Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects

Onshore Substation Hydraulic Modelling Report (Revision B) (Clean)

Revision B
Deadline 3
May 2023
Document Reference: 14.34
APFP Regulation: 5(2)(q)

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Glossary of Acronyms

AP	Annual Probability
DCO	Development Consent Order
DDF	Depth Duration Frequency
DEFRA	Department for the Environment and Rural Affairs
DEL	Dudgeon Extension Limited
DEP	Dudgeon Offshore Wind Farm Extension Project
DTM	Digital Terrain Model
EIA	Environmental Impact Assessment
ES	Environmental Statement
FEH	Flood Estimation Handbook
GIS	Geographical Information System
HT	Head Time
km	Kilometre
LiDAR	Light Detection and Ranging
LPA	Local Planning Authority
MW	Megawatts
m AOD	Metres Above Ordnance Datum
NPPF	National Planning Policy Framework
NSIP	Nationally Significant Infrastructure Project
OnSS	Onshore Substation
OS	Ordnance Survey
PEIR	Preliminary Environmental Information Report
PPG	Planning Practice Guidance
ReFH2	Revitalised Flood Hydrograph model Version 2
RF	Rainfall boundary (in the context of a modelling boundary parameter)
SAAR	Standard Annual Average Rainfall is the average annual rainfall across an area
SEL	Scira Extension Limited
SEP	Sheringham Offshore Wind Farm Extension Project
SuDS	Sustainable Drainage Systems
T_P	Time to Peak

UK	United Kingdom

Glossary of Terms

Annual Probability	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 AP 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.
Depth Duration Frequency	Depths define the predicted total rainfall depth for a specific return period and storm duration.
Digital Terrain Model	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.
Direct Rainfall	The Direct Rainfall method applies rainfall directly to a two-dimensional model of a catchment as a series of design rainfall events and the hydraulic model simulates the subsequent overland flow of rainfall.
Dudgeon Offshore Wind Farm Extension Project (DEP)	The Dudgeon Offshore Wind Farm Extension onshore and offshore sites including all onshore and offshore infrastructure.
DEP onshore site	The Dudgeon Offshore Wind Farm Extension onshore area consisting of the DEP onshore substation site, onshore cable corridor, construction compounds, temporary working areas and onshore landfall area.
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.
Flood Source: Fluvial	When flows within watercourses exceed the capacity of the watercourse causing out of bank flows.
Flood Source: Surface Water (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 having a less than 0.1% annual probability of river or sea flooding. (Shown as ‘clear’ on the Flood Map for Planning – all land outside Zones 2, 3a and 3b)
Flood Zone 2	Medium Probability - Land having between a 1% and 0.1% annual probability of river flooding; or land having between a 0.5% and 0.1% annual probability of sea flooding. (Land shown in light blue on the Flood Map)
Flood Zone 3 (A)	High Probability - Land having a 1% or greater annual probability of river flooding; or Land having a 0.5% or greater annual probability of sea. (Land shown in dark blue on the Flood Map)
Flood Zone 3 (B)	Functional Floodplain - This zone comprises land where water from rivers or the sea has to flow or be stored in times of flood. The identification of functional floodplain should take account of local circumstances and not be defined solely on rigid probability parameters. Functional floodplain will normally comprise: • land having a 3.3% or greater annual probability of flooding, with any existing flood risk management infrastructure operating effectively; or • land that is designed to flood (such as a flood attenuation scheme), even if it would only flood in more extreme events (such as 0.1% annual probability of flooding). Local planning authorities should identify in their Strategic Flood Risk Assessments areas of functional floodplain and its boundaries accordingly, in agreement with the Environment Agency. (Not separately distinguished from Zone 3a on the Flood Map)
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)
Horizontal directional drilling (HDD) zones	The areas within the onshore cable route which would house HDD entry or exit points.
HT	Head-Time boundary (in the context of a modelling boundary parameter)

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 AP storm or flow profile used within the modelling
Model Scenario	Each Model Scenarios considers a range of Model Events to assess the impact of the Scenario. Typical Model Scenarios are; Baseline, post development, post mitigation.
Onshore cable corridor	The area between the landfall and the onshore substation sites, within which the onshore cable circuits will be installed along with other temporary works for construction.
Onshore export cables	The cables which would bring electricity from the landfall to the onshore substation. 220 – 230kV.
Onshore Substation	Compound containing electrical equipment to enable connection to the National Grid.
Order Limits	The area subject to the application for development consent, including all permanent and temporary works for SEP and DEP.
Ordinary Watercourse	A watercourse which does not form part of a Main River
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.
ReFH2	Revitalised Flood Hydrograph model Version 2
RF	Rainfall boundary (in the context of a modelling boundary parameter)
SAAR	Standard Annual Average Rainfall is the average annual rainfall across an area
Sheringham Shoal Offshore Wind Farm Extension Project (SEP)	The Sheringham Shoal Offshore Wind Farm Extension onshore and offshore sites including all onshore and offshore infrastructure.

SEP onshore site	The Sheringham Shoal Wind Farm Extension onshore area consisting of the SEP onshore substation site, onshore cable corridor, construction compounds, temporary working areas and onshore landfall area.
Study area	Area where potential impacts from the project could occur, as defined for each individual Environmental Impact Assessment (EIA) topic.
SuDS	Sustainable Drainage Systems, which are designed to manage surface water flows in order to mimic the Greenfield runoff from an undeveloped site.
The Applicant	Equinor New Energy Limited. As the owners of SEP and DEP, Scira Extension Limited and Dudgeon Extension Limited are the named undertakers that have the benefit of the DCO. References in this document to obligations on, or commitments by, 'the Applicant' are given on behalf of SEL and DEL as the undertakers of SEP and DEP.
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.
Tp	Time to Peak is the time delay between peak rainfall and peak river flow rate
Z-shape	A z-shape is a GIS object which defines the elevations of an area and, where necessary, can be used to manipulate the underlying topography.

1 Executive Summary

1. This Onshore Substation Hydraulic Modelling Report (the Hydraulic Modelling Report) has been undertaken for Equinor New Energy Ltd (the Applicant) to support the assessment of surface water flood risk at the proposed Onshore Substation (OnSS) site to the south west of Norwich. This work was to inform the wider **Flood Risk Assessment** [AS-023] for the onshore cable route and OnSS platform to support the Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects.
2. To understand the above flood risk in greater detail, a 2D direct rainfall model has been constructed, covering the site of the proposed OnSS platform. This Hydraulic Modelling Report provides a summary of the modelling exercise undertaken and the subsequent results which were reviewed to provide a greater understanding of surface water flood risk in this location.
3. Comments from Norfolk County Council, in their role as the Lead Local Flood Authority (LLFA), on the initial hydraulic modelling have been considered and addressed in this report. In particular, this relates to the application of the 1 in 100 year (+45% allowance for climate change) event, the model has been updated to reflect this and the model results included throughout this Hydraulic Modelling Report for comparison.
4. A 2D direct rainfall model was built in the TUFLOW modelling software and initially included gross rainfall hyetographs as inflows. Comparison with the Environment Agency's surface water mapping and anecdotal information, along with best practice application of modelling approaches and the results of the ground investigations, indicated this method was considered unlikely to be representation of the catchment. Therefore, the use of the net rainfall hyetographs was adopted within the hydraulic model.
5. Furthermore, the hydraulic modelling identified that a combination of the net rainfall hyetographs and the use of 0.5m resolution LiDAR provided the best representation of the surface water flood risk for the study area.
6. A Baseline model was developed to understand the nature of the existing surface water flood risk at the OnSS site. This was considered alongside the footprint of the OnSS platform to understand its potential interaction with the surface water flood extent.
7. Following the development of the Baseline model, a number of options for the layout and location of the OnSS platform were considered as part of the design iteration process.
8. Option 1, comprising a large rectangular shape, overlaps the Baseline surface water flood extent in all modelled events. This would result in the displacement of surface water, which would require mitigation / management within the site boundary.
9. Option 2, comprising an irregular polygon shape to allow for either a N-S or E-W orientation for the OnSS, does not overlap with the Baseline surface water flood extent in any event except for the 1 in 100 year (plus 40% for climate change) and 1 in 100 year (plus 45% for climate change) events. On this basis, the volume of displaced water would be much reduced compared with Option 1 requiring less mitigation / management of surface water within the site boundary.

10. Modelling of Option 2 with the Embankments for the OnSS platform did not show any significant impacts to the flood extent when compared to the Baseline results. This option also demonstrates a significant reduction in surface water displacement compared with Option 1.

11. To understand the impact the OnSS platform may have on surface water flood risk and to consider the potential for an increase in off-site flood risk, Option 2 with Embankments was modelled with the platform level set at 28.23m AOD. A review of these results noted that both the surface water flood extent and maximum flood depths are slightly reduced compared with the results from the Baseline modelling.

12. This reduction can be attributed to the incorporation of the OnSS platform in the model. By including the OnSS platform within the model, rainfall falling on the platform during an event does not contribute to the flooding as it is assumed this will be collected by the surface water drainage system to be implemented as part of the project or will naturally infiltrate into the ground on the platform.

13. The OnSS platform requires the provision of an access road to connect it with the higher ground to the north. As a result, this means the southern end of the access road (at the OnSS platform) would be raised above the existing ground level. The access road would need to pass over the existing overland flow path and could potentially block it. As such, it was noted that measures will be required to enable the existing surface water flow paths to continue to pass below the access road.

14. To understand the impact the OnSS platform and access road may have on surface water flood risk and to consider the potential for an increase in off-site flood risk, Option 2 with Embankments was modelled with the North West access road included tying in to the OnSS platform level of 28.23m AOD at the southern end.

15. A large culvert was included within the model beneath the North West access road to allow the continued conveyance of the existing flow path beneath it. The results of this modelling demonstrated very little impact from the North West access road on the overland flow path, with the water continuing to reach the low lying area adjacent to the railway embankment, as is the existing situation. A review of culvert dimensions under the access road has been undertaken, aimed at providing clarification to queries raised by the LLFA, demonstrating there is sufficient elevation above existing ground levels and below the access road for the culvert to pass beneath it.

16. The Baseline and Option 2 with Embankments and North West access road results were compared to determine the areas which experienced an increase in flood extent and depth. This comparison showed there to be a reduction in flood depth adjacent to the platform and the railway line, and a slight increase at the edges of the access road. The locations of these changes are localised, and this demonstrated that the proposals will not increase off-site flooding to others.

17. The conclusions of the hydraulic modelling exercise were originally provided in **Annex 18.2.2 - Onshore Substation Hydraulic Modelling Technical Note** [APP-211]. Following receipt of comments from Norfolk County Council, in their role as the LLFA, the Applicant has undertaken additional work to provide clarification on a number of aspects of the modelling which have been summarised in the production of this updated report.

18. At the request of the LLFA, **Annex 18.2.2 - Onshore Substation Hydraulic Modelling Technical Note** [APP-211] has been amended such that it comprises a standalone and more comprehensive Hydraulic Modelling Report. As such, the Applicant notes this Hydraulic Modelling Report supersedes **Annex 18.2.2 - Onshore Substation Hydraulic Modelling Technical Note** [APP-211].

19. However, the Applicant notes that the original conclusions set out in **Annex 18.2.2 - Onshore Substation Hydraulic Modelling Technical Note** [APP-211] remain unchanged and the proposed OnSS platform and access road will not pose a significant off-site risk to others, or be at significant risk of flooding, for the lifetime of the development.

2 Introduction

2.1 Overview

20. Equinor New Energy Ltd (the Applicant) commissioned the building of a direct rainfall hydraulic model to support the assessment of surface water flood risk at the proposed Onshore Substation (OnSS) site to the south west of Norwich. This work was to inform the wider **Flood Risk Assessment** [AS-023] for the onshore cable route and OnSS platform to support the Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects.

21. A review of the Environment Agency online surface water flood risk mapping was undertaken to inform the understanding of surface water flood risk at the proposed OnSS site to the south west of Norwich.

22. Reference to the Environment Agency's online surface water mapping indicated an overland flow path crosses the proposed OnSS site with water pooling against the railway embankment in the proposed location of the OnSS platform, as shown in **Figure 2-1**. This was based on the Order Limits and proposed location of the OnSS platform at the time of the review. As such, it was considered necessary to investigate this potential flood mechanism further.

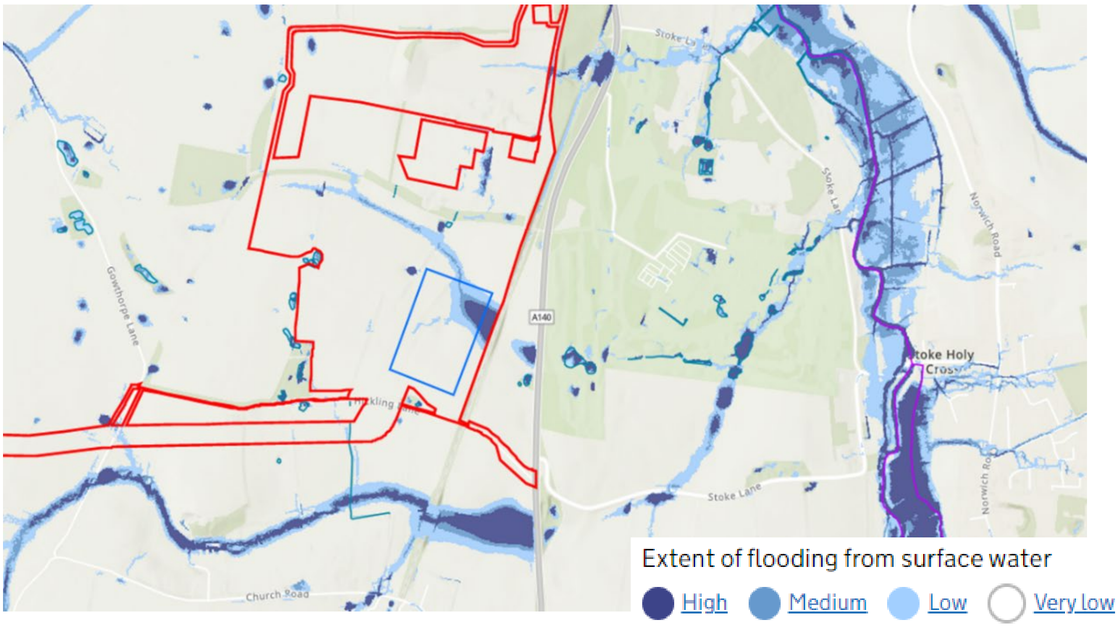

Figure 2-1: Extract of Environment Agency surface water flood risk mapping in comparison with the proposed OnSS platform (at the time of the initial review)

23. To understand the above flood risk in greater detail, a 2D direct rainfall model was constructed, covering the site of the proposed OnSS platform to be located in an existing agricultural field to the west of Ipswich Road and the railway embankment and to the north of Hickling Lane (Grid reference: 621847, 301820; closest postcode NR14 8PW).

24. This Hydraulic Modelling Report provides a summary of the modelling exercise undertaken and the subsequent results which were reviewed to provide a greater

understanding of surface water flood risk in this location. The above review subsequently led to the refinement of the location and layout of the proposed OnSS platform, as well as updates to the Order Limits.

25. This report details the methodology used in developing the hydraulic model, including the hydrological analysis and hydraulic approaches. It provides a summary of the design iterations for the OnSS platform that have been considered and presents the results of the modelling exercise as well as providing conclusions and limitations of the modelling study.

2.2 Scope of Works

26. To aid in the review of flood risk at the proposed OnSS the scope of works included:

- An assessment of the catchment hydrology and the derivation of the critical storm events using data / information obtained from the Flood Estimation Handbook (FEH).
- The construction of a two-dimensional (2D) hydraulic model of the catchment draining towards the proposed OnSS site.
- Identification of the ‘worst-case’ flooding between winter and summer seasons.
- Simulation of the Baseline runs for five design storm events (1 in 30 year, 1 in 100 year, 1 in 100 year plus 20% climate change, 1 in 100 year plus 40% climate change and 1 in 100 year plus 45% climate change).
- Simulation of the proposed development options runs for five design storm events (1 in 30 year, 1 in 100 year, 1 in 100 year plus 20% climate change, 1 in 100 year plus 40% climate change and 1 in 100 year plus 45% climate change).
- The production of flood maps of the different simulated model options and comparison of the flood extents and depths.

2.3 Lead Local Flood Authority Comments

27. Norfolk County Council, in their role as the Lead Local Flood Authority (LLFA), have been consulted throughout the Development Consent Order (DCO) pre-application process and this engagement has continued following submission of the DCO application. As part of the ongoing consultation process the LLFA provided a set of comments on the hydraulic modelling in a letter dated 29 November 2022, included as **Appendix A**.

28. These comments should be read alongside the **Norfolk County Council Relevant Representation** [RR-064] as they provide greater clarity on specific technical concerns. The summary of comments provided in **Appendix A** includes a short response from the Applicant to aid in identifying where, within this Hydraulic Modelling Report, these concerns have been addressed.

29. The key themes of these comments from the LLFA are summarised as follows with a cross reference to where these are addressed within the Hydraulic Modelling Report:

- More detailed summary of the model hydrology is required (**Section 6**);
- Confirmation of the catchment size (**Section 3.1**);

- Confirmation of where the modelled catchment areas extend i.e. Rainfall (RF) boundary and Head-Time (HT) boundary (**Section 7.5**);
- Further information must be provided for the 1% AP (1 in 100 year) for comparative purposes (**Section 9**);
- Both orientations of the proposed OnSS and the access road alignment to be shown on figures (**Section 9**);
- Further justification needed with regard to the embankment size or scale. Clarify whether cut and fill drawing provided to LLFA was used to support the model preparation (**Section 9.3**);
- Further information about TUFLOW and ESTRY model parameters and interaction (**Section 7**);
- Confirmation of the platform levels included in the hydraulic models to better understand the options modelled. Platform levels should be compared directly to the finished platform levels shown in the Substation Cut and Fill – Revised Platform Location Drawing to ensure the modelled events and options represent the proposed design (**Section 9.3**); and
- Model to be run for the 1 in 100 year (plus 45% climate change) event (**Section 9**).

30. In addition, further areas where the LLFA requested clarification are summarised as follows, with a cross reference to where these are addressed within the Hydraulic Modelling Report:

- Clarification on catchment boundary checks (**Section 3**);
- Further information required in relation to Sensitivity Testing (**Section 10**);
- Clarification regarding the alignment of the culvert under the proposed access road (**Section 7.4**); and
- Confirmation with regard to the consideration of the critical storm duration (**Section 6.1**).

31. As noted above, the concerns from the LLFA outlined above have been considered and addressed within this Hydraulic Modelling Report.

3 Hydrological Analysis

3.1 Catchment Characteristics

32. A review of the hydrological catchment was carried out using the FEH Web Service (UK Centre for Ecology & Hydrology, undated) and the British Geological Survey (BGS) online mapping tool, known as the Geology of Britain Viewer (British Geological Survey, undated).

33. The BGS Geology of Britain viewer indicated the OnSS site to be located above a bedrock of chalk with deposits of diamicton. While the chalk would typically indicate infiltration potential, the presence of diamicton could hinder the infiltration rate.

34. **Figure 3-1** shows the catchment draining towards the site as derived from the FEH Web Service (UK Centre for Ecology & Hydrology, undated).

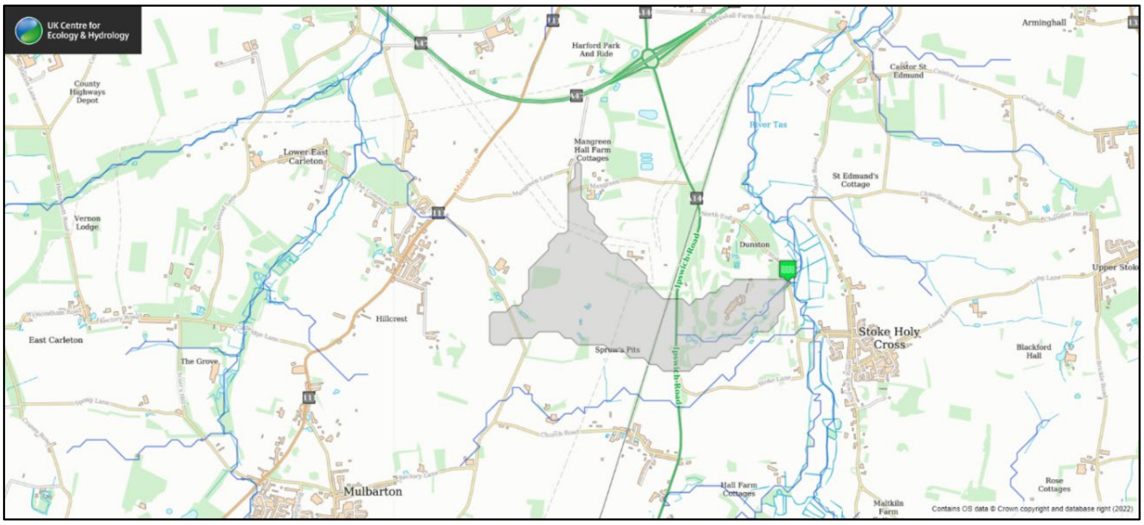

Figure 3-1: Extract from the FEH Web Service showing contributing hydrological catchment (marked in grey)

35. The contributing hydrological catchment is 1.32 km^2 in area, and the key FEH catchment descriptors are summarised in Table 3-1 alongside a brief description of their meaning relative to the catchment. The full catchment descriptors are included in **Appendix B.** The FEH catchment boundary has been compared with topographic data and aerial mapping to inform the delineation of the contributing hydrological catchment, as noted in **Section 3.3** of this report.

Table 3-1: FEH Catchment Descriptors (Source: FEH Web Service)

FEH Descriptor	Value	Meaning
Area	1.32 km^2	
BFIHOST	0.768	Relatively high values indicate greater contribution from Baseflow and therefore relatively high permeability
BFIHOST19	0.795	High Permeability
DPSBAR	17.2 m/km	Drainage Path Slope = This indicates overall a generally flat catchment
FARL	1	No attenuation due to lakes and reservoirs
PROPWET	0.27	27% = Relatively dry soils
SAAR	614	Average annual rainfall in mm (1961-1990)
SAAR4170	596	Average annual rainfall in mm (1941-1970)
SPRHOST	23.86%	Standard percentage runoff indicates a relatively low runoff rate
URBEXT1990	0.0028	Index of urban/suburban land cover as a fraction = very small
URBEXT2000	0.0104	Index of urban/suburban land cover as a fraction = very small

36. A review of the FEH catchment descriptors indicated that the catchment should be highly permeable, with the expectation that a high proportion of rain falling onto the catchment would infiltrate to the underlying ground. The relatively high BFIHOST value indicates high permeability. This is in accordance with the low SPRHOST value which indicates that only 23.86% of the water falling onto the catchment would result in runoff.

37. It is noted that the above catchment descriptors are indicative of the nature and behaviour of the wider contributing catchment and not specifically the OnSS site. There are likely to be variations within a catchment; however, it was important to understand the likely behaviour of the wider catchment when considering its contribution to flood risk within the area of interest.

38. On-site soakaway testing carried out, as part of a series of borehole and trial pit investigations in September 2021 indicated there was very low infiltration across the OnSS site, as shown on **Figure 3-2** .

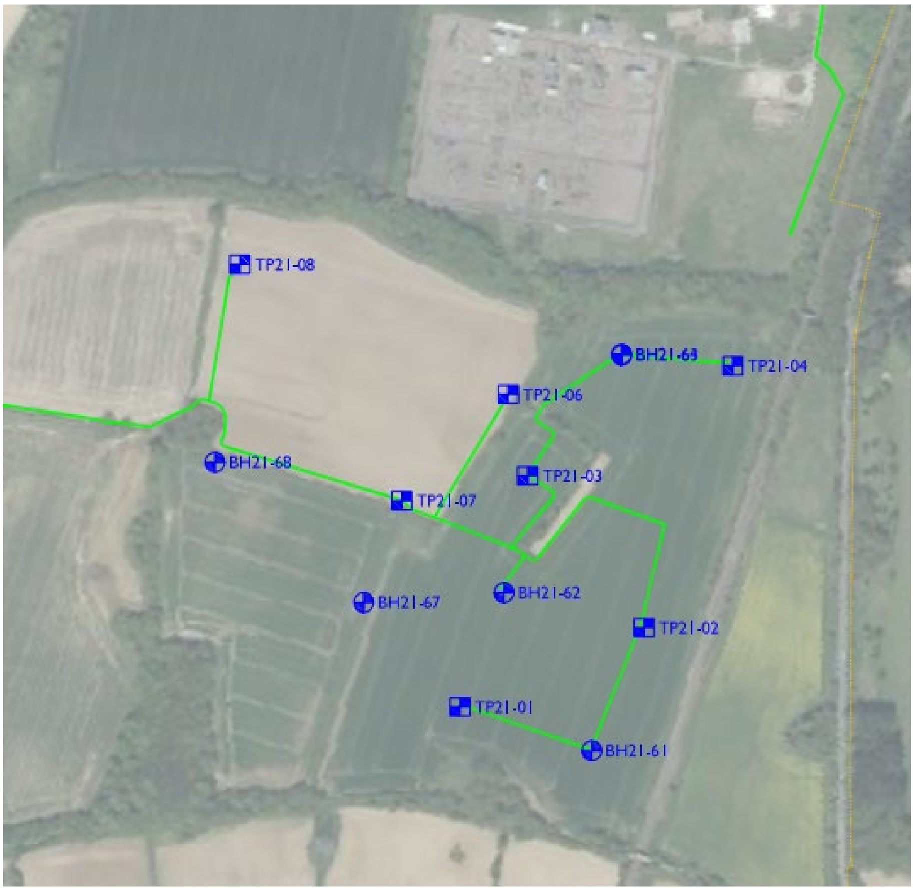

Figure 3-2: September 2021 exploratory hole locations

39. The soakaway tests were abandoned due to a lack of infiltration into the ground over the time period that was monitored (180 – 300 minutes) because water levels had not dropped below 75% of the starting head in the majority of the test locations. As a result, infiltration rates could not be calculated because they require water level data at 75% and 25% of the starting head.
40. Therefore, there was uncertainty with regard to the infiltration potential of the catchment which would be hindered by the presence of other sub-surface layers above the chalk, such that surface water runoff is unlikely to infiltrate into the ground.
41. Ongoing ground investigations have been undertaken including obtaining further information for the area of the proposed OnSS during a geophysical survey in April 2022 and subsequent supplementary ground investigation works in June 2022.
42. The exploratory holes installed as part of the supplementary ground investigations in June 2022, as shown on **Figure 3-3**, have been subject to ongoing monitoring to record information related to groundwater levels. The geophysical surveys in April 2022 identified shallow granular zones potentially suitable for infiltration within the OnSS site. The survey noted that these appear to be linked to a historic river channel that had been infilled with granular deposits to a depth of approximately 10m.

Figure 3-3: June 2022 additional exploratory hole locations

43. As part of the supplementary groundwater investigations, three boreholes were installed to ground truth the geophysical surveys. Each borehole included a groundwater monitoring installation to monitor the granular horizon. In each borehole falling head permeability tests along with borehole soakaway tests were undertaken within the groundwater monitoring installations to determine ground permeability and infiltration rates.

44. All groundwater monitoring shows there is no groundwater encountered in any of the exploratory holes. In addition, the results of the supplementary ground investigations indicated beneficial infiltration rates in key locations around the OnSS site.

45. The results of the additional ground investigations confirms that even within the OnSS site there is variability in ground conditions, which may also be applicable throughout the catchment.

46. The potential uncertainty with regards to ground conditions has been included within the series of sensitivity tests, as summarised in **Section 10**. These include sensitivity tests on other parameters / factors in addition to those highlighted above.

3.2 Watercourses

47. The hydrological setting of the catchment is summarised below and is also discussed in the **Flood Risk Assessment** [AS-023].

48. The River Tas is located approximately 969m away from the OnSS site and the Intwood Stream passes approximately 1.9km away from the OnSS site. In addition, the OnSS site is located entirely within Flood Zone 1.

49. There are no Ordinary Watercourses with the attachment of the OnSS site and whilst there are several field drains and ditches in the local area these are generally dry or do not appear to be in connectivity with the wider network. The nearest Ordinary Watercourse with observable flow appears to be downstream of the OnSS site and located to the south of Hickling Lane.

3.3 Site Walkover

50. A site walkover was undertaken on 13th December 2021 by the Project team including visits to key areas around the wider catchment. Observations related to ditches, general topography, standing and flowing water and land use were made. The site walkover was undertaken following a series of rainfall events which aided in understanding the likely impact of rainfall on the catchment.

51. Information from this site walkover was used in the identification of the contributing hydrological catchment as well as in the setting of model parameters. These were also compared with topographic data in the form of LiDAR and aerial mapping to inform the delineation of the contributing hydrological catchment.

3.4 Summary of Hydrological Analysis

52. Based on the information and checks undertaken above, it has been confirmed that the catchment boundary as defined by the FEH Web Service appears to be reflective of the contributing catchment and areas draining towards the OnSS site. In addition, the FEH catchment descriptor values appear to be reflective of the catchment, whilst it is acknowledged that there is some variability within the catchment as identified by the ground investigations. As noted above, the potential uncertainty with regards to ground conditions has been considered within the series of sensitivity tests, summarised in **Section 10**.

53. Following review of the hydrological catchment, the ReFH2 software was used to generate direct rainfall hyetographs based on the FEH13 Depth-Duration-Frequency (DDF) estimates.

54. The LIT11832 Environment Agency Flood Estimation Guidelines (July 2022) notes:

> *“You should use winter storm rainfall depths, Cini and initial baseflow values and storm profiles in for all catchments, unless:*
>
> $URBEXT_{2000} \geq 0.30$*; or*
>
> *URBEXT2000 ≥ 0.15 and BFIHOST19 ≥ 0.65.”*

55. Guidance provided in the LIT11832 Environment Agency Flood Estimation Guidelines (July 2022) and the FEH Handbook indicates a catchment is classed as Essentially Rural if the $URBEXT_{1990}$ is <0.025 and / or $URBEXT_{2000}$ is <0.03.

56. On this basis, following the above Environment Agency and FEH guidelines, the winter storm profile was used, in line with best practice guidance, on the basis that the URBEXT$_{2000}$ value for the catchment was less than 0.30.

57. Given the poor infiltration observed during the September 2021 ground investigations, a conservative approach to the hydrological analysis was initially adopted whereby the gross rainfall hyetographs were applied as a direct rainfall boundary, rather than the net rainfall. This meant that no losses to the ground were included in the rainfall runoff model.

58. However, as more information became available during the modelling exercise this approach was amended to use the net rainfall hyetographs, as discussed in **Section 8.2**.

4 Methodology

4.1 Choice of Approach

59. There are no open watercourses to the west of the railway embankment at the OnSS site. As the railway embankment forms a barrier to overland flows, it was considered that although the catchment in **Figure 3-1** is shown to discharge to the River Tas, in reality this flow route is bisected by the railway embankment.

60. The primary flood source to the west of the railway embankment is therefore surface water from the overland flow route which crosses the open fields. As such, 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.

61. 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.

62. A limitation of Direct Rainfall includes uncertainty regarding infiltration to the ground. Since the initial site-specific infiltration tests indicated poor infiltration potential, the worst-case was initially assumed whereby gross rainfall hyetographs were applied as inflows to the model, which do not have an allowance for infiltration or discharge to sewers.

63. However, when initial modelling results were compared to the Environment Agency surface water mapping, this indicated that the gross rainfall hyetographs were overestimating the surface water risk.

64. Following additional ground investigations and monitoring it was found that infiltration is greater in some areas within the OnSS site. On this basis, the net rainfall hyetographs were subsequently applied to the hydraulic model to account for losses across the catchment, based on the catchment characteristics. This resulted in a flood extent which was more similar to the Environment Agency mapping. Further information on this approach and the results is provided in **Section 8.2**.

65. **Figure 4-1** provides an overview of the modelling methodology based on the Direct Rainfall approach. The numerical flood model was 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.

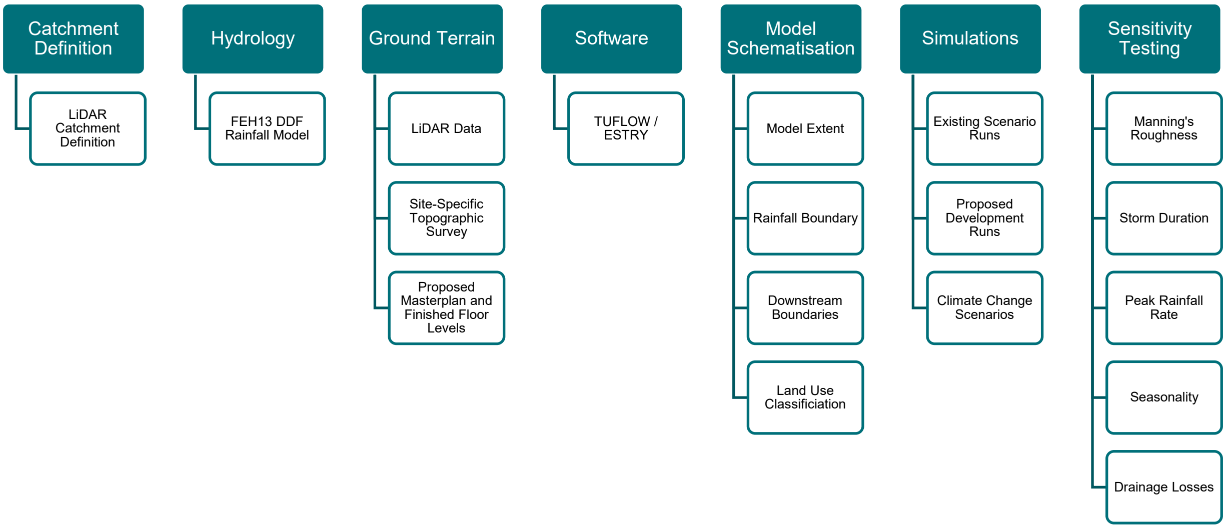

Figure 4-1: Methodology Overview

4.2 Hydrological Approach

66. The Direct Rainfall method requires the derivation of suitable rainfall hyetographs which are applied to the hydraulic model in the form of rainfall timeseries data. The FEH Web Service (UK Centre for Ecology & Hydrology, undated) provided catchment descriptors, were used alongside the ReFH2 software to generate rainfall depth duration frequency (DDF) estimates.

67. ReFH2 was then used to assess the critical storm duration, as summarised in **Section 6.1**, and the rainfall hyetographs were prepared from the estimates of the DDF to provide the rainfall boundary.

4.3 Hydraulic Modelling Approach

68. 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.

69. 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.

70. Based on experience of development of 1D/2D numerical flood models for the assessment of site-specific flood risks, the TUFLOW / ESTRY solver is considered appropriate for the simulation of the Baseline modelling as well as for testing of potential future Post Construction (i.e. once operational) or mitigation options.

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[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).

5 Data Sources

71. Several sources of information have been used within this hydraulic modelling study. **Table 5-1** provides a list of the data used in the development of the hydrological assessment and hydraulic model.

72. The data quality has been assessed in accordance with the Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal, otherwise known as the Multi-Coloured Manual (Flood Hazard Research Centre & Environment 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
2D Geometry	Site-Specific LiDAR Survey	Equinor	2021	1	Best available data covering the site.
	0.50m LiDAR Data	Environment Agency	2018	1	The best data available for the study area was the 2018 composite dataset.
	0.25m LiDAR Data	Equinor	2021	2	Flown by the Client but a review of the data highlighted issues with using this dataset (discussed in **Section 5.1**).
Surface Roughness	Aerial Photography	Various	2021	2	Aerial photography provided a means to confirm the surface roughness assigned by the Ordnance Survey data.
	Open Channel Hydraulics	Chow	1959	2	Manning's roughness values determined based on the value ranges recommended in this industry-standard publication and modelling experience.

5.1 Review of Higher Resolution LiDAR

73. The initial Baseline modelling exercise used the LiDAR data to 0.50m resolution, which meant that ground levels were taken at 0.50m intervals across the catchment.

74. To aid in the refinement of the model, higher resolution 0.25m LiDAR data was obtained from the Client and considered for its suitability within the catchment.

75. The hydraulic model was run for the 1 in 100 year (plus 40% for climate change) rainfall event using the 0.25m LiDAR and the resulting depth map is shown in **Figure 5-1**.

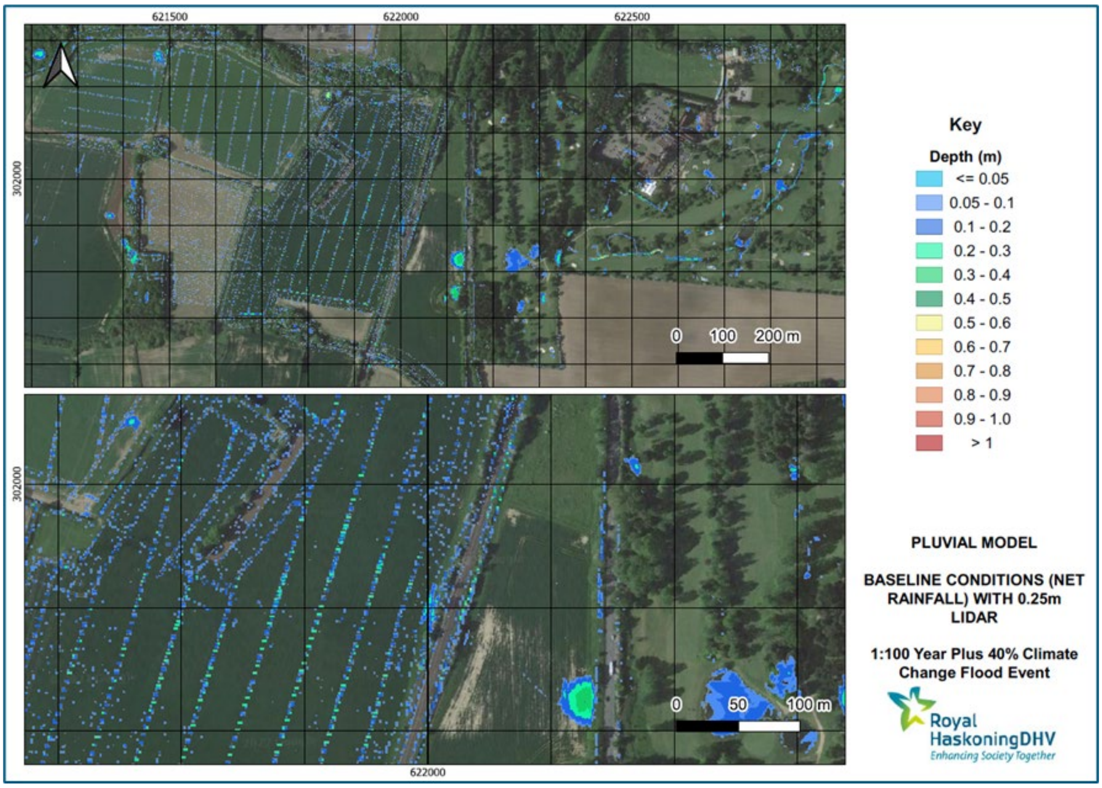

Figure 5-1: 1 in 100 year plus 40% for climate change Baseline (existing) using 0.25m LiDAR

76. It is clear from **Figure 5-1** that the surface water in this modelled event is not pooling in the low point adjacent to the railway embankment, but instead is being held back within the plough lines of the fields to the west and north west of the OnSS site.

77. A review of the 0.25m LiDAR data indicated that it was flown for the Project in August 2021 and therefore this variation is likely to be reflective of the time of year that the 0.25m resolution LiDAR was captured i.e. during crop growth. In addition, when comparing the 0.25m LiDAR data with the 0.5m LiDAR dataset there were inconsistencies in levels within the catchment. This was attributed to the data picking up the variable height of the crops in the field.

78. Use of the 0.25m LIDAR data significantly reduces the flood depth adjacent to the railway line. However, this is not considered to be representative of the typical surface water flooding in this location and is very different to the Environment Agency surface water mapping.

79. While it may be the case that some surface water is held back within the plough lines at certain times of the year (i.e. when the fields have recently been ploughed), for significant periods of the year the plough lines may not be there.

80. On this basis and taking a conservative approach, whereby water is able to reach the low point adjacent to the railway line, the 0.25m resolution LiDAR has not been used for the purposes of the remainder of this modelling exercise, and the 0.50m resolution LiDAR has been used instead.

81. It is within the context of this existing surface water flood risk that the consideration of potential options for the layout and location of the OnSS platform has been assessed.

6 Hydrological Analysis Summary

6.1 FEH13 DDF Rainfall Model

82. The FEH13 DDF Rainfall Model was used to extract rainfall depths for a given return period and storm duration. A review of storm durations for the catchment were undertaken within the ReFH2 software, as part of the hydrological analysis. This is in accordance with best practice whereby it is necessary to identify the rainfall event or storm that is likely to produce the most significant flooding within a catchment.

83. The hydrological analysis included an assessment of storm durations ranging from 2.5 hours through to 18 hours. A review of the various storm durations found that the critical storm duration (i.e. duration of the rainfall event) for this catchment is the 7.5 hours (450 minutes) winter storm. As such, this was then adopted as the critical storm duration within the hydraulic modelling for the assessment of all return period events.

84. On the basis of the above, the model was subsequently run for a total of 12 hours i.e. a further 4.5 hours following the peak of the hyetograph to allow time for surface water to flow through the catchment following the storm and to ensure that maximum depths were modelled in the areas where ponding would occur.

85. For the hydrological inputs to the model, rainfall hyetographs were prepared for the 1 in 30 year, 1 in 100 year, 1 in 100 year (plus 20% for climate change), 1 in 100 year (plus 40% for climate change) and 1 in 100 year (plus 45% climate change) events. The gross rainfall hyetograph for all return period events are included at **Appendix C**.

86. However, following initial Baseline model runs and comparison with the Environment Agency surface water flood maps, the resulting flood extents and depths when using the gross rainfall was considered to be overestimating the flood risk in the local area. Therefore, the model was re-run using net rainfall hyetographs, which include losses accounting for infiltration and sewers.

87. These resulted in flood extents and depths more comparable to the Environment Agency mapping and were used for the final model runs. The net rainfall hyetographs for all return periods are included at **Appendix C**.

88. It is 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.

89. 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.

90. As noted previously, in **Section 3.1**, for this catchment the FEH catchment area boundary is considered appropriate, as it allows for a good understanding of overland flow routes and identification of areas of ponding across the wider rural area.

6.2 Climate Change Allowances

91. When considering surface water flood risk, the Norfolk County Council LLFA Statutory Consultee for Planning Guidance Document (Norfolk County Council, 2022) requires an assessment of the lifetime of the development, the vulnerability of the proposed land use and a justification related to the choice of allowance.

92. Further to the above guidance the Environment Agency issued updated climate change allowance guidance, specifically with regard to the application of peak rainfall allowances on 10th May 2022 (Environment Agency, 2022).

93. The surface water climate change allowances are determined by the predicted increase in peak rainfall intensity. These are determined by regional variations, which are based on management catchments, which are sub-catchments of river basin districts.

94. The OnSS site is located within the Broadland Rivers Management Catchment and therefore the allowances for this Management Catchment have been considered within the surface water modelling.

95. A review of the updated guidance noted that for the OnSS site, assuming 40 years of operation with commencement of operation in 2028, the required allowance to be considered comprises an increase of 20% for the 1 in 100 (1%) year event applying the central allowance, as shown in **Table 6-1** below.

Table 6-1: Peak Rainfall Intensity Allowance for the Broadland Rivers Management Catchment

Broadland Rivers Management Catchment	Central 1 in 30 year (3.3%)	Upper end 1 in 30 year (3.3%)	Central 1 in 100 year (1%)	Upper end 1 in 100 year (1%)
2050s	20%	40%	20%	45%
2070s	20%	40%	**20%**	40%

96. As noted in **Section 6.1**, the rainfall hyetographs for the 1 in 100 year plus 20% for climate change and 1 in 100 year plus 40% for climate change events were considered alongside the layout of the OnSS platform.

97. Following comments from the LLFA, with regard to the lifetime of the development, it was agreed that in the absence of information related to the Decommissioning Phase a conservative allowance of 45% for climate change would be applied.

98. As such, the 1 in 100 year plus 45% for climate change event was also modelled and the resulting flood extents have been considered in this report.

99. This additional check has confirmed there is minimal interaction with the surface water flood extent up to and including the 1 in 100 year plus 45% for climate change event, as discussed in **Section 9**.

7 Hydraulic Modelling

100. The model was built using the TUFLOW 2D modelling software which is benchmarked by the Environment Agency and is considered suitable for predicting flood levels, depths, flow velocities and flood hazard ratings across floodplains.

7.1 2D Domain

101. The Environment Agency open source LiDAR comprising the Digital Terrain Model (DTM) at 0.5m resolution was used to create the digital elevation model i.e. the ground profile over which the rainfall is distributed.

102. As noted previously, this data was also cross referenced with survey data flown for the Project in August 2021 and the equivalent Digital Surface Model (DSM), i.e. unfiltered LiDAR, for validation. The digital elevation model was checked prior to running the modelling to ensure the railway embankment, drainage ditches and other features within the study area were sufficiently picked up.

103. Within the model a cell size of 2m was considered suitable for the study, to capture the flow paths while still allowing a reasonable model simulation time.

7.2 Model Geometry

104. The existing ‘Baseline’ model did not include any specific features to be represented in the model geometry, as the railway embankment and any notable ditches were picked up in the LiDAR.

105. For the proposed options, the OnSS platform was represented as a 2D z-shape region set at a specific elevation. A z-shape is a GIS object which defines the elevations of an area and, where necessary, can be used to manipulate the underlying topography.

106. For the option including the access road, this was also included as a 2D z-shape region using the ‘MAX’ flag. This means that any ground lower than a specified elevation will be raised beneath the z-shape to that elevation, thereby creating a barrier beneath the z-shape.

7.3 Roughness Values

107. Mannings roughness values as defined by Chow (1959) in the publication ‘Open Channel Hydraulics’ were used to define the surface roughness.

108. As much of the modelled catchment comprises fields then roughness values of between 0.035 and 0.045 were typically applied.

109. Where there were areas of denser woodland these were assigned a value of 0.08, to reflect the greater roughness and slowing of flow that they are likely to represent. The Mannings values used in the model are set out in **Table 7-1**.

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

Material Code	Mannings Roughness ‘n’	Description
999	0.045	Default Roughness
101	0.060	Urban Areas
102	0.035	Green Space/Undeveloped Fields
103	0.080	Woodland
104	0.020	Surface Water/Lakes
105	0.050	Foreshore
106	0.020	Waterlines
107	0.040	Buildings
108	0.025	Tracks/Roads

110. Where there were known ground features, for example field boundaries and hedgerows these were not only reviewed within the ground elevation model to ensure they had been appropriately represented but also, where necessary, modifications were made to the roughness values in these locations to be representative of the vegetation.

7.4 1D Network

111. The site and surrounding area were analysed for both open and culverted watercourses. In particular, Network Rail data was reviewed to determine whether there were any culverts beneath the railway embankment which may provide a route beneath the embankment for the overland flow path to pass through. However, no culverts or open sections of watercourse were identified. Therefore, in the Baseline model, it was not necessary to incorporate any 1D network.

112. The Applicant notes that the OnSS will require an access road leading to the OnSS platform. It is recommended that the access road is elevated above the surface water flow path, with water allowed to pass below it.

113. To represent this option, a short section of 1D network was added and modelled as a rectangular culvert (R) with the dimensions of 25m wide and 2.20m high. This culvert dimension has been adopted within the modelling exercise to ensure that, when assessing flood risk in this location, there is no restriction on the conveyance of flow as a result of the access road. During the design process the dimensions of the actual culvert to be provided under the access road will be refined to ensure the conclusions of this modelling exercise remain valid.

114. A review of the existing ground levels in the vicinity of the OnSS access road and the modelled 2.20m high culvert found that this would result in minimal cover between the top of the culvert and the carriageway level for the access road. However, it is noted that the above culvert dimensions were included within the initial modelling exercise principally to ensure continued conveyance of surface water flow.

115. A review of the model results identified that during the 1 in 100 year (plus 45% for climate change) event the maximum water depth at the upstream extent of the culvert is likely to be approximately 0.23m. As such, a 2.20m high culvert would be considerably larger than that required to ensure the continued conveyance of surface water flow.

116. On this basis, it is concluded that the height of the culvert can be refined and reduced during the detailed design process to provide cover levels of between 0.3m and 1m from the top of culvert to the access road carriageway. This would ensure sufficient cover levels, appropriate to the type and nature of the vehicle loading in this location, whilst also maintaining surface water flow conveyance under the access road. As noted above, the dimensions of the culvert under the access road will be refined during the detailed design process to ensure the above conclusions remain valid.

117. ‘SX’ boundary connections were included on each end of the culvert to allow the water to travel from the 1D to the 2D domain and vice versa, shown in **Figure 7-1.** This enabled the water to pass beneath the access road with no restrictions.

Figure 7-1: 1D Network set-up beneath proposed access road (Option 2 with NW Access)

7.5 Boundary Conditions

118. The rainfall boundary was applied, within the model, as a single ‘RF’ polygon which covered the whole of the contributing catchment. A ‘HT’ boundary was applied to the catchment boundary with a constant outflow of -50 to enable any water reaching the edge of the model to flow out and not cause spurious results at the model boundary.

119. **Figure 7-2** shows the RF boundary in purple and the HT boundary in brown. The HT boundary is applied only as a line around the edge of the catchment, i.e. it is not a polygon.

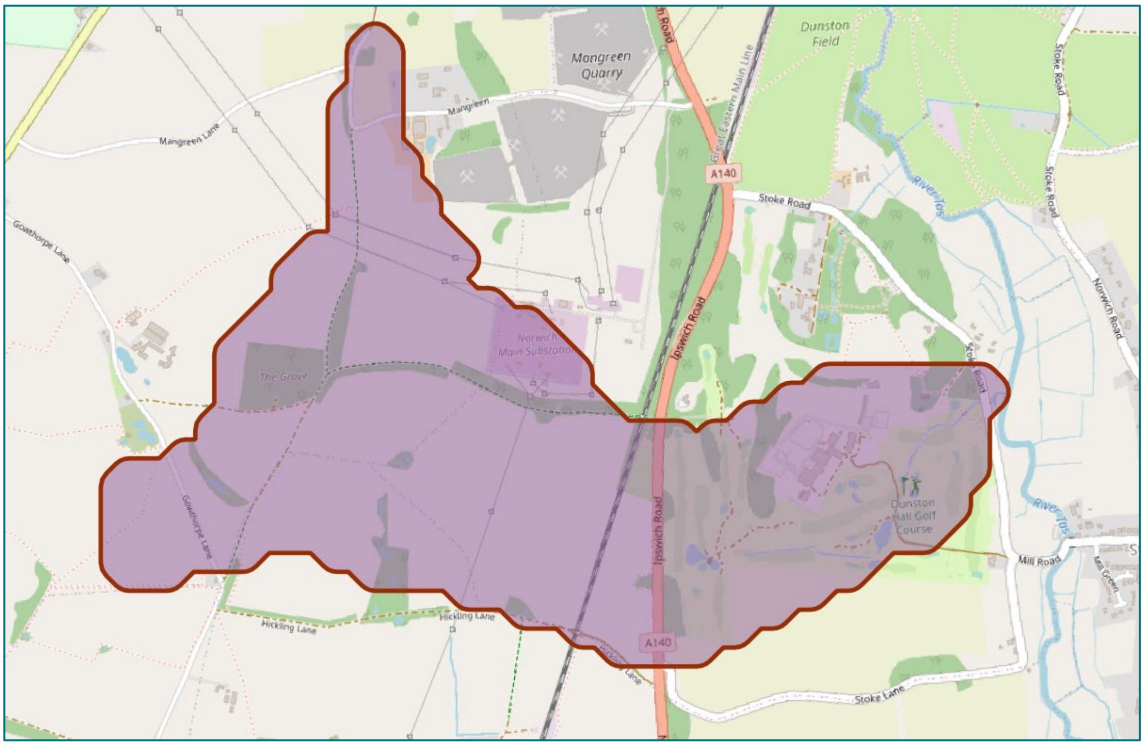

Figure 7-2: Coverage of the RF boundary (purple) and HT boundary (brown)

120. As the contributing catchment extends to the north, west and south of the OnSS site it is considered to be far enough from the edge of the model so as not to affect either the results at the OnSS site or the outflow boundary.

121. In the 'Options' modelled, it is assumed that the surface water drainage system which has been designed to manage the runoff from the OnSS platform will collect and divert the water falling directly onto the platform elsewhere (i.e. via infiltration beneath the platform). Therefore, as the rainfall falling onto the OnSS platform is not contributing to the overland flow and flood extent in this location, the platform has been cut-out of the RF polygon. **Figure 7-3** shows an example of the RF polygon used in the Option 1 modelling. The same approach comprising the use of an RF polygon for the OnSS platform has also been applied to the various iterations of the Option 2 modelling.

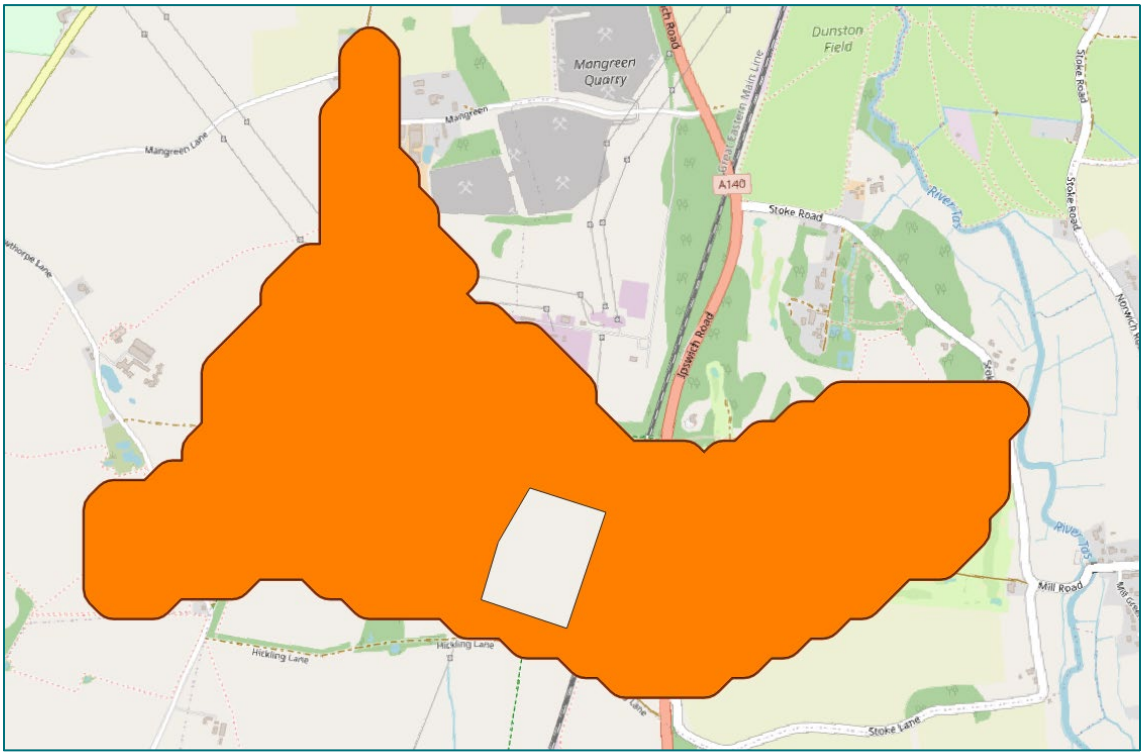

Figure 7-3: RF Polygon with OnSS platform "cut out"

8 Baseline Modelling

8.1 Initial Baseline Modelling

122. The hydraulic model was run for the Baseline (i.e. with no platform included) for the 1 in 100 year event to test the stability. A review of the cumulative error was noted as being 0% and there were no negative depths, which is an indication of a stable model.

123. Following review, the model was subsequently run for the following return period events:

- 1 in 30 year
- 1 in 100 year
- 1 in 100 year (plus 20% for climate change)
- 1 in 100 year (plus 40% for climate change)

124. The Baseline model represented the existing situation, using the gross rainfall hyetographs and the resulting depth maps are included as **Figure 8-1** to **Figure 8-4**.

125. It should be noted that the Baseline model with gross rainfall hyetograph was not run for the 1 in 100 year plus 45% for climate change event on the basis the use of the gross rainfall hyetographs were superseded by the adoption of the net rainfall hyetographs later in the modelling study.

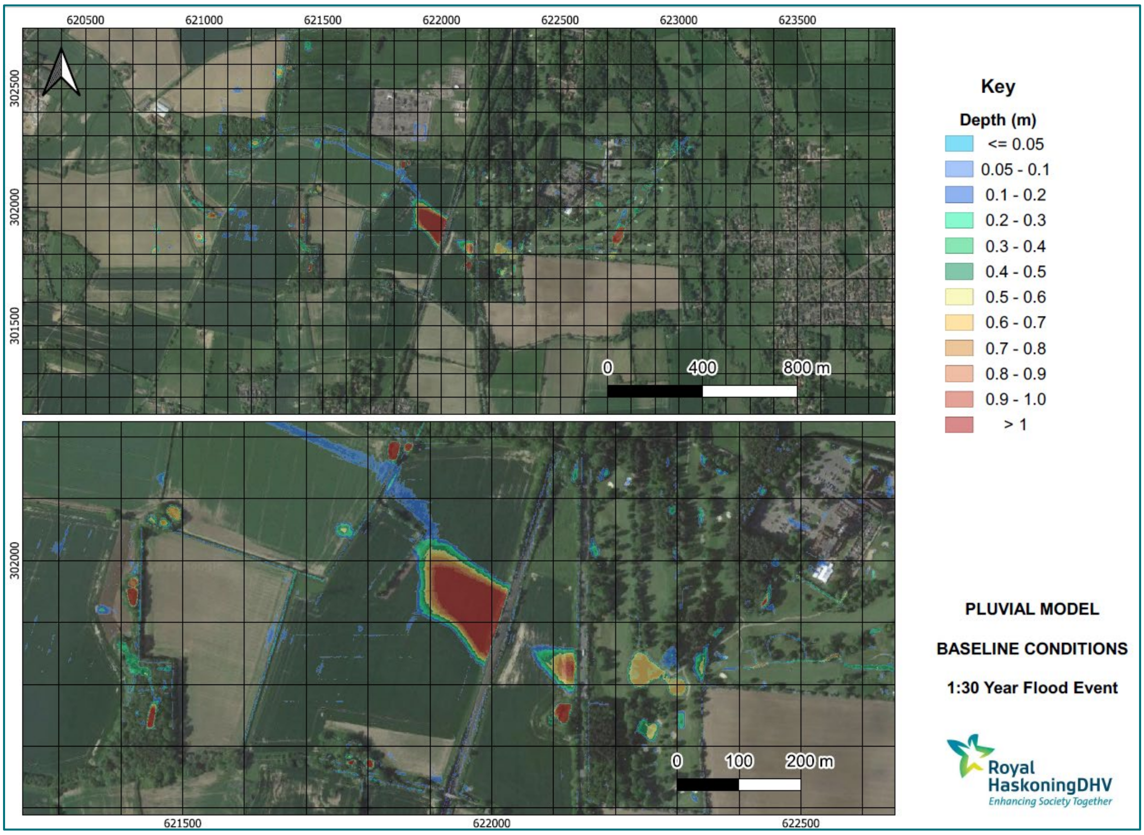

Figure 8-1: 1 in 30 year Baseline (existing) flood depth

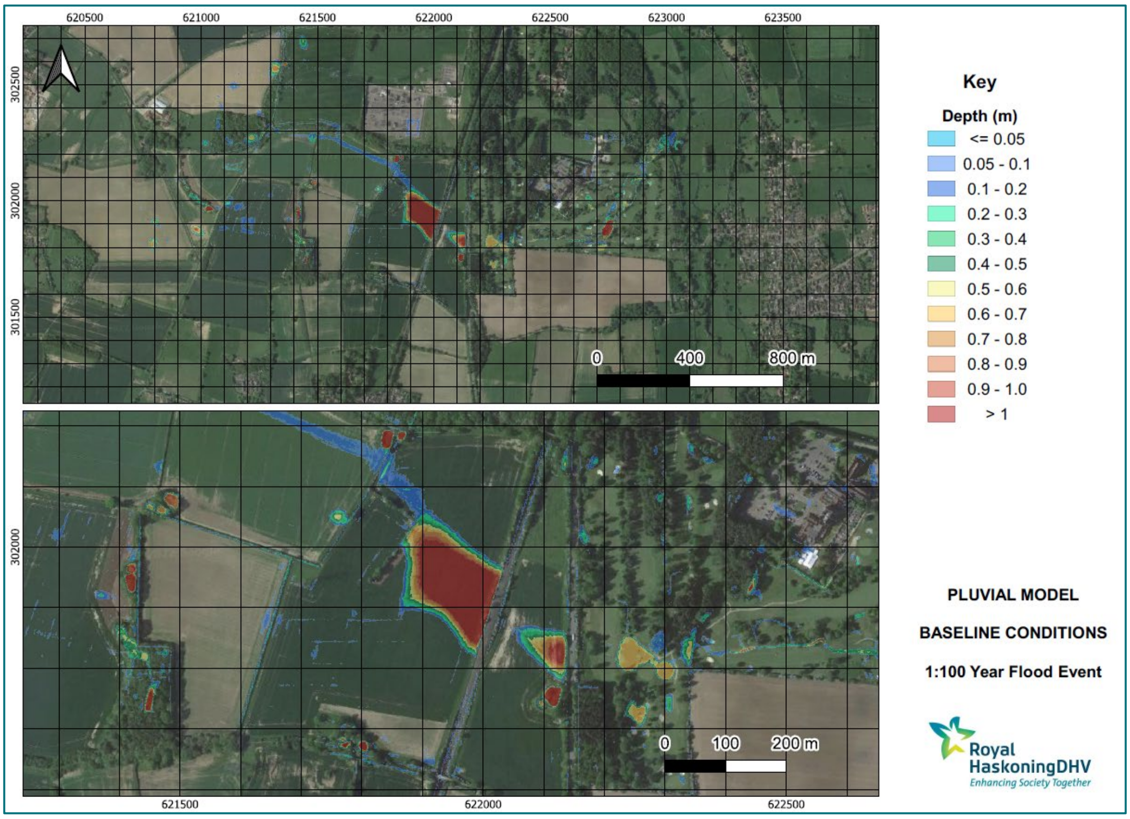

Figure 8-2: 1 in 100 year Baseline (existing) flood depth

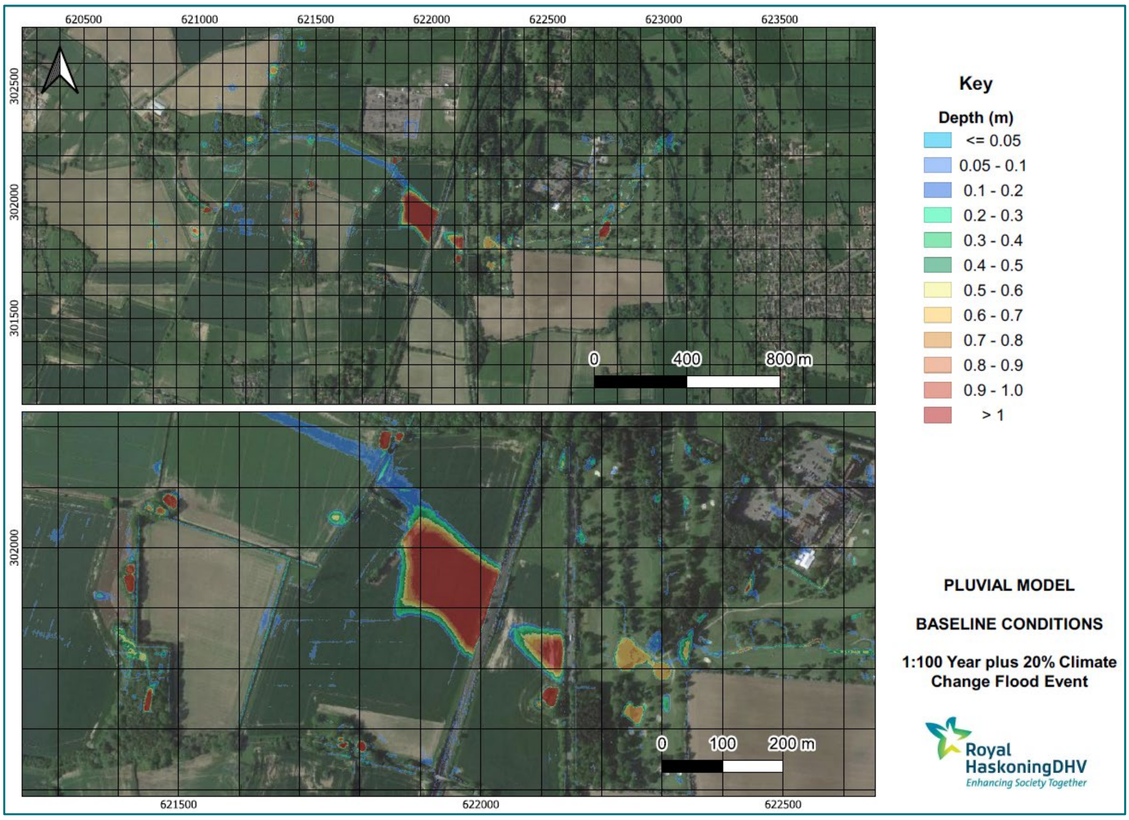

Figure 8-3: 1 in 100 year plus 20% for climate change Baseline (existing) flood depth

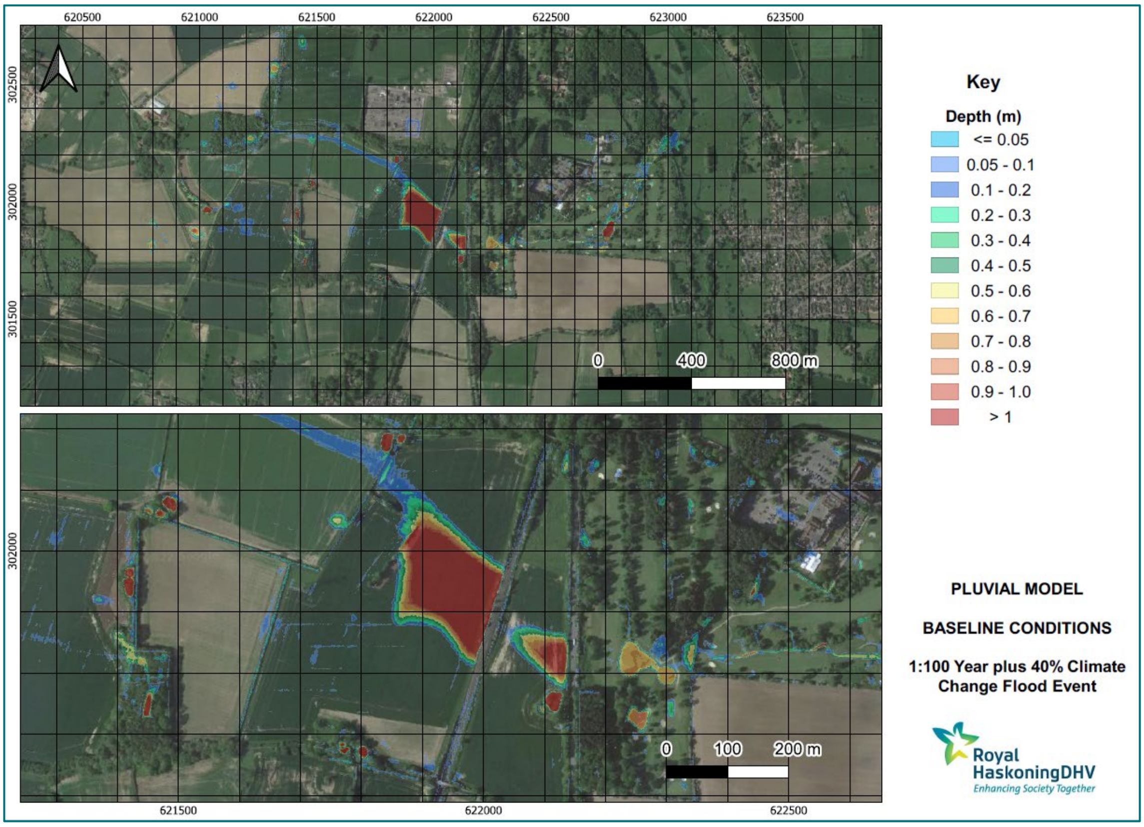

Figure 8-4: 1 in 100 year plus 40% for climate change Baseline (existing) flood depth

126. The results of the modelling show that the Baseline model broadly matches the Environment Agency's surface water mapping (**Figure 8-5**), with an overland surface water flow path through the OnSS site which is obstructed by the railway embankment in the location of the proposed OnSS platform.

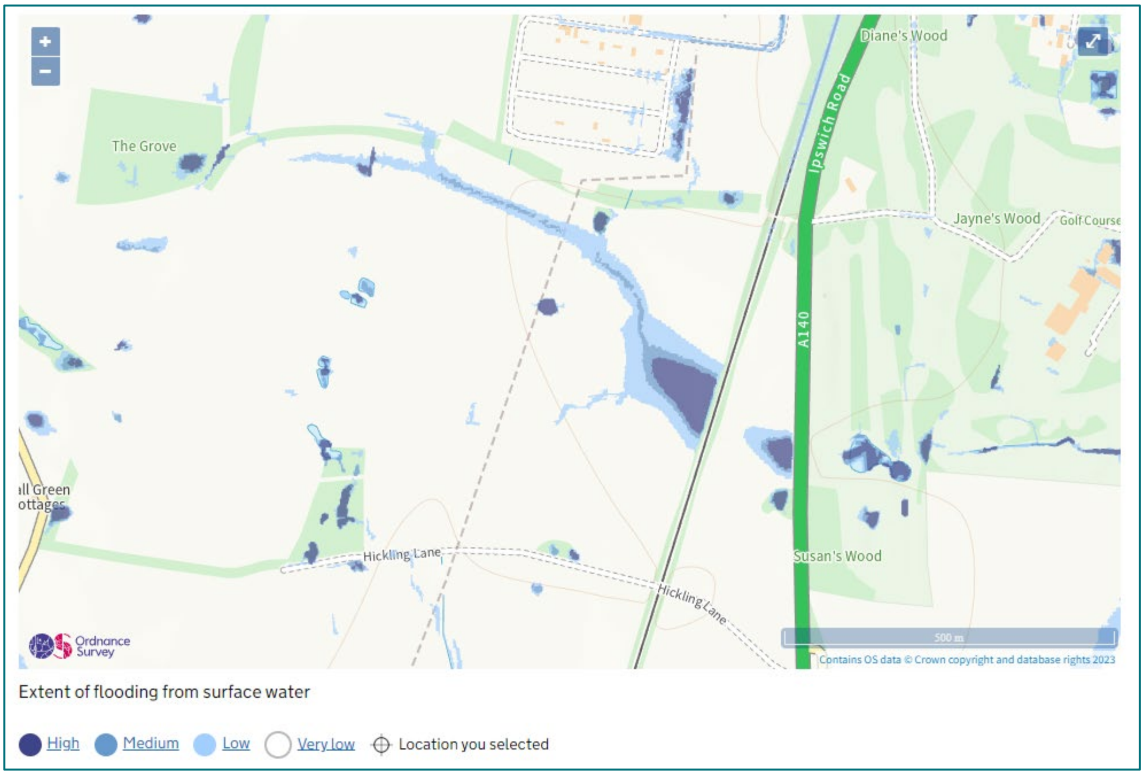

Figure 8-5: Environment Agency Flooding from Surface Water Mapping (Source: https://check-long-term-flood-risk.service.gov.uk/map?easting=621864&northing=301133&map=SurfaceWater)

127. However, the results of the initial Baseline modelling indicated that the extent produced by the modelling exercise appears to be larger than the Environment Agency's surface water flood map.

128. An assessment of the results for the 1 in 100 year (plus 40% for climate change) extent was undertaken as this comprised the most conservative i.e. worst case. In this event it is noted that:

    - There may be up to 3.40m depth of water which would occur adjacent to the railway embankment.
    - This would comprise a maximum water level of around 25.76m AOD.

129. In addition, a review of less extreme events was undertaken as follows:

    - 1 in 30 year event indicates there may be up to 2.53m flood depth (comprising a maximum water level of 25m AOD).
    - 1 in 100 year event indicates there may be up to 2.97m flood depth (comprising a maximum water level of 25.30m AOD).

130. From the results of the initial Baseline modelling exercise, it was noted that the railway embankment appears to be impounding or holding water back resulting in ponding to the lower lying area immediately to the west.

131. In the Baseline modelling the flood depths against the embankment would be relatively significant during an extreme event, with no clear route for water to exit this area.

132. On the basis of anecdotal evidence from the local farmer, noting the lack of overland flow in heavy rainfall events, and following discussions with the Lead Local Flood Authority (LLFA) regarding surface water drainage and flood risk in this location a series of amendments to the initial Baseline model were undertaken, as set out in the following section.

8.2 Amendments to the Baseline Model

133. Although the initial Baseline modelling for the OnSS site broadly matched the Environment Agency's surface water flood mapping, a review of the results indicated that it was most likely overestimating the flood extent and depth in places, particularly adjacent to the railway embankment. As such, it was considered likely that there were losses to the ground by way of infiltration elsewhere in the catchment, despite the results of the initial infiltration tests.

134. This was supported by the results of geophysical surveys and supplementary ground investigations carried out in April 2022 and June 2022, which indicated there are some key areas within the OnSS site which have greater infiltration potential i.e. shallow granular zones, facilitating the infiltration of surface water.

135. It was therefore decided to re-run the direct rainfall model using the net rainfall hyetograph, rather than the gross rainfall hyetograph, to determine the influence of the losses. This approach is in accordance with the best practice adopted for 2D direct rainfall modelling.

136. In addition, as previously noted, discussions with the LLFA indicated that climate change allowances were subject to change and a range of additional Baseline events utilising the net rainfall hyetographs were assessed, as follows:

- 1 in 30 year;
- 1 in 100 year plus 20% for climate change;
- 1 in 100 year plus 40% for climate change; and
- 1 in 100 year plus 45% for climate change.

137. The resulting depth maps are shown in **Figure 8-6** to **Figure 8-10** which show the flood extents for the net rainfall model simulations.

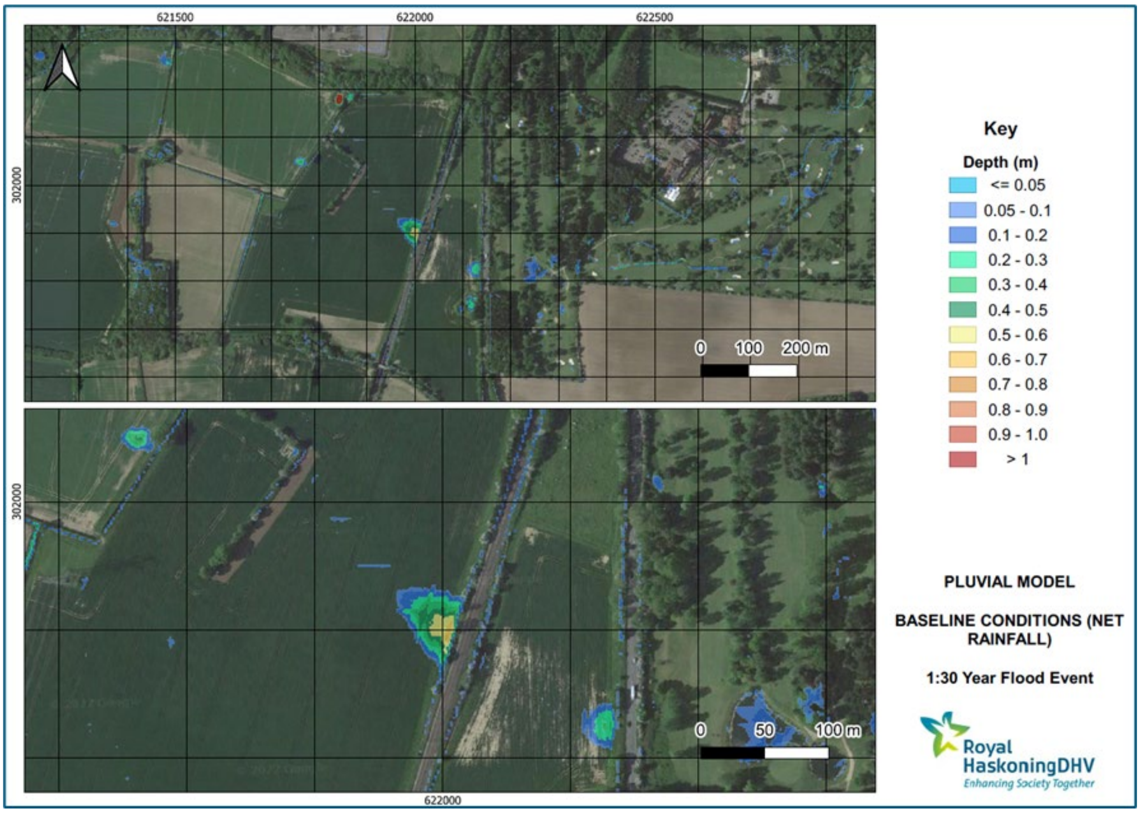

Figure 8-6: 1 in 30 year Baseline (existing) using net rainfall hyetograph

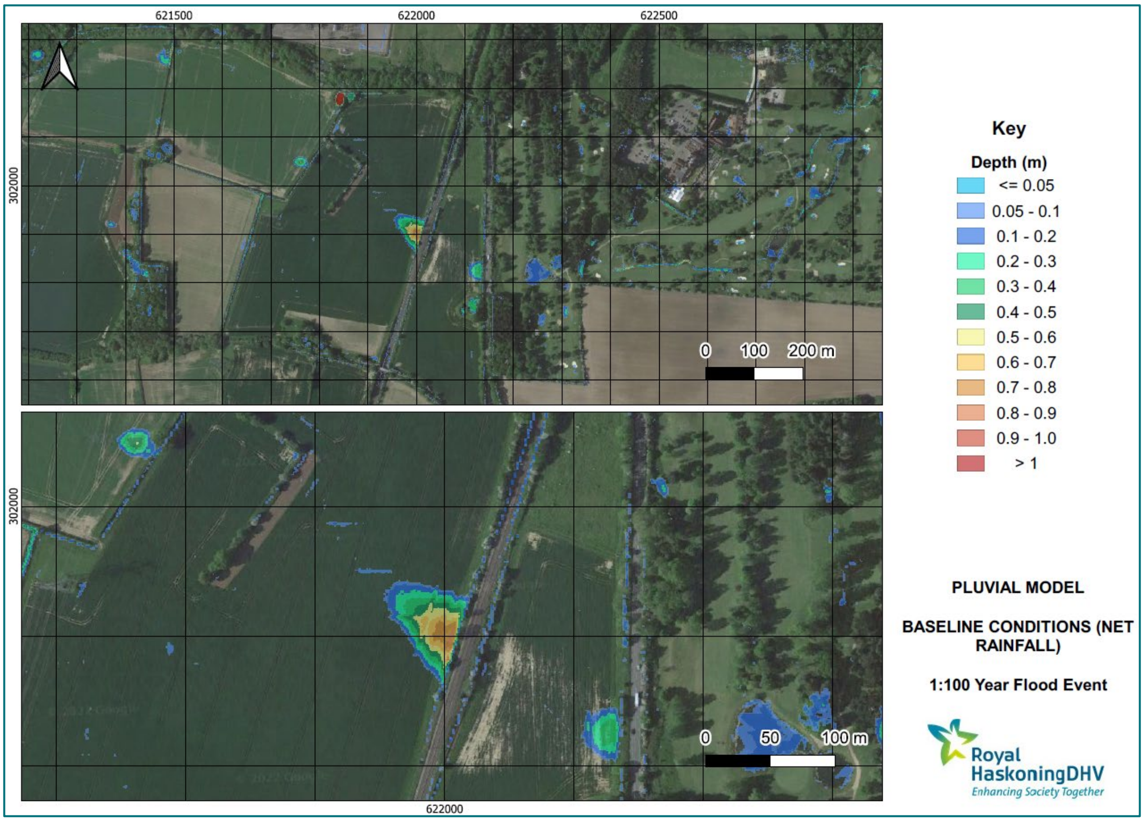

Figure 8-7: 1 in 100 year Baseline (existing) using net rainfall hyetograph

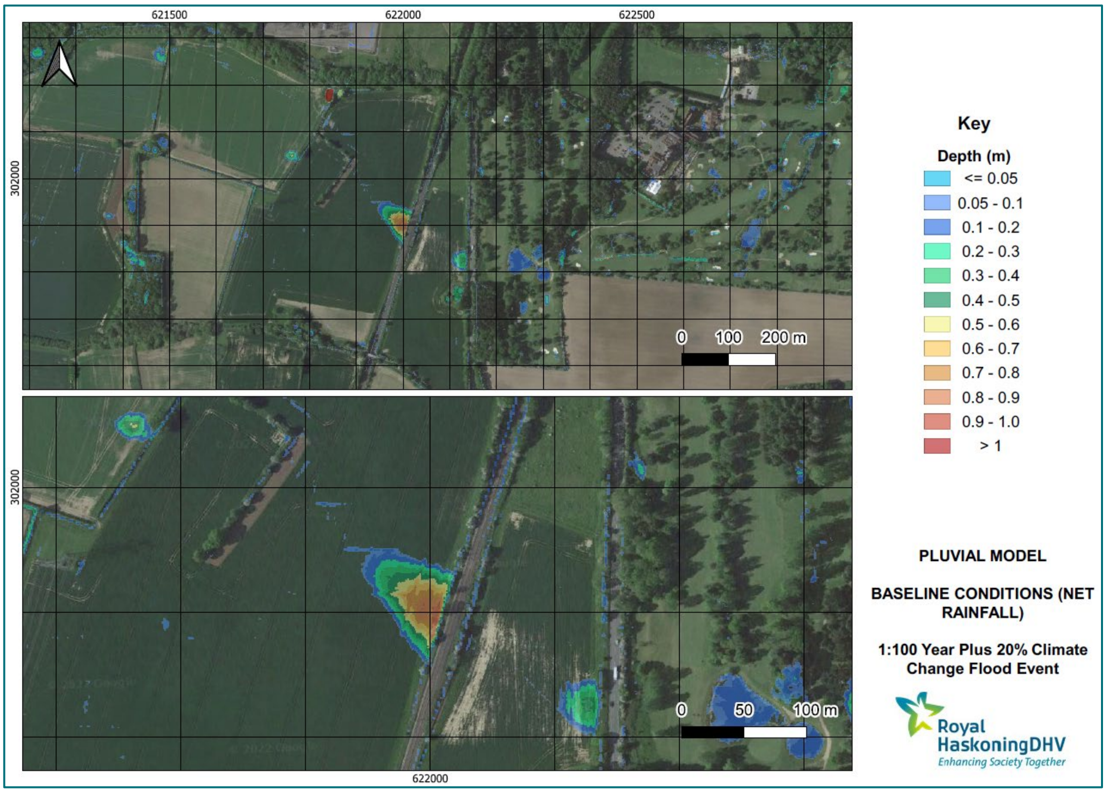

Figure 8-8: 1 in 100 year plus 20% for climate change Baseline (existing) using net rainfall hyetograph

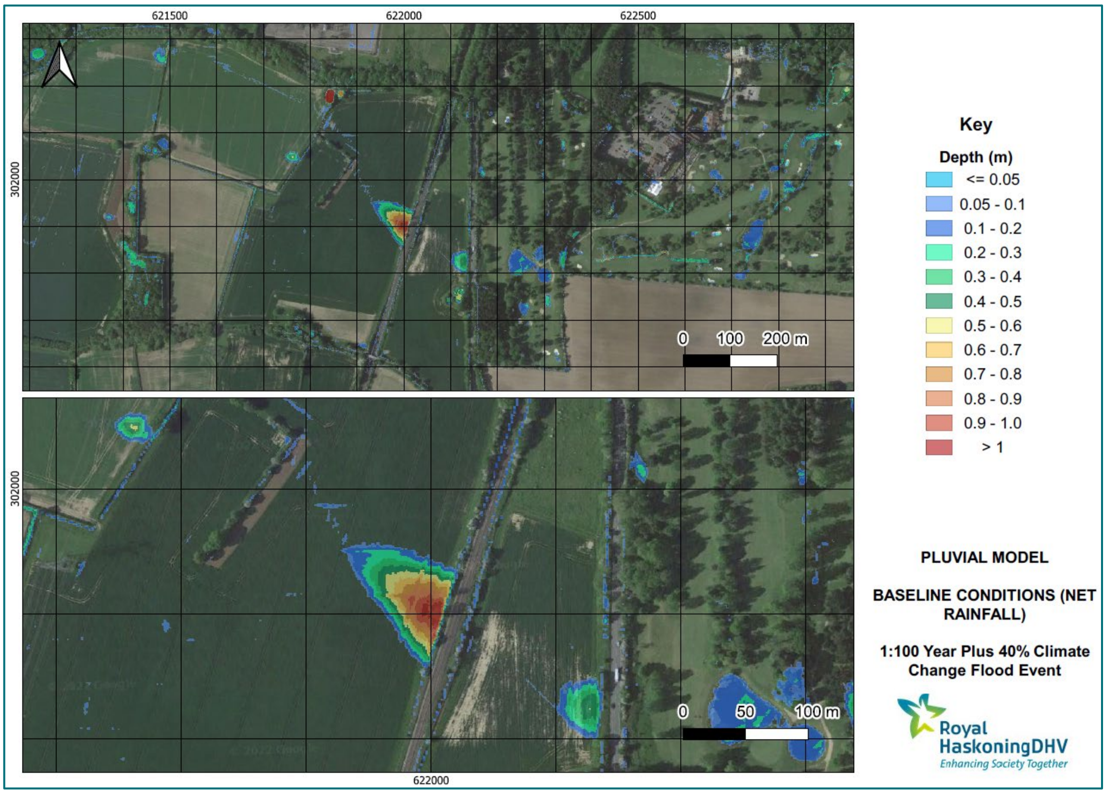

Figure 8-9: 1 in 100 year plus 40% for climate change Baseline (existing) using net rainfall hyetograph

[redacted]

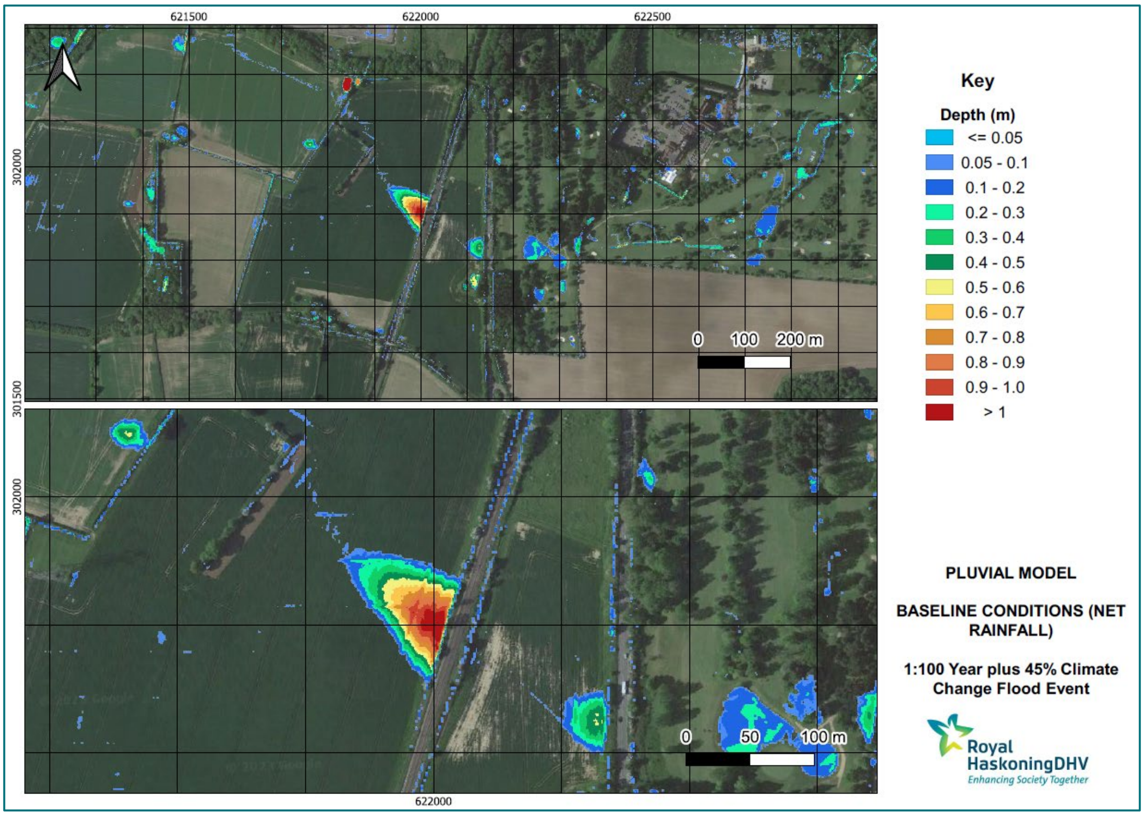

Figure 8-10: 1 in 100 year plus 45% for climate change Baseline (existing) using net rainfall hyetograph

138. The results of the modelling using the net rainfall hyetograph showed a significant reduction in the flood extents and depths. Furthermore, a comparison with the Environment Agency surface water mapping, as shown in **Figure 8-5** indicated the net rainfall hyetographs results are very similar to this mapping.

139. This validation exercise confirmed that the net rainfall hyetographs, which account for potential losses elsewhere in the catchment, should be used to represent the Baseline and proposed Options rather than the gross rainfall hyetographs.

9 Option Modelling

140. Following on from the Baseline modelling exercise, a number of options were considered for the layout and location of the proposed OnSS platform. These were subject to an iterative approach and all options were considered with respect to the model results from the net rainfall hyetographs .

141. A summary of each of the options modelled is set out as follows, with further details on each of the options provided in the following sections:

- Option 1 comprising a simple raised rectangular platform;
- Option 2 comprising a revised rectangular platform;
- Option 2 with Embankments incorporating the side slopes for the OnSS platform;
- Option 2 with Embankments and Platform Level at 28.23m AOD; and
- Option 2 with Embankments and North West Access Road.

9.1 Option 1

142. Option 1 comprised the consideration of a simple raised rectangular platform, similar to that presented at Preliminary Environmental Information Report (PEIR) stage, located adjacent to the railway embankment. The results of the Baseline surface water model were overlain with the Option 1 location, utilising the existing ground levels, to understand the interaction the OnSS platform may have with the surface water flood extent for various events, as shown in **Figure 9-1** to **Figure 9-5**.

143. This assessment utilised the existing ground levels for this option as the focus was on the potential interaction with the surface water to aid in a review of the displacement that may occur should it be located in this position.

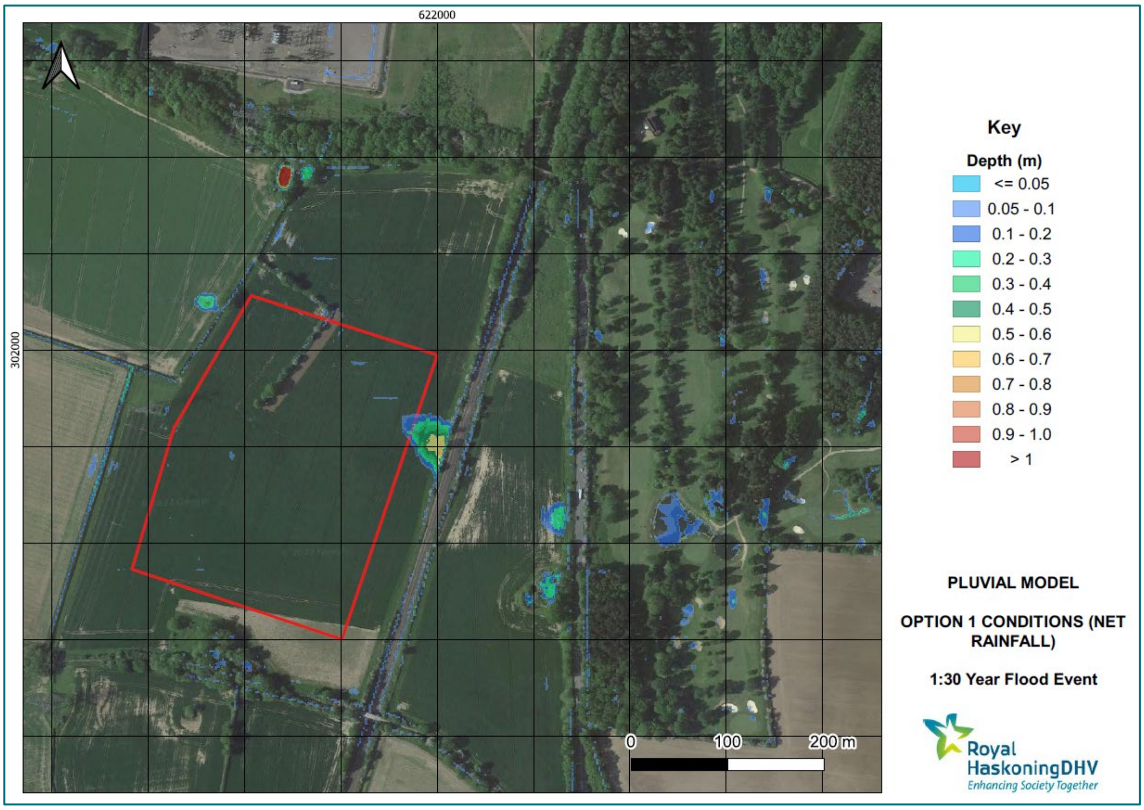

Figure 9-1: 1 in 30 year extent in comparison with Option 1 layout using net rainfall hyetograph

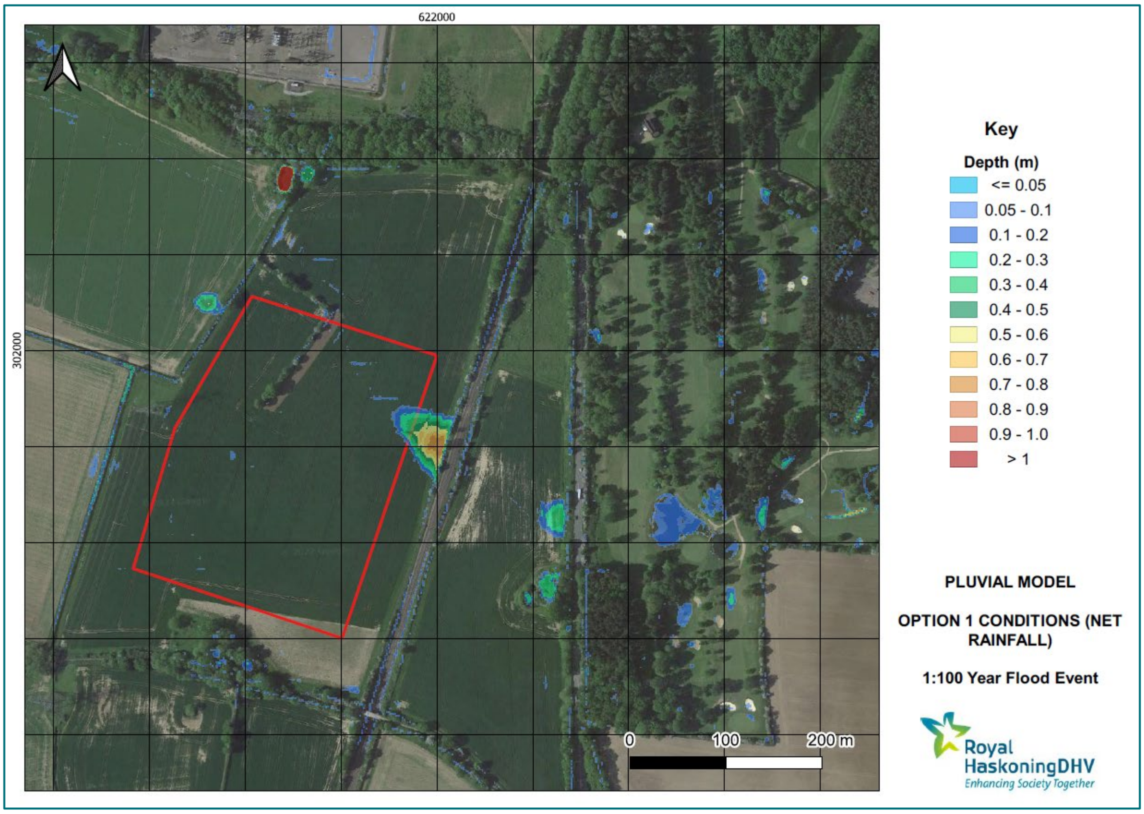

Figure 9-2: 1 in 100 year extent in comparison with Option 1 layout using net rainfall hyetograph

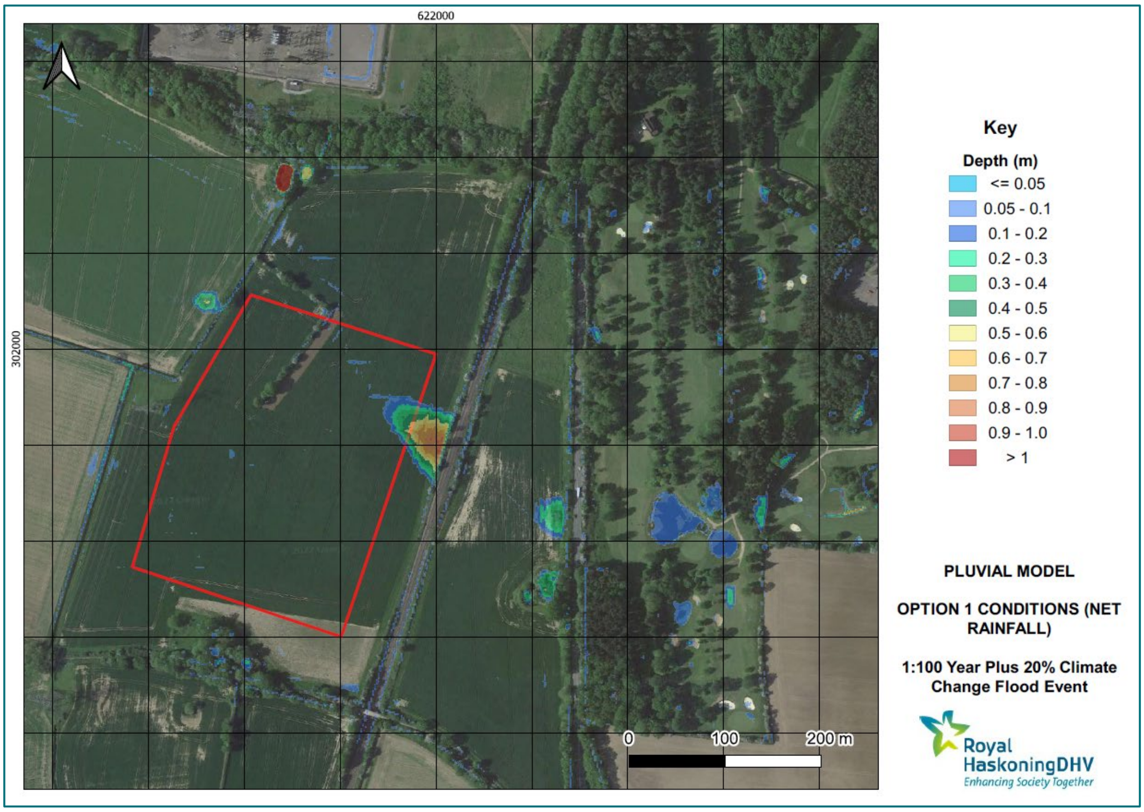

Figure 9-3: 1 in 100 year plus 20% for climate change extent in comparison with Option 1 layout using net rainfall hyetograph

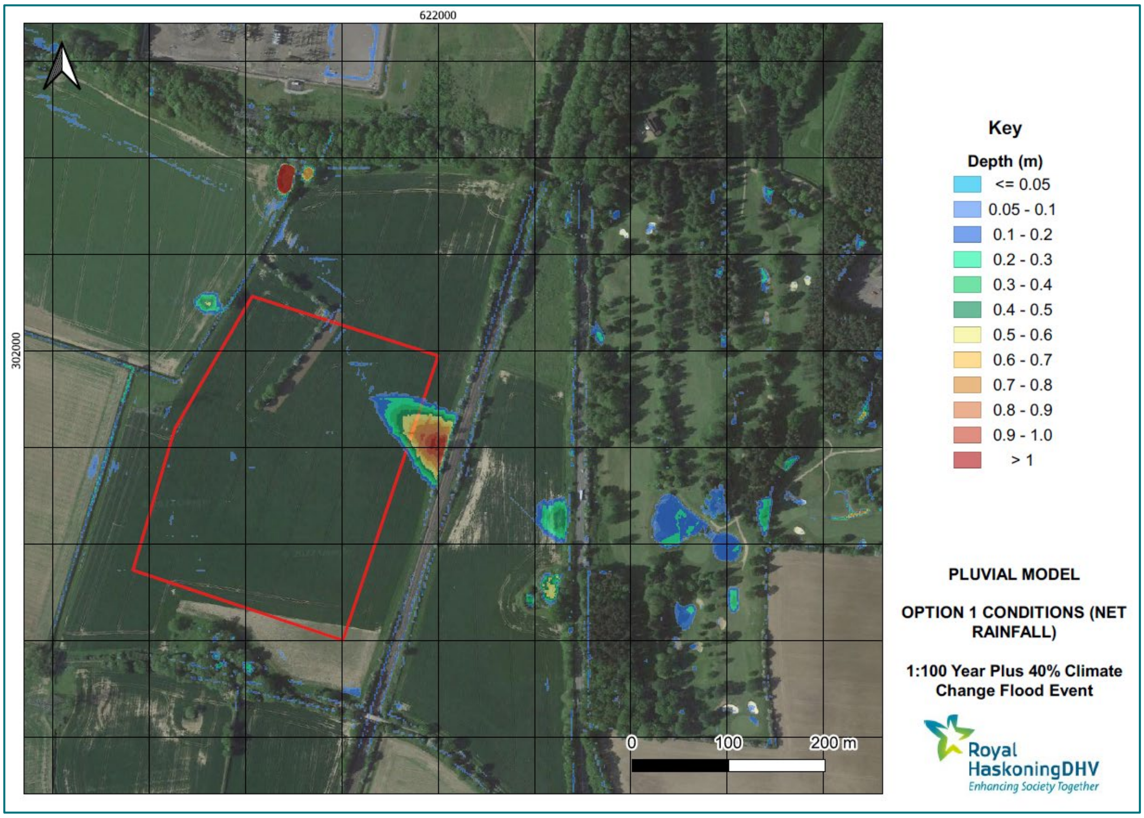

Figure 9-4: 1 in 100 year plus 40% for climate change extent in comparison with Option 1 layout using net rainfall hyetograph

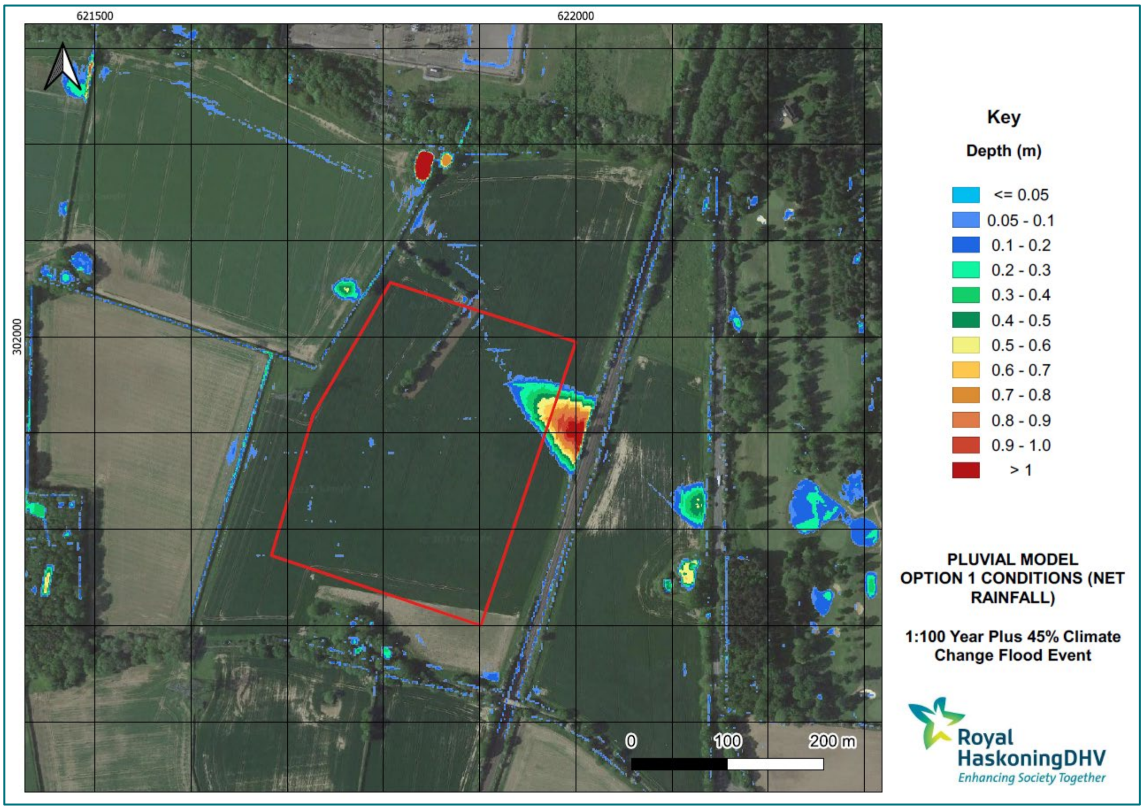

Figure 9-5: 1 in 100 year plus 45% for climate change extent in comparison with Option 1 layout using net rainfall hyetograph

144. The results of the Option 1 modelling shows there is a small amount of surface water within the footprint of the OnSS platform during the 1 in 30 year event.

145. In the 1 in 100 year event with an allowance for climate change this depth increases quite significantly. The results of the modelling indicate up to 0.70m depth within the footprint of the OnSS platform during the 1 in 100 year plus 45% for climate change allowance. The indicative depths within the OnSS footprint are summarised in **Table 9-1**.

Table 9-1: Approximate Depths within the Footprint of the OnSS Platform (Option 1)

Return Period	Approximate Depth on Platform (m)
30yr	0.19
100yr	0.36
100yr (+20%CC)	0.50
100yr (+40%CC)	0.64
100yr (+45%CC)	0.69

146. As the OnSS platform will be raised above ground level, this would result in displacement of surface water. In addition, there will be an access road leading up to the platform which could also obstruct surface water flow paths.

147. If Option 1 had been selected, the displaced volume of surface water for the 1 in 100 year (plus 45% for climate change) event would have needed to be quantified and accounted for elsewhere. In addition, measures to enable the existing surface water flow paths to continue beneath the new access road would have required consideration, for example, including appropriately sized culverts beneath the access road or elevating it above the ground, as a clear span structure.

148. Therefore, further design iterations to the OnSS platform were considered to minimise the potential surface water flood risk both to and from the proposed development.

9.2 Option 2

149. Following an initial design iteration process, Option 2 was developed comprising a slightly smaller, irregular shaped platform which would also be located adjacent to the railway embankment. This shape was developed to enable either a N-S orientation or an E-W orientation for the OnSS platform.

150. On this basis, the required area is likely to be smaller than the shape shown; however, as this would need to be subject to further design refinement the largest conservative shape was assessed within the modelling exercise.

151. **Figure 9-6** depicts the two orientations i.e. N-S and E-W, both of which are contained within the purple outline which has been used within the modelling for the purpose of combining the two orientations. By presenting it in this way the maximum footprint for the OnSS platform has been considered, regardless of which of the two potential orientations are adopted.

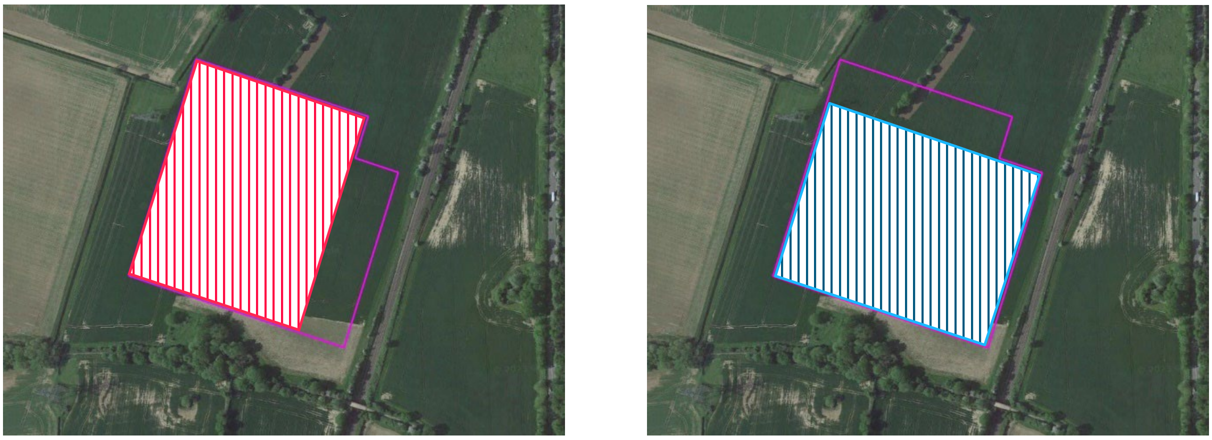

Figure 9-6: Images to depict the two potential platform orientations (N-S orientation (left) or E-W orientation (right))

152. As it is not yet known whether the N-S orientation or the E-W orientation will be progressed the more conservative area including the outline for both options was

used within the assessment of flood risk undertaken as part of the hydraulic modelling exercise.

153. This option continues to utilise the existing ground levels, as the focus of the modelling exercise was on the potential interaction with the surface water to aid in a review of the potential displacement of surface water that may occur.

154. The results of the Baseline surface water model were overlain with the Option 2 location to understand the interaction the OnSS platform may have with the surface water flood extent for various events, as shown in **Figure 9-7** to **Figure 9-10.**

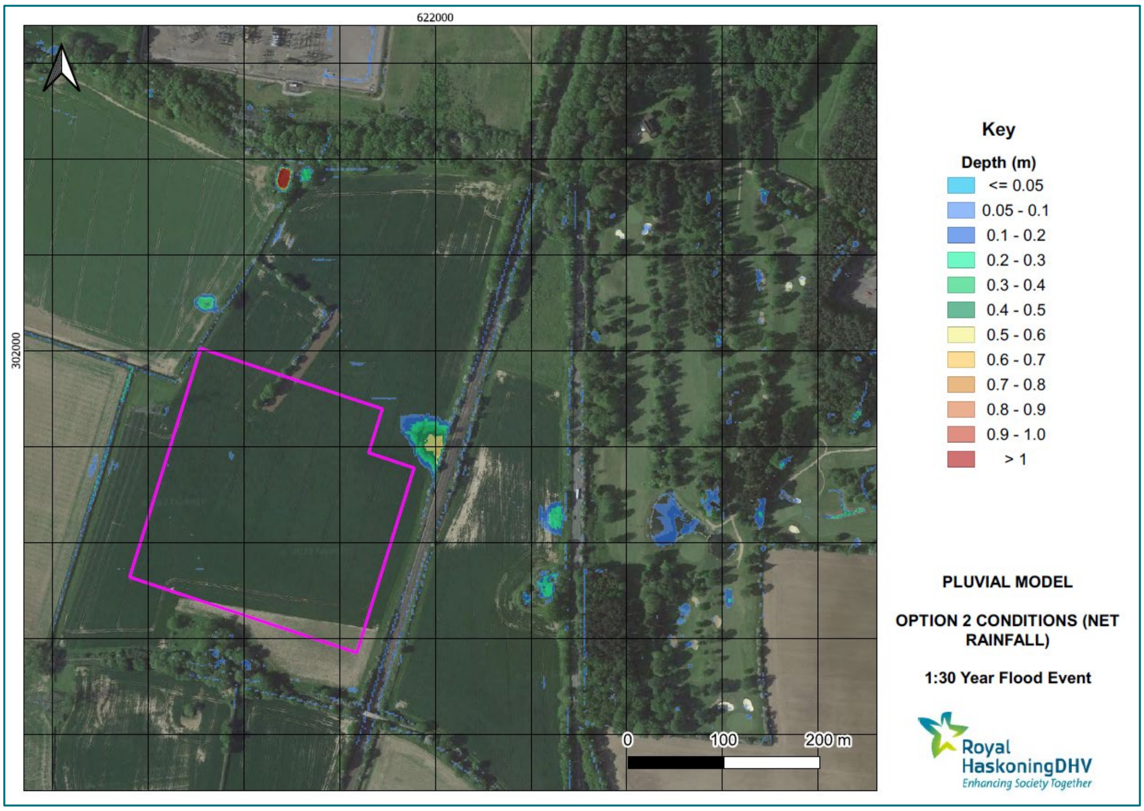

Figure 9-7: 1 in 30 year extent in comparison with Option 2 layout using net rainfall hyetograph

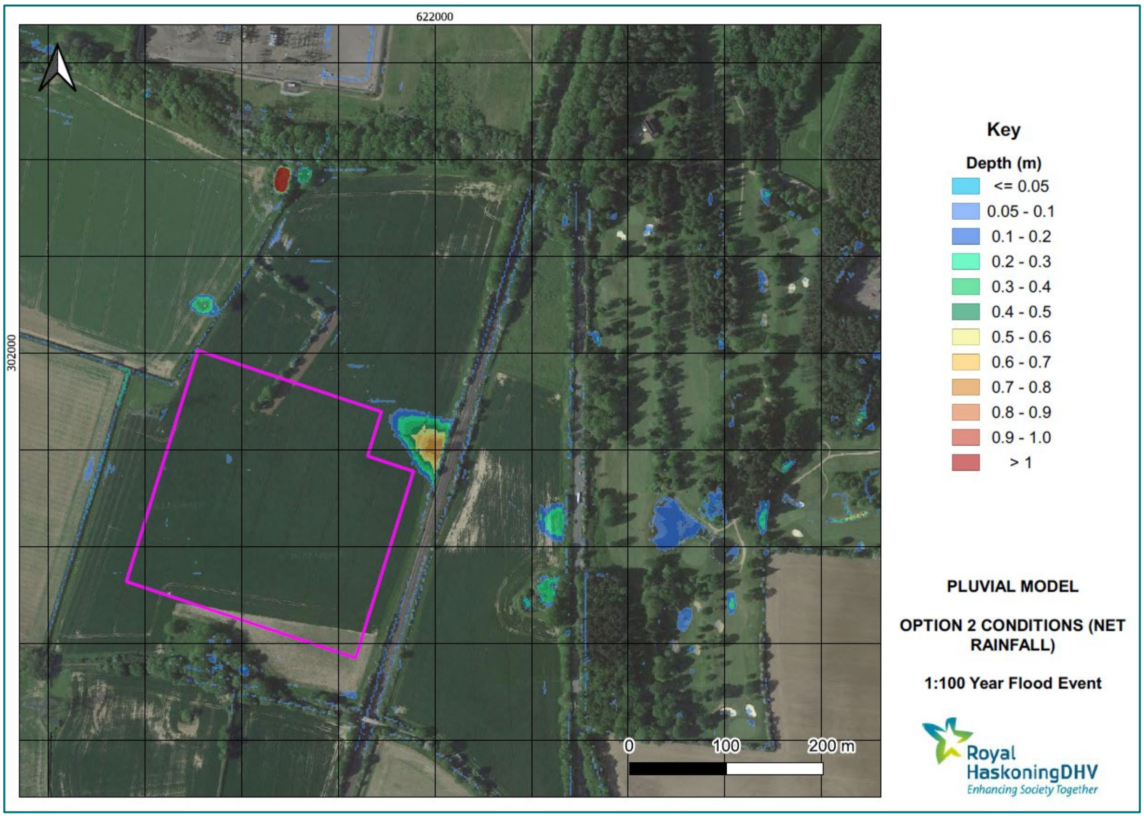

Figure 9-8: 1 in 100 year extent in comparison with Option 2 layout using net rainfall hyetograph

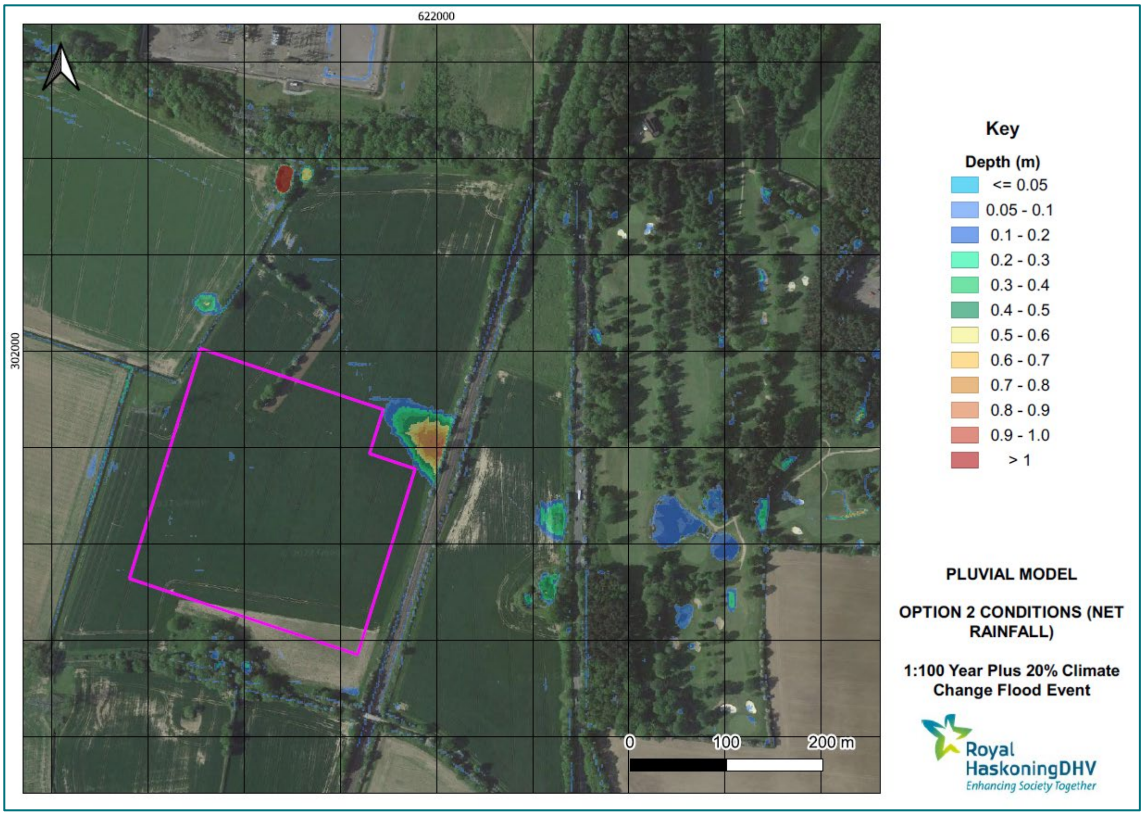

Figure 9-9: 1 in 100 year plus 20% for climate change extent in comparison with Option 2 layout using net rainfall hyetograph

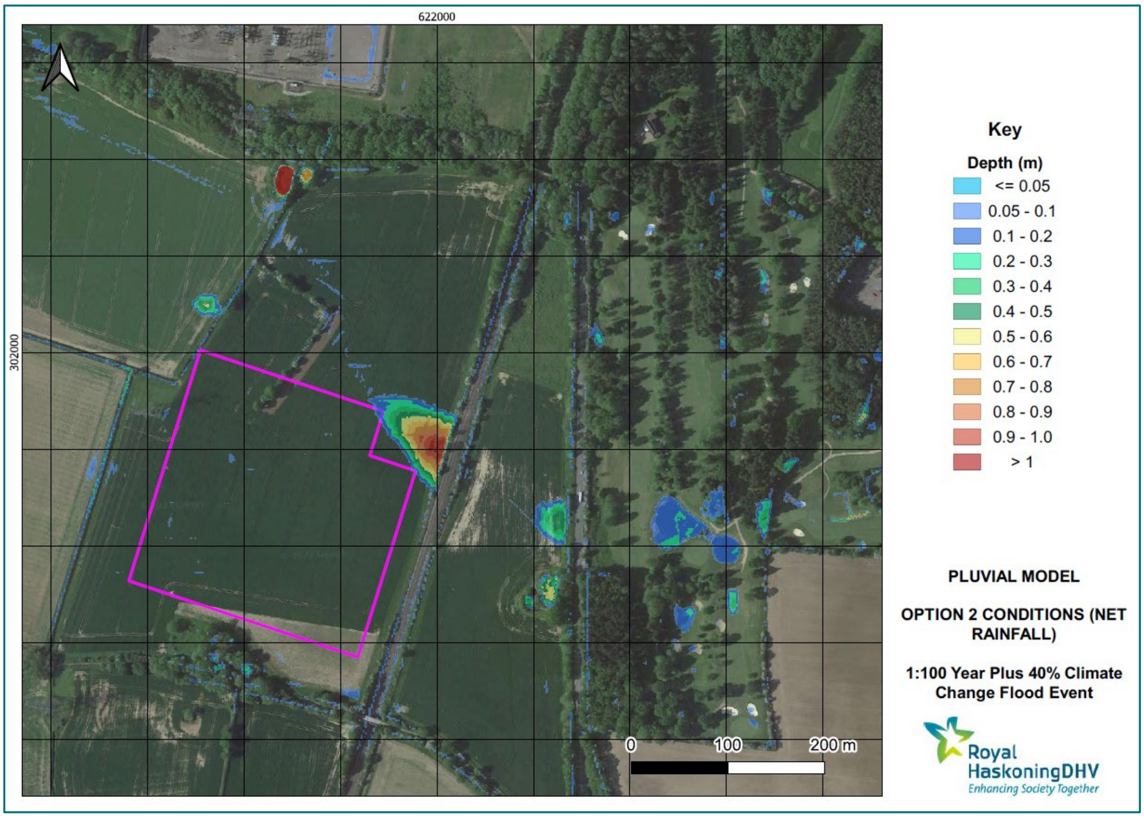

Figure 9-10: 1 in 100 year plus 40% for climate change extent in comparison with Option 2 layout using net rainfall hyetograph

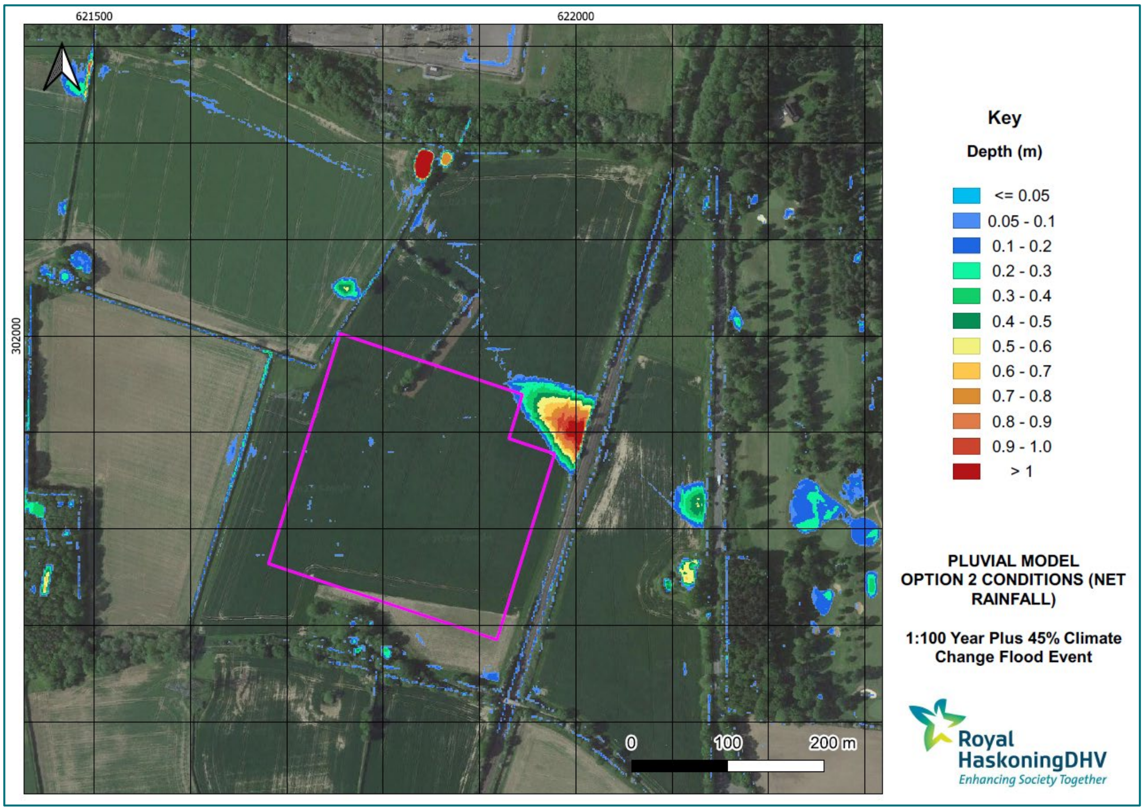

Figure 9-11: 1 in 100 year plus 45% for climate change extent in comparison with Option 2 layout using net rainfall hyetograph

155. The results of the model show that for the majority of the Option 2 extreme events, the flood extent doesn’t extend into the footprint of the OnSS platform.

156. In the most extreme event, the 1 in 100 year (plus 45% for climate change) surface water event, there is a small area where the flood extent is within the corner of the OnSS platform footprint, with the maximum flood depth being up to 0.23m.

157. Although the OnSS platform will be raised above ground level, it is noted that the Option 2 arrangement is unlikely to displace as much surface water as the Option 1 arrangement and for the majority of events the Option 2 arrangement would be entirely located outside the surface water flood extent.

158. In addition, the new access road, is still likely to result in some displacement of water or obstruction to the overland flow path. Therefore, some mitigation measures should be included to manage this, such as including appropriately sized culverts beneath the access road or elevating it above the ground, as a clear span structure.

9.3 Option 2 with Embankments

159. Following a review of the design iteration proposed in Option 2 it was identified that the OnSS platform is likely to incorporate sloped sides rather than a vertical edge. To assess the potential flood risk to the footprint of the OnSS platform, the area required for the platform with sloped sides was compared with the relevant flood extents.

160. This option continued to utilise the existing ground levels, as the focus was on the potential interaction with the surface water to aid in a review of the displacement that may occur should it be located in this position.

161. The Cut and Fill Drawing (Ref: C282-MU-Z-YV-00114) was used to delineate the area covered by the platform including the embankments. An extract of the Cut and Fill Drawing and the Option 2 boundary used within the modelling is included in **Figure 9-12**.

Figure 9-12: Extract of the Cut and Fill Drawing (left) and Option 2 with Embankments z-shape used in model

162. As the ground elevations change in the vicinity of the proposed OnSS platform there is a need to undertake cut to the southern side of the OnSS platform (marked as brown on **Figure 9-12**) and fill to the northern part of the proposed OnSS platform (marked as green on in **Figure 9-12**). This is to achieve a level working area for the OnSS platform, which is shown on the Cut and Fill Drawing (Ref: C282-MU-Z-YV-00114) as being 28.23mm AOD.

163. The analysis was undertaken by overlaying the results of the Baseline surface water model, as used in the Option 2 comparison (i.e. with net rainfall hyetograph), with the outline for the Option 2 with Embankments. This was to aid in understanding the interaction the OnSS platform may have with the surface water flood extent for various events, as shown in **Figure 9-13** to **Figure 9-17**.

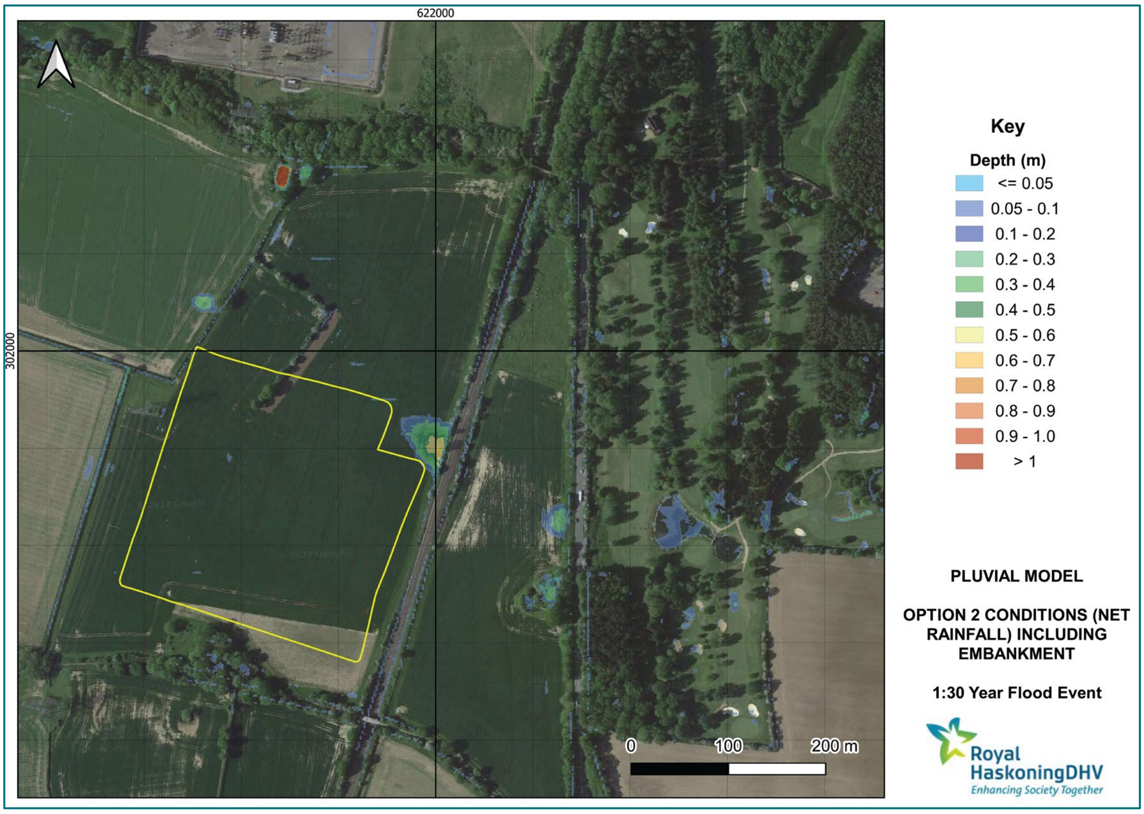

Figure 9-13: 1 in 30 year extent in comparison with Option 2 with embankments layout

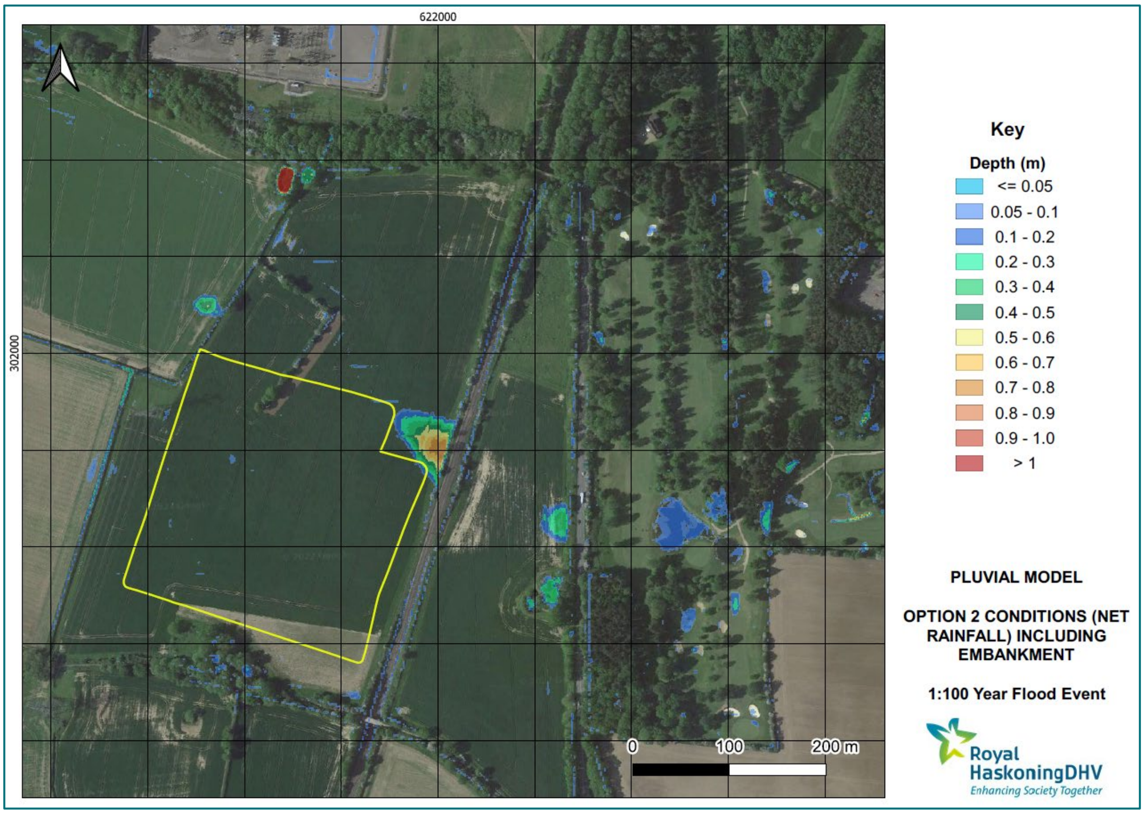

Figure 9-14: 1 in 100 year extent in comparison with Option 2 with embankments layout

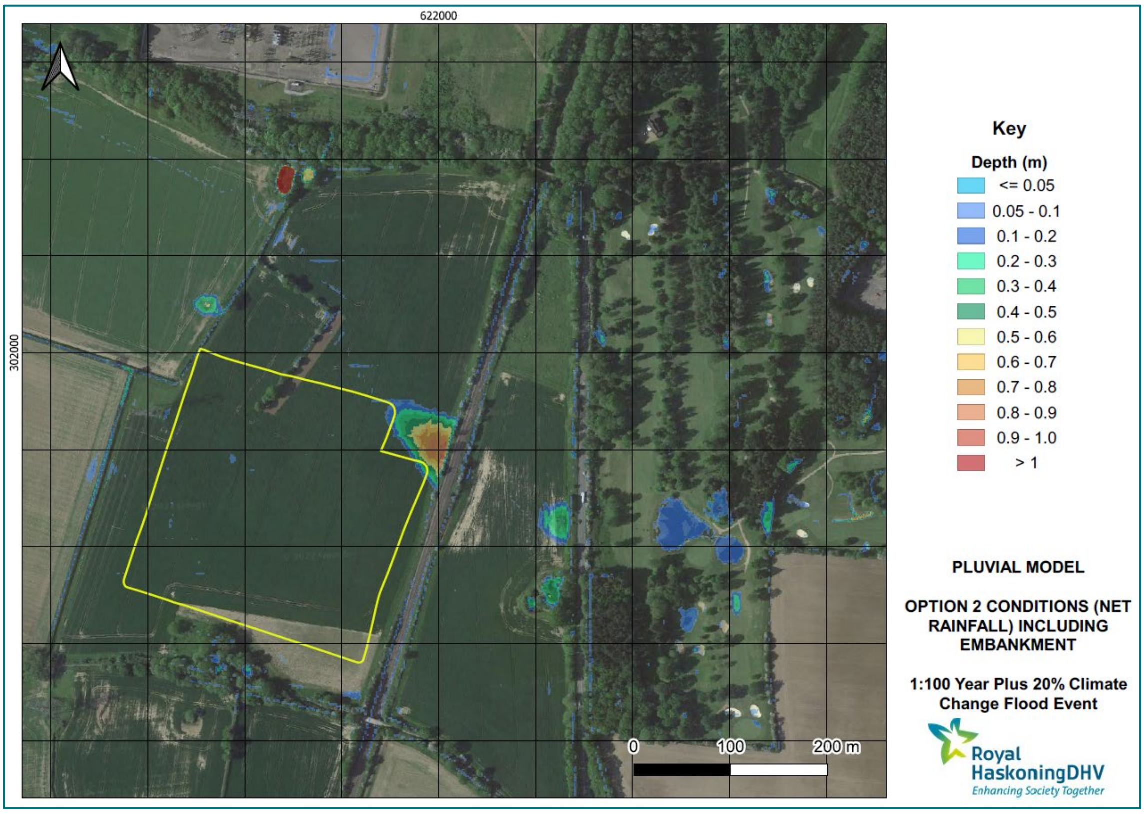

Figure 9-15: 1 in 100 year plus 20% for climate change extent in comparison with Option 2 embankments layout

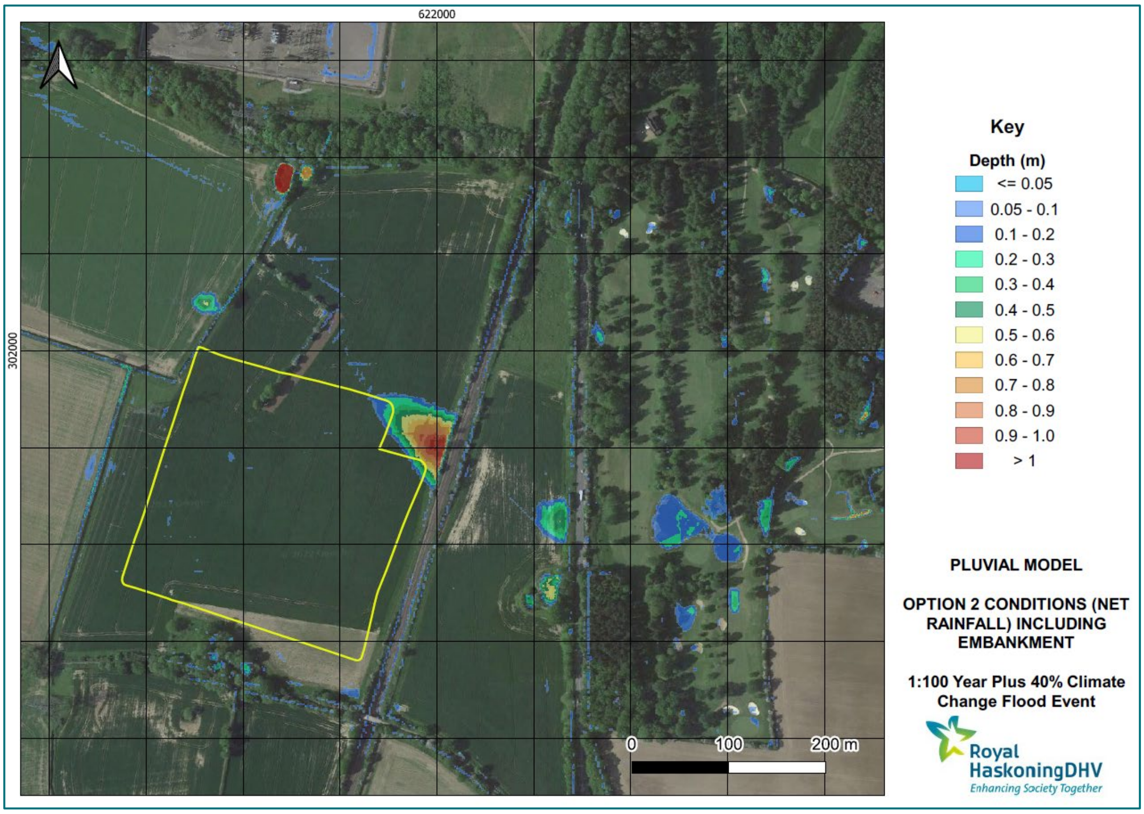

Figure 9-16: 1 in 100 year plus 40% for climate change extent in comparison with Option 2 embankments layout

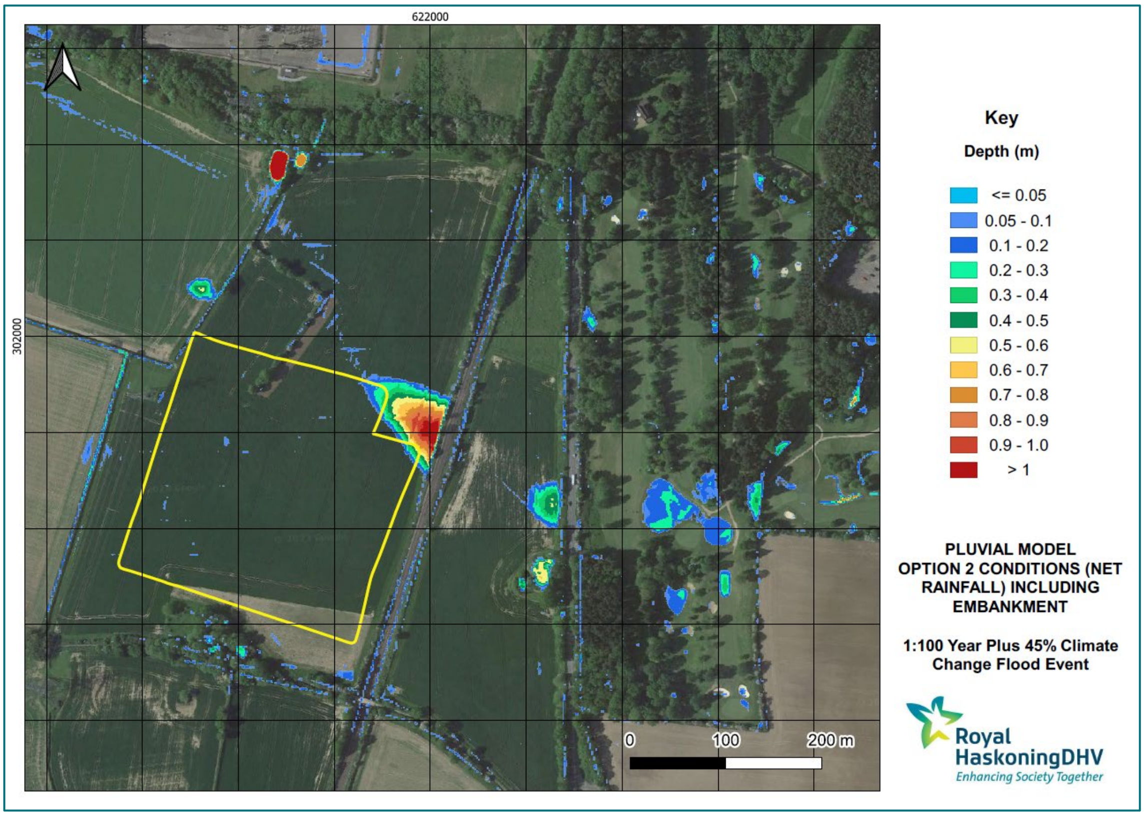

Figure 9-17: 1 in 100 year plus 45% for climate change extent in comparison with Option 2 embankments layout

9.4 Option 2 with Embankments and Platform Level 28.23m AOD

164. Following the process of assessing the potential flood risk to the OnSS by overlaying the Baseline modelling results with the platform outline, in accordance with the guidance set out in the National Planning Policy Framework (NPPF) and its supporting Planning Practice Guidance (PPG) it was necessary to consider any potential change in off-site flood risk as a result of the displacement of flood water during an event.

165. In order to assess the above, the OnSS platform was included within the model, as a non-permeable feature, with a barrier represented in the model geometry, as described in **Section 7.2**. This was the first option where the existing ground levels were no longer used within the footprint of the OnSS platform. Based on the information presented in the **Outline Operational Drainage Plan (onshore substation)** [APP-307] and the Cut and Fill Drawing contained therein (Ref: C282-MU-Z-YV-00114) the OnSS platform level was set at 28.23m AOD.

166. The model was then re-run for the 1 in 100 year event with climate change allowances. **Figure 9-18** to **Figure 9-20** show the results of the 1 in 100 year (plus 20% for climate change), 1 in 100 year (plus 40% for climate change) and 1 in 100 year (plus 45% for climate change) events with the platform (at a level of 28.23m AOD) and embankments included within the model.

167. The results of this modelling exercise were compared with the results presented in **Figure 9-15** to **Figure 9-17** to understand the potential impact as a result of the displacement of surface water.

168. Following review of these results it was noted that both the surface water flood extent and maximum flood depths are slightly reduced compared with the results from the Baseline modelling. This reduction can be attributed to the incorporation of the OnSS platform in the model. By including the OnSS platform within the model, it has been assumed that rainfall falling on the platform during an event does not contribute to the flooding as it will either be collected by the surface water drainage system to be implemented as part of the project or will remain on the OnSS platform and naturally infiltrate into the ground on the platform.

169. As such there is a small reduction in surface water flood depth and extent in the area of potential flooding close to the OnSS platform. In addition, there is no change in the wider off-site flood risk as the surface water flooding is contained in an area within the OnSS site.

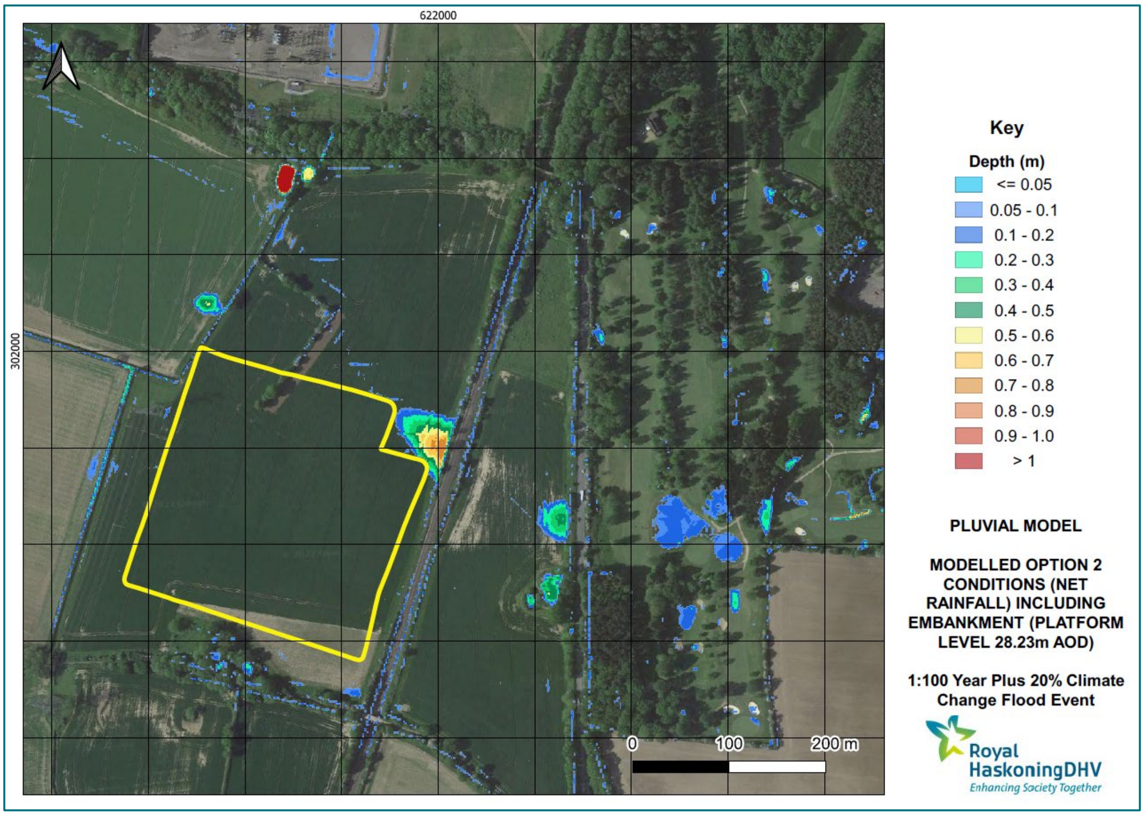

Figure 9-18: 1 in 100 year plus 20% for climate change with OnSS platform level set at 28.23m AOD

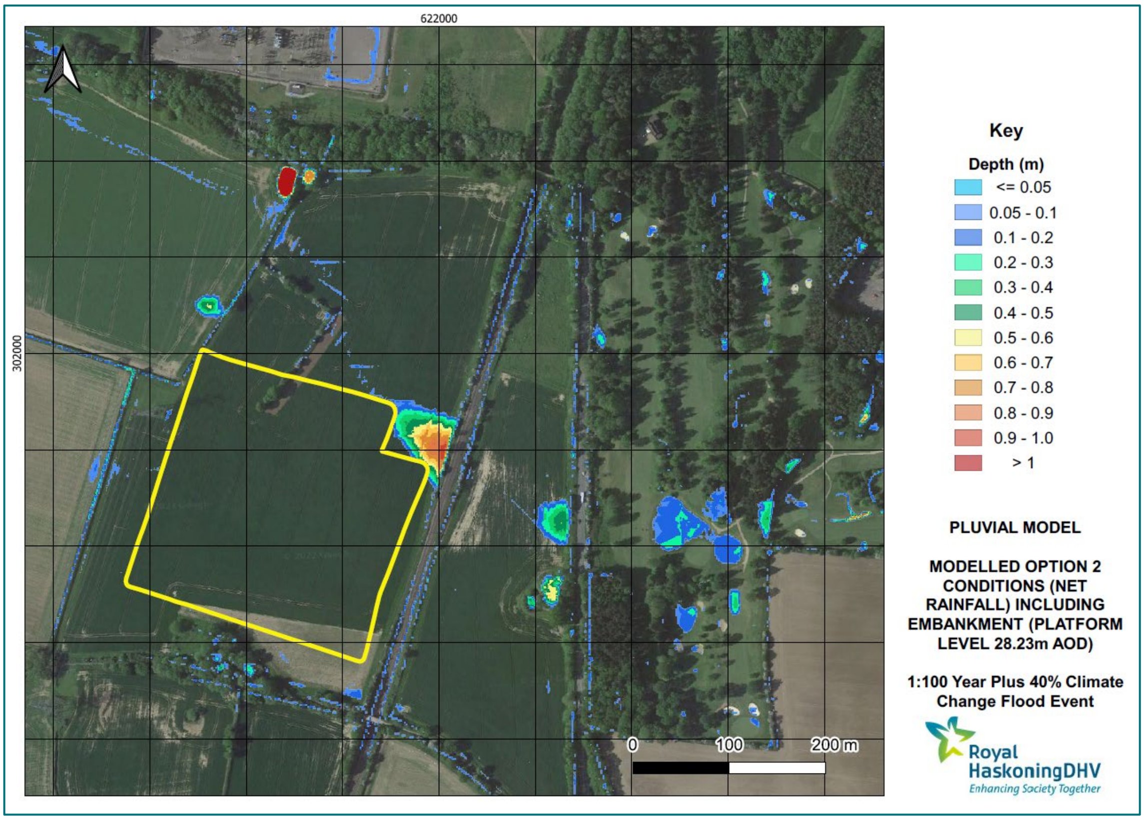

Figure 9-19: 1 in 100 year plus 40% for climate change with OnSS platform level set at 28.23m AOD

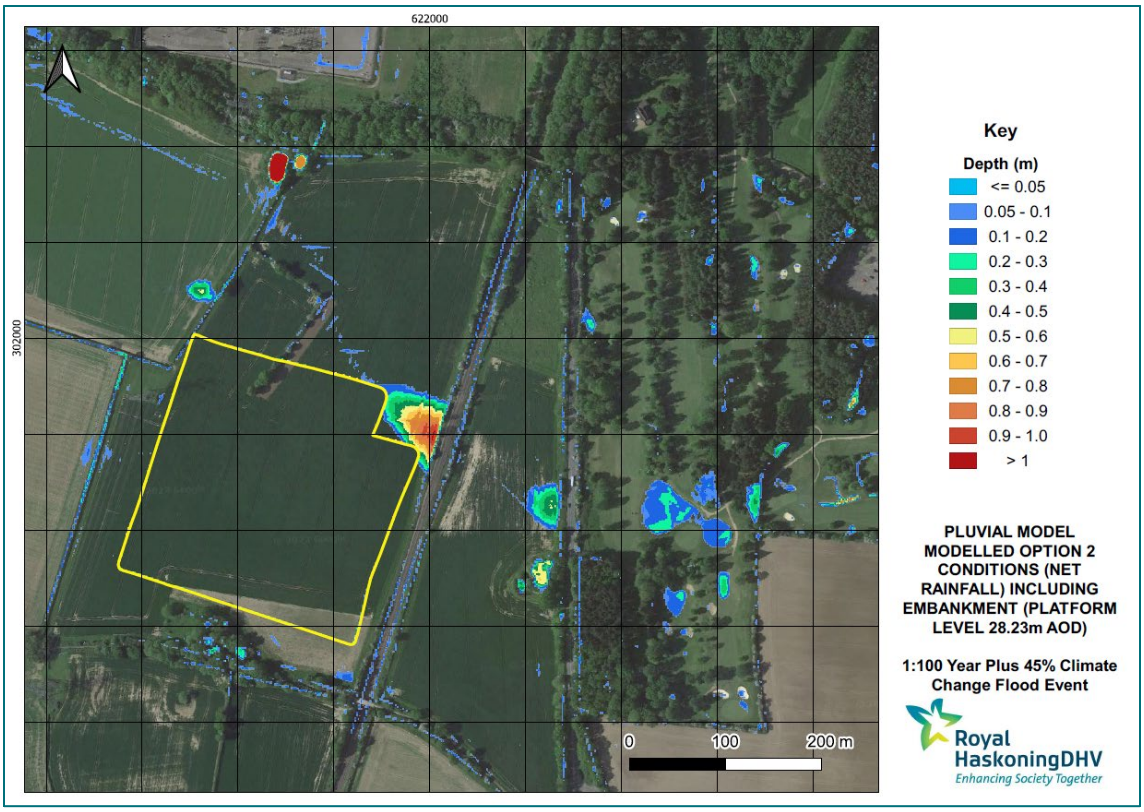

Figure 9-20: 1 in 100 year plus 45% for climate change with OnSS platform level set at 28.23m AOD

9.5 Option 2 with Embankments and North West Access Road

170. Following consideration of the potential impact of the OnSS platform a further option was modelled which included the access road to the OnSS platform. It is proposed that this will tie into the north west corner of the OnSS platform (referred to as the North West access road).

171. Similar to the level used for the OnSS platform, the North West access road was set at 28.23m AOD for the section adjacent to the platform using the 'MAX' flag in the TUFLOW software. This means that any ground levels below the proposed North West access road which are lower than 28.23m AOD were raised to this level.

172. In addition, a large rectangular culvert with the dimensions 25m x 2.2m high was located under the North West access road in the location of the existing overland surface water flow path. The culvert was included as a section of 1D network and modelled in the ESTRY software, as described in **Section 7.4**.

173. A Manning's roughness value of 0.025 was applied to the culvert, similar to that used for a track / road, as this was considered to be suitable as it is likely to be less vegetated than surrounding land and potentially concrete lined.

174. The design of this crossing will be confirmed during the detailed design, however for the purposes of this modelling exercise it was included as a culvert to enable the continued conveyance of the overland flow path beneath the proposed North West access road.

175. **Figure 9-21** to **Figure 9-23** show the results of the 1 in 100 year (plus 20% for climate change), 1 in 100 year (plus 40% for clime change) and 1 in 100 year (plus 45% for climate change) events which include the OnSS platform with embankments and the North West access road.

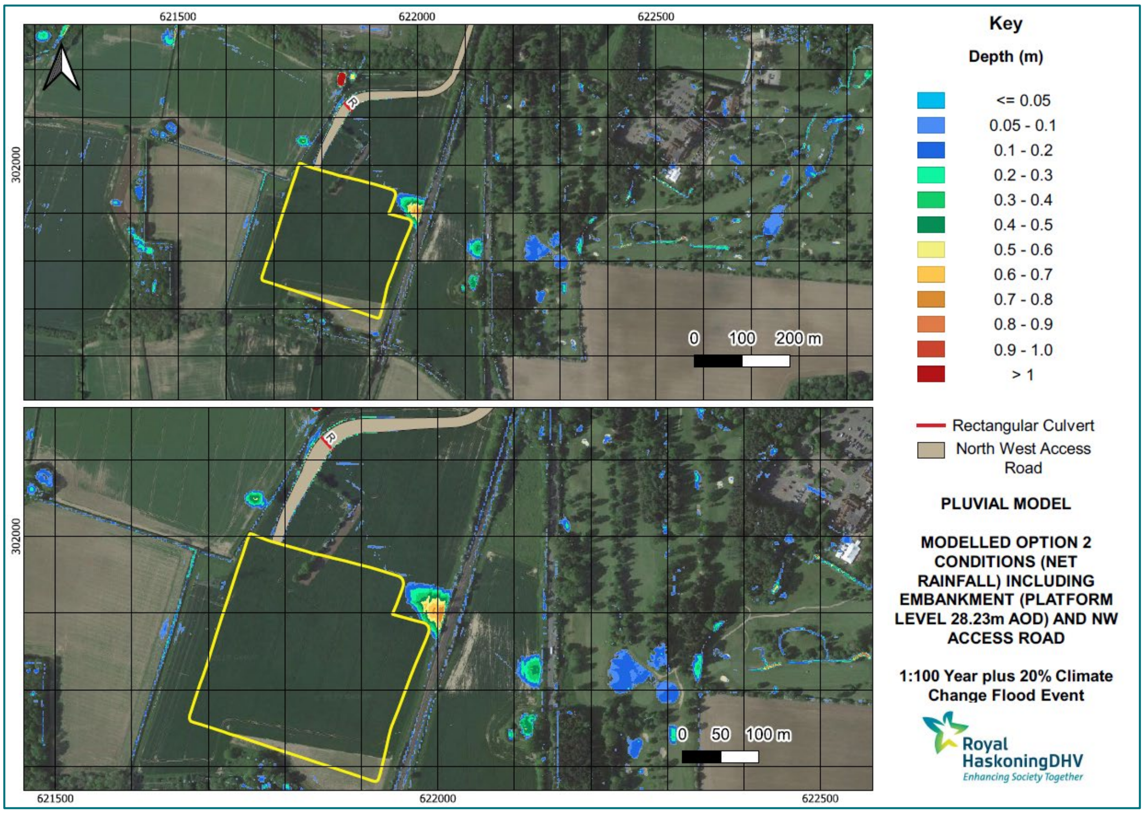

Figure 9-21: 1 in 100 year plus 20% for climate change with OnSS platform level set at 28.23m AOD and NW access road

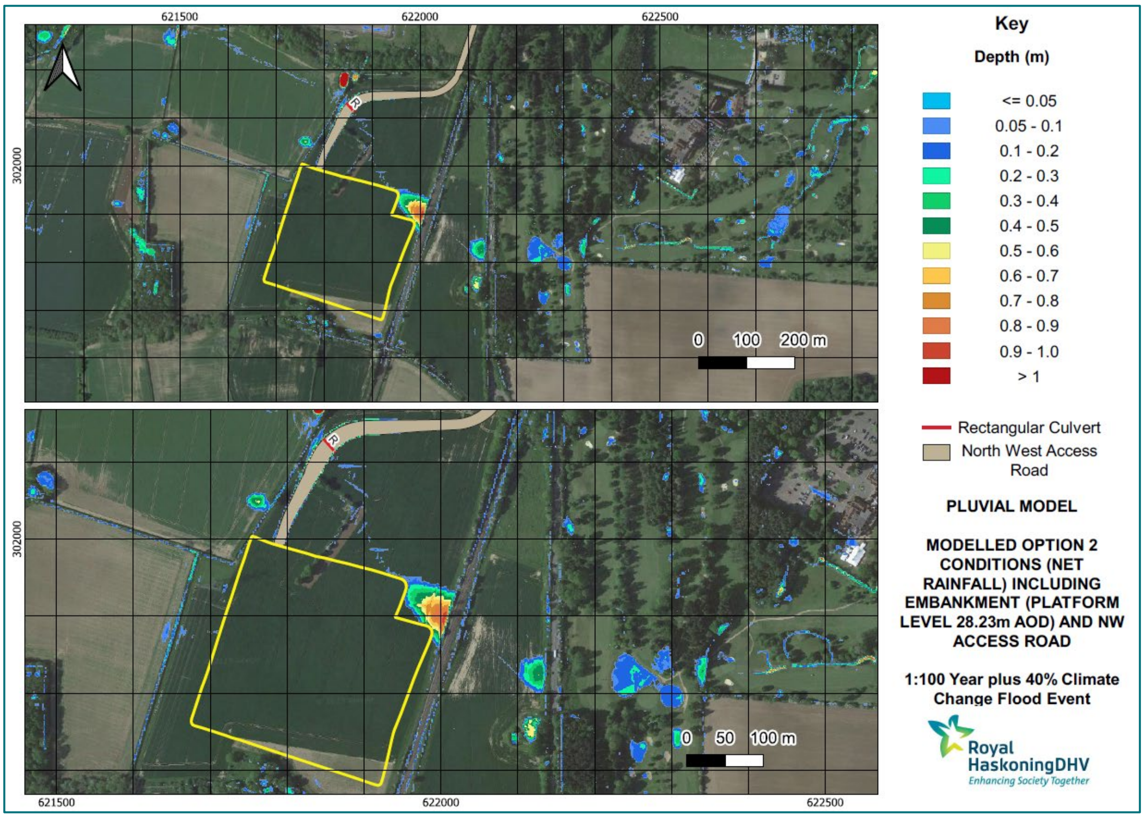

Figure 9-22: 1 in 100 year plus 40% for climate change with OnSS platform level set at 28.23m AOD and NW access road

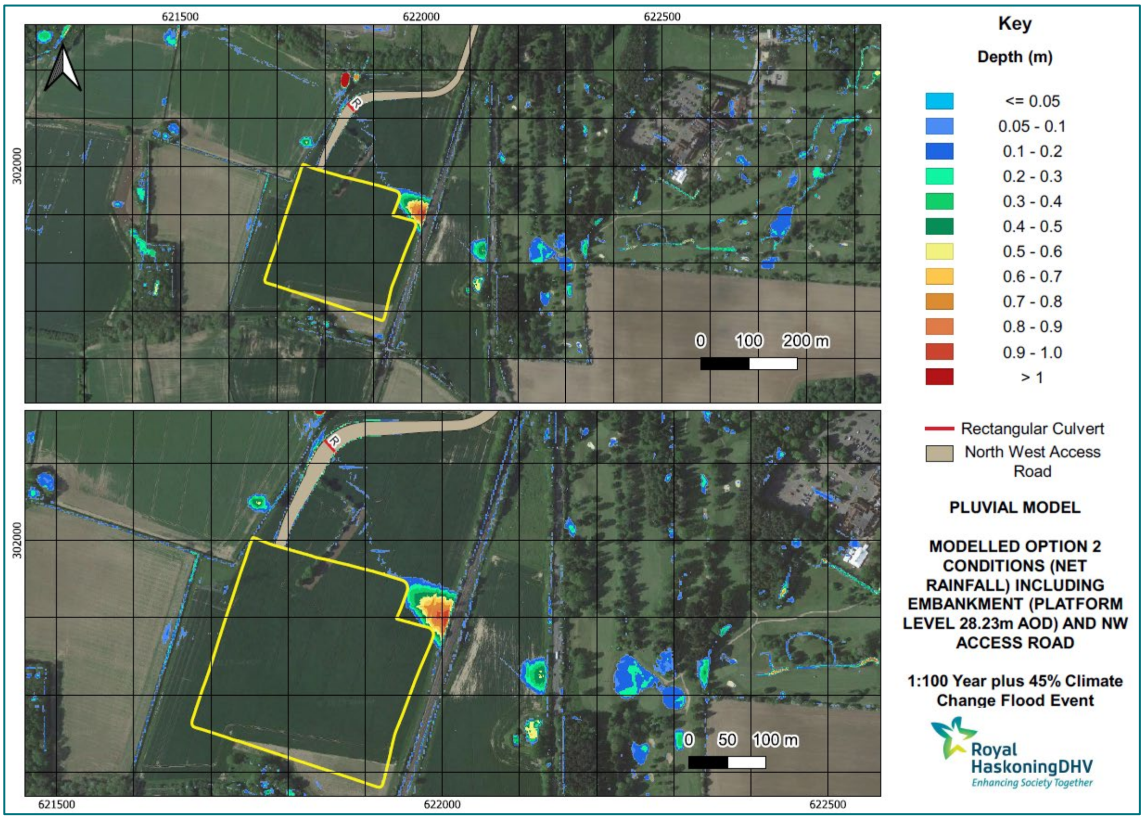

Figure 9-23: 1 in 100 year plus 45% for climate change with OnSS platform level set at 28.23m AOD and NW access road

176. The results of this modelling exercise confirmed that the North West access road can be designed such that there is continued conveyance beneath it. On this basis neither the OnSS platform nor the North West access road will result in displacement of surface water flooding such that there would be an off-site impact on surface water flood risk as a result of the Project.

9.6 Comparison of Baseline and Post Construction (Operational Phase)

177. To demonstrate there is no off-site impact as a result of the Project a comparison of the Baseline has been undertaken in comparison with the Post Construction i.e. Operational Phase.

178. To demonstrate the change in maximum flood extent and depth, the ‘Option 2 with Embankment and North West access road’ results grid was subtracted from the ‘Baseline’ results grid. This was to ensure the difference in flood extents and depths could be depicted more clearly. This exercise was undertaken for the ‘worst case’, which is the 1 in 100 year (+45% climate change) event.

179. **Figure 9-24** demonstrates the differences in extent between the Baseline and Post Construction (i.e. Operational Phase) modelling. While it is clear that there is a reduction in the flood extent at the edge of the OnSS platform (as well as the area that will no longer flood within the footprint), the results of the modelling indicate there is a slight increase in extent along the edges of the raised access road.

[redacted]

180. As previously noted, this reduction in flood extent can be attributed to the incorporation of the OnSS platform in the model. By including the OnSS platform within the model, rainfall falling on the platform during an event does not contribute to the flooding as this will either be collected by the surface water drainage system to be implemented as part of the Project or will naturally infiltrate into the ground on the OnSS platform.

181. A review of the results has confirmed the change in extent adjacent to the access road is very localised and does not extend beyond the immediate area and is related to a minor accumulation of surface water adjacent to the access road structure. Upon review of this data, it is noted that the model is showing surface water from the access road draining off the sides.

182. However, the proposed drainage design for the OnSS platform, as set out in the **Outline Operational Drainage Strategy (onshore substation) (Revision C)** [document reference 9.20], would capture this water within the surface water drainage system and therefore this flow would not exist. It is also noted that there is no restriction of flow as the culvert below the access road.

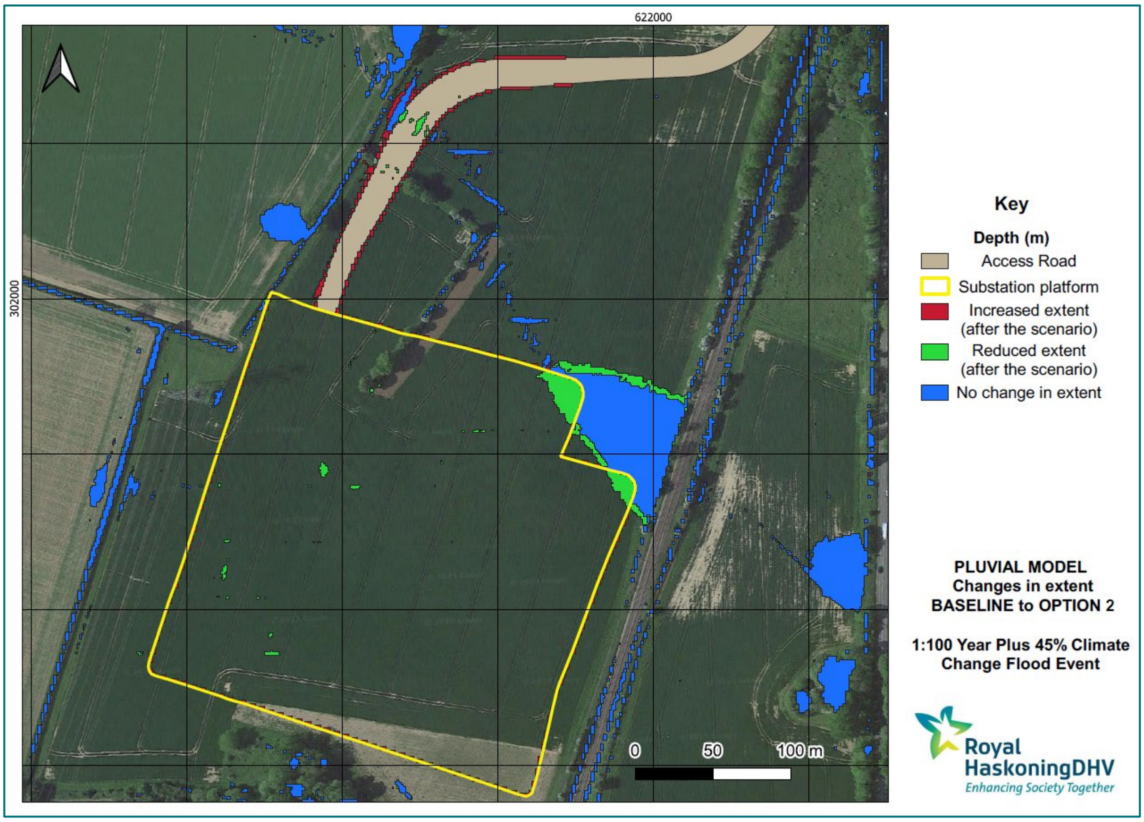

Figure 9-24: 1 in 100 year (plus 45% for climate change) comparison of changes in flood extent

183. To provide greater clarity on the impact of the Post Construction i.e. Operational Phase on surface water flood risk, the changes in depth have also been provided in **Figure 9-25**. This demonstrates that there is a reduction in the flood depth of between 0 - 0.10m adjacent to the railway embankment and the OnSS platform. As noted above, this reduction in flood extent and depth can be attributed to the

incorporation of the OnSS platform in the model and the collection of rainfall falling upon it.

184. There is a slight increase in depth, comprising a maximum depth of 0.09m at the upstream end of the culvert beneath the access road. As noted above, this is likely to relate to the model geometry whereby the surface water would be captured within the surface water system for the OnSS platform and therefore would not drain off the sides of the access road.

185. Furthermore, the areas which experience a change in depth are in locations which are rural and are unlikely to have a significant impact either on or off-site to either people or property. As with the changes in the flood extent, the changes in flood depth are very localised and do not extend beyond the immediate area.

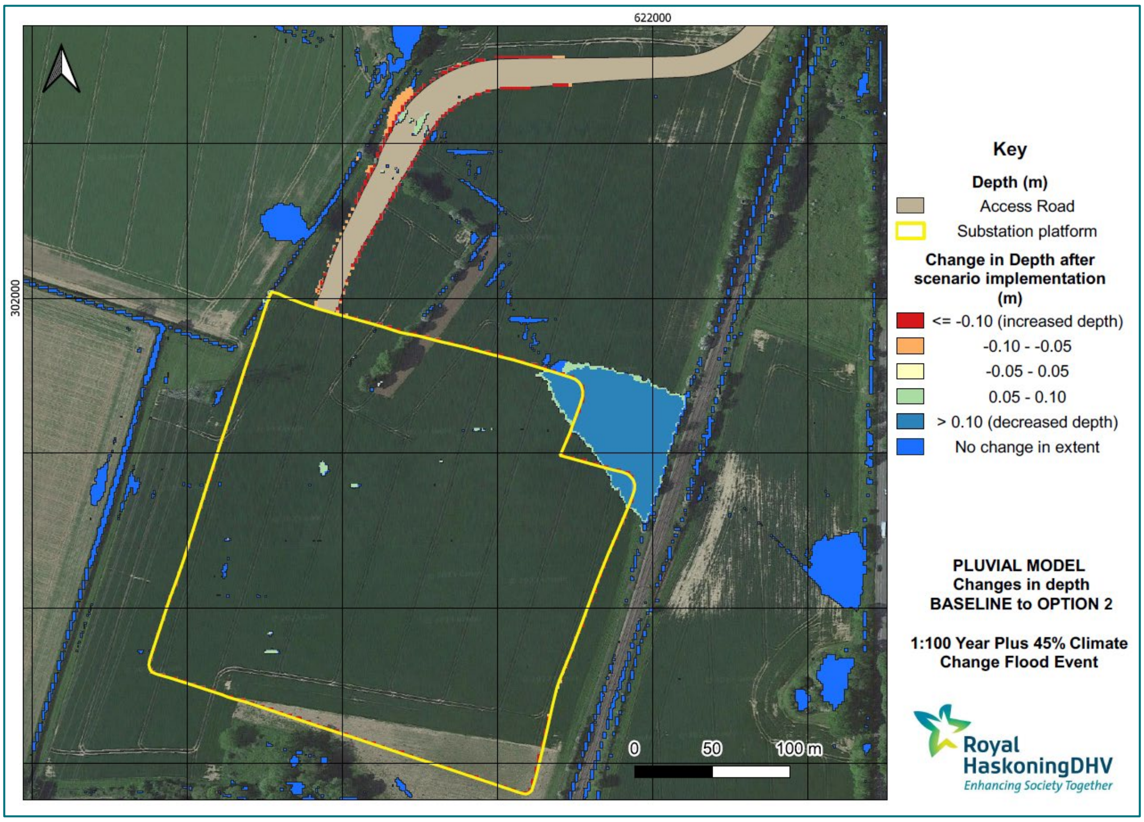

Figure 9-25: 1 in 100 year (plus 45% for climate change) comparison of changes in flood depth

186. A comparison between the Baseline and Post Construction (i.e. Operational Phase) demonstrates that any flood water which is displaced by the proposed OnSS platform is relatively minor and will not result in a significant off-site risk. Furthermore, it also demonstrates there is a slight reduction in the depth of water pooling against the railway embankment.

187. As previously noted, this is due to the rainfall falling directly onto the OnSS platform either being collected by the surface water drainage system to be implemented as part of the project or naturally infiltrating into the ground on the OnSS platform and therefore less water would reach the low-lying area adjacent to the railway line.

10 Sensitivity Testing

188. To ensure that a robust approach has been adopted and in line with the methodology overview identified in **Figure 4-1**, a series of sensitivity checks have been undertaken as part of the hydrological analysis and hydraulic modelling.

189. These sensitivity checks have been summarised as follows:

- Storm duration
- Seasonality
- Manning's roughness
- Peak rainfall rate
- Drainage losses

190. Details of the proposed approach to the sensitivity testing was provided to the LLFA, via email dated 31st March 2023. The aim of this consultation was to ensure that SEP and DEP were aligned with the understanding of the LLFA prior to undertaking a number of the sensitivity checks.

191. The LLFA provided the following response via letter dated 18th April 2023:

> *"We have reviewed your proposed sensitivity testing approaches and are supportive in their application. We look forward to receiving the updated reporting and results soon."*

192. Discussion relating to a number of the sensitivity checks has been included within the relevant preceding sections of this report. However, each of the sensitivity checks has also been summarised in the following sub-sections to provide clarity on the reviews undertaken.

10.1 Storm duration

193. As noted in **Section 6.1**, the critical storm duration was assessed as part of the hydrological analysis. This is in accordance with best practice whereby a study should assess the critical storm duration for each catchment that is being considered. In the context of the SEP and DEP modelling exercise, this comprises a single catchment draining towards the OnSS.

194. As part of the hydrological analysis, a review of the critical storm duration was undertaken for SEP and DEP utilising the industry standard ReFH2 software. This comprises an iterative check whereby a series of storm durations are considered. In the case of the SEP and DEP, storm durations ranging from 2.5 hours through to 18 hours were assessed within the software to identify the storm duration that results in the maximum peak flow.

195. In the case of the catchment draining towards the OnSS this was found to be 7.5 hours (450 minutes). On this basis, it was confirmed that 7.5 hours was the critical storm duration for this catchment, and this was subsequently adopted within the hydraulic modelling.

196. It is also noted that the model was subsequently run for a total of 12 hours i.e. a further 4.5 hours following the peak of the hyetograph to allow time for surface water to flow through the catchment following the storm and to ensure that maximum depths were modelled in the areas where ponding would occur.

10.2 Seasonality

197. As part of the hydrological analysis, the appropriate seasonality (i.e. storm profile) was reviewed to understand the most appropriate approach to be adopted for use within the modelling exercise. As noted in **Section 3.4**, the LIT11832 Environment Agency Flood Estimation Guidelines (July 2022) was reviewed alongside the key catchment descriptors, comprising the URBEXT$_{1990}$ and URBEXT$_{2000}$ values to understand whether the winter or summer storm / rainfall profile should be adopted for this catchment.

198. As the catchment is classified as Essentially Rural (i.e. less than 0.30) the best practice guidance indicates that winter storm rainfall depths should be used. In addition, the URBEXT$_{1990}$ and URBEXT$_{2000}$ values were also compared with the SPRHOST value which is 23.86%, indicating a relatively low runoff rate.

199. Guidance indicates that a winter storm / rainfall profile is reflective of a catchment where runoff is likely to take a longer period of time to flow over the surface and reach the subject location, compared with the summer storm profile whereby rainfall is likely to run over the surface in a relatively short time period following a high intensity storm. Generally, a summer storm profile is reflective of an urbanised and relatively impermeable catchment, which is not hydrologically similar to the characteristics of the SEP and DEP catchment.

200. On this basis, and in accordance with the above best practice guidance, the hydrological analysis adopted the winter storm / rainfall profile within the modelling exercise.

10.3 Manning's roughness

201. As noted in **Section 7.3**, a series of Mannings roughness values were assigned within the hydraulic modelling based on guidance taken from Chow (1959). Based on a review of the Mastermap within the catchment, various Mannings roughness values were assigned to the different ground features, to ensure that each of these was appropriately considered within the hydraulic modelling exercise.

202. To confirm the appropriateness of these values and to understand the sensitivity of the hydraulic modelling to changes in these values, a sensitivity test was undertaken based on varying the Mannings roughness values by +/- 20%. This is in accordance with the standard approach to sensitivity testing used within modelling.

203. The Mannings roughness values adopted within the sensitivity testing are summarised in **Table 10-1**. For the variation of the Manning's roughness value, the Baseline 1 in 100 year return period event was used and the Mannings roughness values in the .tmf materials file were varied by +/- 20%.

Table 10-1: Adjusted Surface Roughness Values

Material Type	Baseline Mannings Roughness Value	+20% Mannings Roughness Value	- 20% Mannings Roughness Value
Default Roughness	0.045	0.054	0.036
Urban Areas	0.06	0.072	0.048
Greenspace	0.035	0.042	0.028
Woodland	0.08	0.096	0.064
Surface Water	0.02	0.024	0.016
Foreshore	0.05	0.06	0.04
Waterlines	0.02	0.024	0.016
Buildings	0.04	0.048	0.032
Roads	0.025	0.03	0.02

204. To assess the impact of the revised Mannings roughness values on the results of the hydraulic modelling a number of inspection points at key locations around the OnSS have been considered, as shown on **Figure 10-1**. The results from the model runs were loaded into GIS and the maximum flood depths extracted at inspection points 1 to 10.

Figure 10-1:Location of Inspection Points

205. The results of the Mannings roughness sensitivity test are provided in **Table 10-2** with the change in Flood Depth compared with the Baseline model presented in **Table 10-3**.

Table 10-2: Mannings roughness value Maximum Flood Depth

Model Run	**Inspection Point Maximum Flood Depth (m)**									
Baseline	0.047	0.066	0.129	0.064	0.468	0.028	0.834	0.069	0.103	0.208
+ 20% Mannings roughness value	0.048	0.07	0.131	0.065	0.467	0.031	0.838	0.072	0.101	0.209
- 20% Mannings roughness value	0.045	0.062	0.126	0.065	0.467	0.025	0.831	0.067	0.105	0.208

Table 10-3: Mannings roughness value Depth change from Baseline

Model Run	**Inspection Point Depth change from Baseline (m)**									
+ 20% Mannings roughness value	0.001	0.004	0.002	0.001	-0.001	0.003	0.004	0.003	-0.002	0.001
- 20% Mannings roughness value	-0.002	-0.004	-0.003	0.001	-0.001	-0.003	-0.003	-0.002	0.002	0.000

206. As can be seen from the Depth changes identified in **Table 10-3** above, there is minimal change in the results from the hydraulic modelling, with the variation only recorded when taking the model results to 3 decimal places.

207. On this basis, it can be concluded that the results of the Manning's roughness values are likely to relate to "noise" differences, which are assumed to be a result of the interpolation and convergence between model time-steps when undertaking the revised runs and that these do not lead to an increase in either the flood extent or peak flood levels.

208. As such, it is concluded that the sensitivity testing considering changes in Mannings roughness values does not have an impact on the model results and therefore does not result in a change to the surface water flood risk around the OnSS.

10.4 Peak rainfall rate

209. Further to the hydrological analysis undertaken with regards to the influence of seasonality and critical storm duration, it is also noted that a degree of sensitivity

testing has been undertaken by considering a number of future climate change scenarios comprising an increase in rainfall of 20%, 40% and 45% as a result of climate change.

210. However, to provide greater clarification, an additional sensitivity test has also been undertaken on the inflows to the model. This comprised an adjustment to the 1 in 100 year rainfall hyetograph (i.e. the inflow boundary) by scaling it up and down by +/- 20% within the model. This was incorporated by applying a scaling factor of 0.8 and 1.2 within the bc_dbase 'ValueMult' column within the hydraulic model files.

211. To assess the impact of the adjusted inflow values on the results of the hydraulic modelling the same inspection points around the OnSS, as shown on **Figure 10-1**, have been considered.

212. The results of the sensitivity testing utilising the adjusted inflow values are provided in **Table 10-4** with the change in Flood Depth compared with the Baseline model presented in **Table 10-5**.

Table 10-4: +/- 20% Inflow values Maximum Flood Depth

Model Run	Inspection Point Maximum Flood Depth (m)									
Baseline	0.047	0.066	0.129	0.064	0.468	0.028	0.834	0.069	0.103	0.208
Inflow +20%	0.054	0.072	0.133	0.082	0.481	0.124	0.936	0.126	0.151	0.244
Inflow -20%	0.038	0.06	0.124	0.036	0.421	0.02	0.728	0.005	0.057	0.171

Table 10-5: +/- 20% Inflow values Depth change from Baseline

Model Run	Inspection Point Depth change from Baseline (m)									
Inflow +20%	0.007	0.006	0.004	0.018	0.013	0.096	0.102	0.057	0.048	0.036
Inflow -20%	-0.009	-0.006	-0.005	-0.028	-0.047	-0.008	-0.106	-0.064	-0.046	-0.037

213. From the results presented in **Table 10-5**, it is noted that although flood depths differ slightly across the area around OnSS site, the variation in flood depth is within 100mm, for all sensitivity runs except for the area around inspection point 7.

214. Notably, this is the location with the greatest flood depths in the Baseline scenario as this is the location where the ground is lowest adjacent to the railway embankment, and where surface water is shown to collect.

215. As such, a variation in inflow is likely to result in more significant changes in depth at this location, since in the other locations water is likely to flow overland towards this area. Other locations where there is likely to be a change in depth of between 50mm and 100mm is at inspection point 6 (for the +20% inflow value run only) and at inspection point 8 (for both the +/- 20% inflow value runs).

216. It is noted that, similarly to inspection point 7, inspection point 6 is also in the area shown to collect surface water in the Baseline model to the west of the railway embankment. In addition, inspection point 8 is adjacent to a hedge line and wooded area where there are likely to be restrictions to flow which result in localised increases in flood depth.

217. The results of the sensitivity test are in accordance with the expected changes within the model outputs i.e. when inflows are increased the model responds accordingly demonstrating an increase in flood depth and vice versa by reducing the inflow values there is a reduction in flood depth compared with the Baseline model.

218. A review of the results from the inflow sensitivity testing notes that it does not result in increased off-site flood risk. Furthermore, the outcomes of the sensitivity testing are also less conservative in their results than the 1 in 100 year (plus 45% for climate change) event which has been assessed within the Option modelling for the purposes of considering the location of the OnSS.

219. Therefore, whilst the above sensitivity test provides an indication of the potential influence that adjusting the inflow value has on the model and the change in flood depth, it does not result in a significant change in either the resulting flood depth or flood extent.

10.5 Drainage Losses

220. As noted in both **Section 4.1** and **Section 8.2**, the hydraulic modelling exercise has considered and undertaken a sensitivity check on the influence that the use of the gross rainfall hyetograph would have on model results in comparison with the application of net rainfall hyetograph. In **Section 4.1** it was noted that a limitation of the use of Direct Rainfall includes uncertainty regarding the potential for infiltration to the ground i.e. resulting from infiltration / drainage losses.

221. Given the initial understanding of the catchment, with regard to the potential for infiltration, the worst-case was initially assumed whereby gross rainfall hyetographs were applied as inflows to the model i.e. reflective of there being no allowance for infiltration or discharge to sewers. On this basis, the model assumes that all rainfall falling on a catchment is likely to run over the surface as overland flow.

222. However, when the initial modelling results from the gross rainfall hyetographs were compared with the Environment Agency surface water mapping, this indicated they were overestimating the surface water risk. This was also considered within the context of historic flooding, anecdotal information and observations during the site walkover of potential overland flow paths. The results of the modelling undertaken utilising the gross rainfall hyetographs were presented to the LLFA during an Expert Topic Group meeting on 10th February 2022.

223. In reviewing the sensitivity of the model to this parameter it was noted that the use of the gross rainfall hyetographs results in flooding in the same locations as the Environment Agency surface water mapping, providing confidence that overall the hydraulic model was reflective of the general overland / surface water flow paths and areas of ponding.

224. Following the initial modelling, additional ground investigations and monitoring found that infiltration is greater in some areas within the OnSS site and that there are areas where infiltration occurs within the wider catchment area. It was on this basis that it was considered unrealistic that no infiltration or drainage losses would occur in the wider catchment and therefore the use of gross rainfall hyetographs, indicating no infiltration or drainage losses, was not reflective of the overall catchment.

225. On this basis, and in accordance with standard modelling practice, the net rainfall hyetographs were subsequently applied to the hydraulic model to account for infiltration / drainage losses across the catchment. The modelling results from the net rainfall hyetographs indicate flooding in locations similar to those identified by the gross rainfall hyetographs, which are also relatively similar in their extent to those identified by the Environment Agency surface water mapping.

226. Therefore, it is concluded that following sensitivity testing the most appropriate, and best practice approach has been adopted to reflect the likely infiltration and drainage losses within the catchment.

11 Assumptions, Limitations and Recommendations

11.1 Modelling Issues

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

11.2 Assumptions

228. Hydrological and hydraulic models are constructed from empirical and numerical components that, by definition, have assumptions built into their underlying parameters and calculations.

229. Other assumptions also arise in their development due to uncertainty in, or absence of suitable input data (e.g. percentage runoff 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.

230. The key assumptions made during this modelling exercise are summarised below:

11.2.1 Hydrological Assumptions

231. The hydrological analysis assumes:

- FEH13 design storm profiles for a 7.5 hour design storm duration has been applied across the whole catchment. This is based on the hydrological analysis, summarised in **Section 6.1** which identified this to be the critical storm duration for the catchment;
- Following initial test runs using the gross rainfall hyetograph the net rainfall hyetograph was adopted for all model runs as this included catchment specific losses;
- Standard Average Annual Rainfall (SAAR) and Design Rainfall depths were similar across the whole catchment; and
- The hydrological assessment identified that the winter storm resulted in the greatest rainfall depths, therefore this was chosen as the design event type.

11.2.2 Hydraulic Assumptions

232. 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 been derived from filtered Environment Agency LiDAR data and checked against survey data provided by the Client to ensure it is accurate and representative of the topography of the catchment;
- 2D surface roughness values are based on online aerial photography and reviewed against Chow (1959); and

- The model was run for a duration of 12 hours, to allow sufficient time for surface water flows to pass through the catchment and the site following the end of the storm.

11.3 Limitations

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

11.4 Validation & Calibration

234. 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.

235. Calibration data in the form of recorded depths and accurate locations of historic flood events was not available, therefore the model could not be calibrated. However, comparison with the Environment Agency surface water flood mapping showed a good similarity, therefore for the purpose of this modelling exercise the results were considered to be acceptable.

12 Conclusions

236. Equinor New Energy Ltd (the Applicant) commissioned the building of a direct rainfall hydraulic model to support the assessment of surface water flood risk at the proposed Onshore Substation (OnSS) site to the south west of Norwich. This work was to inform the wider **Flood Risk Assessment** [AS-023] for the onshore cable route and OnSS platform to support the Sheringham Shoal and Dudgeon Offshore Wind Farm Extension Projects.

237. To understand the above flood risk in greater detail, a 2D direct rainfall model was constructed, covering the site of the proposed OnSS platform. This Hydraulic Modelling Report provides a summary of the modelling exercise undertaken and the subsequent results which were reviewed to provide a greater understanding of surface water flood risk in this location.

238. A review of the hydrological catchment was carried out using the FEH Web Service and the British Geological Survey online mapping tool, known as the Geology of Britain Viewer. The contributing hydrological catchment is 1.32 km^2 in area, and the key FEH catchment descriptors indicate that the catchment is highly permeable, with the expectation that a high proportion of rain falling onto the catchment would infiltrate to the underlying ground.

239. The relatively high BFIHOST value indicates high permeability. This is in accordance with the low SPRHOST value which indicates that only 23.86% of the water falling onto the catchment would result in runoff.

240. Following review of the hydrological catchment, the ReFH2 software was used to generate direct rainfall hyetographs based on the FEH13 Depth-Duration-Frequency estimates. Following FEH guidelines, the winter storm profile was used, in line with best practice guidance, on the basis that the URBEXT2000 value for the catchment was less than 0.30.

241. Given the poor infiltration observed during the September 2021 ground investigations, a conservative approach to the hydrological analysis was initially adopted whereby the gross rainfall hyetographs were applied as a direct rainfall boundary, rather than the net rainfall. This meant that no losses to the ground were included in the rainfall runoff model..

242. For the hydrological inputs to the model, rainfall hyetographs were prepared for the 1 in 30 year, 1 in 100 year, 1 in 100 year (plus 20% for climate change), 1 in 100 year (plus 40% for climate change) and 1 in 100 year (plus 45% climate change) events.

243. Following additional ground investigations and monitoring it was found that infiltration is greater in some areas within the OnSS site. On this basis, the net rainfall hyetographs were subsequently applied to the hydraulic model to account for losses across the catchment, based on the catchment characteristics. This resulted in a flood extent which was more similar to the Environment Agency mapping.

244. The hydraulic modelling identified that a combination of the net rainfall hyetographs and the use of 0.5m resolution LiDAR provides the best representation of the surface water flood risk for the study area.

245. A Baseline model was developed to understand the nature of the existing surface water flood risk at the OnSS site. This was considered alongside the footprint of the OnSS platform to understand its potential interaction with the surface water flood extent.

246. Following the development of the Baseline model, a number of options for the layout and location of the OnSS platform were considered as part of the design iteration process.

247. Option 1, comprising a large rectangular shape, overlaps the Baseline surface water flood extent in all modelled events. This would result in the displacement of surface water, which would require mitigation / management within the site boundary.

248. Option 2, comprising an irregular polygon shape to allow for either a N-S or E-W orientation for the OnSS, does not overlap with the Baseline surface water flood extent in any event except for the 1 in 100 year (plus 40% for climate change) and 1 in 100 year (plus 45% for climate change) events. On this basis, the volume of displaced water would be much reduced compared with Option 1 requiring less mitigation / management of surface water within the site boundary.

249. Modelling of Option 2 with the Embankments for the OnSS platform did not show any significant impacts to the flood extent when compared to the Baseline model results. It also demonstrates a significant reduction in surface water displacement compared with Option 1.

250. To understand the impact the OnSS platform may have on surface water flood risk and to consider the potential for an increase in off-site flood risk, Option 2 with Embankments was modelled with the platform level set at 28.23m AOD. Following review of these results it was noted that both the surface water flood extent and maximum flood depths are slightly reduced compared with the results from the Baseline modelling.

251. This reduction can be attributed to the incorporation of the OnSS platform in the model. By including the OnSS platform within the model, rainfall falling on the platform during an event does not contribute to the flooding as it is assumed this will either be collected by the surface water drainage system to be implemented as part of the project or will naturally infiltrate into the ground on the OnSS platform.

252. The OnSS platform requires the provision of an access road to connect it with the higher ground to the north. As a result, this means the southern end of the access road (at the OnSS platform) would be raised above the existing ground level. The access road would need to pass over the existing overland flow path and could potentially block it. As such, it was noted that measures will be required to enable the existing surface water flow paths to continue to pass below the access road.

253. To understand the impact the OnSS platform and access road may have on surface water flood risk and to consider the potential for an increase in off-site flood risk, Option 2 with Embankments was modelled with the North West access road included tying in to the OnSS platform level of 28.23m AOD at the southern end.

254. A large culvert was included within the model beneath the North West access road to allow the continued conveyance of the existing flow path beneath it. The results of this modelling demonstrated very little impact from the North West access road

on the overland flow path, with the water continuing to reach the low lying area adjacent to the railway embankment, as is the existing situation.

255. The results of this modelling indicated that the surface water flood extent and maximum flood depths are slightly reduced compared with the results from the Baseline modelling. This reduction can be attributed to the incorporation of the OnSS platform in the model. By including the OnSS platform within the model, rainfall falling on the platform during an event does not contribute to flooding as it will be collected by the surface water drainage system to be implemented as part of the project or will naturally infiltrate into the ground on the OnSS platform.

256. Overall, there is a small reduction in the surface water flood depth and extent close to the OnSS platform, with some increased risk adjacent to the access road. However, this is related to the model geometry, is very localised and does not extend beyond the immediate area. In addition, there is no change in the wider off-site flood risk as the surface water flooding is contained within the OnSS site.

257. In addition, a series of sensitivity tests have been undertaken, in accordance with industry standard approaches. The hydraulic modelling has adopted best practice regarding the use of the appropriate seasonality, critical storm duration and net rainfall hyetographs.

258. The results of the sensitivity tests for Mannings roughness values are in accordance with the expected changes within the model outputs i.e. they result in no significant change to the model results. Additionally, when inflow values are increased the model responds accordingly, demonstrating an increase in flood depth and vice versa by reducing the inflow values there is a reduction in flood depth compared with the Baseline model.

259. Overall, the sensitivity testing has confirmed that an appropriate modelling approach has been adopted within the hydraulic modelling exercise and that the flood risk identified by the model appears to be reflective of the characteristics of the catchment.

References

British Geological Survey (undated). Geology of Britain viewer. Available online: [redacted]/ (Accessed:17/12/2021)

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

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

Environment Agency (2022). Guidance on Flood risk assessments: climate change allowances. Available online: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances (Accessed: 06/01/2023)

Flood Hazard Research Centre & Environment Agency (2013). Flood and Coastal Erosion Risk Management, A Manual for Economic Appraisal.

Norfolk County Council (2022). LLFA Statutory Consultee for Planning Guidance Document (Version 6.1). Available online: https://www.norfolk.gov.uk/-/media/norfolk/downloads/rubbish-recycling-planning/flood-and-water-management/lead-local-flood-authority-guidance-document.pdf (Accessed: 06/01/2023)

UK Centre for Ecology & Hydrology (undated). Flood Estimation Handbook Web Service. Available online: [redacted]