

Bellway Homes Ltd (South London)

Land off Church Lane, Ashington

Hydraulic Modelling Report

**REPORT REF.
2305490-01**

May 2024

HEAD OFFICE: 3rd Floor, The Hallmark Building, 52-56 Leadenhall Street, London, EC3M 5JE **T** | 020 7680 4088

EDINBURGH: Suite 35 4-5 Lochside Way Edinburgh EH12 9DT **T** | 0131 516 8111

ESSEX: 1 - 2 Crescent Court, Billericay, Essex, CM12 9AQ **T** | 01277 657 677

KENT: Suite 10, Building 40, Churchill Business Centre, Kings Hill, Kent, ME19 4YU **T** | 01732 752 155

MIDLANDS: Office 3, The Garage Studios, 41-43 St Mary's Gate, Nottingham, NG1 1PU **T** | 0115 697 0940

SOUTH WEST: Temple Studios, Bristol, England, BS1 6QA **T** | 0117 456 4994

SUFFOLK: Suffolk Enterprise Centre, 44 Felaw Street, Ipswich, IP2 8SJ **T** | 01473 407 321

Contents	Page
1. Introduction	1
2. Hydrological Assessment.....	2
3. Baseline model build	4
2D build	4
1D build	5
Boundary conditions	6
Assumptions / limitations	7
4. Baseline modelling results.....	9
Model stability.....	10
5. Post development model scenario	11
Model updates.....	11
6. Post development modelling results.....	14
Comparison Mapping	16
Hazard Ratings.....	17
Model stability.....	18
7. Summary and recommendations	19
Recommendations	20

Appendices

Appendix A – Sensitivity Analysis

Appendix B – 3.3% AEP ReFH2 outputs

Appendix C – Site topographic survey

Appendix D – Proposed Masterplan and Levels Strategy

Figures

Figure 1-1: Site location plan and EA surface water flood mapping	1
Figure 2-1: Estimated catchment boundary	2
Figure 3-1: 2D Model schematic	4
Figure 3-2: 1D Model schematic	6
Figure 3-3: Model boundaries	7
Figure 4-1: Baseline model flood extents	9

Figure 4-2: Peak modelled depths – 1% AEP plus 45% climate change.....	10
Figure 5-1: Post-development model schematic	11
Figure 6-1: Post-development peak modelled flood extents	14
Figure 6-2: Post-development peak depths and levels - 1% AEP plus 45% CC	15
Figure 6-3: Change in peak flood depths – 1% AEP plus 45% climate change	17
Figure 6-4: Post-development peak flood hazard – 1% AEP plus 45% CC	18

Tables

Table 3-1: 2D Manning's 'n' roughness values	5
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1. Introduction

1.1. Ardent Consulting Engineers (hereafter referred to as Ardent) has been instructed by Bellway Homes Ltd (South London) to undertake surface water hydraulic modelling to support a proposed development at Land off Church Lane, Ashington.

1.2. The site location is shown in **Figure 1-1**. The proposed development consists of 180 residential units with public open space, including a sports pavilion and sports pitches. A ditch watercourse runs along the eastern site boundary, flowing north before heading west through the north of the site and exiting the site boundary in the northwest corner. A second ditch watercourse runs along the western site boundary, also flowing northwards. Additionally, a series of small drainage ditches are located around the site.

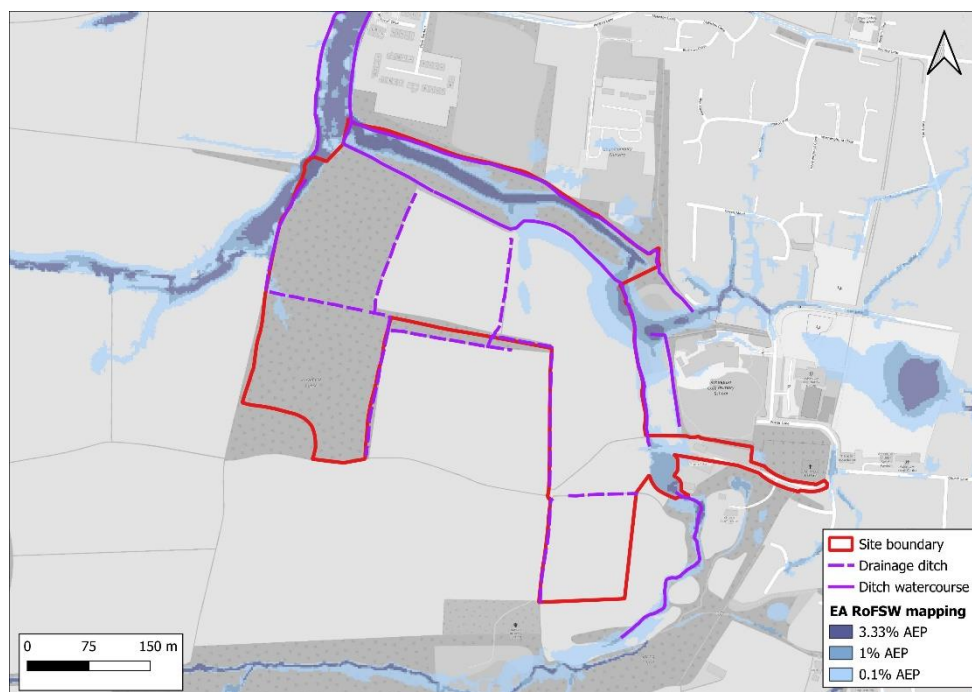


Figure 1-1: Site location plan and EA surface water flood mapping

1.3. Existing Environment Agency mapping of surface water flood risk does not follow the local topography through the site and is assumed to be inaccurate (see **Figure 1-1**).

1.4. Therefore, a detailed 1D-2D linked direct rainfall-runoff model has been developed using TUFLOW software to refine the understanding of surface water flood risk to the site, inform potential flood risk mitigation measures and demonstrate the impact of the development on flood risk to third party land.

2. Hydrological Assessment

2.1. To inform the hydraulic modelling and assess surface water flood risk to the site, rainfall hyetographs were derived to input to the model.

2.2. FEH22 catchment descriptor data was obtained from the Flood Estimation Handbook (FEH) Web Service for the catchment covering the study site, hereafter referred to as the 'Northern Catchment'. Analysis of 1m EA LIDAR DTM flown in 2019 showed that during an extreme flood event flows from a neighbouring catchment to the south could also be conveyed into the watercourse running adjacent to the site ('hereafter referred to as the 'Southern Catchment').

2.3. A catchment analysis was undertaken using catchment delineation tools within QGIS to determine the catchment area draining to the site based on the 1m EA LIDAR DTM flown in 2019. The refined Northern and Southern Catchments were merged to provide a single study catchment for use in the hydrological assessment and is shown in **Figure 2-1**. The merged catchment has an area of 2.23km².

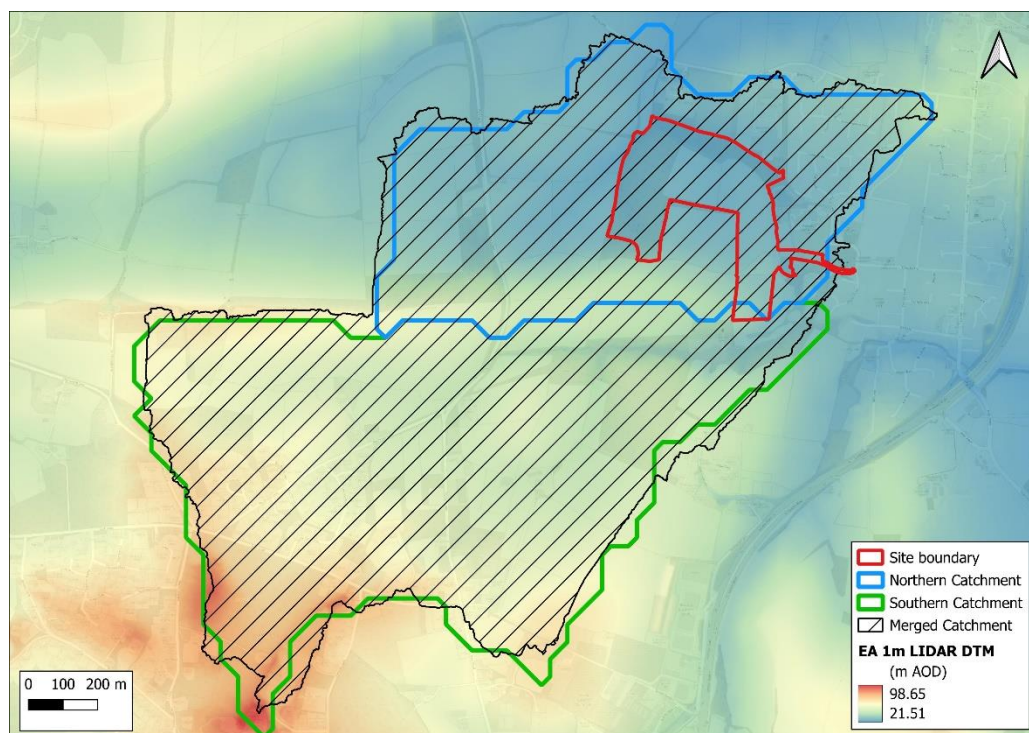


Figure 2-1: Estimated catchment boundary

2.4. The FEH22 data was inputted to the Revitalised Flood Hydrograph 2 (ReFH2) software, which was used to derive rainfall hyetographs for the 3.33%, 1%, and 0.1% Annual Exceedance Probability (AEP) events. As rainfall losses were to be derived within the hydraulic model (see Section 3), only the catchment descriptors that influence the design rainfall were updated. The catchment area was updated to

that of the merged catchment, with the SAAR value of 879 from the Southern Catchment used as the higher of the two catchments to give a conservative estimate of flood risk.

- 2.5. Rainfall hyetographs were also derived for the 1% AEP event uplifted by 45% to account for the potential impacts of climate change, in line with the latest EA guidance for the 2070s epoch upper end allowance in the Arun and Western Streams Management Catchment¹.
- 2.6. A winter storm profile was used to derive the hyetographs as the area upslope of the site is almost entirely rural.
- 2.7. The default storm duration for the catchment is 4.5 hours. Hyetographs were also derived for a 1.5-hour, 2.5-hour, 3.5-hour and 5.5-hour storm duration, with all four durations tested within the model for the 1% AEP plus 45% climate change event in the post-development model. The duration testing found the 2.5-hour storm event resulted in the highest peak flood depths at key locations in the site, with this therefore used as the final design storm duration.
- 2.8. The design rainfall was exported from ReFH2, with losses, then applied within the model domain. An example ReFH2 report for the 3.33% AEP event is provided in **Appendix B**, including details of the descriptor data.

¹ Colne Management Catchment peak rainfall allowances, Environment Agency. Available: <https://environment.data.gov.uk/hydrology/climate-change-allowances/rainfall?mgmtcatid=3004>

3. Baseline model build

3.1. The baseline model has been built using the hydraulic modelling software TUFLOW.

All scenarios have been run using the latest version of the software 2023-03-AC-iSP-w64.

2D build

3.2. A 2D model schematic is shown in **Figure 3-1**.

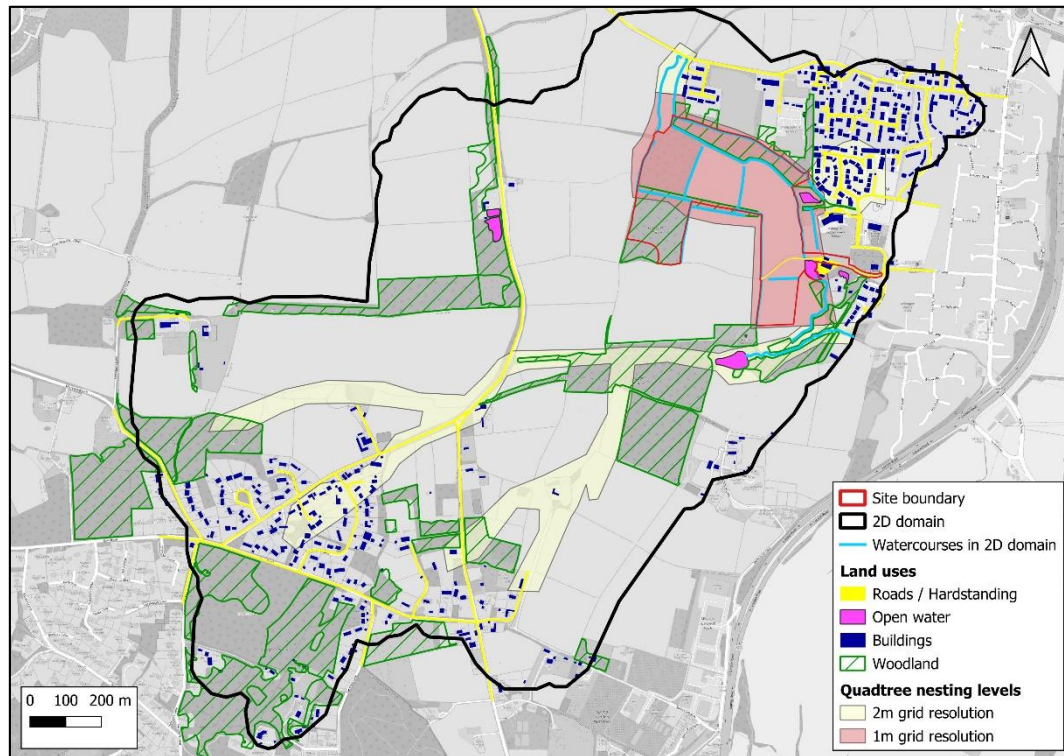


Figure 3-1: 2D Model schematic

3.3. Watercourses and the wider catchment are represented in the 2D domain, which covers an area of 2.68km², including the entire catchment derived in **Section 2**.

3.4. The ground model at the site has been informed using topographic survey collected in December 2021 by Maltby Surveys Ltd (see **Appendix C**). Elevations across the wider catchment were derived from the 2019 EA 1m LIDAR DTM.

3.5. A 4m cell size has been applied across the model with Quadtree used to refine this to a 2m grid size along flow paths upstream of the site and a 1m grid size within the vicinity of the site. Sub-grid sampling has been enabled within TUFLOW, ensuring surface water flow paths were adequately represented.

3.6. Different land uses derived from topographic survey and OS VectorMapping across the model domain have been assigned roughness values within the 2D domain (see **Figure 3-1**). The values applied are shown in **Table 3-1**.

Table 3-1: 2D Manning's 'n' roughness values

Land use	Manning's 'n' roughness value
Pasture / Light vegetation (general surfaces)	0.055
Roads / Hardstanding	0.02
Buildings	1
Woodland	0.1
2D Watercourses	0.04
Open water	0.03

3.7. The ditch watercourses and drainage ditches through the site were represented in the 2D domain, with a Z-line used to stamp in channel levels taken from the topographic survey where available. Upstream and downstream of the site Z-lines have been used to stamp in channel levels taken from LIDAR data(see **Figure 3-1**).

3.8. Ponds / open water have had an initial water level applied inferred from LIDAR, with the initial water level for the pond within the site set at 28.19m AOD, 10mm below the culvert for the outfall from the pond assuming the water level is near full at the beginning of the simulation. Z-shapes have been used to set the bed level at least 0.5m below the inferred initial water level.

1D build

3.9. Six culverts located on the watercourses and ditches around the site were represented in the 1D domain, with the location of these shown in **Figure 3-2**. The culvert dimensions and invert levels were taken from the topographic survey (see **Appendix C**). The spill levels over the culverts were represented in the 2D domain from the topographic survey.

3.10. A pipe roughness of 0.015 was applied in line with available guidance (i.e. Chow, 1959), with standard entry and exit losses applied in line with TUFLOW guidance.

3.11. The topographic survey showed two culverts in the north of the site were collapsed or completely blocked. As a result, these culverts were represented as 100% blocked in the baseline scenario to provide a conservative estimate of the flood risk to the site.

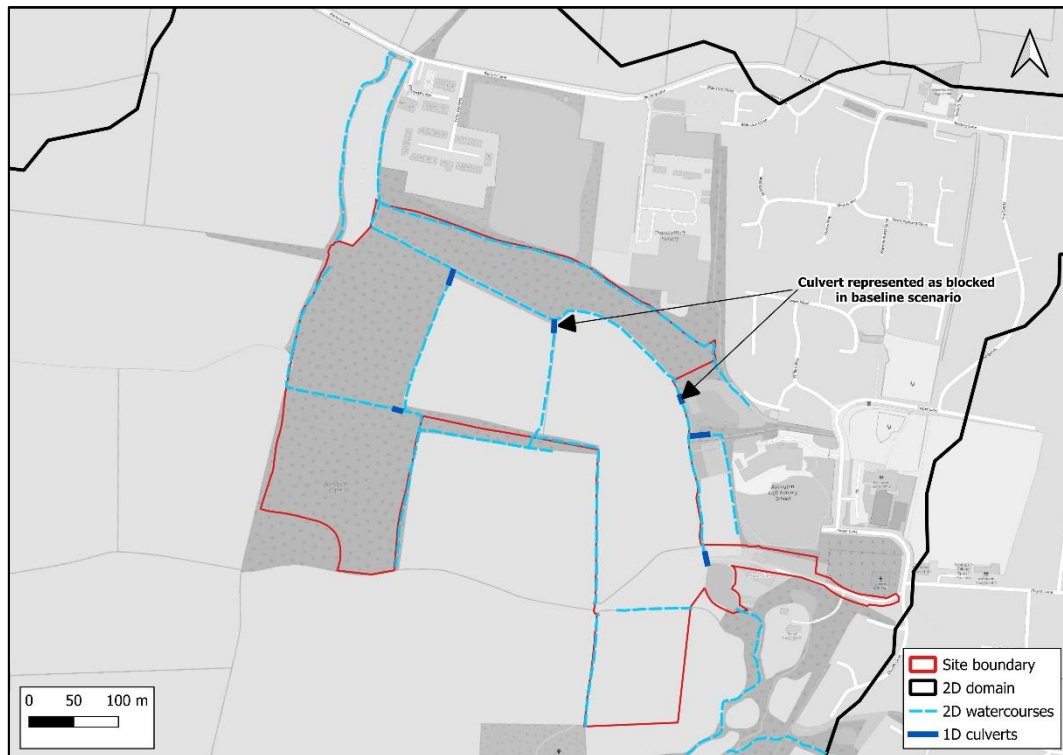


Figure 3-2: 1D Model schematic

Boundary conditions

- 3.12. The final design rainfall hyetographs detailed in **Section 2** have been applied directly to the entire 2D model domain, with no additional inflows applied.
- 3.13. Infiltration losses have been represented using the Green-Ampt method. A sandy loam soil has been applied to the south of the model domain and a loam soil to the centre of the model domain, in line with the Cranfield University Soilscape online mapping (see **Figure 3-3**).
- 3.14. Across the site and north of the catchment a silty clay soil type has been applied, in line with the findings of the on-site ground investigations (Report Ref: **52368-R01(00)**). Sensitivity testing of the infiltration losses has been undertaken and demonstrates the model has a low sensitivity to the values applied (see **Appendix A**).

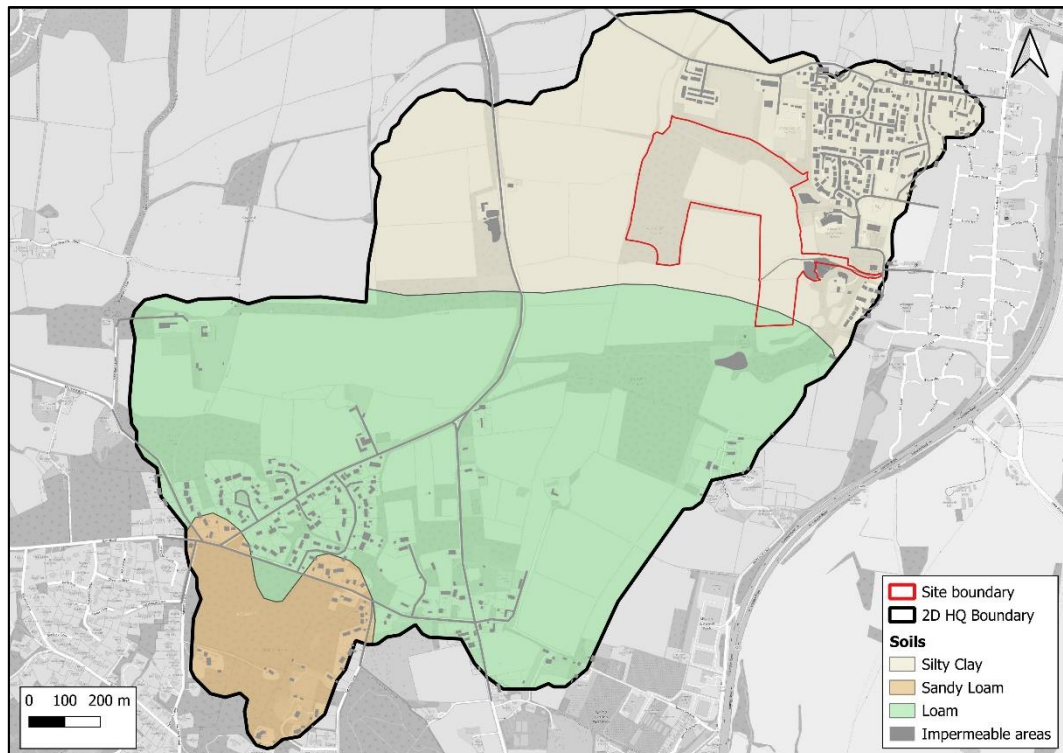


Figure 3-3: Model boundaries

3.15. Buildings, roads, open water and areas of hardstanding have been represented as impermeable, generating 100% runoff with no losses within the 2D domain.

3.16. To allow runoff to pass out of the 2D domain an HQ boundary was applied at the downstream extent of the watercourses in the model domain, with a gradient derived from the EA LIDAR DTM. HQ boundaries with general slope values were applied to the rest of 2D domain to prevent glass-walling (see **Figure 3-3**).

3.17. 2D_bc 'SX' points have been used to link the 1D culverts to the 2D domain.

Assumptions / limitations

3.18. The representation of any complex system by a model requires a number of assumptions to be made. In the case of the 1D and 2D elements of the model, the following assumptions have been made:

- Model parameters, such as roughness and structure coefficients, are representative of the general conditions;
- The units used to represent hydraulic structures within the model represent the situation accurately using the available information, including assumptions made to simplify representations where necessary;
- Culvert dimensions and inverts have been estimated where data is not available;

- The design hydrology accurately represents flows in the models given there was no flow / level data available for the catchment to calibrate flows in the model;
- Watercourses are modelled to be dry at the beginning of the simulation, with inflows solely from rainfall;
- The rainfall losses using catchment scale soil infiltration rates have been applied across the whole 2D domain (excluding impermeable areas); and
- The LIDAR and OS mapping are representative of the land surface and are an up to date reflection of current ground levels and land uses.

4. Baseline modelling results

4.1. The model has been run using the TUFLOW HPC solver with adaptive timestepping.

The model is run for a total duration of 5.5 hours to allow the full storm event to pass through the site. Model results have been filtered to remove depths below 0.05m.

4.2. Peak flood extents for the modelled storm events are shown in **Figure 4-1**. The 0.1% AEP event is almost identical in flood extent to the 1% AEP +45% climate change event and is therefore not shown on the mapping.

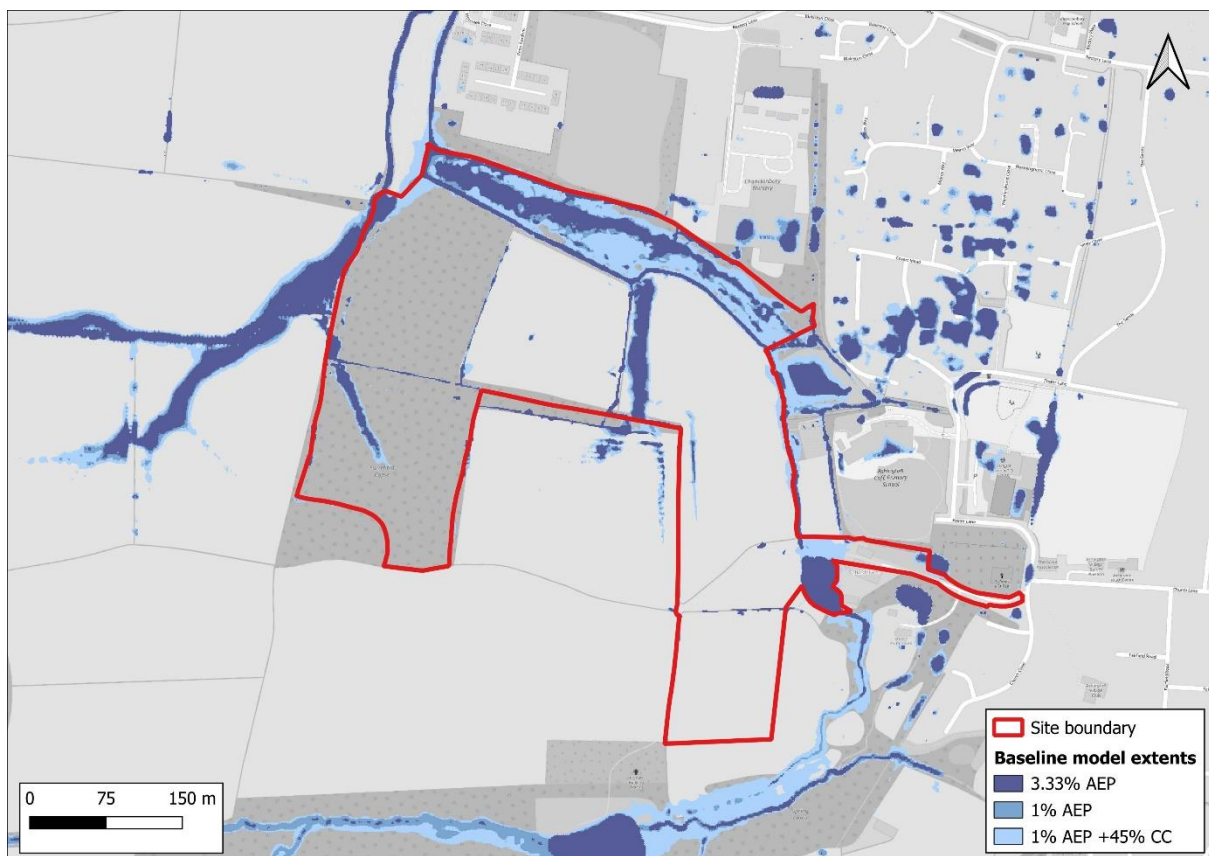


Figure 4-1: Baseline model flood extents

4.3. The results show a more accurate representation of surface water flood risk than the EA mapping, with overland flow paths following the local topography. Flows are largely contained within the watercourse along the eastern boundary, though a wider area of flooding is modelled to occur in the north of the site during all modelled events. A flow path is modelled to enter the centre of the site from the south and flow overland towards the watercourse along the northern boundary. Flows within this area are separated from the existing adjacent ditch watercourse by an area of raised land. To the west of the site an overland flow path is predicted to form within the site boundary in an area of woodland, joining a larger flow path from

the southwest that is largely conveyed along the site boundary with small areas of flooding in the northwest corner during the 1% AEP plus 45% climate change event.

4.4. Peak modelled flood depths during the 1% AEP plus 45% climate change event are presented in **Figure 4-2**. Peak depths within the site are greatest in the northwest corner where depths of up to approximately 0.8m are predicted. Depths across the northern area of the site are generally <0.3m. The flow path through the centre of the site is generally shallow, with peak depths of approximately 0.26m. During the 1% AEP plus 45% climate change event flows are predicted to spill over the existing access road in the east of the site, with depths of up to 0.3m predicted across the road. Flows along the watercourse running along the eastern/northern boundary are typically between 1-1.4m in depth during the 1% AEP plus 45% climate change event.

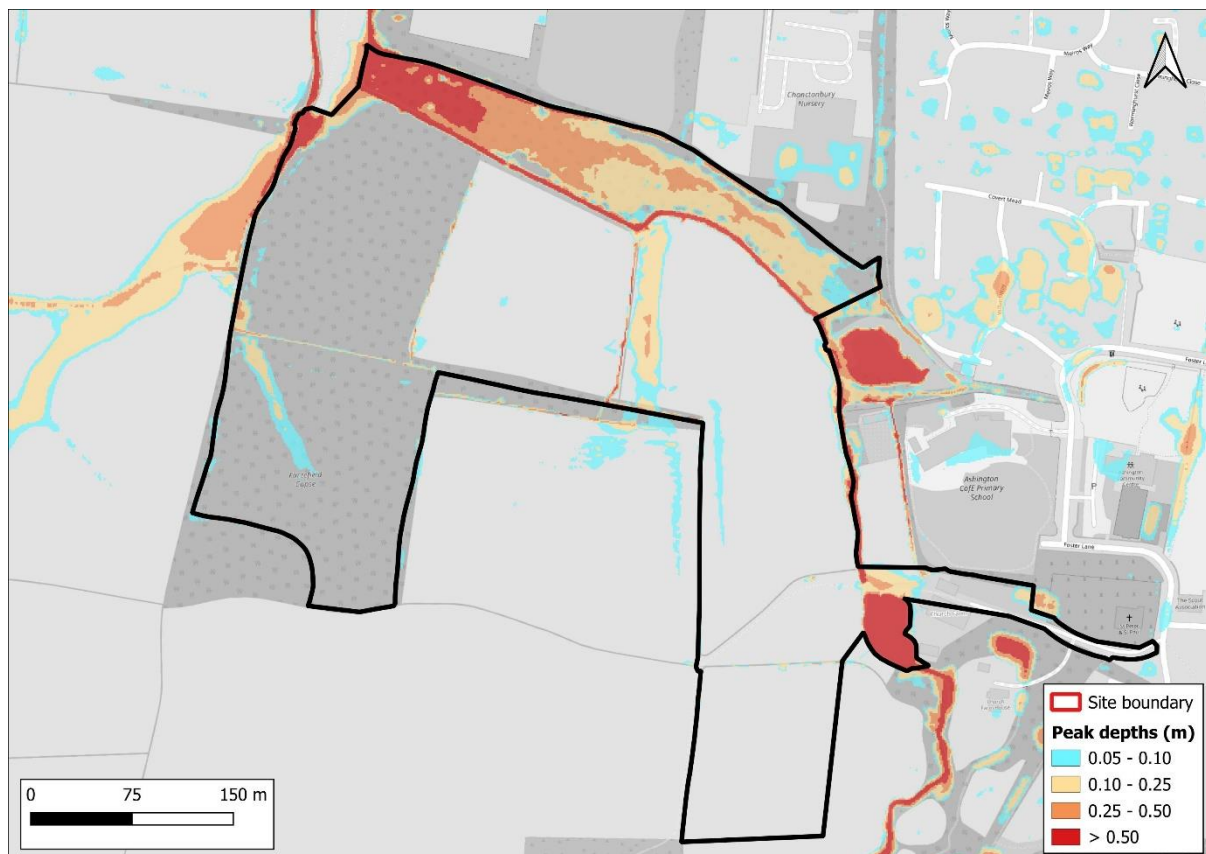


Figure 4-2: Peak modelled depths – 1% AEP plus 45% climate change

Model stability

4.5. A review of the model outputs indicates the modelling is stable for the duration of the event, with total mass errors of 0% and timestep efficiency above 99% after the model initialisation. The model runs have no negative depths or repeated timesteps.

5. Post development model scenario

5.1. To assess the surface water flood risk to the development proposals and demonstrate the impacts on flood risk to third party land the proposed development was represented within the model, including associated flood risk mitigation measures.

5.2. The development proposals were represented in line with the site masterplan and levels strategy (see **Appendix D**), with the peak flood levels during the 1% AEP plus 45% climate change event used to inform ground levels and finished floor levels across the site. A post-development model schematic is provided in **Figure 5-1**.

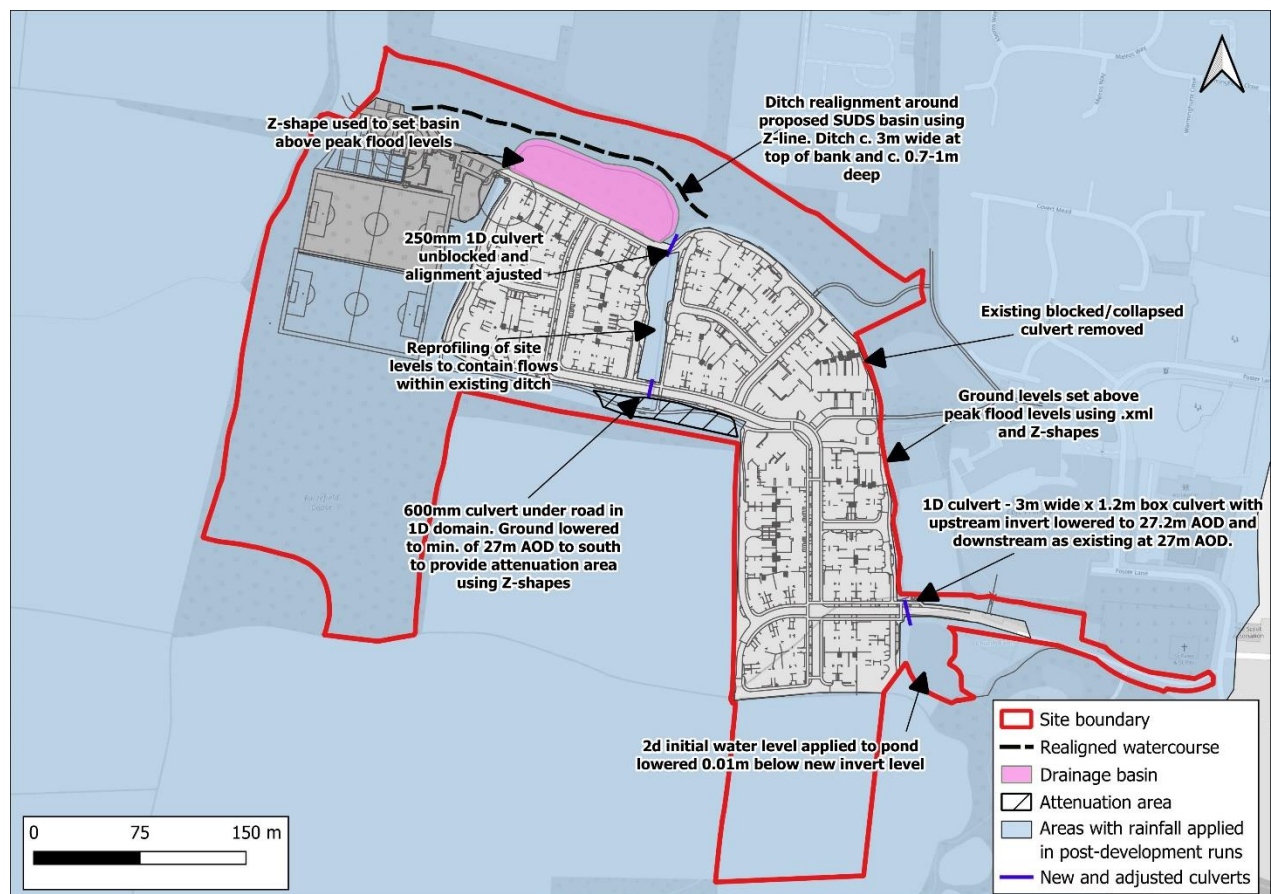


Figure 5-1: Post-development model schematic

Model updates

5.3. To represent the impact of the proposed drainage strategy rainfall was excluded from the area of the site boundary that is to be drained by the proposed surface water sewer network. A point inflow was then applied to the watercourse to the north of the site to represent the outfall from the drainage system. A constant inflow of 15.2l/s was applied for the entirety of the model simulations, assuming a

conservative inflow at the maximum controlled discharge rate in line with the total peak outflow from the drainage network.

- 5.4. The proposed levels strategy for the roads across the site was read into the 2D domain as a .xml file. Elsewhere, levels adjacent to the watercourse/ditches are raised above the peak design flood levels using Z-shapes. This ensures overland flows do not enter the proposed developed areas of the site. As a result, it was not necessary to represent wider levels or buildings across the site.
- 5.5. The culvert under the access road to the east of the site has been upsized to prevent flows from overtopping the highway, as occurs in the baseline scenario. A 3m wide x 1.2m high culvert is represented in the 1D domain at the outfall of the pond. To accommodate this below the proposed access road, the invert level is lowered approximately 1m to 27.2m AOD, with a Manning's 'n' roughness of 0.011 applied. The 2D initial water level applied to the pond is lowered to be near full at 27.19m AOD.
- 5.6. To improve the conveyance of flows along the watercourse, the existing blocked/collapsed culvert located on the northeast site boundary has been removed. This is represented in the 2D domain using a Z-line to interpolate bed levels between the existing upstream and downstream levels.
- 5.7. The proposed drainage basin in the north of the site is represented as a Z-shape with the basin and associated embankments included. The top of bank is set at least 300mm above the peak external flood levels during the 1% AEP plus 45% climate change event to ensure no overland flows from the watercourse can enter the basin.
- 5.8. The existing ditch watercourse is realigned to the north of the basin, represented using a Z-line with a width of 3m. The Z-line interpolates proposed bed level between the existing bed levels at the upstream and downstream ends of the realigned route, with a more naturalised channel than the existing straight channelised ditch. The material file has been updated so the roughnesses in the 2D domain represent the realigned watercourse route, though the proposed development across the wider site is not represented as overland flows are not conveyed within the developed areas of the site.
- 5.9. The existing culvert that joins the central ditch to the watercourse at the eastern end of the proposed basin is represented as unblocked (250mm) in the post-

development scenario. Additionally, the downstream outlet is realigned around the proposed basin. The level of the pedestrian crossing over the culvert is represented in the 2D domain using a Z-shape setting a low point of 26.3m AOD allowing this to overtop during an extreme storm event.

- 5.10. A storage area has been formed in the south of the site by lowering existing ground levels adjacent to the watercourse to a low of 27m AOD using a Z-shape. To the north the highway and associated crossing attenuate flows within the depressed area, with a new 600mm culvert represented in the 1D domain. The culvert invert levels are taken from the existing bed levels, with a roughness of 0.011 applied.
- 5.11. Small pedestrian crossings have not been represented in the post-development model. It is assumed these will either be designed to be set above the peak design flood levels or to overtop with a negligible impact on flows.

6. Post development modelling results

6.1. The post-development model was run for the 30-year event and 100-year plus 45% climate change event using the same parameters as the baseline scenario. Peak flood extents during the post-development scenario for the modelled storm events are shown in **Figure 6-1**.

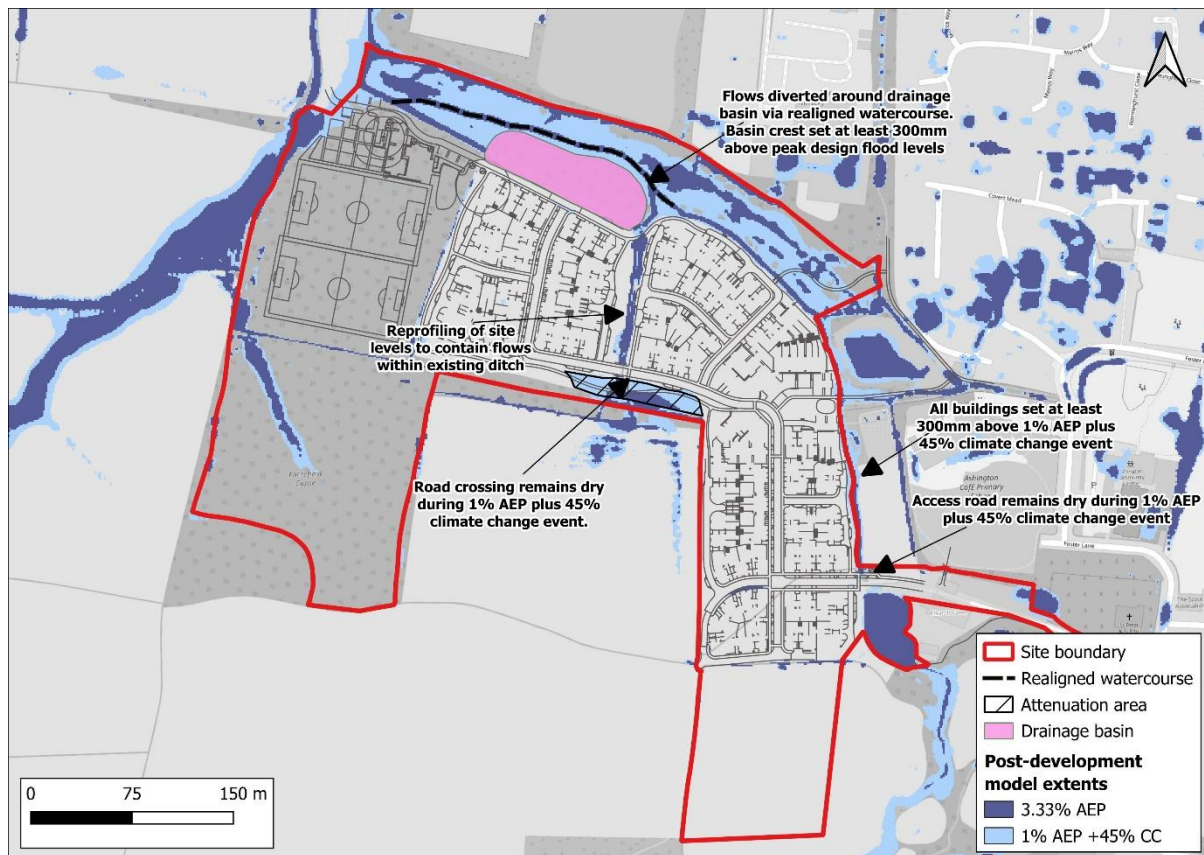


Figure 6-1: Post-development peak modelled flood extents

6.2. The proposed attenuation area and ground reprofiling around the central ditch through the site ensure that flows are contained within the area surrounding the ditch during the 3.3% and 1% AEP plus 45% climate change events, with no flooding predicted to the proposed developed areas. Similarly on the eastern boundary raising of ground levels ensures the developed area remains dry.

6.3. The works to the culvert under the proposed access road and existing pond ensure that during the 1% AEP plus 45% climate change event the access road remains dry, with the road crossing in the centre of the site also dry. As a result, the entire site is afforded dry access and egress via the main site access in the southeast.

6.4. During the 3.3% AEP event flows are largely contained to the realigned watercourse in the north of the site, passing around the proposed drainage basin. As in the

baseline scenario, a wider spread area of flooding is predicted in the north of the site during the 1% AEP plus 45% climate change event with flood waters coming out of bank though still contained to the undeveloped areas of the site.

6.5. A small area of flooding is predicted at the allotments in the northwest corner though only during the 1% AEP plus 45% climate change event. During this event the proposed sports pavilion and pumping station remain outside the modelled flood extents.

6.6. The peak modelled flood depths during the 1% AEP plus 45% climate change event are shown in **Figure 6-2**, along with peak flood levels at locations across the site.

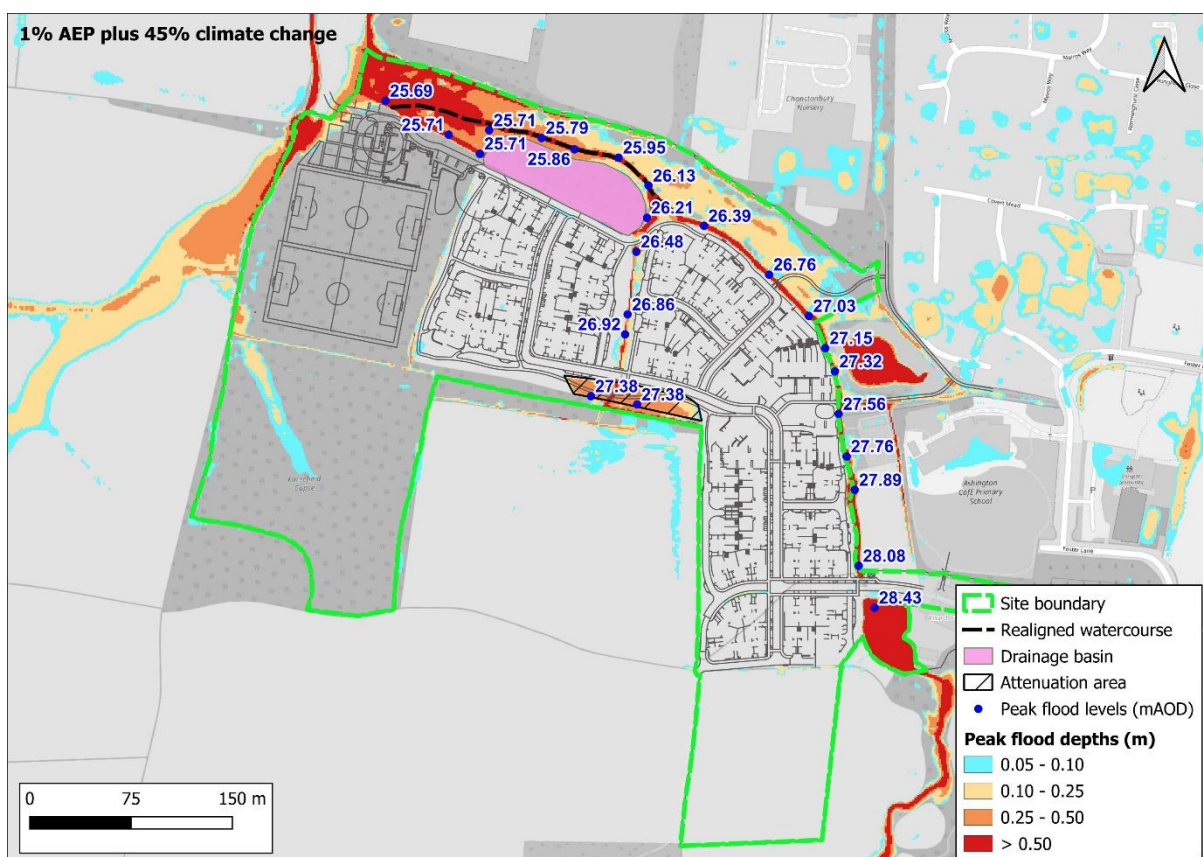


Figure 6-2: Post-development peak depths and levels - 1% AEP plus 45% CC

6.7. Peak flood levels within the existing pond in the southeast of the site of up to 28.43m AOD are predicted to occur during the 1% AEP plus 45% climate change event, approximately 0.65m below the proposed deck level.

6.8. The peak water levels have been used to set the proposed ground levels and finished floor levels across the site, with all buildings provided at least 300mm of

freeboard to the peak 1% AEP plus 45% climate change water level. The crest level of the drainage basin has also been set 300mm above the levels shown.

6.9. Peak depths within the flood storage area in the south of the site of up to 0.38m are predicted to occur. During the 1% AEP plus 45% climate change event this area is only expected to be flooded for approximately two hours before waters drain down via the existing ditch.

6.10. Peak depths of up to approximately 0.35m are predicted around the allotments in the northwest during the 1% AEP plus 45% climate change event, though again only for a short duration of 2 hours.

Comparison Mapping

6.11. Comparison mapping showing the change in peak flood depths between the baseline and post-development scenario during the 1% AEP plus 45% climate change scenario is presented in **Figure 6-3**.

6.12. The results demonstrate the proposed development is not predicted to have a detrimental impact on flood risk to third party land. Due to the proposed attenuation area in the south of the site, lowered pond level in the southeast, and reduction in runoff from the developed areas the proposals are predicted to have a slight reduction in peak depths downstream of up to 9mm. Peak depths within the north of the site are also reduced by up to 50mm.

6.13. The peak water level within the existing pond to the southeast is predicted to decrease from 28.73m AOD to 28.43m AOD due to the lowering of the outgoing pipe invert. The proposed culvert is sized to provide some attenuation within the pond without increasing flood risk upstream and ensuring the access road remains dry.

6.14. The removal of the blocked/collapsed culvert in the northeast of the site removes a notable barrier to flow along the watercourse, reducing peak flood depths within the existing attenuation basin to the east by up to 0.6m.

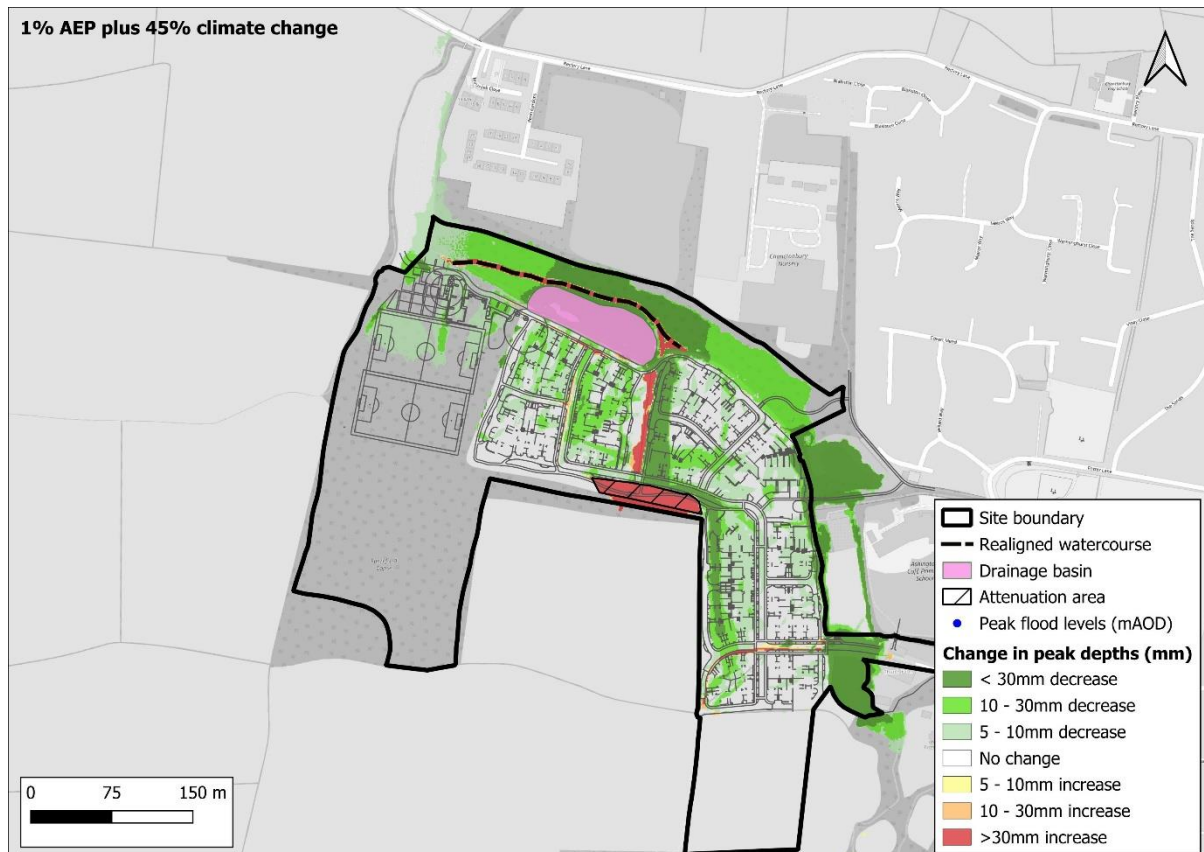


Figure 6-3: Change in peak flood depths – 1% AEP plus 45% climate change
Hazard Ratings

6.15. The peak modelled flood hazard during the 1% AEP plus 45% climate change event in the post-development scenario is shown in **Figure 6-4**. The flood hazard is predicted to be low/negligible across most of the site, and is greatest in the areas of flooding within the open space in the northwest corner.

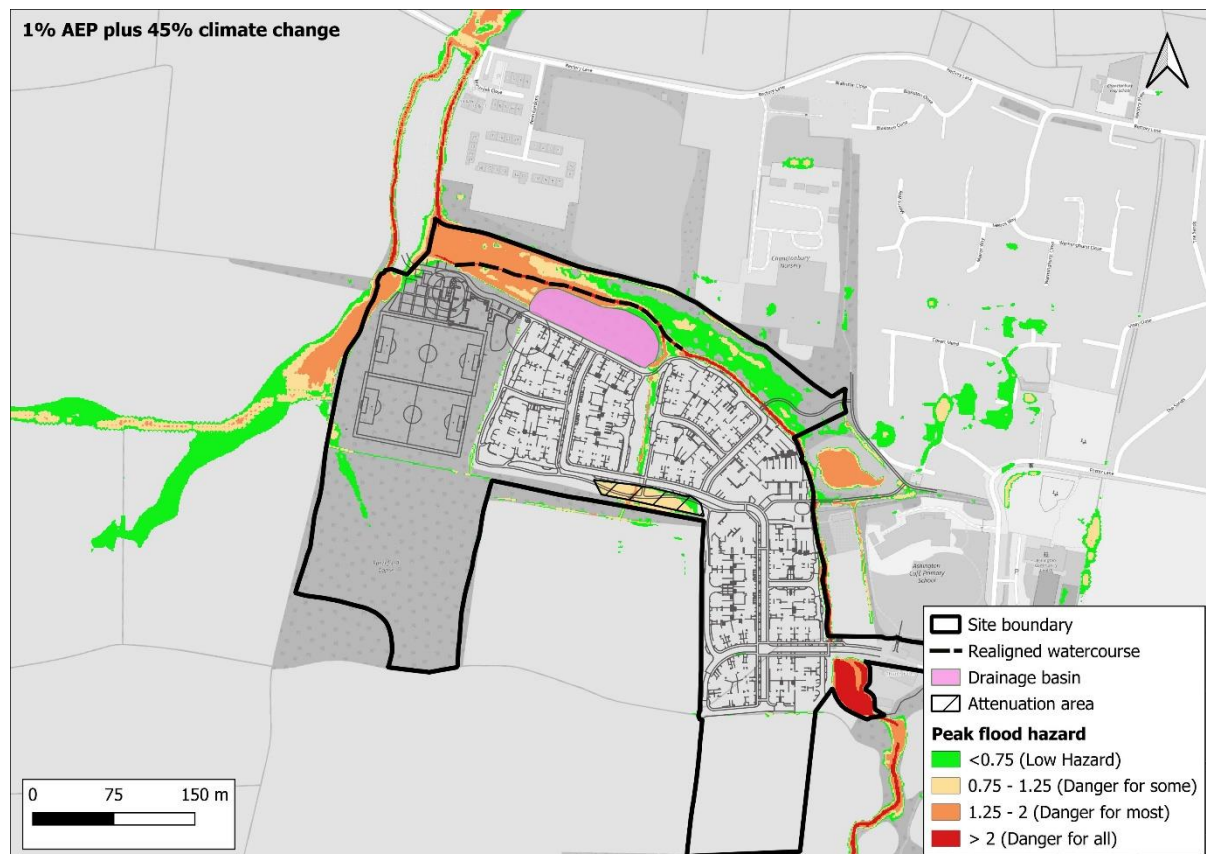


Figure 6-4: Post-development peak flood hazard – 1% AEP plus 45% CC
Model stability

6.16. A review of the model outputs indicates the modelling is stable for the duration of the event, with total mass errors of 0% and timestep efficiency above 99% after the model initialisation. The model runs have no negative depths or repeated timesteps.

7. Summary and recommendations

- 7.1. Ardent Consulting Engineers has been instructed by Bellway Homes Ltd (South London) to undertake surface water hydraulic modelling to support a proposed development at Land off Church Lane, Ashington.
- 7.2. A detailed 1D-2D linked direct rainfall-runoff model has been developed using TUFLOW software to refine the understanding of surface water flood risk to the site, inform potential flood risk mitigation measures and demonstrate the impact of the development on flood risk to third party land.
- 7.3. A hydrological analysis has been undertaken to derive rainfall hyetographs for the study area for the 3.3%, 1%, 1% plus 45% climate change uplift and 0.1% Annual Exceedance Probability Events.
- 7.4. A baseline hydraulic model has been built using a combination of LIDAR data, topographical survey data, and Ordnance Survey land use data.
- 7.5. The baseline model demonstrates that flows are largely contained within the watercourse along the eastern boundary, though a wider area of flooding is modelled to occur in the north of the site during all modelled events. A flow path is modelled to enter the centre of the site from the south and flow overland towards the watercourse along the northern boundary, with depths of up to approximately 0.26m predicted along this flowpath. To the west of the site an overland flow path is predicted to form within the site boundary in an area of woodland, joining a larger flow path from the southwest that is largely conveyed along the site boundary.
- 7.6. The proposed development scenario has been represented in the model, incorporating the proposed levels strategy and flood risk mitigation measures. These measures include ground level reprofiling along the eastern boundary of the site and through the centre, a flood attenuation area, and upsizing the existing culvert under the access road. The existing watercourse is also realigned around a proposed drainage basin in the north of the site.
- 7.7. The proposed attenuation area and ground reprofiling around the central ditch through the site ensure that flows are contained within the area surrounding the ditch during the 3.3% and 1% AEP plus 45% climate change events, with no flooding predicted to the proposed developed areas. Similarly on the eastern boundary raising of ground levels ensures the developed area remains dry.

7.8. The works to the culvert under the proposed access road and existing pond ensure that during the 1% AEP plus 45% climate change event the access road remains dry, with the road crossing in the centre of the site also dry. This ensures the entire site has safe, dry access and egress during a design flood event.

7.9. The peak water levels have been used to set the proposed ground levels and finished floor levels across the site, with all buildings provided at least 300mm of freeboard to the peak 1% AEP plus 45% climate change water level. The crest level of the proposed drainage basin in the north of the site has also been set 300mm above the levels shown to ensure no offsite overland flows can enter the onsite drainage network.

7.10. The results demonstrate the proposed development is not predicted to have a detrimental impact on flood risk to third party land, with slight decreases in flood depths offsite predicted ranging from approximately 9mm downstream of the site to up to 600mm to the east.

7.11. Sensitivity testing of boundary conditions, Manning's 'n' roughness values, critical storm duration, soil infiltration, and blockage has been carried out. The results of the analysis show that the model is not overly sensitive to changes in these parameters and that the proposed mitigation measures are appropriate.

Recommendations

7.12. Based on the outcomes of the hydraulic modelling, it is recommended that:

- The peak flood levels are used to inform finished floor levels at the site;
- The proposed drainage basin in the northwest of the site should have a raised crest level set 300mm above adjacent flood levels to mitigate against ingress from off-site overland flows;
- Proposed ground levels are refined during the detailed design stage;

7.13. The proposed residential development is compliant with national and local policy in terms of pluvial flood risk and will not exacerbate flooding off site. Therefore, there are no pluvial flood risk issues to prevent the development from being implemented.

Appendices

Appendix A – Sensitivity Testing

A. It is standard hydraulic modelling practice to undertake a sensitivity analysis of key model parameters to consider any uncertainty attached to the adopted values and understand how sensitive the model is to changes in these parameters.

B. In the absence of any gauged data / recorded flood events / observable historic information, Ardent have undertaken a sensitivity test of key parameters in order to improve confidence in the model outputs and to ensure the model is robust to changes in these parameters. All sensitivity runs have been undertaken on the 1% AEP plus 45% climate change event.

C. Ardent have undertaken a sensitivity analysis on the following parameters for the post development scenario:

- Manning's 'n' roughness values +/- 20%;
- Soil / Infiltration ;
- Blockage analysis; and
- Downstream boundary conditions.

Manning's 'n' roughness

D. Manning's 'n' roughness values have been adjusted by +/- 20% in the 1D and 2D domains during post-development scenario. The peak modelled extents from the sensitivity testing are shown in **Figure A.1.**, with peak depths at the result points shown in **Figure A.1** presented in **Table A.1.**

Table A.1: Roughness sensitivity peak depths at points shown in Figure A.1

	-20% 'n'	1% AEP plus 45% CC	+20% 'n'
Point	Depth (m)	Depth (m)	Depth (m)
1	1.80	1.79	1.77
2	1.28	1.29	1.30
3	0.31	0.32	0.34
4	0.22	0.23	0.23
5	0.76	0.77	0.77
6	0.80	0.81	0.82

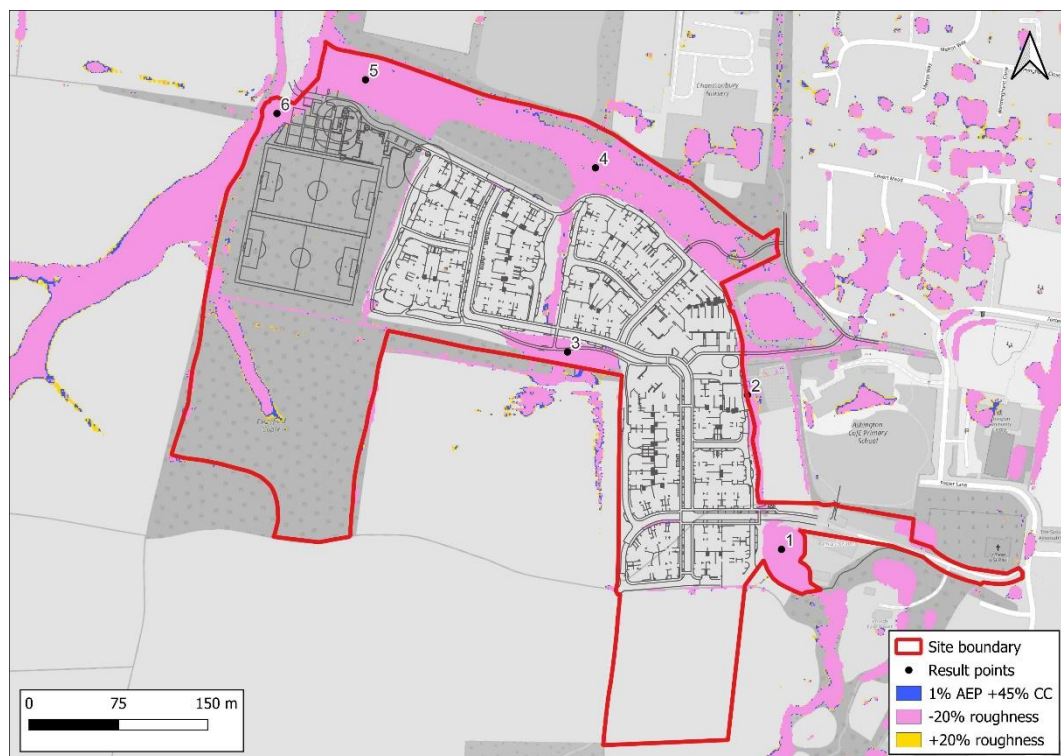


Figure A.1: Roughness sensitivity extents – 1% AEP plus 45% climate change

E. The results show the model has a negligible sensitivity to the roughness values applied to the model domain, with only minor changes in the peak flood extents and negligible differences in peak flood depths ($< \pm 20\text{mm}$) at key locations across the site.

Soil / Infiltration

F. The sensitivity to infiltration parameters has been tested using lower permeability soil types for Green-Ampt infiltration, allowing less infiltration than the design events. Sandy loam has been changed to loam, loam to silt loam, and silty clay to clay. Peak modelled extents in the sensitivity scenario are shown in **Figure A.2** with peak depths at the points shown in **Figure A.2** presented in **Table A.2**. The results show the model generally has a low sensitivity to the infiltration parameters used, with only minor increases in peak flood depths and extents across most of the site that do not impact areas where residential units are proposed. Peak depths increase by approximately 0.3m within the existing pond in the southeast, though still do not overtop the level of the proposed access road. The model parameters used to represent infiltration are therefore considered appropriate.

Table A.2 Roughness sensitivity peak depths at points shown in Figure A.2

	1% AEP plus 45% CC	Soil sensitivity
Point	Depth (m)	Depth (m)
1	1.79	2.09
2	1.29	1.41
3	0.32	0.36
4	0.23	0.26

5	0.77	0.84
6	0.81	0.84

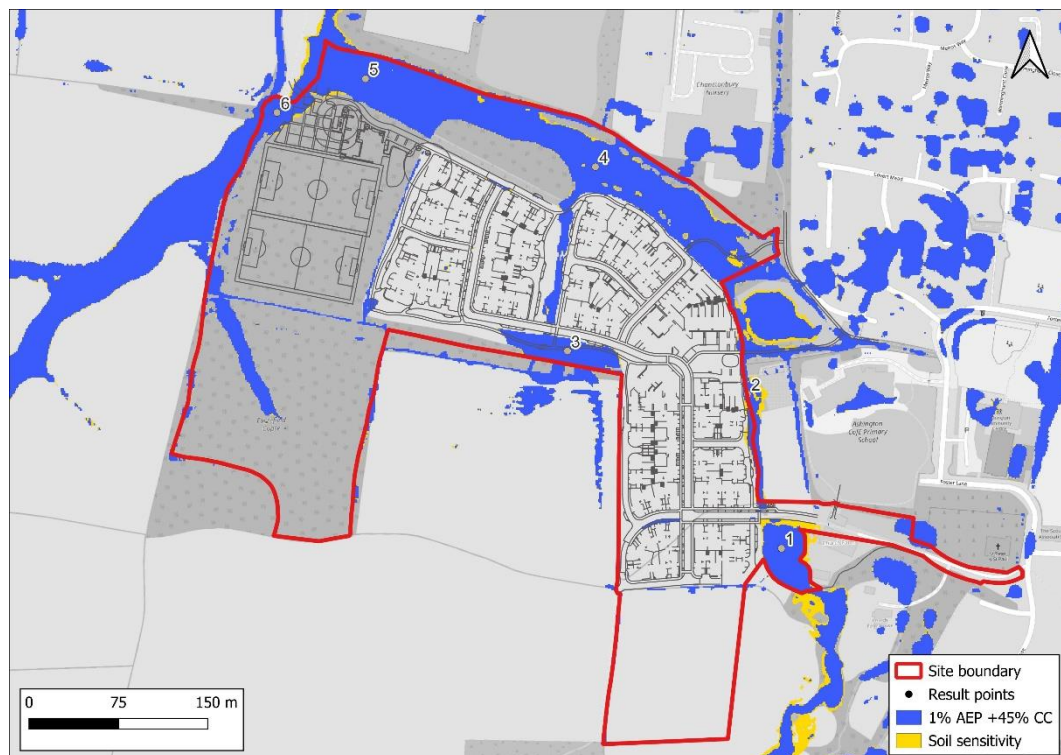


Figure A.2: Soil sensitivity extents – 1% AEP plus 45% climate change

Blockage Analysis

G. A blockage analysis was undertaken on the upsized culvert under the access road to assess the impacts on flood risk. Due to the size of the 3m x 1.2m culvert a blockage is considered unlikely, though siltation of the culvert bed may occur through a lack of maintenance. As a result, the blockage scenario was represented by raising the invert level and reducing the culvert height by 0.48m, effectively resulting in a 40% decrease in the cross-sectional area of the culvert. Peak modelled extents in the sensitivity scenario are shown in **Figure A.3**.

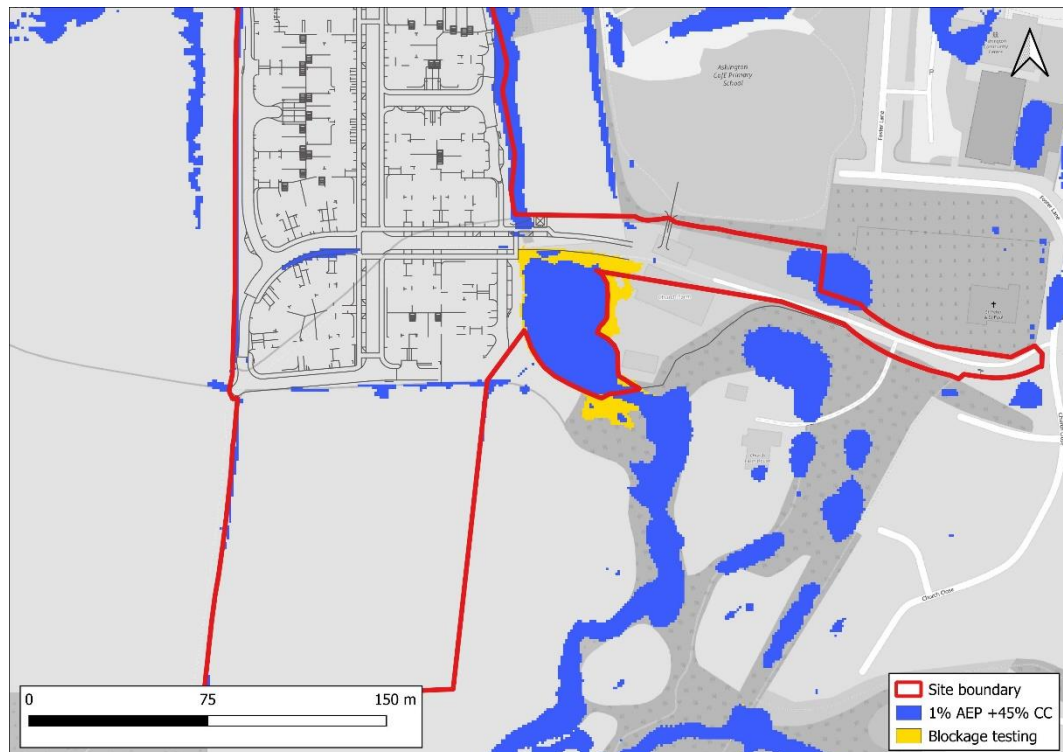


Figure A.3: Blockage sensitivity extents – 1% AEP plus 45% climate change

H. The blockage sensitivity analysis shows that the representation of siltation within the culvert increases the peak flood level within the pond upstream of the culvert by approximately 0.32m to 28.75m AOD. However, this is still approximately 350mm below the design deck level of the road crossing. There is a minor increase in the flood extent offsite to the south during the blockage scenario, though this only impacts a small area of woodland and no properties are affected. As a result, the proposals for the access road are considered appropriate and the residual risk of blockage is low.

Downstream boundary

I. To assess the impact of the downstream boundary conditions a sensitivity analysis was undertaken. The HQ boundaries at the downstream end of the watercourse running adjacent to the site and the downstream end of the watercourse flowing eastwards to the southeast of the site were converted to HT boundaries. A stage-time graph for the 1% AEP plus 45% climate change event was extracted for each location and uplifted by 0.25m for application to the post-development scenario. Peak modelled extents in the sensitivity scenario are shown in **Figure A.4**.

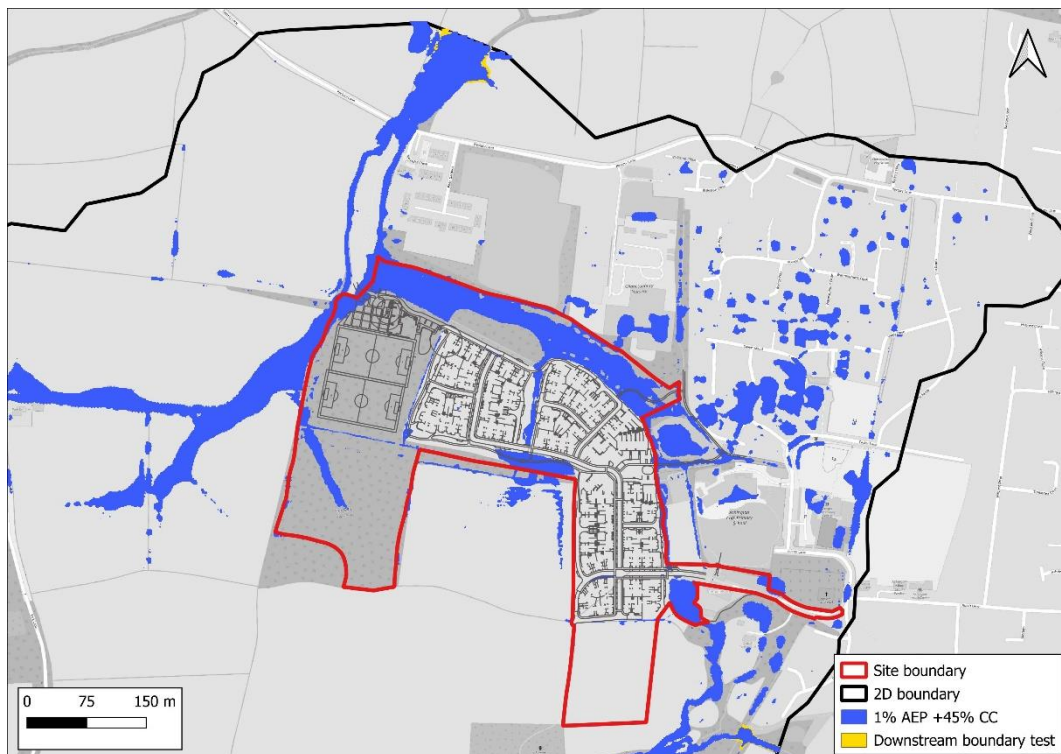


Figure A.4: Downstream sensitivity extents – 1% AEP plus 45% climate change

J. The sensitivity analysis shows the downstream boundary conditions have a negligible impact on the modelled flood extents within the site boundary. The representation of the downstream boundary is therefore considered appropriate.

Sensitivity test conclusions

K. Ardent have carried out a range of sensitivity tests on key parameters for the hydraulic model in order to test the validity of the model outputs and ensure that the proposed mitigation measures are appropriate, and that the proposed residential development can be made safe for the duration of its lifetime. The review of the sensitivity test outlined above suggests that the adopted model parameters are appropriate and that the proposed mitigation scheme is appropriate.