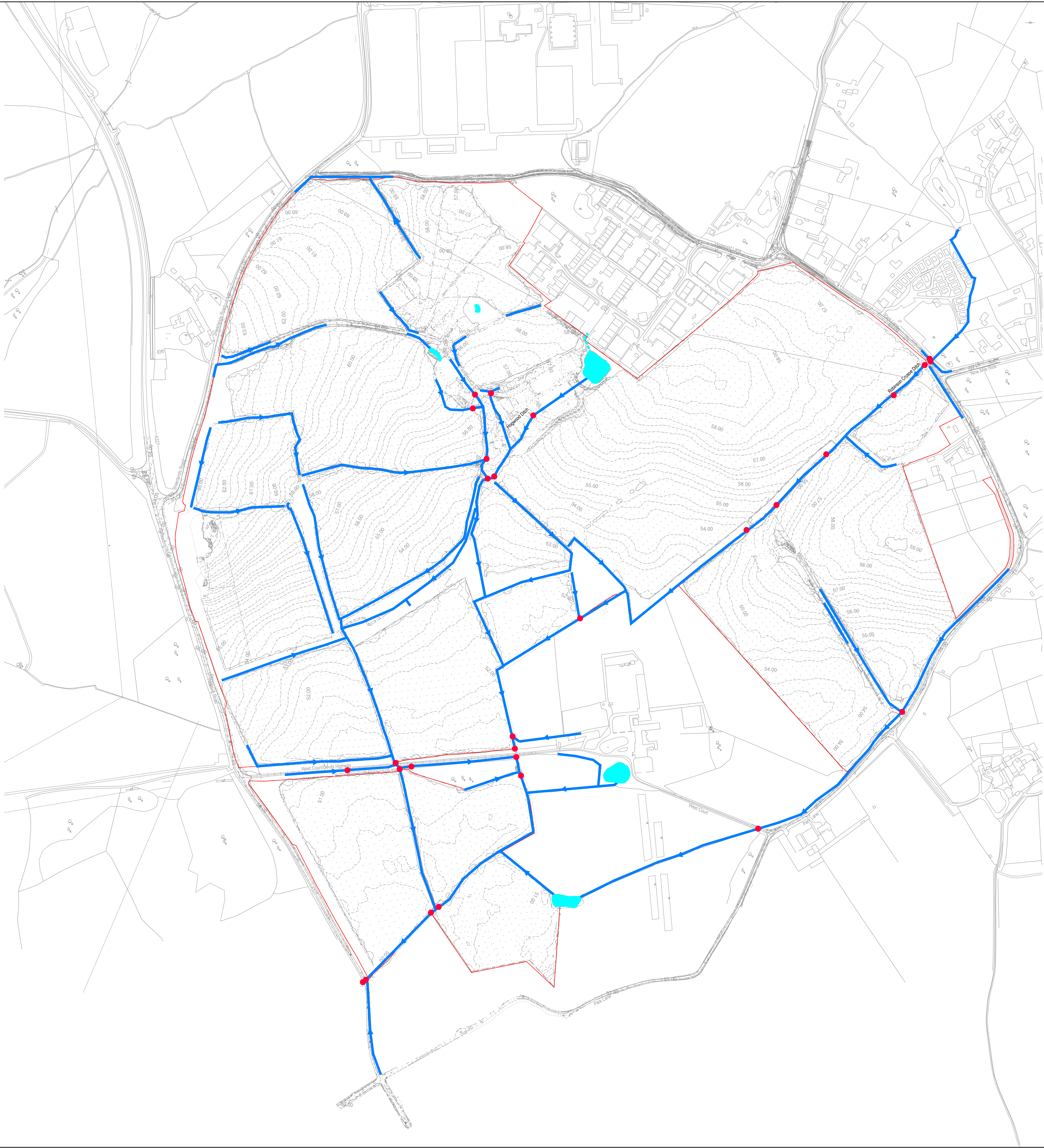




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- Key
- Watercourse
 - Flow Direction
 - Piped Drainage
 - Culvert
 - Pond
 - Site Boundary

- DRAWING REFERENCES:
1. OS Data. © crown copyright and database rights 2016. Ordnance Survey. License Number AL100001776.
 2. Topography based on survey produced by Brunel Surveys Ltd, October 2017 (reference not provided).
- DRAWING NOTES:
1. Watercourses observed during 2nd Site Visit carried out by JNP Group on 09th and 15th November 2017 respectively.
 2. Hogwood Ditch and Robinson Crook Ditch are names given by JNP Group for ease of reference.
 3. Existing ditches that perform only on-site land drainage function can potentially be removed as they are not needed for post development site hydrology. However, these ditches may need to be retained for ecological and arboreal purposes.
 4. Consent for removal, diversion or culverting of any watercourse will be needed from Wokingham Borough Council in their role as Lead Local Flood Authority.

Rev.	Date	Amendment	By	Chk.
A	04.18	Updates to ponds and watercourse layout	JC	
Status Preliminary				



Client	Legal and General Homes
Job	Land at Hogwood Farm
Title	Existing Ditch Network Plan

Scale 1:2500 @ A0 Date 16/11/2017

Drawn By: POF Eng. Check: MAH Tech. Check: MAH



Drawing No.	C85672-SK-011	Rev.	A
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Appendix E: Hydraulic Modelling Report





john newton & partners
jnp group
Consulting Engineers

www.jnpgroup.co.uk

Report

Hydraulic Modelling Report

Project: Hogwood Farm, Finchampstead

Client: Legal & General Homes

Reference: C85672-R002A

Date: February 2018

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Sheffield

DOCUMENT CONTROL SHEET

Hydraulic Modelling Report


Prepared by.....
Jacob Cronin BSc (Hons), MSc
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Director

FOR AND ON BEHALF OF JNP GROUP

Date: April 18

Document Issue Record

Rev	Date	Description	Prepared	Checked	Approved
~	02/18	First Issue / Draft	JC	POF	
A	04/18	Updates to appendix	JC		

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Executive Summary

jnp group was commissioned by Legal & General Homes to undertake a detailed hydraulic modelling project in support of the proposed development at Hogwood Farm, Finchampstead.

There are a number of small ditches on site which drain to 2 primary watercourses named Hogwood Ditch and Robinson Crusoe Ditch. These merge in the centre of the site and Hogwood Ditch continues down through the site and away into Long River via a culvert in the south-west corner. Both watercourses are currently unmodeled but given the flatter areas onsite and sizeable upstream catchments for both, were potential sources of flood risk to the development.

Detailed 1D/2D linked hydraulic modelling of the onsite watercourses was carried out using Flood Modeller Pro.

While the majority of the modelled watercourses floodplain was found to be within areas of the site which will remain undeveloped in the form of SANG or amenity greenspaces; small areas of development were within the 1 in 1000 year fluvial floodplain and 1 in 100 year fluvial floodplain when a 70% allowance for climate change was considered.

To offset this risk and to assess the impact of a number of channel changes to be undertaken for ecological purposes, a proposed model was created. This model considered the following alterations:

-  The removal of all culverts except for the downstream culvert leading offsite and the culvert which goes under the Devil's Highway.
-  Extension of the culvert present at the upstream end of Robinson Crusoe Ditch downstream approximately 50m.
-  Levelling the banks along the stretch of Robinson Crusoe Ditch which floods developable area.
-  Modification of the watercourses inflows to account for the reduction in surface water run-off that the implementation of SuDS will have on the site post-development.

A comparison of the existing model results against the proposed model revealed that the in-channel peak flows and maximum stage are both reduced immediately downstream of the site by the proposed alterations. Therefore, the modelling suitably demonstrates that there will be a reduction in flood risk both on and off site following the proposed watercourse alterations.

Sensitivity testing was carried out upon the model to test various parameters of the model. The model's sensitivity to changing inflows and increased flows from climate change scenarios (35%, 70%) was tested through the modelling of the different storm events. As expected water levels and peak flows increased with the higher modelled inflows (less frequent storm events). Further sensitivity testing was carried out on the model in the form of; raising/lowering the downstream boundary by 20%, increasing/decreasing Manning's Roughness values by 20% and implementing culvert blockages of 90% at the 2 culverts remaining post-development as per BS8533:2011 guidelines.

In conclusion, the hydraulic modelling demonstrates the flood risk to the site and that the proposed alterations to the watercourses will sufficiently offset this risk to the proposed development land whilst also offering a betterment to areas downstream of the site.

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1 INTRODUCTION

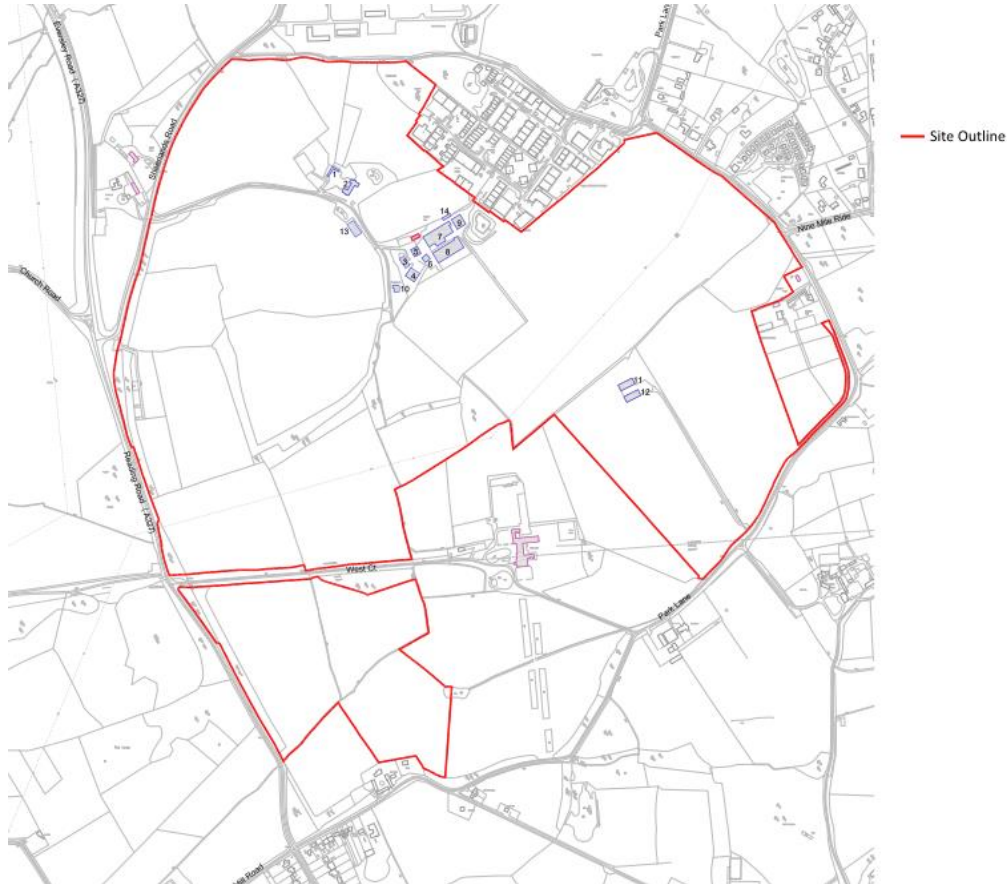
1.1 Terms of Reference

- 1.1.1 **jnp group** was commissioned by Legal & General Homes to develop a hydraulic model to assess the fluvial flood risk associated with the onsite watercourses at Hogwood Farm, Finchampstead. This modelling is being carried out in support of the proposed development. The modelling outputs will be used to understand the existing situation and ensure that all development is set outside the fluvial floodplain with any proposed changes assessed to confirm no negative impacts on fluvial flood risk downstream.
- 1.1.2 The onsite watercourse network consists of two ditches. The first runs from the northern end of the site to the south-western corner and is hereafter referred to as Hogwood Ditch. The second flows from the eastern boundary of the site with Park Lane, towards the south-west and is hereafter referred to as Robinson Crusoe Ditch. Robinson Crusoe Ditch joins Hogwood Ditch in the southern area of the site before flowing to the south-western corner and away to Long River via a culvert.
- 1.1.3 This hydraulic modelling project and report has been carried out following guidance within the Environment Agency's (EA) 2011 'Requirements for completing computer river modelling for Flood Risk Assessments' document and the 2011 British Standards BS8533:2011 (Assessing and Managing Flood Risk in Development – Code of Practice).
- 1.1.4 The outcomes of this hydraulic modelling support a separate Flood Risk Assessment (FRA) carried out by **jnp group** for the proposed development (report reference: C85672-R001).
- 1.1.5 This hydraulic modelling report sets out the nature of the site, including the existing site use, topography, planning context, proposed development, existing flood modelling information, and historical flooding records. The objectives of the modelling study are then set out. The report then moves into an overview of the existing modelling approach, summarizing the software and available data used, the general model schematisation and an overview of the model files including structure representation. The proposed modelling approach, detailed further below, includes the same information as provided within the existing modelling approach. The model run settings are summarized and then the model results for both existing and proposed scenarios are provided and compared. Model stability is reviewed, and the audit trail provided. A section on sensitivity analysis is then provided, revealing which parameters the hydraulic model depends upon most for its accuracy. All model limitations and assumptions are then provided.

1.2 Site Description

- 1.2.1 The site is approximately 109.93ha in size and is located directly south of the Arborfield Garrison (a British Army Garrison). The site is bounded to the west by Reading Road (A327), Park Lane to the east, south-east and north-east and Sheerlands Road to the north-west. Hogwood Lane is present at the sites northern boundary which provides access to pedestrians between Sheerlands Road and Hogwood Industrial Estate. All the sites boundaries are marked by woodland and hedgerows. Adjacent to the sites northern boundary is Hogwood Industrial Estate, located within in this area there is a brewery, multiple garages and offices. Just south of Hogwood Industrial Estate there is another smaller industrial estate located onsite. This onsite industrial estate is mainly comprised of garages for car repairs, there is also an irrigation systems supplier based in this area. Cutting through the sites south-western end is West Court or The Devil's Highway, this road connects directly between Reading Road to the west and West Court house, a Grade II listed 17th Century former manor house. This road is also known as the Devil's Highway and is part of a former Roman Road network which still exists as a footpath through the area.

1.2.2 The site location is shown below in Figure 1. A larger plan of the site is provided in Appendix A.



1.2.3 The land of the site is comprised mainly of large open fields which are used for agricultural purposes and separated by hedgerows and fences. Sections of mature woodland are also present at the site, included in this is the Hogwood Shaw (which is a Wildlife Heritage Site). Various buildings are present across the site, the majority of these buildings are either agricultural (stables etc) or small buildings (garages etc). There are also two houses present; Hogwood Farmhouse and The Lodge. These lie to the north and south of a small private road that leads directly to Hogwood Farm respectively. The development plan for the site specifically excludes the Hogwood Farmhouse which is a Grade 2 Listed Building, located within the on-site Industrial Estate.

 N477056
 E164329
 RG404QY

1.3 Topography

Wider Topography

- 1.3.1 1m resolution Digital Surface Model (DSM) LiDAR data has been provided by the EA; enabling a review of the wider topography around the proposed development site. A map created from this data is provided in Figure 2 below.

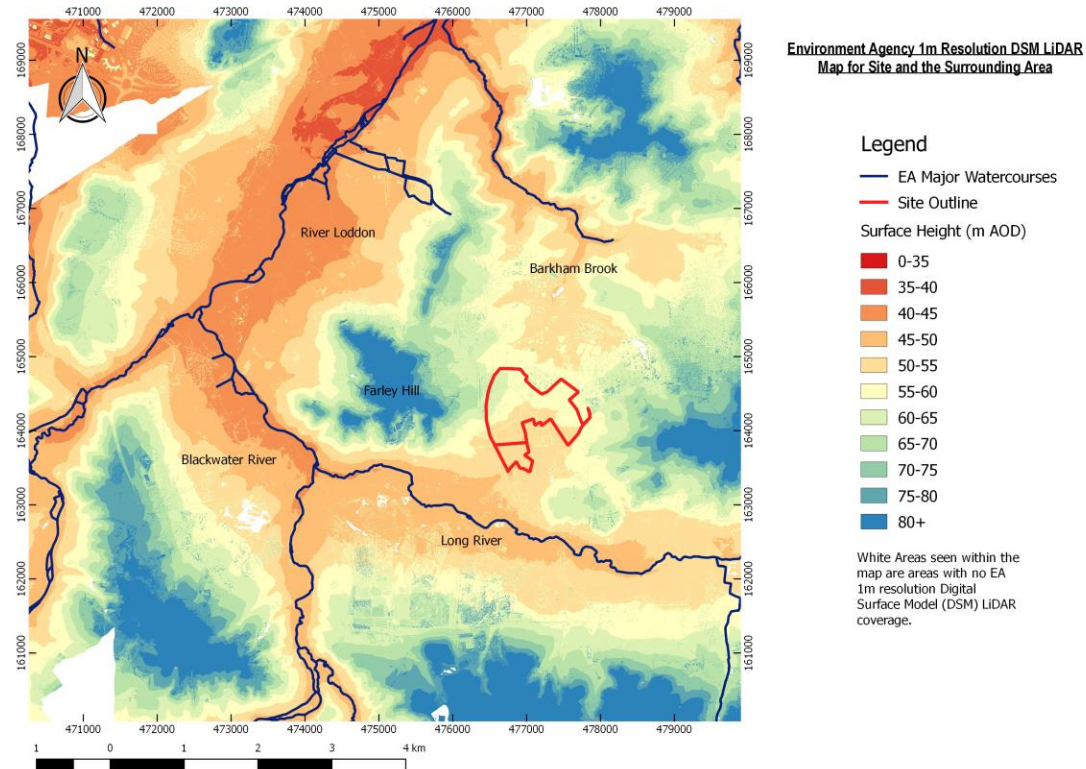


Figure 2: 1m Resolution Environment Agency LiDAR Data for the Wider Area Around the Site

- 1.3.2 The wider area around the site is defined by the River Loddon valley which lies to the west of the site. This in turn is fed by the catchment of Blackwater River to the south-east and Barkham Brook's catchment to the north-west. The majority of the site falls towards the Long River, which flows westwards into the Blackwater River to the south of the site. A tributary of the Long River leaves the site at its south-western corner, forming a valley leading into the wider Long River valley which falls from east to west approximately 0.75km to the south of the site. For ease of reference, this tributary is hereafter called Hogwood Ditch. The wider Barkham Brook valley is located approximately 1.2km north of the site boundary. Part of the sites northern area forms part of the Barkham Brook catchment.
- 1.3.3 Approximately 2km west of the site is Farley Hill, which Figure 2 shows in the LiDAR band of 80+m Above Ordnance Datum (AOD). Approximately 1km east of the site there is another area of high topography in the form of a ridge.
- 1.3.4 The EA's LiDAR information is a useful guide in indicating topographic trends but at a 1m resolution, can be prone to accuracy issues, particularly in areas with extensive waterbodies and trees. Across the site specifically various inaccuracies have been found, especially along the ditch network. This is due to the ditches commonly being surrounded by large hedgerows or woodland. However, the overall general trends for the wider area around the site are considered accurate.

Site Topography

- 1.3.5 This section should be read in conjunction with the site specific topographic survey carried out by Brunel Surveys Ltd in November 2017. A copy of this survey is provided in Appendix B.
- 1.3.6 Generally, the site falls from north to south and from the east and west towards the centre of the site, where Hogwood Ditch flows, before falling towards the south-western corner. However, the onsite topography is undulating, with hills, secondary ditches and smaller valleys all present.
- 1.3.7 63.53m AOD is the peak height found on the site; located adjacent to where the private access road in the north joins Sheerlands Road. However, this was observed as a mound of earth during a site visit in November 2017, giving this area an exaggerated height on the survey. Nevertheless, even without the mound, the land surrounding this point does still fall away from this high point, although the fall is not as pronounced as that suggested by the site specific topographic survey.
- 1.3.8 The land falls from the base of the mound to the east at approximately 1:150. This fall continues to the Hogwood Ditch valley in the centre of the site before rising towards the north-eastern boundary with Hogwood Industrial Estate. The land at the boundary with Hogwood Industrial Estate has a peak height of 58.71m AOD and a fall towards the south-west of 1:70.
- 1.3.9 In addition to the general fall towards the central valley, the land also generally falls from north to south. This fall is approximately 1:194 and continues across the site from the north in general to the south-western boundary with Lea Farm. Past this boundary, the land continues to fall towards Long River.
- 1.3.10 The land also drops from the mound towards the northern site boundary of Hogwood Lane with an average 1:100 fall. Levels at this boundary are a minimum of 59.08m AOD.
- 1.3.11 On the eastern side of the site, the land falls from the boundaries of Shepperlands Farm and Park Lane from north towards the south and west at approximately 1:130 before reaching a valley with a tributary of Hogwood Ditch flowing westwards from the north-east site boundary. This tributary is hereafter referred to as Robinson Crusoe Ditch. On the adjacent side of the valley, land rises at approximately 1:50.
- 1.3.12 As identified in the general site trends, levels fall towards the south and west. However, the site is flatter in the south, with a much gentler fall of approximately 1:318 towards Hogwood Ditch, which leaves via a culvert in the south-western corner and flows away into Long River. Levels in the south-eastern corner are approximately 49.80m AOD.

1.4 Existing Fluvial Flood Modelling Data

- 1.4.1 The Environment Agency (EA) have been approached to obtain site-specific flood risk data, including the onsite ditches. The EA confirmed that they do not have any modelled flood levels for the onsite watercourses that pass through the site. Therefore, the risk of fluvial flooding from these sources are completely unknown.
- 1.4.2 A hydrological study was carried out on the sites watercourses to assess the hydraulic properties of the area and define the inflow conditions for the model using the Revitalised FEH (ReFH) method. This report is provided in Appendix C.

1.5 Historical Fluvial Flood Data

- 1.5.1 The EA were unable to provide any details of historical flooding for the site.
- 1.5.2 A review of the February 2012 Wokingham Borough Council Strategic Flood Risk Assessment (SFRA) shows that there are no records of historical fluvial flooding for the site prior to their publication.

1.5.3 As a result, there are no calibration/verification events to use within the hydraulic modelling project.

1.6 Objectives of the Modelling Study

1.6.1 The modelling exercise aims to define the existing fluvial flood risk at the site from Hogwood Ditch and Robinson Crusoe Ditch across a range of scenarios ranging from frequent to extreme as referenced below:

-  1 in 2year (hereafter referred to as Q2);
-  1 in 5year (hereafter referred to as Q5);
-  1 in 10year (hereafter referred to as Q10);
-  1 in 20year (hereafter referred to as Q20);
-  1 in 30year (hereafter referred to as Q30);
-  1 in 50year (hereafter referred to as Q50);
-  1 in 100year (hereafter referred to as Q100);
-  1 in 200year (hereafter referred to as Q200);
-  1 in 1000year (hereafter referred to as Q1000);
-  1 in 100year including a 35% and 70% allowance for climate change in line with the latest EA guidance (hereafter referred to as Q100CC25, Q100CC35, Q100CC70);

1.6.2 Once defined, the aim is to facilitate the development, achieving the scale of development outlined in the Masterplan while also ensuring that there will be no negative impact on fluvial flood risk either on or off-site as a result of development within the existing fluvial floodplain onsite.

2 EXISTING MODELLING APPROACH

2.1 Choice of Model Software

2.1.1 The modelling approach used Flood Modeller Pro software package to create a linked 1D/2D model.

 Flood Modeller Pro version: 4.3.6458.29637

2.1.2 This 1D/2D linked modelling approach has been used as both elements suit the areas they are modelling best. The 1D modelling elements used to represent the Hogwood and Robinson Crusoe Ditch channels, are based on topographic survey data taken at regular intervals and at all structures to accurately represent the way that floodwater is conveyed down the ditches. Structures are well represented with a 1D approach. A 2D LiDAR grid has been used to represent the floodplain, showing flow paths and velocities in any direction rather than with 1D, which would only assume velocity normal to the channel cross-sections. As there was indicatively significant floodplain storage used by flood events at the site, the 2D element was considered best to represent this.

2.2 Available Data

Table 1: Modelling Data Sources

Item	Notes
Topographic Data	
3D Topographic Survey	Survey provided by Brunel Surveys Ltd in January 2018 (reference: 18215-Hogwood Farm 2D 09.01.18). Including cross sections of the modelled watercourses with increasing regularity at points of interest i.e. Areas of increased sinuosity.
LiDAR	1m DTM LiDAR Data. Obtained from the EA on December 2017.
Plans/Drawings	
Development Plans	Provided by Cooper Baillie (reference: CB_12_103_909 Residential Areas Plan 15.02.2018)
Hydrological Data	
Gauging Stations	Gauging station donor data values used where appropriate. See the hydrological study tech note provided in Appendix C for the site (reference TN-001 Hydrological Study).
Rainfall Data	The rainfall data for this site was derived by carrying out a hydrological study of the sites catchment area (See jnp group report - reference: C85672-TN001). The revitalised flood hydrograph (ReFH) method was used to calculate the watercourses peak flows.

2.3 General Schematisation

Table 2: Schematisation of Model (1D & 2D)

Channel representation	Flood Modeller Pro. (1D & 2D)
Length of Modelled Watercourse	Hogwood Ditch- 1181m Robinson Crusoe Ditch- 987m Total Length- 2168m
Backwater Length	0
Area of 1D Channel	34358m ²

1D topographic data source	3D topographic survey covering the site area. EA DTM LiDAR 1m resolution used in conjunction with the topographic survey data, particularly to cover the area immediately downstream of the site boundary culvert as land inaccessible for surveying.
Total number of nodes: 177	Boundaries-4 River Section-141 Interpolate-7 Culvert Inlet-6 Circular Conduit-12 Culvert Outlet-6 Junction Nodes-2
Labelling/Numbering System	Both Hogwood Ditch and Robinson Crusoe Ditch were included in the same model. Hogwood Ditch labelling system started with Section 1 at the upstream end and counted up from that point. Robinson Crusoe Ditch follow the same scheme, but the section labels start with RC_Ditch (see Figure 3 below). All other nodes followed a similar labelling scheme.
Floodplain representation	Flood Modeller Pro Linked 1D/2D
2D topographic data source	LiDAR DTM, 1m resolution
2D cell size	2m as cell grid size must be double the value of the 1s model time step value.

2.3.1 Figure 3 below shows the modelled watercourse and the components which make up the 1D/2D linked model.

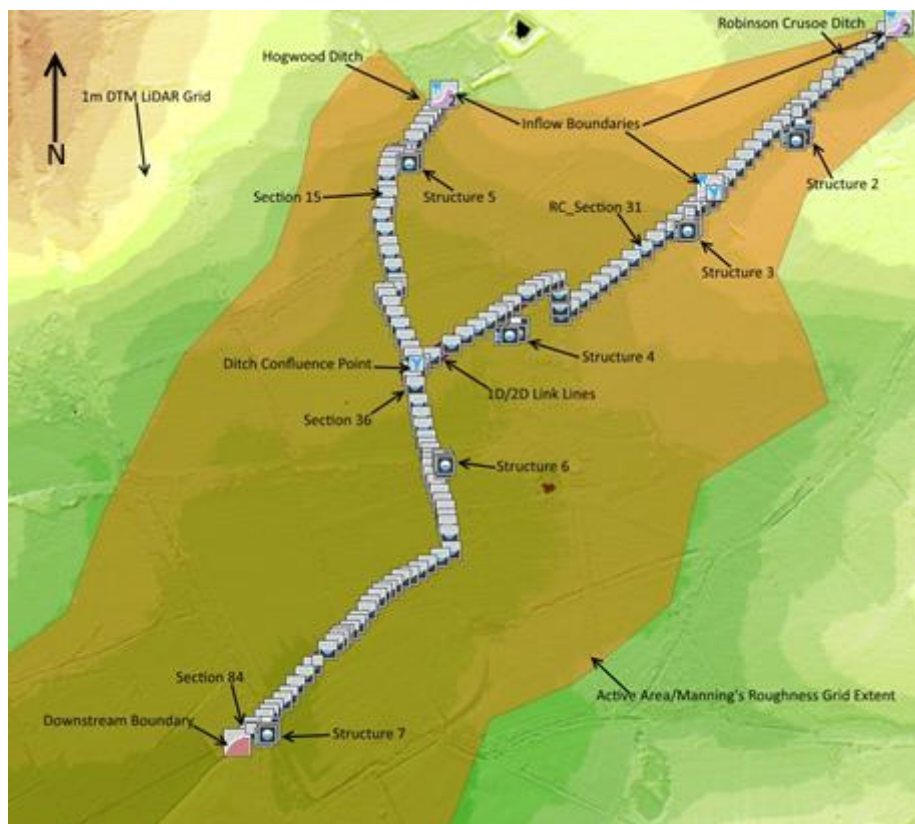


Figure 3: 1D Model Reach Plan with 2D Elements

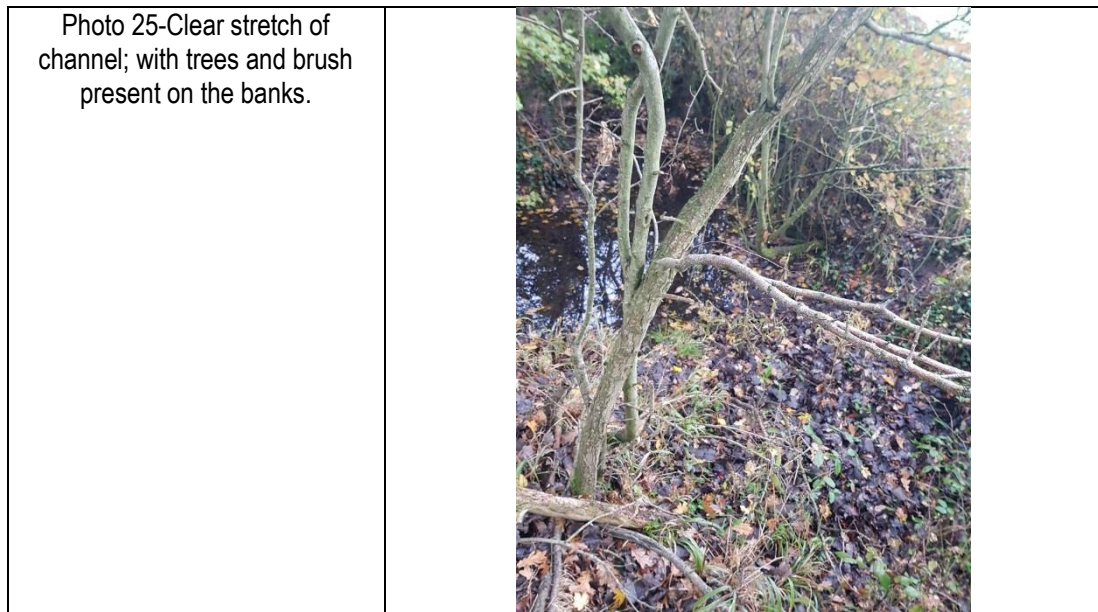
2.4 1D Model Element

2.4.1 All photos shown below were taken during a site visit carried out by JNP Group in November 2017.

Table 3: Breakdown of the Models 1D Components

Item	Comments
Inflow Boundaries	ReFH2 node type, the inflow was divided between the ditches based off of their FEH catchment areas and the topographic data. Minimum flow 0.1m ³ /s The suitable climate change allowances have been applied to the Q100 fluvial flow information based on the latest EA climate change projections
Lateral Catchment Weighting	None
Downstream Boundary	Set downstream of the culvert which leads offsite.
Other information/alterations made to the model	A few small culverts were removed from the model due to a lack of data and the fact that they will not be kept post development. However, all culverts with data were implemented into the existing model even if they are proposed to be removed post development.
Hydraulic Roughness Values	Channel roughness values have been represented in the models by Manning's 'n'. Descriptions in Chow (1959) were examined against photos and conditions seen on the site visit/survey.
Reach	Roughness Value
The modelled watercourses had similar channel roughness values throughout the site. Changes in the roughness are dictated by the bank vegetation.	0.03 – Clear straight channel with little to no weeds and stones 0.035 - straight area of the channel with stones and weeds present. 0.045 – winding area of the channel with weeds and stones present. 0.05 - Scattered brush and heavy weeds on channel banks/floodplain. 0.05 – Light brush with small trees in the winter on the channel banks/floodplain. 0.1 – Hardstanding or fallen large trees
Roughness Evidence/Photographs	

Photo 24- A clear area of channel with vegetated banks.		 A photograph showing a narrow, clear water channel. The banks are covered with dense, low-lying vegetation, including green and yellowish plants. The water is dark and reflects the surrounding foliage.	
Photo 28- A highly vegetated channel with dense weeds and vegetation on the banks.		 A photograph of a channel almost completely obscured by thick, tangled vegetation. The plants are a mix of green and brown, suggesting some are dead or dormant. The water is barely visible in the center.	
Photo 34- Highly vegetated section of channel. On the ditches left side there is woodland, and, on the right, there is open pasture. Past the vegetated ditch bank.		 A photograph taken from a slightly elevated position looking down into a channel. The left bank is covered in dense woodland. The right bank is a steep, vegetated slope. In the background, beyond the channel, there is a green open pasture. A metal railing is visible in the foreground.	



2.5 2D Model Element

Table 4: Breakdown of the Models 2D Components

Item	Comments
Grid Orientation	North to south (following the general orientation of main ditch).
Representation of River Banks	Defined using topographic survey spot levels
Representation of Flood Defences	None present
Nested 1D Element	The 1D channel is linked to the 2D model using a 1D/2D link lines file
Hydraulic Roughness Values	Floodplain roughness values have been represented in the models by Manning's 'n'. Descriptions in Chow (1959) were examined against photos and conditions seen on the site visit/survey.
2D Surface	Roughness Value
0.07	Medium to dense brush in the winter
0.05	Scattered brush and heavy weeds
0.05	Light Brush with small trees in the winter
0.04	Cleared land
0.1	Heavy standing of timber
Roughness Evidence/Photographs	

Photo 32- Open pasture land with medium to long grass Sections: RCSection_3-RCSection_20 (Over top of bank/floodplain)		
Photo 89- Densely vegetated/wooded area. Sections: Section1-Section16 (Over top of bank/floodplain)		
Photo 35- Woodland Sections: Section23-Section30 (Over top of bank/floodplain)		
Photo 09- Open long grass fields with hardstanding large trees. Sections RC_Section21-RC_Section40 (Over top of bank/floodplain)		

Photo 37- High density weeds Sections Section55-Section84 RC_Section45-RC_Section55 (Over top of bank/floodplain)		
Photo 13- Asphalt Road Sections: Section45-Section46 (Over top of bank/floodplain)		

2.6 Model Structure Representation

Name of Structure	Structure Details
Model Representation	Upstream- Structure2_U Downstream- Structure2_D Inlet- RC_Section10 Outlet- Structure2_D
Coefficients Used	Manning's values: 0.019 Corrugated metal pipe
Assumptions	Although the culvert is submerged in the photo below it is assumed to be unblocked in the model.
Photo 31	

Name of Structure	Structure Details
Model Representation	Upstream- Structure3_U Downstream- Structure3_D Inlet- RC_Section27 Outlet- Structure3_D
Coefficients Used	Manning's values: Concrete structure- 0.011,
Assumptions	This culvert was not blocked, and the pipe was intact.
Photo 21	

Name of Structure	Structure Details
Model Representation	Upstream- Structure4_U Downstream- Structure4_D Inlet- RC_Section48 Outlet- Structure4_D
Coefficients Used	Manning's values: 0.011 Concrete structure,
Assumptions	Although the culvert is submerged in this culvert it is assumed to be unblocked in the model.
Photo 34	

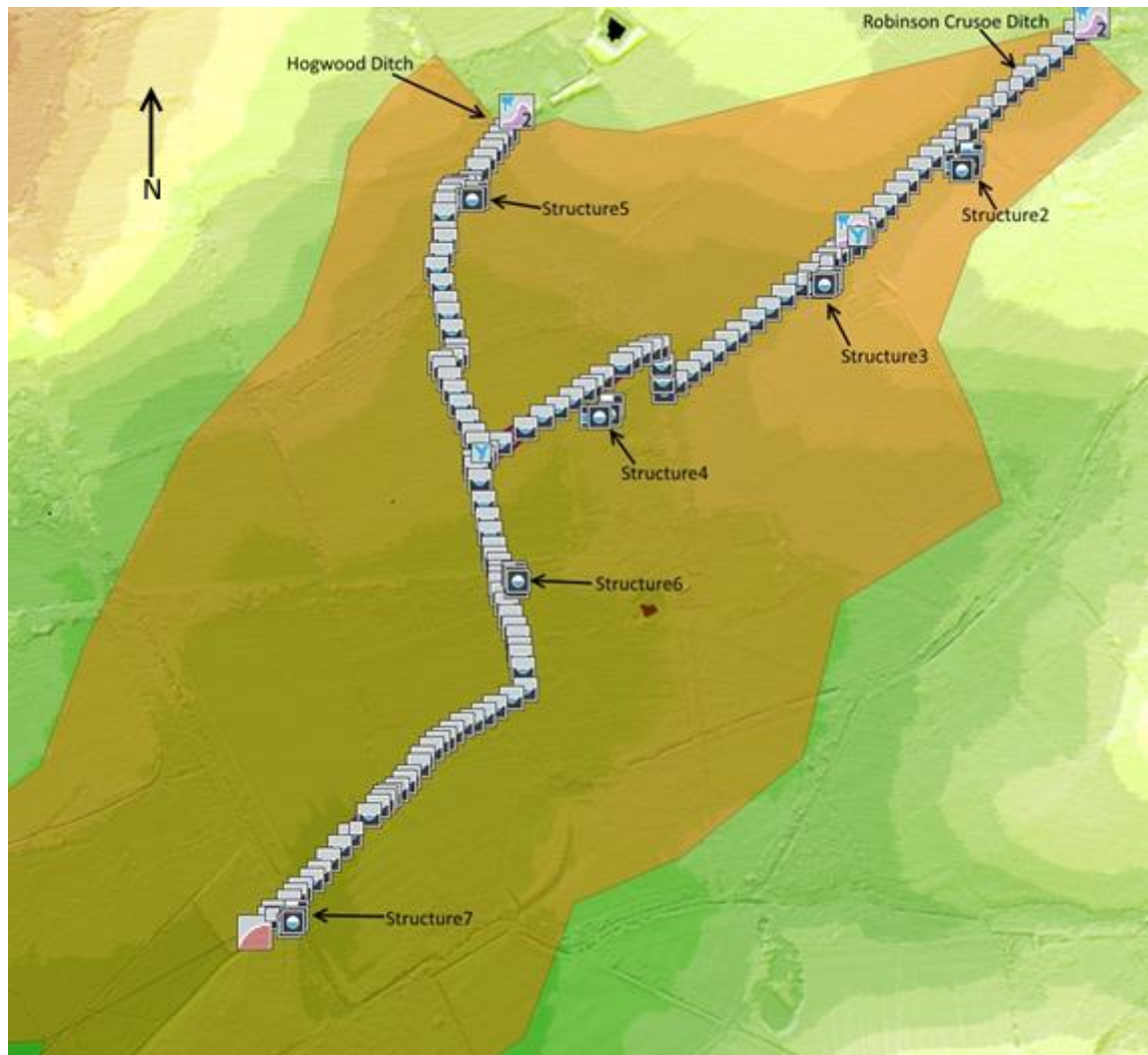
Name of Structure	Structure Details
Model Representation	Upstream- Structure5_U Downstream- Structure5_D Inlet- Section8 Outlet- Structure5_D
Coefficients Used	Manning's values: 0.019 Corrugated metal pipe
Assumptions	The culvert is completely unblocked, and the pipe is intact internally.
Photo 18	

Name of Structure	Structure Details
Model Representation	Upstream- Structure6_U Downstream- Structure6_D Inlet- Section45 Outlet- Structure6_D
Coefficients Used	Manning's values: 0.011 Concrete structure
Assumptions	This culvert was not blocked, and the structure is intact internally.
Photo 40	

Name of Structure	Structure Details
Model Representation	Upstream- Structure7_U Downstream- Structure7_D Inlet- Section82 Outlet- Structure7_D
Coefficients Used	Manning's values: 0.011 Concrete structure
Assumptions	Downstream of the culvert leading off site the river sections are based on upstream cross sections. This is due to the topographic survey not extending past this culvert.
Photo 20	

- 2.6.1 Figure 4 below shows the location of each of the structures stated in the tables above within the 1D node network of the modelled watercourses.

Figure 4: 1D Modelled Structure Location Plan



2.6.2 Figure 5 below shows the locations of each photo referenced in the tables above. The photos were taken during a site visit carried out by JNP Group in November 2017.

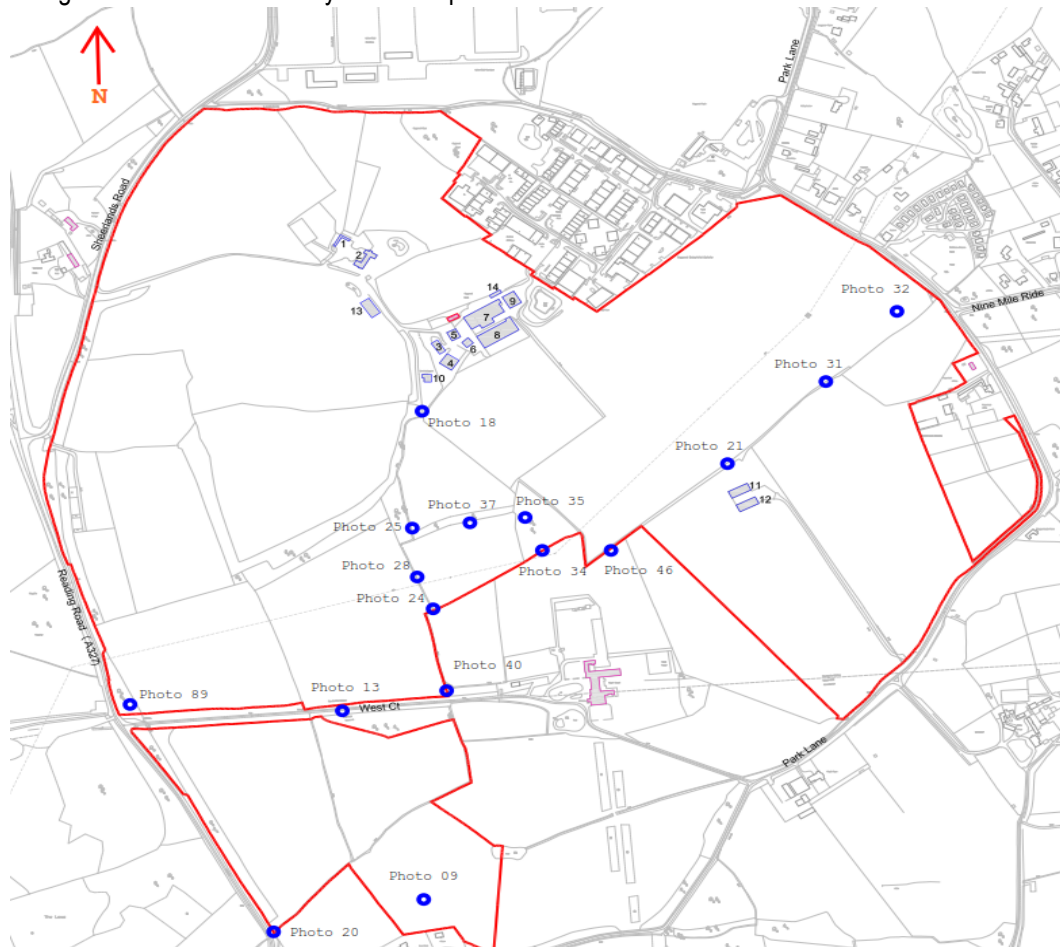


Figure 5: Photograph Location Plan

2.7 Existing Scenarios Modelled

-  Q2
-  Q5
-  Q10
-  Q20
-  Q30
-  Q50
-  Q100
-  Q100CC25
-  Q100CC35
-  Q100CC70
-  Q200
-  Q1000

3 PROPOSED MODELLING APPROACH

3.1 Alterations to the Modelled Watercourses

3.1.1 The alterations proposed to the existing watercourses modelled include:

-  Removal of all non-essential culverts from both Hogwood Ditch and Robinson Crusoe Ditch. This will not only enhance the watercourses ecological value but will also reduce the risk of culvert blockages across the site.
-  Extension of the existing culvert located at the upstream end of Robinson Crusoe Ditch approximately 50m downstream. The extension of this culvert will facilitate the proposed site access located at the eastern boundary of the site. Further details on this proposed culvert extension will be confirmed during the detailed design stage of the project. However, Wokingham Borough Council has agreed to these changes to the watercourses in principle.
-  Lowering of bank level at RC_Section25 to RC_Section37 to enable a floodplain more centralised about the channel in the post-development scenario.
-  The inflow to the model was modified to represent post development runoff rates, following the implementation of SuDS (Details outlined in the site Drainage Assessment report by [jnp group](#) reference: C85672-R003).

3.1.2 The proposed modelling aims to demonstrate that the implementation of these alterations will not cause increased flood risk either on or downstream of the site. The proposed alterations to the watercourses are shown on plan in Appendix D.

3.2 Proposed Scenarios Modelled

3.2.1 The following scenarios have been modelled for comparison with the same existing scenarios:

-  Q2
-  Q5
-  Q10
-  Q20
-  Q30
-  Q50
-  Q100
-  Q100CC25
-  Q100CC35
-  Q100CC70
-  Q200
-  Q1000

4 MODEL RUN SETTINGS

- 4.1.1 The first model run to be carried out for each event is the 1D model. This allows for the 1D network to be tested and gain a set of initial conditions. The steps on setting up and running a 1D simulation are laid out in the Model Log (see Appendix E).
- 4.1.2 All final models were run as 1D/2D linked models with the following settings:
-  All model durations were set to 20 hours with a fixed 1D and 2D timestep of 1 second.
 -  Domain grid sizes all set to 2m, which is the recommended double value of the model timestep.
 -  The models were run for 20 hours to enable the flow and stage to return to normal levels during all return periods.
 -  Each model simulation took approximately 3-6 hours to run on an eight-core Windows 7 Desktop PC. Longer simulations times were seen when carrying out multiple simulations at once i.e. running 4 models simultaneously would take between 7-15 hours.

5 MODEL RESULTS

5.1 Existing Situation Results

5.1.1 Results for the existing situation were taken at Section 84, immediately downstream of the culvert leading from the site. Section 84 is shown above in Figure 3, with the model results summarised in Table 5.

Table 5: Existing Model Results

Flood Event	Maximum Stage (m AOD)	Peak Flow (m ³ s ⁻¹)
Q2	48.654	0.569
Q5	48.791	0.778
Q10	48.880	0.917
Q20	48.965	1.099
Q30	48.995	1.171
Q50	49.041	1.279
Q100	49.104	1.427
Q200	49.163	1.589
Q100CC35%	49.194	1.679
Q100CC70%	49.238	1.807
Q1000	49.246	1.829

5.1.2 The existing fluvial flood risk extents are shown to impact large areas of the site, but the majority of these areas are land which is not going to be developed. The developed land that is impacted is mainly located in the north-east along Robinson Crusoe Ditch.

5.1.3 The total volume of water entering and leaving the model is defined by the inflow hydrographs at the upstream end of Hogwood Ditch and the upstream and midpoint of Robinson Crusoe Ditch.

5.1.4 Mapped flood extents demonstrating the full range of fluvial events on the existing model are provided in Appendix F.

5.2 Proposed Model Results

5.2.1 Results for the proposed model (as defined in the proposed modelling section approach above) were taken at Section 84; a summary of the results are provided in Table 6 below.

Table 6: Proposed Model Results

Flood Event	Maximum Stage (m AOD)	Peak Flow (m ³ s ⁻¹)
Q2	48.617	0.528
Q5	48.741	0.700
Q10	48.814	0.814
Q20	48.894	0.939
Q30	48.943	1.049
Q50	48.991	1.163
Q100	49.050	1.302
Q200	49.122	1.471
Q100CC35%	49.170	1.608
Q100CC70%	49.217	1.744
Q1000	49.220	1.754

5.2.2 All of the proposed fluvial flood risk extents modelled for the proposed watercourse alterations are shown to be restricted to areas outside of the developable areas for all flood events up to and including the Q1000 scenario. Mapped flood extents demonstrating this for the full range of fluvial events on the proposed model are provided in Appendix G.

5.3 Comparison of Results

The maximum stage and peak flows are shown to be lower at River Section 84 for the proposed model when compared to the existing model thus demonstrating a quantifiable reduction in off-site flood risk post-development.

The proposed alterations to the watercourses has no impact on the total volume of water entering the model and as a result, there will be no increase in the total volume of water leaving the site.

5.4 Model Stability

Table 7: Summary of Model Stability Reports

Modelled Scenario	Number of warnings	Max Cumulative Mass Error (%)	Final Cumulative Mass Error (%)	Run Time (hr:min)
Existing Q2	2	-0.02	0	11:41
Existing Q5	2	-0.03	-0.01	11:37
Existing Q10	4	-0.03	0	10:52
Existing Q20	4	-0.03	-0.01	11:40
Existing Q30	4	-0.05	-0.01	12:15
Existing Q50	3	-0.04	0	13:30
Existing Q100	3	-0.06	-0.01	13:51
Existing Q200	3	-0.06	0	14:23
Existing Q100CC35%	3	-0.08	0	14:10
Existing Q100CC70%	3	-0.14	0	14:52
Existing Q1000	3	-0.14	0	3:34
Proposed Q2	3	-0.01	0	5:29
Proposed Q5	2	-0.01	0	5:23
Proposed Q10	3	-0.01	0	7:04
Proposed Q20	4	-0.02	0	4:36
Proposed Q30	3	-0.02	0	4:10
Proposed Q50	4	-0.02	0	6:46
Proposed Q100	3	-0.02	0	5:27
Proposed Q200	3	-0.03	0	6:43
Proposed Q100CC35%	3	-0.04	-0.01	5:40
Proposed Q100CC70%	3	-0.06	-0.01	6:52
Proposed Q1000	4	-0.08	0	4:13

5.4.1 Mass Errors obtained from the individual Flood Modeller Pro 1D/2D linked model files for each event.

5.4.2 Chapter 7 of the EA's 2009 Fluvial Design Guide states:

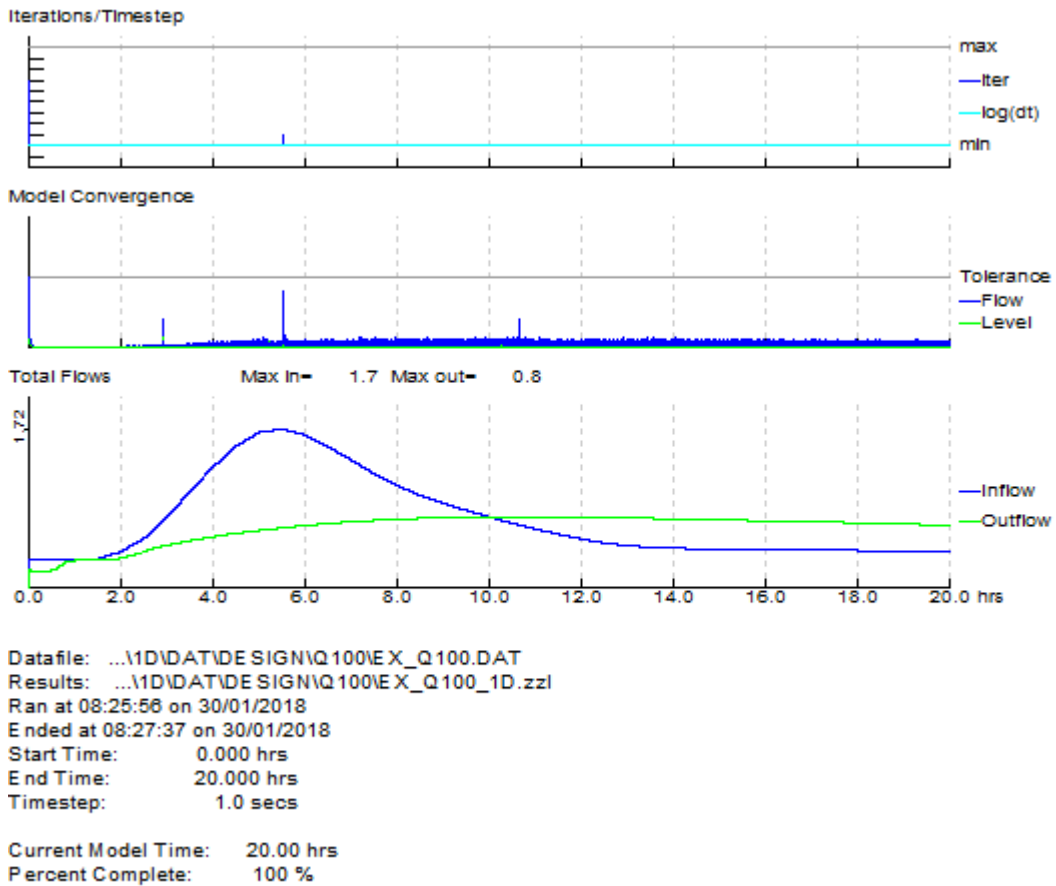
"As a rule of thumb, mass errors should be less than 2%. If the mass error is greater than 2%, the cause and location of the mass error within the model schematisation should be identified and the consequence of this error assessed and improvements to the model considered. If the mass error is greater than 5%, then it suggests that the model schematisation or type of model (software) is not robust and needs to be challenged."

5.4.3 Run times are approximate only. These models were run on an eight-core Windows 7 desktop PC, but the reported times may include variations that arose during differing periods of CPU pressures.

5.4.4 The results appear reasonable and realistic given the applied hydrological boundaries.

5.4.5 The model convergence plot for the existing Q100 design run has been provided below in Figure 6.

Figure 6: Existing Q100 Model Convergence Plot



- 5.4.6 The convergence plot is typical of each of the modelled scenarios and demonstrates good model convergence, below the tolerance level throughout the run.

5.5 Audit Trail

- 5.5.1 All of the existing and proposed model files can be provided separately for independent review.
- 5.5.2 Details of the various build stages and changes made to the model during this process are recorded within the Model Log, which is provided in Appendix E.

6 SENSITIVITY TESTING

6.1 General

- 6.1.1 Sensitivity analysis reveals which parameters the hydraulic model depends upon most for its accuracy. This information raises awareness of the risks associated with model uncertainties and helps inform decisions on the freeboard to be integrated within the development.
- 6.1.2 As part of the model production, the model's sensitivity to changing inflows and to the assumed impacts of Climate Change (estimated to be a 25-70% increase in flows over the 100-year expected development lifetime) have been tested. Flood depths and peak flows increase with higher model inflows (during less frequent storm events) and/or when the modelled impacts of climate change are considered, both in channel and on the floodplain. This is indicative of the model performing as expected. These results are summarised above in Chapter 5.
- 6.1.3 Additional sensitivities to be tested are introduced and detailed below.

6.2 Surface Roughness

- 6.2.1 The roughness of the channel varies with season, flood level and maintenance regime. Therefore, the Manning's values can change within an acceptable range over time. To assess the impact of this variance, the Manning's 'n' values chosen for the 1D channel and 2D floodplain have been globally increased and decreased by 20% respectively and the Q100 existing scenario re-run with these updated values.
- 6.2.2 The flood extents of each of the two surface roughness sensitivity tests have been mapped along with the existing Q100 flood extent. These show a similar extent to the normal scenario with flooding of the proposed development area occurring in the same areas for both sensitivity test outputs.
- 6.2.3 During the modelled scenario with increased surface roughness, the maximum stage and peak flows are shown to be higher and lower respectively when compared to the normal scenario. The opposite is true for the decreased surface roughness scenario. On this basis, it is considered that the normal scenario adopts a suitable middle ground for the potential roughness of the site throughout the development lifetime, with the results reflecting this middle ground. The results are summarised below in Table 8 and a plan showing the fluvial flood extents of both surface roughness tests against the existing Q100 extent is provided in Appendix H.

6.3 Downstream Boundary Condition

- 6.3.1 It is important to ensure that the downstream boundary of the model is set sufficiently downstream so as not to affect the model results at the site. To test that this is the case, the downstream channel section was raised and lowered by 200mm respectively for a Q100 fluvial flood event.
- 6.3.2 The flood extents of each of the two downstream boundary sensitivity tests have been mapped along with the existing Q100 flood extent. These show a similar extent to the normal scenario with similar flooding of the proposed development area for both sensitivity test outputs. A plan showing a comparison of the test results with the existing Q100 fluvial flood extents is provided in Appendix H
- 6.3.3 The maximum stage is shown to be higher and lower at Section 84 for the raised and lowered downstream boundary conditions respectively. The peak flow is shown to be lower and higher at Section 84 for the raised and lowered downstream boundary conditions respectively. At Section 84, the raised downstream boundary condition results in a very minor change to the maximum stage and peak flows but this has no impact on the proposed development area. Upstream of Section 84, the changed downstream boundary conditions have no impact on either maximum stage or peak flow. As a result, it can be considered that the downstream boundary is set sufficiently downstream of the site. The results of these sensitivity tests are summarised below in Table 8.

6.4 Culvert Blockage

- 6.4.1 The blockage of culverts can result in a rapid and unexpected increase in flood levels during a fluvial flood event.
- 6.4.2 The likelihood of a culvert blockage has been assessed based on upstream land use, stream morphology, stream vegetation, the size and shape of the culvert and the presence and design of a trash or security screen as recommended within BS 8533:2011. While the existing stream vegetation is dense, and this could form debris during a flood event, given the large size of the culvert, relative to the channel size, and the lack of a trash or security screen it is considered highly unlikely that a blockage of 10% or more would be possible.
- 6.4.3 Despite the low risk of blockage, we have modelled a 90% blockage of the two culverts to be retained (Structure6 and Structure7) cross-sectional areas during a Q100 fluvial flood event as a cautionary approach. This is in line with BS 8533:2011 guidance for culverts that are less than 1m².
- 6.4.4 Two separate models were setup to accurately simulate what impact the blockage of Structure6 and Structure7 would have on flood risk to the site. The first modelled the blockage at Structure 6 which flows underneath The Devil's Highway, that cuts through the southern area of the site (the road itself is not part of the site). The second modelled the blockage at Structure 7 which is the culvert located at the far south-western corner of the site and leads conveys flows offsite.
- 6.4.5 The flood extents of both culvert blockage scenarios have been mapped along with the existing Q100 flood extent. A comparison of the results shows both modelled blockages have increased flooding upstream of the respective culvert each scenario models. A plan has been prepared showing the existing Q100 and the two modelled culvert blockage scenarios fluvial flood extents in Appendix H.
- 6.4.6 As shown below in Table 8, the results show a slightly higher maximum stage upstream of the culvert entrance for both blockages modelled.
- 6.4.7 The same test was carried out on the proposed model to demonstrate the revised impacts on the post-development situation. The same approach was taken in-line with BS8533:2011. The flood extents of both culvert blockage scenarios have been mapped along with the proposed Q100 flood extent (See Appendix H). A comparison of the results shows no major difference from what was found in the existing culvert blockage tests. Therefore, the changes made in the proposed model will not have any detrimental impacts on the retained culverts. The maximum stage and peak flow results of the proposed model culvert blockages tests are provided below in Table 8.

6.5 Sensitivity Test Results

6.5.1 The results of these sensitivity tests are compiled in Table 8, below and compared to the proposed Q100 event as modelled without any sensitivity testing.

Table 8: Results of Sensitivity Testing

Flood Event	River Section	Max Stage (m AOD)	Peak Flow (m ³ s ⁻¹)
Q100	Section 84	49.104	1.4274
Q100 with +Manning Roughness		49.212	1.4424
Q100 with -Manning Roughness		48.977	1.4123
Q100 with +Downstream Boundary		49.31	1.4423
Q100 with -Downstream Boundary		48.887	1.3864
Ex_Q100 with Culvert Blockage (CB82)		48.641	0.5543
Ex_Q100 with Culvert Blockage (CB45)		49.108	1.4357
Pr_Q100 with Culvert Blockage (CB82)		48.631	0.544
Pr_Q100 with Culvert Blockage (CB45)		49.046	1.292
Q100	Section 15	53.055	0.81077
Q100 with +Manning Roughness		53.107	0.81128
Q100 with -Manning Roughness		52.993	0.83417
Q100 with +Downstream Boundary		53.054	0.81094
Q100 with -Downstream Boundary		53.055	0.81076
Ex_Q100 with Culvert Blockage (CB82)		53.055	0.81109
Ex_Q100 with Culvert Blockage (CB45)		53.055	0.8103
Pr_Q100 with Culvert Blockage (CB82)		55.163	0.284
Pr_Q100 with Culvert Blockage (CB45)		55.263	0.285
Q100	Section 36	51.54	1.6141
Q100 with +Manning Roughness		51.56	1.4961
Q100 with -Manning Roughness		51.488	1.6484
Q100 with +Downstream Boundary		51.54	1.6141
Q100 with -Downstream Boundary		51.54	1.614
Ex_Q100 with Culvert Blockage (CB82)		51.4	1.6141
Ex_Q100 with Culvert Blockage (CB45)		51.536	1.6165
Pr_Q100 with Culvert Blockage (CB82)		52.088	1.476
Pr_Q100 with Culvert Blockage (CB45)		52.088	1.476
Q100	RC_Section 31	53.036	0.40226
Q100 with +Manning Roughness		53.102	0.40219
Q100 with -Manning Roughness		52.961	0.40232
Q100 with +Downstream Boundary		53.036	0.40217
Q100 with -Downstream Boundary		53.036	0.40221
Ex_Q100 with Culvert Blockage (CB82)		53.036	0.40226
Ex_Q100 with Culvert Blockage (CB45)		53.036	0.40221
Pr_Q100 with Culvert Blockage (CB82)		53.007	0.335
Pr_Q100 with Culvert Blockage (CB45)		53.01	0.336

7 LIMITATIONS AND ASSUMPTIONS

7.1 Limitation: Downstream of Site Boundary

- 7.1.1 While the proposed development site has been fully surveyed by a suitably qualified topographic surveyor, access to the land downstream of the culvert which leads offsite was not possible because it is outside of the landowners control and not accessible via public footpaths. For this reason, we utilised the existing 1m resolution DTM LiDAR data and upstream cross sections to inform the channel cross sections in this area.
- 7.1.2 While this could result in minor inaccuracies in this area, the downstream boundary condition sensitivity tests demonstrate that the boundary is sufficiently far enough downstream to have no impact on flood risk at the development site itself.
- 7.1.3 The best available LiDAR data resolution was 1m. Typically, the LiDAR cell size should be less than half the model grid size, but this was not possible as the grid needed to be sufficiently small enough to accurately represent the narrow channel (<4.5m wide in places).

7.2 Assumption: Downstream Depth Boundary

- 7.2.1 The 1D downstream boundary is a normal depth boundary, which extends 40m downstream offsite. This was used in lieu of any other useable data to inform the boundary.

7.3 Assumption: Robinson Crusoe Upstream Culvert

- 7.3.1 The culvert at the upstream end of Robinson Crusoe ditch was not modelled due to a lack of survey information. Instead the existing model starts at the first surveyed cross section approximately 20m downstream.

8 CONCLUSION

- 8.1.1 This Hydraulic Modelling Report has been prepared by **jnp group** for Legal & General Homes in support of the proposed development of land at Hogwood Farm, Finchampstead in Wokingham (south of Arborfield Garrison).
- 8.1.2 The Hydraulic Modelling project follows guidance within the EA's 2008 'Requirements for completing computer river modelling for Flood Risk Assessments' document and the 2011 British Standards BS8533:2011 (Assessing and Managing Flood Risk in Development – Code of Practice).
- 8.1.3 The EA confirmed that they do not have any modelled fluvial flood data for the watercourses which run through the site (Hogwood and Robinson Crusoe Ditch). The hydraulic modelling project was therefore required to assess the risk of fluvial flooding to the site in detail.
- 8.1.4 The detailed hydraulic modelling has shown that the majority of the modelled watercourses floodplain is located in the southern and central areas of the site. These areas are not proposed to be developed into residential or any other forms of property but will be amenity natural space or SANGs. Therefore, no risk is posed to people or property in the event of these areas flooding. However, the modelling did also show that there are a few areas of proposed residential land within the existing watercourses floodplain. These areas were found to flood during the Q1000 and Q10070CC events. Although, the depth of flooding in these areas was found to be shallow, it will still restrict the developable area meaning that the current scale of development as per the allocation within the Master plan cannot be accommodated.
- 8.1.5 To facilitate the safe development of the proposed residential areas, the removal of all non-essential culverts, existing of an existing culvert at the upstream end of Robinson Crusoe Ditch, modification of the watercourses inflows to represent post development runoff rates and lowering the bank level along the stretch of Robinson Crusoe Ditch which flooded the development area to centralise the floodplain are proposed.
- 8.1.6 The modelled watercourses were updated within to represent the proposed alterations and the proposed model was run using the same scenarios as the existing. The results of the modelling demonstrated that there will be no fluvial flooding in the development areas for all events up to and including the Q1000 scenario.
- 8.1.7 A comparison of the results revealed that the in-channel peak flow and the maximum stage (water level) are both reduced immediately downstream of the site for the modelling on the proposed floodplain when compared with the modelling on the existing land/floodplain. Therefore, the modelling suitably demonstrates that there will be a reduction in fluvial flood risk both on and off site (downstream of site boundary) following the proposed alternations to the watercourses.
- 8.1.8 Sensitivity tests were carried out on the model to assess whether the downstream boundary of the model is sufficiently far away from the area of interest to have negligible impacts on the modelling results and the effects that increased/decreased land roughness and culvert blockage will have on the flood risk posed to the site. The results demonstrate that the downstream boundary is set sufficiently downstream of the site and that the effects of culvert blockage and land roughness changes would not cause any increased flood risk to the developable areas.
- 8.1.9 In conclusion, the hydraulic modelling demonstrates the fluvial flood risk to the site and that the proposed removal of culverts and extension of the existing upstream Robinson Crusoe will sufficiently offset the fluvial flood risk to the development site without having detrimental effects further downstream or offsite.

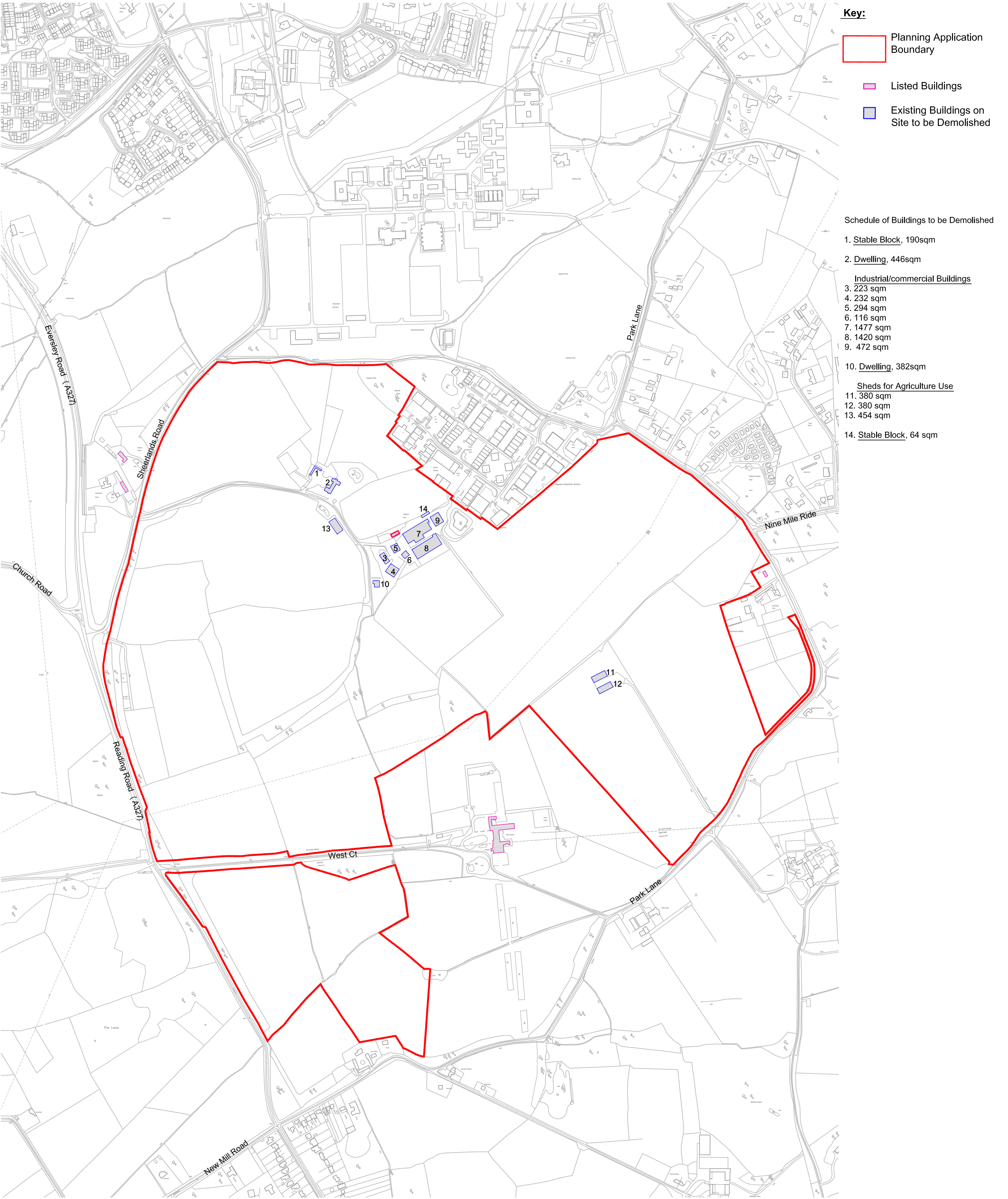
Appendix A: Site Location Plan



Hogwood Garden Village

Part of the Arborfield Garrison Strategic Development Location, Wokingham

Existing Buildings on Site to be Demolished



Appendix B: Site Topographic Survey

