Anglia Square, Norwich
Flood Risk Assessment: Modeling Report

Rev A

Dated July 2022

Weston Homes

REPORT

Anglia Square Norwich Modelling Study

Modelling Report

Client: Weston Homes

Reference: 6645-ZZ-XX-RP-Z-0001

Status: Final/001

Date: 15 July 2022

HASKONINGDHV UK LTD.

1200 West 73rd Avenue Suite 550 Airport Square
Vancouver, BC V6P 6G5
Water & Maritime
VAT registration number: 792428892

+1 604 717 1800 **T**
+1 604 717 1818 **F**
info@www.intervistas.com **E**
royalhaskoningdhv.com **W**

Document title:	Anglia Square Norwich Modelling Study
Document short title:	
Reference:	6645-ZZ-XX-RP-Z-0001
Status:	001/Final
Date:	15 July 2022
Project name:	Anglia Square Norwich Modelling Study
Project number:	6645
Author(s):	Louisa Wade
Drafted by:	Louisa Wade
Checked by:	Steven Brown
Date:	13 July 2022
Approved by:	Steven Brown
Date:	13 July 2022

Classification
Project related

Table of Contents

Royal HaskoningDHV

Table of Tables

Table of Figures

Appendices

Glossary and Acronyms

Term	Definition
AEP	Annual Exceedance Probability is the probability of a rainfall or tidal event occurring within any one year. For example an event of a 100 year return period has an AEP of 1:100 or 1%.
Courant Number	A function of the amount of fluid that crosses the cell in a given time-step. For 2d modelling the Courant Number generally needs to be less than 10 and typically around 5 or less for real-world applications.
Critical Storm Duration	The duration of a specific storm event which creates the largest volume or highest rate of net storm water runoff for typical durations up to and including the 10 day duration event.
DDF	Depth Duration Frequency depths define the predicted total rainfall depth for a specific return period and storm duration.
DTM	Digital Terrain Model (also known as Digital Elevation Model) is a format for describing the topography of a terrain in a digital format. Often a digital terrain is formatted into a regular grid.
ESTRY	Dynamic flow program suitable for mathematic modelling floods and tides (and/or surges) in a virtually unlimited number of combinations.
Flood Defences	Artificial structures maintained to a set operational level designed to protect land people and property from Tidal and Fluvial flood sources to an established AEP threshold.
FEH	Flood Estimation Handbook
ReFH2	Second Revitalised Flood Estimation Handbook
Flood Source: Fluvial	When flows within watercourses exceed the capacity of the watercourse causing out of bank flows.
Flood Source: Pluvial	When rainfall causes overland flows which exceed the capacity of the drainage network, causing flooding to land that is normally dry.
Flood Source: Tidal	When high tide events overtop the shoreline to cause flooding to land behind.
Flood Zone 1	Low Probability. Land defined as having a less than 1:1000 AEP of flooding from tidal and fluvial sources.
Flood Zone 2	Medium Probability. Land defined as having a risk of fluvial flooding between 1:100 AEP and 1:1000 AEP. Or Land defined as having a risk of tidal flooding between 1:200 AEP and 1:1000 AEP.
Flood Zone 3 (A)	High Probability. Land defined as having a fluvial risk of 1:100 AEP or greater. Or a tidal risk of 1:200 AEP or greater.
Flood Zone 3 (B)	Functional Floodplain. Defined by SFRA's as areas where floodwater is stored during lower AEP events, typically the 1:20 AEP.
Flood Zone Map	The Environment Agency has produced a mapping data set which covers England and provides the general extents of Flood Zones 1, 2, and 3. However the national data set available online does not differentiate between Flood Zone 3 (A) and 3 (B)
LiDAR	Light Detection And Ranging is an accurate ground terrain model obtained by aerial survey. The typical vertical accuracy is +/- 150 mm, the horizontal spacing of survey points (resolution) is normally 0.5m in city centres, 1m in urban areas and 2m in rural areas.
Main River	Defined on the Main River map and relate to rivers on which the Environment Agency have powers to carry out flood defence works
Model Event	The Model Event is the AEP storm or flow profile used within each Model Scenario
MHWS	Mean High Water Springs – the mean high water level for spring tides
Model Scenario	Each Model Scenarios considers a range of Model Events to assess the impact of the Scenario, typical Model Scenarios are; base case, post development, post mitigation.
m AOD	Metres Above Ordnance Datum
OS	Ordnance Survey.
Ordinary Watercourse	A watercourse which does not form part of a Main River

Term	Definition
PMF	Probable Maximum Flood
'Ponds'	The 'direct rainfall' modelling process can result in water being caught between local ridges and depressions creating "ponds" these artefacts are normally the result of subtle changes in the ground data that has been sampled to create the DEM.
SAAR	Standard Annual Average Rainfall is the average annual rainfall across an area
SuDS	*Sustainable Drainage Systems*, which are designed to manage surface water flows in order to mimic the Greenfield run-off from an undeveloped site.
TUFLOW	TUFLOW is one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software. It simulates the complex hydrodynamics of floods and tides using the full 1D St Venant equations and the full 2D free-surface shallow water equations.
T_p	Time to Peak is the time delay between peak rainfall and peak river flow rate

Royal HaskoningDHV

1 Executive Summary

This flood modelling report has been undertaken to support the proposed redevelopment of the area known as Anglia Square, Norwich NR3 1DZ. The proposals are for a mixed-use scheme including retail and residential uses. According to Environment Agency surface water mapping the site is in an area at risk of surface water flooding. Consequently, to understand the risk to the site, and the potential changes in flood risk elsewhere as a result of the development proposals, a surface water flood model has been produced.

A two-dimensional direct rainfall hydraulic model of the Catton and Sewell catchment was constructed to understand the surface water flood risk to the site, and the potential impacts elsewhere as a result of the development. The results of this modelling study are to be used to support a planning application at the site and inform suitable flood mitigation measures for the proposed development.

The flood model has been based on the original Catton and Sewell model constructed in 2011 as part of the Norwich Surface Water Management Plan (SWMP). The original hydrological inputs to the model were updated, along with the LIDAR data. The model was run for the baseline scenario, with the existing Anglia Square topographic survey used to inform the site levels. The model was then run for the proposed scenario with the proposed finished floor levels and mitigation measures included, to determine any vulnerable areas and offsite impacts. Direct rainfall hyetographs were applied as the boundary condition over the entire catchment, using the FEH13 DDF rainfalls and ReFH2 methodology. Due to the high URBEXT and BFIHOST values in the catchment, FEH guidelines recommend using the summer profile. Therefore, this was used for the model design, with sensitivity analysis on the winter profiles. The net rainfall was used to derive the hyetographs, as this accounts for several factors such as the area reduction factor and seasonal variation factor. The results of the net rainfall model are similar to the EA's risk of flooding from surface water mapping.

Following comments from the Lead Local Flood Authority (LLFA) on the initial application, the model boundary was extended to capture a wider area, to account for runoff from other parts of the catchment. Anglian Water surface water sewers were also included in the neighbouring roads. Additional scenarios were modelled to include a hump at the entrances of the basement car park and the service yard to mitigate the flood risk to these areas.

The model was simulated for a range of return periods for the present day and with consideration for the impacts of climate change.

The model was tested for sensitivity to several parameters including storm duration, inflows, Manning's roughness and downstream boundary parameters. Additional runs were also included as a rough validation exercise, based on the 27th May 2014 and 20th July 2014 historic events for which there is some evidence of flood extents. These sensitivity tests indicate that the model is relatively unaffected by changes in these parameters and validates well against known flood locations from the historic events.

Flood depth and extents maps were generated from the results.. The flood modelling has been undertaken to support the development proposals for Anglia Square and to determine mitigation measures, thus it may not be appropriate for other sites to make use of the results, especially at the edges of the modelled extent.

Royal HaskoningDHV

2 Introduction

2.1 Appointment

RHDHV were appointed by Weston Homes to build a direct rainfall hydraulic model to support a large mixed-use development at Anglia Square, Norwich NR3 1DZ. The existing site lies within a significant surface water flow path, therefore hydraulic modelling was required to determine the risk to the proposed development and any mitigation measures that may need to be included in the new scheme.

Norfolk County Council (NCC) were approached for initial comments in 2017, relating to an earlier application at the site by Weston Homes. NCC highlighted the surface water risk and identified the site to be within a Critical Drainage Area (CDA). NCC provided their Norwich Urban Surface Water Management Plan Model CDC2 (Catton Grove and Sewell catchment) to base the hydraulic model on. Given the age of the model, updates have been included for the latest analysis, such as the hydrological inflows and LIDAR data.

This report details the methodology used in developing the catchment model, including the hydrological analysis and hydraulic approaches, and presents the results and sensitivity analysis, as well as providing conclusions, limitations and recommendations.

2.2 Brief

The scope of the commission includes:

- An assessment of the catchment hydrology and the derivation of the critical storm events using the Flood Estimation Handbook.
- The construction of a two-dimensional (2D) hydraulic model of the Catton and Sewell catchment.
- Identification of the 'worst-case' flooding scenario between winter and summer seasons.
- Simulation of the baseline runs for five design storm events (1 in 30, 30 plus 40% climate change, 75, 100, 100 plus 20% climate change and 100 plus 45% climate change return periods).
- Simulation of the proposed development runs for five design storm events (1 in 30, 30 plus 40% climate change, 75, 100, 100 plus 20% climate change and 100 plus 45% climate change return periods).
- Sensitivity testing for the impact of:
  - Inflow Boundary (+20% and -20%);
  - Manning's Roughness (+20% and -20%);
  - Downstream Boundary (+0.2m and -0.2m);
  - Storm Duration (1 hour and 3 hour event);
  - Seasonal Change (Summer and Winter storm profiles).
- Rough calibration against two historic storm events in the catchment on 27th May 2014 and 20th July 2014.
- The production of flood maps of the different simulated model runs, scenarios and sensitivity tests.

Royal HaskoningDHV

2.3 Lead Local Flood Authority Pre-Application Comments

The Lead Local Flood Authority (LLFA) were consulted for advice and feedback on the modelling approach. The LLFA comments are included in **Appendix A**. These are summarised below:

- External inflows from adjacent catchments to be scaled up to 1 in 100 year plus 40% climate change rather than 20% climate change;
- 1 hour storm duration to be considered;
- Both summer and winter storm profiles to be considered to determine critical storm;
- Concerns over infiltration parameter using 7mm/hour to represent discharge to sewers and infiltration to ground. Requested including of Anglian Water sewer network within model;
- Ground truthing checks to be carried out;
- Flyover on the southern site boundary to be better represented in 2D domain, using variable levels;
- Culvert representing subway in original model to be removed since it was infilled in 2018;
- Threshold survey carried out along Magdalen Street to better understand risk to the properties;
- Model calibration based on the 2014 storm events;
- Further sensitivity testing to be carried out;
- Model stability checks to be carried out;
- Below ground car park in Block A to be set at or above ground level. Threshold level at car park entrance to be at least 300mm higher than 1 in 100 year plus climate change flood level;

These comments have been considered and addressed in this report.

2.4 LLFA Hydraulic Modelling Comments (April 2022)

Following the initial application in April 2022, the LLFA objected and provided the following comments on the hydraulic modelling (also included in **Appendix A**):

- Confirm that the key parameters (URBEXT, catchment area etc) have been checked and the parameters where appropriate adjusted accordingly.
- Provide an updated model that:
  - Includes sewers in the hydraulic model for the sewer network affecting the parts of the site included in this application to support the full applications that demonstrates there is no increase in flood risk elsewhere;
  - Is extended to cover the full catchment to ensure the inflows are calculated correctly, or includes sensitivity testing showing that these inflows do not impact flood risk or the site.
- Provide clarification on whether Anglian Water has been contacted to supply sewer data. This should be requested and included where interactions with the sewer system are likely to impact flooding.

- The inclusion of information regarding the onset of flooding and its associated duration for vulnerable locations across the site including the basement car park entrance and the service yard and loading facilities.

In addition, it was requested that the latest climate change allowances for rainfall/surface water were used in the model. For this area, this was 45% for the 1 in 100 year event and 40% for the 1 in 30 year event. All model scenarios include the application of the new climate change allowances.

The surface water model prepared for this exercise has been updated accordingly and the latest set of flood maps includes the amendments requested above. It is noted that as alternative mitigation measures have now been considered suitable for the proposed development, there is no longer a requirement for flood warning sensors to trigger an alarm system or evacuation. Therefore, while 'Time of Peak' flood maps have been produced and included with the deliverables, no further analysis of the onset of flooding was carried out. Details of the updated model are included in this report.

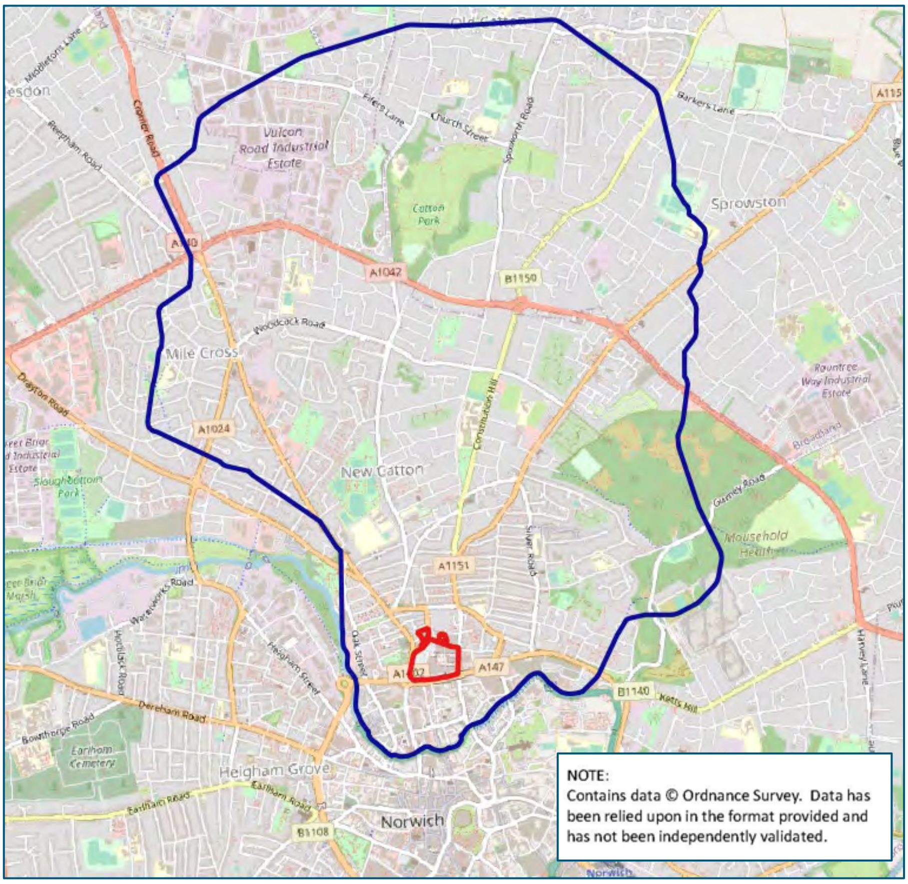
Royal HaskoningDHV

3 The Study Area

3.1 Catchment Location

The Catton and Sewell catchment extent (hereafter referred to as ‘the Catchment’) is shown in Figure 3-1 in blue, with Anglia Square (‘the Site’) in red. The Catchment covers an area of approximately 8.5 km^2 (850 ha). The Catchment is located immediately north of the River Wensum and Norwich city centre. The Catchment boundary shown in Figure 3-1 matches that used in the original CDC2 model, and therefore was initially considered suitable for this analysis. In addition, by modelling the catchment, it would better demonstrate the main overland flow paths which come from the north of the site rather than just applying rainfall to the site itself.

Figure 3-1: Catton and Sewell catchment boundary (from original SWMP model)



However, following comments from the LLFA on the initial Anglia Square application, it was requested that the catchment boundary was extended to cover a wider catchment area, to account for surface water flow paths coming in from outside the Catton and Sewell catchment previously used in the CDC2 model. The FEH Web Service was consulted and it was discovered that by selecting the site, a corresponding catchment was not identified. This appeared to be an anomaly for this particular area, therefore other sources of information were reviewed to determine a suitable wider catchment boundary. The Water Framework Directive (WFD) waterbody catchment boundary for the ‘Wensum DS Norwich’ was considered to be a good representation of the wider catchment. This was downloaded from the WFD river waterbody catchments website (https://data.catchmentbasedapproach.org/datasets/theriverstrust::wfd-river-water-body-catchments-cycle-2/about). The surface water overland flow paths would not extend further south than the River Wensum, therefore the catchment boundary was trimmed at the watercourse. Figure 3-2 shows the

Royal HaskoningDHV

WFD water waterbody catchment boundary and Figure 3-3 shows the trimmed catchment boundary with the River Wensum forming the southern edge of the model.

Figure 3-2: WFD Waterbody Catchment boundary for Wensum DS Norwich

Royal HaskoningDHV

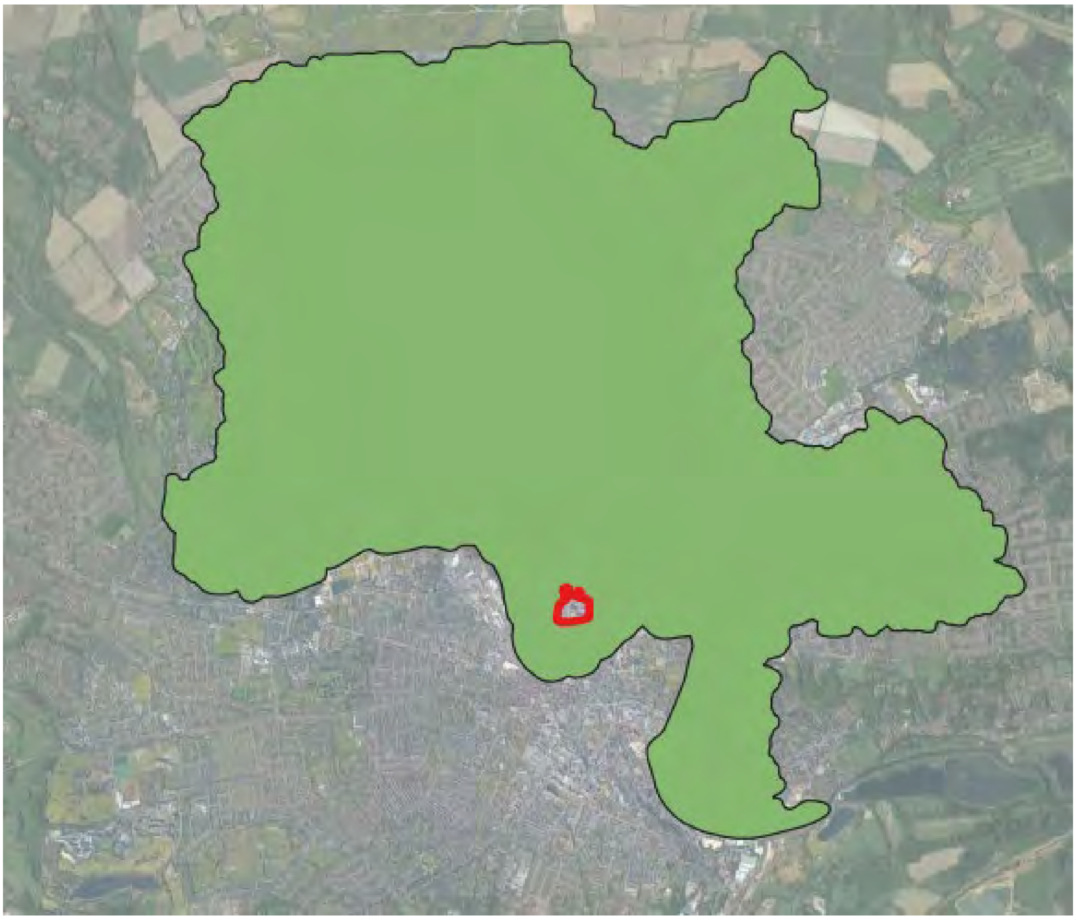


Figure 3-3: Extended Model Boundary (site boundary shown in red)

The extended catchment covered an area of 21.3km^2 (2130 hectares). The catchment is predominantly urban, consisting of residential areas and roads, although the open space areas of Catton Park, Mousehold Heath and part of Norwich Airport are included.

The FEH web-service (https://fehweb.ceh.ac.uk/) provides standardised catchment descriptors for the UK, which enables the national data set to be used to predict the catchment run-off characteristics for most of the UK. As part of this web-service a catchment area for any point of interest can be obtained.

3.1.1 Watercourses

The hydrological setting of the Catchment is summarised below and is also discussed in the FRA.

a) Meanders of the River Wensum are approximately 200m south and west of the site. The confluence of the River Wensum and River Yare are downstream of Norwich city centre.

b) A lost watercourse known as the Dalymond Dyke is understood to pass close to the site. It is understood that this lost watercourse originally followed the natural streams and formed an integral part of the historic sewer system on Norwich. The Dalymond Dyke now forms part of the Anglian Water sewer network so it not considered an open watercourse.

3.2 Site Inspections

No site inspections were conducted by the hydraulic modelling team as part of this study. However, a topographic survey of Anglia Square and photographs have been analysed.

4 Methodology

4.1 Choice of Approach

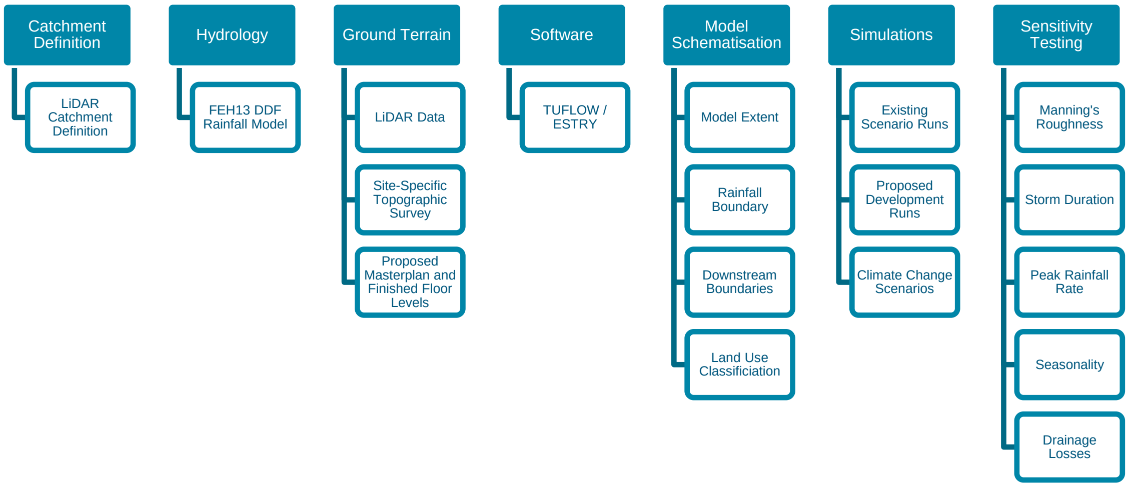
As there were no open watercourses in the catchment (aside from the River Wensum which forms the southern boundary of the model) and the primary flood source is overland flow from surface water, a Direct Rainfall approach was considered most suitable. The Direct Rainfall method applies rainfall directly to a two-dimensional model of the catchment as design rainfall events and the hydraulic model simulates the subsequent overland flow of rainfall.

It should be noted that all hydrological and hydraulic methodologies have limitations and sources of uncertainty, and, therefore, the most appropriate method should be considered based on the type of catchment and the sources of flood risk.

A limitation of Direct Rainfall includes uncertainty regarding infiltration and run-off rates to sewers. As the capacity of the Anglian Water sewer network across the catchment is unknown and outside of the scope of the study, a similar approach to infiltration to sewers was initially used as in the existing CDC2 model, which allowed a constant rate of 7mm/hour as an infiltration boundary to represent losses to sewers or infiltration to the ground. However, a subsequent discussion with the LLFA suggested that 7mm/hour is not considered representative of the whole catchment. Instead, the net rainfall hyetographs were applied which accounted for losses across the catchment based on the catchment characteristics, and the infiltration boundary was removed.

Figure 4-1 provides an overview of the modelling methodology based on the Direct Rainfall approach. The numerical flood model has been developed using a systematic approach of analysing the LiDAR and topographical survey of the site, determining suitable hydrological conditions and then combining the hydraulic characteristics.

Figure 4-1: Methodology Overview



4.2 Hydrological Approach

The Direct Rainfall method required the derivation of suitable rainfall hyetographs applied to the hydraulic model in the form of rainfall timeseries data. The FEH Web Service (https://fehweb.ceh.ac.uk/) provided catchment descriptors, which were used alongside the ReFH2 software to generate rainfall depth duration frequency (DDF) estimates. ReFH2 was used to assess the critical storm duration, and the hyetographs were prepared from the DDF estimated as the rainfall boundary.

4.3 Hydraulic Modelling Approach

Based on the study area and the considerations above, it was considered most suitable to implement a 2D[1] flood modelling regime, using the TUFLOW computational engine. As no watercourses or culverts are located within the catchment, there is no 1D element so the ESTRY 1D component is not required.

The TUFLOW/ESTRY computational engine has been benchmarked by the Environment Agency (Environment Agency, 2013), and is considered suitable for predicting flood levels and depths, flow velocities, and flood hazard ratings associated with tidal and fluvial flood inundation as well as direct rainfall modelling.

Based on experience of development of 1D/2D numerical flood models for assessment of site-specific flood risks, the TUFLOW/ESTRY solver is considered appropriate for the simulation of the baseline scenario, and for testing of potential future mitigation options.

[1] A 2D solver enables an estimation of water level and flow rates in a dual vector direction, usually forwards and backwards along a channel, and perpendicular to the channel. These solvers are usually slower than 1D solvers, and can encounter problems when dealing with small channel widths (less than 3 model cell widths).

Royal HaskoningDHV

5 Data Sources

Several sources of information have been used in this study. Table 5-1 provides a list of the data used in the development of the hydrological assessment and hydraulic model. The data quality has been assessed in accordance with the Multi-Coloured Manual (Flood Hazard Research Centre & Envrionment Agency, 2013) and scored accordingly where:

- 1 - Best possible;
- 2 - Data with known deficiencies;
- 3 - Gross assumptions; and
- 4 - Heroic assumptions.

Table 5-1: Data type and sources

Data Type	Sub Type	Source	Date	Score	Comment
Hydrology	Historic Flooding Records	Norfolk County Council	2014	3	Description of flooded areas from the Norwich Urban Area Investigation Report (2014). LLFA requested the model to be calibrated using this information.
2D Geometry	Site-Specific Topographic Survey	Weston Homes	2016, updated 2022	1	Best available data covering the site
	LiDAR Data	Environment Agency	2020	1	The best data available for the study area was the 2019 composite dataset.
	NextMap 5m Data	Environment Agency	2021	2	Where gaps in the Environment Agency LiDAR dataset were present, this has been substituted with NextMap 5m DTM data.
Surface Roughness	Aerial Photography	Various	2021	2	Aerial photography provided a means to confirm the surface roughness assigned by the Ordnance Survey data.
	Original Model Materials Layers	Various	2011	2	Original materials layers were used where possible as these covered the catchment area and were previously accepted by NCC. Materials layers were checked in the vicinity of the site and updated where necessary based on aerial imagery and topographic survey data.

5.1 Ground Truthing

The LLFA requested that ground truthing checks were carried out to ensure the EA LiDAR data was representative of the ground levels. Some inspection points were selected across the site area where site-specific topographic survey data was available, and the topographic survey levels were compared to the LiDAR levels. As no survey data was available offsite, this was the best method of ground truthing, with the assumption that any differences between the survey data and LiDAR within the site boundary would be similar across the catchment. Figure 5-1 shows the locations of the inspection points and Table 5-2 contains the elevations and differences.

Royal HaskoningDHV

Figure 5-1: Ground Truthing Coverage

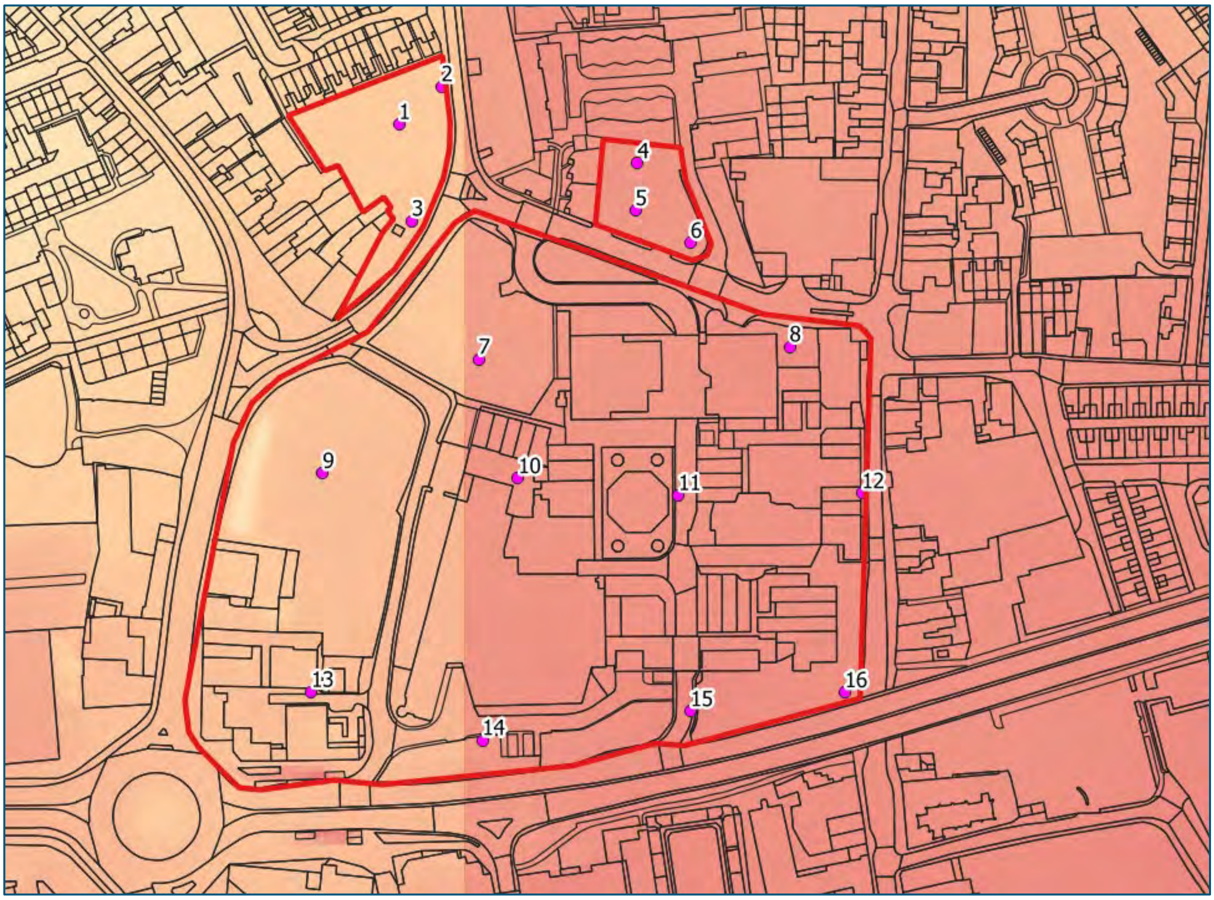


Table 5-2: Ground Truthing Results

Inspection Point	Z LIDAR (m AOD)	Z TOPO (m AOD)	Difference (m)
1	5.41	5.37	0.04
2	5.45	5.39	0.06
3	5.16	5.09	0.07
4	4.00	3.97	0.03
5	4.16	4.09	0.07
6	4.28	4.20	0.08
7	5.19	5.12	0.07
8	3.35	3.30	0.05
9	4.71	4.70	0.01
10	3.93	3.84	0.09
11	3.92	3.90	0.02
12	3.51	3.55	0.04

Inspection Point	Z LIDAR (m AOD)	Z TOPO (m AOD)	Difference (m)
13	4.82	4.79	0.03
14	4.48	4.38	0.10
15	2.77	2.77	0.00
16	3.53	3.47	0.06

The EA website (data.gov.uk) states that all LiDAR data has a vertical accuracy of +/-15cm (0.15m). All of the points interrogated above show the LIDAR data is within +/-0.15m of the topographic survey, and therefore can be considered to be acceptable for the purpose of this modelling study.

Royal HaskoningDHV

6 Hydrological Analysis Summary

6.1 FEH13 DDF Rainfall Model

The FEH13 DDF Rainfall Model was used to extract rainfall depths for a given return period and storm duration. The catchment boundary identified on the FEH Web Service contained inconsistencies, notably stopping short of covering the site regardless of where the catchment outflow point was selected. Therefore, catchment descriptors from the closest catchment boundary to the site were used. FEH catchment descriptors are included in **Appendix A** along with the hyetographs.

Rainfall depths were retrieved for a suite of return periods and storm durations to produce both Summer and Winter FEH storm profiles in the ReFH2 model. These are summarised below in ***Table 6-1***.

Table 6-1 DDF Gross Design Rainfall depths [mm]

Season	Storm Duration [hr]	Return Period		
		30-year	75-year	100-year
Winter	1	16.8	20.8	22.2
Summer	1	30.6	37.9	40.4
Winter	3	27.1	34.0	36.6
Summer	3	43.5	54.7	58.7

It is important and considered standard practice in UK hydrology assessments and subsequent fluvial hydraulic modelling to undertake at least a rudimentary check on some of the FEH catchment descriptors obtained from the FEH Web Service before proceeding with in-depth hydrological catchment analysis. With regards to the direct rainfall approach used in surface water or pluvial modelling the checking of FEH catchment descriptors is viewed as not so critical. However, confirmation that the catchment boundary is appropriate for the study site in question should be checked. In this study case the FEH catchment area boundary is considered conservative but appropriate, as it allows for a good understanding of overland flow routes and identification of areas of ponding across the wider urban area.

The BFIHOST value assigned to the study catchment is 0.861, suggests a highly permeable underlying geological strata. This correlates with the geology data held on the BGS Geology of Britain Viewer Web Service which indicates the catchment is underlain by a bedrock of the chalk formations covered with a superficial geology of locally derived Alluvium deposits comprising of Clay, Silt, Sand and Gravel.

The high BFIHOST value is also confirmed by soil data mapping held on the Soilscapes Web Service which indicates that the majority of the study catchment sits on Soilscape 6 type soil, described as freely draining, slightly acid loamy soils where rainfall drains to local groundwater and rivers.

The URBEXT2000 value assigned to the study catchment of 0.39 categorises the catchment area as very heavily urbanised. Confirmation of the extent of urban coverage can be undertaken in a GIS using suitable mapping data. However, this is considered only necessary when there are doubts over the degree of urban and rural coverage across a more heterogenous catchment area, which in this study this is not the case as the study area is obviously heavily urbanised.

Royal HaskoningDHV

Given the joint high URBEXT (0.39) and high BFIHOST (0.861) values assigned to the FEH catchment, the FEH guidelines recommend the use of the FEH 50% summer design storm profile. As the summer 3-hour storm duration resulted in the greatest rainfall depths, this was considered to be the critical storm duration and was used in the design runs. The ReFH2 model was used to generate design event urban hyetographs based on the DDF peak rainfall depth data as outlined in **Table 6-1**. The LLFA requested that both winter and summer profiles were considered, along with the 1 hour storm duration. Therefore, these runs were also simulated as part of the sensitivity tests.

Table 6-2. Net Design Rainfall Depths (mm)

Season	Storm Duration [hr]	Return Period		
		30-year	75-year	100-year
Summer	3	9.1	11.7	12.7

The gross design rainfall depth was initially used to generate the urban storm hyetographs, as this did not include any losses. The losses to sewers or the ground were subsequently included as part of the TUFLOW model as a second rainfall polygon with a negative value of 7mm/hour. However, following discussions with the LLFA, it was determined that 'Net Rainfall'[2] data would be more appropriate for use with a surface water model. This is due to this data accounting for several factors such as the area reduction factor (ARF) and seasonal correction factor (SCF), as well as taking into account losses due to catchment area infiltration rates . Notably, the 'Net Rainfall' hyetographs does not include any losses to sewers, thereby representing a worst-case scenario assuming sewers are at capacity. Therefore, the 'Net Rainfall' depth data, as shown in Table 4, was utilised for input into the hydraulic model as it provided the most representative design rainfall profile and depths for the catchment. The second rainfall polygon which applied the infiltration loss was removed from the model for the final set of model simulations.

6.2 Climate Change Allowances

The latest climate change allowances for rainfall were applied to the rainfall hyetographs input into this model. **Table 6-3** reproduces the Environment Agency climate change allowances for peak rainfall intensity for England, for the 1 in 100 year event. **Table 6-4** shows the peak rainfall intensities for the 1 in 30 year event.

Table 6-3: 1% Peak Rainfall Intensities, Environment Agency 2022

Allowance Category	2050s	2070s
Upper End	20%	45%
Central	20%	40%

Table 6-4: 3.3% Peak Rainfall Intensities, Environment Agency 2022

Allowance Category	2050s	2070s
Upper End	20%	40%
Central	20%	40%

[2] Net Rainfall applies the FEH equations to determine the resultant rainfall that would run-off taking into account the catchment descriptors for the area. The Design Rainfall does not factor for the interception or evaporation of rainfall, and therefore if the Design Rainfall was used, these factors would need to be defined within the rainfall run-off model.

Accordingly, the climate change allowances for the 2070s have been applied to the hyetographs to provide a direct rainfall assessment. Therefore, an increase of 40% was applied to the direct rainfall hyetographs for the 1 in 30 year event, and 45% was applied to the direct rainfall hyetographs for the 1 in 100 year event.

Royal HaskoningDHV

7 Hydraulic Modelling

7.1 Model Schematisation

The hydraulic model schematisation was based on an inspection of the hydrological characteristics and geometric features within the study. The schematisation of the 2D model domain is discussed below to provide clarity of approach.

The original SWMP model included a pedestrian subway beneath St Crispins Road to the southwest of Anglia Square. This was represented in the model as a section of 1D culvert within ESTRY, enabling surface water to flow beneath the road at this location. Following receipt of the pre-application comments from the LLFA, it is understood that this subway was infilled in 2018, and so the section of 1D culvert was removed from the model.

7.2 1D Network

Following a request from the LLFA, the Anglian Water sewer network was included in the model for the surrounding streets. The Anglian Water sewer records (obtained June 2022) were used to determine the dimensions of the sewers and manholes in the surrounding roads. The sewers were included in the model as sections of '1d_nwk' and the manholes were included as rectangular inlet pits with 'SX' boundaries. This meant that any water in the inlet pit cell would be directed into the 1D sewer network. The downstream end of the sewer networks (at the edge of the Anglian Water mapping) were represented as 'HT' boundaries which allowed water to freely exit the sewers.

7.3 2D Domain

The basis of the 2D domain was developed using Environment Agency LiDAR DTM data. A 2m cell size was used which would allow the main flow paths to be picked up without compromising the simulation time.

7.3.1 Digital Elevation Model

The 2019 composite 0.50m grid resolution LiDAR data set was retrieved from the Environment Agency open source web portal and covers the model extent.

7.3.2 Z-Shape Geometry

The site-specific topographic survey, updated in 2022, was then used to include more accurate ground levels within Anglia Square. It was noted that the upper and lower levels of Anglia Square was not accurately picked up in the LiDAR, therefore a number of Z-shape polygons were included to better represent the finished floor levels (FFL) across the existing site.

The existing St Crispins Road flyover, which forms the southern boundary, was also not represented very well within the original CDC2 model. This was included in the existing and proposed models as a Z-shape which used topographic levels to represent the slope from 4.48m AOD to 8.63m AOD.

The original model set the FFL of all buildings across the catchment to consistently be raised 0.10m above the LiDAR elevation, and all roads to be set -0.125m below the LiDAR elevation. The purpose of this was to represent the building thresholds in areas which could not be surveyed. The LLFA acknowledged this approach but requested that building thresholds along Magdalen Street are surveyed as some of the premises to the immediately east and south east of Anglia Square are known to have thresholds at the same

Royal HaskoningDHV

level as the pavement. The buildings and thresholds cannot be surveyed due to access constraints. Instead, the model was updated to remove the buildings along Magdalen Street from the Z-shape layer, essentially lowering them all in the assumption that all threshold levels of these properties were at ground level, matching the LiDAR. This is a conservative approach but presents a worst-case scenario.

The proposed development model runs included all ground FFLs of the buildings where known, as Z-shapes. The basement car park located in Block A is within the surface water flow path and therefore identified as a vulnerable part of the development. The LLFA requested that the basement car park was set at ground floor level, or the entrance to the car park is raised 300mm above the 1 in 100 year (+45%CC) flood level. Discussion with the Applicant confirmed that humps could be located at the entrance to the basement car park and the entrance to the low lying service yard, which would be set 300mm higher than the 1 in 100 year (+45%CC) flood level. The humps were represented as Z-lines which were set at the level 300mm higher than the flood level at these locations. For the entrance car park, this was a level of 4.80m AOD and for the service yard it was a level of 4.45m AOD. This prevented any water from entering these two vulnerable parts of the site. Walls were located around the service yard and basement car park entrance ramp, to prevent water from flowing 'through' walls and into the low lying areas. The walls were represented as Z-lines and set at 999m high within the model, to prevent any water passing through.

The proposed model was run for both the 'no mitigation' and 'mitigation' scenarios upon the request of the LLFA, and flood maps have been prepared for both. The 'no mitigation' runs are called 'Proposed' and the 'mitigation' scenarios including the humps at the car park and service yard entrances are called 'Proposed_Barrier'.

As it is not possible to prevent surface water flows from passing through the site without causing an offsite risk to others, a system had to be designed whereby flows would continue to pass through the site in a managed approach. Therefore, it is recommended that the roads and pedestrian footways throughout the site are lowered in the centre to enable water to flow through the site. Walkways and roads were lowered based on an approximate crossfall of 1:80, using Z-points and Z-shapes to create TINS throughout the site to direct flow to the southeastern corner in a similar manner to the existing overland flow path.

7.3.3 Surface Roughness

Definition of surface roughness within the floodplain is important especially for areas of shallow flow, where the surface roughness factor of the ground can have an impact on the flow velocity, due to the impacts of friction. Surface roughness values were determined using industry standard methods (Chow, 1959).

A global Manning's *n* roughness of 0.035 was applied to the whole catchment initially. The materials file was then read in to specify roughness values for individual features.

The materials layers for the original CDC2 model were used for the most part and applied as a .tmf file within TUFLOW. This was reviewed in the vicinity of the site to ensure the land types were as accurate as possible in the local area. Where necessary, the materials layers were updated. The original Manning's roughness values were used, although the buildings roughness value was increased from 0.04 to 0.1 as it was considered to be more representative of flows passing through buildings. Table 7-1 provides the surface roughness values (as Manning's *n* values) used for each land use classification.

Royal HaskoningDHV

Table 7-1: Definition of Surface Roughness Values (Chow, 1959)

Material Code	Manning's Roughness 'n'	Description
999	0.035	Default Roughness
109	0.020	General Surface: Manmade
110	0.030	General Surface: Natural
111	0.040	General Surface: Residential Yards
112	0.100	Buildings
113	0.020	Roads Tarmac
114	0.080	Trees
115	0.025	Tracks/Dirt Roads
116	0.020	Pavement
117	0.035	Land Unclassified

7.4 Boundary Conditions

The boundary conditions represent the inflow and outflow conditions of the model and at any external model connections. The purpose of the boundary conditions is to provide a realistic simulation of the way in which water flows in and out of the modelled domain. For this model the following conditions have been used:

a. Rainfall boundary;

b. Sewer inflow boundaries; and

c. Outflow boundary.

Rainfall was applied to the whole catchment of the model as rainfall hyetographs as described in Section 4. A 2d_rf boundary covering the entire catchment has been included within the model to apply this boundary.

The original CDC2 model and report assessed the influence of the Anglian Water sewer system within the catchment and determined that a constant 7mm/hour loss to the sewers was a reasonable estimate. Therefore the same approach was initially adopted here. The losses to the sewer network were represented as a second '2d_rf' boundary with a negative inflow applied at regular intervals. However, following discussion with the LLFA, it was decided that the 'Net Rainfall' would be more representative of the catchment and the second '2d_rf' polygon was removed from the model.

Anglian Water sewers were included in the model for the roads surrounding the site. The sizes of these sewers and manholes were taken from the latest sewer records. 'SX' boundaries and inlet pits were included at each manhole to enable water reaching these cells to be taken into the sewer network. At the downstream ends of the sewer networks, which were between 140m and 500m from the site, 'HT' boundaries were included to allow water to discharge freely.

In the proposed scenario model runs, the rainfall boundary was removed from the site and runoff from the onsite drainage system was represented as '1d_bc' inflow points connected to the existing Anglian Water sewer network. The inflow locations were based on the drainage strategy prepared by EAS, and discharged at the specific rates as stated in the Anglia Square drainage report.

An inlet pit with an 'SX' connection and a flap valve was included along with a short section of '1d_nwk' in the service yard in the proposed scenario, as a precautionary measure, to act as an overflow and drain any water reaching this area in an event greater than that modelled. This connected into the Anglian Water sewer via the onsite drainage system; however, as no water reached this area in any mitigation scenario, it is unlikely that this pipe section would be used very often so it has not been accounted for in the drainage system prepared by EAS.

An outflow boundary was applied around the edge of the model using the '2d_bc' layer. This applied a HT boundary around the catchment boundary, to enable water to leave the model freely. The '2d_bc_ boundary was set a significant distance from the site to reduce any impacts on the study area.

Royal HaskoningDHV

8 Model Simulations

8.1 Overview and Naming Convention

Given the various model input parameters such as seasonality, storm duration etc. a coded naming convention was applied to the model run files, summarised in Table 8-1. The final runs were labelled '_016'. The following key should be used to understand the nomenclature:

- *Existing* – Existing/Baseline
- *Proposed* – Proposed Development included
- *Proposed_Barrier* – Proposed Development with mitigation measures included (humps at basement car park and service yard)
- *P* – Pluvial Return Period
- *CC* – % Climate Change Allowance
- *hr* – Storm Duration in Hours (sensitivity test)
- *SM* – Summer Storm Profile
- *WT* – Winter Storm Profile

Table 8-1 Model Run Files

Name [.tcf] and Results File	Scenario	Return Period [year]	Storm Duration [hr]	Epoch	Version
Design Runs					
Anglia_Square_Existing_P0030_3hr_SM_016	Existing	30	3	2020	1
Anglia_Square_Existing_P0075_3hr_SM_016	Existing	75	3	2020	1
Anglia_Square_Existing_P0100_3hr_SM_016	Existing	100	3	2020	1
Anglia_Square_Existing_P01000_3hr_SM_016	Existing	1000	3	2020	1
Anglia_Square_Proposed_P0030_3hr_SM_016	Proposed	30	3	2020	1
Anglia_Square_Proposed_P0075_3hr_SM_016	Proposed	75	3	2020	1
Anglia_Square_Proposed_P0100_3hr_SM_016	Proposed	100	3	2020	1
Anglia_Square_Proposed_P01000_3hr_SM_016	Proposed	1000	3	2020	1
Anglia_Square_Proposed_Barrier_P0030_3hr_SM_016	Mitigation	30	3	2020	1
Anglia_Square_Proposed_Barrier_P0100_3hr_SM_016	Mitigation	75	3	2020	1
Anglia_Square_Proposed_Barrier_P0100_3hr_SM_016	Mitigation	100	3	2020	1
Anglia_Square_Proposed_Barrier_P0100_3hr_SM_016	Mitigation	1000	3	2020	1
Climate Change Runs					
Anglia_Square_Existing_P0030_40CC_3hr_SM_016	Existing	30	3	2070	1
Anglia_Square_Existing_P0100_20CC_3hr_SM_016	Existing	100	3	2070	1
Anglia_Square_Existing_P0100_45CC_3hr_SM_016	Existing	100	3	2070	1
Anglia_Square_Proposed_P0030_40CC_3hr_SM_016	Proposed	30	3	2070	1
Anglia_Square_Proposed_P0100_20CC_3hr_SM_016	Proposed	100	3	2070	1
Anglia_Square_Proposed_P0100_45CC_3hr_SM_016	Proposed	100	3	2070	1
Anglia_Square_Proposed_Barrier_P0030_40CC_3hr_SM_016	Mitigation	30	3	2070	1

Anglia_Square_Proposed_Barrier_P0100_20CC_3hr_SM_016	Mitigation	100	3	2070	1
Anglia_Square_Proposed_Barrier_P0100_45CC_3hr_SM_016	Mitigation	100	3	2070	1
Sensitivities					
Anglia_Square_Duration_P0100_1hr_SM_016	1 Hour Duration Sensitivity Summer	100	1	2020	1
Anglia_Square_Duration_P0100_1hr_WT_016	1 Hour Duration Sensitivity Winter	100	1	2020	1
Anglia_Square_Season_P0100_3hr_WT_016	3 Hour Winter Sensitivity	100	3	2020	1
Anglia_Square_n+20_P0100_3hr_SM_016	Manning's Roughness + 20%	100	3	2020	1
Anglia_Square_n-20_P0100_3hr_SM_016	Manning's Roughness - 20%	100	3	2020	1
Anglia_Square_P+20_P0100_3hr_SM_016	Pluvial Inflow +20%	100	3	2020	1
Anglia_Square_P-20_P0100_3hr_SM_016	Pluvial Inflow - 20%	100	3	2020	1
Anglia_Square_DB+02m_P0100_3hr_SM_016	0.2m downstream boundary increase	100	3	2020	1
Anglia_Square_DB-02m_P0100_3hr_SM_016	0.2m downstream boundary decrease	100	3	2020	1
Validation					
Anglia_Square_Historic_P27MAY2014_016	39.4mm Rainfall applied over 4hr 15mins	N/A	4.25	N/A	1
Anglia_Square_Historic_P20JULY2014_016	45.8mm Rainfall applied in 1 hour	N/A	1	N/A	1

8.2 Return Periods

The model was simulated for three design events, these were:

- 1 in 30 year design storm;
- 1 in 75 year design storm;
- 1 in 100 year design storm.

8.3 Significant Issues

In the development of this numerical flood model, no significant issues have been determined. The model runs within normal operating parameters, and the outputs have been visually verified through anecdotal evidence.

Royal HaskoningDHV

8.4 Choice of Seasonality

The hydrological assessment identified that the summer storm resulted in the greatest rainfall depths, therefore this was chosen as the design scenario. The model was run for a duration of 6 hours, to allow surface water flows to pass through the catchment and the site following the end of the storm.

8.5 Validation & Calibration

Calibration is the adjustment of a model's parameters, such as roughness, and hydraulic structure coefficients, so that it reproduces observed data to an acceptable accuracy.

No calibration data was available for the model and therefore calibration has not been undertaken.

The LLFA highlighted two significant rainfall events within the catchment, which were detailed in the report published by NCC titled 'Investigation Report into the flooding within the Norwich Urban Area during the summer of 2014' (Ref: FIR008). Section 5 details the historic events as:

- 27th May 2014 - 39.4mm was recorded as falling in 4 hours 15 minutes by the Heigham rainfall monitoring station. This intensity of rainfall equates to a 1 in 16 year rainfall event.

- 20th July 2014 – Hourly rainfall totals from the Norwich Airport rainfall monitoring station show 45.8mm fell in 1 hour from 14:00. This intensity of rainfall equates to a 1 in 121 year rainfall event.

Hyetographs were designed to replicate these events, with 39.4mm rainfall split across a 4.25 hour time period for the May 2014 event and 45.8mm rainfall split over 1 hour for the July 2014 event. A minimal infiltration factor was applied to represent drainage losses.

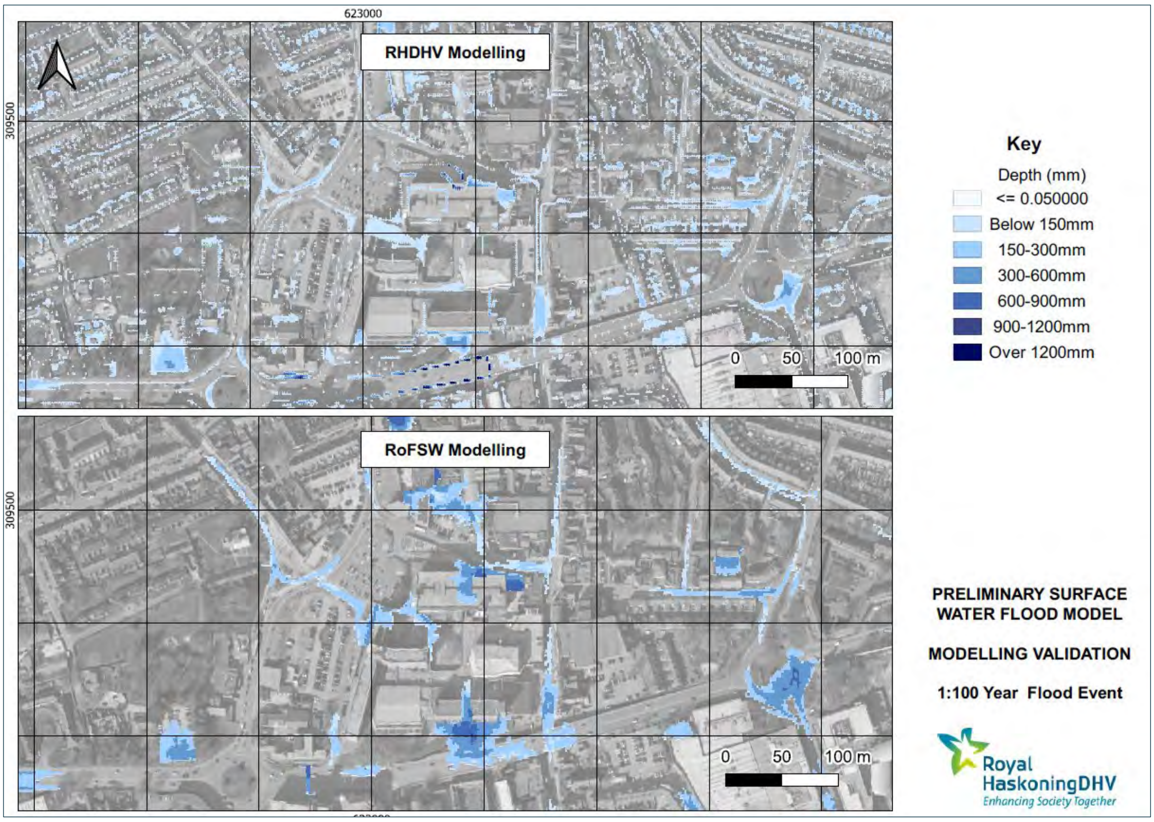
Although flood depths and levels are not recorded in the document, notable locations flooded within the Dalimond Catchment are:
- North Walsham Road (one property flooded in May 2014 event)
- Oak Lane (three properties flooded in May 2014, 2 properties flooded in July 2014)
- Orchard Close (three properties flooded in May 2014, two flooded in July 2014)
- Edge of Mousehold Heath (external flooding)

A full validation cannot be undertaken without knowing the exact locations of the properties or depth of flooding, but a crude validation through visual analysis was carried out.

- North Walsham Road – The May 2014 model run shows flooding to properties in a similar location to that indicated on Map 3 of the Norwich Urban Area Investigation report.
- Oak Lane – Both the May 2014 and July 2014 model runs resulted in significant flooding at the junction of Oak Lane and Mile Cross Lane, an area highlighted in the report as having several recorded flood events.
- Orchard Close – The model extent doesn't cover this area, therefore no results are available.
- Edge of Mousehold Heath – Near the junction of Mousehold Road and Gurney Road, flooding is noted in both 2014 events.

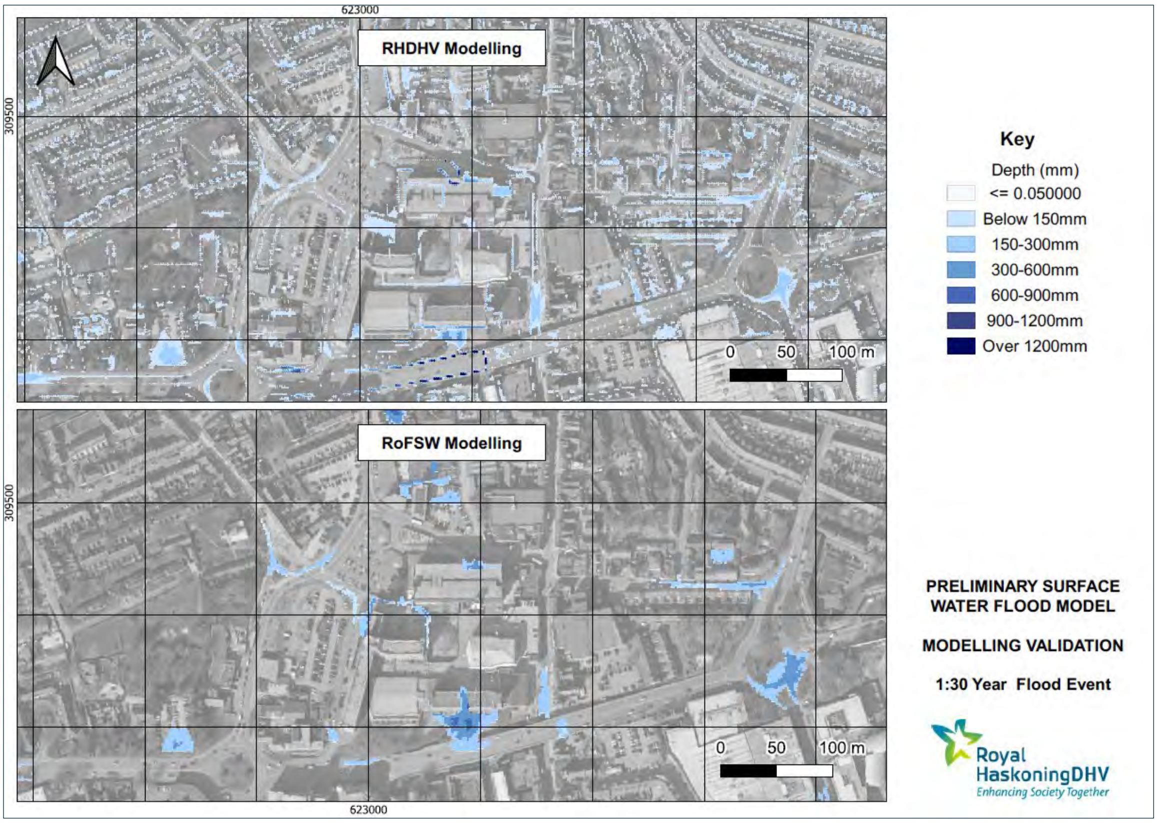
Although the validation demonstrates that the model results are broadly similar to the flooding experienced in the 2014 events, the validation exercise is limited in its precision. A second validation exercise was carried out, comparing the model results in the 1 in 30 and 1 in 100 year events to the EA's risk of surface water flooding maps for 'medium' and 'high' frequency events. The comparison shows generally a good correlation between the two sets of results, which suggests the use of the 'Net Rainfall' hyetographs and the losses included within the ReFH2 model represent the catchment and the area around the site well. It is noted that the updates to the topography across the site and updated hydrological parameters appear to have resulted in a reduction in flood depth when compared to the EA mapping. However, the same locations appear to show pooling of surface water on both maps. **Figure 8-1** and **Figure 8-2** show the comparison maps, and the full maps can be downloaded via the link referred to in **Appendix B**.

Figure 8-1: Comparison between 1:100 model results and EA's RoFSW map



Royal HaskoningDHV

Figure 8-2: Comparison between 1:30 model results and EA's RoFSW map



8.6 Sensitivity Analysis

A range of sensitivity tests were performed to understand the impact on water levels due to variations in antecedent conditions as a substitute for a more-precise validation exercise.

Sensitivity analysis was performed to understand the models tolerance to physical parameters. The 1 in 100-year design event for the baseline scenario was used to assess model sensitivity.

Sensitivity runs were carried out by varying the following parameters by +/-20%:

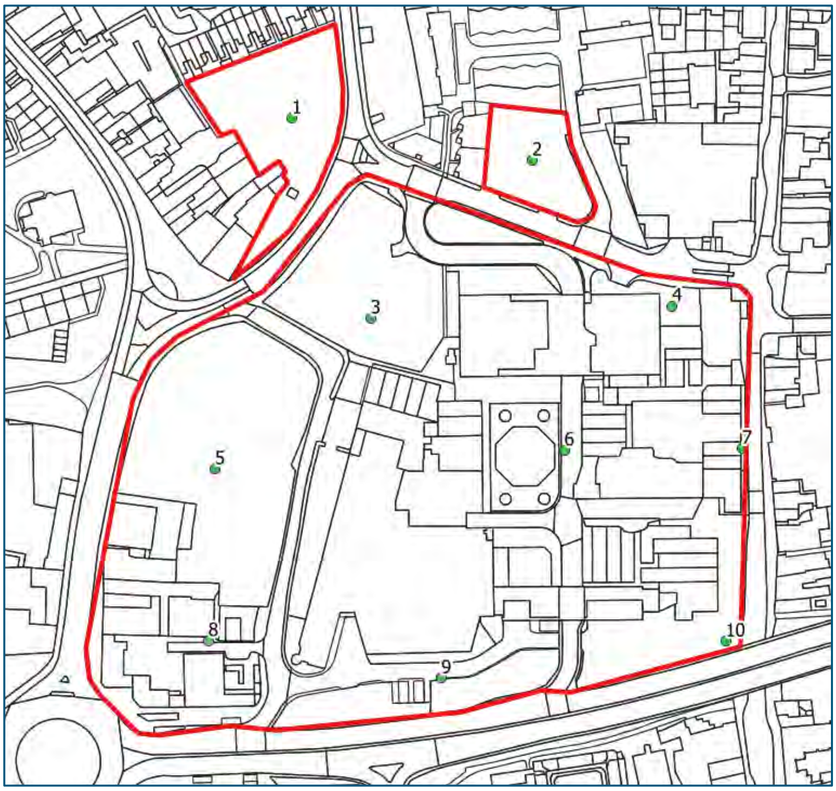
- Rainfall Hyetograph /Inflow - The direct rainfall boundary and external inflow boundaries have been varied by +/-20%;
- Manning's Roughness – All materials values, including the default roughness value, have been varied by +/-20%;
- Downstream Boundary – The boundaries at the end of the modelled Anglian Water sewer networks were varied by +/-0.20m.

In addition, the 3 hour winter profile was run as well as the 1 hour summer and winter storm profiles, to determine the variability of the season and storm duration.

8.6.1 Review of Sensitivity

A number of inspection points were digitised across the Anglia Square site. Depth grid results were then interrogated at each inspection point for the 1 in 100 year event, and each of the sensitivity runs. The inspection points are shown in Figure 8-3.

Figure 8-3: Sensitivity Review Inspection Points



The sensitivity matrix table in **Table 8-2** summarises the flood depths of the baseline 1 in 100 year event and each of the sensitivity runs. **Table 8-3** shows the depth change relative to the baseline scenario.

Table 8-2: Sensitivity Matrix Depths

Scenario	Inspection Point Maximum Flood Depth (m)									
	1	2	3	4	5	6	7	8	9	10
Baseline	0.024	0.002	0.003	0.19	0.027	0.021	0.003	0.003	0.306	0.002
Rainfall Boundary (+20%)	0.025	0.179	0.003	0.627	0.029	0.061	0.036	0.003	0.781	0.002
Rainfall Boundary (-20%)	0.024	0.002	0.003	0.146	0.025	0.019	0.003	0.003	0.278	0.002

Manning's Roughness (+20%)	0.024	0.002	0.003	0.189	0.028	0.022	0.004	0.003	0.303	0.002
Manning's Roughness (-20%)	0.024	0.002	0.003	0.191	0.026	0.021	0.003	0.003	0.308	0.002
Downstream Boundary (+0.2m)	0.024	0.002	0.003	0.19	0.027	0.021	0.003	0.003	0.306	0.002
Downstream Boundary (-0.2m)	0.024	0.002	0.003	0.19	0.027	0.021	0.003	0.003	0.306	0.002
Winter Profile 3hr	0.023	0.002	0.003	0.11	0.023	0.016	0.002	0.003	0.229	0.002
Summer Profile 1hr	0.024	0.002	0.003	0.11	0.026	0.02	0.004	0.003	0.232	0.002
Winter Profile 1hr	0.022	0.002	0.003	0.037	0.015	0.013	0.003	0.003	0.112	0.002

Table 8-3: Depth Change from Baseline (m)

Scenario	Inspection Point Change from Baseline (m)									
	1	2	3	4	5	6	7	8	9	10
Rainfall Boundary (+20%)	0.001	0.177	0.000	0.437	0.002	0.040	0.033	0.000	0.475	0.000
Rainfall Boundary (-20%)	0.000	0.000	0.000	-0.044	-0.002	-0.002	0.000	0.000	-0.028	0.000
Manning's Roughness (+20%)	0.000	0.000	0.000	-0.001	0.001	0.001	0.001	0.000	-0.003	0.000
Manning's Roughness (-20%)	0.000	0.000	0.000	0.001	-0.001	0.000	0.000	0.000	0.002	0.000
Downstream Boundary (+0.2m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Downstream Boundary (-0.2m)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Winter Profile 3hr	-0.001	0.000	0.000	-0.080	-0.004	-0.005	-0.001	0.000	-0.077	0.000
Summer Profile 1hr	0.000	0.000	0.000	-0.080	-0.001	-0.001	0.001	0.000	-0.074	0.000
Winter Profile 1hr	-0.002	0.000	0.000	-0.153	-0.012	-0.008	0.000	0.000	-0.194	0.000

The results for the sensitivity runs show that although flood depths differ slightly across the site, the difference is within 100mm, for all sensitivity runs except the increase in rainfall inflow. The depth changes highlighted red indicate the greatest variations from the baseline, and it is clear that these changes are more likely at inspection points 4 and 9. With reference to **Figure 8-3**, inspection point 4 is in the low lying loading bay and inspection point 9 is at one of the lowest areas of the site. Therefore, any increase in rainfall intensity is likely to affect these areas the most, as surface water would pool in the lower areas of the site.

The Manning's roughness values are likely to be "noise" differences, assumed to be as a result of the interpolation and convergence between model time-steps and do not lead to any increase in flood extent or peak flood level.

The model results also show more variation due to changes to the changes in seasonal profile and duration of the storm event, with the winter profile resulting in the most reduction in flood depth. The use of the 1 hour storm duration for the summer profile also results in a relatively large change from the baseline. Again, these changes are more obvious at the low lying inspection points 4 and 9, which is to be expected.

The sensitivity matrix demonstrates that the model:

- Is sensitive to changes in the rainfall hyetograph;
- Is not sensitive to changes to the Manning's roughness values;
- Is not sensitive to changes in the downstream boundary;
- Is sensitive to seasonal profile;
- Is sensitive to storm duration.

Given the above, the model is considered to provide a robust prediction of the storm events simulated.

9 Model Results

Model results are presented in the form of mapped flood extent and depth outputs. The most extreme event (1 in 100 year (+45%CC) maps have been included in **Appendix B** and the other return period events can be downloaded via the link provided in **Appendix B**.

Flood depths of less than 0.005m (5mm) were removed from the depth maps to provide a clearer presentation of areas at risk of flooding, at the request of the LLFA.

9.1 Summary of Results

9.1.1 Present Day

The flood extents broadly match the SWMP mapping and EA surface water maps. The overland flow path from the north of the catchment is clearly visible, even in the 1 in 30 year return period event. EA surface water mapping indicates a vulnerable area within the site boundary to be to the south of the existing buildings, where water appears to pool against the flyover. Additionally, the south east part of the site and Magdalen Street are flooded in the extreme scenarios. The model results show this to be the case for the baseline existing and proposed scenarios, although the flood extent within the site appears to be greater than the EA mapping suggests.

9.1.2 Impacts of Climate Change

Climate change is predicted to increase flood extents in those areas highlighted as being at most risk in the present day scenario. The model results can therefore be used to investigate suitable mitigation measures and inform flood warning systems within the site.

9.1.3 Model Health

The model simulation log files (TUFLOW *.tlf* files) show that the model is healthy, with peak and final mass errors of less than 1% for all of the simulated events. There were no recorded model warnings during any of the simulations for all events. The .tlf files are summarised for the 1 in 30, 1 in 30 (+40%CC), 1 in 100, 1 in 100 (+20%CC) and 1 in 100 (+45%CC) events in **Appendix C**.

Royal HaskoningDHV

10 Assumptions, Limitations and Recommendations

10.1 Assumptions

Hydrological and hydraulic models are constructed from empirical and numerical components that, by definition, have assumptions built into their underlying parameters and calculations. Other assumptions also arise in their development due to uncertainty in, or absence of suitable input data (e.g. percentage run-off or losses to sewers). Therefore, it is important to understand what assumptions have been made in the development of a model so as to appreciate the limitations of the results and draw appropriate conclusions.

The key assumptions made during this study are listed below:

10.1.1 Hydrological Assumptions

The hydrological analysis assumes:

- FEH13 design storm profiles for a 3 hour design storm duration across the whole catchment;
- Net rainfall was used as this included catchment specific losses;
- Average Standard Annual Average Rainfall (SAAR) and Design Rainfall depths across the whole Catchment;

10.1.2 Hydraulic Assumptions

The 2D hydraulic model assumes:

- The application of a single rainfall boundary to apply inflow hyetographs covering the whole catchment;
- The Digital Elevation Model has derived from filtered Environment Agency LiDAR data is accurate and representative of the topography of the catchment;
- 2D surface roughness values based on the original CDC2 model are acceptable. Verification of roughness in the vicinity of the site has been undertaken, using online aerial photography and reviewed against Chow (1959);

10.2 Limitations

The limitations in any numerical model are generally related to the quality and comprehension of the available input data. In particular to this study, the detail and availability of the antecedent conditions limits the accuracy to which the simulated design events reflect the response of the catchment.

Calibration data in the form of recorded depths and accurate locations of flooding historic events was not available, therefore the model could only be crudely validated against the 2014 storm events.

There were several data limitations to the construction of the model. These included unknown threshold levels of individual properties offsite and limited information on external inflows from adjacent catchments into the study area. The assumptions used in the original CDC2 modelling carried out by NCC were accepted and applied to this study in the absence of data on the threshold levels.

10.3 Recommendations

The model was initially built using the gross rainfall hyetographs with drainage applied as losses at a rate of 7mm/hour, which represented a worst-case scenario given the rate of 7mm/hour is very low.

Further to discussions with the LLFA, they identified that they believed that this rate was not representative of the whole catchment. Consequently, it was decided that the net rainfall hyetographs should be used, as these included losses in the form of seasonal variation factor and area reduction factors. The negative rainfall boundary was therefore removed, as the losses where factored into the input hyetograph.

The net rainfall model results present a more likely representation of the flood risk to the catchment, which is demonstrated by the similarities with the EA’s online surface water mapping. It is therefore recommended that these results should be used to design mitigation measures, as this demonstrates a worst-case scenario and would result in more robust flood mitigation in the event that sewers are at capacity.

The LLFA also highlighted that the Anglian Water sewer network in the vicinity of the site should be included. This has now been included in the updated model. The model boundary has also been extended to capture the wider catchment.

The model has been run for a proposed ‘unmitigated’ and proposed ‘mitigated’ scenario to demonstrate the impact of the mitigation measures, namely having raised humps at the entrance to the basement car park and service yard.

Royal HaskoningDHV

11 Conclusions

A two-dimensional direct rainfall hydraulic model of the Catton and Sewell catchment was constructed to understand the surface water flood risk to Anglia Square, Norwich NR3 1DZ. The purpose of the modelling study is to support a planning application at the site and to inform suitable flood mitigation measures for the proposed development.

The model has been based on the original Catton and Sewell model constructed in 2011 as part of the Norwich Surface Water Management Plan (SWMP). It was necessary to build a model to cover the whole catchment, given the main flood risk results from an overland surface water flow path originating in the north of the catchment, which flows through the site. Discussions with the LLFA highlighted the age of the original model and the need to update certain elements, therefore a hydrological analysis was carried out and the hyetographs were updated using the FEH13 Depth Duration Frequency rainfall depths. The latest EA LiDAR data was used to cover the catchment outside of the site boundary, while the topographic survey of the site and proposed development plans were used to create the geometry of Anglia Square.

Following comments from the LLFA on the model submitted as part of an earlier application at the site, further amendments were made to extend the model to cover the wider catchment (based on the WFD waterbody catchment boundary) and to include Anglian Water sewers in the surrounding roads. The model was also run with the updated rainfall climate change allowances.

During the hydrological analysis, a comparison was made between the summer and winter profiles. FEH guidelines recommend using the summer profile due to high URBEXT and BFIHOST values. The summer profile and 3 hour storm duration were the critical storm event, so this was used in all design events. Sensitivity tests were carried out on the winter profile and 1 hour storm duration. It was noted that the 1 hour storm duration resulted in much shallower flood depths than the design storm duration.

The original model applied a constant infiltration value of 7mm/hour to represent drainage losses. This approach was initially used for the model, as specific information on the Anglian Water sewer network was unknown, however further comments resulted in the nearby Anglian Water sewers being included in the model. The gross rainfall was used to derive the hyetographs, with the drainage losses applied in TUFLOW as a negative rainfall boundary. Subsequent discussion with the LLFA highlighted that this may not be representative of the whole catchment. Therefore, the ‘Net Rainfall’ hyetographs were used as these included losses, although notably did not include any losses to sewers, thus representing a worst-case scenario.

Materials layers from the original model were used for most of the catchment. The local area close to the site was checked and materials layers amended where necessary.

The model was simulated for a range of return periods for the present day and with consideration for the impacts of climate change. A ‘mitigation measures’ proposed scenario was also run, which included installing a hump at the entrance to the basement car park and service yard to prevent water entering these areas.

The model was tested for sensitivity to several parameters including storm duration, rainfall, downstream boundary and Manning’s roughness. Additional runs were also included as a rough validation exercise, based on the 27th May 2014 and 20th July 2014 historic events for which there is some evidence of flooding locations. These sensitivity tests indicate that the model is relatively unaffected by changes in these parameters and validates well against known flood locations from the historic events. Flood extents and depths were also compared against the EA Risk of Surface Water flood maps, and showed the model results to reflect this well.

Flood depth and extents maps were generated from the results. It is not recommended that the results be used at the individual property scale given the coarse resolution relative to the size of properties. It is however considered suitable to inform the Flood Risk Assessment for the proposed development at Anglia Square and to determine mitigation measures.

12 Bibliography

Centre for Ecology & Hydrology. (2019). *Flood Estimation Handbook Web Service*. Retrieved from https://fehweb.ceh.ac.uk/

Chow, V. T. (1959). *Open Channel Hydraulics.*

Environment Agency. (2013). *Benchmarking the latest generation of 2D hydraulic modelling pacakages.* Defra and Environment Agency.

Environment Agency. (2019). *Coastal flood boundary conditions for the UK: update 2018.* Bristol: Environment Agency.

Environment Agency. (2020, July 22). *Guidance, Flood risk assessments: climate change allowances*. Retrieved from Gov.uk: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

IWEM. (1987). *Water Practice Mannual No. 7, River Engineering I; Design Principles.* Institute of Water and Environmental Management.

Ordnance Survey. (n.d.). *Master Map Data* . Retrieved 2019, from 5.2.6. The land use classification has been determined by the use of Ordnance Survey MasterMap Data

Appendix A: FEH Data

VERSION	"FEH CD-R	Version	4.0.0	exported a	16:11:19	GMT	Tue	01-Feb-22
CATCHMEI	GB		622800	309650	TG 22800	09650		
CENTROID	GB		623425	311523	TG 23425	11523		
AREA	10.6375							
ALTBAR	29							
ASPBAR	215							
ASPVAR	0.18							
BFIHOST	0.859							
BFIHOST19	0.861							
DPLBAR	3.4							
DPSBAR	17.9							
FARL	1							
FPEXT	0.1456							
FPDBAR	0.556							
FPLOC	0.964							
LDP	5.93							
PROPWET	0.27							
RMED-1H	11.2							
RMED-1D	27.4							
RMED-2D	34.7							
SAAR	615							
SAAR4170	634							
SPRHOST	16.43							
URBCONC1	0.885							
URBEXT19	0.3853							
URBLOC19	0.923							
URBCONC2	0.928							
URBEXT20	0.3899							
URBLOC20	0.953							
C	-0.02352							
D1	0.27622							
D2	0.36542							
D3	0.25417							
E	0.31058							
F	2.48834							
C(1 km)	-0.024							
D1(1 km)	0.275							
D2(1 km)	0.37							
D3(1 km)	0.255							
E(1 km)	0.31							
F(1 km)	2.498							

P0030_3hr_SM

Time	Rain
0	0
0.01	0.040443
0.066667	0.044408
0.133333	0.049218
0.2	0.054312
0.266667	0.059883
0.333333	0.066131
0.4	0.073156
0.466667	0.081082
0.533333	0.090055
0.6	0.100255
0.666667	0.111905
0.733333	0.125281
0.8	0.140736
0.866667	0.158729
0.933333	0.179867
1	0.204988
1.066667	0.235283
1.133333	0.27255
1.2	0.319713
1.266667	0.382095
1.333333	0.471474
1.4	0.627752
1.466667	0.997533
1.533333	0.645658
1.6	0.494359
1.666667	0.406742
1.733333	0.344623
1.8	0.296926
1.866667	0.258686
1.933333	0.227185
2	0.200748
2.066667	0.178256
2.133333	0.158921
2.2	0.142164
2.266667	0.127543
2.333333	0.114715
2.4	0.103407
2.466667	0.0934
2.533333	0.084513
2.6	0.076596
2.666667	0.069523
2.733333	0.06319
2.8	0.057506
2.866667	0.052395
2.933333	0.047791
3	0

Time	Rain
0	0
0.01	0.05662
0.066667	0.062171
0.133333	0.068905
0.2	0.076037
0.266667	0.083837
0.333333	0.092583
0.4	0.102418
0.466667	0.113514
0.533333	0.126077
0.6	0.140358
0.666667	0.156667
0.733333	0.175393
0.8	0.197031
0.866667	0.22222
0.933333	0.251814
1	0.286983
1.066667	0.329396
1.133333	0.38157
1.2	0.447598
1.266667	0.534934
1.333333	0.660063
1.4	0.878853
1.466667	1.396546
1.533333	0.903921
1.6	0.692103
1.666667	0.569438
1.733333	0.482472
1.8	0.415696
1.866667	0.362161
1.933333	0.31806
2	0.281047
2.066667	0.249558
2.133333	0.22249
2.2	0.199029
2.266667	0.17856
2.333333	0.160601
2.4	0.14477
2.466667	0.13076
2.533333	0.118318
2.6	0.107234
2.666667	0.097333
2.733333	0.088466
2.8	0.080509
2.866667	0.073353
2.933333	0.066907
3	0

P0075_3hr_SM

Time	Rain
0	0
0.01	0.05084
0.066667	0.055949
0.133333	0.062043
0.2	0.068325
0.266667	0.075356
0.333333	0.083244
0.4	0.09212
0.466667	0.102141
0.533333	0.113494
0.6	0.126409
0.666667	0.141173
0.733333	0.15814
0.8	0.177765
0.866667	0.200638
0.933333	0.227543
1	0.25956
1.066667	0.298229
1.133333	0.345874
1.2	0.406272
1.266667	0.486307
1.333333	0.601182
1.4	0.802324
1.466667	1.279171
1.533333	0.830614
1.6	0.63734
1.666667	0.525246
1.733333	0.445628
1.8	0.384386
1.866667	0.335205
1.933333	0.294631
2	0.260533
2.066667	0.23149
2.133333	0.206496
2.2	0.184814
2.266667	0.165879
2.333333	0.149254
2.4	0.13459
2.466667	0.121603
2.533333	0.110064
2.6	0.099778
2.666667	0.090586
2.733333	0.082352
2.8	0.074959
2.866667	0.068309
2.933333	0.062315
3	0

P0100_3hr_SM

Time	Rain
0	0
0.01	0.054588
0.066667	0.060152
0.133333	0.066628
0.2	0.073382
0.266667	0.080942
0.333333	0.089425
0.4	0.098973
0.466667	0.109754
0.533333	0.121972
0.6	0.135876
0.666667	0.151774
0.733333	0.170051
0.8	0.191199
0.866667	0.215856
0.933333	0.244874
1	0.279421
1.066667	0.321167
1.133333	0.372633
1.2	0.437915
1.266667	0.524474
1.333333	0.648794
1.4	0.866578
1.466667	1.383226
1.533333	0.899192
1.6	0.690476
1.666667	0.569364
1.733333	0.483284
1.8	0.41703
1.866667	0.363793
1.933333	0.319851
2	0.282905
2.066667	0.251422
2.133333	0.22432
2.2	0.2008
2.266667	0.180255
2.333333	0.162211
2.4	0.146292
2.466667	0.132191
2.533333	0.119658
2.6	0.108486
2.666667	0.098499
2.733333	0.089552
2.8	0.081518
2.866667	0.07429
2.933333	0.067776
3	0

P0100_20CC_3hr_SM

Time	Rain
0	0
0.01	0.065505
0.066667	0.072182
0.133333	0.079953
0.2	0.088059
0.266667	0.09713
0.333333	0.10731
0.4	0.118768
0.466667	0.131705
0.533333	0.146367
0.6	0.163051
0.666667	0.182129
0.733333	0.204061
0.8	0.229439
0.866667	0.259028
0.933333	0.293849
1	0.335305
1.066667	0.385401
1.133333	0.44716
1.2	0.525498
1.266667	0.629369
1.333333	0.778552
1.4	1.039894
1.466667	1.659871
1.533333	1.07903
1.6	0.828571
1.666667	0.683237
1.733333	0.579941
1.8	0.500436
1.866667	0.436552
1.933333	0.383821
2	0.339486
2.066667	0.301707
2.133333	0.269184
2.2	0.24096
2.266667	0.216306
2.333333	0.194654
2.4	0.17555
2.466667	0.158629
2.533333	0.14359
2.6	0.130183
2.666667	0.118199
2.733333	0.107462
2.8	0.097822
2.866667	0.089148
2.933333	0.081331
3	0

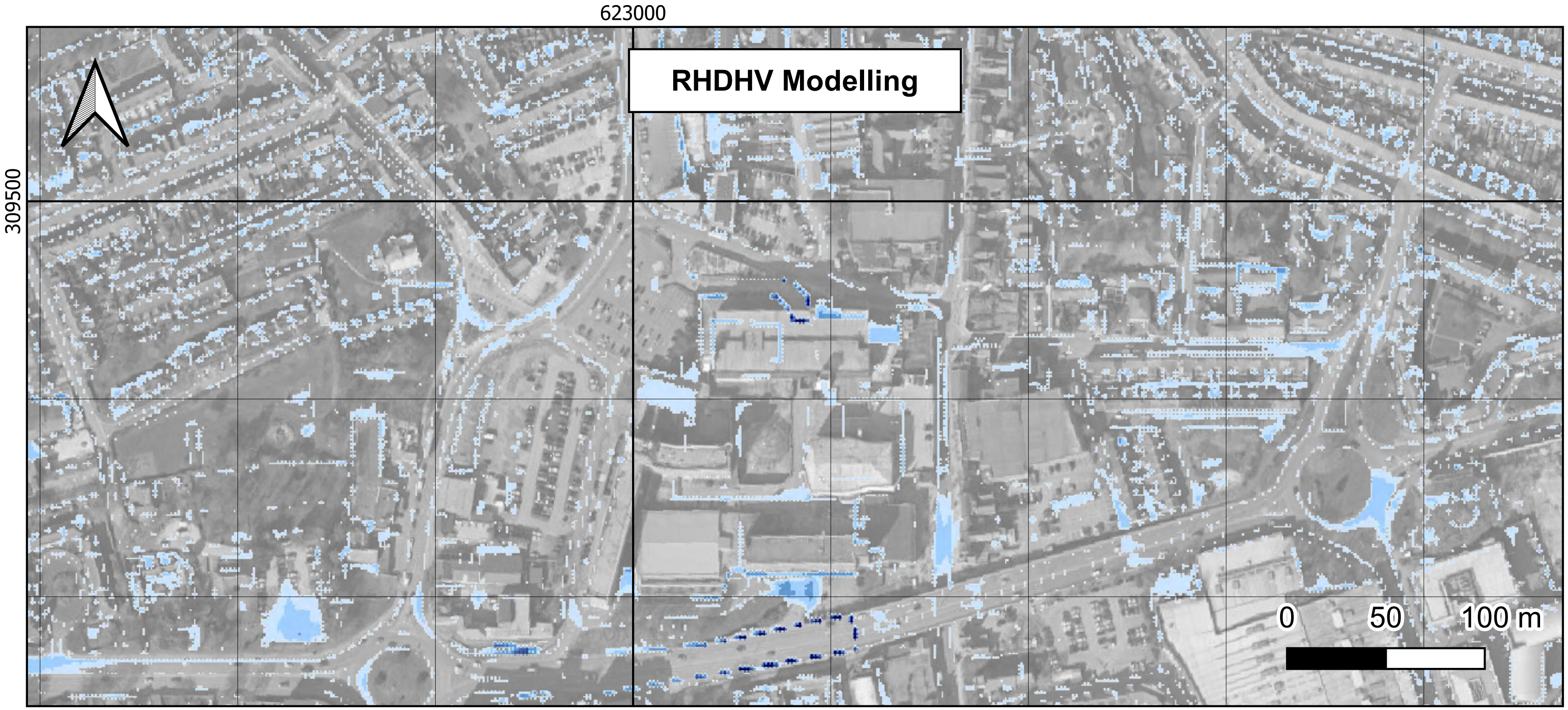
P0100_40CC_3hr_SM

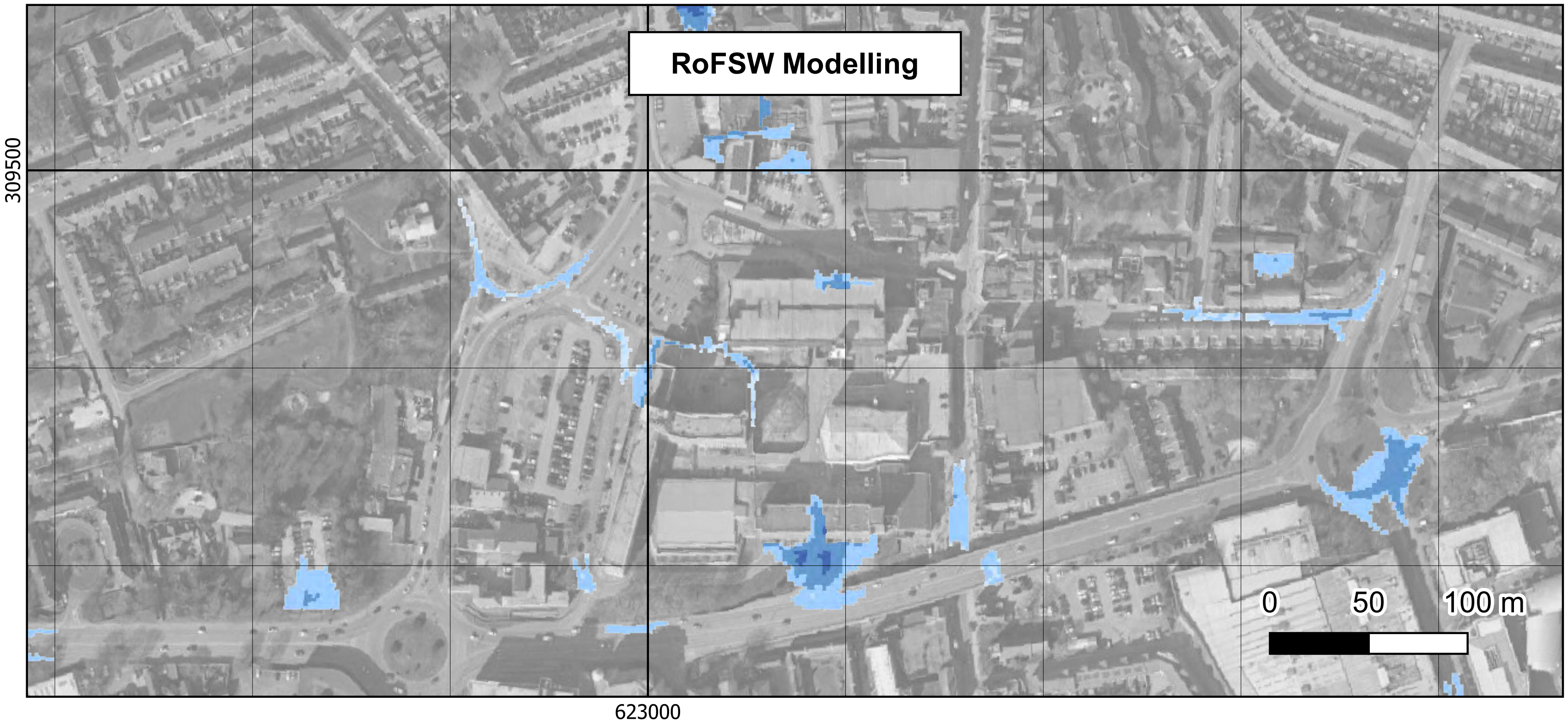
Time	Rain
0	0
0.01	0.076423
0.066667	0.084212
0.133333	0.093279
0.2	0.102735
0.266667	0.113318
0.333333	0.125195
0.4	0.138562
0.466667	0.153656
0.533333	0.170761
0.6	0.190227
0.666667	0.212483
0.733333	0.238071
0.8	0.267679
0.866667	0.302199
0.933333	0.342824
1	0.391189
1.066667	0.449634
1.133333	0.521686
1.2	0.613081
1.266667	0.734264
1.333333	0.908311
1.4	1.21321
1.466667	1.936516
1.533333	1.258868
1.6	0.966666
1.666667	0.79711
1.733333	0.676598
1.8	0.583841
1.866667	0.509311
1.933333	0.447791
2	0.396067
2.066667	0.351991
2.133333	0.314048
2.2	0.28112
2.266667	0.252357
2.333333	0.227096
2.4	0.204808
2.466667	0.185067
2.533333	0.167521
2.6	0.15188
2.666667	0.137899
2.733333	0.125373
2.8	0.114125
2.866667	0.104006
2.933333	0.094886
3	0

Time	Rain
0	0
0.01	0.079152
0.066667	0.08722
0.133333	0.09661
0.2	0.106404
0.266667	0.117365
0.333333	0.129666
0.4	0.143511
0.466667	0.159143
0.533333	0.17686
0.6	0.19702
0.666667	0.220072
0.733333	0.246574
0.8	0.277238
0.866667	0.312992
0.933333	0.355067
1	0.40516
1.066667	0.465692
1.133333	0.540318
1.2	0.634976
1.266667	0.760488
1.333333	0.940751
1.4	1.256539
1.466667	2.005677
1.533333	1.303828
1.6	1.00119
1.666667	0.825578
1.733333	0.700762
1.8	0.604693
1.866667	0.5275
1.933333	0.463783
2	0.410212
2.066667	0.364562
2.133333	0.325264
2.2	0.29116
2.266667	0.26137
2.333333	0.235207
2.4	0.212123
2.466667	0.191677
2.533333	0.173504
2.6	0.157304
2.666667	0.142824
2.733333	0.12985
2.8	0.118201
2.866667	0.107721
2.933333	0.098275
3	0

Appendix B: Flood Maps

All Flood Maps can be downloaded using the link:
https://royalhaskoningdhv.box.com/s/riqektt5l5imndj4ah9uj9x0lj6nbyzv





Key

Depth (mm)

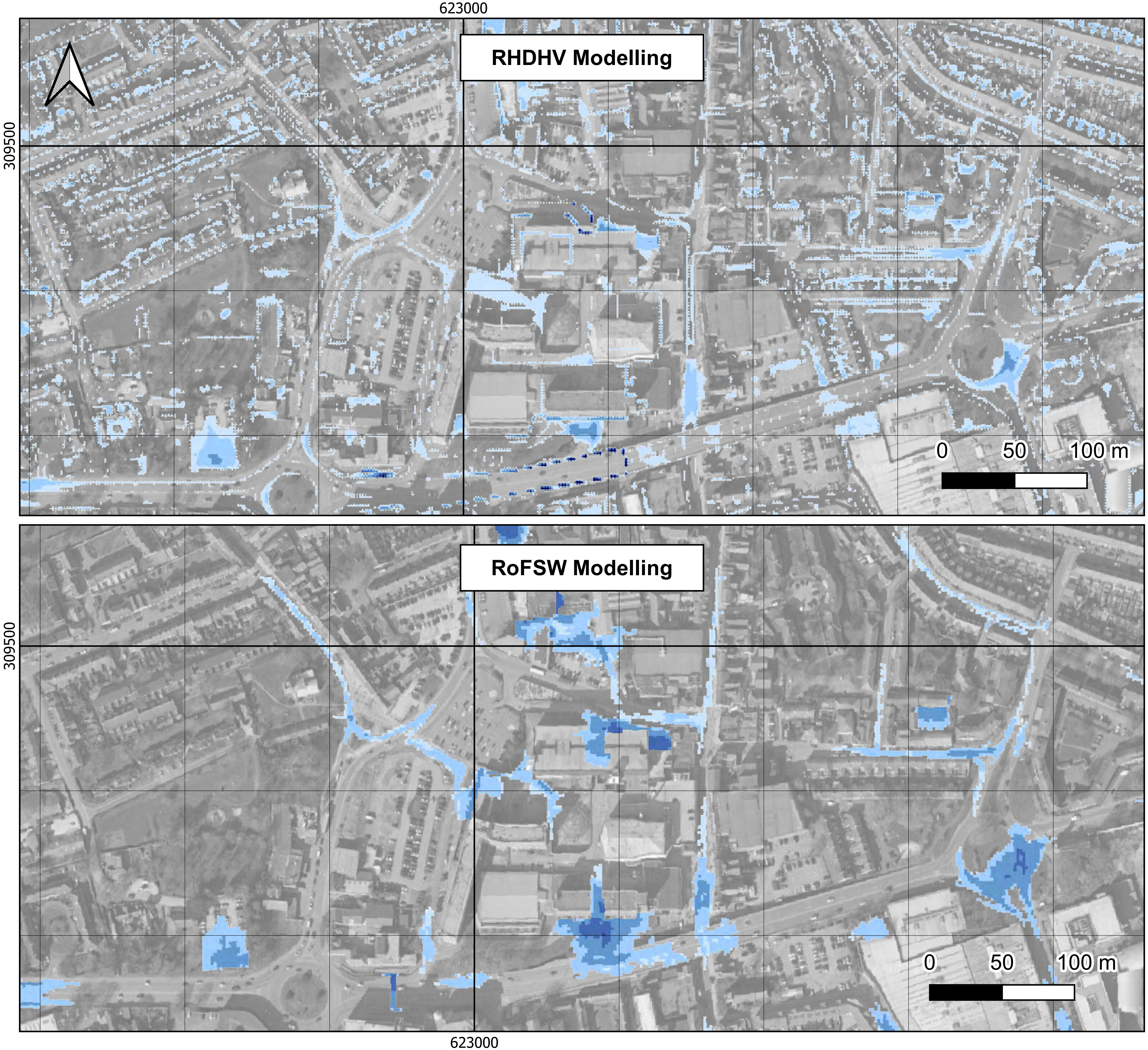
- <= 0.050000
- Below 150mm
- 150-300mm
- 300-600mm
- 600-900mm
- 900-1200mm
- Over 1200mm

PRELIMINARY SURFACE WATER FLOOD MODEL

MODELLING VALIDATION

1:30 Year Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

Depth (mm)

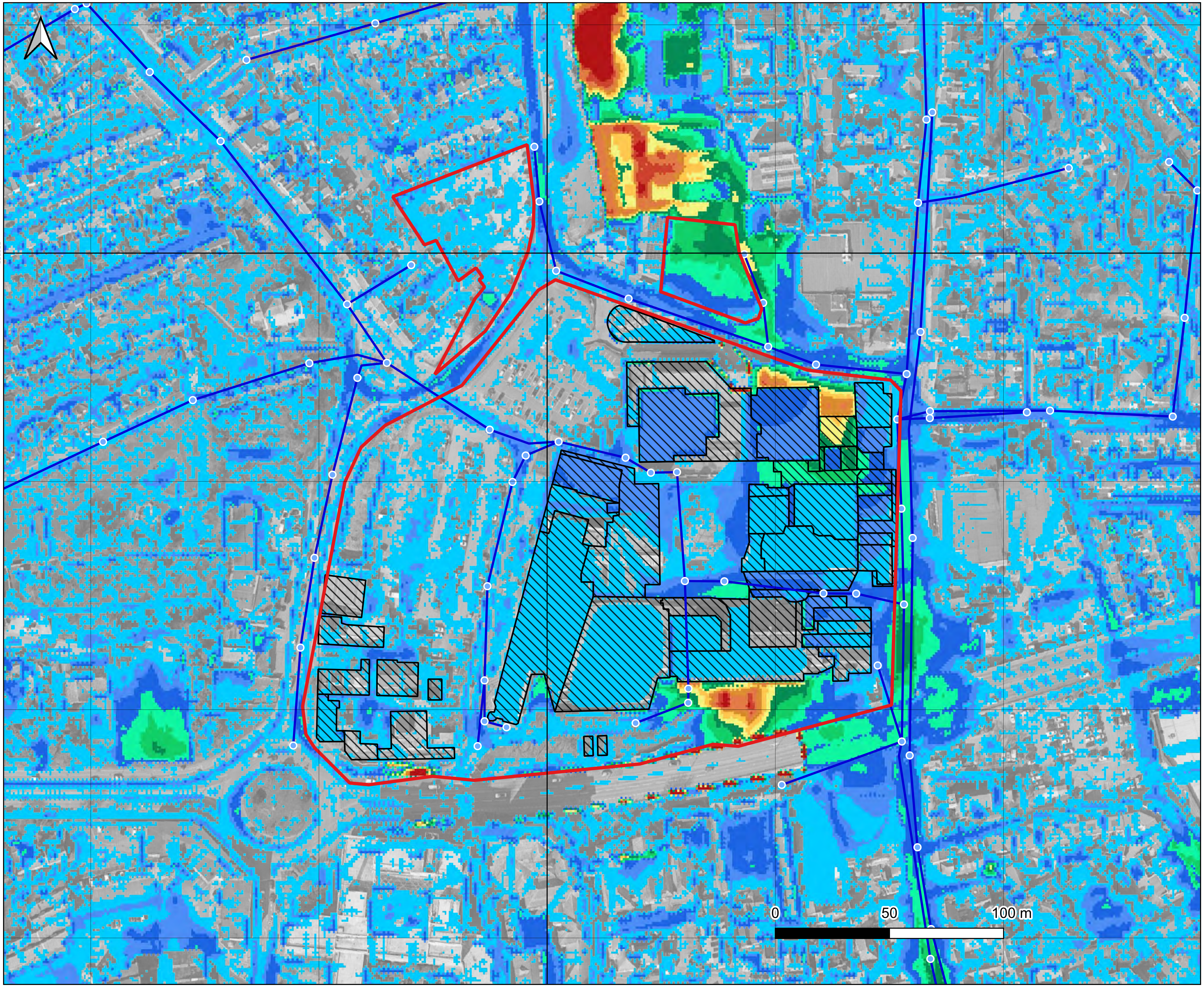
- <= 0.050000
- Below 150mm
- 150-300mm
- 300-600mm
- 600-900mm
- 900-1200mm
- Over 1200mm

PRELIMINARY SURFACE WATER FLOOD MODEL

MODELLING VALIDATION

1:100 Year Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Existing Sewer Pits
- Existing Culverts
- Existing OnSite Buildings

Flood Depth (m)

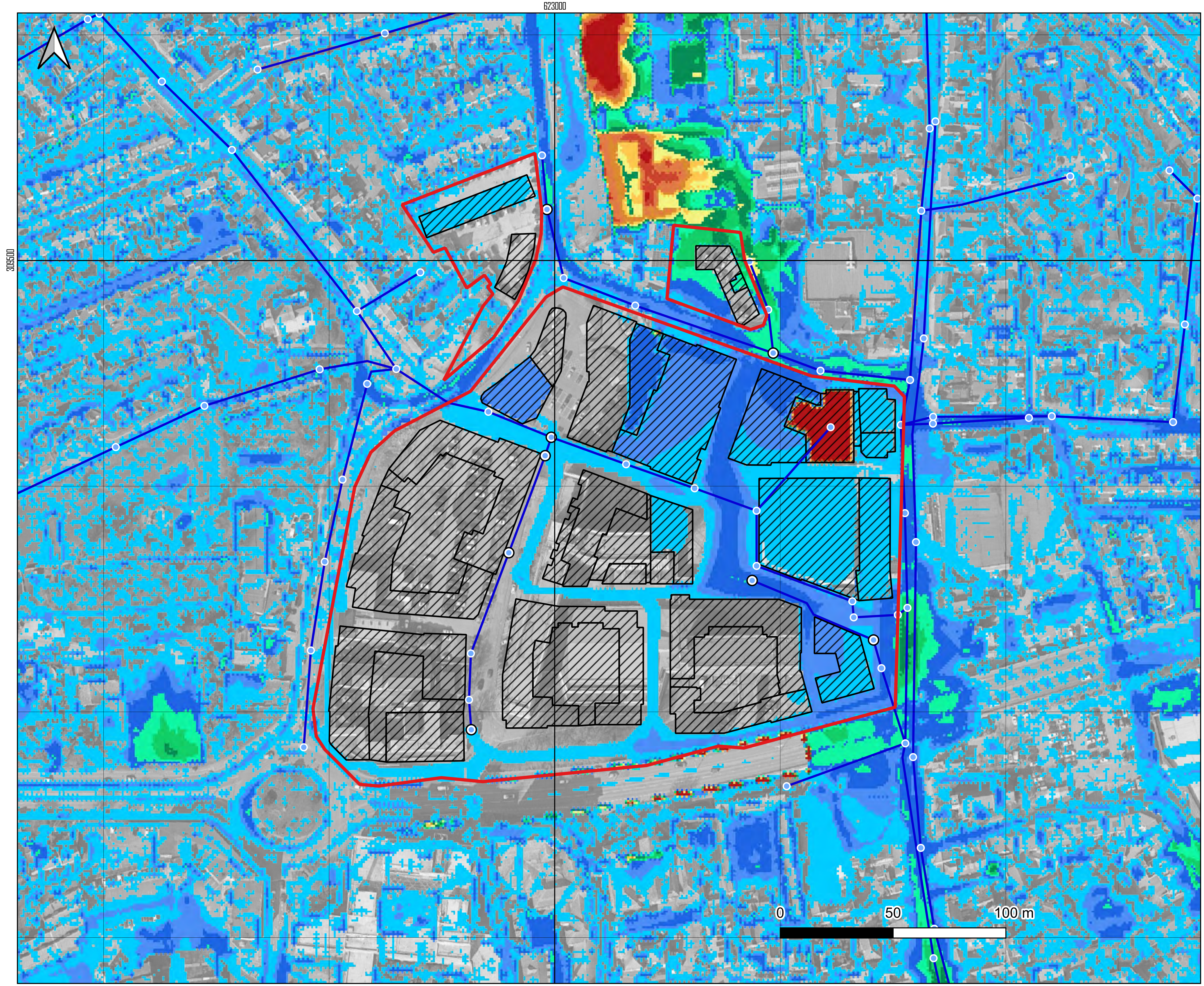
- <= 0.005
- 0.005 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1.0
- \> 1.0

ANGLIA SQUARE
SURFACE WATER MODEL

Existing Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Proposed Sewer Pits
- Proposed Culverts
- Proposed OnSite Buildings
- On Site Drainage Inflows

Flood Depth (m)

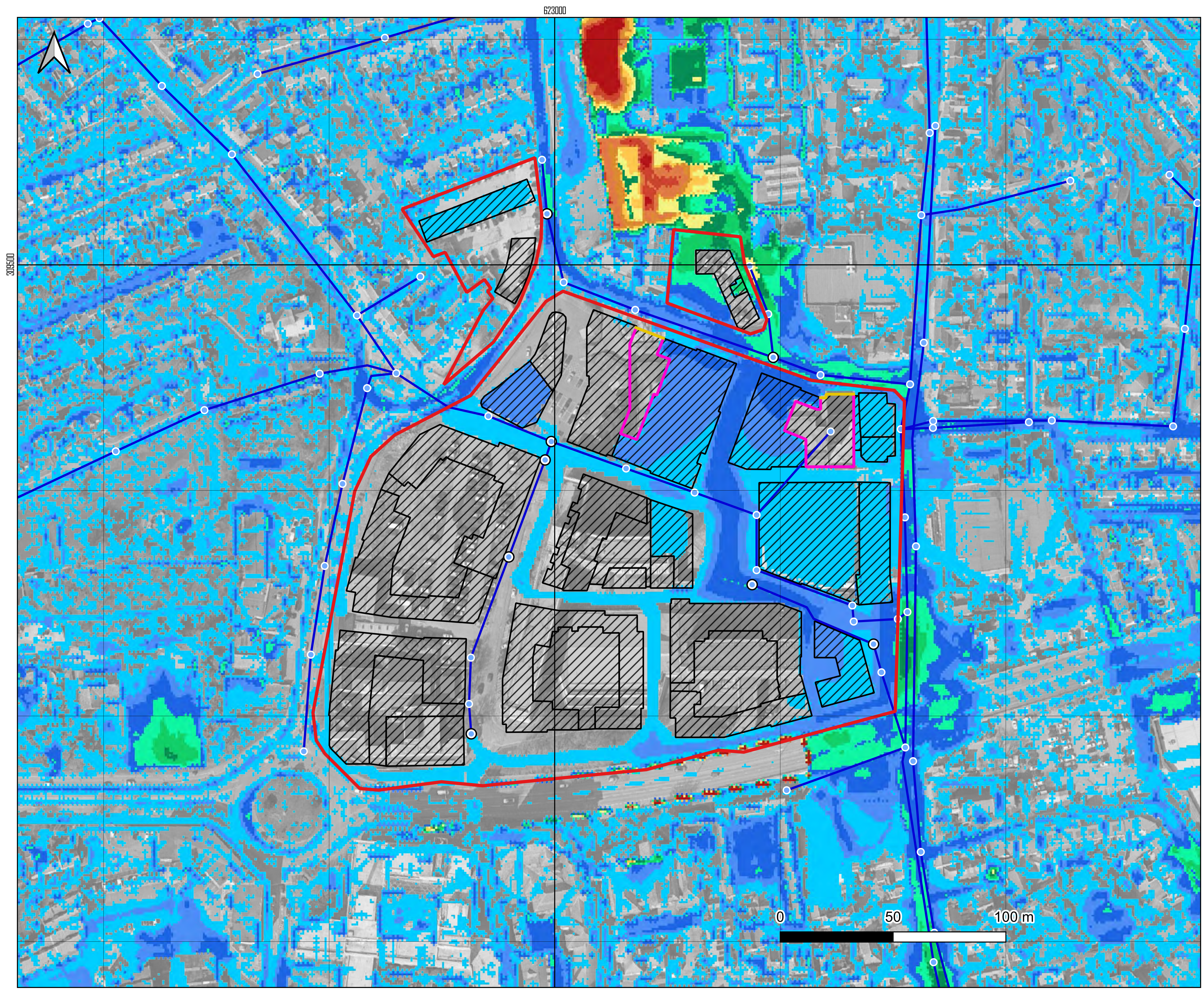
- <= 0.005
- 0.005 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1.0
- > 1.0

ANGLIA SQUARE SURFACE WATER MODEL

Proposed (Unmitigated) Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Proposed Sewer Pits
- Proposed Culverts
- Proposed Barriers
- Proposed Walls
- Proposed OnSite Buildings
- On Site Drainage Inflows

Flood Depth (m)

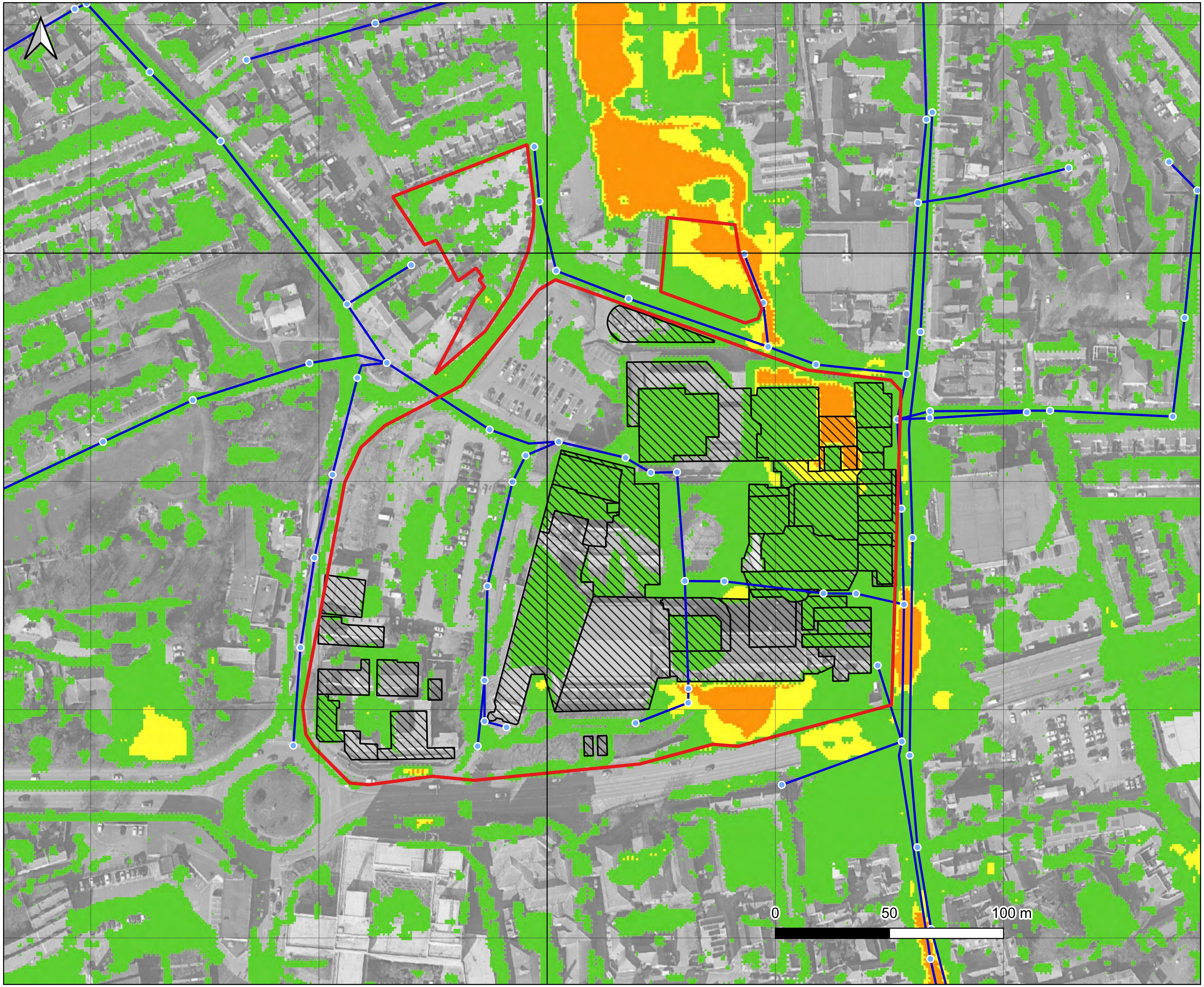
- <= 0.005
- 0.005 - 0.05
- 0.05 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1.0
- > 1.0

ANGLIA SQUARE SURFACE WATER MODEL

Proposed (Mitigated) Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Existing Sewer Pits
- Existing Culverts
- Existing OnSite Buildings

Flood Hazard Rating

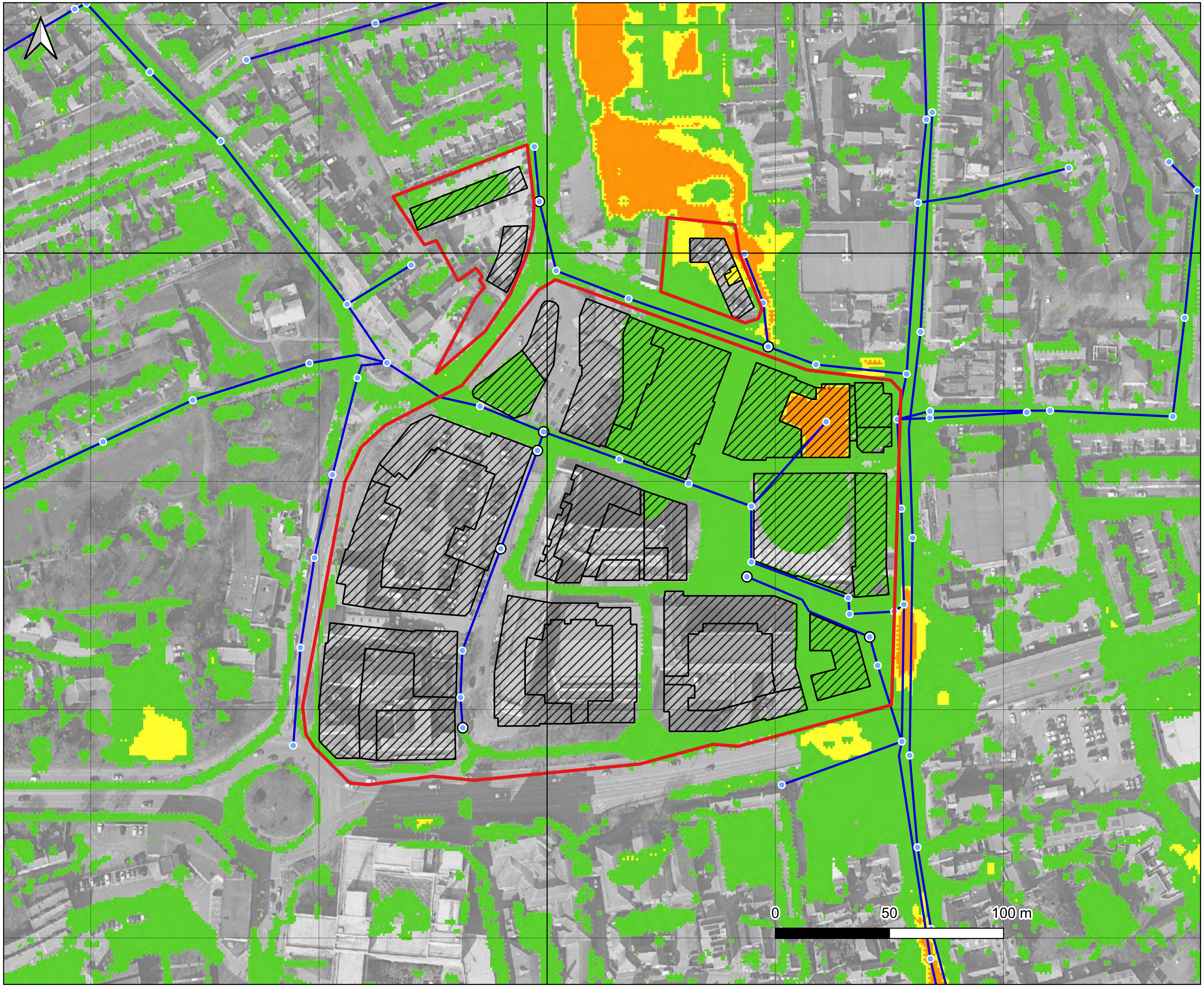
- <= 0.005
- 0.005 - 0.75
- 0.75 - 1.25
- 1.25 - 2.00
- > 2.00

ANGLIA SQUARE SURFACE WATER MODEL

Existing Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Proposed Sewer Pits
- Proposed Culverts
- Proposed OnSite Buildings
- On Site Drainage Inflows

Flood Hazard Rating

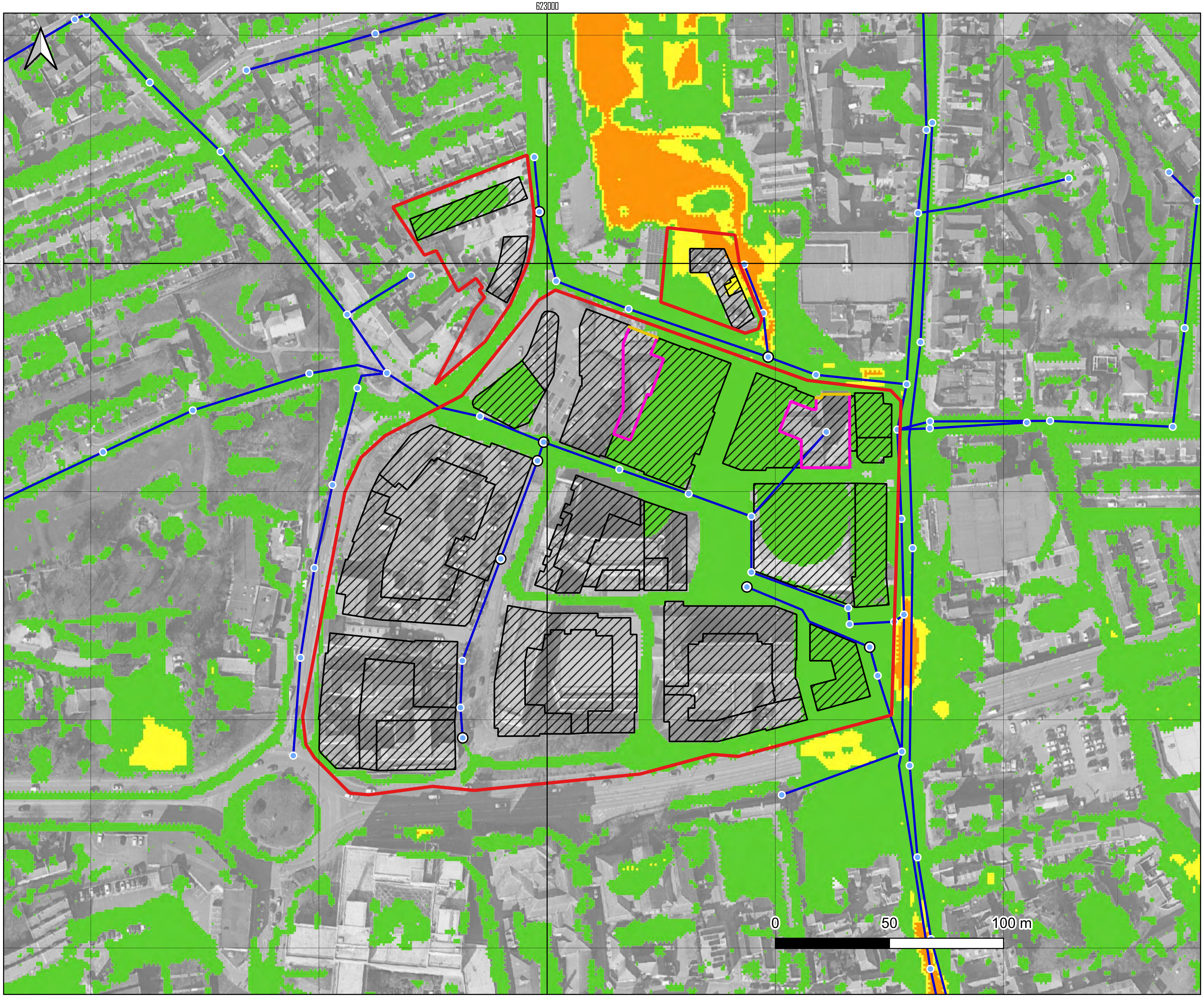
- <= 0.005
- 0.005 - 0.75
- 0.75 - 1.25
- 1.25 - 2.00
- > 2.00

ANGLIA SQUARE SURFACE WATER MODEL

Proposed (Unmitigated) Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together



Key

- Application Boundary
- Proposed Sewer Pits
- Proposed Culverts
- Proposed Barriers
- Proposed Walls
- Proposed OnSite Buildings
- On Site Drainage Inflows

Flood Hazard Rating

- <= 0.005
- 0.005 - 0.75
- 0.75 - 1.25
- 1.25 - 2.00
- > 2.00

ANGLIA SQUARE SURFACE WATER MODEL

Proposed (Mitigated) Conditions

1:100 Year plus 45% Climate Change Flood Event

Royal HaskoningDHV
Enhancing Society Together

Royal HaskoningDHV

Appendix C: TLF File Summary

Anglia_Square_Existing_P0030_3hr_SM_01(
Model Parameters & Statistics

Royal HaskoningDHV

BUILD SETTINGS

TUFLOW Engine = 2020-10-AA-iSP-w64
HPC Build = 2.16.

TEMPORAL SETTINGS

1D Timestep (s) = 0.25
2D Timestep (s) = 1.000
Start Time (hrs) = 0.000
Finish Time (hrs) = 6.00

GRID SETTINGS

Cell Size (m) = 2
Grid Size (m) = 3195,3456
Grid Origin (British Grid) = 619728.406 307509.768
Grid Rotation (degrees) = 0.000000

BOUNDARIES

Number of HS Boundaries = 0
Number of HT Boundaries = 4
Number of HQ Boundaries = 0

Number of QC Boundaries = 0
Number of QT Boundaries = 0
Number of QH Boundaries = 0

1D STRUCTURES

Number of Normal (Blank) Channels = 0
Number of B (Bridge) Structures = 0
Number of BB (Bridge) Structures = 0
Number of C (Circular) Culverts = 85
Number of G (Gradient) Channels = 0
Number of I (Irregular) Culverts = 0
Number of M (hQh Matrix) Channels = 0
Number of N (Non-Inertial) Channels = 0
Number of O (Operated) Structures = 0
Number of P (Pump) Channels = 0
Number of Q (Depth-Discharge) Channels = 0
Number of Q (Depth-Discharge) Pits = 0
Number of VPI Virtual Pipe Inlet Pits = 0
Number of VPO Virtual Pipe Outlet Pits = 0

Number of R (Rectangular) Structures = 85
Number of RG (Radial Gate) Structures = 0
Number of S (Sloping Open) Channels = 0
Number of SG (Sluice Gate) Structures = 0
Number of SP (Spillway) Structures = 0
Number of W (Original Weir) Structures = 0
Number of WB (Broad-crested Weirs)= 0
Number of WC (Crump Weirs)= 0
Number of WD (User-defined Weirs)= 0
Number of WO (Ogee-crested Weirs)= 0
Number of WR (Rectangular Weirs)= 0
Number of WT (Trapezoidal Weirs)= 0
Number of WV (V-Notch Weirs)= 0
Number of WW (Standard Weirs)= 0

WARNINGS AND CHECKS

Number of 1D Negative Depths = 0
Number of 2D Negative Depths = 0

Number of Prior Warnings = 16
Number of Prior Checks = 4
Number of Post Warnings = 0
Number of Post Checks = 0

OUTPUT STATISTICS

Start Volume (m^3) = 8619
End Volume (m^3) = 202118
Volume In (m^3) = 209990
Volume Out (m^3) = 16637
Volume Error (m^3) = 146 or 0.1% of Volume In + Out
Final Cumulative Mass Error = 0.06%
Peak Cumulative Mass Error = 0.08%

Anglia_Square_Existing_P0030_40CC_3hr_S
Model Parameters & Statistics

BUILD SETTINGS

TUFLOW Engine = 2020-10-AA-iSP-w64
HPC Build = 2.16.

TEMPORAL SETTINGS

1D Timestep (s) = 0.25
2D Timestep (s) = 1.000
Start Time (hrs) = 0.000
Finish Time (hrs) = 6.00

GRID SETTINGS

Cell Size (m) = 2
Grid Size (m) = 3195,3456
Grid Origin (British Grid) = 619728.406 307509.768
Grid Rotation (degrees) = 0.000000

BOUNDARIES

Number of HS Boundaries = 0
Number of HT Boundaries = 4
Number of HQ Boundaries = 0

Number of QC Boundaries = 0
Number of QT Boundaries = 0
Number of QH Boundaries = 0

1D STRUCTURES

Number of Normal (Blank) Channels = 0
Number of B (Bridge) Structures = 0
Number of BB (Bridge) Structures = 0
Number of C (Circular) Culverts = 85
Number of G (Gradient) Channels = 0
Number of I (Irregular) Culverts = 0
Number of M (hQh Matrix) Channels = 0
Number of N (Non-Inertial) Channels = 0
Number of O (Operated) Structures = 0
Number of P (Pump) Channels = 0
Number of Q (Depth-Discharge) Channels = 0
Number of Q (Depth-Discharge) Pits = 0
Number of VPI Virtual Pipe Inlet Pits = 0
Number of VPO Virtual Pipe Outlet Pits = 0

Number of R (Rectangular) Structures = 85
Number of RG (Radial Gate) Structures = 0
Number of S (Sloping Open) Channels = 0
Number of SG (Sluice Gate) Structures = 0
Number of SP (Spillway) Structures = 0
Number of W (Original Weir) Structures = 0
Number of WB (Broad-crested Weirs)= 0
Number of WC (Crump Weirs)= 0
Number of WD (User-defined Weirs)= 0
Number of WO (Ogee-crested Weirs)= 0
Number of WR (Rectangular Weirs)= 0
Number of WT (Trapezoidal Weirs)= 0
Number of WV (V-Notch Weirs)= 0
Number of WW (Standard Weirs)= 0

WARNINGS AND CHECKS

Number of 1D Negative Depths = 0
Number of 2D Negative Depths = 0

Number of Prior Warnings = 16
Number of Prior Checks = 5
Number of Post Warnings = 0
Number of Post Checks = 0

OUTPUT STATISTICS

Start Volume (m^3) = 8619
End Volume (m^3) = 279415
Volume In (m^3) = 294038
Volume Out (m^3) = 23202
Volume Error (m^3) = -40 or -0.0% of Volume In + Out
Final Cumulative Mass Error = -0.01%
Peak Cumulative Mass Error = 0.16%

Anglia_Square_Existing_P0100_3hr_SM_01(
Model Parameters & Statistics

Royal HaskoningDHV

BUILD SETTINGS

TUFLOW Engine = 2020-10-AA-iSP-w64
HPC Build = 2.16.

TEMPORAL SETTINGS

1D Timestep (s) = 0.25
2D Timestep (s) = 1.000
Start Time (hrs) = 0.000
Finish Time (hrs) = 6.00

GRID SETTINGS

Cell Size (m) = 2
Grid Size (m) = 3195,3456
Grid Origin (British Grid) = 619728.406 307509.768
Grid Rotation (degrees) = 0.000000

BOUNDARIES

Number of HS Boundaries = 0
Number of HT Boundaries = 4
Number of HQ Boundaries = 0
Number of QC Boundaries = 0
Number of QT Boundaries = 0
Number of QH Boundaries = 0

1D STRUCTURES

Number of Normal (Blank) Channels = 0
Number of B (Bridge) Structures = 0
Number of BB (Bridge) Structures = 0
Number of C (Circular) Culverts = 85
Number of G (Gradient) Channels = 0
Number of I (Irregular) Culverts = 0
Number of M (hQh Matrix) Channels = 0
Number of N (Non-Inertial) Channels = 0
Number of O (Operated) Structures = 0
Number of P (Pump) Channels = 0
Number of Q (Depth-Discharge) Channels = 0
Number of Q (Depth-Discharge) Pits = 0
Number of VPI Virtual Pipe Inlet Pits = 0
Number of VPO Virtual Pipe Outlet Pits = 0
Number of R (Rectangular) Structures = 85
Number of RG (Radial Gate) Structures = 0
Number of S (Sloping Open) Channels = 0
Number of SG (Sluice Gate) Structures = 0
Number of SP (Spillway) Structures = 0
Number of W (Original Weir) Structures = 0
Number of WB (Broad-crested Weirs)= 0
Number of WC (Crump Weirs)= 0
Number of WD (User-defined Weirs)= 0
Number of WO (Ogee-crested Weirs)= 0
Number of WR (Rectangular Weirs)= 0
Number of WT (Trapezoidal Weirs)= 0
Number of WV (V-Notch Weirs)= 0
Number of WW (Standard Weirs)= 0

WARNINGS AND CHECKS

Number of 1D Negative Depths = 0
Number of 2D Negative Depths = 0

Number of Prior Warnings = 16
Number of Prior Checks = 7
Number of Post Warnings = 0
Number of Post Checks = 0

OUTPUT STATISTICS

Start Volume (m^3) = 8619
End Volume (m^3) = 276899
Volume In (m^3) = 291220
Volume Out (m^3) = 22943
Volume Error (m^3) = 2 or 0.0% of Volume In + Out
Final Cumulative Mass Error = 0.00%
Peak Cumulative Mass Error = -0.1%

Anglia_Square_Existing_P0100_20CC_3hr_S
Model Parameters & Statistics

Royal HaskoningDHV

BUILD SETTINGS

TUFLOW Engine = 2020-10-AA-iSP-w64
HPC Build = 2.16.

TEMPORAL SETTINGS

1D Timestep (s) = 0.25
2D Timestep (s) = 1.000
Start Time (hrs) = 0.000
Finish Time (hrs) = 6.00

GRID SETTINGS

Cell Size (m) = 2
Grid Size (m) = 3195,3456
Grid Origin (British Grid) = 619728.406 307509.768
Grid Rotation (degrees) = 0.000000

BOUNDARIES

Number of HS Boundaries = 0
Number of HT Boundaries = 4
Number of HQ Boundaries = 0
Number of QC Boundaries = 0
Number of QT Boundaries = 0
Number of QH Boundaries = 0

1D STRUCTURES

Number of Normal (Blank) Channels = 0
Number of B (Bridge) Structures = 0
Number of BB (Bridge) Structures = 0
Number of C (Circular) Culverts = 85
Number of G (Gradient) Channels = 0
Number of I (Irregular) Culverts = 0
Number of M (hQh Matrix) Channels = 0
Number of N (Non-Inertial) Channels = 0
Number of O (Operated) Structures = 0
Number of P (Pump) Channels = 0
Number of Q (Depth-Discharge) Channels = 0
Number of Q (Depth-Discharge) Pits = 0
Number of VPI Virtual Pipe Inlet Pits = 0
Number of VPO Virtual Pipe Outlet Pits = 0

Number of R (Rectangular) Structures = 85
Number of RG (Radial Gate) Structures = 0
Number of S (Sloping Open) Channels = 0
Number of SG (Sluice Gate) Structures = 0
Number of SP (Spillway) Structures = 0
Number of W (Original Weir) Structures = 0
Number of WB (Broad-crested Weirs)= 0
Number of WC (Crump Weirs)= 0
Number of WD (User-defined Weirs)= 0
Number of WO (Ogee-crested Weirs)= 0
Number of WR (Rectangular Weirs)= 0
Number of WT (Trapezoidal Weirs)= 0
Number of WV (V-Notch Weirs)= 0
Number of WW (Standard Weirs)= 0

WARNINGS AND CHECKS

Number of 1D Negative Depths = 0
Number of 2D Negative Depths = 0

Number of Prior Warnings = 16
Number of Prior Checks = 4
Number of Post Warnings = 0
Number of Post Checks = 0

OUTPUT STATISTICS

Start Volume (m^3) = 8619
End Volume (m^3) = 327854
Volume In (m^3) = 349116
Volume Out (m^3) = 29857
Volume Error (m^3) = -24 or -0.0% of Volume In + Out
Final Cumulative Mass Error = -0.01%
Peak Cumulative Mass Error = 0.09%

Anglia_Square_Existing_P0100_45CC_3hr_S
Model Parameters & Statistics

BUILD SETTINGS

TUFLOW Engine = 2020-10-AA-iSP-w64
HPC Build = 2.16.

TEMPORAL SETTINGS

1D Timestep (s) = 0.25
2D Timestep (s) = 1.000
Start Time (hrs) = 0.000
Finish Time (hrs) = 6.00

GRID SETTINGS

Cell Size (m) = 2
Grid Size (m) = 3195,3456
Grid Origin (British Grid) = 619728.406 307509.768
Grid Rotation (degrees) = 0.000000

BOUNDARIES

Number of HS Boundaries = 0
Number of HT Boundaries = 4
Number of HQ Boundaries = 0
Number of QC Boundaries = 0
Number of QT Boundaries = 0
Number of QH Boundaries = 0

1D STRUCTURES

Number of Normal (Blank) Channels = 0
Number of B (Bridge) Structures = 0
Number of BB (Bridge) Structures = 0
Number of C (Circular) Culverts = 85
Number of G (Gradient) Channels = 0
Number of I (Irregular) Culverts = 0
Number of M (hQh Matrix) Channels = 0
Number of N (Non-Inertial) Channels = 0
Number of O (Operated) Structures = 0
Number of P (Pump) Channels = 0
Number of Q (Depth-Discharge) Channels = 0
Number of Q (Depth-Discharge) Pits = 0
Number of VPI Virtual Pipe Inlet Pits = 0
Number of VPO Virtual Pipe Outlet Pits = 0

Number of R (Rectangular) Structures = 85
Number of RG (Radial Gate) Structures = 0
Number of S (Sloping Open) Channels = 0
Number of SG (Sluice Gate) Structures = 0
Number of SP (Spillway) Structures = 0
Number of W (Original Weir) Structures = 0
Number of WB (Broad-crested Weirs)= 0
Number of WC (Crump Weirs)= 0
Number of WD (User-defined Weirs)= 0
Number of WO (Ogee-crested Weirs)= 0
Number of WR (Rectangular Weirs)= 0
Number of WT (Trapezoidal Weirs)= 0
Number of WV (V-Notch Weirs)= 0
Number of WW (Standard Weirs)= 0

WARNINGS AND CHECKS

Number of 1D Negative Depths = 0
Number of 2D Negative Depths = 0

Number of Prior Warnings = 16
Number of Prior Checks = 2
Number of Post Warnings = 0
Number of Post Checks = 0

OUTPUT STATISTICS

Start Volume (m^3) = 8619
End Volume (m^3) = 386645
Volume In (m^3) = 421826
Volume Out (m^3) = 43602
Volume Error (m^3) = -198 or -0.0% of Volume In + Out
Final Cumulative Mass Error = -0.04%
Peak Cumulative Mass Error = 0.15%