Flood Risk Modelling

Project: Officers' Meadow, Shenfield

Client: Croudace Homes

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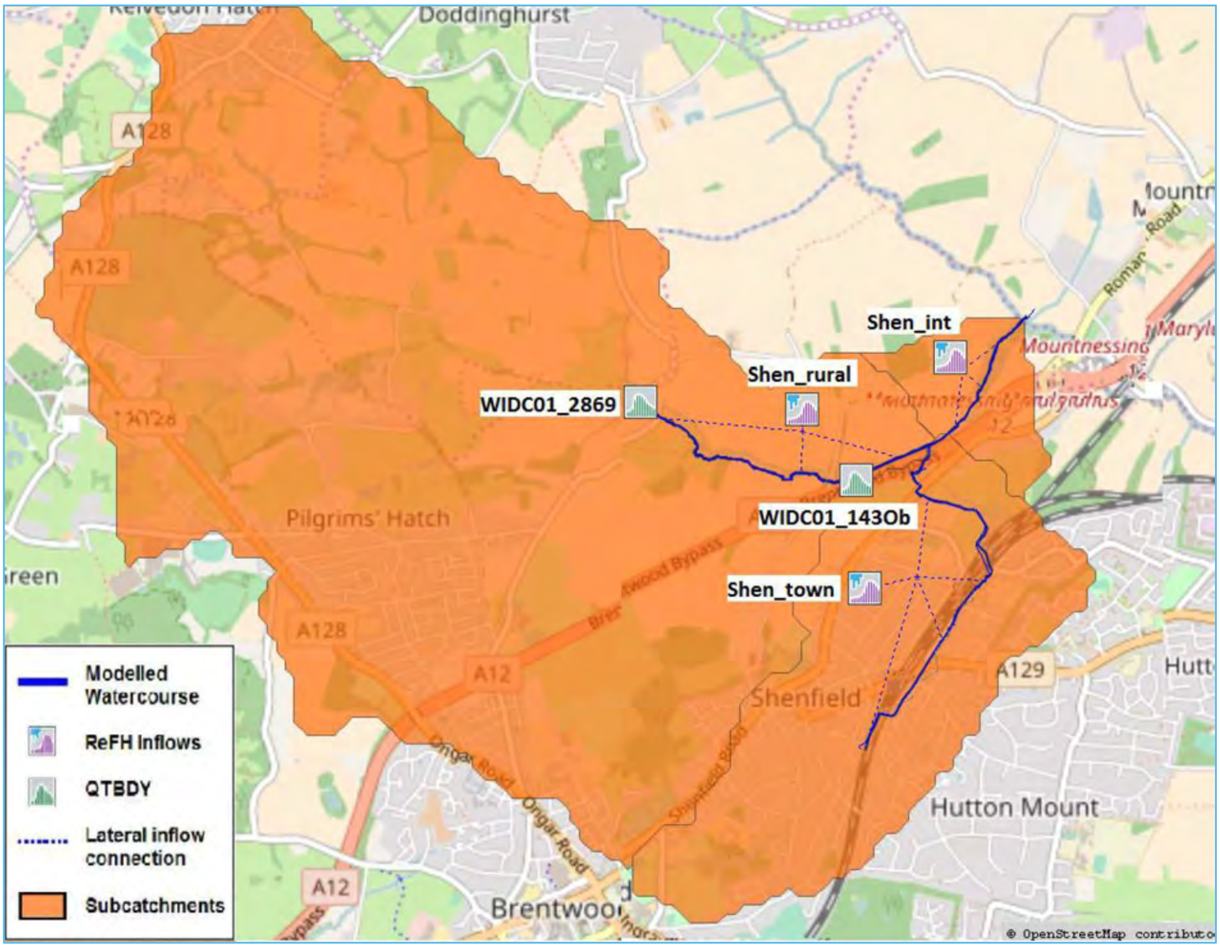
1 INTRODUCTION

1.1.1 This report presents the results of the hydrological assessment and hydraulic modelling work undertaken by JNP Group for the Officers' Meadow development in Shenfield, Brentwood, Essex (National Grid Reference TQ 616 960).

1.1.2 Following a review of the EA's *M+F M1 Fluvial Package Modelling: Tributaries of the Rivers Wid and Crouch Model* (CH2M HILL, February 2018), a site-specific (2D) model was deemed necessary to better represent and understand flood risk at the development site and to facilitate the assessment of some of the (complex) mitigation measures envisaged.

1.1.3 The EA's *M+F M1 Fluvial Package Modelling: Tributaries of the Rivers Wid and Crouch Model* comprises five tributaries of the River Wid and one tributary of the River Crouch. Its purpose is to provide flood mapping and modelling outputs that meet the EA's strategic role in the planning and flood risk management processes. More importantly, the EA model comprises the Shenfield Watercourse and Shenfield Tributary relevant for the Officers' Meadow development (Figure 1.1).

Figure 1.1: EA's Model Extent (Shenfield)



1.1.4 At project outset, the EA model was intended to be 1D-2D. However, a 1D-only approach was agreed for the Shenfield watercourses in order "*to address the risk of 1D-2D numerical instabilities due to the small channel size relative to the 2D cell size*".

1.1.5 While the need to address the risk of 1D-2D numerical instabilities due to the small channel size relative to the 2D cell size is justified, we believe that a 2D-only approach (as used in JNP Group's site-specific model) is significantly more appropriate to represent the area's hydraulics than the 1D-only approach taken by CH2M Hill. This is because out-of-bank flows which are difficult to represent accurately in 1D are expected/known to largely exceed in-bank flows within the area of interest for most of the extreme storm events being considered (particularly the key storm event for planning).

2 HYDROLOGICAL ASSESSMENT

2.1 Overview

2.1.1 A hydrological assessment in line with current best practices was undertaken to establish inflows to the site-specific model using the Flood Estimation Handbook (FEH) Statistical Method and the Revitalised Flood Hydrograph (ReFH) Method.

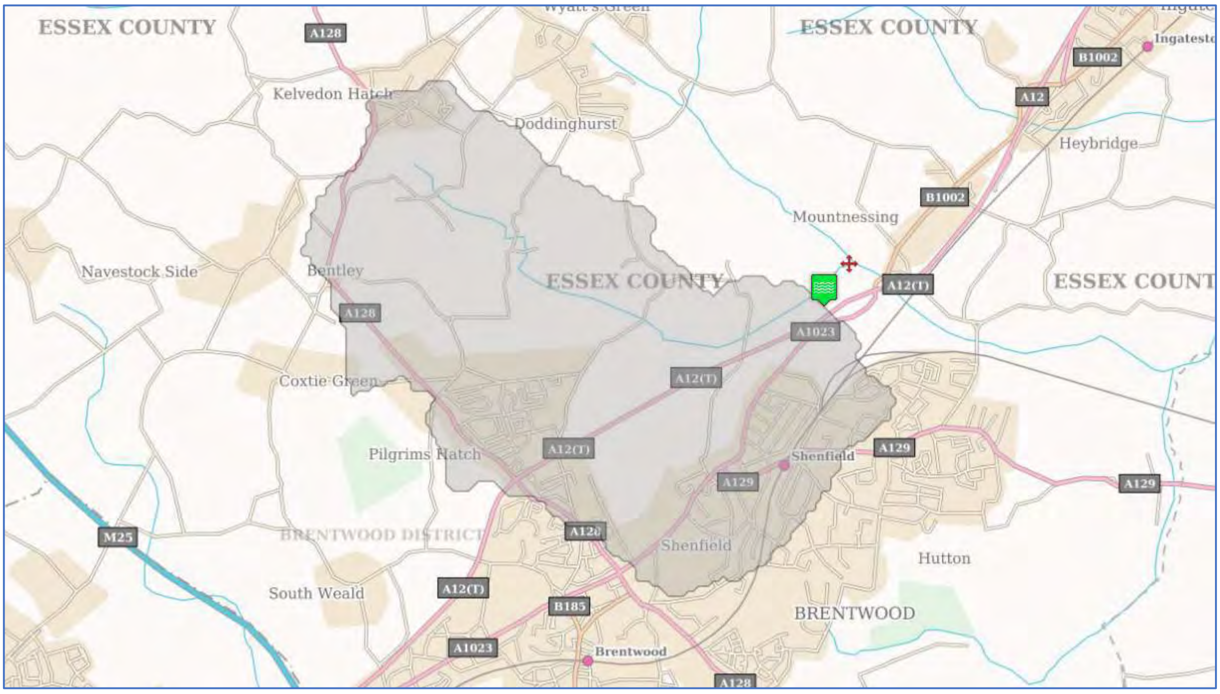
2.1.2 The inflow hydrographs for the storm events with annual exceedance probabilities (AEP) of 50.0% (1 in 2 year), 10.0% (1 in 10 year), 3.3% (1 in 30 year), 1.0% (1 in 100 year) and 0.1% (1 in 1000 year) were established as described in the following sections.

2.2 Catchment Areas

2.2.1 The proposed development is within the 16.07 km² ungauged catchment of the River Wid defined near junction 12 of the A12 (Figure 2.1) and comprises three key sub-catchments (Appendix A) analysed individually in this study:

- The 2.64 km² sub-catchment of the Shenfield Watercourse (main river) defined at the crossing of the A1023 (Chelmsford Road).
- The 0.51 km² sub-catchment of the small tributary (ordinary watercourse) between the A1023 and the A12.
- The 12.92 km² sub-catchment of the River Wid near the downstream end of the modelled extent.

Figure 2.1: Total Catchment Area (River Wid near J12 of the A12)



2.2.2 The sub-catchments are moderately to heavily urbanised and do not comprise any significant lakes or reservoirs.

2.2.3 In accordance with British Geological Survey's (BGS) *GeoIndex*, the sub-catchments' geology comprises superficial deposits of Stanmore Gravel (sand and gravel), Lowestoft Formation and Head (clay, silt, sand, and gravel) underlain by Claygate Member (clay, silt, and sand) and London Clay Formation (clay, silt, and sand).

2.2.4 The key catchment descriptors obtained from the FEH Web Service (July 2021) are summarised in Table 2.1.

2.2.5 The key catchment descriptors are consistent with the available geological and topographical information and there are no unexpected/unusual values requiring adjustment, thus the original descriptors obtained from the FEH Web Service were used in this hydrological assessment.

Table 2.1: Key Catchment Descriptors
(source: FEH Web Service)

Watercourse	OS Easting	OS Northing	AREA
Shenfield Watercourse	561500	196150	2.6400

BFIHOST19	DPLBAR	DPSBAR	FARL	FPEXT	PROPWET	SAAR	SPRHOST	URBEXT
0.288	1.84	24.7	1.000	0.0881	0.27	597	47.38	0.3896

Watercourse	OS Easting	OS Northing	AREA
Small Tributary	561450	196200	0.5075

BFIHOST19	DPLBAR	DPSBAR	FARL	FPEXT	PROPWET	SAAR	SPRHOST	URBEXT
0.217	0.79	23.6	1.000	0.1379	0.27	598	50.54	0.2562

Watercourse	OS Easting	OS Northing	AREA
River Wid	561550	196400	12.9225

BFIHOST19	DPLBAR	DPSBAR	FARL	FPEXT	PROPWET	SAAR	SPRHOST	URBEXT
0.307	3.66	22.4	0.996	0.0754	0.27	604	44.86	0.0741

2.3 Flood Estimation Handbook (FEH) Statistical Method

2.3.1 WINFAP (Version 4.2) was used to implement the FEH statistical method using the key catchment descriptors summarised in Table 2.1.

2.3.2 Q_{MED} was estimated from catchment descriptors in Table 2.1 and urban adjustment factors based on default parameters (Kjeldsen 2010), as summarised in Table 2.2. Q_{MED} incorporated the information from 1 donor catchment.

Table 2.2: Q_{MED} Summary

Parameter	Value		
	Shenfield Watercourse	Small Tributary	River Wid
Q_{MED} (catchment descriptors)	0.637	0.176	2.433
Urban Adjustment Factor	1.369	1.212	1.067
Adjusted Q_{MED}	**0.839**	**0.205**	**2.596**

2.3.3 The composition of the pooling groups used in the FEH statistical method are given in Appendix A and summarised in Table 2.3. The pooling groups are (strongly) heterogeneous, but contains no discordant stations, and a best fit is achieved with the generalised logistics (GL) distribution ($|Z| < 0.1076$).

2.3.4 The peak flows with annual exceedance probabilities (AEP) of 50.0% (1 in 2 year), 10.0% (1 in 10 year), 3.3% (1 in 30 year), 1.0% (1 in 100 year) and 0.1% (1 in 1000 year) estimated using the FEH statistical method are presented in Table 2.4.

Table 2.3: Pooling Group Summary

Parameter	Value		
	Shenfield Watercourse	Small Tributary	River Wid
Years of Data	515	512	509
Similarity Distance	1.3 to 2.3	2.0 to 3.6	0.6 to 1.2
L-CV (weighted mean)	0.224	0.230	0.288
L-Skew (weighted mean)	0.314	0.284	0.194

Table 2.4: Peak Flows (FEH Statistical Method)

AEP (Return Period)	Peak Flow (m^3/s)		
	Shenfield Watercourse (GL)	Small Tributary (GL)	River Wid (GEV)
50.0% (1 in 2 year)	0.8	0.2	2.6
10.0% (1 in 10 year)	1.4	0.4	4.8
3.3% (1 in 30 year)	1.9	0.5	6.3
1.0% (1 in 100 year)	2.7	0.6	8.2
0.1% (1 in 1000 year)	5.2	1.0	12.6

2.4 Revitalised Flood Hydrograph (ReFH) Method

2.4.1 ReFH2 (Version 3.2) was used to implement the ReFH method using the key catchment descriptors summarised in Table 2.1.

2.4.2 Table 2.5 summarises the parameters of the ReFH model. Flood hydrographs were established using the default storm duration of 6.5 hours (Shenfield Watercourse), default urban model and 2013 rainfall data.

2.4.3 The peak flows with annual exceedance probabilities (AEP) of 50.0% (1 in 2 year), 10.0% (1 in 10 year), 3.3% (1 in 30 year), 1.0% (1 in 100 year) and 0.1% (1 in 1000 year) estimated using the ReFH method are presented in Table 2.6.

Table 2.5: ReFH Model Parameters

Parameter	Value		
	Shenfield Watercourse	Small Tributary	River Wid
Cini (mm)	116.529	157.632	137.039
Cmax (mm)	247.229	205.591	259.737
Tp (hours)	4.361	2.728	6.667
BL	30.282	21.211	36.572
BR	0.912	0.236	0.786

Table 2.6: Peak Flows (ReFH Method)

AEP (Return Period)	Peak Flow (m^3/s)		
	Shenfield Watercourse	Small Tributary	River Wid
50.0% (1 in 2 year)	1.7	0.4	3.7
10.0% (1 in 10 year)	3.1	0.7	6.2
3.3% (1 in 30 year)	4.2	0.9	8.3
1.0% (1 in 100 year)	6.1	1.3	11.7
0.1% (1 in 1000 year)	11.5	2.3	21.2
Storm profile	summer	winter	winter

2.5 EA Model

2.5.1 The peak flows with annual exceedance probabilities (AEP) of 50.0% (1 in 2 year), 10.0% (1 in 10 year), 3.3% (1 in 30 year), 1.0% (1 in 100 year) and 0.1% (1 in 1000 year) extracted from the EA model (unscaled ReFH inflow hydrographs) are presented in Table 2.7.

Table 2.7: Peak Flows (EA Model)

AEP (Return Period)	Peak Flow (m^3/s)		
	Shenfield Watercourse[†]	Small Tributary[†]	River Wid
50.0% (1 in 2 year)	1.4	0.3	3.6
10.0% (1 in 10 year)	2.3	0.4	5.9
3.3% (1 in 30 year)	3.1	0.6	7.8
1.0% (1 in 100 year)	4.3	0.8	10.5
0.1% (1 in 1000 year)	8.5	1.6	20.6

2.6 Summary of Results

2.6.1 As shown in Table 2.4 and Table 2.6, the two methods produce considerably different peak flow estimates, with the ReFH method leading to significantly higher values similar to those extracted from the EA model (Appendix A).

2.6.2 Although the peak flows from the EA model (Table 2.7) were used as the baseline scenario in the site-specific model, a sensitivity test using the slightly higher flows obtained through the ReFH method (Table 2.6) was undertaken as detailed in Section 3.5.

[†] As the EA's strategic model does not consider the small tributary (ordinary watercourse) between the A1023 and the A12, peak flows extracted from the EA model were split between the sub-catchments proportionally to the respective catchment areas.

3 HYDRAULIC MODEL

3.1 Method Statement

3.1.1 ESTRY-TUFLOW (Build 2020-10-AA-iDP-w64) was used in the site-specific modelling work. ESTRY-TUFLOW is a 1D-2D hydrodynamic simulator for modelling flows in urban waterways, rivers, floodplains, estuaries, and coastlines. It can model complex hydraulic systems comprising all the features present within the area of interest, namely the key hydraulic structures (i.e., culverts) and out-of-bank flow paths that would otherwise be difficult and less accurate to represent using simpler 1D or quasi-2D models.

3.2 Sources of Information

3.2.1 The sources of information used to build the hydraulic model are summarised in Table 3.1.

Table 3.1: Sources of Information

Source	Description
Environment Agency's Model	*M+F M1 Fluvial Package Modelling: Tributaries of the Rivers Wid and Crouch Model* (CH2M HILL, February 2018) comprising the Shenfield Watercourse and Shenfield Tributary (Figure 1.1) and information about off-site culverts.
Environment Agency's LiDAR	Composite Digital Terrain Model (DTM) at 1 m resolution (tile TQ69nw) (flown between December 2018 and January 2019 and downloaded from DATA.GOV.UK in July 2021).
Ordnance Survey's MasterMap	Detailed land use information including buildings, general surfaces (manmade and natural), surface water features, natural environment areas, paths, railways, roads, and roadsides (downloaded from Promap in May 2019).
Site Visit	On-site measurement and verification of key culverts undertaken by JNP Group in May 2019.
Site-Specific Topographic Survey	Topographic survey of the development site and key surrounding features undertaken by Aworth Survey Consultants in February 2020.
Site-Specific CCTV Survey	CCTV survey of culverts under the A1023 (Chelmsford Road) undertaken by Aworth Survey Consultants in November 2020.

3.3 Model Description (Pre-Development)

3.3.1 The site-specific model covers a total area of 152 ha comprising 0.9 km of the Shenfield Watercourse (main river) flowing through the development site and 1.3 km of the River Wid flowing along the A12 to the north of the development site.

3.3.2 To avoid 1D-2D numerical instabilities due to the small channel size relative to the 2D cell size, the watercourses' main channels were modelled in the 2D domain. Where appropriate, main channels, raised embankments and road layouts were carved into the model using (3D) "*Z Shapes*" based on information from the site-specific topographic survey and the EA model.

3.3.3 The modelled extent includes the following (1D) structures (i.e., culverts):

- Ø800 mm corrugated metal culvert associated with the flood attenuation scheme located immediately east of the development site (*C01.000*) (Figure 3.1).

- Ø600 mm to Ø750 mm concrete culvert under the A1023 (*C02.000* to *C02.001*) (Figure 3.2).
- Ø525 mm concrete culvert under the site's access off the A1023 (*C03.000*).
- Ø300 mm to Ø900 mm concrete flood relief culverts under the A1023 (*C04.000* to *C04.002*, *C05.000* and *C06.000*) (Figure 3.2 and Figure 3.3).
- 2.0 m x 1.0 m concrete box-culvert under rural track between the A1023 and A12 (C07.000).
- Ø1050 mm concrete culvert under the A12 (*C08.000*).
- 2.4 m x 1.6 m box-culverts under rural tracks (*C09.000* and *C10.000*) (Figure 3.4).
- 3.0 m x 2.1 m concrete box-culvert under Hall Lane (*C11.000*) (Figure 3.5).

3.3.4 All culverts were modelled in the 1D domain. A sensitivity test assuming severe blockage of the culverts under the A1023 (Chelmsford Road) was undertaken as detailed in Section 3.5.

3.3.5 Out-of-bank flow paths were modelled in the 2D domain using a 2 m grid. The 2 m grid resolution is compatible with the available topographic information and the key features present in the modelled extent.

3.3.6 The (pre-development) model is schematically represented in Map 1 in Appendix C.

Figure 3.1: Outlet of the Ø800 mm culvert immediately east of the development site (*C01.000*)

Figure 3.2: Outlets of the Ø900 mm and Ø750 mm culverts under the A1023 (*C02.001* and *C04.002*)

Figure 3.3: Inlet of Ø300 mm culvert under the A1023 (*C06.000*)

Figure 3.4: Outlet of the 2.4 m x 1.6 m box-culvert under a rural track (*C10.000*)

Figure 3.5: Outlet of the 3.0 m x 2.1 m box-culvert under Hall Lane (*C11.000*)

3.4 Modelling Parameters and Boundary Conditions

3.4.1 Roughness coefficients (Manning's 'n') were estimated to range between 0.013 and 0.100. The estimates are in accordance with CHOW (1959) for the descriptions presented in Table 3.2. Roughness coefficients were subject to a sensitivity test using the more conservative values also shown in Table 3.2, as detailed in Section 3.5.

Table 3.2: Roughness Coefficients (Manning's 'n')

Location	Description	Manning's 'n' ($m^{1/3}s$)	
		Baseline	Conservative
Main Channel	Channel not maintained with clean bottom and brush on sides	0.050	0.060
	Culvert:		
	• Corrugated metal	0.025	0.030
	• Concrete	0.015	0.018
Floodplains	*Building / Structure*	*1.000*	*1.000*
	General Surface:		
	• Back garden (short grass)	0.030	0.036
	• Pavement (rough asphalt)	0.016	0.019
	• Field (high grass)	0.035	0.042
	Natural Environment:		
	• Heavy stand of timber, down trees, some undergrowth	0.100	0.120
	• Medium to dense brush	0.070	0.084
	• Cleared land with tree stumps	0.040	0.048
	Path (gravel)	0.020	0.024
	Rail:		
	• Track (rip rap)	0.033	0.040
	• Trackside (high grass)	0.035	0.042
	Road or Track (smooth asphalt)	0.013	0.016
	Roadside:		
	• Pavement (rough asphalt)	0.016	0.019
	• Grass Verge (high grass)	0.035	0.042

3.4.2 In the absence of more detailed information, all other coefficients (e.g., head losses at culverts' inlets/outlets) used default/recommended values.

3.4.3 The boundary conditions used in the hydraulic model are described in Table 3.3. The boundary conditions subject to sensitivity testing as detailed in Section 3.5.

Table 3.3: Boundary Conditions

Boundary	Comments
Upstream	Hydrographs for the 50.0%, 10.0%, 3.3%, 1.0% and 0.1% AEP storm were extracted from the EA model and used as inflows to the site-specific model (Section 2.5 and Appendix A).
Downstream	Normal-depth flow for the River Wid's average bed slope through the modelled extent of 0.00333 m/m (~1:300) was used as the model's downstream boundary condition.

3.5 Calibration and Sensitivity Testing

3.5.1 In the absence of calibration data, the site-specific model was subject to a range of sensitivity tests selected to assess the impact on estimated results of changes to the following assumptions, parameters, and boundary conditions:

- Conservative roughness coefficients 20% higher than the recommended values (Table 3.2) were used to test the model's sensitivity to the baseline coefficients.
- The higher flows obtained through the ReFH method (Table 2.6) were used to assess the influence of the adopted upstream boundary condition on flood risk at the development site.
- A more conservative slope of 0.00166 m/m (~1:600) was used to assess the model's sensitivity to the baseline downstream boundary condition.
- Severe (95%) blockage of all culverts under the A1023 (*C02.000* to *C02.001*, *C04.000* to *C04.002*, *C05.000* and *C06.000*) was used to assess its impact on flood risk at the development site.

3.5.2 The above sensitivity tests were applied to the key storm events for planning (i.e., 3.3%, 1.0% and 0.1% AEP).

3.5.3 The potential impact of climate change on flood risk at the development site was assessed by adding the higher central (38%) and upper end (72%) climate change allowances to the 1.0% AEP inflows, in line with the EA's latest guidance.

3.6 Proposed Development (Post-Development)

3.6.1 The proposed development will require a new (roundabout) access off the A1023 (Chelmsford Road) and a new (embanked) crossing of the Shenfield Watercourse (main river) linking the northern and southern parts of the site with two new box culverts (C12.000 and C13.000) each having dimensions of 3.9 m x 1.8 m.

3.6.2 The new transport corridor has been preliminarily designed to:

- Minimise the loss of floodplain caused by the new (roundabout) access off the A1023 (Chelmsford Road).
- Hold flood flows in the area between the existing flood attenuation scheme located immediately east (upstream) of the development site and the new crossing of the Shenfield Watercourse, thus compensating for the loss off floodplain caused by the proposed works.

3.6.3 The post-development model is schematically represented in Map 2 in Appendix C.

4 MODEL PREDICTIONS

4.1 Model Stability

4.1.1 The site-specific model uses a 2D timestep of 0.5 seconds, within the 0.4 to 1.0 seconds range recommended for a 2 m grid. The 1D timestep is 0.1 seconds.

4.1.2 All scenarios (pre-development, sensitivity tests and post-development) ran without unexpected warnings, errors or negative depths for all storm events considered. Mass balance errors are within the desired range of ±2.0% and Qi, Qo and dV values are stable throughout all simulations, indicating a healthy hydraulic model.

4.1.3 All 1D and 2D outputs have been reviewed and are also indicative of a healthy hydraulic model.

4.2 Pre-Development (Baseline) Scenario

4.2.1 Maximum flood depths for the pre-development (baseline) scenario are shown in Map 3 (50.0% AEP), Map 4 (10.0% AEP), Map 5 (3.3% AEP), Map 6 (1.0% AEP) and Map 7 (0.1% AEP).

4.2.2 Results predict out-of-bank flows within the low-laying areas of the development site for all storm events considered, with overtopping of the A1023 (Chelmsford Road) starting at 3.3% AEP and overtopping of the A12 by the Shenfield Watercourse starting at 1.0% AEP. For the 0.1% AEP the River Wid also overflows onto the A12 upstream of the culvert under Hall Lane (*C11.000*).

4.3 Conservative Roughness Coefficients Scenario

4.3.1 Changes in maximum flood depths for the conservative roughness coefficients scenario are shown in Map 8 (3.3% AEP), Map 9 (1.0% AEP) and Map 10 (0.1% AEP) for pre-development conditions.

4.3.2 Results show that roughness coefficients have a considerable impact on maximum flood depths within the low-laying areas of the development site adjacent to the Shenfield Watercourse. However, the predicted increases in maximum flood depths of up to 50 mm have little impact on the estimated flood extents (i.e., developable area) and key conclusions of this report.

4.3.3 It is important to note that the influence of roughness coefficients on the estimated flood risk at the development dissipates as storm events become more extreme.

4.4 Conservative Upstream Boundary Conditions Scenario

4.4.1 Changes in maximum flood depths for the conservative upstream boundary conditions scenario are shown in Map 11 (3.3% AEP), Map 12 (1.0% AEP) and Map 13 (0.1% AEP) for pre-development conditions.

4.4.2 Results show that inflows have a significant impact on maximum flood depths within the low-laying areas of the development site adjacent to the Shenfield Watercourse. Nevertheless, the predicted increases in maximum flood depths of up to 150 mm still have limited impact on the estimated flood extents (i.e., developable area) and key conclusions of this report.

4.4.3 The influence of inflows on the estimated flood risk at the development site also dissipates as storm events become more extreme.

4.5 Conservative Downstream Boundary Condition Scenario

4.5.1 Changes in maximum flood depths for the conservative downstream boundary scenario are shown in Map 14 (3.3% AEP), Map 15 (1.0% AEP) and Map 16 (0.1% AEP) for pre-development conditions.

4.5.2 Results show that the downstream boundary condition has negligible impact on flood risk at the development, with increases in maximum flood depths restricted to the downstream edge of the model (River Wid).

4.6 Severe (95%) Blockage Scenario (Culverts Under A1023)

4.6.1 Changes in maximum flood depths for the severe (95%) blockage scenario are shown in Map 17 (3.3% AEP), Map 18 (1.0% AEP) and Map 19 (0.1% AEP) for pre-development conditions.

4.6.2 Results show that severe blockage of the culverts under the A1023 (Chelmsford Road) have a significant impact on maximum flood depths within the low-laying areas of the development site adjacent to the Shenfield Watercourse. Nevertheless, the predicted increases in maximum flood depths of up to 150 mm still have limited impact on the estimated flood extents (i.e., developable area) and key conclusions of this report.

4.6.3 The influence of severe blockage of the culverts under the A1023 on the estimated flood risk at the development site also dissipates as storm events become more extreme, turning out to be almost negligible for the 0.1% AEP storm event, with predicted increases in maximum flood depths of less than 25 mm.

4.7 Climate Change Scenarios

4.7.1 Maximum flood depths for the climate change scenarios are shown in Map 20 (1.0% AEP + 38% climate change allowance) and Map 21 (1.0% AEP + 72% climate change allowance) for pre-development conditions.

4.7.2 Changes in maximum flood depths for the climate change scenarios are shown in Map 22 (1.0% AEP + 38% climate change allowance) and Map 23 (1.0% AEP + 72% climate change allowance).

4.7.3 Results show that climate change can have a significant impact on maximum flood depths within the low-laying areas of the development site adjacent to the Shenfield Watercourse. However, the predicted increases in maximum flood depths of 25 mm to 50 mm (38% climate change allowance) and 50 mm to 100 mm (72% climate change allowance) still have limited impact on the estimated flood extents (i.e., developable area) and key conclusions of this report.

4.8 Post-Development Scenario

4.8.1 Maximum flood depths for the post-development scenario are shown in Map 24 (50.0% AEP), Map 25 (10.0% AEP), Map 26 (3.3% AEP), Map 27 (1.0% AEP), Map 28 (1.0% AEP + 38%), Map 29 (1.0% AEP + 72%) and Map 30 (0.1% AEP).

4.8.2 Changes in maximum flood depths for the post-development scenario are shown in Map 31 (50.0% AEP), Map 32 (10.0% AEP), Map 33 (3.3% AEP), Map 34 (1.0% AEP), Map 35 (1.0% AEP + 38%), Map 36 (1.0% AEP + 72%) and Map 37 (0.1% AEP).

4.8.3 Changes in maximum flood depths for sensitivity tests between post-development and pre-development conditions for storm events with 3.3% AEP, 1.0%AEP and 0.1% AEP are shown in Maps 38 to 40 (sensitivity with conservative roughness), Maps 38 to 40 (conservative downstream boundary), Maps 44 to 46 (severe 95% culvert blockage) and Maps 47 to 49 (conservative upstream boundary).

4.8.4 The proposed (roundabout) access off the A1023 (Chelmsford Road) has been preliminarily designed to minimise the loss of floodplain volume, thus it is predicted to start flooding at 3.3% AEP. Safe access to the proposed development for storm events up to 0.1% AEP is provided via the new (embanked) crossing of the Shenfield Watercourse linking the northern and southern parts of the site (off Alexander Lane).

4.8.5 Results indicate that the culverts under the proposed (embanked) crossing of the Shenfield Watercourse linking the northern and southern parts of the site can be sized to hold flood flows in the area between the existing flood attenuation scheme located immediately east (upstream) of the development site and the new crossing of the Shenfield Watercourse, thus compensating for the loss off floodplain caused by the proposed works and avoiding any increase in off-site flood risk for a range of storm events (50.0% to 0.1% AEP).

4.8.6 The sensitivity tests for post-development conditions show that changes to hydraulic roughness and boundary conditions do not exacerbate the increases in maximum flood depths and extents predicted with the same changes for pre-development conditions excepting the area immediately upstream of the new watercourse crossing. The greater flood depth in this area is caused by the attenuation of downstream flow by the crossing's culverts.

4.8.7 A severe blockage of culverts at the new Shenfield crossing would cause a significant increase in upstream flood depths compared to existing conditions and would cause flooding of proposed properties next to the southern approaches of the new crossing during the storm events considered (3.3% to 0.1% AEP). It would also lower flood depths downstream of the crossing due to the attenuation effects of the crossing's culverts. However, it is important that the risk of severe blockage of the two large box-culverts proposed is deemed very low.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1.1 Following a review of the EA's *M+F M1 Fluvial Package Modelling: Tributaries of the Rivers Wid and Crouch Model* (CH2M HILL, February 2018), a site-specific (2D) model was deemed necessary to better represent and understand flood risk at the development site and to facilitate the assessment of some of the (complex) mitigation measures envisaged.

5.1.2 While the need to address the risk of 1D-2D numerical instabilities due to the small channel size relative to the 2D cell size is justified, we believe that a 2D-only approach is significantly more appropriate to represent the area's hydraulics than the 1D-only approach taken by CH2M Hill. This is because out-of-bank flows which are difficult to represent accurately in 1D are expected/known to largely exceed in bank flows within the area of interest for most of the extreme storm events being considered (particularly the key storm event for planning).

5.1.3 Results for the pre-development (baseline) scenario predict out of bank flows within the low-laying areas of the development site for all storm events considered, with overtopping of the A1023 (Chelmsford Road) starting at 3.3% AEP and overtopping of the A12 by the Shenfield Watercourse starting at 1.0% AEP. For the 0.1% AEP the River Wid also overflows onto the A12 upstream of the culvert under Hall Lane.

5.1.4 In the absence of calibration data, the site-specific model was subject to a range of sensitivity tests selected to assess the impact on estimated results of changes to key assumptions, parameters, and boundary conditions.

5.1.5 Results for the sensitivity tests show that some assumptions have considerable impact on maximum flood depths within the low-laying areas of the development site adjacent to the Shenfield Watercourse. However, the predicted increases in maximum flood depths of up to 150 mm have little impact on the estimated flood extents (i.e., developable area) and the key conclusions of this report.

5.1.6 The proposed (roundabout) access off the A1023 (Chelmsford Road) has been preliminarily designed to minimise the loss of floodplain volume. Results for the post-development scenario predict the proposed access starts flooding at 3.3% AEP. Nevertheless, safe access to the proposed development for storm events up to 0.1% AEP is provided via the new (embanked) crossing of the Shenfield Watercourse linking the northern and southern parts of the site (off Alexander Lane).

5.1.7 Results for the post-development scenario indicate that the culverts under the proposed (embanked) crossing of the Shenfield Watercourse linking the northern and southern parts of the site can be sized to hold flood flows in the area between the existing flood attenuation scheme located immediately east (upstream) of the development site and the new crossing of the Shenfield Watercourse, thus compensating for the loss off floodplain caused by the proposed works and avoiding any increase in off-site flood risk for a range of storm events (50.0% to 0.1% AEP). Severe blockage of these culverts would cause flooding of properties next to the southern approaches of the new crossing (albeit the risk of severe blockage of the two large box-culverts is deemed very low).