Green Hill Solar Farm

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Hydraulic Modelling Technical Note BESS

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Hydraulic Modelling Technical Note BESS

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For: Island Green Power UK Ltd

Site: Green Hill Solar

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Contents

Tables

Figures

Appendices

Reference of Terms

Annual Exceedance Probability (AEP)

The AEP is the chance or probability of a natural hazard event (usually a rainfall or flooding event) occurring annually and is usually expressed as a percentage.

Aquifers[1]

- Principal Aquifers are layers of rock or drift deposits that have high intergranular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale.
- Secondary A Aquifers are 'permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers'.
- Secondary B Aquifers are 'predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of the former non-aquifers'.
- Secondary Undifferentiated Aquifers are assigned in 'cases where it has not been possible to attribute either category A or B to a rock type. In most cases, this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type'.
- Unproductive Strata are 'rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow'.

Canal Failure

Canal failure can occur due to high-intensity rainfall or structural failure and can be dangerous due to the rapid release of large volumes of water. It is typically limited to raised canal reaches and can result in a rapid peak in flow followed by a gradual reduction.

Climate Change (CC)

A change in global or regional climate patterns. For flood risk, CC is assessed in terms of allowances which are predictions of anticipated change for peak river flow, peak rainfall intensity, sea level rise and offshore wind speed and extreme wave height. CC scenario data exists across different epochs (time periods) to determine the needs for climate resilience measures. CC data is requested as part of an EAPD request. If a separate ESG Flood Risk and CC Assessment is needed, additional CC data will be required.

Environment Agency (EA) and EA Product Data (EAPD)

The EA is the lead organisation for providing flood and coastal risk management and warnings of flooding from Main Rivers and on the coast. For sites within or in close elevational proximity to Flood Zone 2 or Flood Zone 3, EAPD is ordered to obtain more detailed flood risk data such as flood depths, breach and overtopping mapping and fluvial/tidal risks associated with CC.

[1] Groundwater protection: Principles and practice (GP3) Version 1.1 (published August 2013, Environment Agency / Department for Environment, Food & Rural Affairs)

Fluvial Flooding

Fluvial flooding typically occurs when a river's capacity is exceeded, and the excess water overtops the riverbanks. It can also occur when the watercourse has a high level downstream, perhaps due to structures or blockage, thus limiting conveyance. This creates a backup of water which can overtop the banks. Typical flooding issues occur when the natural floodplain has been urbanised and the river has been confined. EA mapping defines three zones of different flood risk, the third of which is subdivided into two categories:

- Zone 1 "Low probability of flooding" – This zone comprises land assessed as having a less than 1 in 1,000 annual probability of river or sea flooding (<0.1%);
- Zone 2 "Medium probability of flooding" – This zone comprises land assessed as having between a 1 in 100 and 1 in 1,000 annual probability of river flooding (1% – 0.1%), or between a 1 in 200 and 1 in 1,000 annual probability of sea flooding (0.5% – 0.1%) in any year;
- Zone 3a "High probability of flooding" – This zone comprises land assessed as having a 1 in 100 or greater annual probability of river flooding (>1%), or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year; and
- Zone 3b "Functional floodplain" – A sub-part of Zone 3, this zone comprises land where water has to flow or be stored in times of flood. This zone is not normally included within the national Flood Map for Planning and is calculated where necessary using detailed hydraulic modelling.

Groundwater Flooding

Groundwater flooding is caused by the emergence of water from beneath the ground at either point or diffuse locations when the natural level of the water table rises above ground level. This can result in deep and long-lasting flooding of low-lying or below-ground infrastructure such as underpasses and basements. Groundwater flooding can cause significant damage to property, especially in urban areas, and can pose further risks to the environment and ground stability.

Sewer Flooding

Flooding from sewers primarily occurs when flow entering a system exceeds available capacity or if the network capacity has been reduced through blockage or collapse. In the case of surface water sewers that discharge to watercourses, the same effect can be caused as a result of high-water levels in the receiving watercourse. As a result, water can begin to surcharge the sewer network, emerging at ground level through gullies and manholes and potentially causing flooding to highways and properties. If this occurs flooding can represent a significant hazard to human health due to the potential for contaminants in flood water.

Source Protection Zones

Source Protection Zones (SPZs) are areas of land through which water infiltrates into a groundwater borehole, well or spring that is used for public drinking water supply. These zones show the risk of contamination from potential pollution. SPZ's have been created as public facing boundaries where discrete groundwater bodies within SPZ's have been dissolved on zone number where common boundaries and overlaps have been removed. SPZs are defined around large and public potable groundwater abstraction sites. The purpose of SPZs is to provide additional protection to safeguard drinking water quality through constraining the proximity of an activity that may impact upon a drinking water abstraction.

- Zone 1 (Inner Protection Zone) is defined by a travel time of 50-days or less from any point within the zone at, or below, the water table. Additionally, the zone has as a minimum a 50-metre radius.
- Zone 2: (Outer Protection Zone) - This zone is defined by the 400-day travel time from a point below the water table. Additionally, this zone has a minimum radius of 250 or 500 metres, depending on the size of the abstraction.

- Zone 3: (Total catchment) - This zone is defined as the total area needed to support the abstraction or discharge from the protected groundwater source. A further Zone 4, or ‘Zone of Special Interest’ was previously defined for some groundwater sources.

Surface Water Runoff

Surface water runoff is defined as water flowing over the ground that has not yet entered a drainage channel or similar. It usually occurs because of an intense period of rainfall which exceeds the infiltration capacity of the ground. Typically, runoff occurs on sloping land or where the ground surface is relatively impermeable. The ground can be impermeable either naturally due to the soil type or geology, or due to development which places impervious material over the ground surface (e.g. paving and roads).

Tidal Flooding

Tidal flooding is caused by high tides coinciding with a low-pressure storm system which raises sea and tidal water levels, overwhelming coastal and river defences. This may be made worse by gale-force winds blowing the raised body of water up tidal river basins some distance from the coast, due to floodwater being forced up the tidal reaches of rivers and estuaries. Such flooding may become more frequent in future years due to rising sea levels.

Reservoirs Failure

Reservoir failure can be a particularly dangerous form of flooding as it results in the sudden release of large volumes of water that can travel at high velocity, causing deep and widespread flooding. The likelihood of this occurring is low as large reservoirs are managed in accordance with the Reservoirs Act 1975. The EA's online reservoir inundation map illustrates the maximum flood extents that could occur in the event of a reservoir.

1. Introduction

1.1 Acknowledgement

1.1.1 This report has been prepared for the sole and exclusive use of Island Green Power UK Ltd in accordance with the scope of work presented via email by Arthian, dated 02/10/2023. This report is based on information and data collected by Arthian. Should any of the information be incorrect, incomplete, or subject to change, Arthian may wish to revise the report accordingly.

1.1.2 Arthian has been instructed to provide hydraulic modelling in support of the Flood Risk Assessment for a proposed solar development in Northamptonshire, known as Green Hill Solar Farm (**Chapter 10 Hydrology Flood Risk and Drainage Revision A [REP1-023]**).

1.2 Project Understanding

1.2.1 The proposed Green Hill Solar Farm development comprises a number of fields (the "Site" or "Sites") described as Green Hill A, A.2, B, C, D, E, F, G for the solar arrays, grid connection infrastructure and Battery Energy Storage System (BESS), and the Cable Route Corridor. The hydraulic modelling exercise focusses solely on the Green Hill BESS (BESS Site).

1.2.2 The proposed BESS Site is shown within Environment Agency (EA) flood mapping to be positioned within Flood Zone 3, an area considered to have a 1% or higher chance of flooding from watercourses in any given year. Nearby watercourses include the River Nene and Grendon Brook, along with several smaller tributaries of these watercourses. The key watercourses are shown in Figure 1.

1.2.3 The aim of the hydraulic modelling exercise is to provide a site-specific assessment of fluvial flood risk to the proposed BESS Site from these watercourses and their tributaries.

1.2.4 Comments from the EA on the initial FRA and associated hydraulic modelling submitted as part of Lot 2, who requested further detail on the modelling methodology, limitations, and outputs. These comments are reproduced in Appendix A, together with references to the sections of this report that address each point.

1.2.5 The EA supplied two existing Flood Modeller 1D models for this assessment, both developed during the 2013 Nene Flood Map Improvements Project – one covering the Middle Nene (referred to herein as the EA Middle Nene model) and the other focusing on Grendon Brook and its tributaries (referred to herein as the EA Grendon Brook model). The extent of these EA models is shown in Figure 2 and Figure 3.

1.2.6 A 2D model of an unnamed tributary of Grendon Brook not included within the EA Grendon Brook model has also been constructed for this assessment using TUFLOW, referred to herein as the Arthian Field Drain model. The extent of this model is shown in Figure 4.

1.2.7 The report is structured by model, with each section detailing the review/build, refinement, and simulation process used to assess site-specific flood risk from the different watercourses. The final assessment of fluvial flood risk used in the BESS layout and design uses the worst case from each model.

1.2.8 Options to combine the EA Middle Nene and EA Grendon Brook models, expand the EA Grendon Brook model to include the nearby field drain, and/or convert either 1D model to a 1D–2D configuration were considered as part of the modelling scoping exercise. However, these approaches were ultimately not taken forward for the following reasons:

- **Model size and complexity:** The EA Middle Nene and Grendon Brook models already contain 3,846 and 2,289 nodes respectively. Developing a combined model or rebuilding the systems into a linked 1D-2D configuration would require substantial additional modelling effort well beyond the proportionate scope of a -site-specific FRA for a solar development, and would be unlikely to provide a meaningful improvement in the understanding of fluvial flood risk at the Site.

- **Lack of a viable trim location:** The Middle Nene has a wide, shallow floodplain with complex flow pathways, and no suitable upstream or downstream trim location exists that would allow a combined or expanded model to operate reliably. A 1D-2D configuration across both watercourses would also impose significant computational demands, resulting in slow runtimes and reduced ability to undertake efficient scenario testing – an essential part of a robust FRA. The nature of the floodplain also increases the risk of numerical instability, meaning substantial effort would likely be spent resolving solver behaviour rather than producing useful outputs.

- **Catchment scale disparity:** Grendon Brook drains a catchment area of approximately 51km^2, whereas the catchment of the River Nene at the confluence with Grendon Brook is over 650km^2. Given this significant difference in scale, coincident peak flows are unlikely, and joint-probability interactions are not expected to materially influence flood risk at the Site.

- **Adequacy of the existing strategic models:** Whilst strategic, the existing EA models are well-constructed 1D representations of the key watercourses that capture the dominant hydraulic processes governing flood levels in each reach. For a low-vulnerability solar NSIP, this level of modelling is proportionate and aligned with established practice for assessing fluvial risk. Redeveloping the models into a bespoke combined or 1D-2D system would significantly increase complexity without providing a clear, defensible benefit to the assessment.

1.2.9 This report takes into account the EA guidance document, “Using modelling for flood risk assessments (2023)[2]”.

1.3 Project Limitations

1.3.1 The wider Arthian limitations are contained within Appendix B.

[2] https://www.gov.uk/guidance/using-modelling-for-flood-risk-assessments

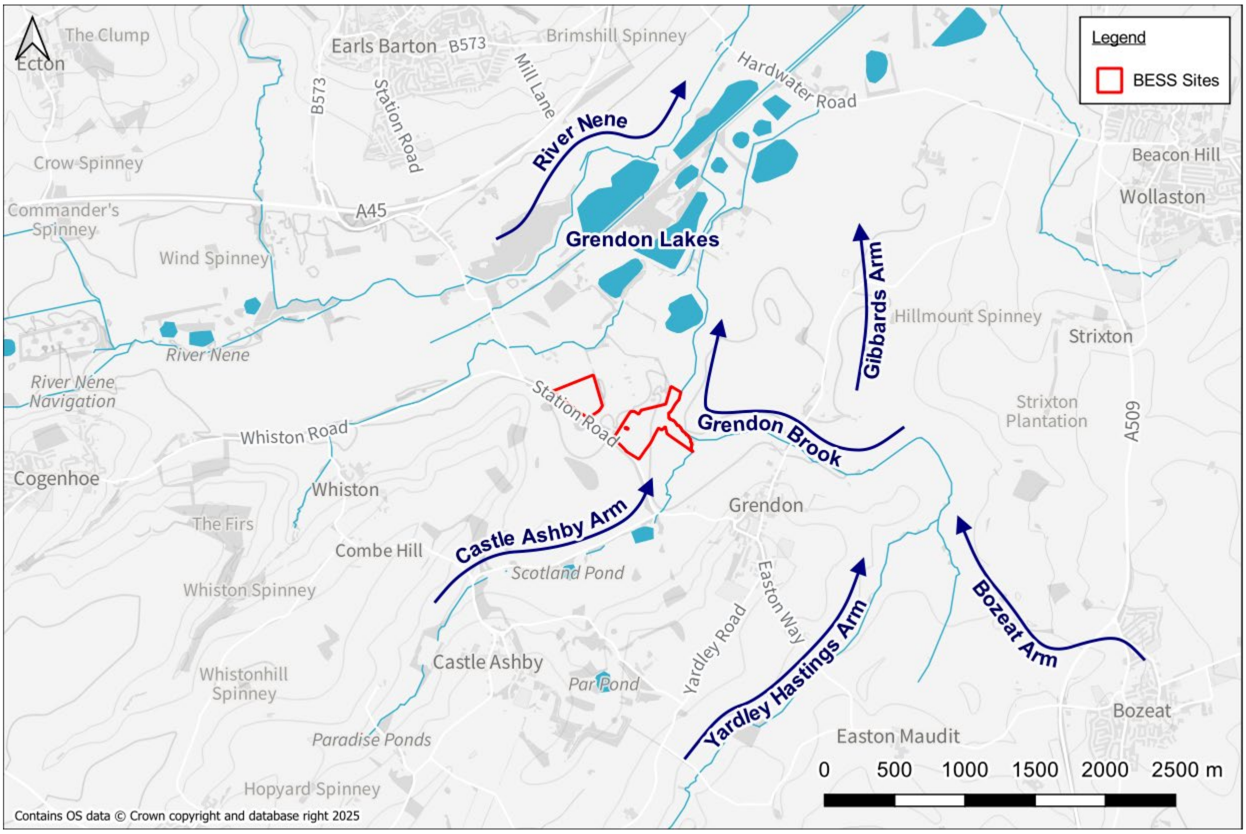

Figure 1: BESS Site location and key watercourses

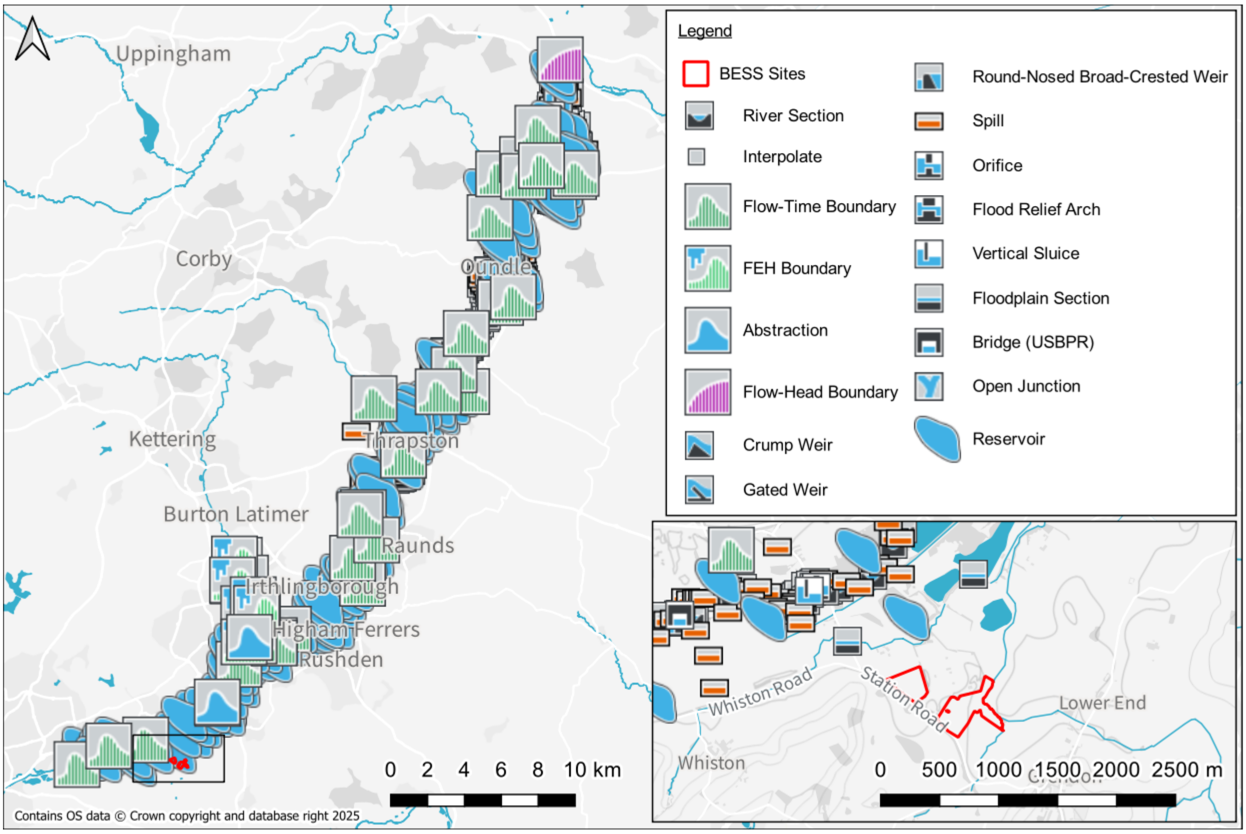

Figure 2: EA Middle Nene model coverage

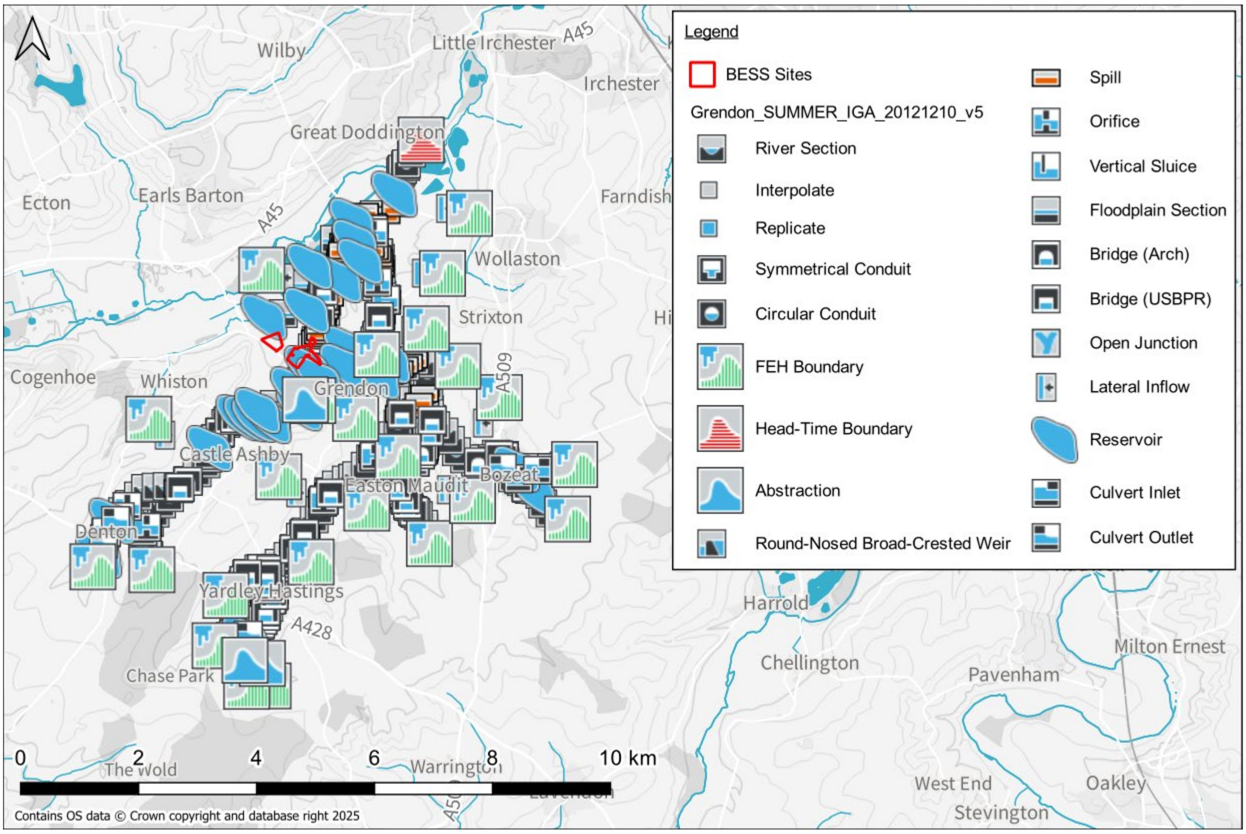

Figure 3: EA Grendon Brook model coverage

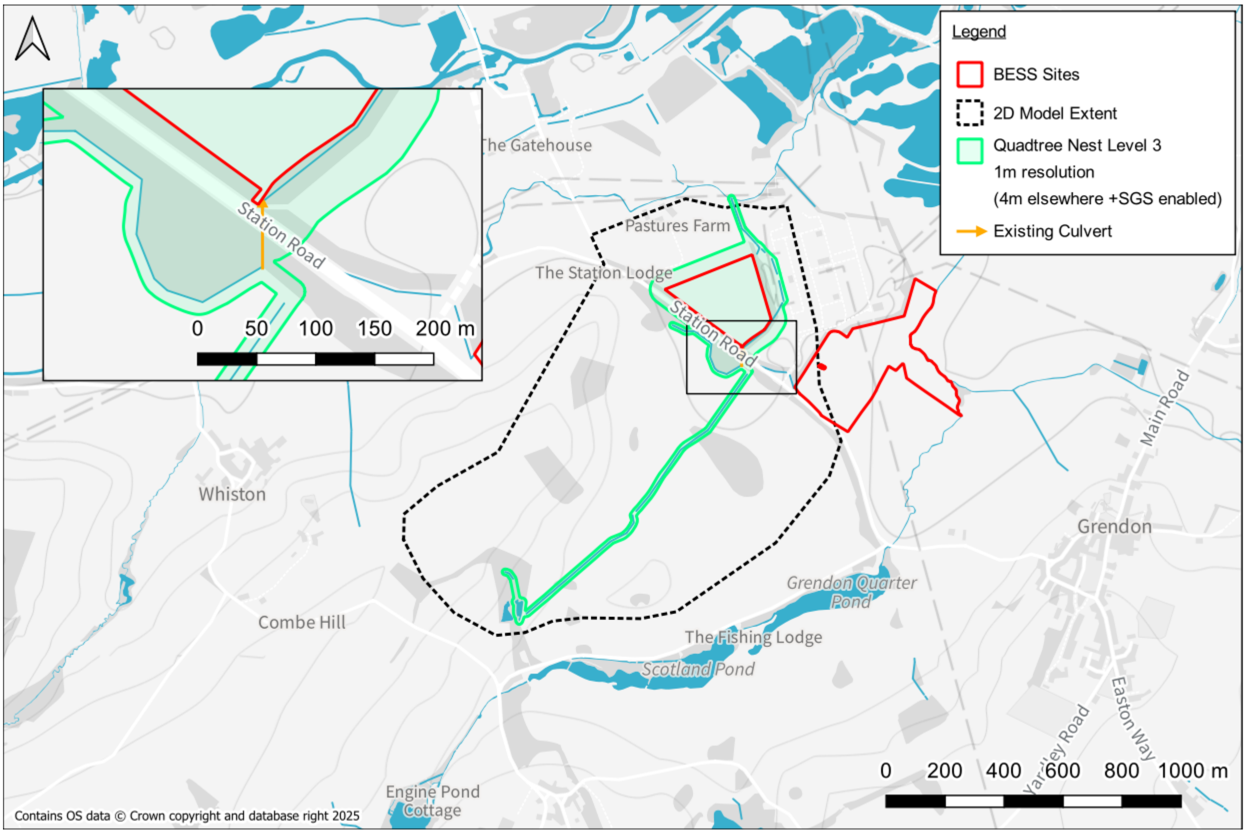

Figure 4: Arthian Field Drain model coverage

2. 2013 Nene Flood Map Improvements Project – Middle Nene Model

2.1 Model Setup and Updates

Table 1: Middle Nene – Model details, methodology, and parameters

Arthian Model Reference and Version:	313532_Middle_Nene_v3
Simulation Type:	Fluvial
Model Type:	1D
Software Builds:	Flood Modeller 7.3.1 *(latest build available at the time of simulation)*
Model Extent:	The extent of the EA Middle Nene model is shown in Figure 2. The model covers approximately 57km of the River Nene, generally flowing in a northeasterly direction between Billing Marina, Northampton (NGR 481475, 261050) and Wansford (NGR 507500, 299100). The Site lies within an area covered by reservoir unit “ResL4-20Ru”, approximately 5km downstream of the model’s upstream boundary.
Data Sources:	The EA Middle Nene model uses Flood Estimation Handbook (FEH) hydrological inputs, gauged flow and rating data from key Nene catchment stations, legacy channel and structure survey (primarily from the 1980s–1990s), and recent LiDAR for floodplain topography. The age of the in-channel survey is acknowledged, however, given the strategic, predominantly 1D nature of the model, the length and complexity of the river system, and the limited influence that a short reach of updated survey would have on overall model behaviour, commissioning new survey was considered disproportionate in both cost and value. Instead, uncertainty in channel form has been addressed through targeted sensitivity testing of bed levels within the vicinity of the Site, providing an appropriate and proportionate means of considering survey age within the context of this assessment and is discussed further later in this table. Similarly, the existing hydrology data provided with the model setup has been retained and is discussed further later in this table.

Digital Terrain Model (DTM) Data Sources:	Much of the original EA Middle Nene configuration remains unchanged, except in the vicinity of the BESS Site where floodplain elevations have been updated using the latest EA National Light Detection and Ranging (LiDAR) Programme data (1m resolution, dated March 2020). Elevation–area curves for reservoir units L5-019DResLB, L5-019DResRB, spill6333Ld, ResL6-022Rdd, ResL4-20Ru and ResL5-20RRd were recalculated from 1m LiDAR levels. The extents used are available upon request. For floodplain sections ResL4-19RRdd and ResL5-20RRd, Easting and Northing values had been placed in the wrong columns in the original model. These were corrected and a uniform roughness value of n=0.05 applied, informed by Site knowledge, aerial imagery and Chow (1959). All other DTM components remain unchanged from the original EA model.
Cross-Section Spacing:	Cross-sections near the Site are spaced at approximately 100-350m intervals, which is suitable for a river of this size and gentle slope, and for the wide, low-energy floodplain of the Middle Nene. Hydraulic behaviour in this reach is governed mainly by broad-scale channel form and extensive floodplain storage. No additional cross-sections or interpolate units have been added.
Existing Flood Defences:	No flood defences are present within the vicinity of the Site. No changes to EA Middle Nene model setup.
Boundary Conditions:	The hydrology provided with the EA Middle Nene model has been retained. Re-deriving catchment hydrology for a system as extensive and hydraulically complex as the Middle Nene would require substantial redevelopment of the EA's strategic methodology and sits well beyond the reasonable scope of a site-specific FRA for a solar development, particularly given the low vulnerability of the proposed development. The existing EA hydrology remains internally consistent with the structure and assumptions of the model, and its age does not undermine its suitability for assessing a development of this type. To address potential uncertainty in inflows, targeted sensitivity testing has been undertaken to explore the influence of plausible variation in peak flows. This involved two simulations, the first increasing the climate change uplift from the "higher" value for the Nene Management Catchment of +13% to the "upper" value of +36% (net +20%) and the second a net reduction in flows of 20%. The EA Middle Nene model was supplied with inflow hydrographs for four storm durations: 31, 41, 49, and 59 hours. Each duration was tested using the 1% AEP +13%CC event to identify which produced the most conservative hydraulic response. Nodes in the vicinity of the BESS Site recorded the highest peak levels during the 31-hour event, which is consistent with the Site's upstream position. The 31-hour storm duration was therefore taken forward for all subsequent simulations. To obtain an estimate of the 3.3% AEP event (1 in 30) without re-deriving hydrology, the available inflow-frequency values were interpolated on a logarithmic scale. This provides a proportionate and internally consistent means of deriving the functional floodplain event, avoiding the need to undertake a full hydrological review or rely on nearby smaller events (such as the 5% or 4% AEP flows) as proxies. This approach is appropriate for a strategic model of this type and ensures that the 3.3% AEP estimate remains aligned with the structure and assumptions of the underlying EA model.

Roughness Approach and Values:	Manning's n roughness coefficients were reviewed and left unchanged, with sensitivity testing used to assess the effect of plausible variation (±20%). Although the EA provided both summer and winter model setups, the winter configuration lacked a full set of key supporting files such as inflows and simulation setup files, so the summer setup was taken forward as the working model, with sensitivity testing used to consider and quantify any associated uncertainty.
Structures:	No changes to EA Middle Nene model setup
Timestep:	Adaptive timestep = enabled Initial timestep = 2s Minimum timestep = 1s The settings above are in line with the EA Middle Nene model as received and are considered appropriate.
Initial Conditions:	Initial water levels supplied with the EA's Middle Nene model were reviewed and retained, as they remain appropriate for the hydraulic configuration of the system. Minor adjustments were applied at select nodes where required only during sensitivity testing to support initial model stability, and these do not influence the assessment of flood risk or the interpretation of parameter sensitivity.
Non-Default Parameters:	The EA Middle Nene model was supplied with several non-default parameter values. These have been reviewed and are considered suitable for this assessment. Altering these settings could undermine the calibration and stability of the original EA model and would offer no clear benefit to the site-specific FRA. They have therefore been retained as provided. No further changes to parameters were required.
Further Comments:	This hydraulic modelling has been undertaken solely for the proposed BESS compound. Development impact modelling has not been taken forward because the proposed BESS platform does not introduce ground raising, changes to floodplain storage, new structures, or any other features that could meaningfully influence fluvial hydraulics within the River Nene system. As there is no credible mechanism for the development to alter flood levels, a separate development model would not provide additional value and is not required under EA guidance. The wider solar array fields are considered separately within the Flood Risk Assessment and Drainage Strategy Report [APP-097] . The panels are positioned to minimise their exposure to flood risk, and the support posts represent a negligible and spatially dispersed footprint that does not materially affect conveyance or floodplain storage. These very small-scale elements cannot be meaningfully represented within the EA's 1D strategic hydraulic model and are more appropriately assessed using EA Flood Zone mapping and planning-level analysis rather than detailed hydraulic simulation as discussed in the relevant FRA reports.

2.2 Simulated Flood Events and Scenarios

2.2.1 The model was used to simulate three present-day flood events: 3.3%, 1%, and 0.1% AEP. Each event was also simulated with a 13% climate change uplift (2080s higher) applied in accordance with EA guidance at the time of modelling. The 2080s upper allowance has also been modelled to provide an understanding of residual risk and to provide additional confidence in both the assessment of fluvial flood risk and the BESS design.

2.2.2 Only the baseline scenario was modelled, as the proposed development does not involve significant changes to topography, land use, or drainage characteristics that would affect the modelled flood response. As such, the development is not expected to materially alter flood risk within the domain.

2.3 Model Assumptions and Limitations

2.3.1 The hydraulic model has been developed using industry-standard methods in accordance with current EA guidance. Nevertheless, all models are simplifications of real-world systems, and several assumptions and limitations apply.

Model Resolution and Cross-section Spacing: The model is a 1D-only representation of the Middle Nene and relies on cross-sections spaced at typical intervals of approximately 100-350m in the vicinity of the Site. This spacing is appropriate for a low-gradient, broad-floodplain river system where hydraulic behaviour is governed by large-scale channel form and extensive floodplain storage. A 1D model of this nature does not resolve small-scale features such as field drains, minor bunds, or local platform changes, but this does not materially affect assessment of fluvial risk from the Middle Nene.

Survey Data Age: Much of the channel survey within the EA Middle Nene model originates from work completed between the late 1980s and early 2000s. Any unrecorded modification to channel form or structures since that time will not be reflected. This is a common and expected limitation in strategic EA models covering long river systems. For the purposes of a site-specific FRA for a solar NSIP, this level of accuracy is proportionate, and channel-form uncertainty has been considered through targeted sensitivity testing.

Calibration Limits: The model is part of the EA's wider strategic modelling suite for the Nene catchment. While it is not specifically calibrated at the Site location, the model structure, hydrology and boundary conditions are consistent with EA practice for large catchments with extensive floodplain storage. Flood levels near the Site should therefore be interpreted in the context of the model's strategic purpose and inherent uncertainties.

Hydrological Inputs: The hydrology provided with the EA Middle Nene model has been retained. Re-deriving catchment hydrology for a system of this scale and complexity would require major redevelopment of the EA's strategic analysis and is outside the reasonable scope for a solar NSIP FRA. The retained EA hydrology remains internally consistent with the model, and uncertainty has been explored through inflow sensitivity testing. The EA supplied both summer and winter model setups, but the winter configuration lacked supporting inflow files; the summer setup was therefore adopted as the working version.

Downstream Boundary: Boundary conditions within the model follow the EA's original specification, representing appropriate hydraulic controls for this reach of the Middle Nene. These have been retained as provided, and sensitivity testing has been undertaken where relevant to ensure the conclusions of the FRA remain robust to reasonable variation.

2.4 Model Health and Verification

2.4.1 A review of the 1D log files shows that whilst there are comments and warnings generated during the model initialisation process, all are pre-existing, and many are located a significant distance from the Site. There are no comments, warnings, or errors warranting attention.

2.4.2 Mass balance error statistics show the 1D mass balance error (of peak system volume) peaks at -1.19% for all simulations including sensitivity tests, which is considered acceptable, particularly given the complexity of the model.

2.4.3 All simulations report several timesteps with poor convergence. This is consistent with the behaviour noted in the 2013 EA report, which described the model as running "satisfactorily with limited non-convergence". The model remains stable in the vicinity of the Site, and the assessment of fluvial flood risk is unaffected by these isolated convergence issues.

2.4.4 Comparison of the modelled 1% AEP +13%CC flood extent with the EA recorded flood outlines dataset shows very good agreement, providing confidence in the model outputs. The comparison is presented in Figure 5.

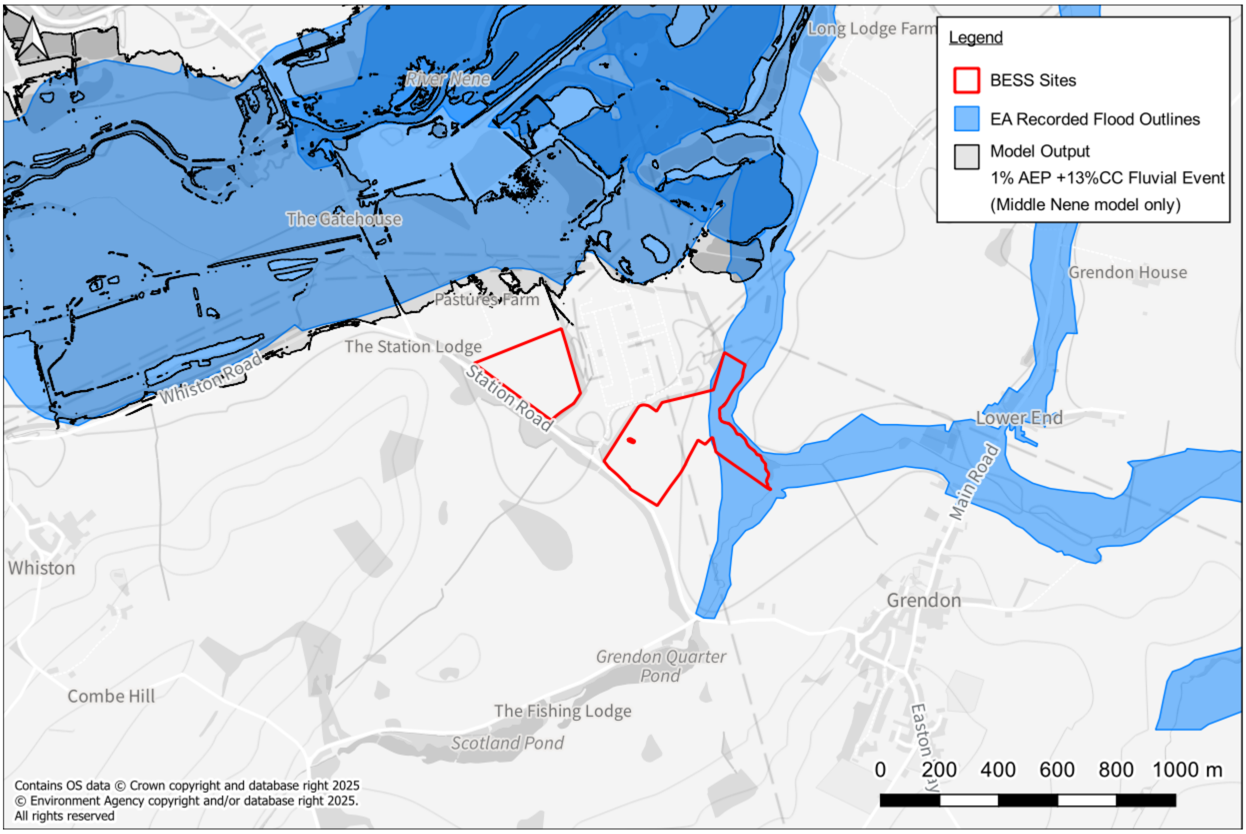

Figure 5: Comparison of modelled 1% AEP +13%CC flood extent and EA recorded flood outlines

2.5 Results Summary

2.5.1 Model results show the Site to remain flood free during all simulated events along the River Nene. Maximum flood depths during the 1% AEP +13%CC and 0.1% AEP +13%CC events are presented in Figure 6 and Figure 7 respectively.

2.5.2 The modelled flood extents are locally smaller than those shown in the EA Flood Zone mapping. Given the 1D nature of the modelling and the minor adjustments made relative to the overall model scale, these differences are likely to reflect localised interpolation effects, generalisation within the Flood Zone mapping, or subtle changes in topography between datasets rather than any systematic under-prediction. The updated model is based on the EA's original configuration and has been tested through a comprehensive sensitivity programme, which showed no undue sensitivity or instability. The results are therefore considered robust for the purpose of assessing flood risk to the Site.

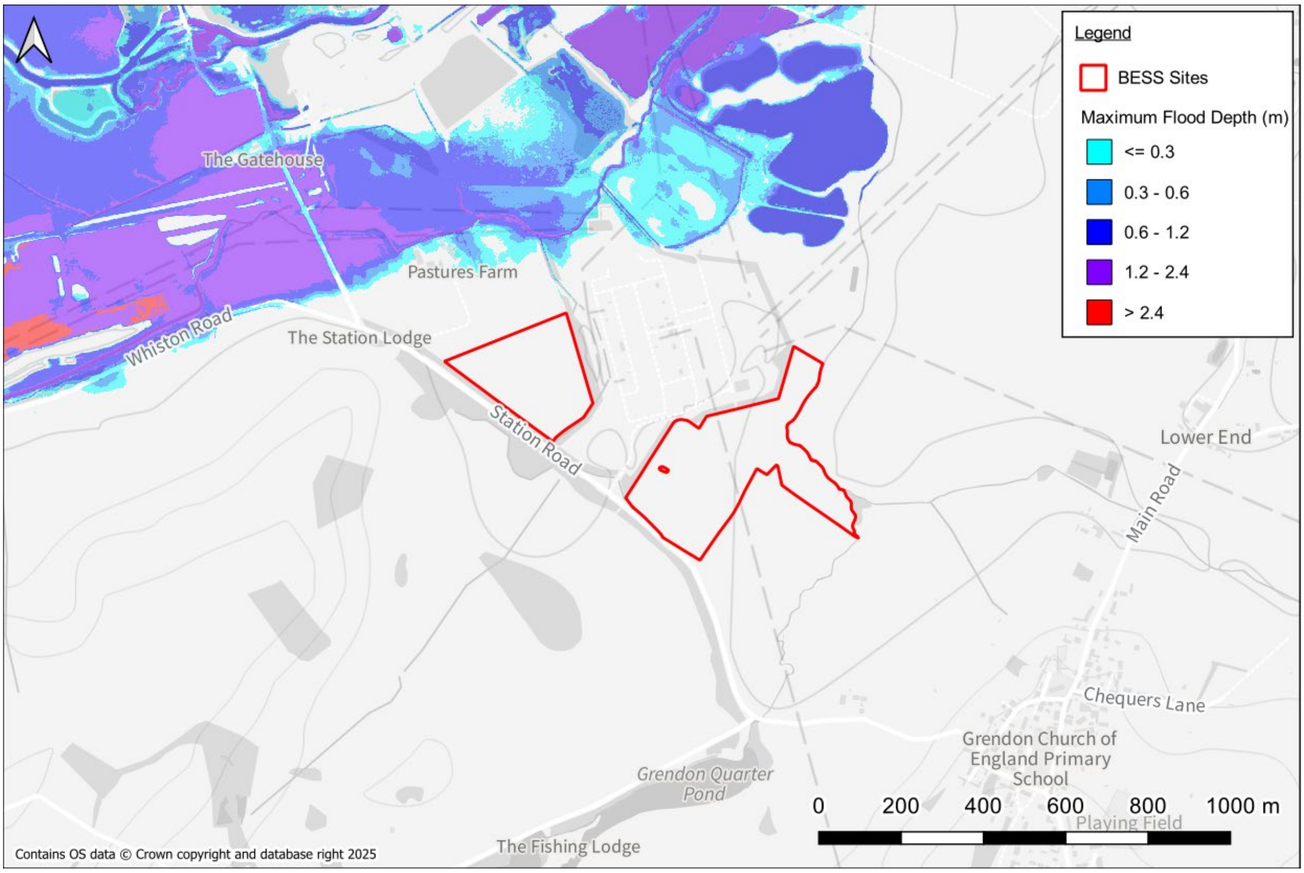

Figure 6: Maximum flood depths, 1% AEP +13%CC fluvial event, baseline site layout

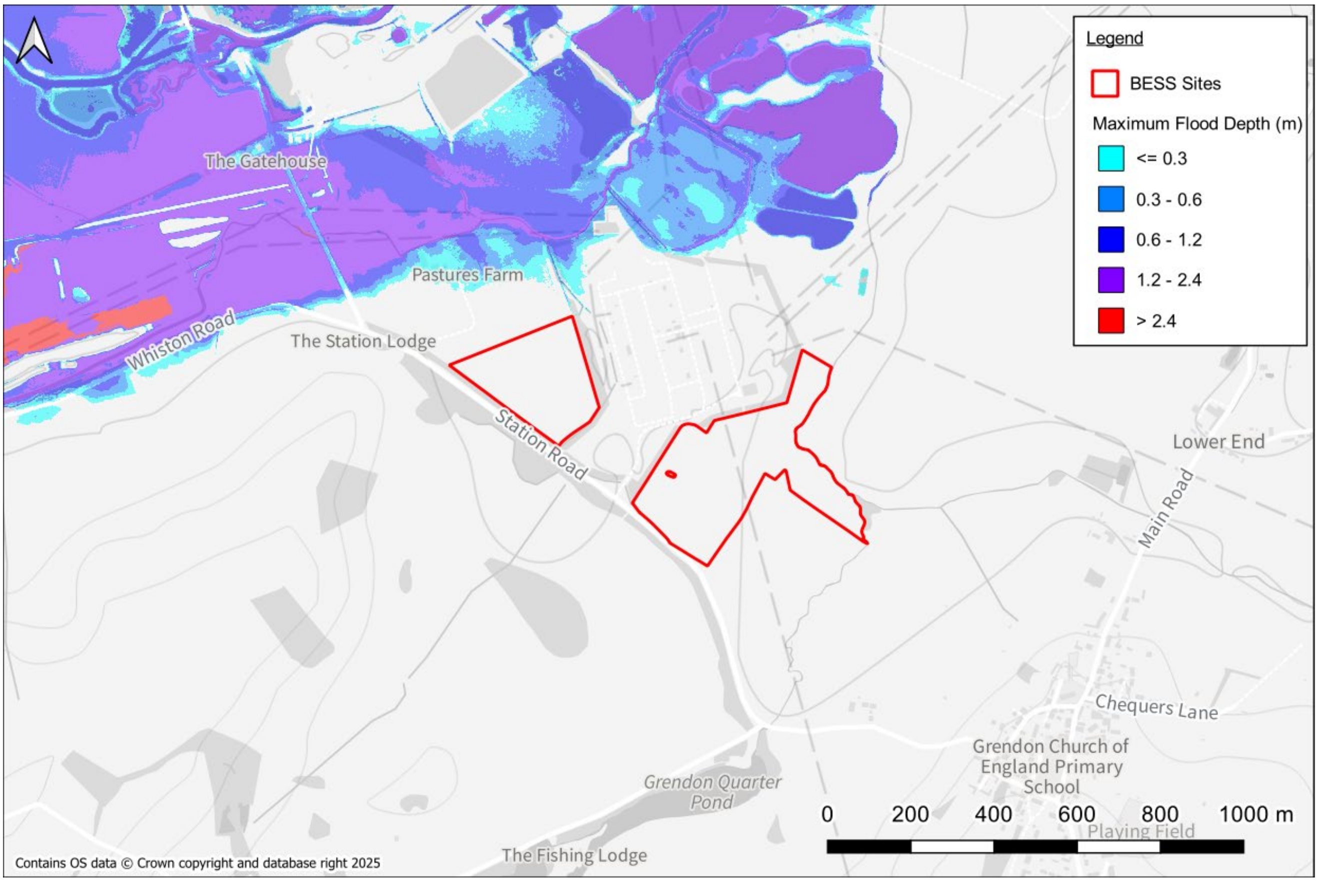

Figure 7: Maximum flood depths, 0.1% AEP +13%CC fluvial event, baseline site layout

2.6 Sensitivity Testing

2.6.1 Sensitivity testing (ST) was undertaken on key model parameters to assess the robustness of results. The following variations were applied to the 1% AEP +13%CC simulation:

- ST1 and ST2 – Roughness (global): ±20%
- ST3 and ST4 – Flows: uplift set to +36% in line with EA "upper" climate change allowance, and a reduction of 20%
- ST5 and ST6 – Channel bed levels: ±200mm upstream of the Site (between nodes a6597 and a6360u in line with the EA comments)

2.6.2 The downstream boundary condition would ordinarily be subject to sensitivity testing, however, its location more than 50km downstream of the Site, combined with a bed-level fall of over 30m along the reach between nodes adjacent to the Site and the downstream extent of the model means that the boundary condition has no realistic hydraulic influence on water levels at the Site. Any variation at the downstream limit would therefore have a negligible effect on the assessment of fluvial flood risk to the BESS location and sensitivity testing is not required.

2.6.3 The model shows limited sensitivity to changes in roughness. Variations in peak water levels within approximately 1.5km of the Site remain within ±125mm, and changes in local flood extent are minimal. This level of sensitivity is consistent with expectations for a large, low-gradient river system.

2.6.4 Adjusting inflows to reflect the EA's upper climate change allowance, and a corresponding reduction test, results in changes in peak water levels within ±115mm in the vicinity of the Site. These differences are modest and do not indicate any change in the overall pattern of flooding.

2.6.5 A ±200mm adjustment to channel bed levels upstream of the Site produces only minor changes in predicted water levels at the BESS location, remaining within ±60mm. This indicates that reasonable uncertainty in bed levels does not materially influence the assessment.

2.6.6 The model is therefore considered to respond in a manner that is proportionate and consistent with expectations for a strategic 1D representation of the River Nene. The conclusions drawn regarding fluvial flood risk to the proposed BESS Site remain robust to reasonable variation in key parameters.

3. 2013 Nene Flood Map Improvements Project – Grendon Brook Model

3.1 Model Setup and Updates

Table 2: Grendon Brook – Model details, methodology, and parameters

Arthian Model Reference and Version:	313532_Grendon_Brook_v6
Simulation Type:	Fluvial
Model Type:	1D
Software Builds:	Flood Modeller 7.3.1 *(latest build available at the time of simulation)*
Model Extent:	The extent of the EA Grendon Brook model is shown in Figure 3. The EA Grendon Brook model represents Grendon Brook and its Main River tributaries, including the Gibbards, Castle Ashby, Yardley Hastings, Easton Maudit and Bozeat branches. These watercourses drain a rural catchment of approximately 48.4km^2, flowing northwards to join the River Nene near Great Doddington (NGR 489900, 264400).
Data Sources:	The EA Grendon Brook model uses FEH hydrological inputs, gauged flow and rating data relevant to the Nene catchment, legacy channel and structure survey (primarily from the late 1980s–1990s), and EA LiDAR data to define floodplain levels. The age of the in-channel survey is acknowledged, however, given the strategic, predominantly 1D nature of the model, the length and complexity of the river system, and the limited influence that a short reach of updated survey would have on overall model behaviour, commissioning new survey was considered disproportionate in both cost and value. Instead, uncertainty in channel form has been addressed through targeted sensitivity testing of bed levels within the vicinity of the Site, providing an appropriate and proportionate means of considering survey age within the context of this assessment and is discussed further later in this table. Similarly, the existing hydrology data provided with the model setup has been retained and is discussed further later in this table.

Digital Terrain Model (DTM) Data Sources:	Much of the original EA Grendon Brook configuration remains unchanged, except in the vicinity of the BESS Site where floodplain elevations have been updated using the latest EA National LiDAR Programme data (1m resolution, dated March 2020). Elevation–area curves for reservoir units CA1330, CA1330lspd, CA772drspd, GB5168dlspd, CA772dlspd, GB5168drspd, and GB3097drspd were recalculated from 1m LiDAR levels. The extents used are available upon request. Reservoirs "GB3807lspd", "Pas_Farm", and "Gren_Lakes" added for improved representation of flowpaths throughout the area. Floodplain cross-sections connected to all reservoir units listed updated based on underlying LiDAR levels. All other DTM components remain unchanged from the original EA model.
Cross-Section Spacing:	Cross-sections within the Grendon Brook model are typically spaced at approximately 150m intervals in the vicinity of the Site, with interpolate units included to increase model resolution. This density is appropriate for a narrow tributary catchment where floodplain widths are limited and hydraulic behaviour is governed primarily by channel form, structures, and tributary synchronisation.
Existing Flood Defences:	No formal flood defences are present within the vicinity of the Site. No changes to EA Grendon Brook model setup.
Boundary Conditions:	The hydrology provided with the EA Grendon Brook model has been retained. Re-deriving catchment hydrology for a system as extensive and hydraulically complex as Grendon Brook would require substantial redevelopment of the EA's strategic methodology and sits well beyond the reasonable scope of a site-specific FRA for a solar development, particularly given the low vulnerability of the proposed development. The existing EA hydrology remains internally consistent with the structure and assumptions of the model, and its age does not undermine its suitability for assessing a development of this type. To address potential uncertainty in inflows, targeted sensitivity testing has been undertaken to explore the influence of plausible variation in peak flows. This involved two simulations, the first increasing the climate change uplift from the "higher" value for the Nene Management Catchment of +13% to the "upper" value of +36% (net +20%) and the second a net reduction in flows of 20%. The model was supplied with inflow hydrographs for four storm durations: 7, 9, 12 and 15 hours. Each duration was tested using the 1% AEP +13%CC event to establish which produced the more conservative hydraulic response. Nodes in the vicinity of the BESS Site recorded the highest peak levels during the 9-hour event, indicating that this duration generated the most critical local flood conditions. The 9-hour storm duration was therefore adopted for all subsequent simulations. To obtain an estimate of the 3.3% AEP event (1 in 30) without re-deriving hydrology, the available inflow-frequency values were interpolated on a logarithmic scale. This provides a proportionate and internally consistent means of deriving the functional floodplain event, avoiding the need to undertake a full hydrological review or rely on nearby smaller events (such as the 5% or 4% AEP flows) as proxies. This approach is appropriate for a strategic model of this type and ensures that the 3.3% AEP estimate remains aligned with the structure and assumptions of the underlying EA model.

Roughness Approach and Values:	The EA Grendon Brook model was supplied with both summer and winter configurations, with the summer setup incorporating increased roughness to represent seasonal weed growth. Initial testing of both profiles, together with a review of storm duration, was undertaken to identify the most precautionary representation of flood behaviour. The configuration producing the highest water levels was adopted as the baseline for all subsequent simulations. Further detail is provided in the boundary conditions section of this table. Manning's n roughness coefficients within both the summer and winter networks were reviewed and left unchanged, with sensitivity testing used to assess the effect of plausible variation (±20%).
Structures:	No changes to EA Grendon Brook model setup
Timestep:	Timestep = 1s The settings above are in line with the EA Grendon Brook model as received and are considered appropriate.
Initial Conditions:	Initial water levels supplied with the EA's Grendon Brook model were reviewed and retained, as they remain appropriate for the hydraulic configuration of the system. Minor adjustments were applied only during sensitivity testing to support model stability, and these do not influence the assessment of flood risk or the interpretation of parameter sensitivity.
Non-Default Parameters:	The EA Grendon Brook model was supplied with several non-default parameter values. These have been reviewed and are considered suitable for this assessment. Altering these settings could undermine the calibration and stability of the original EA model, and would offer no clear benefit to a site-specific FRA. They have therefore been retained as provided. No further changes to parameters were required.
Further Comments:	This hydraulic modelling has been undertaken solely for the proposed BESS compound. Development impact modelling has not been taken forward because the proposed BESS platform does not introduce ground raising, changes to floodplain storage, new structures, or any other features that could meaningfully influence fluvial hydraulics within the Grendon Brook system. As there is no credible mechanism for the development to alter flood levels, a separate development model would not provide additional value and is not required under EA guidance. The wider solar array fields are considered separately within the Flood Risk Assessment and Drainage Strategy Report [APP-097]. The panels are positioned to minimise their exposure to flood risk, and the support posts represent a negligible and spatially dispersed footprint that does not materially affect conveyance or floodplain storage. These very small-scale elements cannot be meaningfully represented within the EA's 1D strategic hydraulic model and are more appropriately assessed using EA Flood Zone mapping and planning-level analysis rather than detailed hydraulic simulation as discussed in the relevant FRA reports.

3.2 Simulated Flood Events and Scenarios

3.2.1 The model was used to simulate three present-day flood events: 3.3%, 1%, and 0.1% AEP. Each event was also simulated with a 13% climate change uplift (2080s higher) applied in accordance with EA guidance at the time of modelling. The 2080s upper allowance has also been modelled to provide an understanding of residual risk and to provide additional confidence in both the assessment of fluvial flood risk and the BESS design.

3.2.2 Only the baseline scenario was modelled, as the proposed development does not involve significant changes to topography, land use, or drainage characteristics that would affect the modelled flood response. As such, the development is not expected to materially alter flood risk within the domain.

3.3 Model Assumptions and Limitations

3.3.1 The hydraulic model has been developed using industry-standard methods in accordance with current EA guidance. Nevertheless, all models are simplifications of real-world systems, and several assumptions and limitations apply.

Model Resolution and Cross-section Spacing: The model is a 1D-only representation of the Middle Nene and relies on cross-sections spaced at typical intervals of approximately 150m in the vicinity of the Site. This spacing is considered appropriate for a narrow tributary catchment where floodplain widths are limited and hydraulic behaviour is governed primarily by channel form, structures, and tributary synchronisation. A 1D model of this nature does not resolve small-scale features such as field drains, minor bunds, or local platform changes, but this does not materially affect assessment of fluvial risk from Grendon Brook.

Survey Data Age: Much of the channel survey within the EA Grendon Brook model originates from work completed between the late 1980s and early 2000s. Any unrecorded modification to channel form or structures since that time will not be reflected. This is a common and expected limitation in strategic EA models covering complex river systems. For the purposes of a site-specific FRA for a solar NSIP, this level of accuracy is proportionate, and channel-form uncertainty has been considered through targeted sensitivity testing.

Calibration Limits: The model is part of the EA's wider strategic modelling suite for the Nene catchment. While it is not specifically calibrated at the Site location, the model structure, hydrology and boundary conditions are consistent with EA practice for large catchments with extensive floodplain storage. Flood levels near the Site should therefore be interpreted in the context of the model's strategic purpose and inherent uncertainties.

Hydrological inputs: The hydrology provided with the EA Grendon Brook model has been retained. Re-deriving catchment hydrology for a system of this scale and complexity would require major redevelopment of the EA's strategic analysis and is outside the reasonable scope for a solar NSIP FRA. The retained EA hydrology remains internally consistent with the model, and uncertainty has been explored through inflow sensitivity testing and testing of the summer and winter profiles and storm durations.

Downstream Boundary: The downstream boundary is a fixed level–time condition inherited directly from the EA's Grendon Brook strategic model, representing a conservative assumption about water levels at the confluence with the River Nene. As Grendon Brook is hydraulically subordinate to the Nene, and because the EA boundary is designed to avoid under-estimating backwater influence, the condition is considered appropriate and has been retained. Adjusting it without re-deriving the linked Nene hydrodynamics would introduce unnecessary inconsistency.

3.4 Model Health and Verification

3.4.1 A review of the 1D log files shows that whilst there are comments and warnings generated during the model initialisation process, all are pre-existing, and many are located a significant distance from the Site. There are no comments, warnings, or errors warranting attention.

3.4.2 Mass balance error statistics show the 1D mass balance error (of peak system volume) peaks at +0.08% for all simulations including sensitivity tests, which is considered acceptable, particularly given the complexity of the model.

3.4.3 All simulations report several timesteps with poor convergence. This is consistent with the behaviour noted in the 2013 EA report, which described the model as running "satisfactorily with limited non-convergence". The model remains stable in the vicinity of the Site, and the assessment of fluvial flood risk is unaffected by these isolated convergence issues.

3.4.4 Comparison of the modelled 1% AEP +13%CC flood extent with the EA recorded flood outlines dataset shows very good agreement, providing confidence in the model outputs. The comparison is presented in Figure 8.

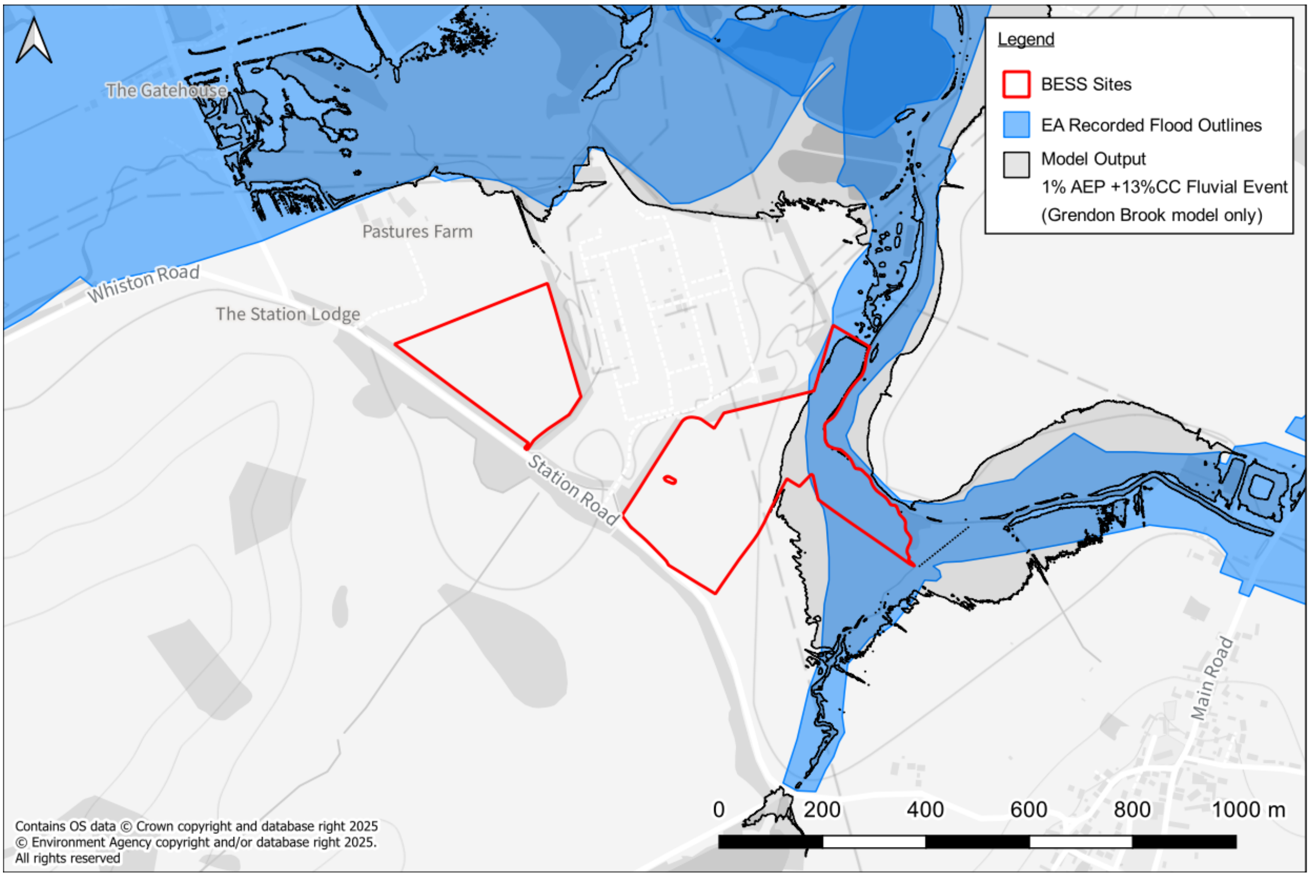

Figure 8: Comparison of modelled 1% AEP +13%CC flood extent and EA recorded flood outlines

3.5 Results Summary

3.5.1 Model results show much of the Site to remain flood free during all simulated events along Grendon Brook. Lower lying portions of the Site directly adjacent to Grendon Brook experience flood depths of up to 1.4m during a 1% AEP +13%CC fluvial event. Whilst depths in this area increase with event severity, local site levels mean flood extents remain similar. Maximum flood depths during the 1% AEP +13%CC and 0.1% AEP +13%CC events are presented in Figure 9 and Figure 10 respectively.

3.5.2 The modelled flood extents are locally smaller than those shown in the EA Flood Zone mapping. Given the 1D nature of the modelling and the minor adjustments made relative to the overall model scale, these differences are likely to reflect localised interpolation effects, generalisation within the Flood Zone mapping, or subtle changes in topography between datasets rather than any systematic under-prediction. The updated model is based on the EA's original configuration and has been tested through a comprehensive sensitivity programme, which showed no undue sensitivity or instability. The results are therefore considered robust for the purpose of assessing flood risk to the Site.

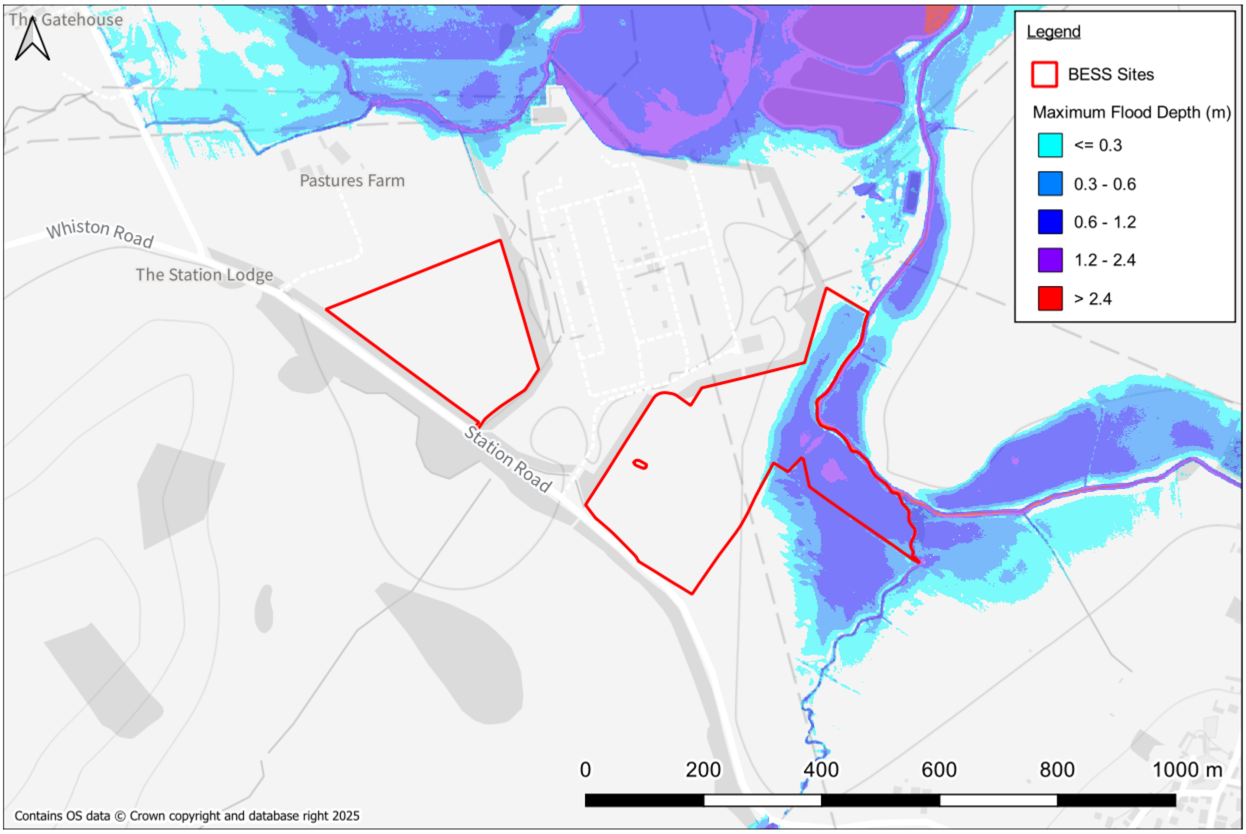

Figure 9: Maximum flood depths, 1% AEP +13%CC fluvial event, baseline site layout

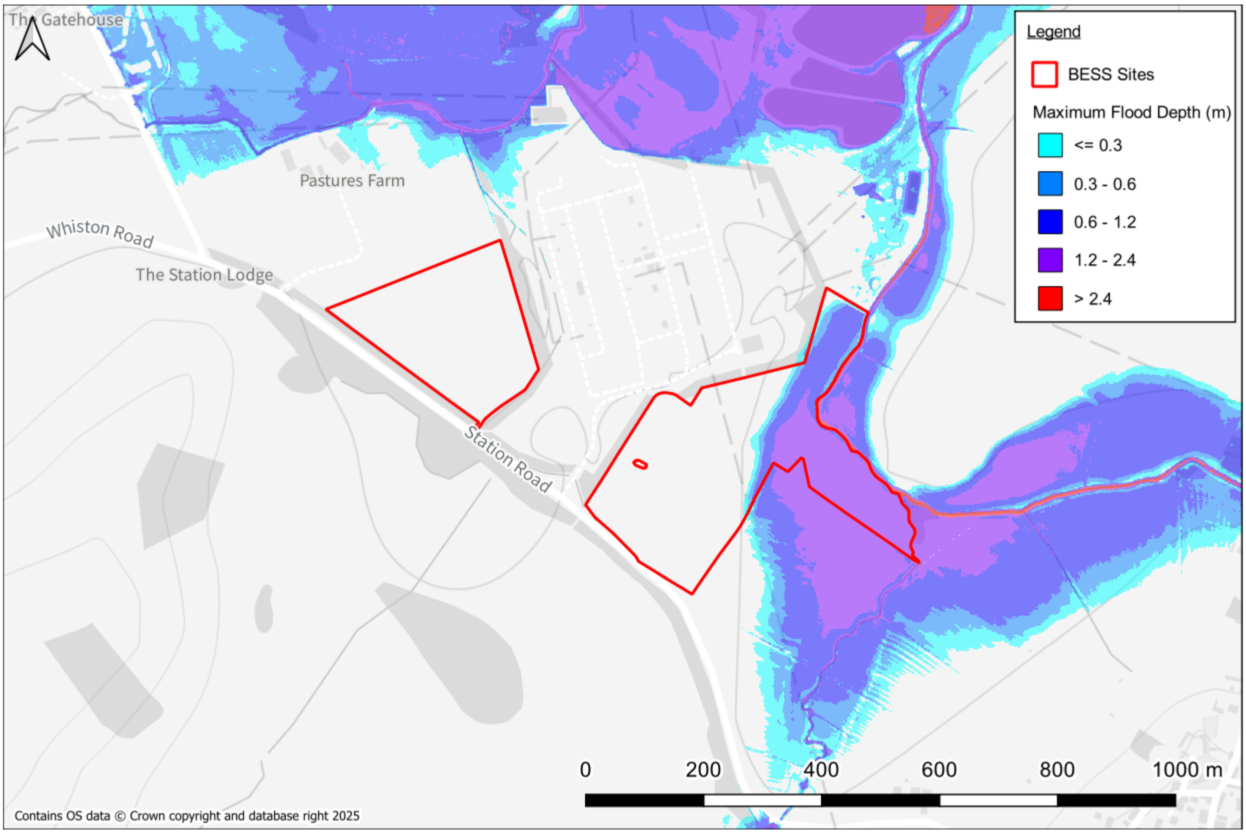

Figure 10: Maximum flood depths, 0.1% AEP +13%CC fluvial event, baseline site layout

3.6 Sensitivity Testing

3.6.1 Sensitivity testing (ST) was undertaken on key model parameters to assess the robustness of results. The following variations were applied to the 1% AEP +13%CC simulation:

- ST1 and ST2 – Roughness (global): ±20%
- ST3 and ST4 – Flows: uplift set to +36% in line with EA "upper" climate change allowance, and a reduction of 20%
- ST5 and ST6 – Downstream boundary level: ±200mm
- ST7 and ST8 – Channel bed levels: ±100mm throughout the model *

** A global bed level adjustment of ±200mm was tested but significant stability issues were encountered, particularly relating to initial conditions and around structures.*

3.6.2 The model shows limited sensitivity to changes in roughness. Variations in peak water levels within approximately 1.5km of the Site remain within ±125mm, and changes in local flood extent are minimal. This level of sensitivity is consistent with expectations for a large, low-gradient river system.

3.6.3 Adjusting inflows to reflect the EA's upper climate change allowance, and a corresponding reduction test, results in changes in peak water levels within ±115mm in the vicinity of the Site. These differences are modest and do not indicate any change in the overall pattern of flooding.

3.6.4 Adjusting the fixed water level at the downstream end of the model produces a measurable backwater effect extending approximately 3km upstream. As the BESS Site lies around 3.9 km from the confluence, flood levels at the Site are unaffected by the boundary adjustment. The downstream boundary has therefore been retained as provided in the EA model, as it represents a conservative assumption with negligible influence on the assessment of flood risk.

3.6.5 A ±100mm adjustment to channel bed levels upstream of the Site produces only minor changes in predicted water levels at the BESS location, remaining within ±60mm. This indicates that reasonable uncertainty in bed levels does not materially influence the assessment.

3.6.6 The model is therefore considered to respond in a manner that is proportionate and consistent with expectations for a strategic 1D representation of Grendon Brook. The conclusions drawn regarding fluvial flood risk to the proposed BESS Site remain robust to reasonable variation in key parameters.

4. 2025 Arthian Field Drain Model

4.1 Model Setup

Table 3: Field Drain – Model details, methodology, and parameters

Arthian Model Reference and Version:	313532_Field_Drain_v2
Simulation Type:	Direct rainfall (small watercourses)
Model Type:	2D
Software Builds:	TUFLOW 2025.2.2 *(latest build available at the time of simulation)*
Model Extent:	The model extent is shown in Figure 4.
Digital Terrain Model (DTM) Data Sources:	The latest EA National LiDAR Programme data available at the time of model construction was used to define elevations throughout the domain. No topographic survey or channel survey was available. Given the scale of the catchment, the size of the channel, and initial model outputs, commissioning new survey was considered disproportionate in both cost and value.
Cell Size:	TUFLOW Quadtree has been uses to allow varied resolution across the model, with a base cell size of 4m, reducing down to 1m along channels and across the proposed BESS Site. Sub-grid sampling has been used to ensure that any minor features/dips within the wider floodplain are appropriately represented by the 4m grid without impacting simulation run times.
Building Representation:	OS MasterMap data used to define land use throughout the model, including buildings. High roughness applied to all buildings to represent internal walls and contents – 0.5s/m$^{1/3}$.
Existing Flood Defences:	No formal flood defences are present within the vicinity of the Site.
Roughness Approach and Values:	Manning's n based on Chow (1959), survey, photographs, and aerial imagery. Land use based on OS MasterMap data. <u>Land Use Type</u> <u>Roughness (s/m$^{1/3}$)</u> General surface .... 0.030 Industrial land............................... 0.030 Land/gardens .... 0.060 Rough ground/scrub .... 0.080 Roads, tracks, and paths................ 0.020 Buildings .... 0.500 Inland waters 0.030

Boundary Conditions:	Rainfall inputs were derived using ReFH2, with catchment descriptors obtained directly from the FEH Web Service, reviewed, and applied without alteration. The ReFH2 hyetographs provide a consistent and defensible basis for representing design rainfall across a small, responsive catchment, in line with current EA guidance. As part of the model proving process, sensitivity testing has been undertaken on the ReFH2 hyetographs to examine the influence of reasonable variation in storm profiles. The results of this testing are presented later in the report. The catchment descriptors are provided electronically along with the model files. A fixed-level downstream boundary has been applied to the channel and adjacent floodplain, set to 45.83m AOD based on the peak water level at reservoir node ResL4-20Ru in the EA Middle Nene model for the 3.3% AEP +13%CC event. This represents a deliberately conservative assumption given the large difference in catchment scale and expected hydraulic response. Sensitivity testing has been undertaken to ensure that this boundary choice does not affect the robustness of the assessment.
Structures:	A single culvert is present under Station Road, south-west of the proposed BESS Site. Whilst no survey data was available, a Site visit measurement taken using iPhone LiDAR suggested the culvert was approximately 750mm in diameter and lay several hundred millimetres below ground level with significant standing water present. Given the potential for this structure to influence flows from the wider catchment reaching the Site, sensitivity testing on the diameter of the culvert has been undertaken, with the invert remaining consistent. This is discussed later in this section of the report. A photo of the upstream face of the Station Road culvert showing the approximate measurement is presented in Figure 11.
Timestep:	Initial timestep set to 1s. TUFLOW HPC uses an adaptive timestepping process to maintain model stability. The control number factor has been left at the default value of 1.0.
Initial Conditions:	Initial water levels around the downstream boundary were set to match the boundary condition for model stability. The remainder of the domain starts dry.
Non-Default Parameters:	No changes to parameters provided with the existing model setup. To aid with mapping and visualisation of results: • Map Cutoff Depth set to 0.1m • Map Cutoff SGS value set to “Percentile | 25”

Figure 11: Upstream face of the Station Road culvert showing approximate dimensions

4.2 Simulated Flood Events and Scenarios

4.2.1 The model was used to simulate three present-day rainfall events: 3.3%, 1%, and 0.1% AEP. Each event was also simulated with both the 2070s central and upper end climate change uplifts, ranging from +25% to +40% in accordance with EA guidance at the time of modelling. The upper allowance was modelled to provide an understanding of residual risk and to provide additional confidence in both the assessment of fluvial flood risk and the BESS design.

4.2.2 Only the baseline (pre-development) scenario was modelled, as the proposed solar development does not involve significant changes to topography, land use, or drainage characteristics that would affect the modelled flood response. As such, the development is not expected to materially alter flood risk within the model domain.

4.3 Model Assumptions and Limitations

4.3.1 The hydraulic model has been developed using industry-standard methods in accordance with current EA guidance. Nevertheless, all models are simplifications of real-world systems, and several assumptions and limitations apply.

Direct rainfall approach: The model applies a direct-rainfall methodology to represent runoff and overland flow within the small unnamed tributary catchment. Given the limited size of the catchment and the absence of any significant upstream storage or inflow controls, this approach provides a proportionate proxy for assessing fluvial behaviour in a reach that would not be meaningfully resolved in a 1D model.

Topographic data and channel representation: No detailed ground or channel survey was available; the model uses 1 m resolution EA National LiDAR data for terrain representation. Channel depressions have been incorporated implicitly within the LiDAR surface, with local adjustments made where the LiDAR is known to overshoot water levels. This level of representation is appropriate for a small tributary assessment, though it does not capture sub-bank channel geometry in detail.

Culvert representation: The culvert beneath the access track was included based on dimensions measured during a site visit using an iPhone LiDAR scan. These dimensions provide an approximate but reasonable representation of the structure. Sensitivity testing of the culvert diameter (±150 mm) has been undertaken to confirm that uncertainty in the measurement does not materially affect model behaviour.

Calibration and validation: No hydrometric or historical flood data exist for the catchment, and the model has not been calibrated. This is typical for a small ungauged catchment of this nature. Model confidence is instead supported through targeted sensitivity testing of key parameters.

Downstream boundary condition: A fixed-level boundary has been applied at the model outlet, set to the 1 in 30 AEP + CC water level in the River Nene from the EA Middle Nene model. This represents a conservative assumption that captures potential backwater influence from the Nene. Sensitivity testing of ±200 mm has been undertaken to verify that this assumption does not materially influence predicted flood levels in the tributary.

Sensitivity testing: Sensitivity testing has been undertaken on key model parameters to assess robustness. Tests included rainfall rate (±20 %), downstream boundary level (±200 mm), roughness (±20 %), TUFLOW control number factor (±20 %), culvert diameter (±150 mm), sub-grid sampling (off vs on), and channel elevation adjustments to LiDAR level. Results confirm that the model performs in a stable and hydraulically consistent manner under these variations.

Hydrological input consistency: ReFH2 catchment descriptors were taken directly from the FEH Web Service and applied without modification to ensure internal consistency with standard EA datasets. These descriptors have not been locally refined, as such refinement would not materially alter results given the scale of the catchment and the use of sensitivity testing to capture parameter uncertainty.

Event independence: Each design event has been run independently, without consideration of antecedent wetness or storm sequencing. This is consistent with standard practice for design-event assessment but may not capture compound or consecutive storm effects. These effects are outside the reasonable scope of a site-specific FRA for a solar NSIP.

4.4 Model Health and Verification

4.4.1 A review of the 2D log files shows that there are no comments, warnings or errors warranting attention.

4.4.2 Mass balance error statistics show the 2D mass balance error sits close to 0.0% for all simulations including sensitivity tests, as expected for a healthy TUFLOW HPC simulation.

4.4.3 There are no negative depths reported in any simulations.

4.4.4 The EA hold no historic records of flooding along this unnamed tributary therefore it was not possible to perform any comparison with the model outputs. However, results showed good agreement with the NaFRA2 CC surface water flood maps, providing confidence in the model setup. A comparison is presented in Figure 14.

4.5 Results Summary

4.5.1 Model results show very shallow ponding (<120mm) on site during the 1% AEP +25%CC pluvial event. This is a result of the direct rainfall methodology and is not representative of fluvial flooding. Any such ponding would be managed by the associated drainage features. This is presented in Figure 12. Flood depths across the Site during the 0.1% AEP +25%CC pluvial event remain consistent and are presented in Figure 13.

4.5.2 The field drain modelling demonstrates that flood risk to the BESS Site from the field drain can be considered negligible.

4.5.3 Peak flows reported by the model within the field drain were $0.86m^3/s$ and $0.37m^3/s$ upstream and downstream of Station Road, respectively, compared with a ReFH2 peak flow estimate of $0.70m^3/s$. The upstream value aligns reasonably well with the ReFH2 estimate, while the reduction downstream reflects the attenuating influence of the culvert and associated upstream storage.

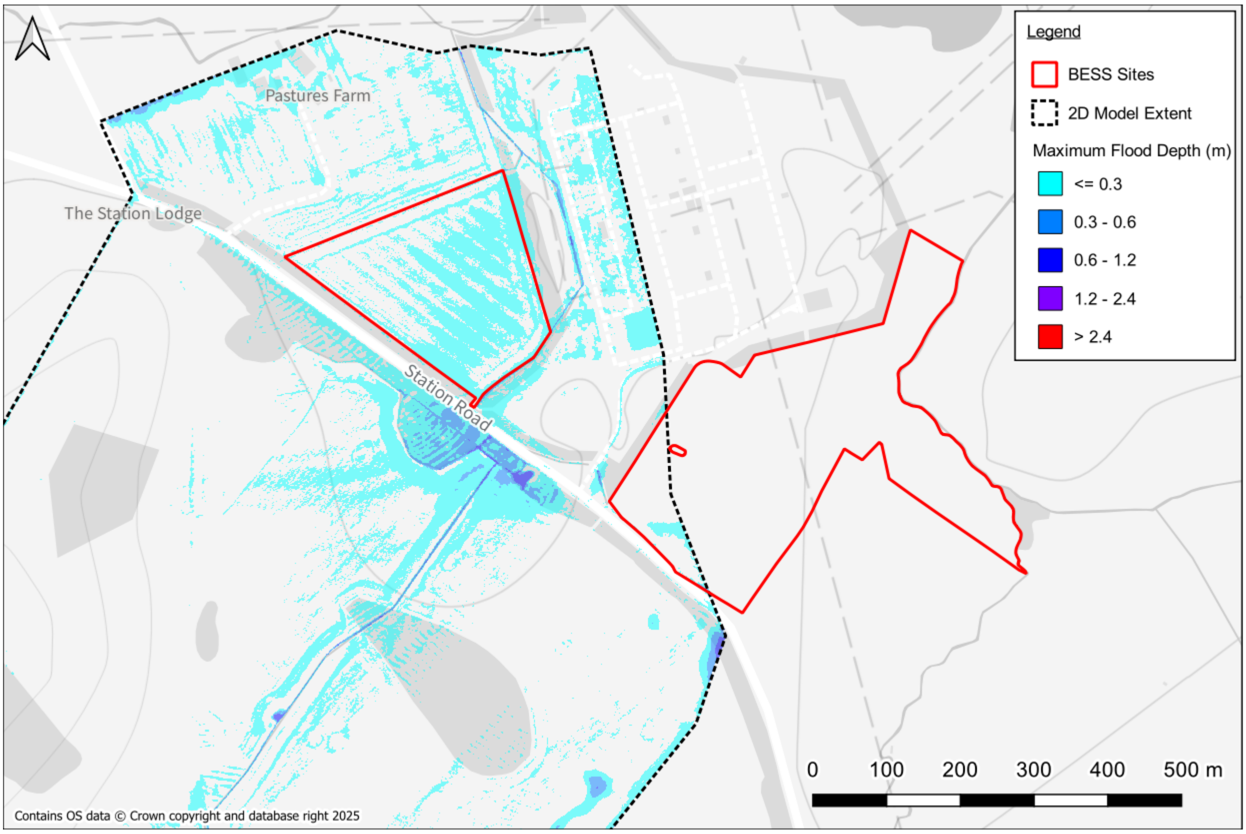

Figure 12: Maximum flood depths, 1% AEP +25%CC pluvial event, baseline site layout

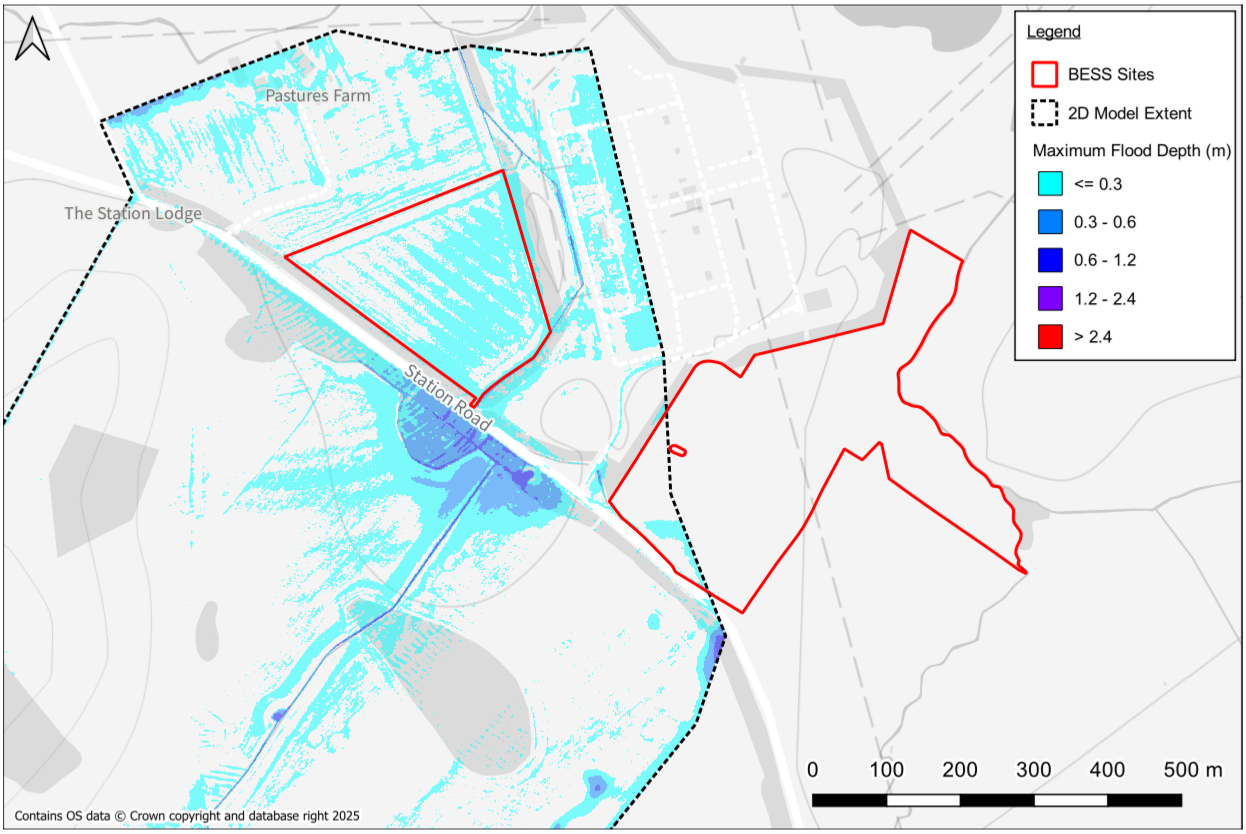

Figure 13: Maximum flood depths, 0.1% AEP +25%CC pluvial event, baseline site layout

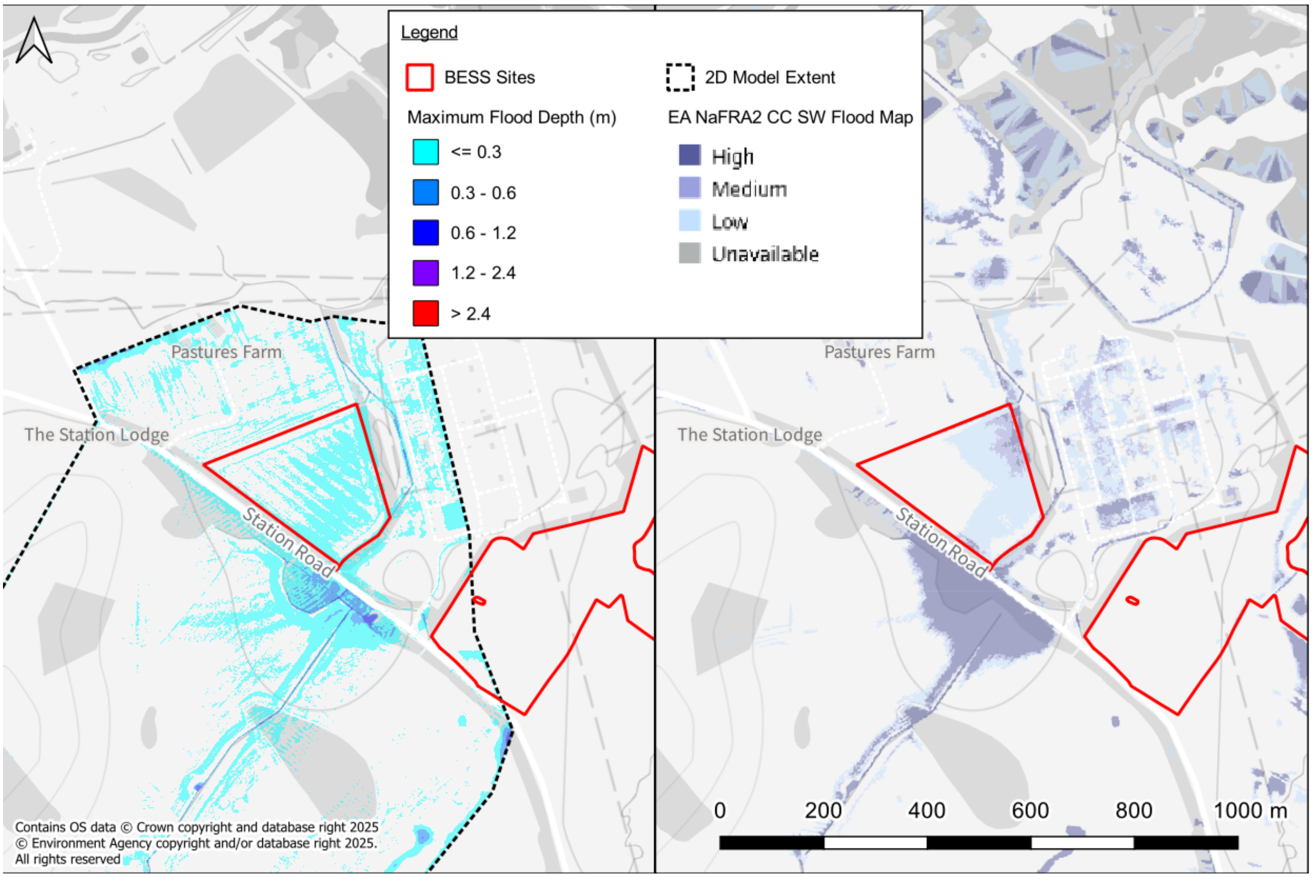

Figure 14: Comparison of Arthian Field Drain model outputs and EA NaFRA2 CC SW Flood Map

4.6 Sensitivity Testing

4.6.1 Extensive sensitivity testing was undertaken on key model parameters to assess the robustness of results. The following variations were applied to the 1% AEP +25%CC simulation:

- ST1 and ST2 – Rainfall rate: ±20%
- ST3 and ST4 – Downstream boundary level ±300mm
- ST5 and ST6 – Roughness (global): ±20%
- ST7 and ST8 – TUFLOW control number factor: ±20%
- ST9 and ST10 – Station Road culvert diameter: ±150mm (invert remains unchanged)
- ST11 – Channel levels extracted directly below spot levels within the LiDAR DTM rather than applying lowest level within radius (i.e. slightly higher)
- ST12 – Sub-grid sampling: OFF

4.6.2 The model outputs were not found to be particularly sensitive to any of the tests, with maximum differences across the BESS Site below ±50mm for all simulations.

5. Combined Assessment of Fluvial Flood Risk

5.1 Data Merging

5.1.1 Maximum flood depths from the three models were compared in GIS to create a merged depth grid showing the worst case from any model for each simulated event to inform the BESS design. Sensitivity test outputs were excluded from this process.

5.1.2 The Arthian Field Drain model used a direct-rainfall approach, meaning its rainfall climate change uplifts did not align directly with the river flow uplifts. To maintain consistency and simplicity when merging datasets, the 2080s higher river-flow uplift (+13%) was paired with the 2070s central rainfall uplift (+25%), and the 2080s upper river-flow uplift (+36%) was paired with the 2070s upper-end rainfall uplift (+35%).

5.1.3 The merged depth grids, along with the individual model depth grids, are included with the model files to allow full review of both the combined and separate results.

6. Conclusions and Recommendations

6.1 Conclusions

6.1.1 Three hydraulic models have been used or developed to inform the assessment of fluvial flood risk to the proposed solar sites:

2013 Nene Flood Map Improvements Project – Middle Nene Model: The existing EA Middle Nene model was partially updated to incorporate new LiDAR (March 2020). The associated hydrology has been retained due to the size and complexity of the River Nene system and supported by sensitivity testing. Model results show the Site remains flood free from the River Nene during all simulated events.

2013 Nene Flood Map Improvements Project – Grendon Brook Model: The existing EA Grendon Brook model was partially updated to incorporate new LiDAR (March 2020). The associated hydrology has been retained due to the size and complexity of the Grendon Brook system and supported by sensitivity testing. Model results show the Site remains mostly flood free from Grendon Brook during all simulated events with lower lying areas directly adjacent to the watercourse experiencing flooding of up to 1.4m during the 1% AEP +13%CC fluvial event.

2025 Arthian Field Drain Model: A direct-rainfall model was developed to assess flood risk from a small, unnamed tributary southwest of the BESS Site. Results confirm that fluvial risk to the Site from this watercourse is negligible.

6.2 Recommendations

6.2.1 The three models described in this report provide an appropriate technical basis for assessing fluvial flood risk to the proposed BESS Site. It is recommended that the outputs from these models are used to inform the Flood Risk Assessment prepared for the scheme.

Appendices

Appendix A – EA Model Review Comments

This appendix sets out the Environment Agency's previous review comments on the initial version of the model together with the corresponding Arthian responses. The comments for each model are reproduced verbatim for transparency and to show how each point was addressed during the latest modelling updates. They do not represent the status of the revised models, which now incorporates all agreed changes.

Middle Nene

The model setup is broadly reasonable and is based on the existing Environment Agency hydraulic model of the River Nene (Halcrow, 2013). There are however some areas for further consideration which have been addressed and summarised below. Further details can be found in the attached model review workbook.

Comment	Review Comment	Arthian Response	Relevant Section References
1	Given the age of the survey used within the hydraulic model (1980's/1990s) it would be sensible to capture some check surveyed channel cross sections in the vicinity of the order limits for the development or alternatively undertake a sensitivity test on channel bed levels, perhaps increasing bed levels between cross sections a6597 and a6360u to help understand the impact that uncertainties in the surveyed channel cross section geometry might have on model results in the area of interest. Of particular concern is the Battery Energy Storage System (BESS) area as this is in an area near the design flood extent.	The Applicant notes the Environment Agency's comments. The age of survey data in the Middle Nene model is acknowledged. As part of the modelling update, the Applicant will consider options such as localised check survey or sensitivity testing of channel bed levels to confirm resilience. Outcomes will be reported in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	2.1 Table 1 2.6 Model sensitivity tests ST5 and ST6.

Comment	Review Comment	Arthian Response	Relevant Section References
2	Please review the design hydrology to confirm that the design event is still representative and is not underestimated or alternatively demonstrate that flood risk to the proposed development, and particularly the Battery Energy Storage System (BESS) is insensitive to changes in flood flows. Please document any checks undertaken on the hydrology within a model report which should form an appendix to the Flood Risk Assessment.	The Applicant notes the Environment Agency's comments. The design hydrology will be reviewed, including sensitivity to flow assumptions, to confirm the representativeness of the design event. Findings will be set out in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	2.1 Table 1 2.6 Model sensitivity tests ST3 and ST4.
3	Please undertake sensitivity testing on channel roughness. For information, the summer sensitivity model geometry file MiddleNene_Section1to6_2012-08 28_summer_XW02.dat may be of use for this assessment	The Applicant notes the Environment Agency's comments. Sensitivity testing on channel roughness will be undertaken and reported in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	2.1 Table 1 2.6 Model sensitivity tests ST1 and ST2.
4	Given the age of the hydraulic model, it would be sensible to verify that it still accurately represents flooding mechanisms for the River Nene in the area of the proposed development. This could be achieved by running a verification event for a more recent flood through the hydraulic model or alternatively demonstrating the sensitivities associated with model schematisation and design flow magnitude in the area interest. For example, if it can be demonstrated that model results in the area of interest are relatively insensitive to changes in flow, channel representation given the age of the survey, and Mannings roughness this could limit the need for further model verification.	The Applicant notes the Environment Agency's comments. The Middle Nene model will be reviewed to confirm it adequately represents local flood mechanisms, with sensitivities or verification against recent flood events considered where appropriate. Results will be presented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	2.1 Table 1 2.6 Model sensitivity tests ST3 and ST4.

Comment	Review Comment	Arthian Response	Relevant Section References
5	Please include a map within the model report/Flood Risk Assessment which compares model results to recorded flood outlines. Recorded flood outlines held by the Environment Agency can be downloaded from the Defra Data Services Platform (environment.data.gov.uk)	The Applicant notes the Environment Agency's comments. Comparison maps of model results with recorded flood outlines will be prepared and included in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	Figure 5
6	Please review the design flood extent in the vicinity of the land designated for the Battery Energy Storage System. The design flood extent is smaller when compared to the Environment Agency's existing 1% (1 in 100) Annual Exceedance Probability extent for the Nene (Halcrow, 2013). Whilst this does not necessarily indicate that the model schematisation is incorrect it does warrant a check to establish why these differences might be occurring, particularly given the sensitivities associated with the BESS.	The Applicant notes the Environment Agency's comments. Differences in design flood extent for the Battery Energy Storage System area compared to the existing Environment Agency model of the Nene will be reviewed, with outcomes documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	2.4.4 2.5.2

Comment	Review Comment	Arthian Response	Relevant Section References
7	Please produce a hydraulic model report for this model build. This should be included as an appendix to the Flood Risk Assessment and should include the following information: 1. Details on the source information used to construct the model geometry 2. Details regarding the model hydrology and any checks that have been undertaken on this to confirm its suitability to assess present day baseline flood risk 3. Details regarding whether any calibration or verification of the model results have been undertaken 4. Details on any sensitivity tests undertaken. 5. Details on associated uncertainties and limitations 6. The rationale for not undertaking "with development" modelling	The Applicant notes the Environment Agency's request. A Hydraulic Modelling Report will be produced for the Middle Nene model build and appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]** covering geometry, hydrology, calibration or verification, sensitivity testing, uncertainties, and the rationale for not undertaking with-development modelling.	This document

Grendon Brook

The model setup is broadly reasonable and is based on the existing Environment Agency hydraulic model of the Grendon Brook (Halcrow, 2013). There are however some areas for further consideration which are summarised below.

Comment	Review Comment	Arthian Response	Relevant Section References
1	Given the age of the survey used within the hydraulic model (2008) it would be sensible to capture some check surveyed channel cross sections in the vicinity of the Battery Energy Storage System location or alternatively undertake a sensitivity test on channel bed levels in this area. Alternatively, it might be possible to refer to other sensitivity tests or more conservative annual exceedance probability scenarios (for example the 0.1% plus climate change scenario) to demonstrate that the development remains resilient and will not increase flood risk to third parties given some of the uncertainties associated with the age of the survey used for the channel. Please see comment 3.3 within worksheet 1D_Model_Build within the attached spreadsheet.	The Applicant notes the Environment Agency's comments regarding the age of survey data in the Grendon Brook model. As part of the modelling update, the Applicant will consider options such as localised check survey, sensitivity testing of channel bed levels, or use of conservative design scenarios to confirm the Scheme's resilience. The agreed approach and outcomes will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.1 Table 2 3.6 Model sensitivity tests ST7 and ST8.

Comment	Review Comment	Arthian Response	Relevant Section References
2	Please review water level results at reservoir unit GB3807lspd. These appear quite low when compared to existing Environment Agency model results. This reservoir unit is important as it is adjacent to the BESS area. The lower water levels could be due to the application of downstream boundary conditions within the model or potentially spill linkages to the reservoir unit itself. Please see comment 4.1 within worksheet 1D_Boundary_Conditions within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Water level results at reservoir unit GB3807lspd will be reviewed as part of the modelling update, including checks on downstream boundary conditions and spill linkages. Findings and any resulting refinements will be set out in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.1 Table 2 3.6 Model sensitivity tests ST5 and ST6.
3	Please review the design hydrology to confirm that the design event is still representative and is not underestimated or alternatively demonstrate that flood risk to the proposed development and in particular the Battery Energy Storage System and solar panel area F is insensitive to changes in flood flows. Furthermore, it is noted that a storm duration of 9 hours has been considered. Please confirm if any consideration has been given to other storm durations such as 7, 12 and 15 hours? Please document any checks undertaken on the hydrology within a model report which should form an appendix to the Flood Risk Assessment. Please see comment 4.2 within worksheet 1D_Boundary_Conditions within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. The design hydrology will be reviewed and sensitivity testing undertaken (including alternative storm durations such as 7, 9, 12 and 15 hours) to confirm representativeness or demonstrate insensitivity of flood risk at the Battery Energy Storage System and panel area F to changes in flows. Checks and outcomes will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.1 Table 2 3.6 Model sensitivity tests ST3 and ST4.

Comment	Review Comment	Arthian Response	Relevant Section References
4	Please consider the application of downstream conditions within the hydraulic model. It appears that the applied water levels could be underestimated. An approach like the existing Environment Agency hydraulic model should be taken or alternatively sensitivity tests should be undertaken to confirm that the downstream boundary conditions have no impact on flood risk within the order limits for the development. Please see comment 4.3 within worksheet 1D_Boundary_Conditions within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Downstream boundary conditions will be reviewed, and either aligned with the existing Environment Agency model approach or tested through sensitivity analyses to confirm no material impact within the Order Limits. Findings will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.1 Table 2 3.6 Model sensitivity tests ST5 and ST6.
5	Please include a map within the model report/Flood Risk Assessment which compares model results to recorded flood outlines. Recorded flood outlines held by the Environment Agency can be downloaded from the Defra Data Services Platform (environment.data.gov.uk). Please see comment 15.3 within worksheet Model Performance within the attached spreadsheet.	The Applicant notes the Environment Agency's request. A comparison map of model outputs against recorded flood outlines (sourced from the Defra Data Services Platform) will be produced and included within the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.4

Comment	Review Comment	Arthian Response	Relevant Section References
6	Please review the design flood extent in the vicinity of the land designated for the Battery Energy Storage system. The design flood extent is smaller when compared to the Environment Agency's existing 1% (1 in 100) Annual Exceedance Probability extent for the Grendon Brook (Halcrow, 2013). Whilst this does not necessarily indicate that the model schematisation is incorrect it does warrant a check to establish why these differences might be occurring, particularly given the sensitivities associated with the BESS. Please see comment 15.7 within worksheet Model Performance within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Differences between the design flood extent and the existing Environment Agency model of the Grendon Brook will be reviewed as part of the modelling update, with outcomes reported in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097].**	3.4.4 3.5.2
7	Please ensure depth grids are produced for the full extent of the hydraulic model where this intersects with the order limits for the development. At present the model extends into panel area F, however, there is no associated flood extent mapping for this portion of the model. Please see comment 2.4 within worksheet Model Scenarios within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. This assessment is focussed solely on the BESS Site, with the solar remainder of the order limits assessed separately using existing flood risk and drainage datasets. There has been no change to the extent of the flood mapping as a result.	N/A

Comment	Review Comment	Arthian Response	Relevant Section References
8	Please produce a hydraulic model report for this model build. This should be included as an appendix to the Flood Risk Assessment and should include the following information: 1. Details on the source information used to construct the model geometry 2. Details regarding the model hydrology and any checks that have been undertaken on this to confirm its suitability to assess present day baseline flood risk 3. Details on any sensitivity tests undertaken. 4. Details on associated uncertainties and limitations 5. The rationale for not undertaking "with development" modelling	The Applicant notes the Environment Agency's request. A Hydraulic Modelling Report will be prepared for this model build and appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]** setting out geometry, hydrology, sensitivity tests, uncertainties and the rationale for not undertaking with-development modelling.	This document

Field Drain Model

The model is broadly reasonable, however, there are some uncertainties with the hydraulic modelling which should be investigated further so that there is confidence that these uncertainties will not impact flood risk at the proposed BESS Site. Please see the key comments on the model review below.

Comment	Review Comment	Arthian Response	Relevant Section References
1	Please undertake a sensitivity test on channel bed levels perhaps just applying the point inspected values to each z point (rather than the lowest value within a 5-metre radius) and re-run the model. This will help to quantify any impact from the uncertainties associated with channel bed levels and the impact at the BESS Site. Please see worksheet 2D_Model_Build within the attached spreadsheet	The Applicant notes the Environment Agency's comments. A sensitivity test on channel bed levels will be undertaken for the Field Drain 2D direct rainfall model, with results reported in the Hydraulic Modelling Report to be appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	4.1 Table 3
2	It would be sensible to validate the Station Road culvert dimensions by undertaking a survey of the upstream and downstream opening. If this is not possible then some sensitivity testing of culvert dimensions is critical given the large amount of attenuation upstream which could be conveyed downstream if culvert dimensions are underestimated. Please see worksheet 2D_Structures within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. The Station Road culvert dimensions will be validated by survey where practicable; if not feasible, sensitivity testing of culvert dimensions will be undertaken. Findings will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.and agreed with the Environment Agency/LLFA at detailed design as secured in schedule 2, Requirement 11 of the **Draft DCO Revision A [EX1/GH3.1_A].**	4.1 Table 3 Figure 11 4.6 Sensitivity tests ST9 and ST10

Comment	Review Comment	Arthian Response	Relevant Section References
3	At present a slope of 0.01 metres per metre has been applied at the downstream boundary. Sensitivity testing should be undertaken on the downstream boundary conditions, particularly as the Grendon Brook and River Nene result in flooding in the vicinity of the downstream boundary. The influence that the downstream boundary conditions have on model results should be quantified through some sensitivity testing. Please also undertake sensitivity testing on Mannings Roughness. Please see worksheet Model Performance within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Sensitivity testing of downstream boundary conditions and Manning's roughness will be undertaken and the influence on model results quantified for the relevant models. Findings will be reported in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]** and agreed with the Environment Agency at detailed design.	4.1 Table 3 4.6 Sensitivity tests ST3, ST4, ST5, and ST6

Comment	Review Comment	Arthian Response	Relevant Section References
4	It would be sensible to compare the outputs from the direct rainfall model at the catchment outlet with the calculated total flow outputs from the ReFH2 hydrological approach. This would be useful as it would help determine how well the direct rainfall model is performing and whether aspects such as depression storage and attenuation are influencing model results. Do the outputs align or are there notable differences? Please see worksheet Model_Performance within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. A comparison of direct rainfall model outputs at the catchment outlet with ReFH2 hydrological flow estimates will be undertaken to confirm model performance and identify any differences. This will be reported in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	4.5.3
5	Please review the warning and check messages and update the model as necessary. Please see worksheet Model_Stability within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Model warning and check messages will be reviewed and addressed, with any updates incorporated into the model. [JC11] [AR12] Outcomes will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	4.4

Comment	Review Comment	Arthian Response	Relevant Section References
6	The Environment Agency do not hold any recorded flood outlines for this unnamed ordinary watercourse, this does not mean that historic flooding has not occurred just that the Environment Agency do not hold any records of flooding. Do the Lead Local Flood Authority have any historic data to validate the model outputs against? Please see worksheet Model_Performance within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Enquiries have been made with the Lead Local Flood Authority regarding historic flood records for the unnamed ordinary watercourse. No such records have been identified to date, but the Applicant will continue to engage with the LLFA to confirm whether any information is available to support validation of the model outputs. Findings will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	4.4.4
7	As this is a direct rainfall model has any consideration been given to filtering the model results so that flood risk from the unnamed ordinary watercourses can be properly visualised. Typically, this is done by applying a depth or hazard threshold to the data. Please see worksheet Flood_Extent_Check within the attached spreadsheet.	The Applicant notes the Environment Agency's comments. Filtering of the direct rainfall model outputs will be undertaken using appropriate depth or hazard thresholds to aid interpretation of flood risk from the unnamed ordinary watercourses. This will be documented in the Hydraulic Modelling Report appended to the **ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]**.	4.1 Table 3

Comment	Review Comment	Arthian Response	Relevant Section References
8	Please produce a hydraulic model and hydrology report for this model build. This should be included as an appendix to the Flood Risk Assessment and should include the following information: 1. Details on the source information used to construct the model geometry 2. Details regarding the model hydrology and in particular the ReFH2 model parameters and rainfall used. 3. Details regarding whether any calibration or verification of the model results have been undertaken (for example if the LLFA have any data to validate against) 4. Details on any sensitivity tests undertaken. 5. Details on associated uncertainties and limitations	The Applicant notes the Environment Agency's comments. A Hydraulic Modelling Report will be produced for this model build and appended [JC19] to the ES Appendix 10.1 Flood Risk Assessment and Drainage Strategy Report [APP-097]. The report will set out the model geometry, hydrology (including ReFH2 parameters and rainfall), any calibration or verification undertaken, sensitivity tests, and associated uncertainties and limitations.	This document

Appendix B – Limitations

Limitations

Client: The organisation identified on the report cover after “For”, being the commissioning party.

This report contains recommendations from Arthian, which are based on the information listed in the report and reflect the professional opinions of an experienced Environmental Consultant. Arthian obtained, reviewed, and evaluated information from the Client and others to prepare this report. The conclusions, opinions, and recommendations presented in this report are based on this information. However, Arthian does not guarantee the accuracy of the information provided and will not be held responsible for any opinions or conclusions reached based on information that is later proven to be inaccurate.

This report was prepared exclusively for the Client and for the specific purpose for which Arthian was instructed. It is not intended for use by anyone other than the Client without Arthian’s written consent. Any unauthorized use of this report is at the sole risk of the user. Anyone using or relying on this report, other than the Client, agrees to indemnify and hold harmless Arthian from any claims, losses, or damages arising from the performance of the work by the Consultant.