JBA consulting

Surface Water Modelling Study at YMCA 90 Peartree Lane

Final report

May 2020

www.jbaconsulting.com

Pinnacle Consulting Engineers
Alchemy
Bessemer Road
WELWYN GARDEN CITY
Buckinghamshire
AL7 1HE

PINNACLE
CONSULTING ENGINEERS

JBA Project Manager

Olivier Saillofest
The Library
St Philips Courtyard
Church Hill
Coleshill
Warwickshire
UNITED KINGDOM
B46 3AD

Revision History

Revision Ref/Date	Amendments	Issued to
S3-P01 / Mar. 20	Draft Report	Iran Limbu, Pinnacle Consulting Engineers.
A1-P01 / Apr. 20	Final Report	Iran Limbu, Pinnacle Consulting Engineers.
A1-P02 / Apr. 20	Final Report (following client comments)	Iran Limbu, Pinnacle Consulting Engineers.
A1-P03 / May. 20	Final Report (following client comments)	Iran Limbu, Pinnacle Consulting Engineers.
A1-P04 / May. 20	Final Report (following client comments)	Iran Limbu, Pinnacle Consulting Engineers.

Contract

This report describes work commissioned by Pinnacle Consulting Engineers by an e-mail dated 17 February 2020. Pinnacle Consulting Engineers' representative for the contract was Iran Limbu. Ella Albrighton of JBA Consulting carried out this work.

Prepared by .... Ella Albrighton BSc

Technical Assistant

Reviewed by .... Olivier Saillofest BEng MSc CEng MCIWEM C.WEM

Technical Director

Purpose

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JBA is aiming to reduce its per capita carbon emissions.

Executive summary

Pinnacle Consulting Engineers commissioned JBA Consulting to assess surface water flood risk in relation to a proposed development site at YMCA Peartree Lane, Welwyn Garden City.

A rainfall-runoff model was created using the ESTRY-TUFLOW software to represent surface water flood mechanisms, calculate flood levels and assess the impact of the proposal. The model was run for the 30-year (3.3% AEP), 100-year (1% AEP), 100-year plus 40% climate change (1.4% AEP) and 1,000-year (0.1% AEP) rainfall-runoff events using the 1-hour critical (summer) storm duration.

The baseline model results indicate that

- The proposed development site is partially at risk of flooding from the 30-year, 100-year, 100-year plus 40% climate change and the 1,000-year storm events;
- During the 100-year plus 40% climate change event, with water pooling towards the western side of the site. Maximum flood depths of 0.62m occurs along the western site boundary;
- Flood levels within the site during the 100-year plus 40% climate change event are between 83.00m AOD and 83.75m AOD;
- Results from the sensitivity analysis indicate that the model results within the site are relatively insensitive to changes in roughness values.

The impact of the proposal was modelled during the 100-year with (+40%) climate change storm event. Post-development model results indicate that:

- The proposal will generate no detrimental impacts across third-party land.
- The proposal will reduce flood risk third-party land located to the north-east of the site.
- The peak water levels along the proposed buildings vary between 83.01 and is 83.89m, as shown in Figure 0-1.

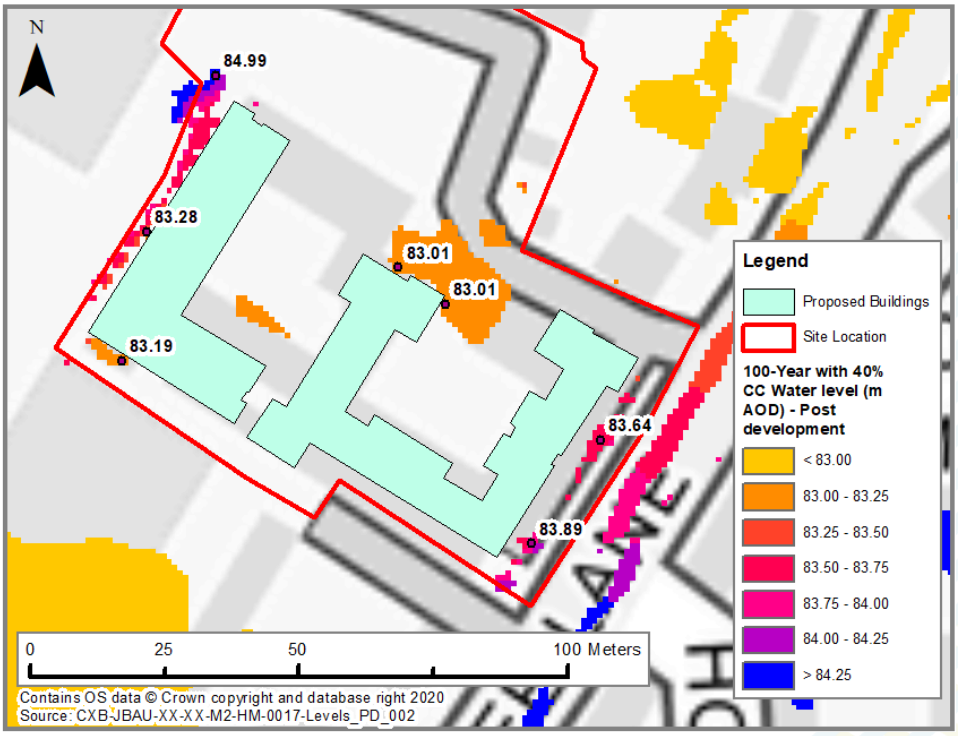

Figure 0-1: Model extent

It is recommended that results from this hydraulic modelling study are submitted to the Lead Local Flood Authority for validation prior to planning submission.

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Abbreviations

2D	Two Dimensional
CC	Climate Change
DTM	Digital Terrain Model
EA	Environment Agency
ESTRY	Primary 1D engine used by TUFLOW.
FEH	Flood Estimation Handbook
FFL	Finished Floor Levels
GCS	Grantham Coates Surveyors
Ha	Hectares
HQ	Head-Flow
JBA	Jeremy Benn Associates
LiDAR	Light Detection and Ranging
m AOD	Metres Above Ordnance Datum
QMED	Median annual flow
QT	Flow-Time
ReFH	Revitalised Flood Hydrograph
TUFLOW	2D Hydraulic Modelling Software

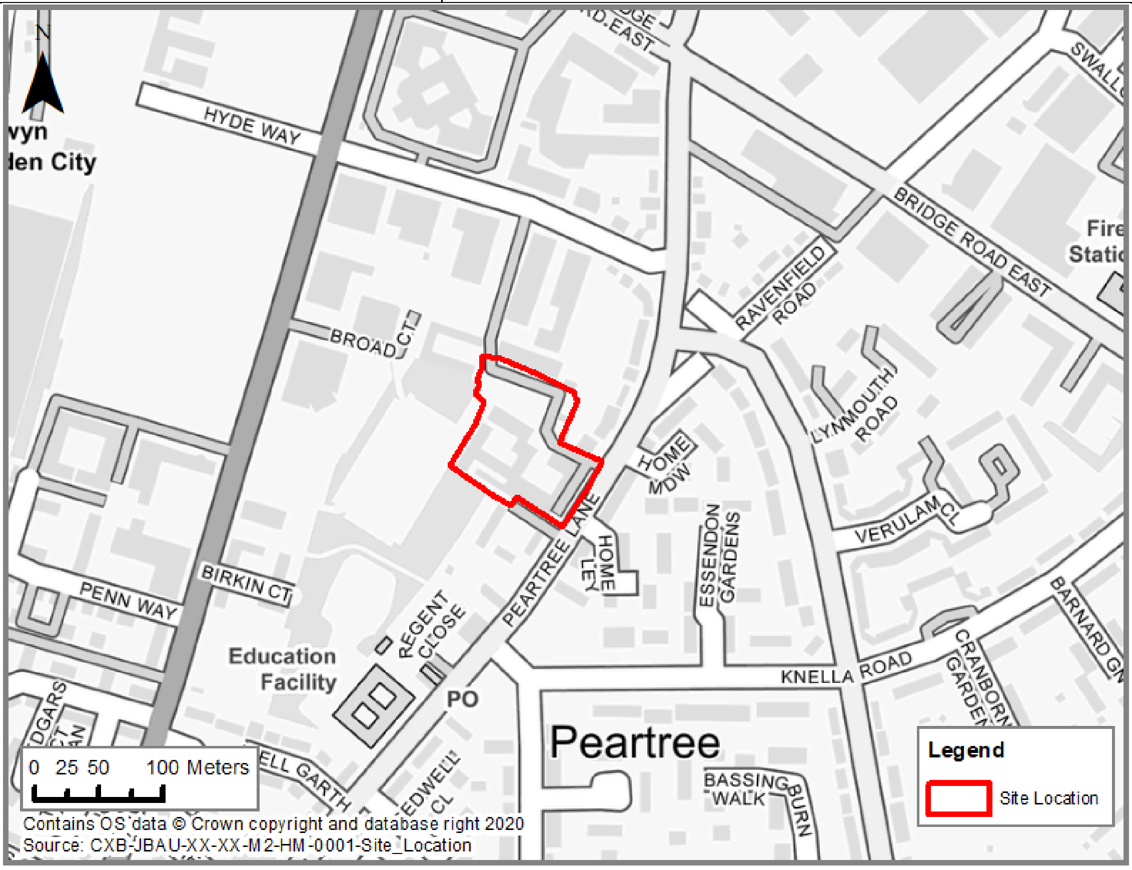
1 Introduction

1.1 Terms of reference

JBA Consulting (JBA) were commissioned by Pinnacle Consulting Engineers to undertake a surface water modelling study in relation to a proposed development site at 90 Peartree Lane, Welwyn Garden City.

1.2 Site details

Table 1-1: Site details	
Site name	One YMCA 90 Peartree Lane, Welwyn Garden City
Site area	0.86ha
Existing land-use	Brownfield
OS NGR	TL 24423 12577
County	Hertfordshire
Country	England



1.3 Site description

The proposed development is off Peartree Lane, Welwyn Garden City and is currently occupied by hardstanding areas used for parking with a number of buildings in use on the site.

1.4 Existing flood data

It is our understanding the that the Environment Agency's RoFSW maps in relation to the site originates from broadscale modelling and does not account for the high capacity of the drainage network along Broadwater lane. Therefore, JBA Consulting has been commissioned to carry out a surface water modelling study in relation to the proposed development site.

1.5 General Approach

To support this assessment, a hydrological assessment was carried out to derive rainfall hyetographs and a 2D TUFLOW hydraulic model was produced to allow the accurate representation of flood depths, velocity and hazard within the site boundary.

The hydraulic model's sensitivity to roughness values was tested to improve confidence in the model results within the development site boundary.

2 Model approach

2.1 Model geometry

2.1.1 Data availability

LiDAR data was obtained from the Open Data website to represent ground levels within the floodplain. The LiDAR has a grid resolution of 1m and was last flown in 2011. To provide greater levels of detail, site topographic survey was also converted into a DTM and read into the model. The site topographic survey was collected by Malcom Hughes Chartered Land Surveyors in July 2019 and is included in Appendix A.

2.1.2 Input data quality assessment

Site topographic survey data collected by Malcolm Hughes Chartered Land Surveyors was compared with the 2011 LiDAR data (Appendix B). Overall, results show a good correlation between both datasets across most of the site. As a result, both datasets have been used in the simulation.

2.1.3 Model extend and build

The hydraulic model represents the surface water floodplain in the vicinity of the proposed site. The extent of the hydraulic model built is shown in Figure 2-1.

The 2D domain was built using TUFLOW (2018-03-AE-iDP-W64), LiDAR data and topographic survey data provided by the client. The 2D domain has an area of 52ha and a 2m grid resolution. The 2D domains can be seen in Figure 2-1.

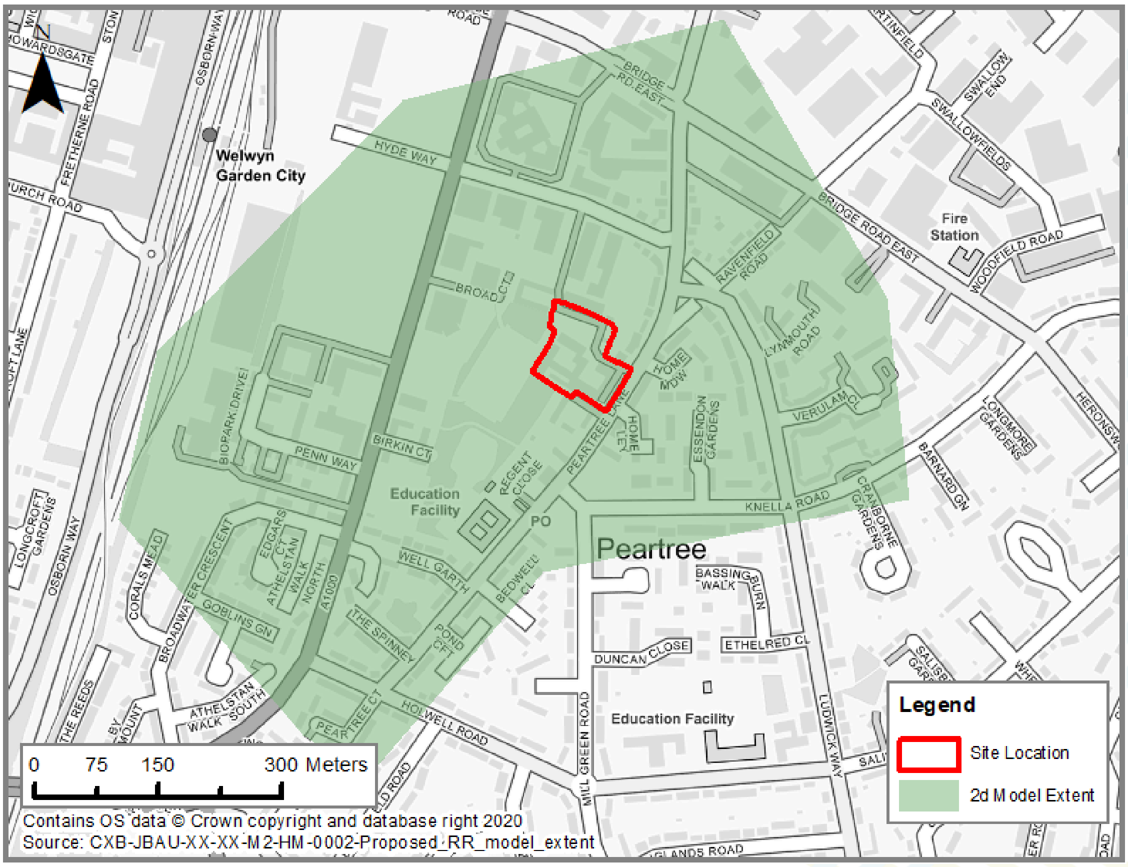


Figure 2-1: Model extent

2.1.4 Model roughness parameters

Manning's *n* was used to represent roughness values for the floodplain. Manning's *n* values in the floodplain were based on different land uses in the 2D domain. Land uses were defined using OS mapping and satellite imagery. Table 2-1 gives the range of Manning's *n* values used in the 2D domain.

Table 2-1: Manning's *n* range within the hydraulic model

General Surface	0.050
Less dense woodland	0.070
Dense woodland	0.100
Hedges	0.080
Roads and footpaths	0.025
Gravel roads	0.035
Buildings	0.300
Water	0.020
Rail	0.060

2.2 Model boundary conditions

2.2.1 Model inflows

A hydrological assessment was carried out to derive inputs for the surface water modelling. The hydrological assessment is documented in Appendix C.

Rainfall hyetographs for the 30-year (3.3% AEP), 100-year (1% AEP) and 1,000-year (0.1% AEP) flood events were generated by the ReFH2 rainfall-runoff model.

In line with the Environment Agency's guidance for rainfall-runoff modelling, a runoff coefficient of 70% (chosen for urban areas) was applied to the rainfall hyetographs and 18mm/hr has been subtracted from each time interval to account for the local drainage system. The revised rainfall hyetographs were then applied over the 2D hydraulic model domain.

In line with the new Guidance on Climate Change issued by the Environment Agency in February 2016[3], the effect of climate change was assessed by increasing the peak rainfall by 40% (Upper end allowance for the 2080s epoch).

Figure 2-2 below shows the extent of the flooding during the 100-year event during each of the storm durations tested.

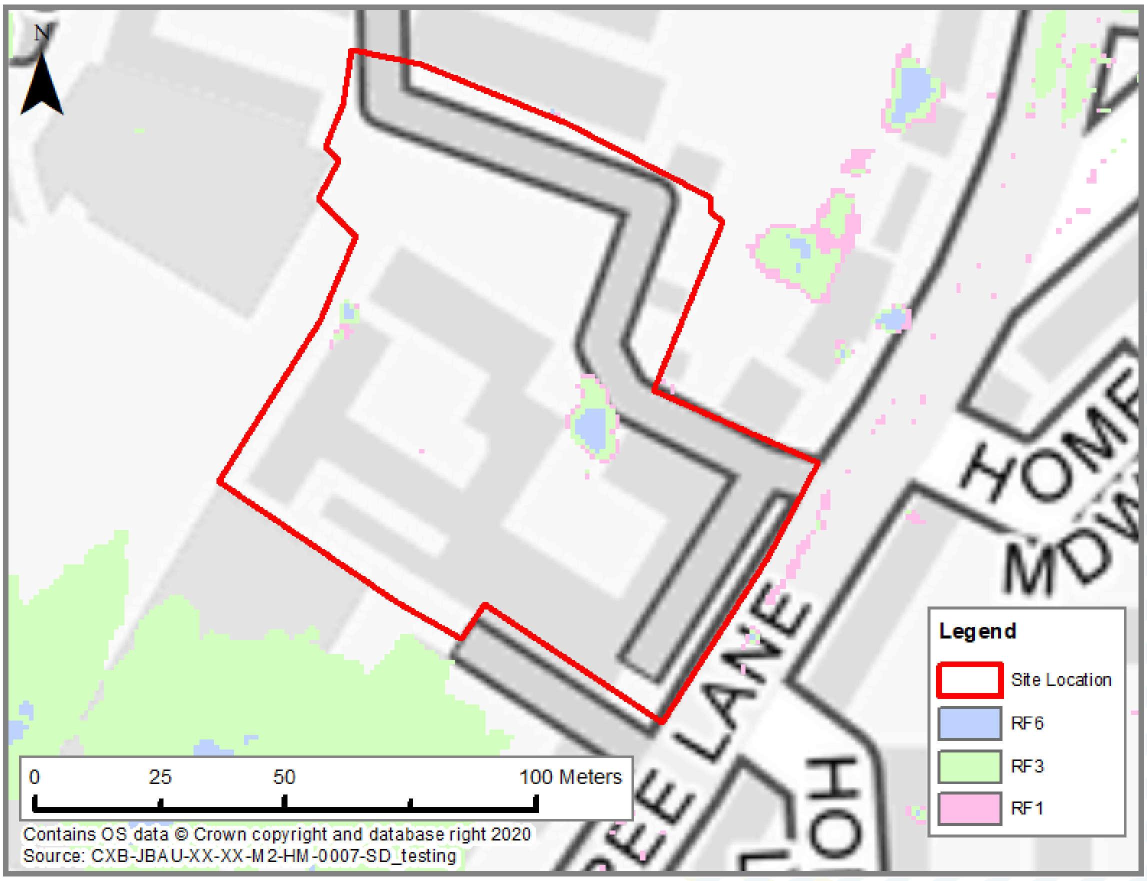


Figure 2-2: Storm duration test

Rainfall was estimated for a 1-hour, 3-hour and 6-hour storm duration for each event. A review of the initial model results indicated that the 1-hour storm duration generated the largest flood extents on site.

2.2.2 Downstream boundary conditions

In the 2D domain, one HQ line based on the average slope in the floodplain downstream was used to represent the downstream boundary conditions in the floodplain/2D domain.

2.3 Calibration

No specific flood levels or flow data could be found over the modelled extent. As a result, the model is uncalibrated.

2.4 Model Runs

2.4.1 Modelled Scenarios

The following flood scenarios were simulated by the model:

- **[Baseline scenario]** 30-year (3.3% AEP) flood event - existing condition scenario
- **[Baseline scenario]** 100-year (1% AEP) flood event - existing condition scenario
- **[Baseline scenario]** 100-year (1% AEP) plus Climate Change (40%) flood event - existing condition scenario
- **[Baseline scenario]** 1000-year (0.1% AEP) flood event - existing condition scenario
- **[Sensitivity analysis]** 100-year (1% AEP) flood event with +20% increase in roughness value
- **[Post Development scenario]** 30-year (3.3% AEP) flood event – proposed development scenario
- **[Post Development scenario]** 100-year (1% AEP) flood event - proposed development scenario
- **[Post Development scenario]** 100-year (1% AEP) plus Climate Change (40%) flood event - proposed development scenario
- **[Post Development scenario]** 1000-year (0.1% AEP) flood event - proposed development scenario.

3 Model validation

To confirm the validity of the model results and ensure the model is fit for purpose, the surface water modelling results were compared with the EA's Risk of Flooding from Surface Water (RoFfSW) maps in two return periods.

3.1 Comparison with the EA's 30-year surface water map

Figure 3-1 shows the EA's 30-year surface water extent compared to the 30-year surface water extent modelled as part of this study.

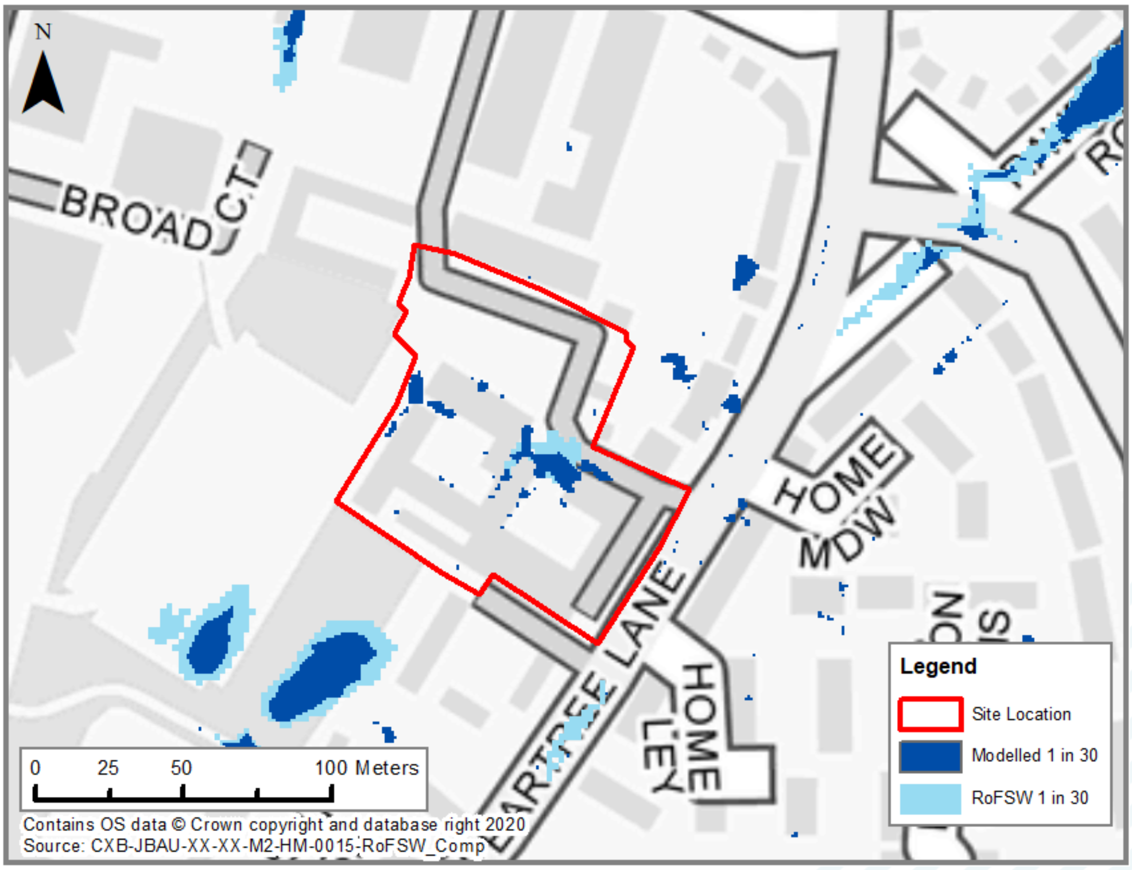


Figure 3-1: 1 in 30-year comparison

Figure 3-1 illustrates that in a 30-year surface water flooding event the model results and the EA's RoFSW show different flood extents surrounding the proposed site. The detailed model results show smaller flood extents than the EA surface water flood extents. This is due to the inclusion of a site topographic survey which will improve the accuracy of the ground levels when modelling the flood extent for the 1-hour storm event and the increase of rainfall captured within the local drainage system.

3.2 Comparison with the EA's 1 in 100-year surface water extent

Figure 3-2 shows the EA's 100-year surface water extent compared to the 100-year surface water extent modelled as part of this study.

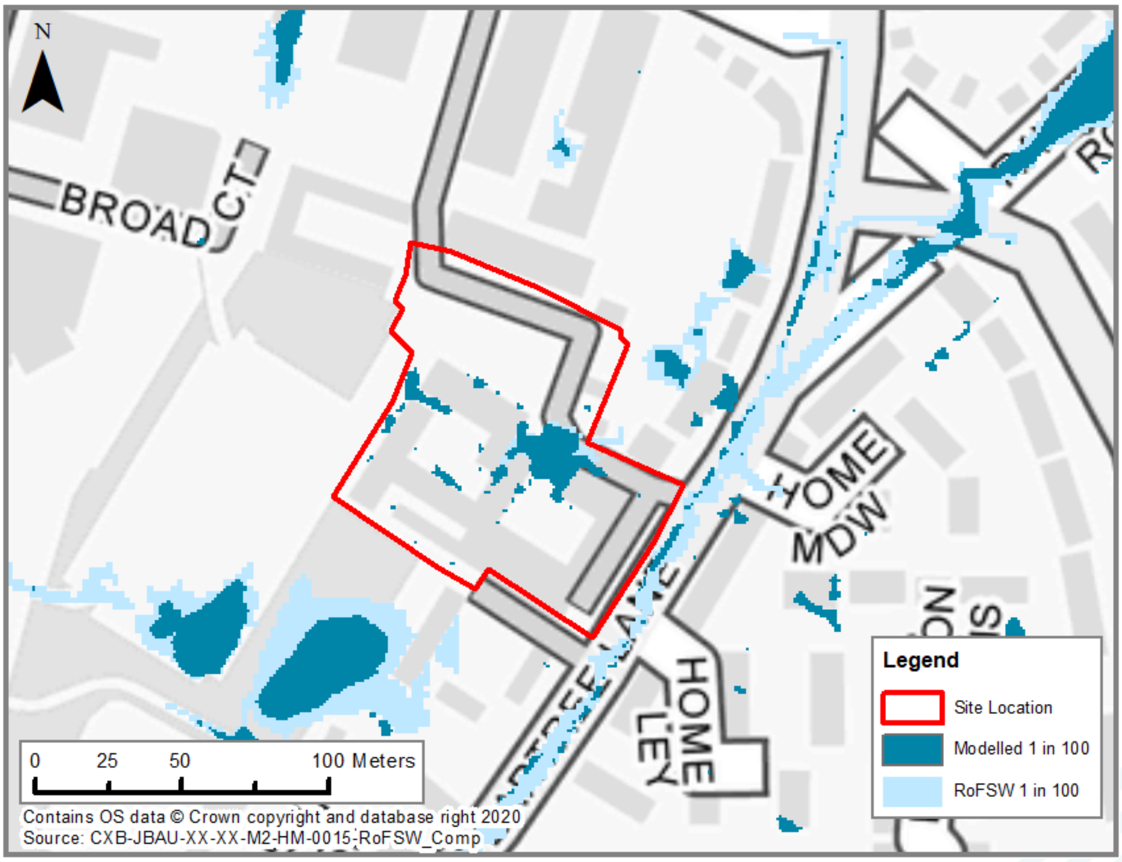


Figure 3-2: 1 in 100-year comparison

Figure 3-1 and Figure 3-2 indicate that the hydraulic modelling is able to provide reliable results and the model results are comparable with the EA's data. This model has the capacity to support the flood risk study in this project.

4 Hydraulic model results

4.1 Existing conditions/baseline scenarios

4.1.1 Flood extents

Figure 4-1 shows the baseline modelled surface water flood extents at the site.

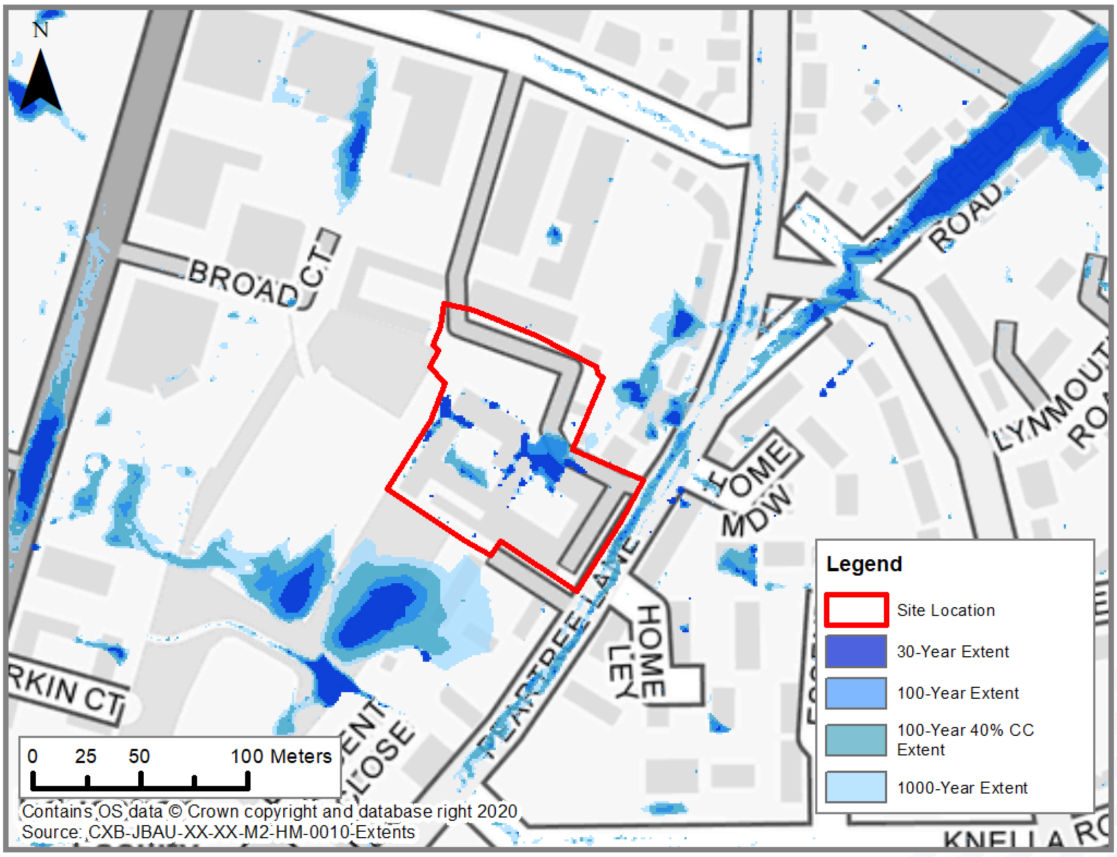


Figure 4-1: Baseline flood extents

Figure 4-1 shows that the surface water flooding within the site is from the 30-year event. It also shows that there is a depression south of the site which attenuates some of the surface water.

4.1.2 Flood depths

Figure 4-2 shows the depth of flooding within the site during the 100-Year with 40% climate change event for the baseline scenario.

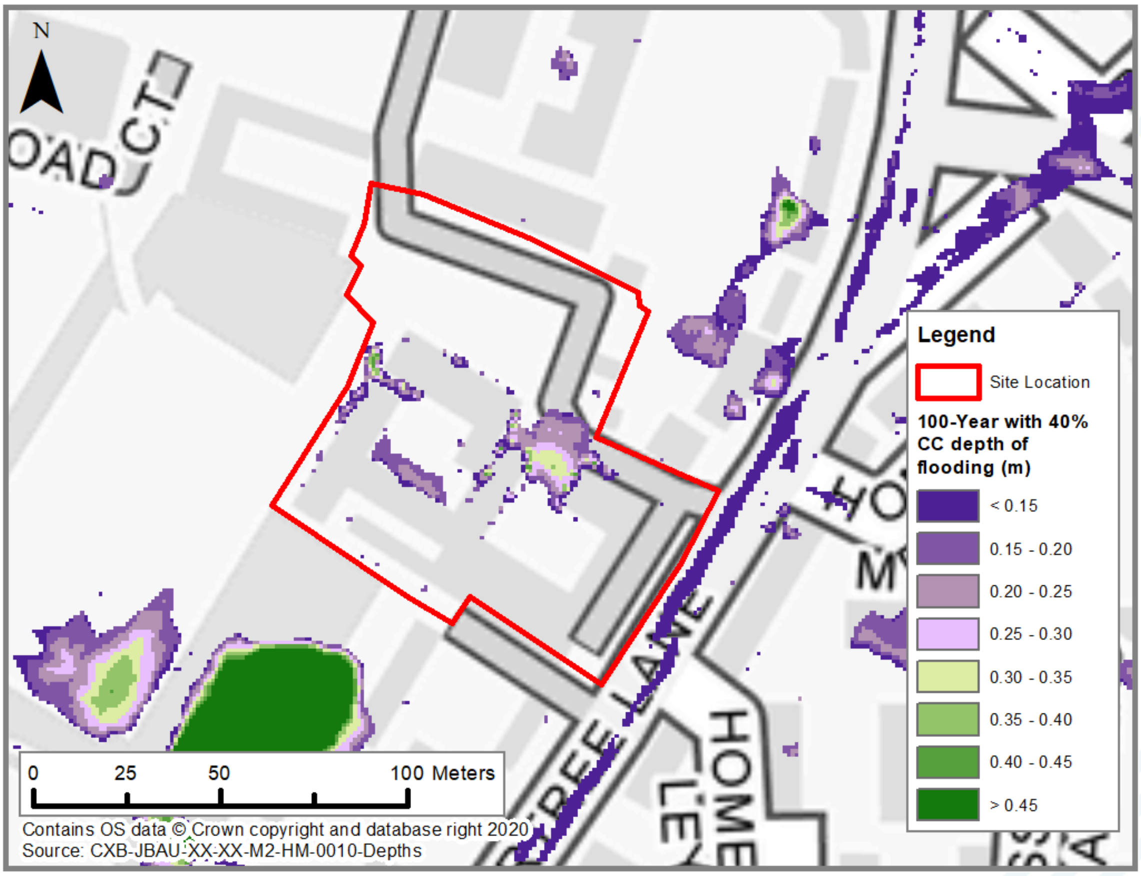


Figure 4-2: Baseline flood depths

Figure 4-2 shows that within the site the surface water flooding is mostly within the central areas of the site, around the existing buildings. The greatest depth within the site is 0.45m, which can be found within the area of deeper flood depths within the western area of the site. Within the centre of the site the greatest depth of flooding is 0.42m.

4.1.3 Flood levels

Modelled flood levels within the site boundary for the 100-year plus 40% climate change event are represented in Figure 4-3 below.

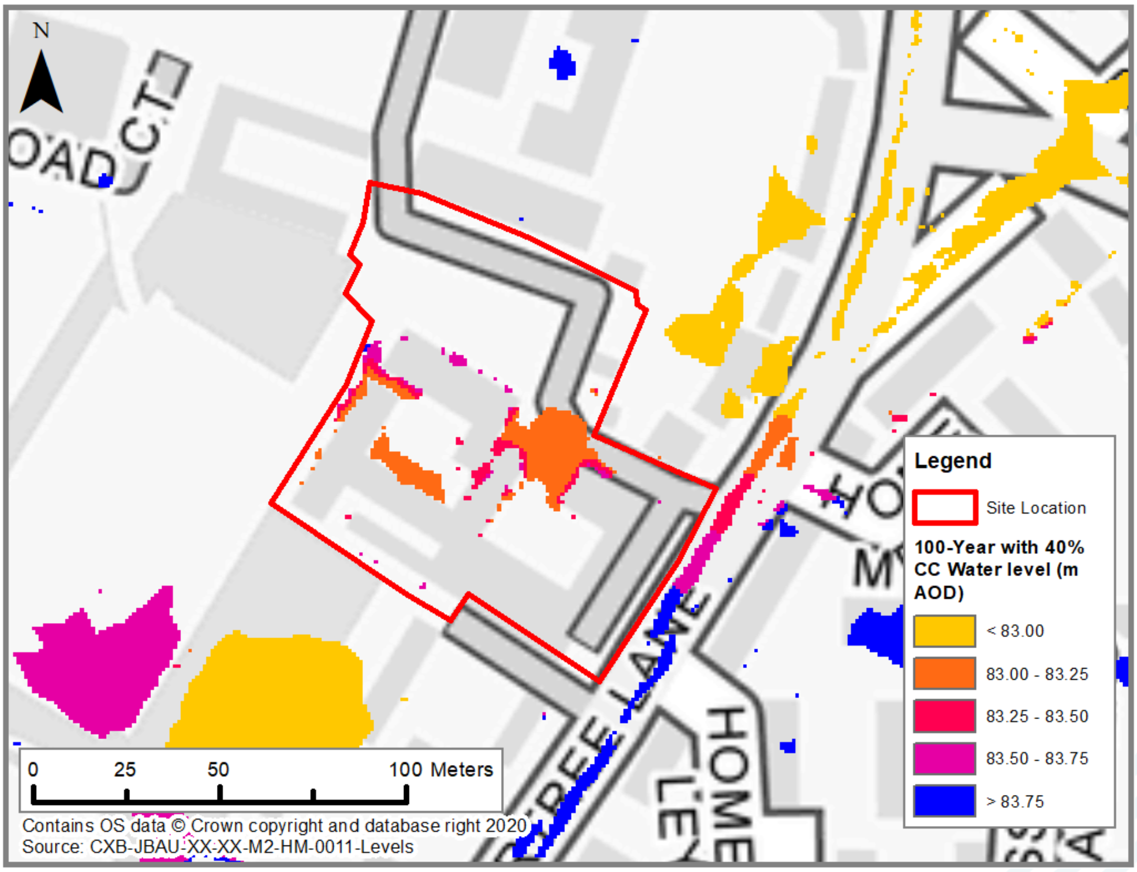


Figure 4-3: Baseline water levels

The maximum flood levels within the site during the 100-year plus 40% climate change event are approximately 83.95m AOD, this is found within the area of blue along the western boundary of the site.

4.2 Post-development

The post-development scenario has been modelled with the proposed buildings represented as being raised by 10m in order to 'glass wall' the development, representing the worst-case scenario within the site.

4.2.1 Flood extents

The extent of the flooding within each of the modelled return periods in the post-development scenario is shown within Figure 4-4 below.

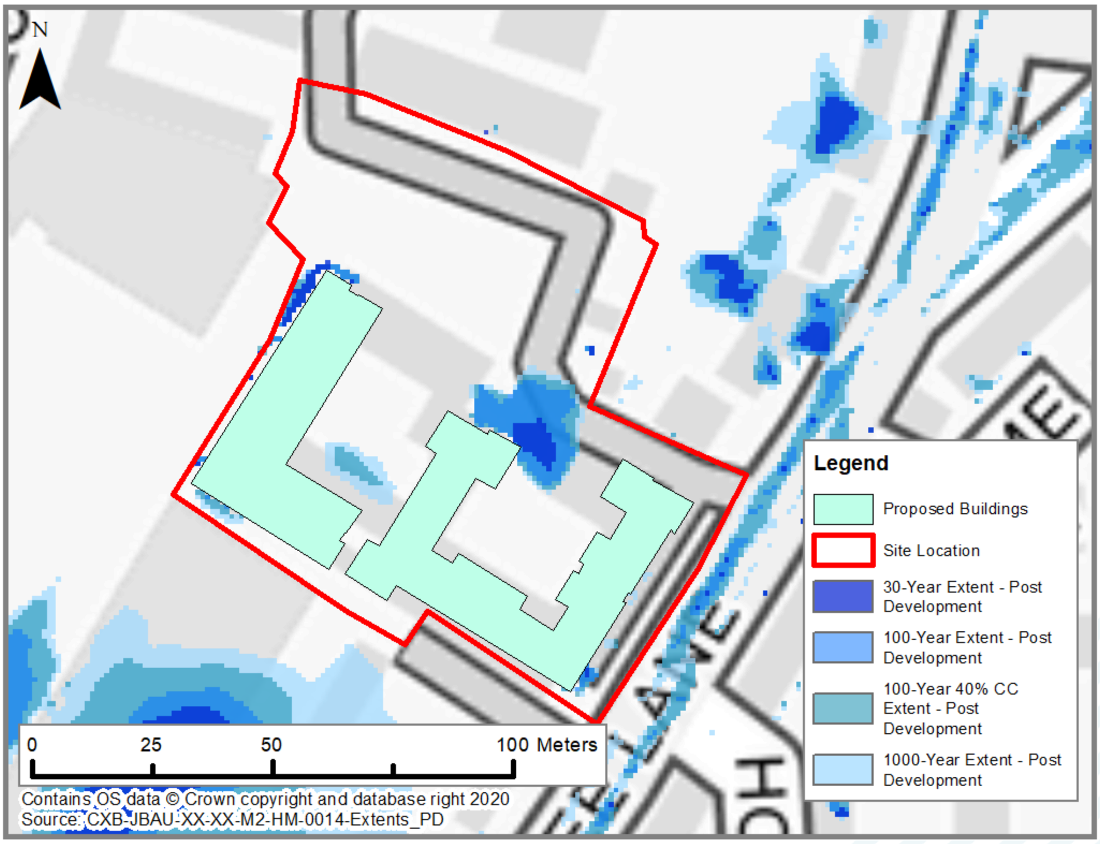


Figure 4-4: Post development flood extents

4.2.2 Flood depths

Figure 4-5 shows the depths of flooding within the site during the 100-year with 40% climate change event.

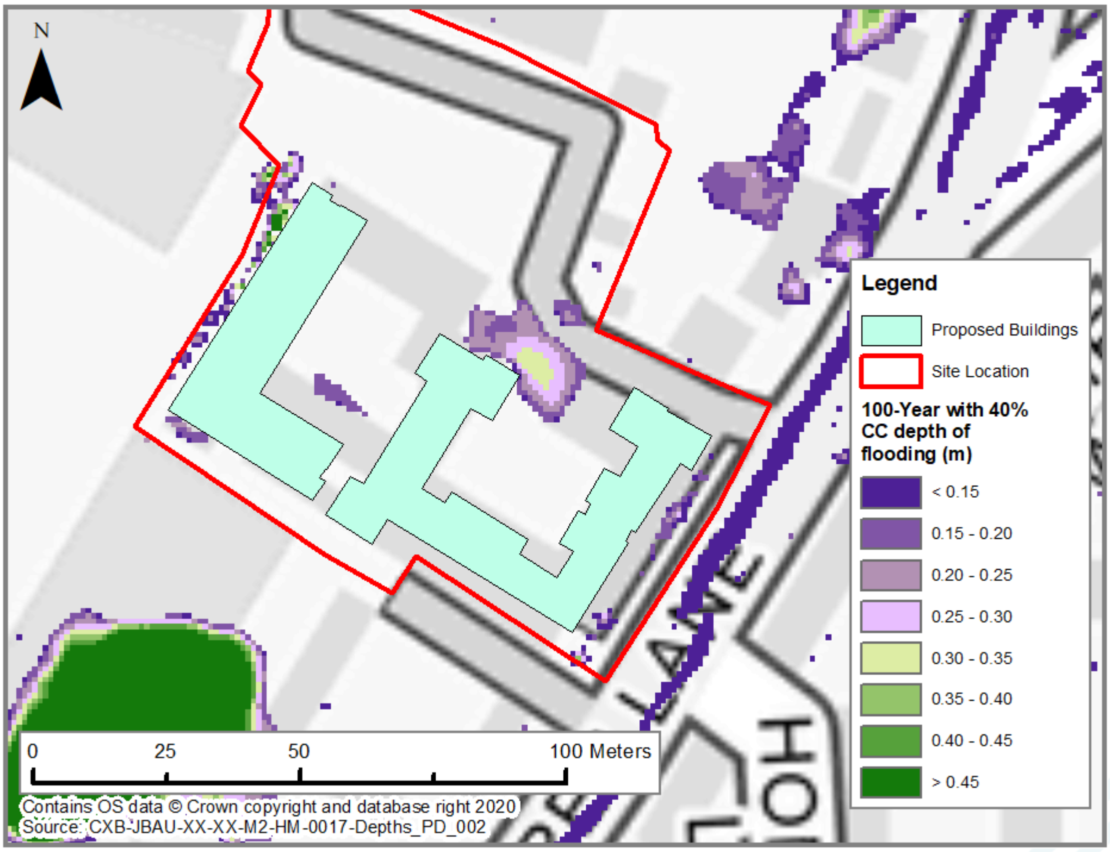


Figure 4-5: Post development flood depths

Figure 4-5 shows that the maximum flood depth within the site is located along the western boundary along the edge of one of the proposed buildings (0.62m), in the centre of the site the maximum depth of flooding is 0.34m.

4.2.3 Flood levels

Figure 4-6 shows the level of the surface water flooding within the site during the post-development 100-year with 40% climate change event.

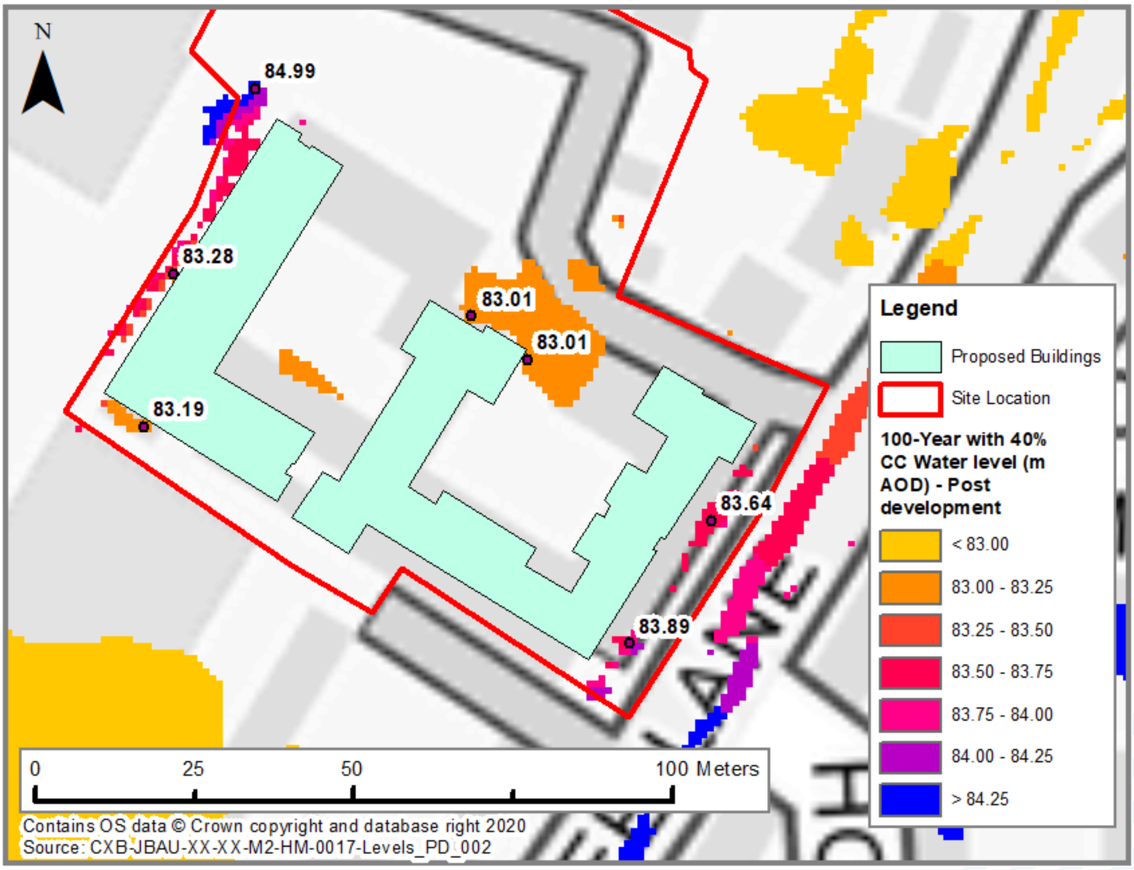


Figure 4-6: Post development water levels

The maximum water level on site, 84.99m AOD, occurs along the north-eastern site boundary, away from the proposed buildings and thus will not be taken into consideration as part of the design.

The peak water levels along the proposed buildings vary between 83.01 and is 83.89m.

4.2.4 Impact of proposal

The impact on flood depths from the proposal has been assessed for the 100-year with 40% climate change.

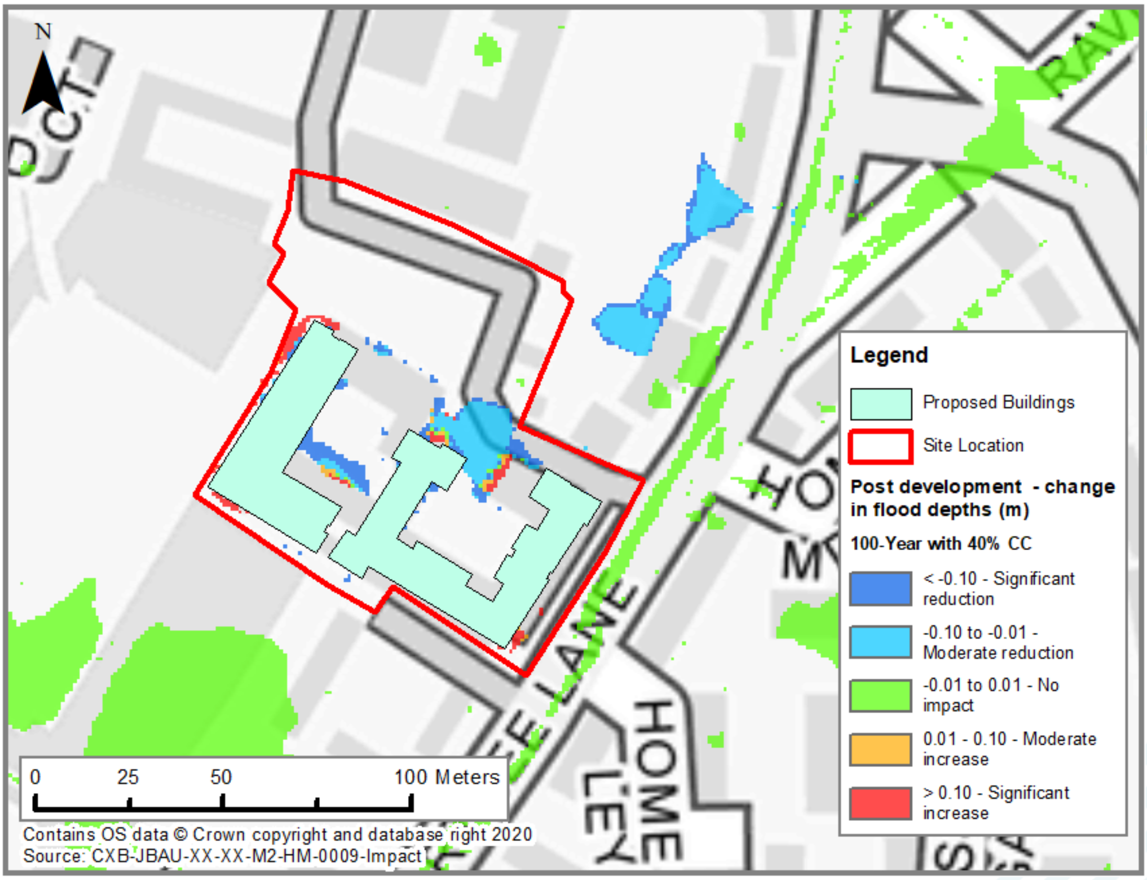


Figure 4-7: Post-development impact

Figure 4-7 shows that the proposed development does not have a detrimental impact on third-party land, there is in an area to the north of the site in which there is a significant reduction in the depth of flooding as a result of the proposed buildings.

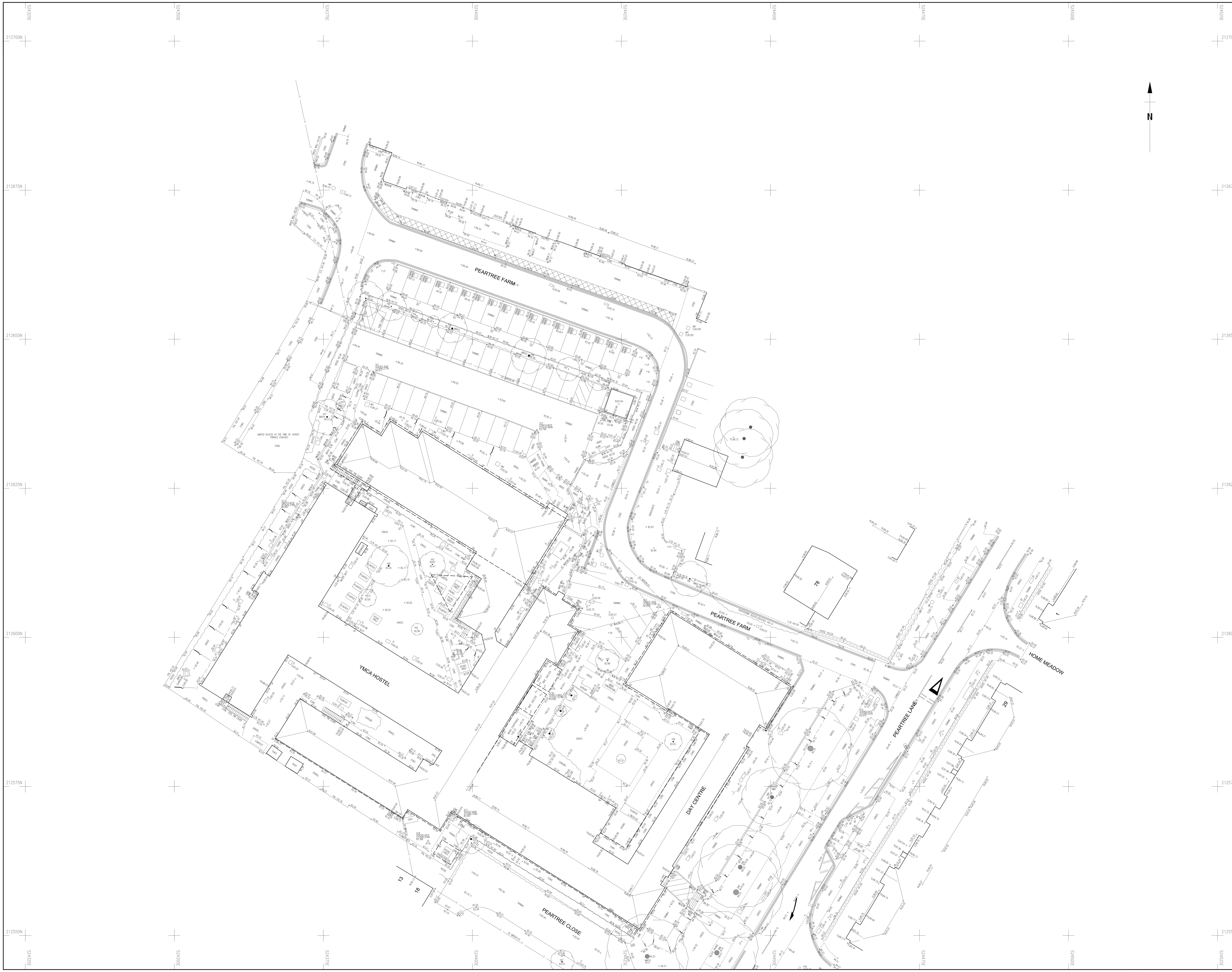
Within the site there are some areas with an increase in flooding, the area which has the maximum depth of flooding in Figure 4-5 has an increase in flood depth from the baseline.

5 Conclusions and Recommendations

- Pinnacle Consulting Engineers commissioned JBA Consulting to assess surface water flood risk in relation to a proposed development site at YMCA Peartree Lane, Welwyn Garden City.
- A rainfall-runoff model was created using the ESTRY-TUFLOW software to represent surface water flood mechanisms, calculate flood levels and assess the impact of the proposal. The model was run for the 30-year (3.3% AEP), 100-year (1% AEP), 100-year plus 40% climate change (1.4% AEP) and 1,000-year (0.1% AEP) rainfall-runoff events using the 1-hour critical (summer) storm duration.
- The baseline model results indicate that
  - The proposed development site is partially at risk of flooding from the 30-year, 100-year, 100-year plus 40% climate change and the 1,000-year storm events;
  - During the 100-year plus 40% climate change event, with water pooling towards the western side of the site. Maximum flood depths of 0.62m occurs along the western site boundary;
  - Flood levels within the site during the 100-year plus 40% climate change event are between 83.0m AOD and 84.48m AOD;
  - Results from the sensitivity analysis indicate that the model results within the site are relatively insensitive to changes in roughness values.
- The impact of the proposal was modelled during the 100-year with (+40%) climate change storm event. Post-development model results indicate that:
  - The proposal will generate no detrimental impacts across third-party land.
  - The proposal will reduce flood risk third-party land located to the north-east of the site.
  - The peak water levels along the proposed buildings vary between 83.01 and is 83.89m.
- It is recommended that the drainage system along the north-western side of the proposed western building is adequately sized/designed to prevent the build-up of surface water.
- It is recommended that results from this hydraulic modelling study are submitted to the Lead Local Flood Authority for validation prior to planning submission.

Appendices

A Appendix A – Topographic Survey



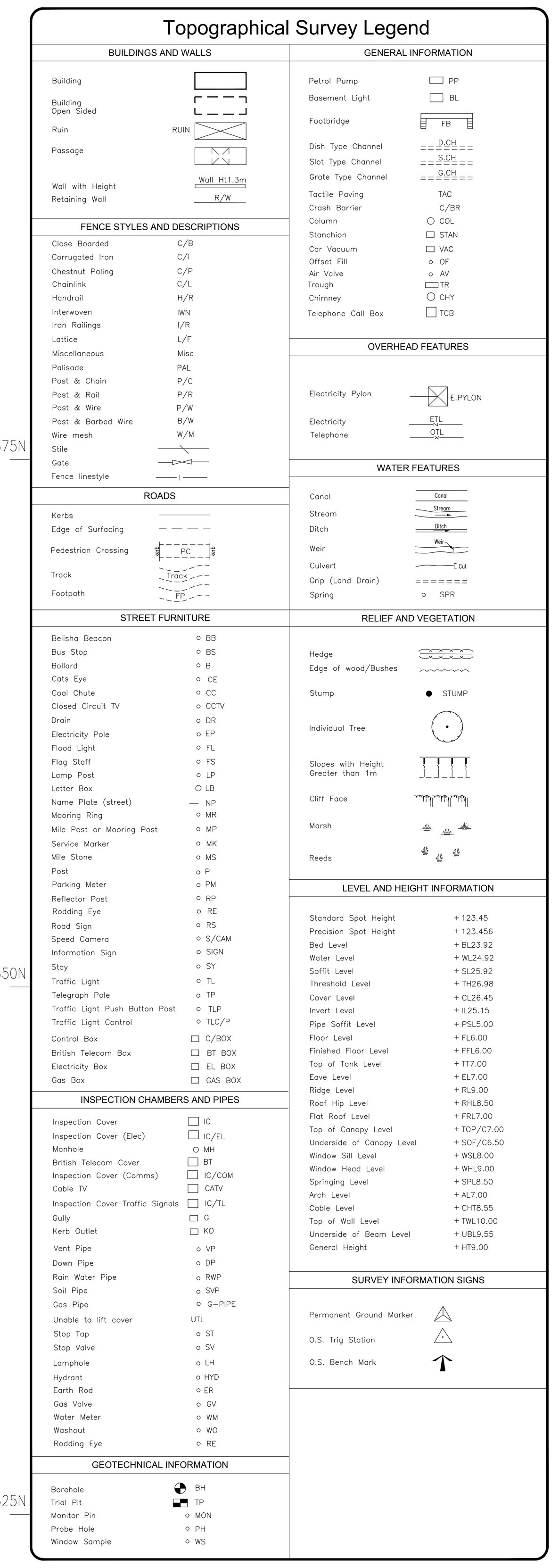
Survey Notes

Grid: Local, plane, metric fixed to National Grid fixed at Stn SC5

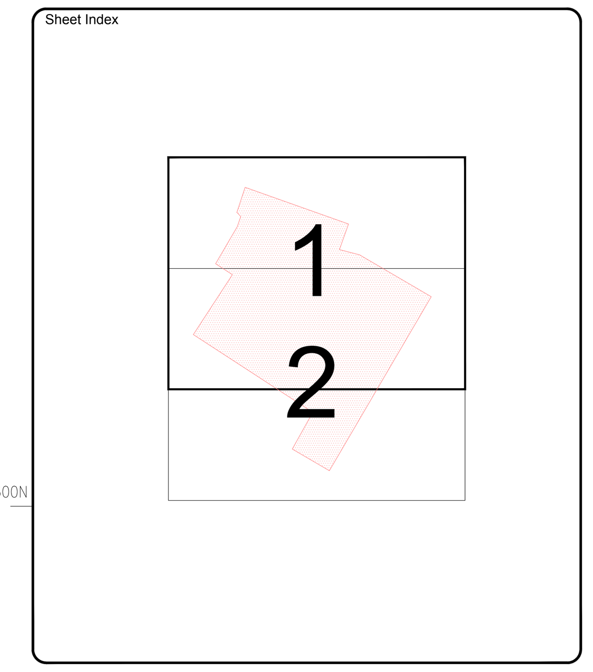
Levels: OS datum from GNSS positioning converted using the National Geoid Model OSGM15

Notes

Topographical Survey Legend



Sheet Index



Rev.	Date	Description

MALCOLM HUGHES
CHARTERED LAND SURVEYORS

65 Cross Street, Sale, Manchester
M33 7HF, Tel: 0161 905 1265
www.malcolmhughes.co.uk
survey@mhls.co.uk

Accreditations

RICS · THE SURVEY ASSOCIATION · chartered ices · RISQS QUALIFIED · bsi ISO 9001 Quality Management FS 14126

Client

SAUNDERS PARTNERSHIP
STUDIO FOUR, 37 BROADWATER ROAD
WELWYN GARDEN CITY, AL7 3AX

Project

ONE YMCA, PEARTREE LANE
WELWYN GARDEN CITY
AL7 3UL

Drawing Title

TOPOGRAPHICAL SURVEY

Drawn By	CPT	28/07/19
Checked by	SC	28/07/19
Survey Date	June 2019	
Scale	1:200 @ A0	

Drawing No: 53948-1

Revision:

B Appendix B – Quality Assessment

B.1 Topographic survey vs. LiDAR

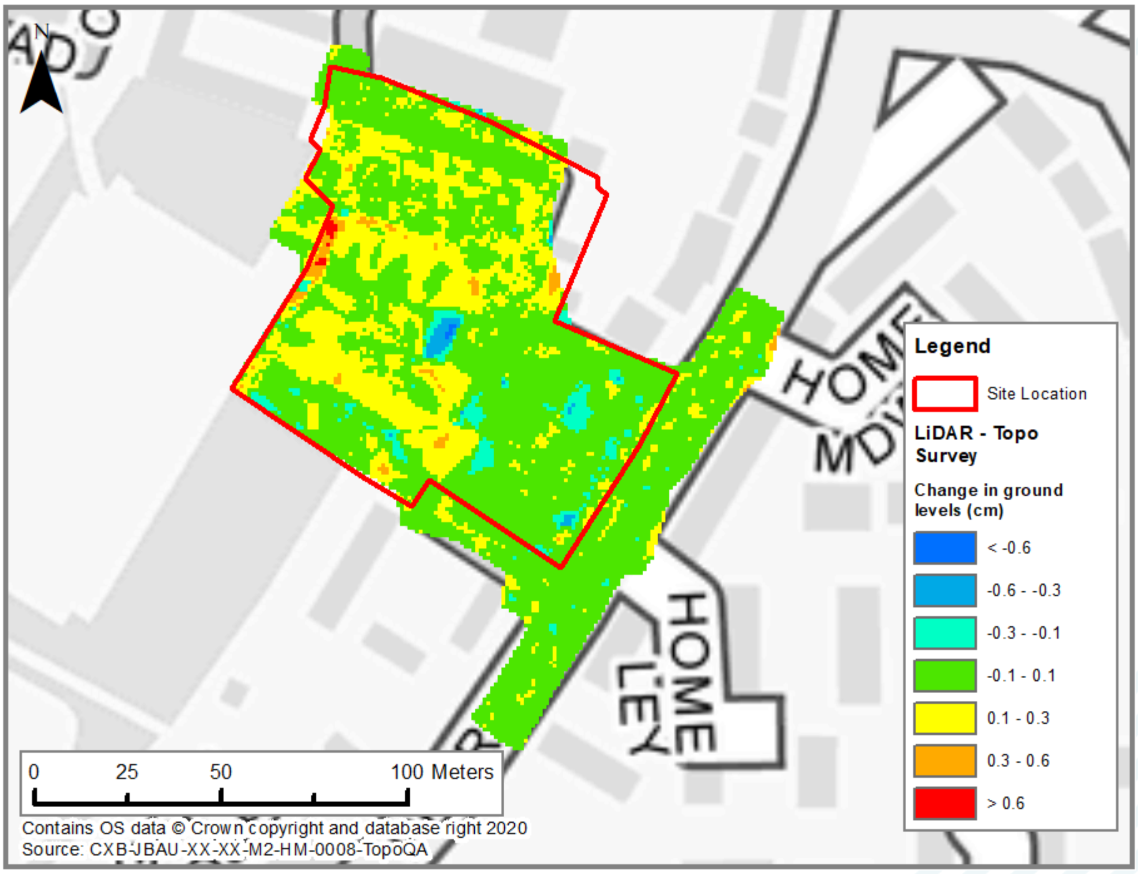


Figure C-1: Topographic survey vs LiDAR

Figure C-1 shows that there is generally a good correlation of elevations between the two DTMs, as a result both will be read into the model.

C Appendix C – Hydrological Assessment

Flood estimation report: Peartree Lane

Introduction

This report template is based on a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results.

Contents

Approval

	Name and qualifications	Date
Method statement prepared by:	Bryony McLeod BSc MSc	28/02/2019
Method statement reviewed by:	Eva Kordomenidi BSc MSc MCIWEM CWEM , CSci	12/03/2020
Calculations prepared by:	Bryony McLeod BSc MSc	28/02/2019
Calculations reviewed by:	Eva Kordomenidi BSc MSc MCIWEM CWEM , CSci	12/03/2020

Revision History

Revision reference	Date issued	Amendments	Issued to

Abbreviations

AM..........................Annual Maximum

AREA ....Catchment area (km^2)

BFI ....Base Flow Index

BFIHOST ....Base Flow Index derived using the HOST soil classification

CFMP ....Catchment Flood Management Plan

CPRE ....Council for the Protection of Rural England

FARL........................FEH index of flood attenuation due to reservoirs and lakes

FEH ....Flood Estimation Handbook

FSR ....Flood Studies Report

HOST ....Hydrology of Soil Types

NRFA ....National River Flow Archive

POT ....Peaks Over a Threshold

QMED ....Median Annual Flood (with return period 2 years)

ReFH........................Revitalised Flood Hydrograph method

SAAR ....Standard Average Annual Rainfall (mm)

SPR ....Standard percentage runoff

SPRHOST ....Standard percentage runoff derived using the HOST soil classification

Tp(0) ....Time to peak of the instantaneous unit hydrograph

URBAN ....Flood Studies Report index of fractional urban extent

URBEXT1990 ....FEH index of fractional urban extent

URBEXT2000 ....Revised index of urban extent, measured differently from URBEXT1990

WINFAP-FEH ....Windows Frequency Analysis Package – used for FEH statistical method

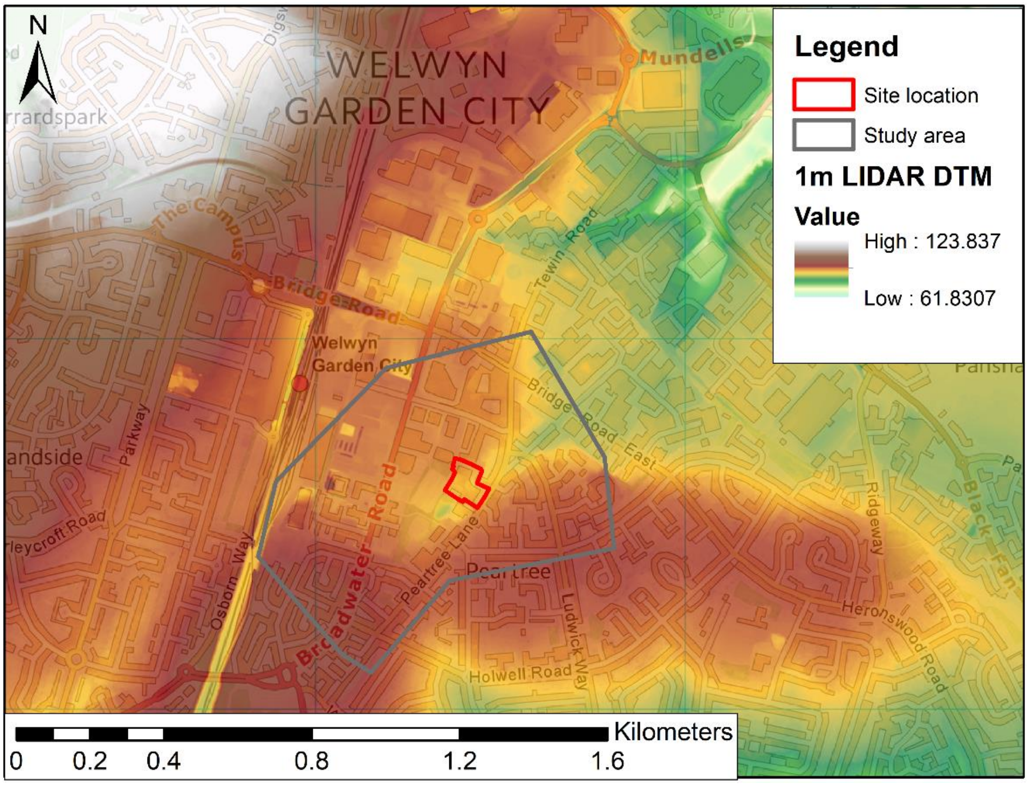
1 Method statement

1.1 Requirements for flood estimates

Overview • Purpose of study • Peak flows or hydrographs? • Range of return periods and locations	Rainfall hyetographs are required for a surface water model at One YMCA 90 Peartree Lane, Welwyn Garden City. The model will be developed using the methodology described in the EA's "Updated Flood Map for Surface Water – National Scale Surface Water Flood Mapping Methodology" and will provide a detailed assessment of surface water flood risk at the site. The modelled rainfall return period events will be 3.3%, 1% and 0.1%, with a 1-hour, 3-hour and 6-hour storm duration for each return period.

1.2 The study area

Map



Description Include topography, climate, geology, soils, land use and any unusual features that may affect the flood hydrology.	The study area is located in the centre of Welwyn Garden City and is predominantly urban. There doesn't appear to be any open watercourses within the study area, though LiDAR data indicated it is located in the middle of a natural drainage catchment. The site will drain away towards the north east of the study area. According to the EA's Risk of Flooding from Surface Water (RoFfSW) maps the site partially falls within an area at risk of flooding from a 30-year, 100-year and 1,000-year storm event. This is based on broadscale modelling.

1.3 Hydrological understanding of catchment

Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	The main site of interest is at the centre of the model domain, at the YMCA. Rainfall will be applied consistently across the whole model area.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – seek local flow data; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing, extensive floodplain storage – consider choice of method carefully	The study area is predominantly urban, and therefore only an urban loss model will be used for the design rainfall hyetograph.

1.4 Initial choice of approach

Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	Hyetographs will be derived using ReFH2 with FEH2013 design rainfall for 1,3 and 6 hour storm durations for the 30-year, 100 and 100-year return periods and tested using the hydraulic model to determine the critical storm duration for each area.
Software to be used	FEH Web Service[1] /ReFH2.3

[1] CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, Oxon, UK.

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Type of estimate L: Lumped catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km^2)
YMCA	L	N/A	Catchment at YMCA site	524450	212600	0.615

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
YMCA	1	0.3	0.498	0.93	19.1	656	0.7541	0.1504

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes	Catchment boundary checked against LIDAR and appears appropriate.
Record how other catchment descriptors were checked and describe any changes.	Qualitative check on FARL and BFIHOST using mapping. No amendments were made.
Source of URBEXT	URBEXT2000

3 Rainfall hyetographs

Rainfall hyetographs are required as input to the surface water hydraulic model. The Updated Flood Map for Surface Water (uFMfSW) methodology has been followed to generate the hyetographs for this study.

In the uFMfSW method, the hyetographs were derived for rural and urban areas. Due to the highly urbanised nature of this study area only the urban losses approach is used in this case. The urban losses approach applies a runoff coefficient of 70% to the design rainfall hyetograph and the removes a drainage capacity of 12mm/hr.

Due to the age of the uFMfSW it is assumed they used FEH99 rainfall statistics for the design rainfall. Since this time the FEH13 rainfall statistics have been made available and it has been decided to use the values for this study.

Following the uFMfSW methodology an areal reduction factor (ARF) has not been applied to the data. This means in the ReFH2 software the ARF is set to 1, and the seasonal correction factor was left at the default value. This is due to there being no defined catchment into which the rain is falling, and so the direct rainfall is applied as point rainfall across the study area.

The storm profile has been set as the 50% summer profile, which is generally recommended for urban areas. In the uFMfSW this profile was chosen due to its peakier nature, so is more likely to be critical for surface water flooding.

Hyetographs for a 1.1hr, 3.1hr and 6.25hr storm duration were generated. ReFH2 requires the use of a data interval which gives an odd integer when divided by the storm duration. A data interval of 0.1 hours was used for the 1.1-hour and 3.1-hour storms and a timestep of 0.25 hours was used for the 6.25-hour storm. Multiple durations are chosen initially and the modelling determines the critical duration. The uFMfSW discusses how critical duration is linked to the topography, where low lying areas are linked to longer durations. Whereas this site is on a slope so will tend towards shorter duration.

The runoff coefficient for the urban runoff was chosen as 70% in the uFMfSW study. This was generalised for the nationwide study, so has been reviewed for this specific site. The site is a mixture of industrial land, car parks, suburban style housing (with gardens) and small wooded/park areas. Using OS OpenMap data and OS 50k mapping the impermeable area was calculated at 50-85%. The uFMfSW study quotes standard hydrology guidelines that city centre runoff coefficients are in the range 70-95% and suburban runoff coefficients are in the range 50-70%. Following these guidelines the runoff coefficient of 70% was verified as appropriate for this site.

3.1.1 Rainfall hyetographs

Using ReFH2 software the design rainfall hyetographs were generated for the site. To apply the urban losses each hyetograph was multiplied by 0.7 to represent the losses by infiltration. The loss of 12mm/hr to represent the drainage system was then applied to the resulting hyetograph. This loss was calculated as a depth for each time interval, for example, 0.1hr (6 minute) data interval has a loss of 1.2mm/6 minutes. If the hyetograph depth was already below the drainage capacity, then the depth was set to zero.

Time (hr)	Design rainfall (mm)	Rainfall with 70% runoff (mm)	Drainage capacity (mm)	Urban net rainfall (mm)
00:00:00	0.995	0.697	1.2	0
00:06:00	1.480	1.036	1.2	0
00:12:00	2.266	1.587	1.2	0.387
00:18:00	3.643	2.550	1.2	1.350
00:24:00	6.510	4.557	1.2	3.357
00:30:00	13.337	9.336	1.2	8.136
00:36:00	6.510	4.557	1.2	3.357
00:42:00	3.643	2.550	1.2	1.350
00:48:00	2.266	1.587	1.2	0.387
00:54:00	1.480	1.036	1.2	0
01:00:00	0.995	0.697	1.2	0
Total	43.124	30.187		18.322

Figure 3-1: Calculations used to generate the 100-year, 1-hour inflow rainfall hyetograph.

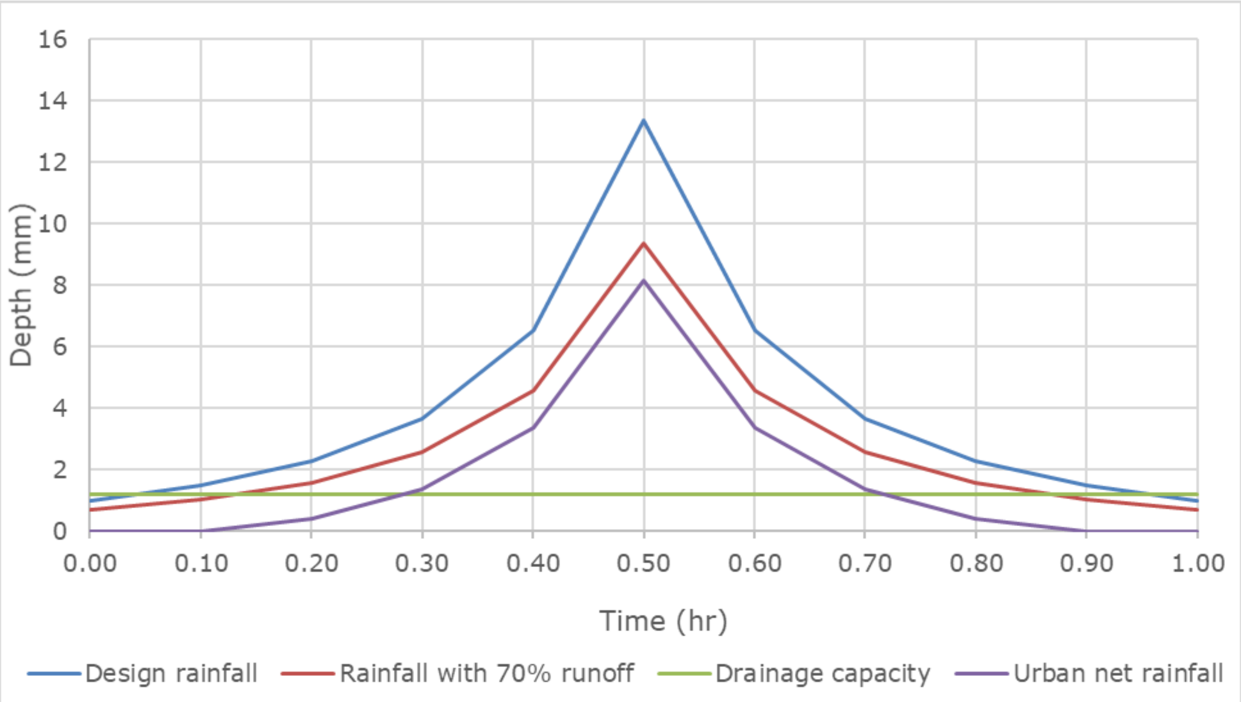


Figure 3-2: Graph illustrating the stages in hyetograph calculations, demonstrated using the 100-year, 1-hour storm.

4 Discussion and summary of results

4.1 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It is assumed that the rainfall statistics give an accurate representation of rainfall over the study area.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed.	There is no data for checking the rainfall depths against to verify their validity for the site.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	It is emphasised that the results of the analysis should be considered in the context of the needs of this study. The results of this assessment should be revisited for use on future studies.

4.2 Final results

4.2.1 Rainfall

These are the peak rainfalls for each hyetograph, with urban losses applied, intended for use in the direct rainfall surface water modelling component.

Return Period	Peak Rainfall (mm)		
	1hr	**3hr**	**6hr**
1 in 30-year (3.3% AEP)	5.9	3.4	3.2
1 in 100-year (1% AEP)	8.1	4.8	5.2
1 in 1,000-year (0.1% AEP)	15.0	9.4	11.4

Rainfall hyetographs for the next stage of the study are provided:	Rainfall hyetographs are required for the direct rainfall component of this study. These are provided in a separate file.

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Broughton Hall
SKIPTON
North Yorkshire
BD23 3AE
United Kingdom

+44(0)1756 799919
info@jbaconsulting.com
www.jbaconsulting.com
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D Appendix D – Sensitivity analysis

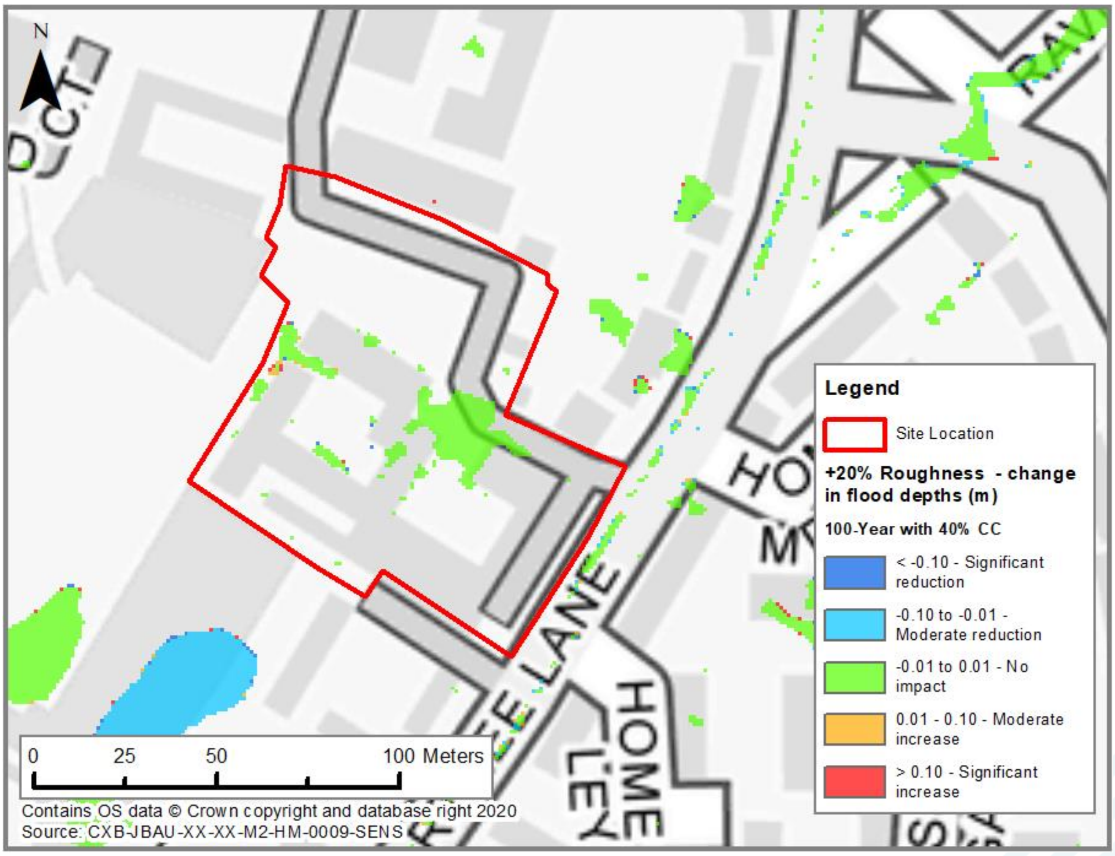

Figure E-2: Sensitivity to an increase in roughness

Figure E-1 shows the impact on flood depths within the site when the Manning's 'n' values are increased by 20%. It shows that within the site flood depths are relatively insensitive to model roughness changes.

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Registered Office
1 Broughton Park
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Broughton
SKIPTON
North Yorkshire
BD23 3FD
United Kingdom

+44(0)1756 799919
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