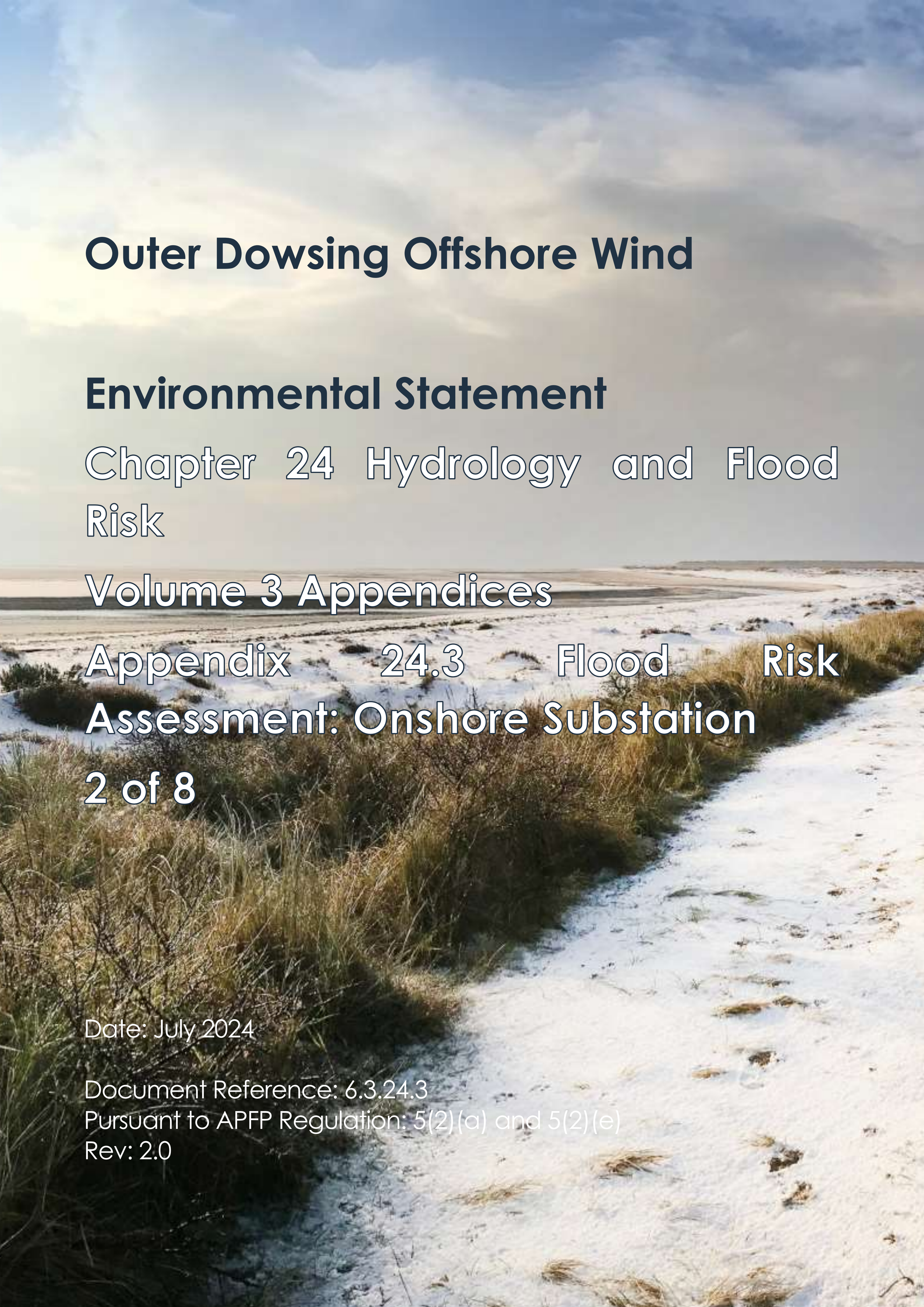

Outer Dowsing Offshore Wind

Environmental Statement

Chapter 24 Hydrology and Flood Risk

Volume 3 Appendices

Appendix 24.3 Flood Risk Assessment: Onshore Substation

2 of 8

Date: July 2024

Document Reference: 6.3.24.3
Pursuant to APFP Regulation: 5(2)(a) and 5(2)(e)
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Document Reference: 6.3.24.3

Appendix A Hydraulic Modelling Report

Appendix 24.3 Flood Risk Assessment Onshore Substation

Outer Dowsing Offshore Wind Environmental Statement

GoBe Consultants Ltd.

SLR Project No.: 410.V05356.00013

12 June 2024

Chapter 24 Appendix 3 Annex 1 River Welland Breach Modelling

Outer Dowsing Offshore Wind Environmental Statement

GoBe Consultants Ltd

Prepared by:

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SLR Project No.: 410.V05356.00013

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12 June 2024

Revision: V3.0(Clean)

Revision Record

Revision	Date	Prepared By	Checked By	Authorised By
V1.0	6 November 2023	SLR Consulting Ltd	GoBe	Outer Dowsing Offshore Wind
V2.0	26 February 2024	SLR Consulting Ltd	GoBe	Outer Dowsing Offshore Wind
V3.0	12 June 2024	SLR Consulting Ltd	GoBe	Outer Dowsing Offshore Wind

Basis of Report

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Change Log Summary of Revisions

Date	Figure number	Figure name	Change made	Reason for Change	Revision
June 2024	3.1	Maximum Flood Depths Baseline Overtopping 0.1% AEP+CC	Update with new model run results	Response to EA model review (Item No. 7.9)	3.0
June 2024	3.10	Values of HPC run parameters	Additional data added to assessment	Response to EA model review (Item No. 14.4)	3.0
June 2024	3.11	Comparison of dVol for Overtopping and Breach scenarios	Additional data added to assessment	Response to EA model review (Item No. 14.4)	3.0
June 2024	4.1	Flood extent of difference cell size sensitivity runs	Additional data added to assessment	Response to EA model review (Item No. 16.2)	3.0
June 2024	4.2	Flood depth difference between 6m and 10m grid cell size (Overtopping - 0.1% AEP+CC)	Additional data added to assessment	Response to EA model review (Item No. 16.2)	3.0
June 2024	4.3	Flood depth difference between normal and -20% roughness (Breach 1 - 0.1% AEP+CC)	Additional data added to assessment	Response to EA model review (Item No. 16.2)	3.0
June 2024	Appendix A	All Figures	Update with new model run results	Response to EA model review (Item No. 7.9)	3.0
June 2024	Appendix B	All Figures	Update with new model run results	Response to EA model review (Item No. 7.9)	3.0

1.0 Introduction

1.1 Context

1. SLR Consulting Limited has been appointed by GoBe Consultants Ltd to prepare a Hydraulic Modelling Technical Report in support of a Flood Risk Assessment (FRA) for the proposed Outer Dowsing Offshore Wind (ODOW) Onshore Substation (OnSS), to be located at Surfleet Marsh, south of Boston, Lincolnshire. The modelling was commissioned prior to the final selection of the OnSS site and therefore covered two site search areas that were under consideration for the Preliminary Environmental Impact Assessment (PEIR). Subsequently, following a site selection and evaluation process, the site at Surfleet Marsh, to the north of the River Welland was selected.
2. The development is part of a Nationally Significant Infrastructure Project (NSIP) that must be designed to remain operational under a 1 in 1,000-year flood event (including climate change). The objective of the modelling is to determine the maximum flood depth under these conditions in order to establish the appropriate design level to provide the necessary protection.
3. This technical report has been prepared under the direction of a Technical Director for Hydrology at SLR who specialises in flood risk and associated planning matters. The report summarises the construction of a 2-Dimensional (2D) hydraulic model for the River Welland and its associated floodplain. The model is newly developed using freely available datasets. The aim of this model is to evaluate the flood risk to the ODOW OnSS site at Surfleet Marsh in the event of a tidal surge and subsequent breach of defences along the River Welland.
4. The outputs of the hydraulic model are considered to provide the best currently available information on the tidal flood risk to the site.
5. This updated version of the report (Version 3.0,June 2024) has been produced following an external audit and review of the modelling , by the Environment Agency.

1.1.1 Consultation

6. A technical note explaining the methodology was submitted to the Environment Agency prior commencement of the modelling. This was reviewed by external consultants and the methodology was amended to address the comments received. Addressed comments and responses are summarised in Table 1-1:. The remaining comments were already incorporated into the methodology.

Table 1-1: Technical note review comments/responses matrix

EA Comment	SLR Response
The methodology doesn't detail how land use will be considered within the 2D Domain i.e., Manning's roughness. The consultant should delineate areas of land use and apply appropriate roughness values.	For land use, the Land Cover Map 2021 (LCM2021) provided by the UK Centre for Ecology & Hydrology (UKCEH) has been utilized, along with the standard roughness values. Specifically, in accordance with EA guidance, we have increased the roughness value within the model to 0.1 for the building footprints.
A 10m 2D grid resolution is proposed based on 1m DTM composite LIDAR data. This is considered appropriate based on the Site topography and nature of the assessment. A check should be undertaken to ensure the river	The modelling was carried out using the 2D TUFLOW software, employing a base grid size of 10m for the floodplain with sub-grid sampling

EA Comment	SLR Response
channel is of an appropriate size to convey flow along the channel to the breach.	(SGS). A cell size sensitivity check will be carried out.
Two breach locations have been proposed; a northern and southern location, which are located on the northern and southern River Welland defence embankments. The Site area shown in Figure 1.1 is large and as such, it is unclear where the substation will be located within the Site boundary. As such, it is not possible to determine whether the breach locations represent the worst case to the proposed development. The methodology states 'Proposed southern and northern breach locations along the River Welland have been located at critical locations along the primary flood defences, which will allow for worst case flood events to the proposed substation site option search areas. As such, it is assumed that the substation locations will be determined from the results of the modelling assessment. If this is the case, then multiple and alternative breach locations should be considered in order to determine the most flood risk resilient substation location. By not having a defined substation location, it cannot be determined if the proposed breach locations represent worst case scenarios.	When the initially submission of the methodology, the site location has not been finalized. Now that it is, determined the proposed location, simulations will be undertaken with alternative breach locations to identify the worst-case scenario.
The Environment Agency have stated that model runs need to consider overtopping and breach with defences at their current levels and if they were to be increased in line with sea level rise. However, the breach methodology proposed will only increase the defence crest to an elevation that does not overtop in the 1000yr + CC peak. This approach only assesses a breach scenario when defence crests are raised in line with climate change. The consideration that defences are not raised should not be limited to overtopping runs but should also be undertaken in breach runs whereby defence crests remain as per the present day.	The defence crests have been kept as per the present day.
The methodology states that all runs will be modelled with a base date of 2006 for the present day. It is unclear what is meant by this as supplied HT tidal curves have been developed using a 2018 base date.	The climate change allowances are defined with a base date of 2000 for the present day. However, the climate change allowance has been calculated based on a 2018 base date." Climate change allowances 2018 – 2035 – 17yrs x 7mm = 119mm 2036 – 2065 – 339mm Total sea level rise (2018-2065) = 458mm
The consultant has stated that only the 1000yr + CC tidal level exceeds the existing defence crest levels. We have not been provided with	0.1% AEP is the first overtopping event, and the model has already been run for the 0.1% AEP tidal level as well.

EA Comment	SLR Response
the defence crest levels so can't confirm if this statement is correct or whether there is significant variation in defence crest heights. We accept the overtopping methodology, however, in light of not knowing the defence crest height, the consultant should undertake an overtopping run for all return period events where the tidal peak level is greater than the lowest defence crest elevation.	
The methodology states that a sensitivity test for the H++ climate change allowances will be undertaken. This should occur for both overtopping and breach runs. Excel spreadsheet 'HT_BC.xlsx' does not include proposed H++ tidal curves. Environment Agency guidance 2 states that tidal H++ runs should apply an increase of 1.9m for total sea level rise to the year 2100.	Sensitivity analysis for the H++ has been completed (Appendix B).
As discussed above, a 70-hour simulation duration is proposed. However, the consultant should consider a 36-hr simulation, in line with guidance, with the breach occurring on the first tidal peak, and maximum tidal peak occurring as the middle curve.	Since the peak flood level occurs within the first 36 hours of the run time, it will be reduced to 36 hours. Model breaches at the first and highest tidal cycle, which is what is recommended in the EA guidance[1], so it will not conform with the "max tidal peak occurring as the middle curve" as mentioned above. The original guidance from the EA will be followed.

7. A draft River Welland Breach Modelling report was submitted to the Environment Agency on 21st December 2024, and following this a meeting was held with the Environment Agency on 10th January 2024 to discuss the contents of the draft report.

8. Following this meeting, two further actions were taken with regard to amendments to the modelling and presentation of results:
   - The access road to the substation was amended to provide a more accurate portrayal of the proposed levels and grading on site; and
   - Hazard class change figures have been provided in order to identify any potential properties which result in hazard classification changes as a result of the proposed development.

9. At the end of February 2024, Version 2.0 of this report, along with the modelling technical data files, were submitted to the Environment Agency for formal review and audit. The audit report, received in May 2024, confirmed that the basis of the model was robust whilst identifying a small number of technical aspects that required clarification (through the audit response spreadsheet) or adjustment in the model. The model was duly adjusted and re-run. The update to the model, reported in Version 3.0 has not had any impact on the flood depth results reported in Version 2.0.

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[1] Environment Agency, Anglian Region, Northern Area Requirements for Hazard Mapping. January 2014

1.2 Model Selection

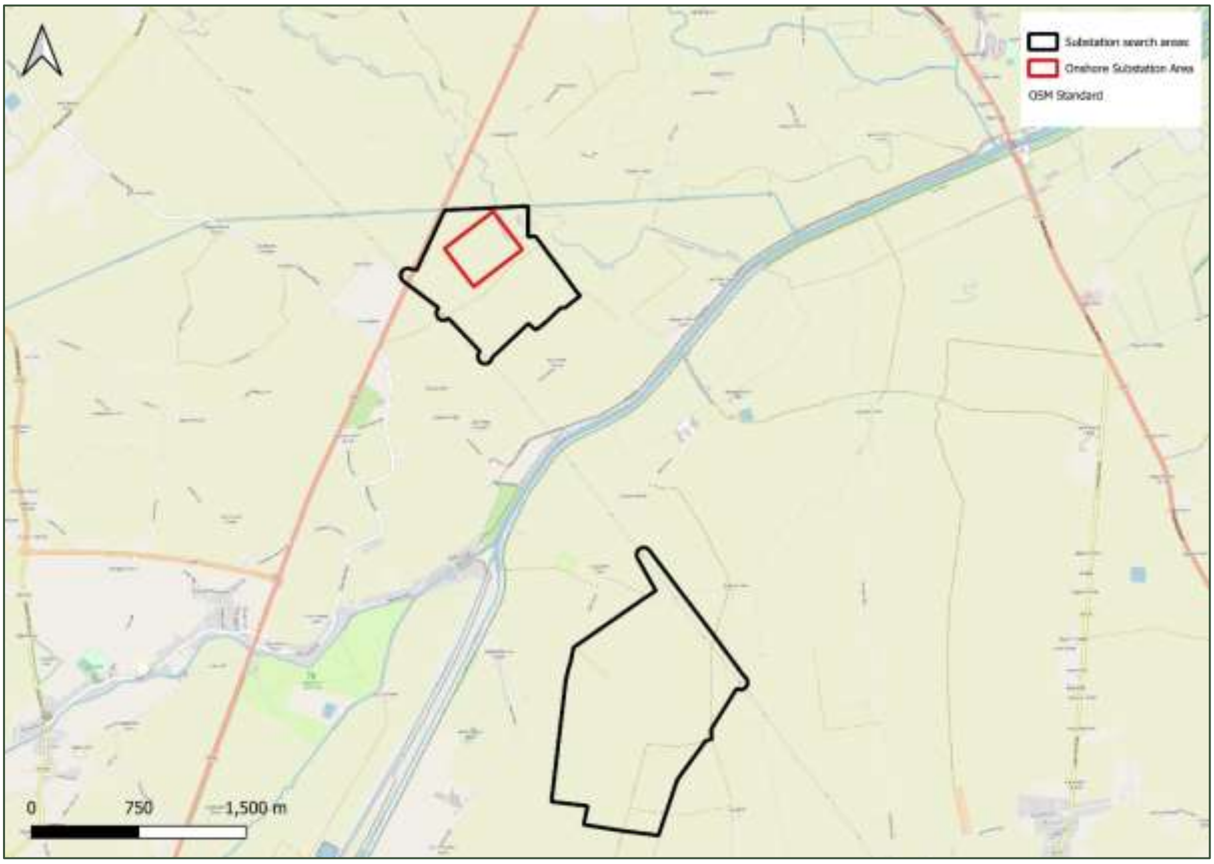
10. The River Welland breach model has been constructed using the TUFLOW hydraulic modelling package (Build: 2023-03-AB-iSP-w64).

11. The TUFLOW HPC module was selected as the numerical solver for the development of the coastal 2D hydraulic model. The High-Performance Compute (HPC) module solves the full 2D shallow water equations, including inertia and turbulence, and is suited to floodplain, open channel, and pipe hydraulics. The HPC solver also enables adaptive time-stepping in conjunction with smaller grid resolutions for greater granularity of results and topographic features where this is required. This package, which is distributed by BMT is widely used in the UK and has been benchmarked by the Environment Agency.

1.3 Site Location

12. The proposed site is situated in an area of Lincolnshire known as ‘The Fens’. This is a low-lying coastal area surrounding the River Welland and is drained by a series of artificial ditches with embankments to prevent flooding from seawater. The proposed OnSS site is located approximately 1.3km to the northeast of the River Welland. The River Welland is tidally influenced until it meets Spalding Lock and Coronation Channel Dam at the town of Spalding, 6km south (upstream) of the proposed site. The northern corner of the site is adjacent to the Risegate Eau drain and the Bicker Creek drains the eastern area of the site. The A16 highway is situated 100m to the west of the site. The proposed site location is indicated in Figure 1-1 below.

Figure 1-1 Site Location Plan



2.0 Methodology

13. This section of the report summarises the construction of the 2-Dimensional (2D) hydraulic model of the River Welland in Lincolnshire.

14. The construction of 2D hydraulic models requires a number of data sets and parameters, of which the key items are summarised below:

    - Model extent;
    - Floodplain topography in the form of a digital terrain model (DTM);
    - Cell size;
    - Topography edits;
    - Hydraulic structures;
    - Hydraulic boundaries; and
    - Roughness (Manning's n).

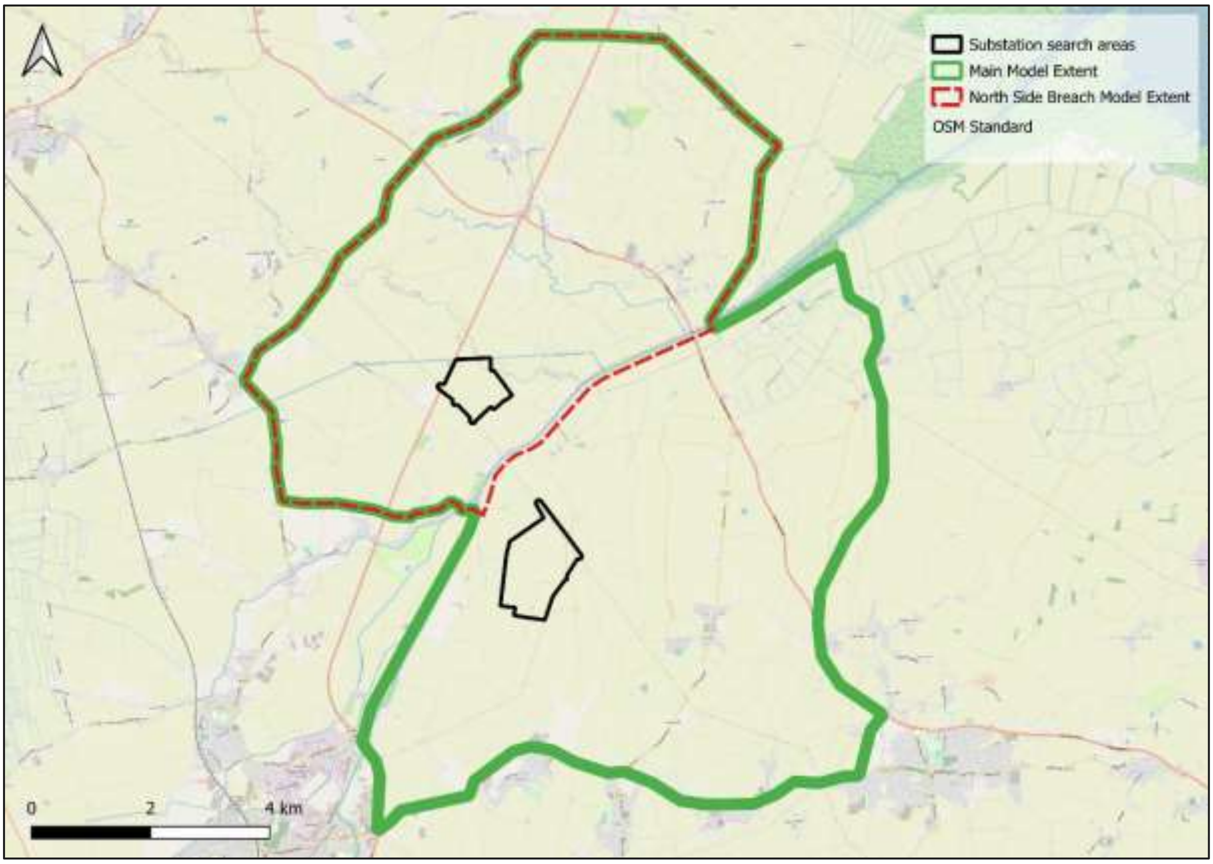
2.1 Model Extent

15. The main hydraulic model domain extends from A151 High Road located between Holbeach and Spalding of the south side of the River Welland, and to the north side of the River Welland covering up to of the B1397 Spalding Road.

16. Two model domains, one for the north of the river and one for the north and south as shown in Figure 2-1 below, were used to facilitate breach and overtopping scenarios to be tested independently while also optimizing model runtimes.

17. The main model extent is used for all overtopping runs and the 'North Side' domain is used to simulate the breach scenarios.

Figure 2-1 Hydraulic Model Extents



18. For the overtopping scenario modelling, the full model extent was used to allow an assessment of spill on either bank of the River Welland.

2.2 Topography (DTM)

19. The underlying base topography for the hydraulic model of the study area has been generated from the filtered aerial photogrammetry (LiDAR) data obtained from the Defra website[2] *'TF11ne_DTM_1m.* This 2022 LiDAR dataset adequately represents the floodplain topography, allowing for accurate flood routing for out of bank 2D flow, while also providing coverage of the full model extents as shown in Figure 2-2 below.

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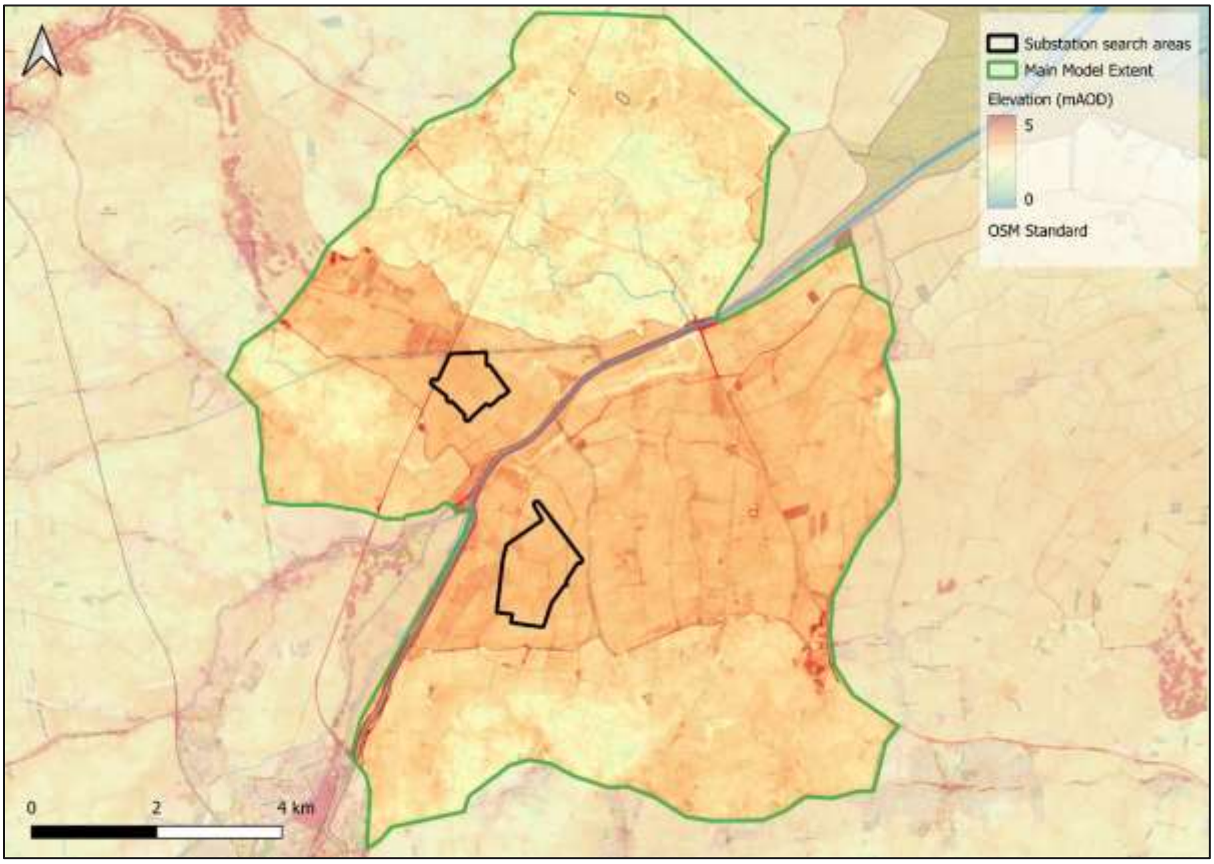
[2] Defra Data Services Platform, June 2023. https://environment.data.gov.uk/DefraDataDownload/?Mode=survey

Figure 2-2 Regional Topography



2.3 Topography Edits

20. The following key components were also added to the baseline LiDAR DTM to add more detail to the 2D domain of the flood model:

    - In accordance with EA guidance[3], building footprints within the model extent have been raised by 0.3 meters. OS Open Map – Local (OML)[4] was used to represent the building footprints in the hydraulic model using a 2D_zsh layer.
    - In accordance with EA guidance, pumping stations along the river have been assumed to be inoperative during a tidal event and subsequently disregarded. Therefore, the openings of these pumping stations in the LiDAR data were patched using 2D_zsh layers.
    - The heights of riverbank defences in the River Welland study area are defined by a series of Z lines in TUFLOW. The elevations used for the defences were obtained from a combination of AIMS Spatial Flood Defences[5] data and LIDAR data.
    - For the proposed development model scenario, the footprint of the site (OnSS) has been raised using a 2D_zsh so that the final development platform is above the peak water level for the maximum assessed scenario (a design level of 4.2 mAOD defined by the Project has been adopted for modelling purposes).

21. The above key topographical edits are also indicated in Figure 2-3 below.

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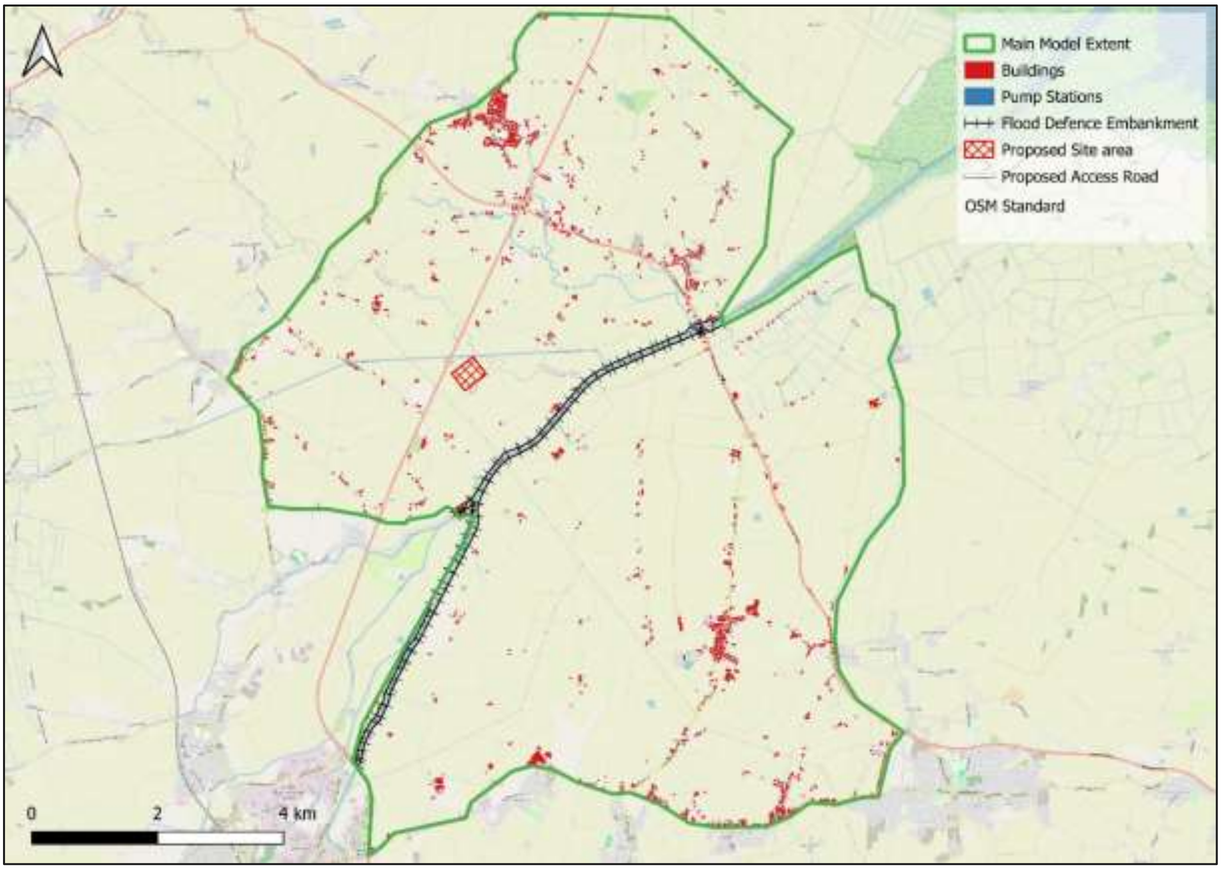
[3] Environment Agency, Anglian Region, Northern Area Requirements for Hazard Mapping. January 2014

[4] Ordnance Survey Platform, Aug 2023, https://www.ordnancesurvey.co.uk/products/os-open-map-local

[5] AIMS Spatial Flood Defences (inc. standardised attributes), Sep 2023, https://www.data.gov.uk/dataset/cc76738e-fc17-49f9-a216-977c61858dda/aims-spatial-flood-defences-inc-standardised-attributes

Figure 2-3 Key Topographic Edits



2.4 Cell Size

22. A 10m model grid cell size was utilized taking into account the floodplain's expansive area and likely flow paths, relatively minimal variation in regional topography and largely rural nature. This cell size has also been determined to be sufficient for incorporating crucial details such as channel width, breach length, flood embankment width, and the width of main roads surrounding the study area. These factors were carefully considered to provide an accurate evaluation of the flood risk model grid cell size, ensuring a thorough and robust assessment of potential vulnerabilities and hazards.

2.5 Breach Locations

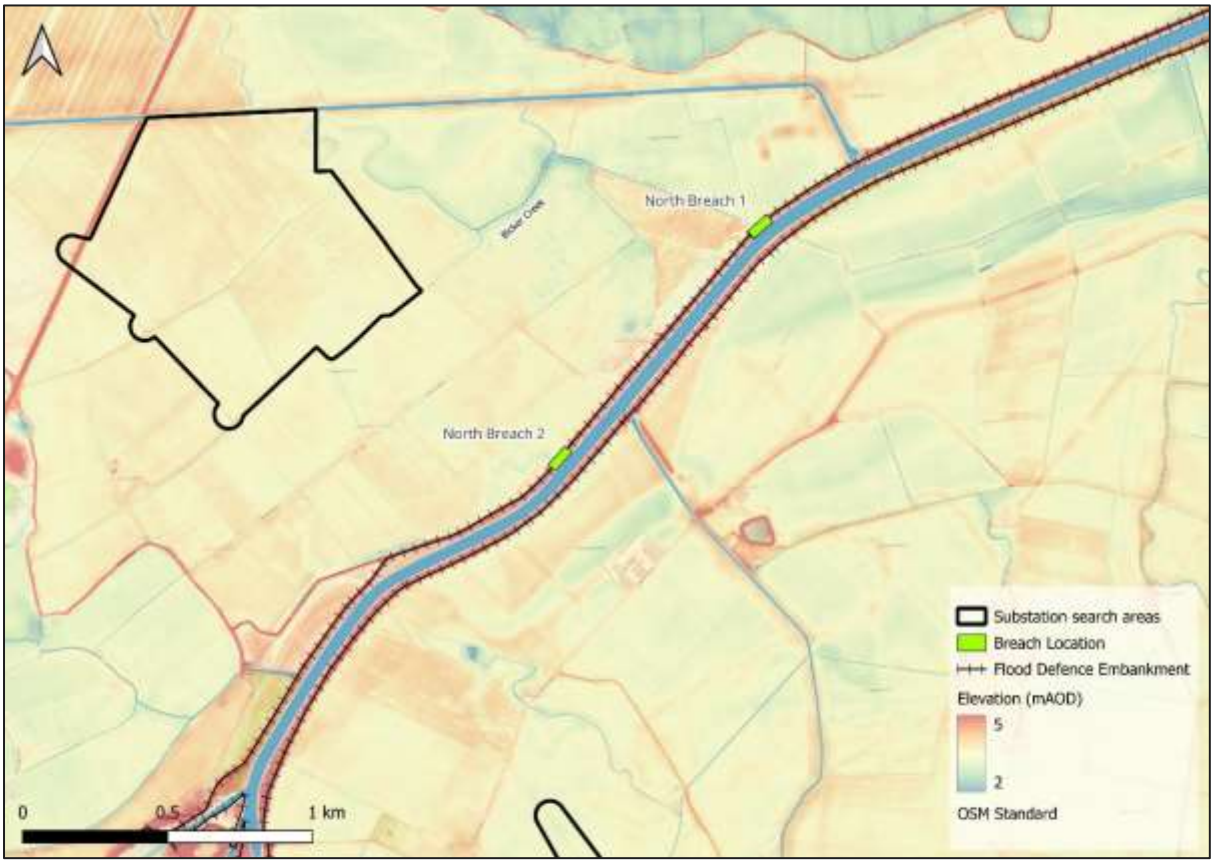
23. Two primary breaches were considered:

- North Breach 1; and,
- North Breach 2.

24. These breach locations were selected considering the distance to the proposed site location, watercourses surrounding the study area and regional topography. Breach 1 was selected because flood flow will more easily reach the OnSS site area through Bicker Creek. Breach 2 was chosen because the area near it has the lowest floodplain elevation along the flood defences, and it is closer to the OnSS site. Each breach was triggered to occur one hour before the peak water level time, as per Environment Agency

Guidance[6] and were represented in TUFLOW using variable (2d_vzsh) shape files. The location of the breaches is shown in Figure 2-4.

Figure 2-4 River Welland Breach Locations



2.6 Hydraulic Boundaries

25. The boundary condition applied to the TUFLOW model was a Head-Time (HT) boundary placed across the river at the Fosdyke Bridge. This boundary is used to assign the tidal curves for the 1 in 200 annual chance (0.5% Annual Exceedance Probability (AEP), 1 in 1,000 annual chance (0.1% AEP), 1 in 200 annual chances plus an allowance for climate change and 1 in 1,000 annual chance plus an allowance for climate change events.

26. Previous studies commissioned by the Environment Agency show coastal flooding to be the critical flood mechanism for this area of The Fens. This is considered mutually exclusive from fluvial flooding, as the same conditions that generate peak coastal flooding levels on this section of coastline are not thought to be linked with storm conditions which will generate large fluvial floods. Therefore, this study focuses solely on coastal / tidal flooding mechanisms.

27. The shape of the astronomical tidal curves used in the modelling were taken from the 2011 Hyder River Welland Hydraulic modelling report[7]. CFB 97.5% confidence levels has been selected to minimis the uncertainty. These tidal curves have then been scaled

---

[6] Environment Agency, Anglian Region, Northern Area Requirements for Hazard Mapping. January 2014

[7] April 2011, Hyder/Environment Agency: Strategic Flood Risk Management Framework Tidal Nene and Tidal Welland Hazard Mapping Hydraulic Modelling Report

to fit the extreme water levels estimated at Fosdyke Bridge[8] (*CFB conditions for the UK 2018 for 'Location: ESTURY_RiverWELLAND Chainage: _3992_5*).

28. Climate change allowances for sea level rise have been calculated from a base year of 2018 using the current Guidance from the EA for the Anglian Region for the Upper End Scenario (Flood risk assessments climate change allowances).

29. Resultant Peak Tidal Levels at Fosdyke Bridge are summarised below in Table 2-1.

Table 2-1: Summary of Peak Tidal Levels at Fosdyke Bridge

AEP%	EA Report[9] (m)	CFB (m)	CFB (97.5% confidence levels)
1:200 (0.5% AEP)	5.99	5.98	6.38
1:200 (0.5% AEP) + CC	7.13	6.44	6.84
1:1000 (0.1% AEP)	6.69	6.29	6.97
1:1000 (0.1% AEP) + CC	7.83	6.75	7.43

Climate change allowances:

2018 – 2035 – 17yrs x 7mm = 119mm

2036 – 2065 – 30yrs x 11.3mm = 339mm

Total cumulative sea level rise (2018-2065) = 458mm

2.7 Manning's n

30. The definition of the extent of each of the roughness values in the 2D domain was determined using the Land Cover Map 2021 (LCM2021) provided by the UK Centre for Ecology & Hydrology (UKCEH). This was correlated with aerial photography to delineate different land use areas based on ground surface characteristics (Table 2-2-). Each land use type was assigned a corresponding Manning's n value in the TUFLOW Materials File as shown below in Table 2-2, with a set default Manning's value of 0.04 (99).

31. On review of the LCM2021 several amendments were made to the land use classifications. Adjustments were made to the in-channel and flood defences roughness, along with the standard roughness values. Specifically, in accordance with EA guidance, the roughness value within the model for building footprints has been increased to 0.1.

32. The material roughness across the model domain has been read into the hydraulic model using a TUFLOW standard Material.csv with Manning's n values derived from Chow[10].

---

[8] 2018, Environment Agency: Coastal Flood Boundary Extreme Sea Levels

[9] April 2011, Hyder/Environment Agency: Strategic Flood Risk Management Framework Tidal Nene and Tidal Welland Hazard Mapping Hydraulic Modelling Report

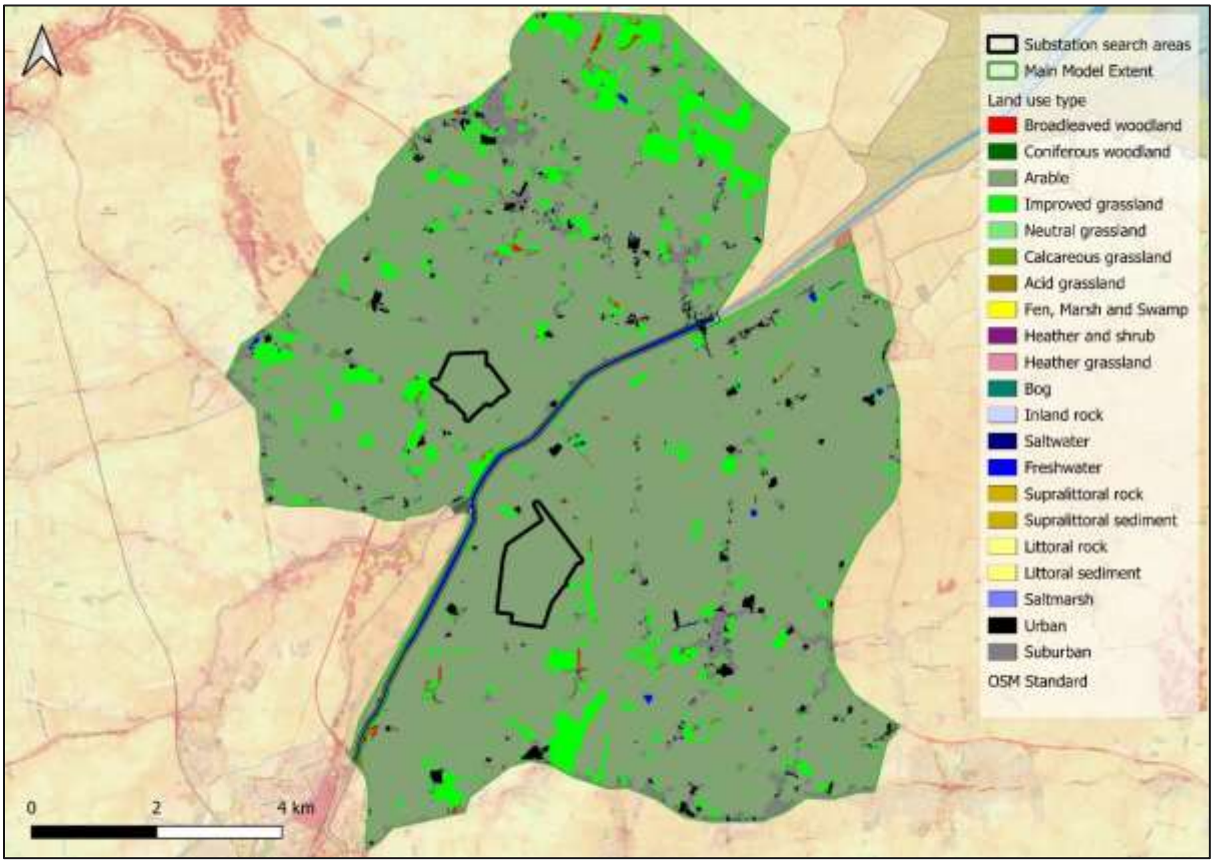
[10] Chow, V.T., (1959). Open-channel hydraulics, McGraw-Hill, New York

Table 2-2: Modelled material Properties

Material ID as referenced in GIS layer	Manning's n value	Land use type
1	0.100	Deciduous woodland
2	0.060	Coniferous woodland
3	0.035	Arable
4	0.030	Improve grassland
5	0.035	Neutral grassland
6	0.035	Calcareous grassland
7	0.030	Acid grassland
8	0.035	Fen
9	0.050	Heather
10	0.050	Heather grassland
11	0.035	Bog
12	0.040	Inland rock
13	0.025	Saltwater
14	0.025	Freshwater
15	0.040	Supralittoral rock
16	0.040	Supralittoral sediment
17	0.050	Littoral rock
18	0.040	Littoral sediment
19	0.035	Saltmarsh
20	0.100	Urban
21	0.060	Suburban
22	0.100	Buildings
99	0.040	Default value

33. Figure 2-5 below shows the applied Manning’s n roughness values applied to varying land uses within the model.

Figure 2-5 Hydraulic Model Material Roughness



2.8 Software Version

34. In line with best practice, the TUFLOW model was constructed using the latest commercially available software version at project outset: TUFLOW HPC 2023-03-AB (single precision).

2.9 Modelling Parameters

35. The underlying 2D digital terrain model (DTM) was generated using the base 1m LiDAR grid described in Section 2.2. Sub-grid sampling (SGS) testing was undertaken during the initial model build. It was decided to continue using HPC with SGS functionality in 10m grid cell size.

36. All modelled scenarios have been simulated for 36 hours to allow for the inflow boundaries to peak across the model domain. The computational timesteps used by HPC are adaptive over the course of the simulation, with 2D time-varying outputs generated every 15 minutes.

2.10 Model Operation

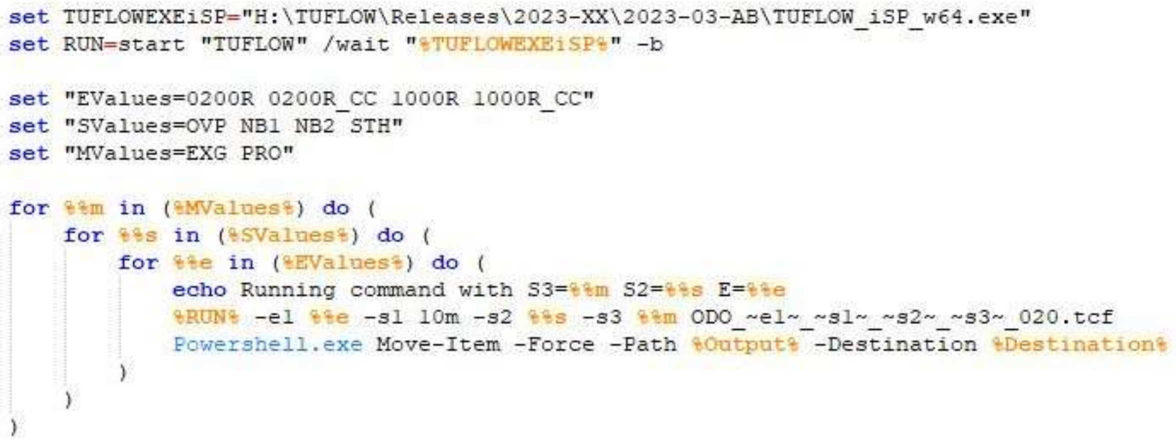
37. The hydraulic model was simulated using the HPC Solver for TUFLOW build 2023-03-AB single precision (iSP). Initialisation of the TUFLOW model utilised a standard Windows Batch file linking the TUFLOW executable, TUFLOW control file (.tcf) and relevant event and scenario logic, as defined in Table 2-3 below.

Table 2-3: Model Scenario Definitions

Run Reference:	ODO_~e1~_~s1~_~s2~_~s3~_022.tcf
Scenario Description (-s1)	10m (10m cell size)
Scenario Description (-s2)	OVP - Overtopping NB1 - North Side Breach 1 NB2 - North Side Breach 2
Scenario Description (-s3)	EXG (Existing/baseline) PRO (Proposed)
Return Periods (-e1)	0200R 0.5% AEP 0200R_CC 0.5% AEP + Climate Change 1000R 0.1% AEP 1000R_CC 0.1% AEP + Climate Change

38. All simulations were executed using a Windows batch file (.bat). Batch files are text files which contain a series of commands and allow for a large degree of flexibility in starting TUFLOW simulations. Due to the number of variables being modelled, event and scenario management wildcards (e.g., ~s1~, ~e1~) were utilised within the batch file to easily run simulations in series or concurrently.

39. An example batch file configuration for the Baseline runs is given below:



```
set TUFLOWEXEiSP="H:\TUFLOW\Releases\2023-XX\2023-03-AB\TUFLOW_iSP_w64.exe"
set RUN=start "TUFLOW" /wait "%TUFLOWEXEiSP%" -b

set "EValues=0200R 0200R_CC 1000R 1000R_CC"
set "SValues=OVP NB1 NB2 STH"
set "MValues=EXG PRO"

for %%m in (%MValues%) do (
    for %%s in (%SValues%) do (
        for %%e in (%EValues%) do (
            echo Running command with S3=%%m S2=%%s E=%%e
            %RUN% -e1 %%e -s1 10m -s2 %%s -s3 %%m ODO_~e1~_~s1~_~s2~_~s3~_020.tcf
            Powershell.exe Move-Item -Force -Path %Output% -Destination %Destination%
        )
    )
)
```

3.0 Model Results

40. Maximum flood extents and depths, maximum velocities, and hazard rating results for the areas on and surrounding the site are presented in Figure 3-1 through to Figure 3-9 below. Appendix A also contains depth difference outputs of the proposed and baseline model scenarios for better representation of flood extents and changes after construction of the OnSS.

3.1 Scenarios and Events

41. The peak flood extents of the overtopping model do not reach the OnSS site, even during the most extreme event (0.1% AEP + Climate change).
42. The peak flood extents for both breach flood events under baseline conditions show significant flooding in the site area, which is summarized in Tables 3.1 and 3.2 below. The A16 road plays a significant role in controlling flood depths around the Project site area, acting as an obstruction to flow, holding water between the river and the road. The peak flood extents for baseline conditions under all scenarios for the largest event (0.1% AEP + Climate change) are shown in Figure 3-1 to Figure 3-3.

Under the proposed conditions, the OnSS remains free from flooding for both breach 1 and 2 in any event. The peak flood extents for the proposed condition for the 0.1% AEP + climate change event for breach 1 & 2, the flood depth difference between baseline and proposed conditions and hazard class changes, are presented in Figure 3-4- to Figure 3-9, with peak flood levels and depths on-site for baseline scenario provided in Table 3-1 and

43. Table 3-2 below.
44. As shown in Figure 3-4 and Figure 3-7Figure 3-8, in both breach scenarios the OnSS is safe from flooding up to the 1 in 1000 year plus climate change event.
45. Figure 3-66 and Figure 3-99 show the hazard class changes due to the development of the OnSS platform for breach scenarios 1 and 2, respectively. These maps provide insights into which receptors will be affected by the development of the OnSS. In breach scenario 1, there are 11 receptors which move to a higher hazard class category. There is no change in the hazard class of any receptor in breach scenario 2. The effect on receptors has been discussed further in Appendix 24.3 (OnSS Flood Risk Assessment).

Table 3-1: Baseline Peak Water Levels across the Site

Maximum Flood Levels (m AOD)	Overtopping	Breach 1	Breach 2
1:200 (0.5% AEP)	-	3.972	3.940
1:200 (0.5% AEP) + CC	-	3.999	3.991
1:1000 (0.1% AEP)	-	4.019	4.024
1:1000 (0.1% AEP) + CC	-	4.082	4.093

Table 3-2: Baseline Peak Water Depths across the Site

Maximum Flood Depths (m)	Overtopping	Breach 1	Breach 2
1:200 (0.5% AEP)	**-**	**0.572**	**0.547**
1:200 (0.5% AEP) + CC	**-**	**0.601**	**0.591**

1:1000 (0.1% AEP)	**-**	**0.621**	**0.623**
1:1000 (0.1% AEP) + CC	**-**	**0.688**	**0.690**

Figure 3-1 Maximum Flood Depths Baseline Overtopping 0.1% AEP+CC

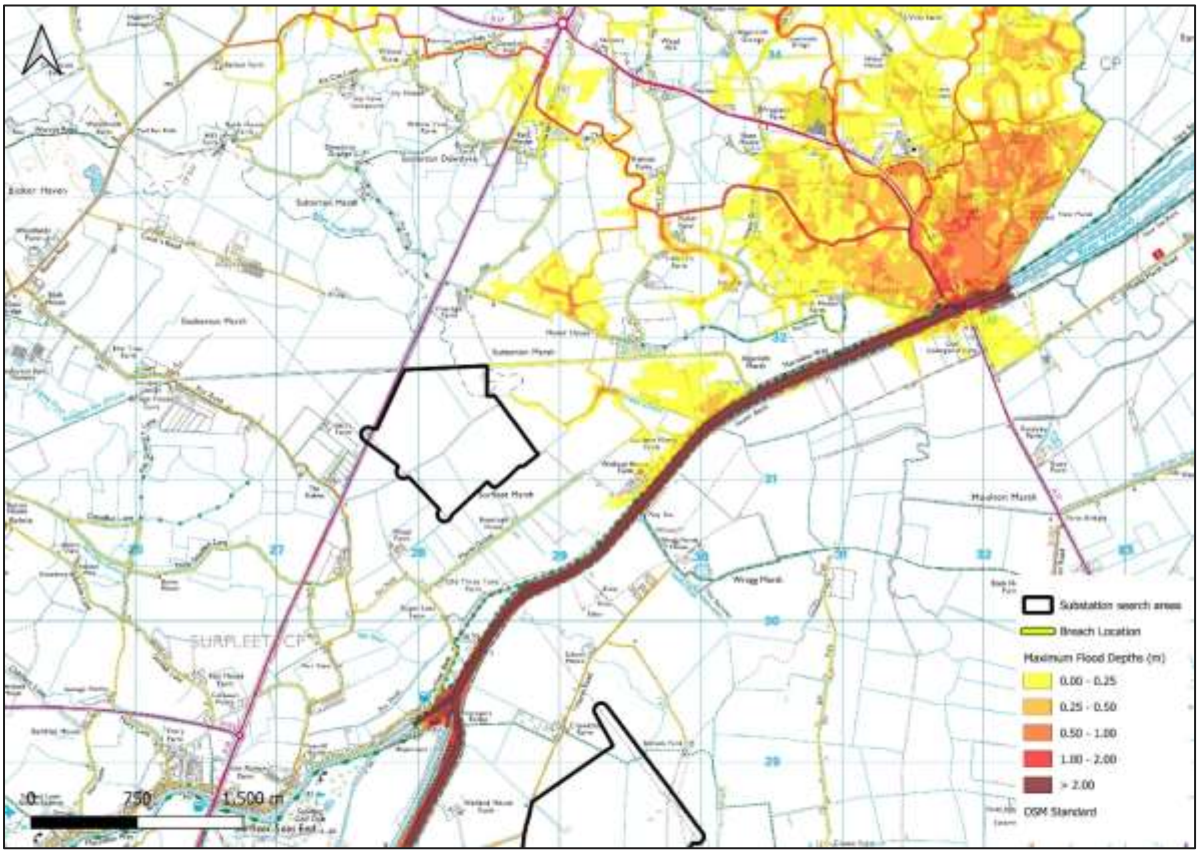


Figure 3-2 Maximum Flood Depths Baseline Breach 1 - 0.1% AEP+CC

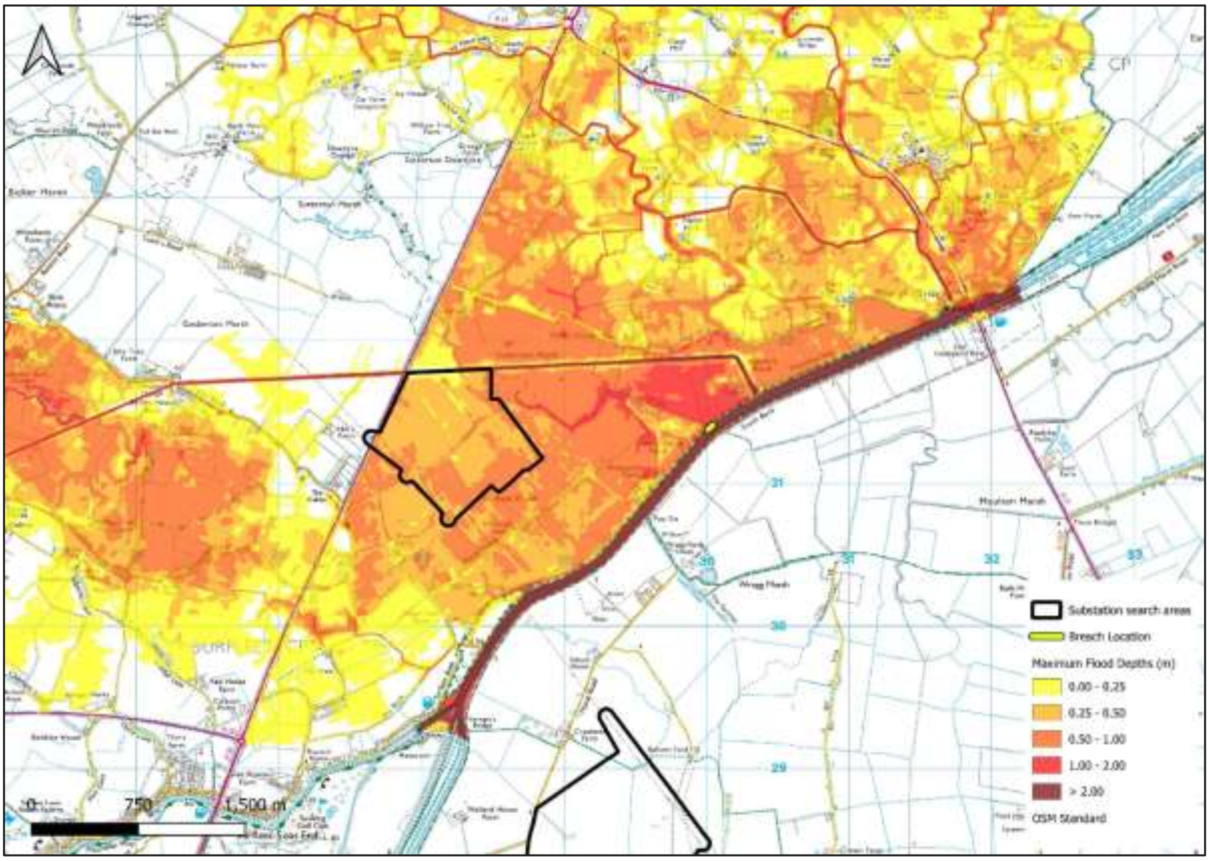


Figure 3-3 Maximum Flood Depths Baseline Breach 2 - 0.1% AEP+CC

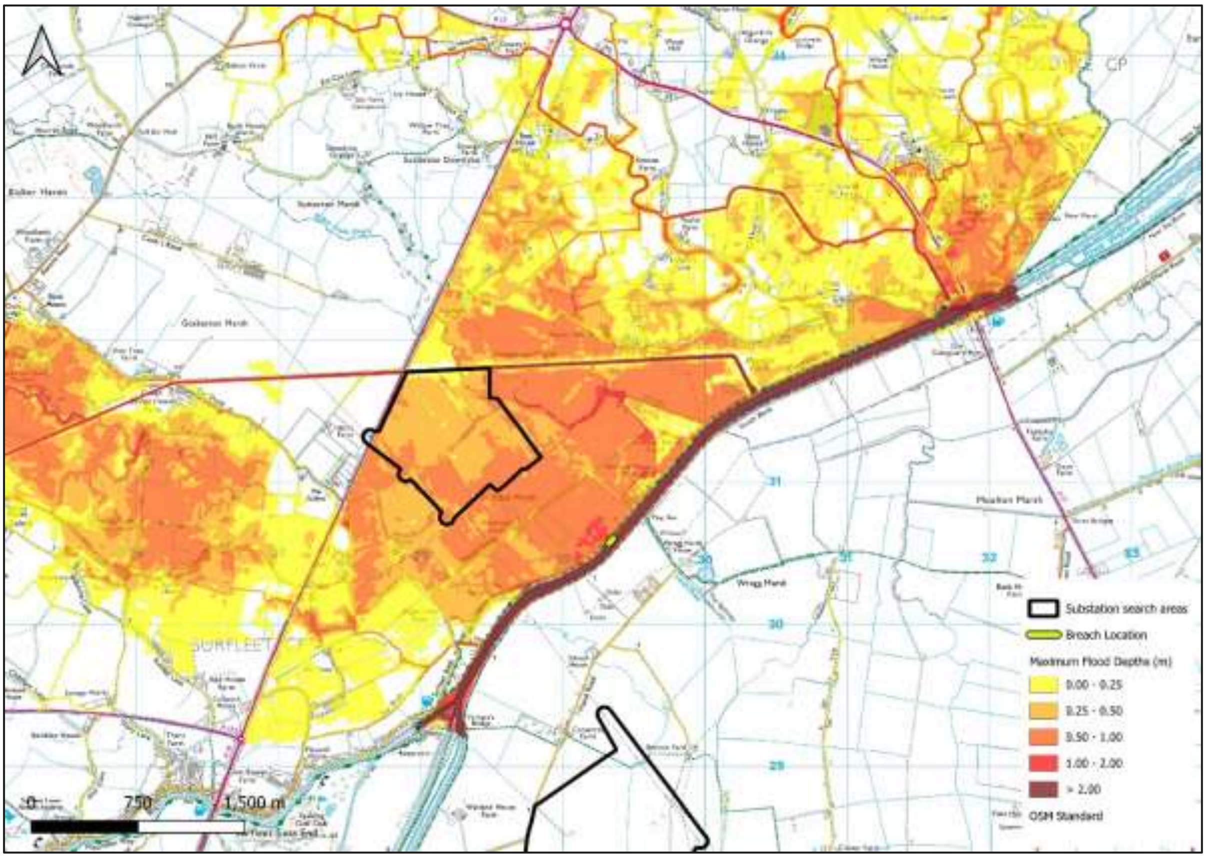


Figure 3-4 Maximum Flood Depths Proposed Breach 1 - 0.1% AEP+CC

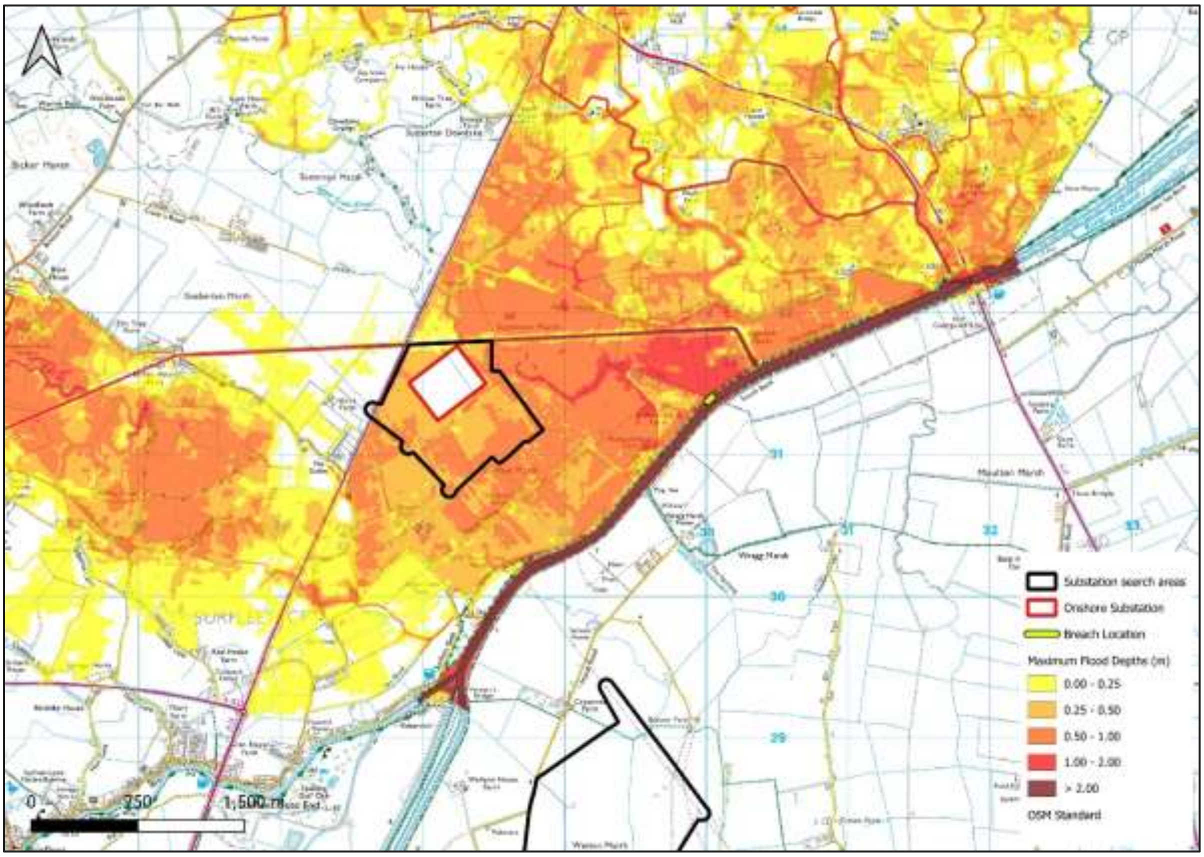


Figure 3-5 Flood Depth Difference Breach 1 - 0.1% AEP+CC

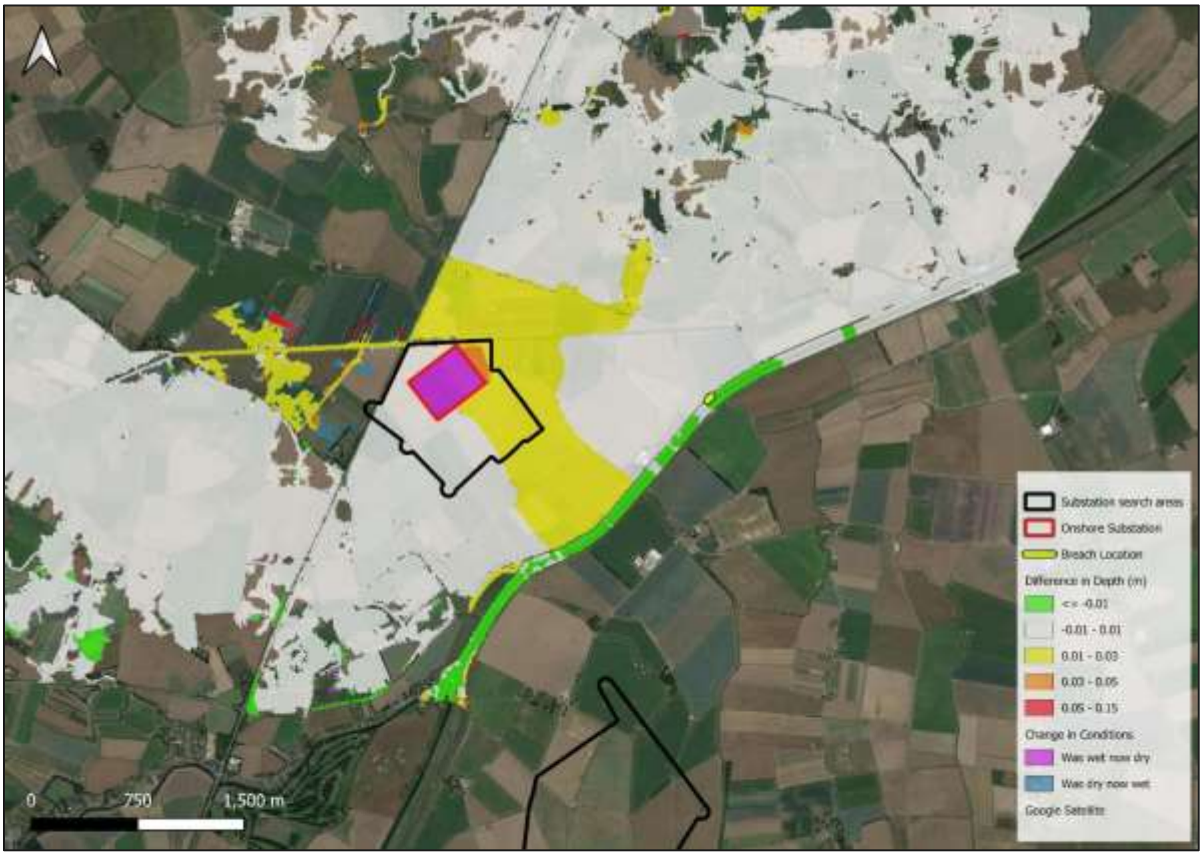


Figure 3-6 Hazard Class Changes Breach 1 - 0.1% AEP+CC

Figure 3-7 Maximum Flood Depths Proposed Breach 2 - 0.1% AEP+CC

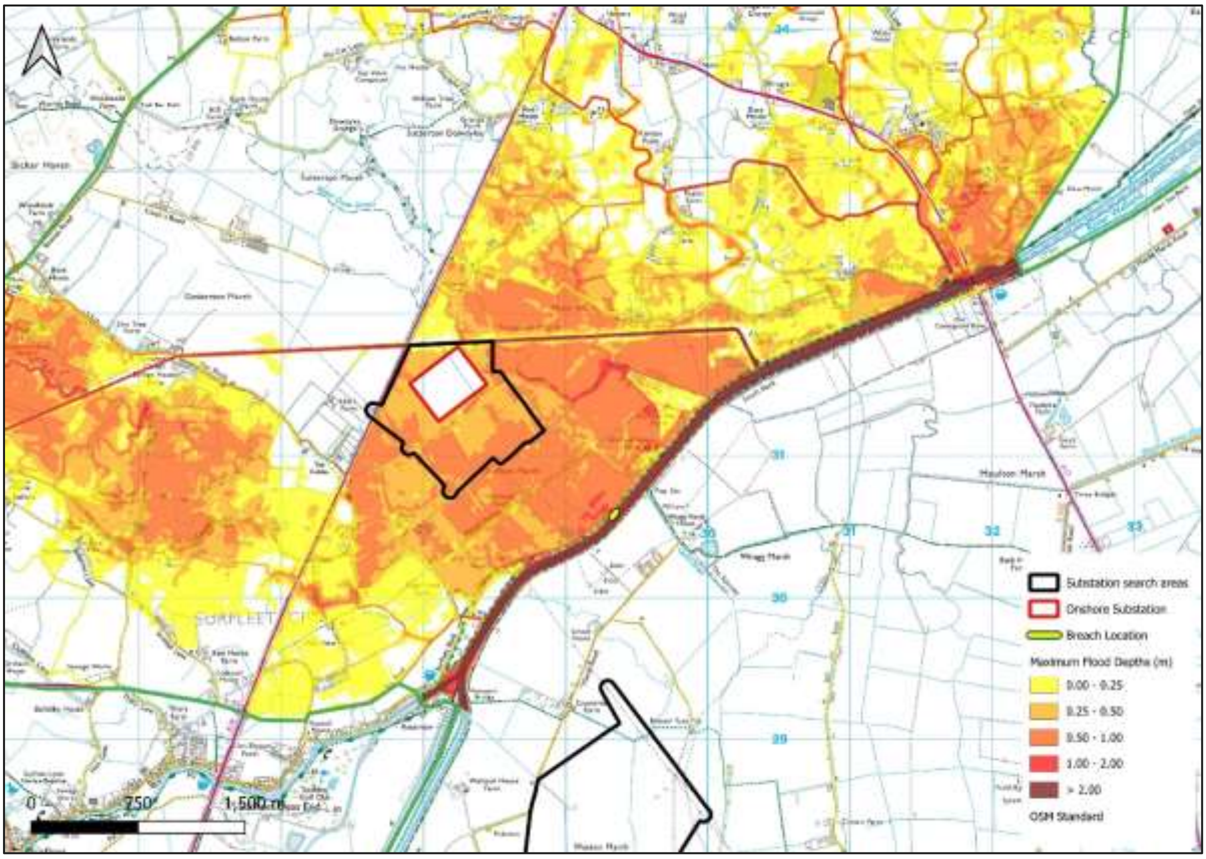


Figure 3-8 Flood Depth Difference Breach 2 - 0.1% AEP+CC

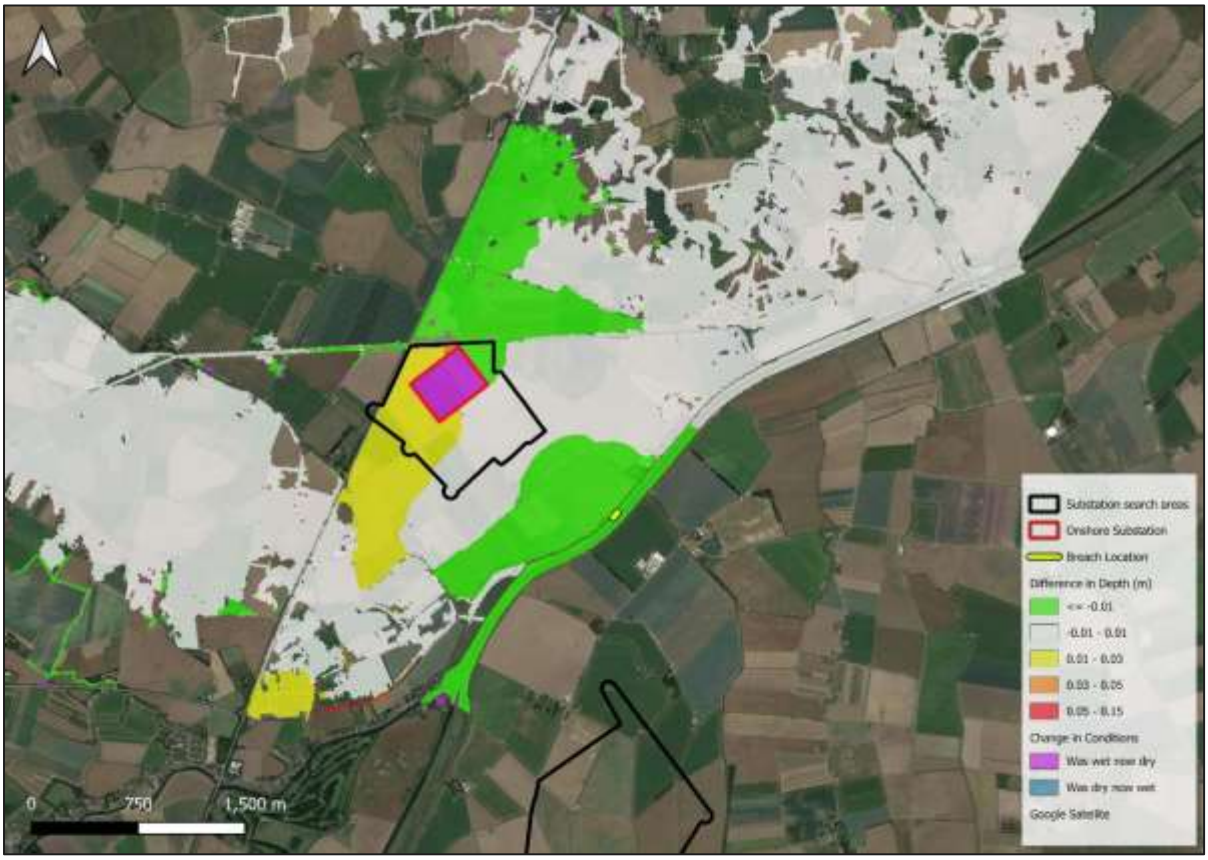


Figure 3-9 Hazard Class Changes Breach 2 - 0.1% AEP+CC

3.2 Quality Assurance

46. This section outlines the Quality Assurance (QA) measures undertaken in developing the River Welland hydraulic model.

47. Part of the general model QA process involves reviewing the TUFLOW messages generated during the model compilation stage and resolving any issues. Warnings produced by TUFLOW during the run are also investigated. Locations causing recurring warnings were identified and a solution implemented to reduce or remove the source of the issue. Model logs have also been utilised to record the key decisions made when developing the model, allowing for traceability and aid in the transfer of the models between different users. The main components of the River Welland model build, configuration and application were recorded and have been reviewed and signed-off by a senior hydraulic modeller.

48. Further QA over the course of the model build was undertaken, including:

- Material roughness was checked by importing and thematically mapping the grd_check file to ensure surface resistance was applied correctly with respect to aerial images.
- The extent of the 2D domain was reviewed to ensure it was not limiting flood extents in the larger flood events within the area of interest.
- Minimum dT values across the 2D domain were reviewed to highlight any troublesome areas that were slowing down overall run time; and
- Flow rates within the river channel were reviewed to check for high velocities and potential instabilities.

3.3 Model Stability

49. The model has been reviewed and found to be generally stable and appropriate for its intended use. TUFLOW HPC is inherently stable by nature of the adaptive time-stepping, with low time-steps (dT) typically occurring along or near the 2D HT boundary where high velocities are passing through 2D cells. Many check messages (CHECK 3505 - SGS TIN outside model domain) occur in breach scenario runs due to buildings' footprints being raised by using a single layer for both overtopping and breach scenarios. This discrepancy arises from the use of different model domains for overtopping and breach scenarios. Few warning (2250) messages occurred in the breach scenario runs. These instabilities occurred near the HQ normal depth boundary conditions upstream. The material layer has been updated to improve stability. All these instabilities occur due to the introduction of a large volume of water during the first hour of the simulation and have no impact on the peak water level results. Nu, Nc, Nd and dt output for HPC indicted that the model runs were all within the suitable stability threshold (Nu<1.0, Nc<1.0, Nd<0.03).

Figure 3-10 - Values of HPC run parameters

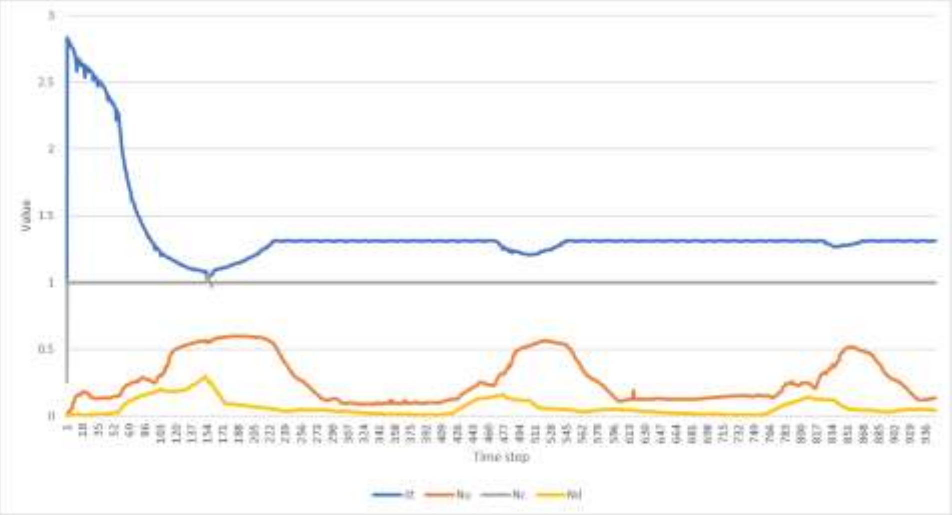


Figure 3-11 Comparison of dVol for Overtopping and Breach Scenarios

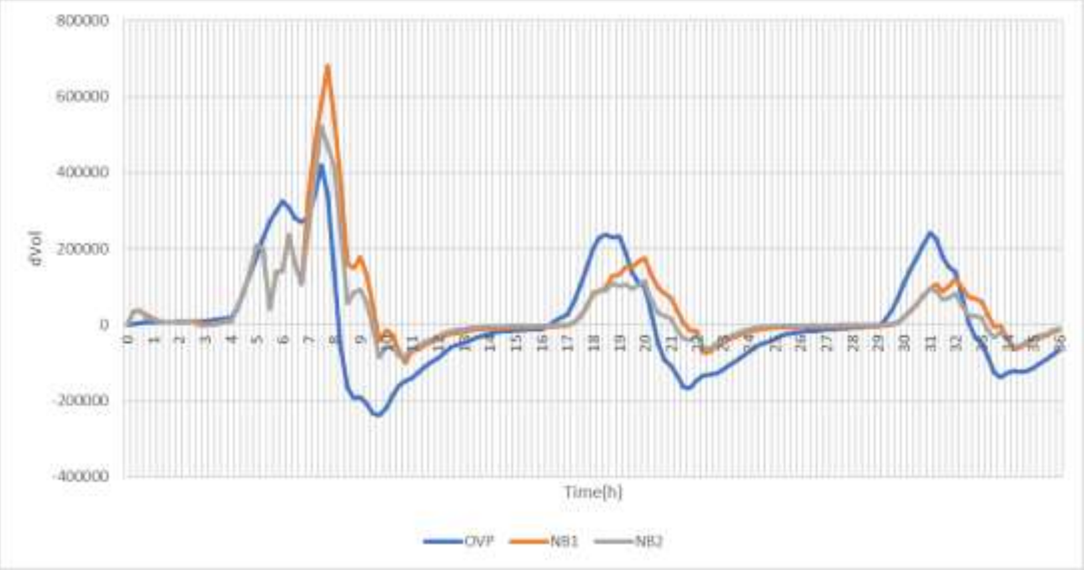


Figure 3-10 and Figure 3-11 show the HPC run parameters and dVol comparison for different scenarios. In the first tidal cycle, the dVol is higher in the breach scenarios compared to the overtopping scenario. This is due to the flood defence breach allowing a greater volume of water to flow into the model domain than in the overtopping scenario. However, in the second and third tidal cycles, the overtopping scenario shows a higher dVol. This is because the water in the floodplain re-enters the channel as the water level decreases, reducing the amount of water entering the model domain in the next cycle. This results in an overall higher dVol in the overtopping scenario.

3.4 Model Limitations

50. This model has been developed to take advantage of the most accurate available data to help inform flood risk at the site. There are however several limitations to the hydraulic model worth noting:

- The downstream tidal hydrograph that is based on the original coastal model produced by Mott MacDonald[11] only has a relatively small number of data points per tide cycle, resulting in a sparsely defined curve. This may mean that the full complexity of the tidal hydrograph may not be reproduced in the model.
- The breach base levels were determined solely on ground profiles on a hypothetical basis, which is likely to provide conservative results; no consideration was given to the structural integrity and probability of failure of the defences and embankments.
- The fluvial inflows have not been considered in this study.

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[11] April 2011, Hyder/Environment Agency: Strategic Flood Risk Management Framework Tidal Nene and Tidal Welland Hazard Mapping Hydraulic Modelling Report

4.0 Sensitivity Analysis

51. Sensitivity analysis is the study of how the variation in the output of the model (depth) can be apportioned, qualitatively or quantitatively, to difference changes in the model inputs (model variables, boundary conditions and parameters). Appendix B contains plans of select sensitivity results.

52. Sensitivity analysis is used to identify:

- The factors that potentially have the most influence on the model outputs.
- The factors that need further investigation to improve confidence in the model; and
- Regions in space where the variation in the model output is greatest.

53. In line with good practice, the following parameters, and variables for the hydraulic model have been varied in accordance with the % uplift / parameter change specified below:

Table 4-1: Sensitivity Analysis Variables

Parameter	Value change
Model Cell Size	14m and 6m
Channel and floodplain roughness	± 20 %
Model Inflows	H++ CC on the 0.1% and 0.5% AEP

4.1 Model Cell Size

54. The initial run was conducted with a 10m cell size. Subsequent sensitivity tests were carried out with 14m and 6m cell sizes. Interestingly, the 6m run exhibited striking similarities to the 10m model, suggesting a robust representation of the floodplain. However, the 14m run showed more significant flooding, presumably the 14m resolution have resulted in a more simplified DTM which ignores smaller changes in topography. As an example, it did not accurately capture the flood defences and the A16 road as well as the 6m or 10m grids. These findings indicate that the 10m cell size strikes a balance, effectively capturing important features in the floodplain while reducing the model run time without compromising result quality. Peak depth results for 14m and 6m can be seen in Appendix B. The flood extent of model cell size sensitivity runs and depth difference map between 6m and 10m cell size grids is presented in Figure 4-2 and Figure 4-2.

Figure 4-1 - Flood Extent of Difference Cell Size Sensitivity Runs

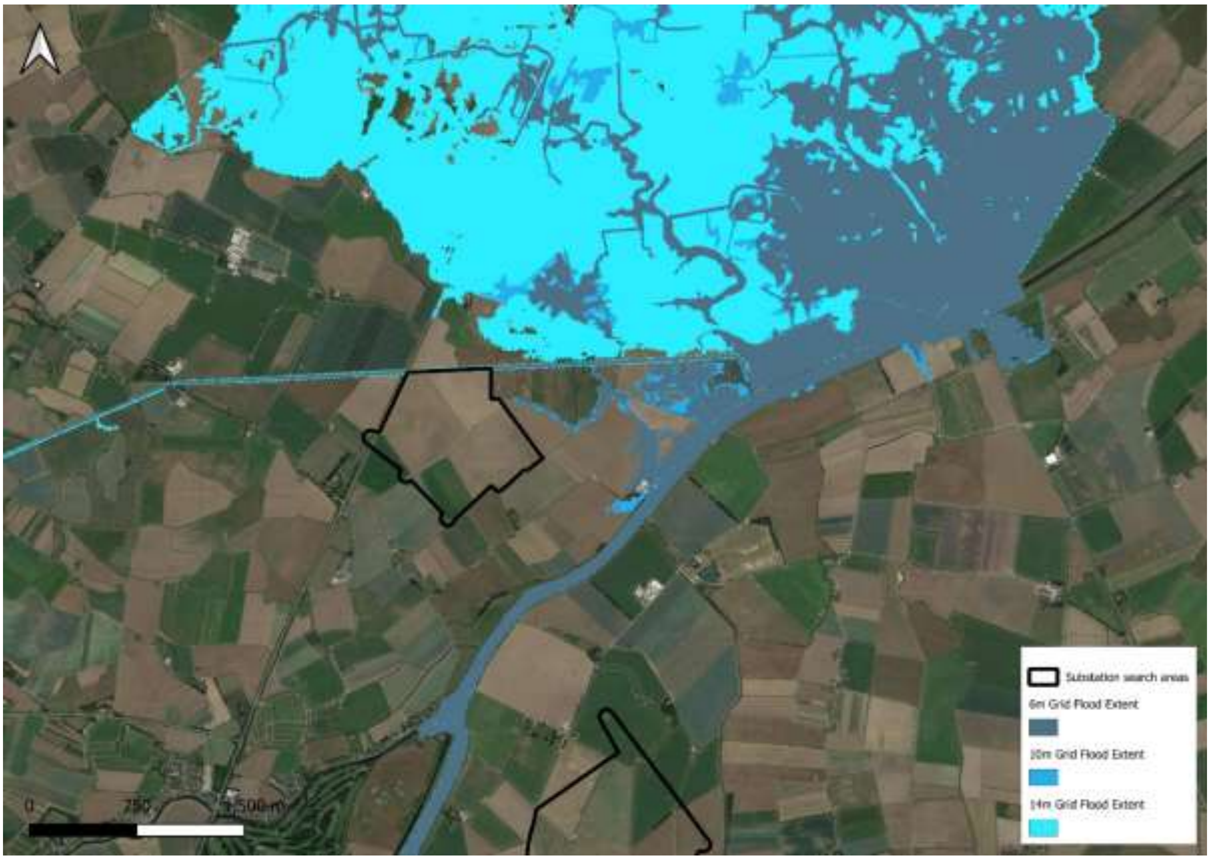
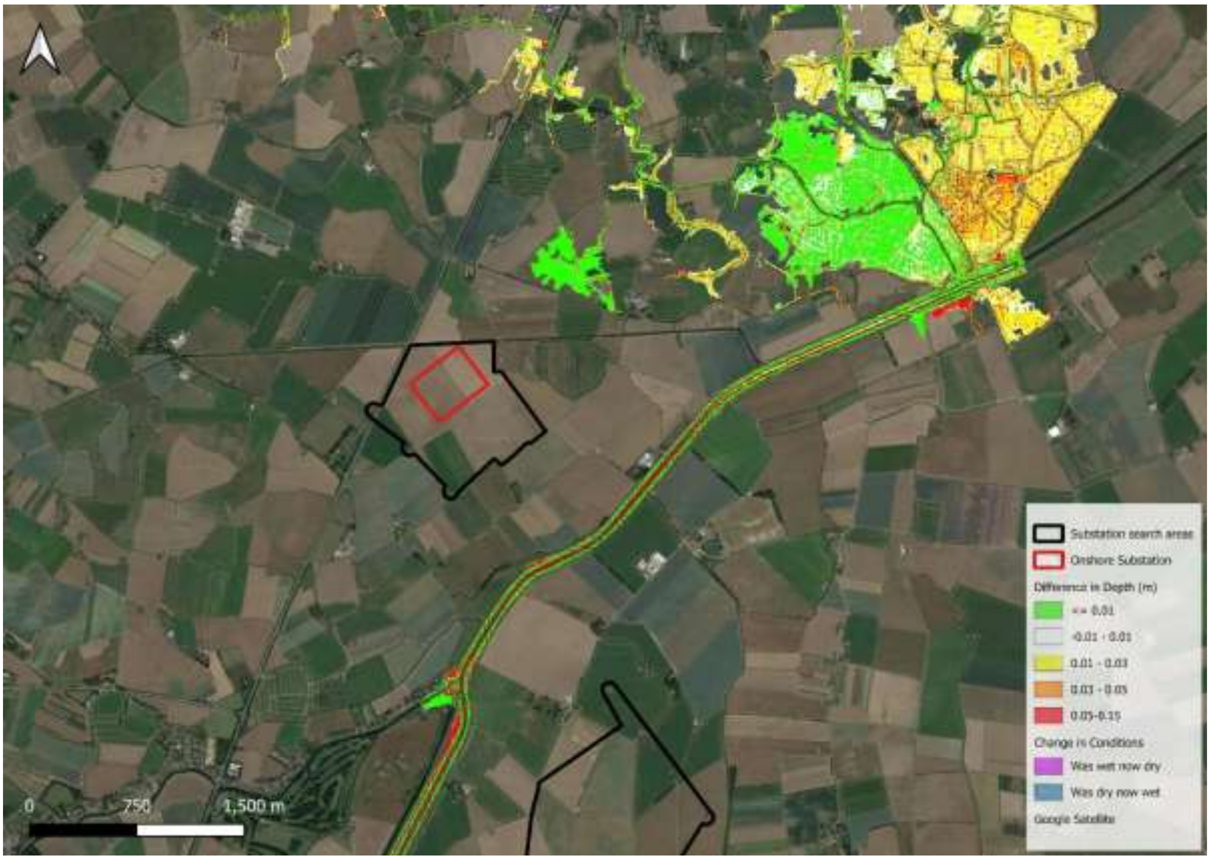


Figure 4-2 - Flood Depth Difference between 6m and 10m Grid Cell Size (Overtopping - 0.1% AEP+CC)-

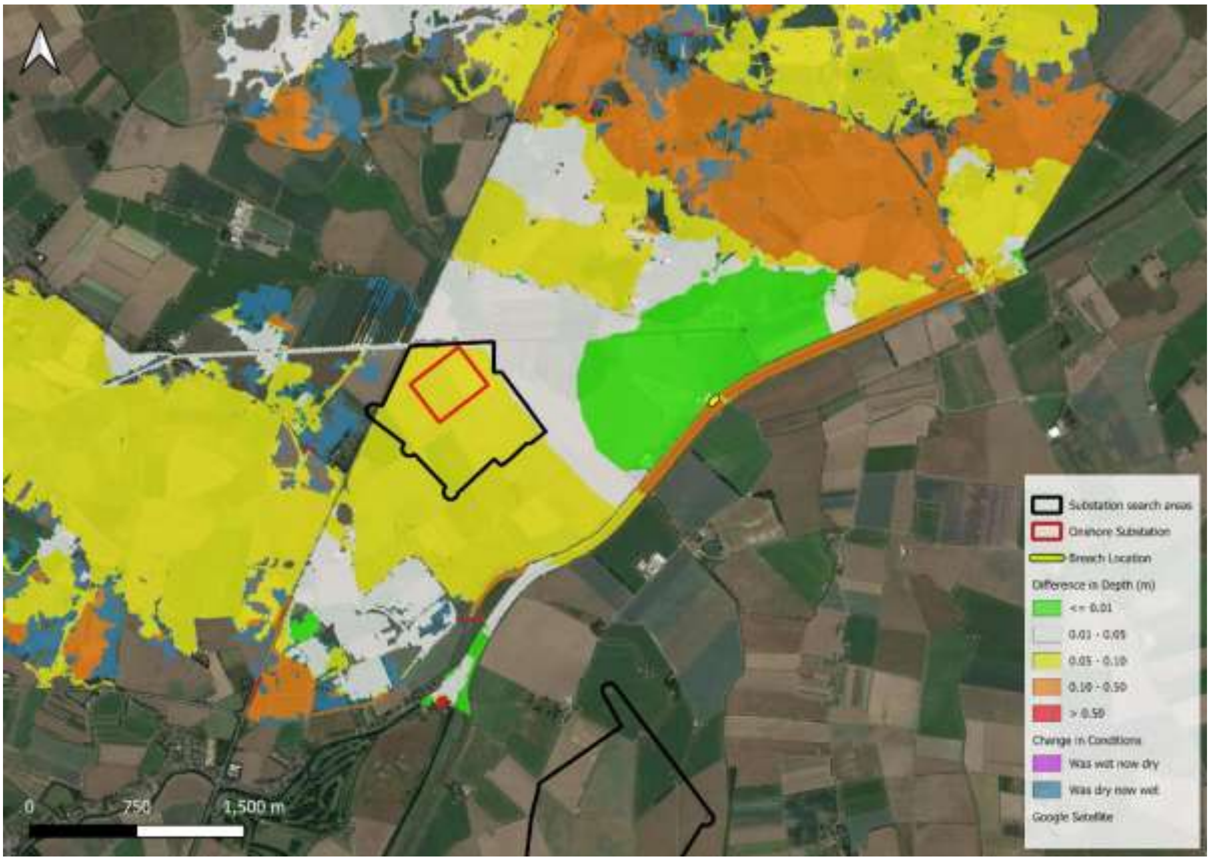


4.2 Channel and Floodplain Roughness

55. A universal separate increase and decrease of 20% to the Manning's roughness values was applied across the entirety of the model domain. Generally, the model results demonstrated little difference in the extents of the flooding resulting from these changes. This is due to the generally even nature of the topography.

56. Within key areas inside the site boundary, peak differences in the order of ±0.1m between each roughness scenario can be observed. As such the hydraulic model is seen as slightly sensitive to changes in Manning's roughness, this is expected with the flat terrain of the model extent.

Figure 4-3 - Flood Depth Difference between Normal and -20% Roughness (Breach 1 - 0.1% AEP+CC)



4.3 Model Inflows

57. The H++ Climate Change Allowance is a scenario in which sea levels are projected to rise significantly due to climate change. The "H++" terminology is often used in climate change assessments to represent a high-end or extreme sea-level rise scenario. This means that a substantial increase in sea levels, which may be driven by factors such as the melting of terrestrial ice masses and thermal expansion of seawater due to global warming, is given consideration.

58. Environment Agency guidance[12] states that tidal H++ runs should apply an increase of 1.9m for total sea level rise to the year 2100. In this case, the sensitivity check is aimed at understanding how the tidal model responds to changes in sea level driven by the H++ climate change allowance. Results for the overtopping and the two north breach scenarios, for the 0.1% and 0.5% with H++ climate change allowance events, can be seen in Appendix B.

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[12] Flood risk assessments: climate change allowances https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#H-plus-plus

5.0 Conclusion and Recommendations

59. SLR Consulting Limited was appointed by GoBe Consultants to prepare a hydraulic model to quantify the flood risk to the site using the latest available information. The detailed hydraulic modelling has confirmed that there is no risk of overtopping conditions. Still, there is a reasonable estimate of flood risk in the event of flood defence failures on or around the site.

60. The maximum water level within the proposed substation area reaches up to 4.093 mAOD with the north breach 2 scenario for 0.1% AEP + climate change event. The modelled development platform remains dry for all events up to and including the maximum studied flood event.

61. A 2-D TUFLOW model has been developed in order to understand the risks of flooding to the site. TUFLOW's HPC module has been used due to its performance and its ability to ensure stable model simulations through the use of adaptive time stepping.

62. Model simulations have been completed for a range of events and scenarios in order to fully assess and understand the risk of flooding to the site and local area.

63. The model has been checked via a QA process, with stability checks and sensitivity tests being completed to ensure that the model is healthy and suitable for use.

64. The model results for the proposed development scenario demonstrate that even in the event of a failure of the flood defences along the River Welland, the site will be safe, and the construction of the site will not result in a material increase to flooding elsewhere.

Appendix A Flood Maps