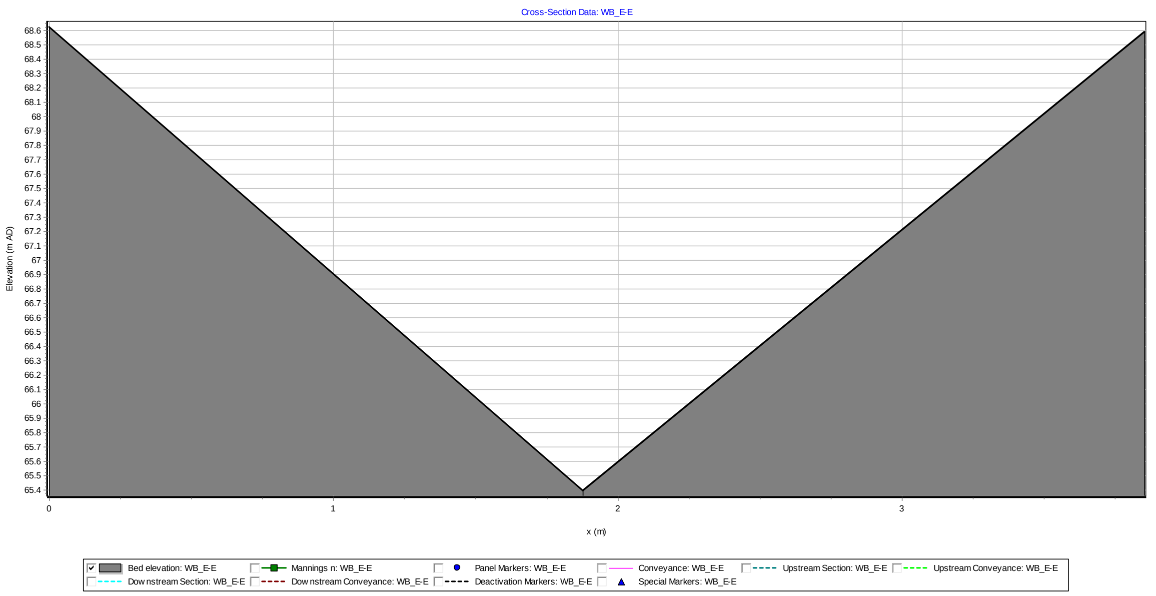


Figure 10 - WB_E-E Cross-Section (Typical Realigned Channel Cross-Section)

Table 9 - Updated Channel Section Data

Node Label	Manning's n	Left Bank		Bed		Right Bank		Chainage (m)	Lateral Inflow Label
		Level (mAOD)	Chainage (m)	Level (mAOD)	Chainage (m)	Level (mAOD)	Chainage (m)		
WB_G-G	0.040	66.805	0.000	65.800	1.875	66.800	3.750	64.885	-
WB_F-F	0.040	67.510	0.000	65.644	1.876	67.515	3.752	100.240	WB02a_10
WB_E-E	0.040	68.622	0.000	65.397	1.876	68.588	3.852	59.076	-
WB_D-D	0.040	68.693	0.000	65.203	1.854	68.635	3.730	203.725	-
WB_C-C	0.040	67.610	0.000	64.708	1.957	67.702	3.818	200.000	WB02a_11
WB_C-Ci	Interpolate Section							96.380	WB02a_12
WB_B-B	0.040	66.306	0.000	63.988	2.034	66.324	3.913	143.586	WB02a_13
WB_A-A	0.040	64.900	0.000	63.637	2.168	64.919	3.752	0.000	-
WB-A-Ad	0.040	64.900	0.367	63.637	2.168	64.919	3.752	85.766	-

4.2 TuFLOW Updates

For the post-development model, several updates were made to the TuFLOW model, these consisted of updating the 1D/2D linkage, the digital terrain model (DTM) and the 2D active and de-active domains.

The DTM updates consisted of updating the thick Z shape line files for the bank levels of the Wendlebury Brook upstream of the A41, to follow the bank of the proposed channel. This was done using a zsh line shapefile, with corresponding points file containing elevation levels along the bank of the proposed channel. These levels were obtained from the proposed development CAD available in Appendix 1.

The ground levels of the proposed development have not been included as there is no out of bank flooding in the proposed development scenario.

In addition to the DTM updates, the 1D nodes, 1D network and 1D water level lines (WLL) were updated to match the FMP updates outlined in section 4.1. The inactive area in the TuFLOW model was also updated to follow the proposed channel alignment, new HX links were added to connect the realigned sections to the TuFLOW model.

A summary of the updates made to the TuFLOW model for the post-development model is in Table 10 and the 2D representation of the baseline and post-development model can be seen in Figure 11.

Table 10 – Post Development Model TuFLOW Changes

Baseline File	Updated Files	Description	Descriptions of Updates
WBs_~s1~_~s2~_e1~_003.tcf			
1D_ND_ISIS_08.shp	*1d_wb_OP3_FMP_Nodes_P_002.shp*	FMP Node Location	Realigned channel nodes added and old channel nodes removed
1d_x1d_ISIS_nwk_WB_04.shp	*1d_x1d_wb_OP3_FMP_nwk_L_002.shp*	FMP channel lines	Updated to connect realigned channel nodes
1d_WLL_03.shp	*1d_WLL_PDM_001.shp*	1D water level lines	Updated to follow realigned channel
WB_21_SLext_with_SP_002.tgc			
2d_code_WB_1d_05.shp	*2d_code_WB_PDM_1d_R_001.shp*	2D inactive area.	Inactive area updated to follow realigned channel extent
2d_zln_bank_levels_Upstream_A41_L.shp | 2d_zln_bank_levels_Upstream_A41_P.shp	*2d_zsh_OP3_Bank_L_001.shp | 2d_zsh_PDM_Bank_P_001.shp*	Bank levels upstream of A41	Updated to follow realigned channel bank and to use proposed channel bank levels
WB_16SLext.tbc			
2d_bc_hxi_wb_07_L.shp | 2d_bc_hxi_07_P.shp	*2d_bc_hxi_OP3_L_002.shp | 2d_bc_hxi_wb_PDM_P_001.shp*	1D 2D link for the Wendlebury Brook	Updated to follow realigned channel banks

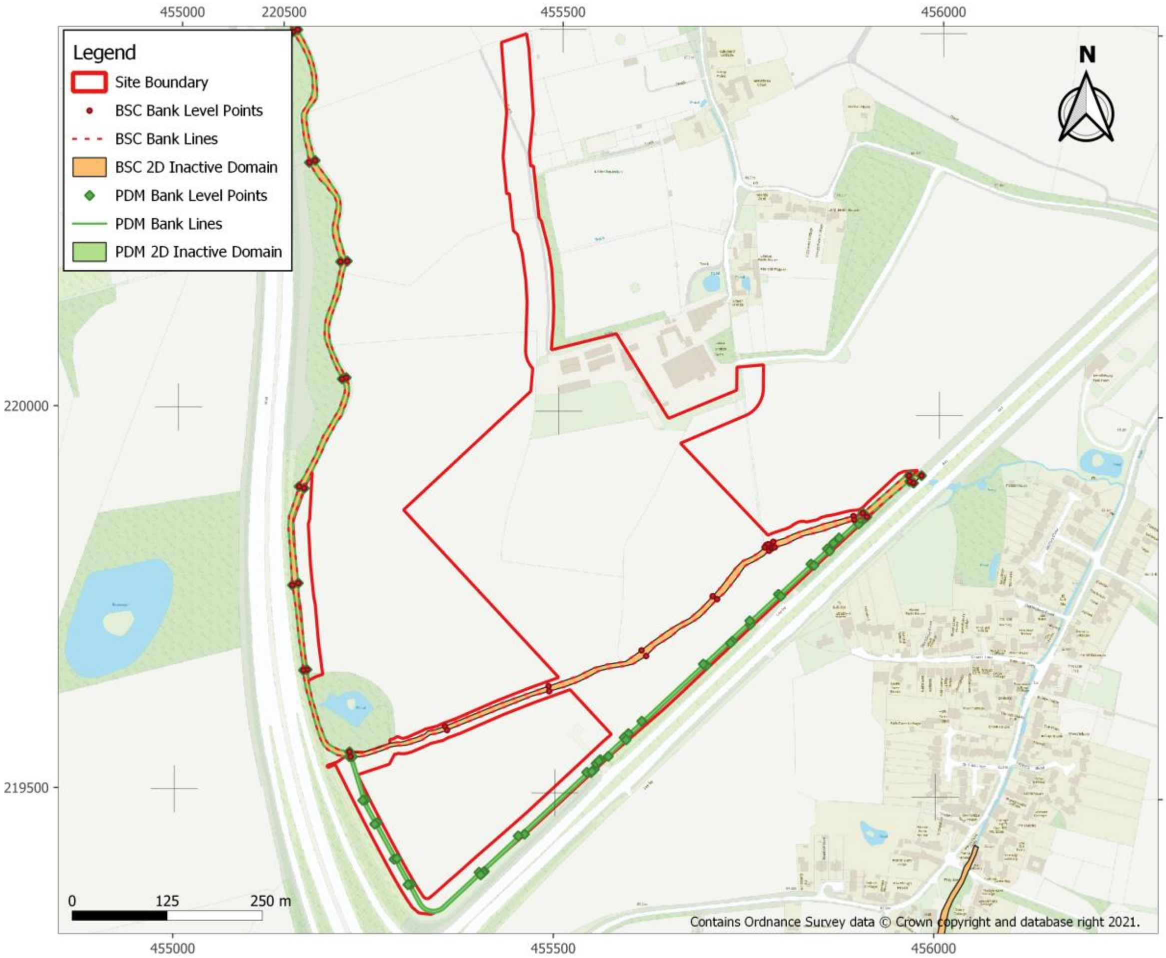


Figure 11 - Baseline and Post Development 2D Representation

5 Mitigation

Following a review of the modelled flooding for the proposed development scenario, it was identified that the proposed design resulted in increased flood depths and extent at the development site. As such mitigation scenario modelling was undertaken to offset these increases in flood risk. The following sections detail the updates made to the proposed development model to assess mitigation options.

5.1 Mitigation Scenario 1

For mitigation scenario 1 the bed levels of river section WB_G-G and WB_F-F from the proposed development scenario were lowered, to achieve a more consistent gradient through the proposed channel. The proposed development and mitigation scenario 1 bed levels for sections WB_G-G and WB_F-F can be seen in Table 11 and the updated long-section of the realigned channel can be seen in Figure 12.

Table 11 - Mitigation Scenario 1 Bed Level Updates

Model Node	Proposed Development Bed Level (mAOD)	Mitigation Scenario 1 Bed Levels (mAOD)
WB_G-G	65.800	65.605
WB_F-F	65.644	65.523

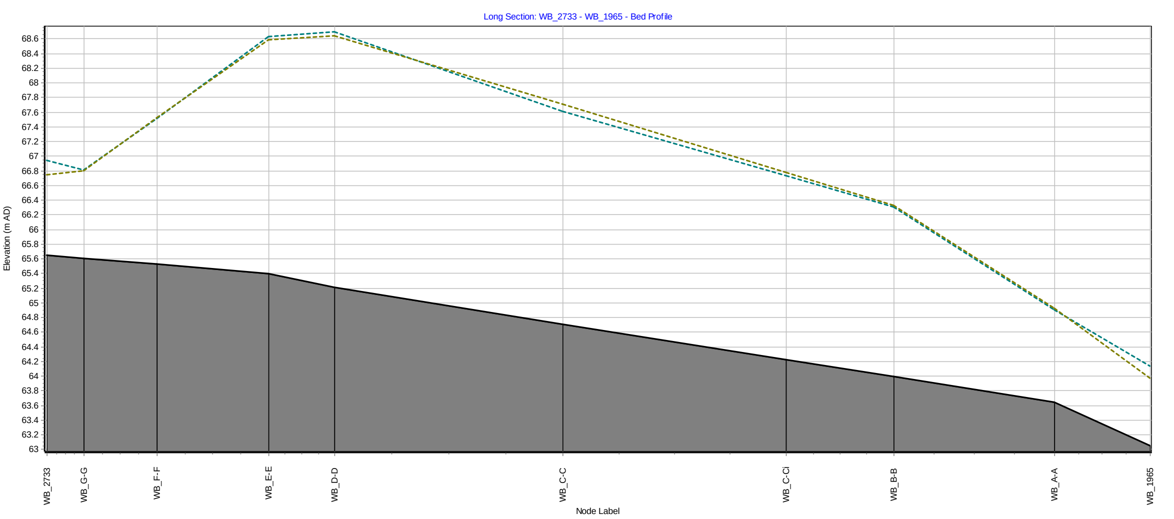


Figure 12 - Mitigation Scenario 1 WB_2733 it WB_1965 Long-section

5.2 Mitigation Scenario 2

Mitigation scenario 2 includes the bed level adjustment in mitigation 1. It also adjusts the channel cross sections, with these updated to consist of trapezoidal sections. The updated section have a bank to bank width of 4.0m and a bed width of 1.5m. The bed and bank levels from mitigation scenario 1 were retained. The typical cross-section for the realigned channel in mitigation scenario 2 can be seen in Figure 13. The details of the updates to the cross-sections of the realigned channel are summarised in Table 12.

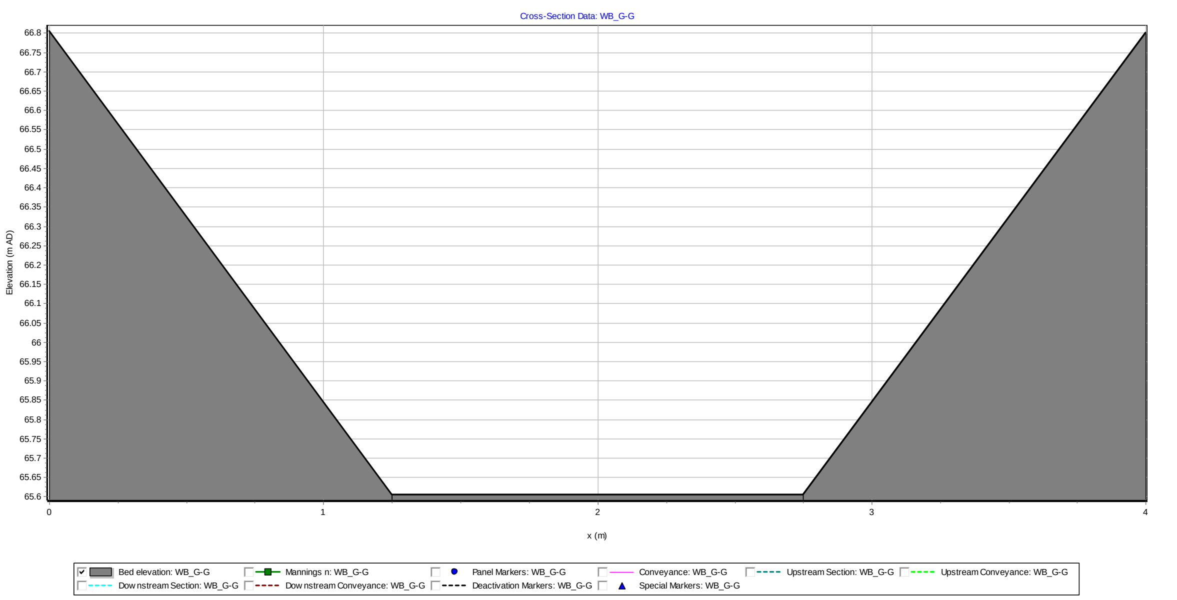


Figure 13 - Mitigation Scenario 2 WB_G-G Cross-Section (Typical realigned channel cross-section)

Table 12 - Scenario 2 Cross-section width updates

Model Node	Bank to Bank width Scenario 1 (m)	Change in bank width (Scenario 2 – Scenario 1) (m)
WB_G-G	3.750	0.250
WB_F-F	3.752	0.248
WB_E-E	3.852	0.148
WB_D-D	3.730	0.270
WB_C-C	3.818	0.182
WB_C-Ci	Interpolate Section	
WB_B-B	3.913	0.087
WB_A-A	3.385	0.615
WB_A-Ad	3.385	0.615

5.3 Mitigation Scenario 3

Mitigation scenario 3 retains the updates made for scenario 2. For mitigation scenario 3 the bed levels of the channel were updated again, to ensure the slope at the upstream and downstream extents of the realigned channel are similar to those of the natural channel it replaces. The realigned channel bed levels for scenarios 2 and 3 can be seen in Table 13. Figure 14 shows the realigned channel long-section for scenario 3. Mitigation scenario 3 is the preferred option with the results from this scenario presented in the next section.

Table 13 - Mitigation Scenario 3 Updated Bed Levels

Model Node	Scenario 2 Bed Level (mAOD)	Scenario 3 Bed Level (mAOD)	Change in Bed Level (m)
WB_G-G	65.605	65.563	-0.042
WB_F-F	65.523	65.304	-0.219
WB_E-E	65.397	65.049	-0.348
WB_D-D	65.203	64.899	-0.304
WB_C-C	64.708	64.382	-0.326
WB_C-Ci	Interpolate Section		
WB_B-B	63.988	63.630	-0.358
WB_A-A	63.637	63.265	-0.372
WB_A-Ad	63.637	63.265	-0.372

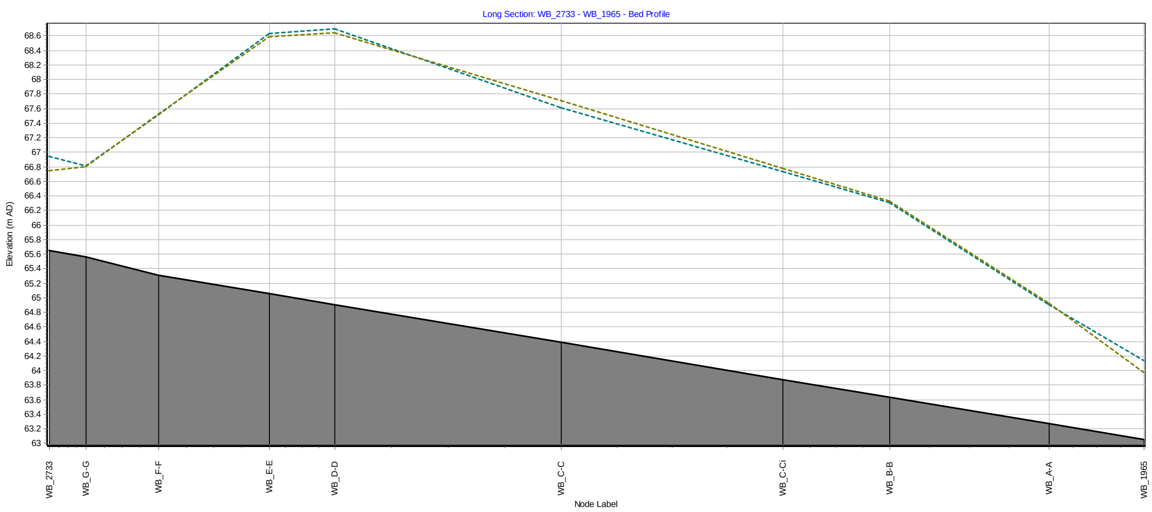


Figure 14 - Mitigation Scenario 3 WB_2733 to WB_1965 Long-section

6 Mitigation Scenario 3 Results

6.1 1.0% AEP Event

The modelled flood depths for the 1.0% AEP flood event can be seen in Figure 15. For mitigation scenario 3 there are no out of bank flows shown for the 1.0% AEP event upstream of the A41 culvert as in the baseline model.

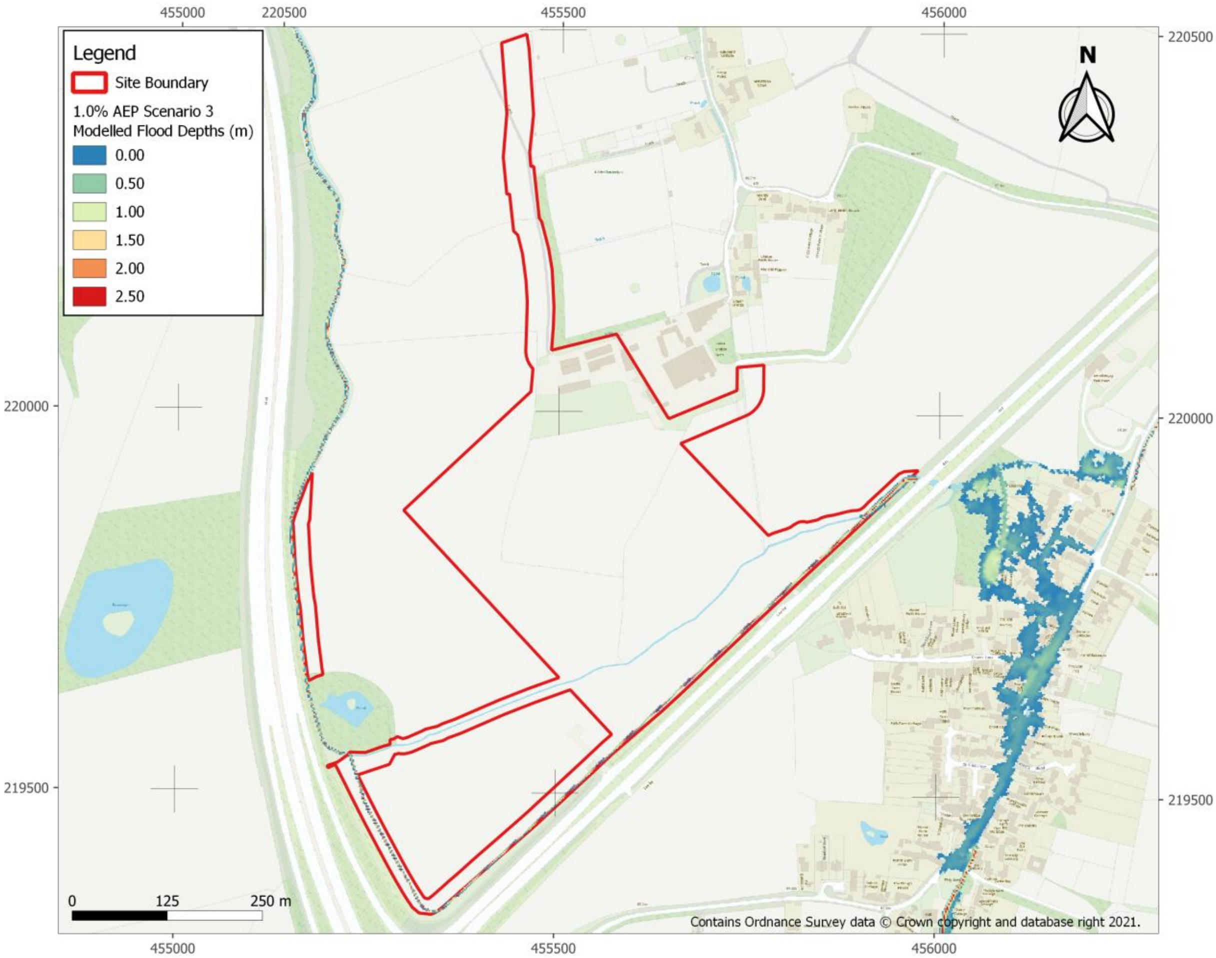


Figure 15 - Mitigation Scenario 3 1.0% AEP Modelled Flood Depths

Figure 16, shows the change in depth plot for mitigation scenario 3 against the baseline. As can be seen below during the 1.0% AEP event there is no modelled impact.

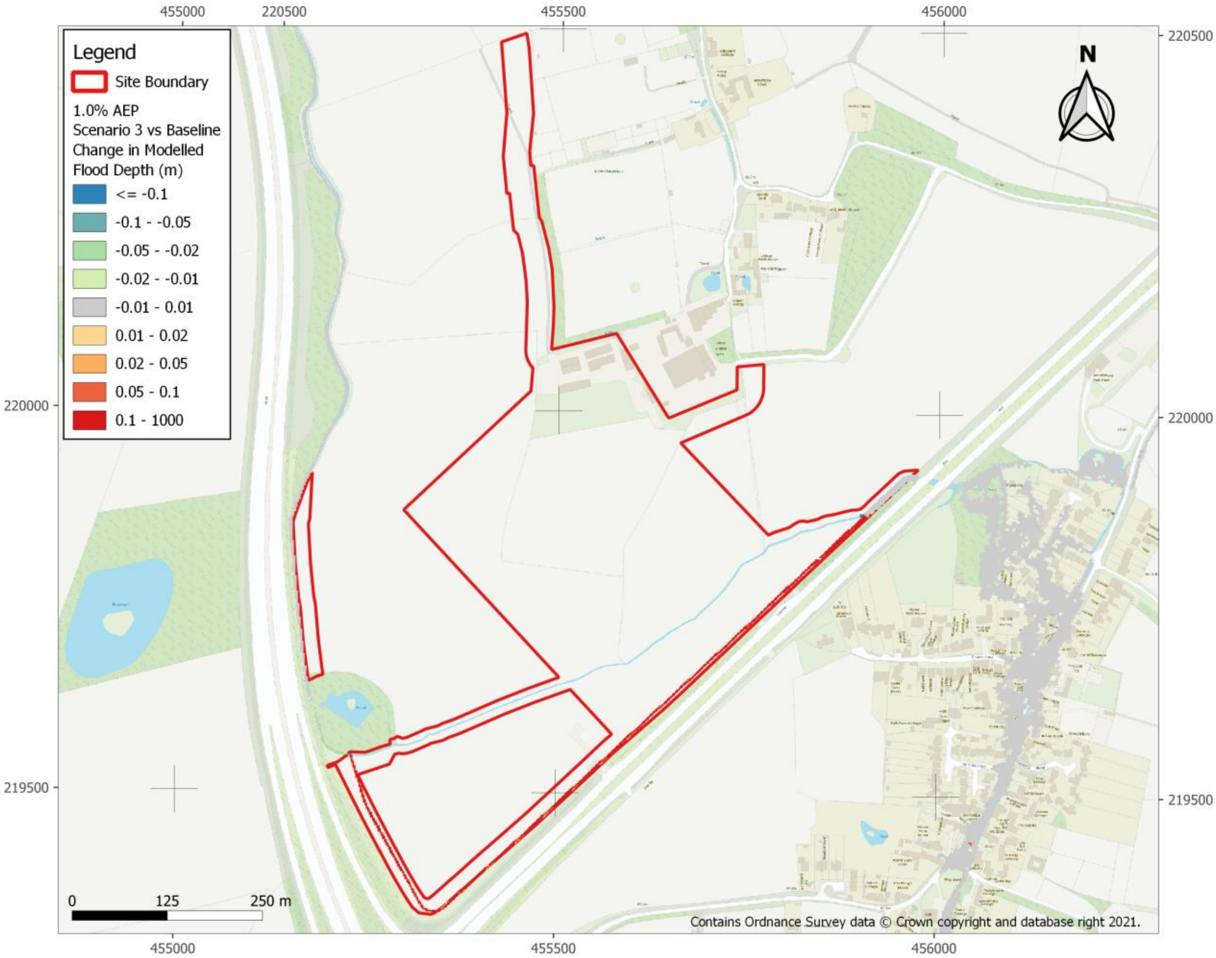


Figure 16 - Mitigation Scenario 3 1.0% AEP Change in Modelled Flood Depth

6.2 1.0% AEP + 15% Climate Change (Central) Event

As can be seen in Figure 17, for the 1.0% AEP + climate change event no out of bank flows are modelled upstream of the A41 culvert, as in the baseline model.

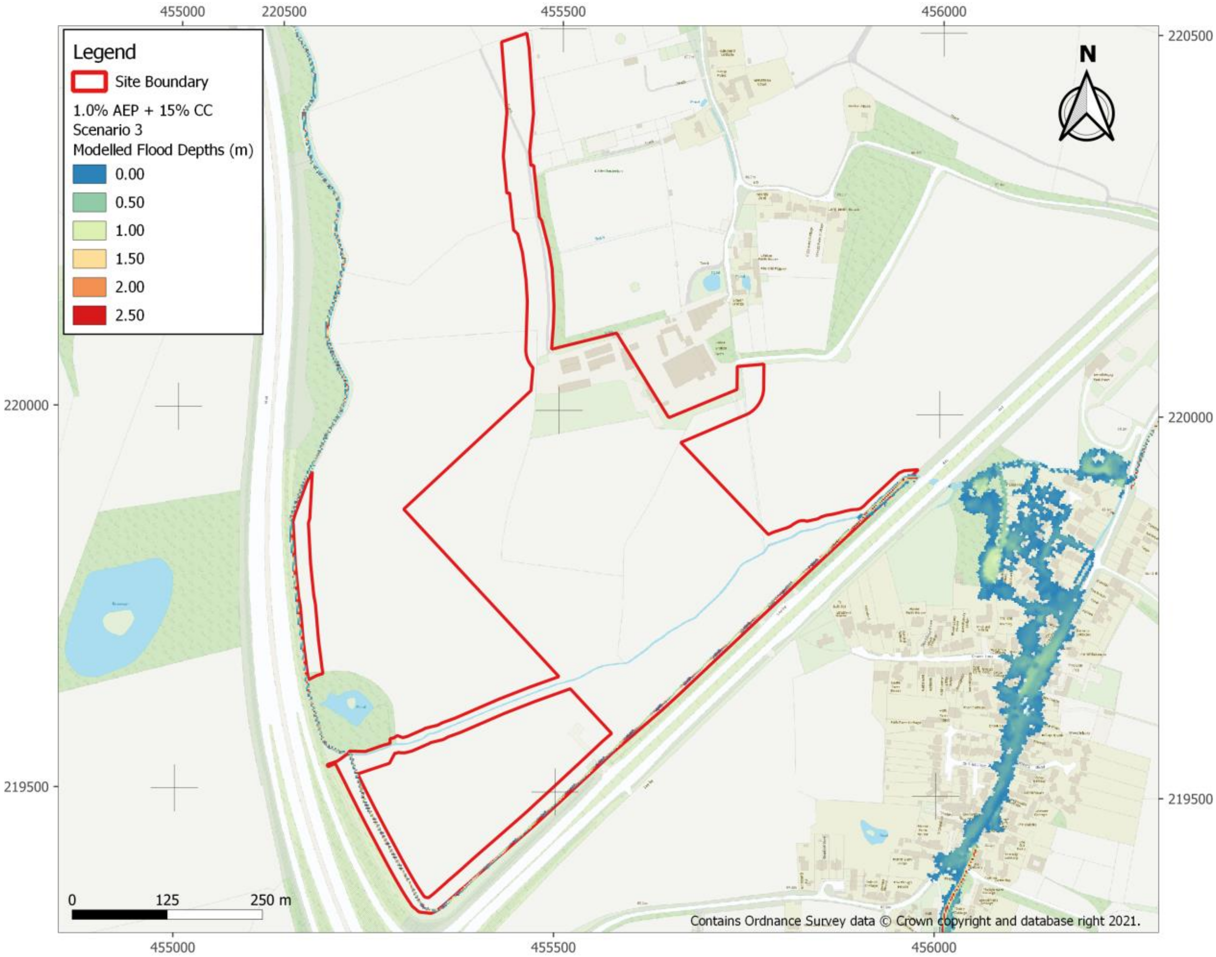


Figure 17 - Mitigation Scenario 3 1.0% AEP + CC Modelled Flood Depths

Figure 18, shows the change in modelled flood depths when compared to the baseline model. As can be seen during the 1.0% AEP + CC there is no modelled impact.

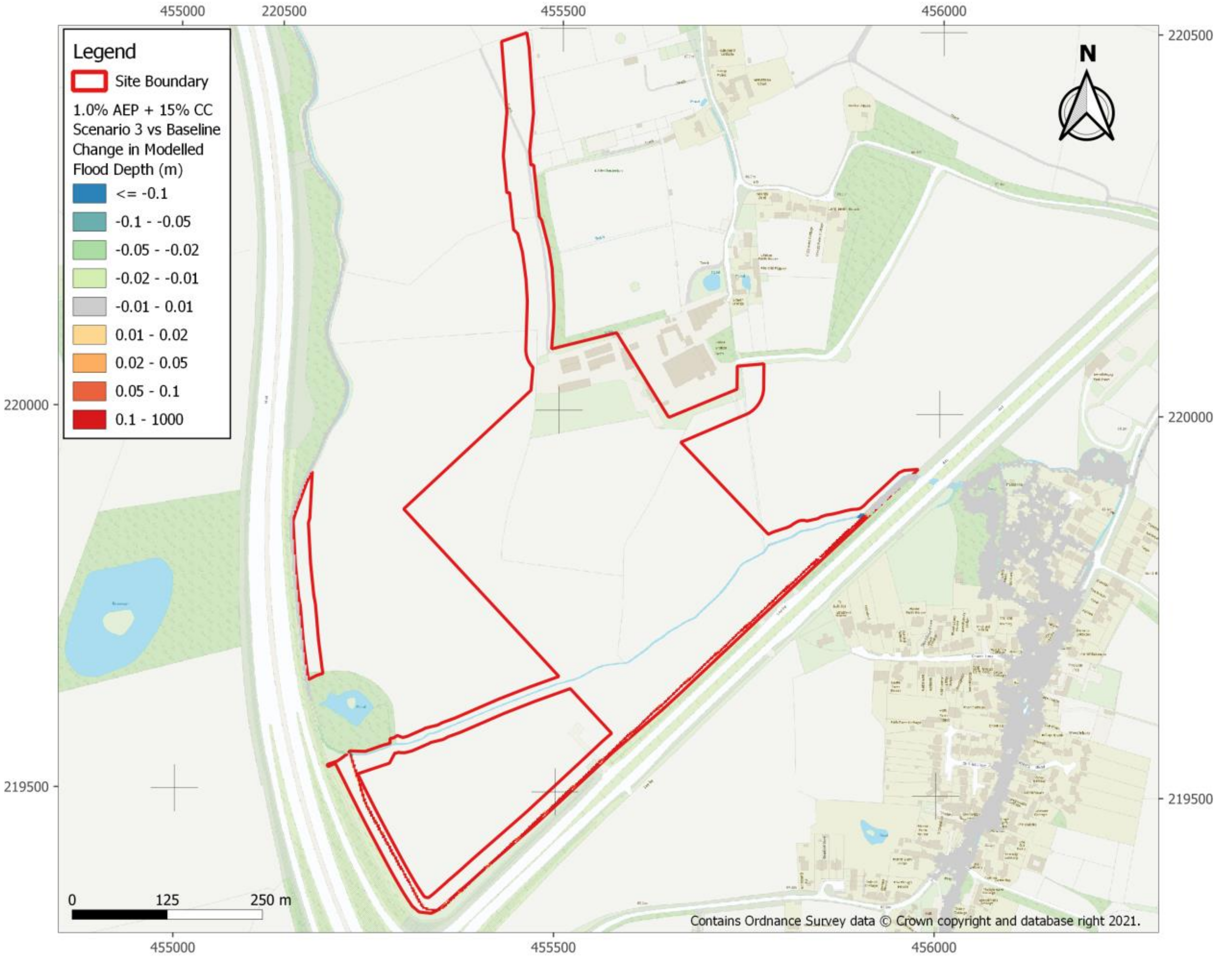


Figure 18 - Mitigation Scenario 3 1.0% AEP + CC Change in Modelled Flood Depth

6.3 0.1% AEP Event

As can be seen in Figure 19, for the 0.1% AEP event a small flood extent just upstream of the A41 culvert can be seen, this is smaller than the extent upstream of the culvert in the baseline model.

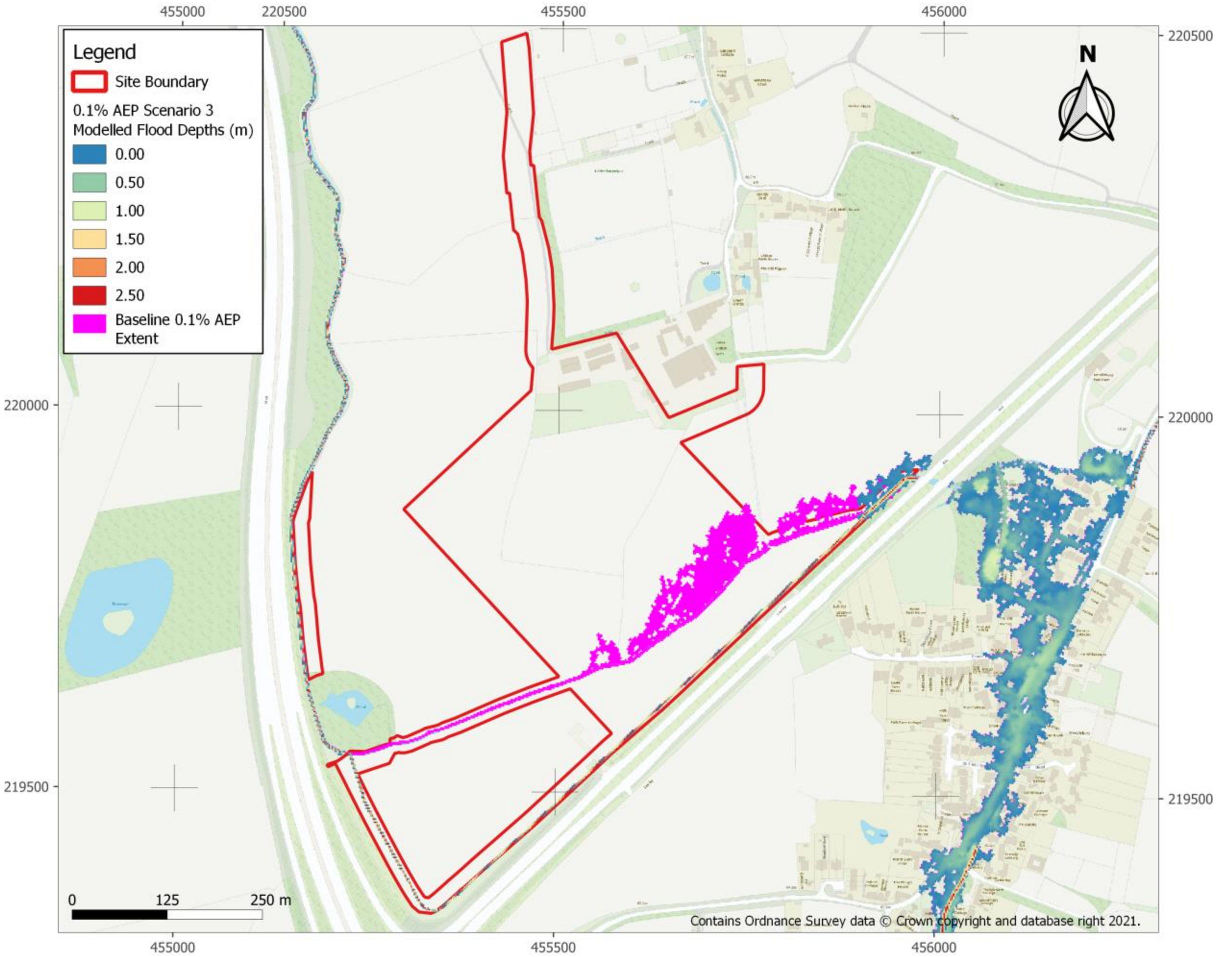


Figure 19 - Mitigation Scenario 3 0.1% AEP Modelled Flood Depths

Figure 20, shows the change in modelled flood depths. As can be seen at the upstream extremity of the realigned channel, some increases in depth can be seen. However, for the majority of the modelled extent, no impact is apparent.

Upstream of the A41 culvert, the majority of changes in depth lie within the +/- 10mm band, however there are some isolated areas where the changes are greater. Downstream of the A41 culvert, there are some isolated areas of increased flood depth in Wendlebury, however for the most part changes lie within the +/- 10mm band.

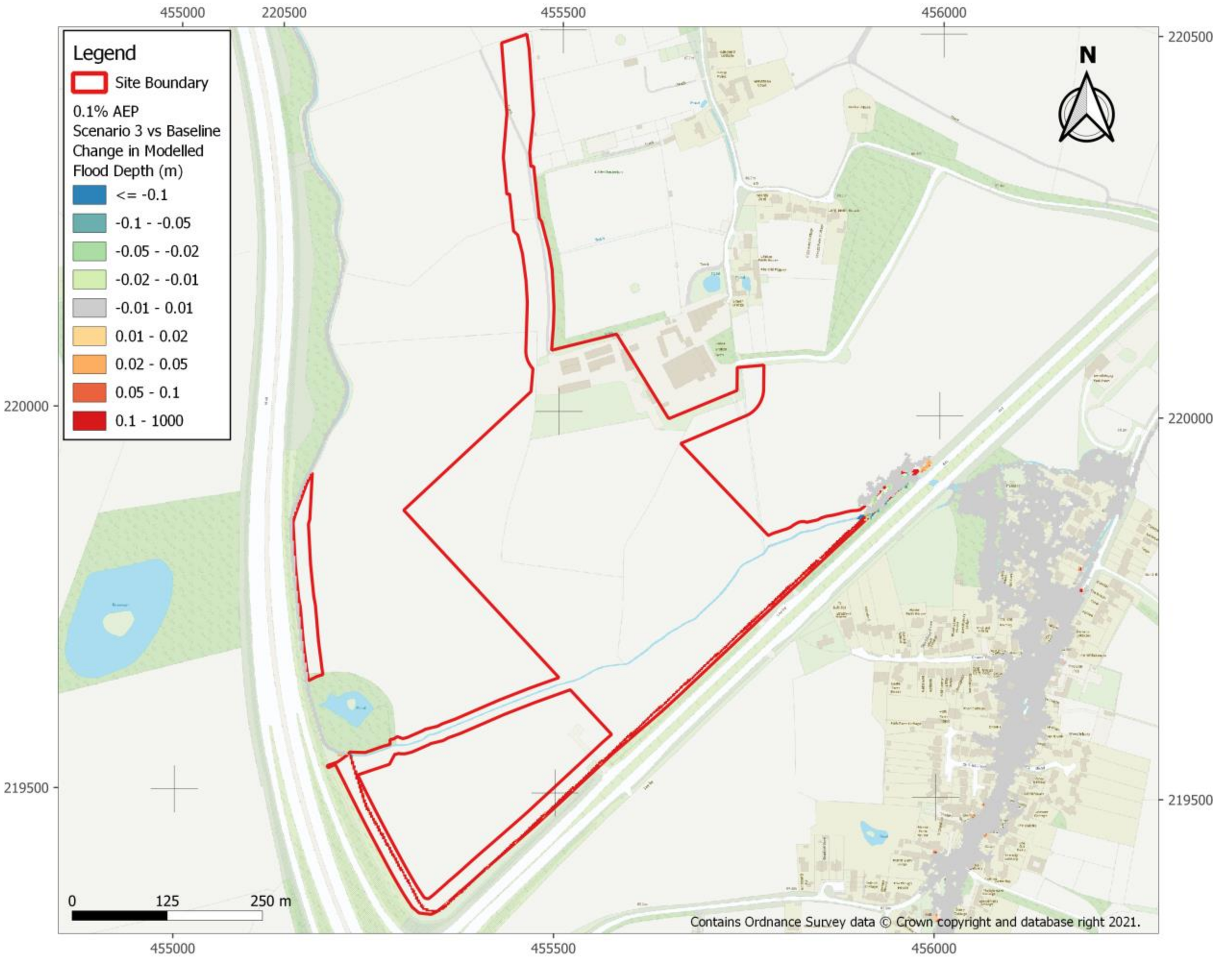


Figure 20 - Mitigation Scenario 3 0.1% AEP Change in Modelled Flood Depth

6.4 Summary of Mitigation Scenario 3 Results

The proposed site is shown to be flood-free during the 1.0% AEP and 1.0% AEP + CC events, with a small amount of flooding shown during the 0.1% AEP event at the eastern site boundary. During the 1.0% AEP and 1.0% AEP + CC events the modelled change in flood depth through Wendlebury shows no impact as a result of the proposed development.

As can be seen in Table 14, mitigation scenario 3 does not result in a significant increase in peak flows through the A41 culvert (model node WB_1878cu) and therefore Wendlebury. For the 0.1% AEP event there are some isolated cells of flood depth increases beyond 10mm in Wendlebury. Due to the inherited instabilities in the baseline model through Wendlebury, the cause of these increases is thought to be a result of oscillations in the modelling results rather than as a result of the proposed development.

Table 14 - Peak Flows through the A41 Culvert

Event	Baseline A41 Culvert Peak Flow (m^3/s)	Mitigation 3 A41 Culvert Peak Flow (m^3/s)	Change in Peak Flow (m^3/s)
1.0% AEP	1.797	1.794	-0.003
1.0% AEP + 15% CC	2.070	2.073	0.003
0.1% AEP	3.141	3.163	0.022

7 Blockage Scenario

To assess the impact of a blockage of the culvert under the A41 (FMP node WB_1878cu), a blockage scenario was run. Following a review of the risk of a blockage occurring, it was determined that the risk at this location was low, as a result of the large culvert size and lack of potential debris sources.

As such a 33% blockage ratio is considered appropriate for this location. The updates made to represent this consisted of; the insertion of blockage unit upstream of the culvert inlet in FMP, with a 33% blockage ratio and updated initial conditions for the model.

7.1 Mitigation Scenario 3 1.0% AEP + 15% CC Blockage Scenario

Figure 21 below shows the modelled flood depths for the mitigation scenario 3 model with a 33% blockage ratio for the culvert under the A41. In this scenario out of bank flooding can be seen just upstream of the A41 culvert as a result of the blockage. This small increase in extent does not pose any additional risk to the proposed development site and is limited to a small area of agricultural land.

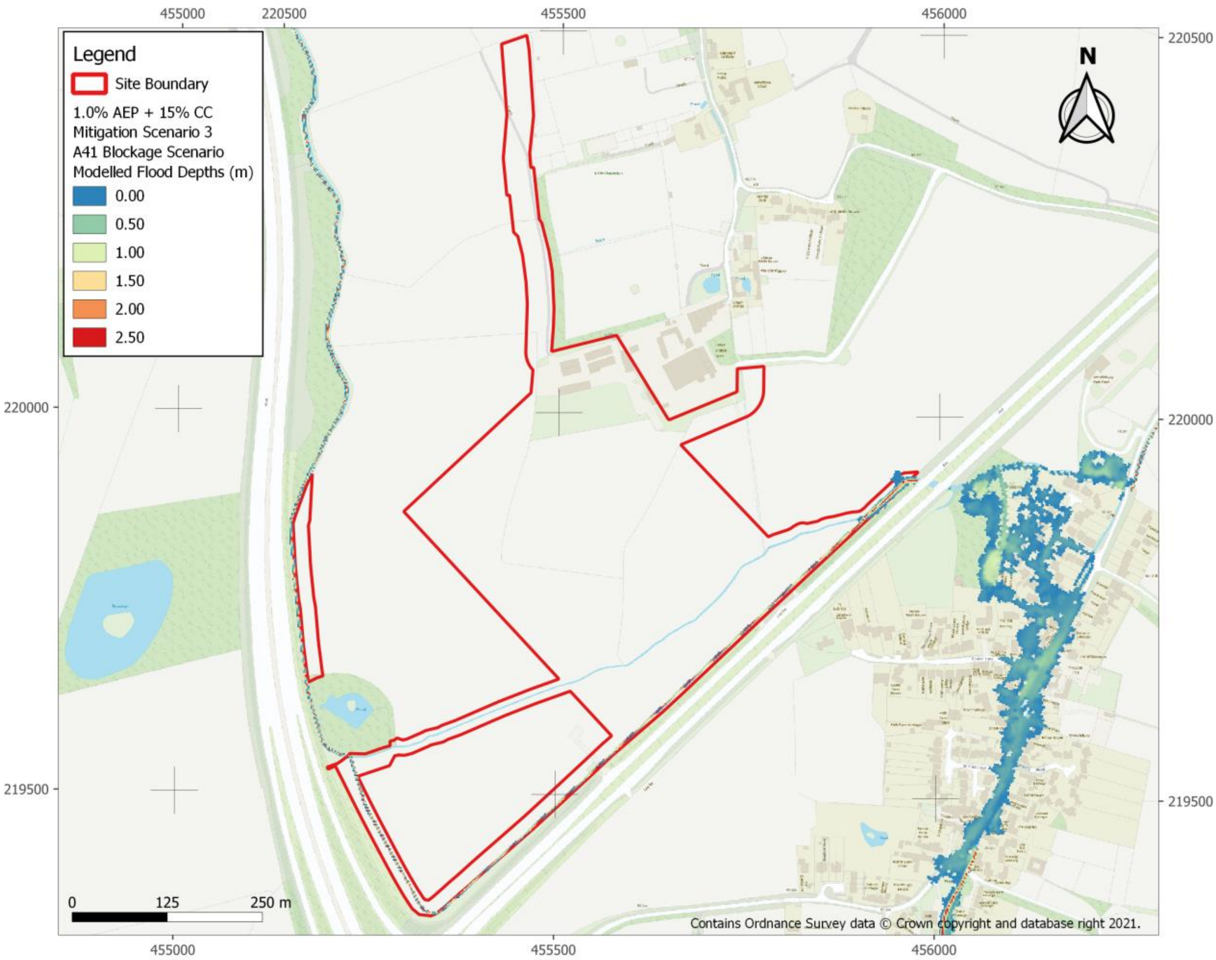


Figure 21 – Mitigation Scenario 3 1.0% AEP + CC Blockage Scenario

8 Hydrock Updates (Sep-22)

8.1 Truncated Model Extent

The model of the Wendlebury Brook has subsequently been updated by Hydrock on 27/09/2022. This consisted of truncating the model at the confluence of the Wendlebury Brook and the unnamed drainage channel (NGR: 456238, 219911) approximately 340m downstream of the site. The model stability outputs (section 8.2) have been extracted from the updated Hydrock model.

In order to assess the impacts of the updates made by Hydrock, the peak modelled flows through the A41 culvert (model node WB_1878cu) have been compared between the truncated Hydrock and untruncated EA model. As can be seen in Table 15 below, the updates have not significantly changed the modelled peak flows through the culvert.

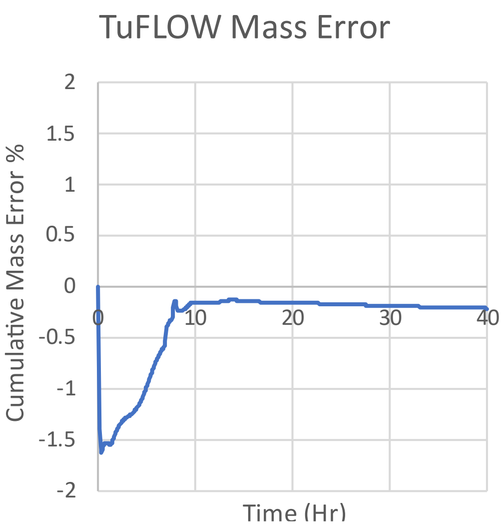
Table 15 – Truncated vs Non-Truncated A41 Culvert Peak Flows

Event	Untruncated A41 Culvert Peak Flow (m^3/s)	Truncated A41 Culvert Peak Flow (m^3/s)	Change in Peak Flow (m^3/s)
1.0% AEP	1.797	1.799	0.003
1.0% AEP + 15% CC	2.070	2.049	-0.021
0.1% AEP	3.141	3.128	-0.013

8.2 Mass Balance

The 2D mass balance plots and 1D mass balance errors from the truncated Hydrock model are show below and it is concluded that the mass balance is acceptable.

Baseline - 1.0% AEP

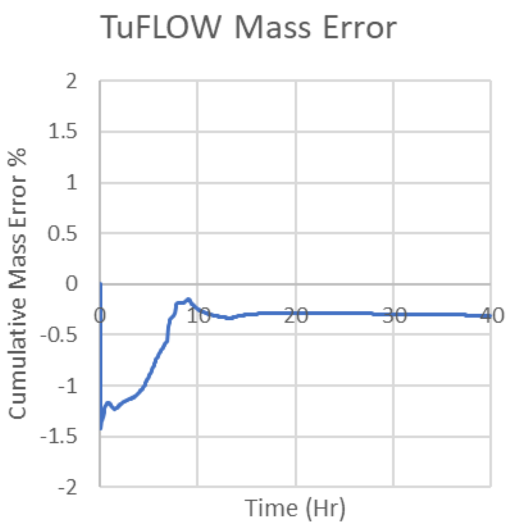


Flood Modeller Mass Balance Summary:

Mass balance error: 0.04% (of peak system volume)

Mass balance error [2]: 0.00% (of boundary inflow volume)

Mitigation Scenario 3 - 1.0% AEP

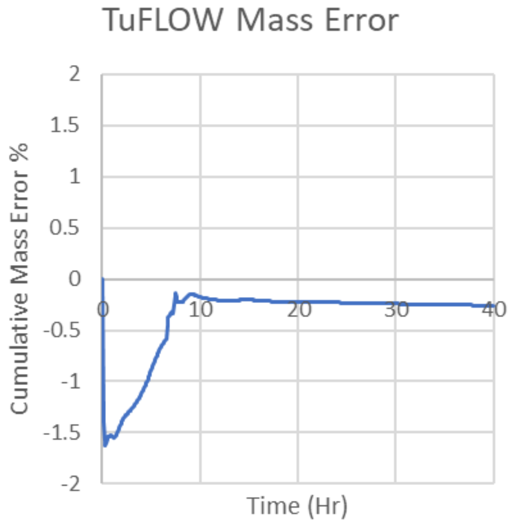


Flood Modeller Mass Balance Summary:

Mass balance error: -0.01% (of peak system volume)

Mass balance error [2]: -0.00% (of boundary inflow volume)

Baseline - 1.0% AEP + CC

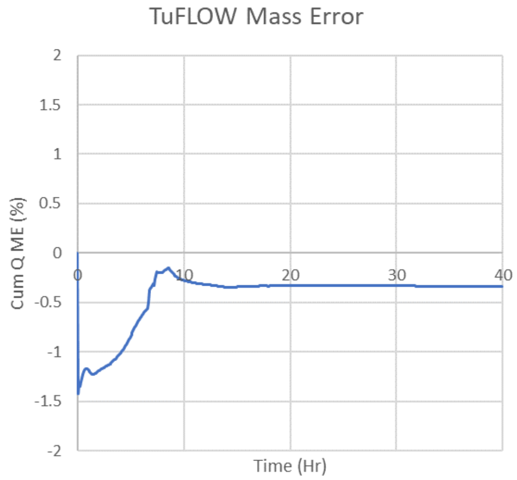


Flood Modeller Mass Balance Summary:

Mass balance error: -0.04% (of peak system volume)

Mass balance error [2]: -0.00% (of boundary inflow volume)

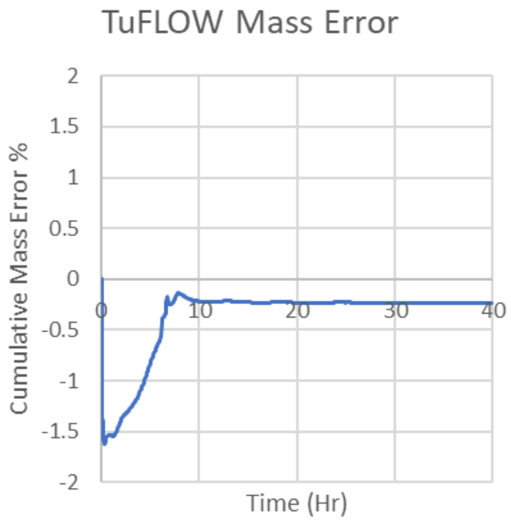
Mitigation Scenario 3 – 1.0% AEP + CC



Flood Modeller Mass Balance Summary:

1D results not available

Baseline - 0.1% AEP



Flood Modeller Mass Balance Summary*:

Mass balance error: -0.25% (of peak system volume)

Mass balance error [2]: -0.01% (of boundary inflow volume)

Mitigation Option 3 – 0.1% AEP

Modelling results unavailable

*For Hydrock runs FMP v4.6 was used, whilst v5.0 in untruncated model

8.3 Review of LiDAR Data

Since the development of the original model, new LiDAR data has been flown. Although this lidar data has not been incorporated into the model, it has been reviewed by Hydrock to identify the difference against the DTM being used in the model.

Hydrock looked at ten points (Table 10) and differences ranged from 20mm to 560mm, with an average difference of 160mm. Although there are some outliers, it was concluded that the new lidar data would materially change the results of the study, particularly as the proposed development is flood free.

Table 16 – Comparison of most recent LiDAR vs Existing Model

	2020 LiDAR (mAOD)	Existing Model (mAOD)	Difference (m)
Point 1:	64.944	64.884	0.060
Point 2:	64.136	64.162	-0.026
Point 3:	66.673	66.466	0.207
Point 4:	63.553	64.117	-0.564
Point 5:	64.935	64.892	0.043
Point 6:	63.346	63.801	-0.455
Point 7:	65.166	65.122	0.044
Point 8:	65.818	65.753	0.065
Point 9:	64.194	64.25	-0.056
Point 10	63.966	64.043	-0.077

8.4 Sensitivity Analysis on Truncated Model

Whilst truncating the model, Hydrock also completed a range of sensitivity tests on the baseline model. These sensitivity tests looked at increasing and decreasing manning's number and downstream boundary gradient by ±20%, Table 17.

It is concluded that the downstream boundary has negligible impact on modelled flood levels, and that manning's value has a small impact. Although Manning's values have a small impact. They are still within the expected range of results as all changes in modelled flood level are below ±60mm.

Table 17 – Comparison

	BSC	Sen(D+20)	Delta	Sen(D-20)	Delta	Sen(N+20)	Delta	Sen(N-20)	Delta
WB_3578	69.763	69.763	0.000	69.763	0.000	69.8	-0.038	69.721	0.042
WB_3114	67.724	67.725	-0.001	67.725	-0.001	67.778	-0.053	67.665	0.059
WB_1965	64.022	64.026	-0.004	64.026	-0.004	64.061	-0.039	63.988	0.034
WB_1757	63.813	63.809	0.004	63.809	0.004	63.829	-0.016	63.784	0.029

9 Proposed Culvert under Access Road (Nov-22)

9.1 Summary of Proposed Culvert

As part of the proposed scheme, a new access road is required and this access road crosses a section of the realigned water course (455831, 219798). At this crossing, a 2.5m wide and 1.5m high rectangular culvert[4] is proposed, see Figure 22m and Figure 23.

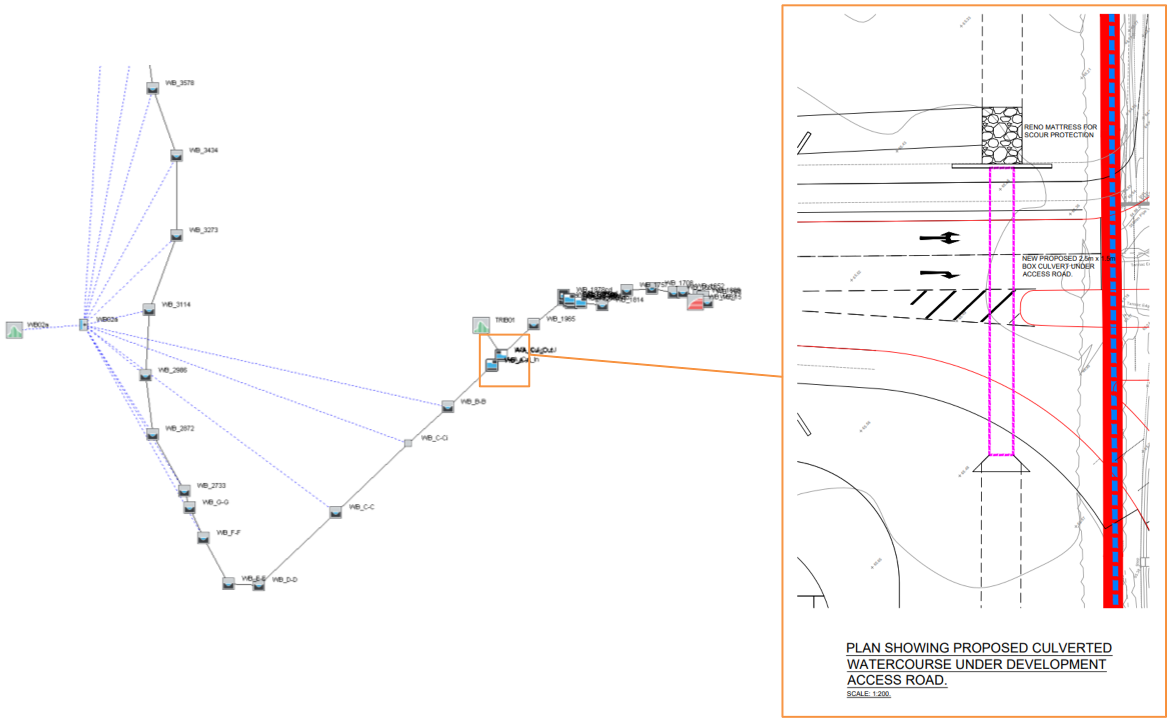


Figure 22 – Plan Location of Proposed Culvert

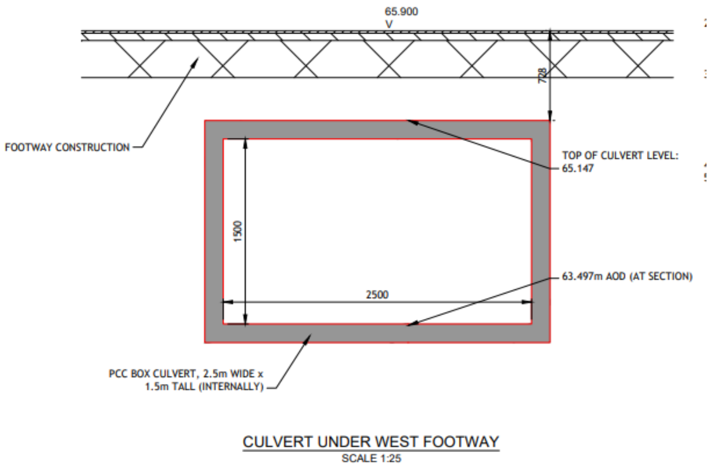


Figure 23 – Typical Culvert Cross Section

[4] TIER (2022). *Proposed Culverted Watercourse Details.* T/21/2407 CIV-SK-101 Rev: T4.

9.2 Modelling of the Proposed Culvert

This culvert has been modelled based on the dimensions and invert levels provided by Tier Consulting. The culvert is approximately 30m long and has been modelled with an internal roughness value of n=0.013.

Inlet losses have been included in the model using the standard inlet loss unit and these losses are based on a rectangular single-barrel concrete culvert with flared wing walls.

In addition to adding the culvert to the 1D domain, additional 2D updates were required. These include;

- Updated revision number of control files to 005
- Relocate node A-A 30m upstream to the location of the inlet of the proposed culvert
- Update the 1d_nwk line to connect to the relocated 1d_node
- Update the HX links to terminate at the inlet and then start again at the outlet
- Update the 2d inactive code area so that the 2d domain above the culvert is active
- Update the WLL to coincide with the updated 2d inactive code area

As there is no flooding of the site during the 0.1% AEP flood event, no additional 2D updates were considered necessary.

9.3 Modelled impacts of the proposed culvert

The impact that the proposed culvert has on in-channel flood levels during the 0.1% AEP flood event is shown in Figure 24 and a summary of peak flows under the A41 culvert (model node WB_1878cu) is provided in The peak flows under the A41 culvert (model node WB_1878cu) are essentially the same as the modelling results without the proposed culvert (see section 6.4). Note that the baseline flows are slightly different, and this is attributed to re-running the model in a more recent version of FMP and TuFLOW.

Table 18.

It can be seen in Figure 24 that the proposed culvert locally raises flood levels and the modelling results show a maximum increase of +180mm during the 0.1% AEP flood event. In comparison to the bank levels (green) and access road level (red), it can be concluded that the culvert will not be overtopped during the 0.1% AEP flood event. This is also evident in the 2d results which also show no overtopping.

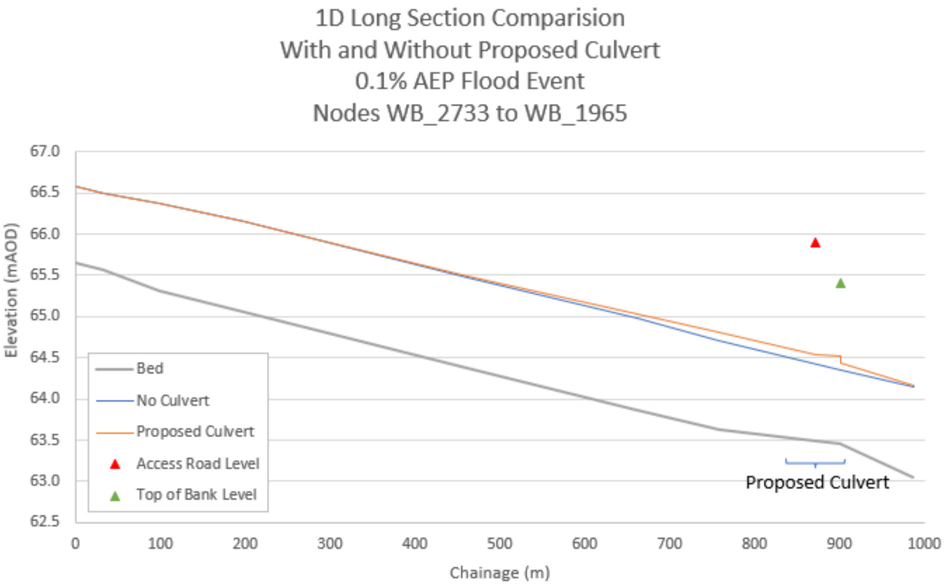


Figure 24 – 1D long section comparison, with and without the proposed culvert

The peak flows under the A41 culvert (model node WB_1878cu) are essentially the same as the modelling results without the proposed culvert (see section 6.4). Note that the baseline flows are slightly different, and this is attributed to re-running the model in a more recent version of FMP and TuFLOW.

Table 18 - Peak Flows through the A41 Culvert

Event	Baseline A41 Culvert Peak Flow (m^3/s)	Mitigation 3 A41 Culvert Peak Flow (m^3/s)	Change in Peak Flow (m^3/s)
1.0% AEP	1.799	1.798	-0.001
1.0% AEP + 15% CC	2.069	2.068	-0.001
0.1% AEP	3.128	3.147	+0.019

As such, it is concluded that the proposed culvert has no impact on peak flows under the A41 and that there are only locally increased flood levels at the location of the proposed culvert. Although there are local increases in flood level, there is sufficient freeboard within the design to ensure that there is no flooding within the site for any of the events that have been modelled.

9.4 Blockage Risk

To assess the impact of a blockage of the proposed culvert (FMP node A-A_Cul_In), a blockage scenario was run. Following a review of the risk of a blockage occurring, it was determined that the risk at this location was low, as a result of the large culvert size and lack of potential debris sources.

As such a 33% blockage ratio was considered appropriate for this location. The updates made to represent this consisted of; the insertion of a blockage unit upstream of the culvert inlet in FMP, with a 33% blockage ratio.

Figure 25 below shows the modelled flood depths for mitigation scenario 3 with the proposed culvert and with a 33% blockage ratio. In this scenario the flood levels are raised by approximately 50mm, however, this does not result in any out-of-bank flood flows.

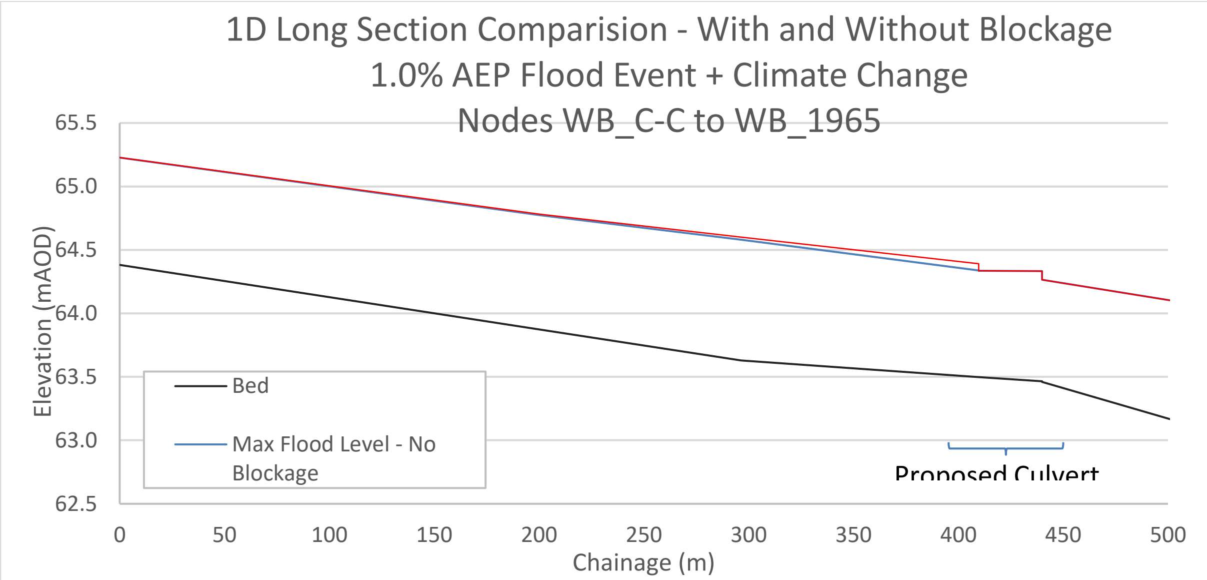


Figure 25 – 1D long section comparison, with and without the proposed culvert

10 Limitations and Conclusions

10.1 Limitations

Following the EA's review[5] of the model, several green and amber comments have been made on the model build. Where appropriate, these comments can be resolved with additional justifications and identification of any limitations within this section of the report.

- Footbridge at WL_2099 (EA Comment 5.1) – This small footbridge was excluded from the original model build for the EA. Given its small size and that it will only have a very localised impact on the hydraulics, it's continued exclusion is considered to be justified.

- Topographic Survey Data (EA Comment 7.7 and 7.9) – Although there is topographic survey data at the proposed site, it was not considered necessary to include within the DTM (Digital Terrain Model) of the baseline model. There are two main reasons for this decision; First is that the objective of the study was to ensure that the site was flood free for all events, hence the benefit of knowing the absolute baseline flood level using survey data has limited value as it is being compared to a flood free site (this decision would be different if there was a residual flood risk as we would want to have more certainty on depth change, but as the site is dry, there is no depth change to asses). Second, there is only a baseline flood risk during the 0.1% AEP flood event, meaning that topographic survey data would have no impact for the majority of flood events.

- Model Calibration and verification (EA Comment 15.1 and 15.4) - Given the purpose and size of the study, calibration of the model above what was already completed for the EA by JBA was not considered to be proportionate. Furthermore, there were only limited updates to the baseline model and as such the baseline flood extents only have minimal changes within the update. There is also a level gauge in Wendlebury, but this gauge is outside of the truncated.

10.2 Conclusions

Modelling of the Wendlebury Brook was undertaken to determine the impact of the proposed development on flood risk. This consisted of a baseline scenario and four different proposed development scenarios.

Mitigation scenario 3 is the final preferred option and has no impact on flood risk to the development site or the town of Wendlebury for the 1.0% AEP and 1.0% AEP + CC events. For the 0.1% AEP event across the majority of the model domain, no detrimental impact is shown, however, there are some isolated cells showing impact. Due to the inherited instabilities in the baseline model through Wendlebury these impacts are believed to be a result of oscillations in the modelling results rather than the development. Further to this, no significant increase in peak flows through Wendlebury are seen as a result of the development supporting the suggestion that the impacts seen in the 0.1% AEP event are not a result of the proposed development. As the other proposed development scenarios resulted in detrimental impacts on flood risk as a result of the development, mitigation scenario 3 should be incorporated into the final scheme.

[5] EA Review (25th Oct 2022). LIT 17617 – Non-realtime Hydraulic Model Review – Cheserton.xlsm.

Appendix 1 – Proposed Development CAD