Hallam Land Management Ltd

BOGNOR GOLF COURSE

Hydraulic Modelling Report - Site A and Site B



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MARCH 2022

ARUN DISTRICT COUNCIL Private

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Hallam Land Management Ltd

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1 INTRODUCTION

1.1.1. WSP UK Ltd (WSP) has been appointed by Hallam Land Management Ltd. (HLM) to undertake hydraulic modelling to support two planning applications in Bognor Regis and Middleton: the first (Site A) for the re-development of Bognor Regis Golf Course to a residential led development scheme, as shown in Figure 1, planning reference: FP/274/21/OUT; the second (Site B) is for the relocation of the Bognor Regis Golf Course at a greenfield site in Middleton south of the A259, as shown in Figure 2, planning reference M/16/22/PL.

1.1.2. This Report summarises the hydraulic modelling that has been undertaken to develop the baseline and post development hydraulic models for both sites, the findings of which are reported within the associated Flood Risk Assessments. It also responds to the Arun District Council Drainage Engineer's comments regarding surface water drainage and flood risk at Site A, dated 08 March 2022. The Lead Local Flood Authority's comments for Sites A and B, dated 15 March 2022, and the Arun District Council Drainage Engineer's comments regarding surface water drainage at Site B, dated 10 March, remain under consideration.

1.1.3. This Report is supported by the following Appendices:

- Appendix A - Modelling Methodology;
- Appendix B - Hydrological Assessment;
- Appendix C – Site A and Site B Re-grading Plans;
- Appendix D – Flood Impact Maps;
- Appendix E – Extract of the Design and Access Statement.

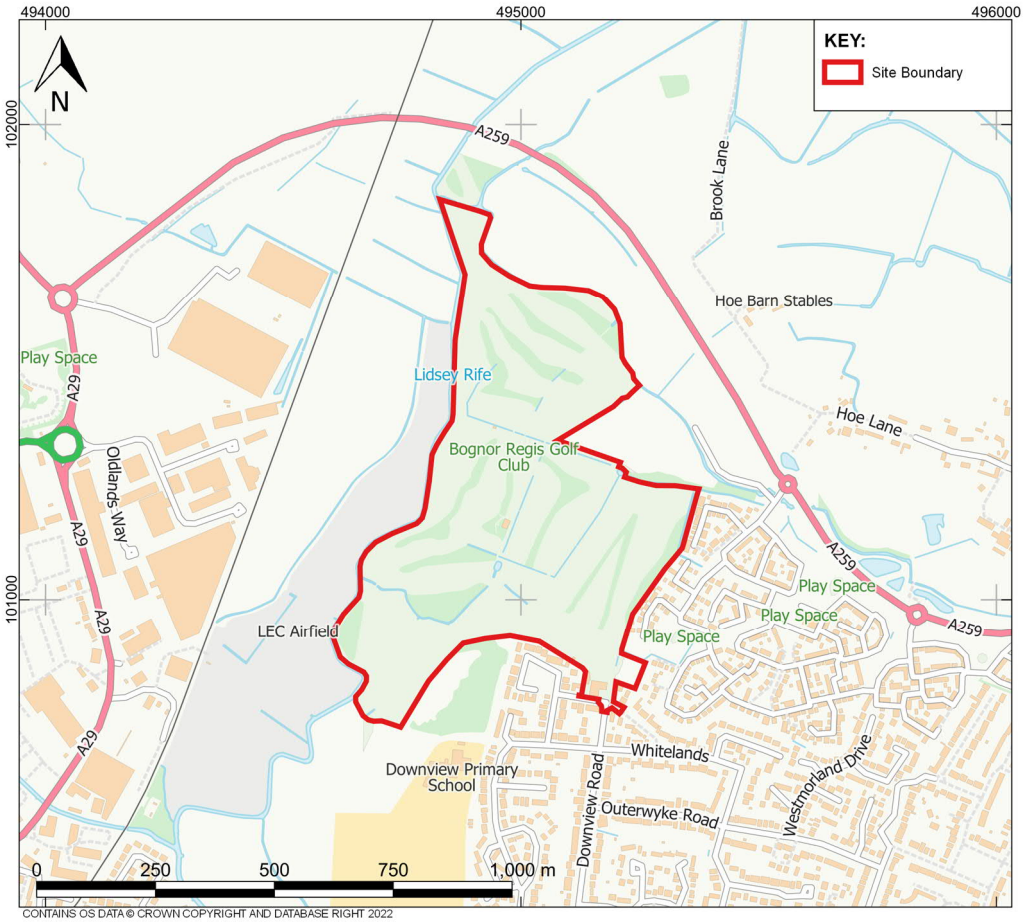


Figure 1: Site A - Existing Golf Course Site Boundary

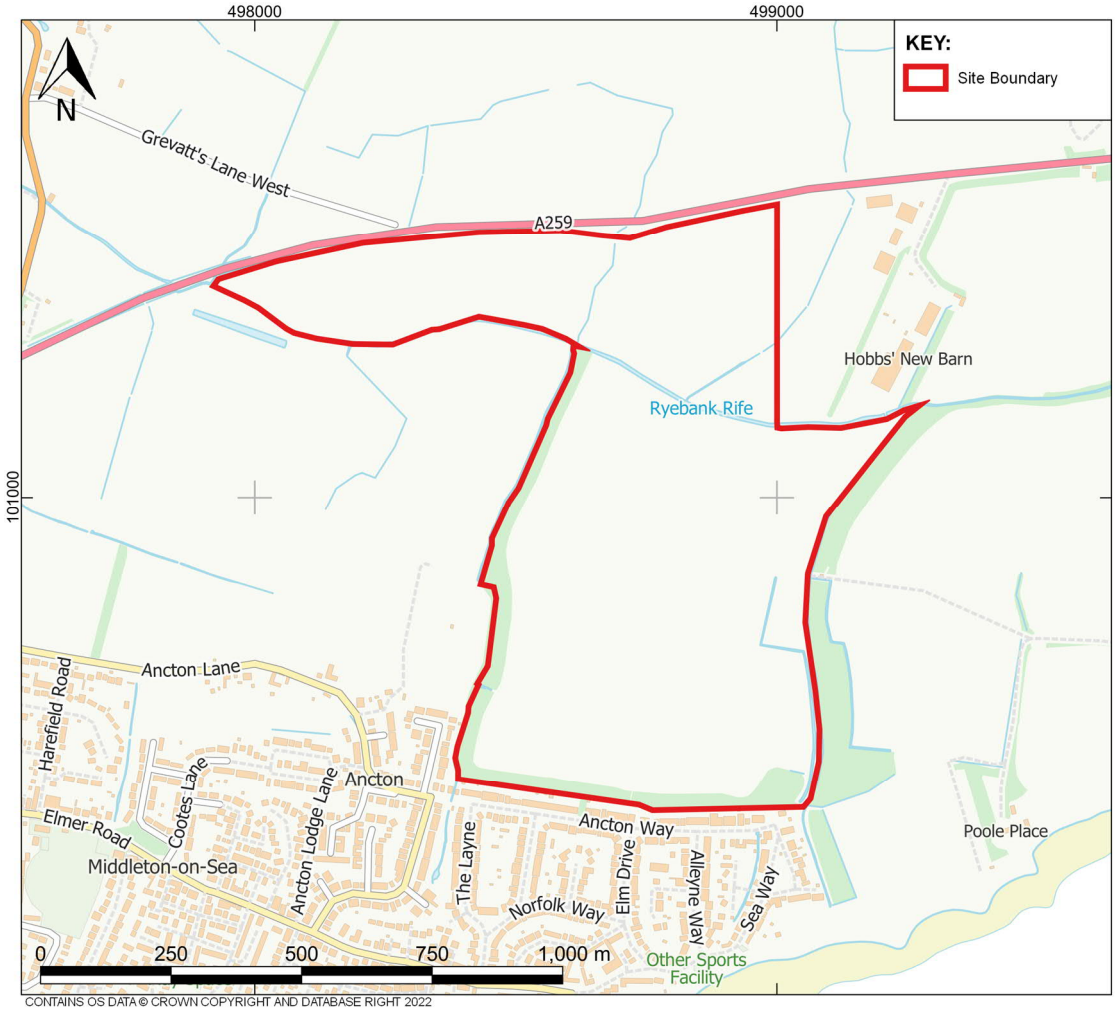


Figure 2: Site B - Land North of Ancton (Golf Course Relocation) Site Boundary

2 MODELLING APPROACH AND METHODOLOGY

2.1.1. The modelling approach involved making relatively minor modifications to the Environment Agency's 2015 Aldingbourne direct rainfall ICM model, hereafter referred to as the 2015 Model, to make it suitable for the purposes of site-specific assessment of flood risk at both sites. The modelling approach was discussed during, and subsequent to, a meeting with the Environment Agency in January 2020. The modelling methodology agreed at the time is included at Appendix A . Since completion of the modelling methodology an additional review of the model was undertaken, this determined that an appropriate representation of the flood risk to the site could be achieved with a reduced number of changes to the Environment Agency's model, with the aim of reducing the risk of non-acceptance by the Environment Agency. The changes subsequently made to the Environment Agency's model are outlined in Table 1.

2.2 HYDROLOGY

2.2.1. In the reporting produced for the 2015 Model, notably the 'Aldingbourne and Barnham Rifes Interim Hydrology Report – Direct Rainfall' (JBA, 2014), it was noted that when considering hydrological methods for applying inflows to the model, "*direct rainfall became the preferred option as there are potential problems with applying standard methods to this catchment. This is due to low gradients in the downstream catchment which makes it difficult to select inflow points that properly represent the contribution of flow in the catchment*."

2.2.2. As there have been no changes to the methods of flow estimation in the intervening period which would change this finding, the direct rainfall nature of the model has been retained.

2.2.3. Our review of the hydrology utilised within the 2015 Model, identified that it was based on the Flood Estimation Handbook1999 rainfall model, which has since been superseded by the FEH2013 model. The hydrology has been updated using the FEH 2013 model, utilising a similar overall approach as adopted in the 2015 Model study.

2.2.4. This is primarily a direct rainfall approach using a storm duration of 10.25 hours, as used in the Environment Agency model, with this duration adopted for all model runs. This assumption was checked via a sensitivity analysis testing shorter and longer storm durations, with the 10.25 hour showing the largest flood extents within the existing golf course (the most critical of the two sites).

2.2.5. A detailed analysis of the hydrology approach taken forwards within this hydraulic modelling can be seen in Appendix B.

2.3 HYDRAULIC MODELLING

HYDRAULIC MODEL UPDATES

2.3.1. The 2015 Model is a 1D-2D, direct rainfall Integrated Catchment Model (ICM), which was commissioned by the Environment Agency for the Aldingbourne Flood Risk Mapping Study. It includes a fluvial and surface water drainage component and allows water to flow from the modelled 1D watercourses into the 2D floodplain.

2.3.2. It was originally envisaged that a number of changes to the model were outlined in a Technical Note (Appendix A) which was submitted to the Environment Agency in November 2019. Since completion of the modelling methodology an additional review of the model was undertaken, this determined that an appropriate representation of the flood risk to the site could be achieved with a reduced

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number of changes to the Environment Agency's model, with the aim of reducing the risk of non-acceptance by the Environment Agency. The changes subsequently made to the Environment Agency's model are outlined in Table 1.

Table 1: 2015 Model Issues and Proposed Updates

2015 Model Deficiency	Updates Made
Runoff parameters incorrectly defined for buildings, resulting in nil runoff from buildings roofs in the model	*Runoff parameters for buildings added to individual sub-catchments to represent roof runoff.*
Attempt made to apply roughness to 1D elements with 2D polygons	*Roughness applied to all river reaches based on the roughness zones from previous modelling. Where values were not present, updates were made to ensure no 1D elements had a roughness of 0.000.*
Poorly digitised 1D elements have created voids within the 2D domain around river reaches	*Confluences updated within the area of interest to ensure that there was no double accounting of flow, along with correct usage of storage areas within confluences and between river reaches.*
Manholes have incorrectly been used as breakpoints between river reaches and culverts	*Updates made to have break nodes between river reaches and structures.*
A roughness value for light brush and trees in summer land use has been applied throughout the 2D domain, including urban areas	*No changes made as this is a conservative approach. The overall 2D domain remains set to 0.06.*
Use of stored flood type within the 2D domain, and with poorly defined flood cones	*Updates to stored manholes to ensure that within the 2D zone all SWS are set to 2D manholes to allow surcharging on to the mesh.*
Discharge coefficients were left as default values for flap valves, screens and other ancillary structures, which may not be appropriate	*Updated discharge coefficients where appropriate*
The roughness equivalent to a foul sewer was applied to the surface water systems	*No changes made, roughness values at 0.6 can be identified as suitable within a SWS.*
Headloss coefficients were not calculated for all 1D links	*Updates to coefficients made where appropriate.*

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Joint probability of MHWS and rainfall events has not been considered	*No change to the approach for the hydrology estimation have been made.*
Antecedent conditions have been applied equivalent to 100% saturation of all soils within the catchment	*No changes have been made to the losses from the previous modelling following hydrological analysis.*

2.3.3. In addition to the above changes, the following updates have been made to the model:

- Enhancements to the LiDAR has been included around the existing golf course (Site A) in the form of topographic survey to improve the topographic representation at the development site. These enhancements have been made by incorporating the topographic survey data within the ground model. The benefit of this is that it allows surface water run off to follow the flow paths of drainage ditches within the golf course. These flow paths were not represented within the 2015 Model, due to its strategic nature.
- No localised structures have been incorporated as they are not believed to be restricting flow.
- An additional structure was added to the north of the development site to represent a bridge at Charles Purley Way.
- Additional baseflow added to river reaches of 0.01m^3/s where instabilities were identified. This is purely to improve the overall performance of the model and does not impact on the results.

CLIMATE CHANGE SCENARIOS

2.3.4. Climate change scenarios have been included within the modelling updates based on the Environment Agency's guidance. The catchment is larger than 5km^2 and thus considered a rural drainage catchment for which the use the peak river flow allowances is recommended.

2.3.5. The Environment Agency's climate change guidance is based around the NPPF Annex 3 vulnerability classification of the proposed land uses. The Scheme contains:

- Site A – Residential land use – More Vulnerable
- Site B – Golf Course land use – Water-compatible Development

2.3.6. The Environment Agency's guidance for both of these vulnerabilities is to use the central allowance, which for the Arun and Western Streams Management Catchment is 25% for the for the 2080s[1]. This was applied to the 1 in 100 year rainfall event.

2.3.7. Climate change uplifts were also applied to the design sea levels to represent the tidal influence downstream. Sea level rise was tested within the model with an increases of 1.2m and 1.6m to represent the higher central and upper end respectively. This was undertaken by applying the increases to the level files used within the model.

DEFENDED SCENARIO

2.3.8. The model has been run for the defended scenario only, given that the Environment Agency's position for the defences in Bognor is to maintain pace with climate change.

[1] Environment Agency Climate Change Guidance: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

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3 POST-DEVELOPMENT MODELLING

3.1.1. The baseline model was modified to incorporate the proposed developments. The differences between the baseline model and the post-development model at Site A (the existing golf course site) are as follows:

- Inclusion of the post-development ground model (as detailed within the Surface Water Drainage Strategy – key plan in Appendix C), which includes:
- Development platforms – The creation of raised development platforms is essential to facilitate gravity based surface water drainage;
- Road network;
- Surface water channels;
- Surface Water Drainage features (e.g. SuDs ponds);
- Flood management features in the north and south of the site (i.e. flood berms);
- Inclusion of a sub-catchment which removes rainfall from the development platforms and the road network, as the surface water runoff from these areas will be managed through the SuDS strategy. A scenario was also run without this sub-catchment to simulate a surcharged drainage system, as discussed in the Sensitivity Assessment section below;
- Inclusion of breaklines to allow the mesh to pick up topographic features more clearly (i.e. surface water channels), and around the site boundary to limit changes in the mesh between the baseline and post-development models;
- Inclusion of a speed table adjacent to the south east access to the site, raised 0.125m above the surrounding ground level. This has been represented by a mesh level zone; and
- Inclusion of an inflow on the Lidsey Rife representing the outflow from the drainage system. Scenarios have been run with and without the inflow included to determine the effect the inflow has on the Lidsey Rife, as discussed in the Sensitivity Assessment section below.

3.1.2. The changes in the post-development model at Site B (the new golf course site) are as follows:

- Inclusion of the proposed ground model, which shows how the site will be regraded (Appendix C);
- An increased model mesh resolution, with a maximum triangle area of 25m^2 and a minimum element area of 5m^2 in the southern half of the new golf course site. This is due to the added complexity of the watercourse interactions in this area, which required a more enhanced representation to ensure the flow routes were sufficiently incorporated within the model;
- The proposed access bridges across the Ryebank Rife were not incorporated within the model as they are set above the design flood level; and
- The proposed culverting of the minor field drain which flows between the car park and the club house was not included within the model, as the detailed design of this will be undertaken to ensure free flow for the 1 in 100 year plus climate change event.

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4 SENSITIVITY ASSESSMENT

4.1.1. As part of the development of the 2015 Model, a sensitivity assessments were undertaken. This included: +/- 20% change in channel roughness, +/- 20% change in floodplain roughness and +/- 20% change in peak water level of downstream boundary condition. As detailed in the Environment Agency's report, this demonstrated that the baseline model was not sensitive to any of the assessed parameters. Given that the refinements detailed above are relatively local and limited in scale it is considered that these will not change the outcome of the sensitivity assessment, thus there is no requirement to repeat this for the post development models.

4.1.2. However, particularly the development of Site A, has the potential to be sensitive to the model parameters in terms of sea level rise and surcharging of the outfalls. These have therefore been assessed within the model.

4.1.3. In terms of sea level rise the model has been run for the higher central and upper end scenarios which equate to a sea level rise of 1.2m and 1.6m respectively, given a design life of approximately 100 years, or until 2125. The model demonstrates that there is negligible difference in flood depths at Site A between the higher central and upper end sea level rise scenarios.

4.1.4. To assess the impacts of surcharged outfalls the post development model was run with the rainfall applied across the development platforms and roads to assess whether any additional areas of the site would be at risk during this scenario or if there would be an increase in risk off site. The modelling demonstrates that there is an increase in depths on site, in particular within the drainage ditches on site and in the northern section of the site. Increases in depth are observed only within the site boundary, with only negligible increases in depth observed outside the site.

4.1.5. To assess the impact that discharge from the proposed SuDS features from the site into the Lidsey Rife, an inflow hydrograph was applied to the Lidsey Rife at the downstream extent of Site A. A constant flow of 51.9l/s was applied throughout the model simulation to give a conservative estimate, this equates to the peak flow detailed within the Surface Water Drainage Strategy. The model demonstrates that the addition of this inflow has a negligible effect on flooding within and outside the site boundary; the flood impact maps are contained in Appendix D. The location of the inflow is shown in Figure 3 below.

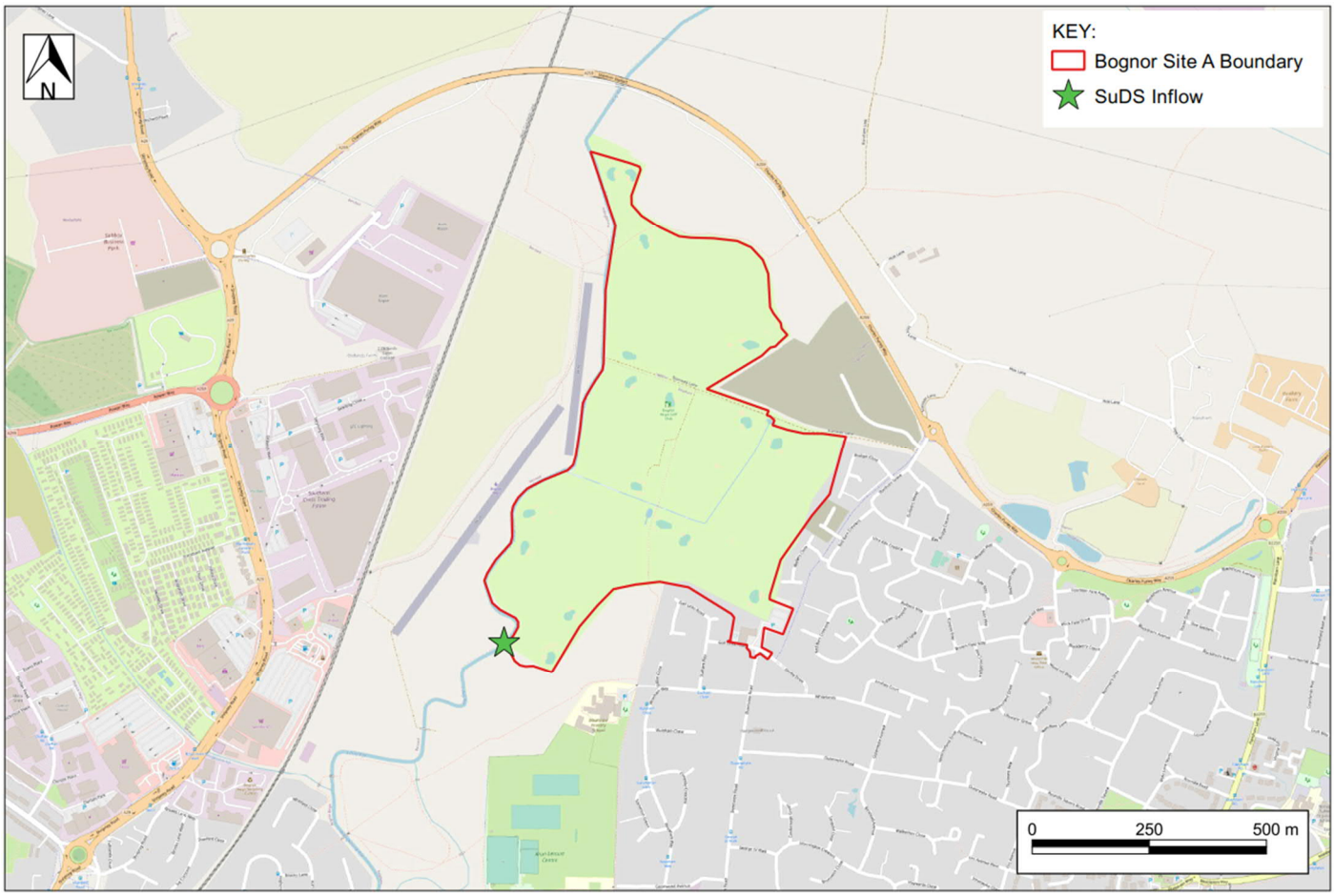


Figure 3 - SuDS Inflow Location

5 MODEL RESULTS

5.1.1. The model results are detailed and discussed in the accompanying Flood Risk Assessments.

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6 FLOW PATHS TO THE SOUTH EAST OF SITE A

6.1.1. The Arun District Council drainage engineer has requested further information on the flood risk to the area immediately south east of Site A to aid their understanding of the risk in this area.

6.2 MODEL SET UP

6.2.1. The understanding of flood risk in this area is relatively complex as it has been adjusted by the construction of a new residential led development to the east. This has involved changing overland flow paths, construction of new drainage features including surface water sewers. At the time of the construction of the hydraulic model not all the surface water sewer network had been adopted and thus was not available on the Portsmouth Water Sewer Plans, this meant that it could not be included within the model. Additionally, the new buildings are represented within the model by the latest OS MasterMap data available at the time of the model build. Instead, infiltration surfaces have been used to model the area as an urban surface and the ground model utilised the most recent LiDAR available at the time of the model build.

6.2.2. This is considered to be a conservative approach as the drainage strategy implemented as part of this scheme would be expected to reduce the overland flow routes as currently shown in the model.

6.3 BASELINE

6.3.1. The baseline model results for the 1 in 100 year + 25% climate change allowance shows that flooding is most prevalent in the existing ditches in the southern section of the site. However, there is a large offsite surface water flowpath that flows north west along Shirley Road before entering the site in the south eastern corner. This then flows overland through the southern section of the site in a north western direction, with depths approximately ranging between 100-200mm. There are some other isolated areas of flooding in the southern section of the site, however these typically range between 50-100mm depth.

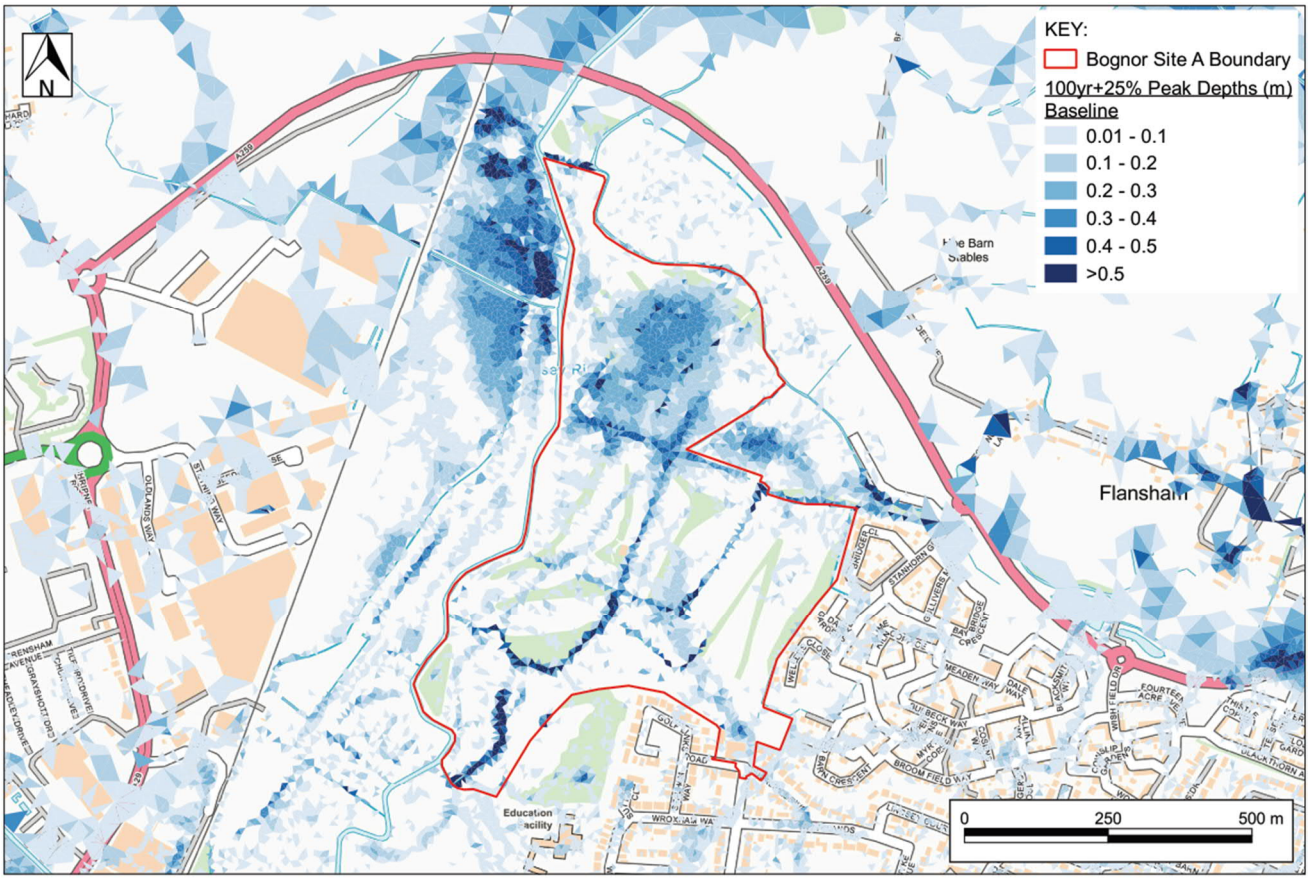
6.3.2. The majority of the baseline flood risk to the site is in the northern section, with large areas of flooding of over 300mm. A surface water flowpath enters the site from the east, originating at Stanhorn Grove before flowing westwards into the northern section of the site. Depths within this flowpath range from approximately 100-500mm.

6.3.3. A shallow surface water flowpath, with depths below 50mm, is shown to flow westwards through the recently constructed development to the east of Site A, towards the south eastern corner of the site. This flowpath is likely to be altered by the recently constructed development.

6.3.4. The hydraulic model for the site is a direct rainfall model, this means that rainfall is applied across the whole of the study area. Which by association means that there will be wet surfaces across the whole of the model. Given that shallow depths of rainfall landing on / flowing across the ground surface does not equate to flooding, it is necessary to remove these shallow depths from the flood maps (which are included in the accompanying FRA). The shallow depth of water which has been removed is below 50mm, which is an industry accepted cut off depth for displaying such flood risk information. However, for the purposes of aiding the interpretation of the flood difference maps, the cut off depth has been reduced to 10mm in the figures below.

6.3.5. The baseline model results for the 1 in 100 year +25% climate change allowance at Site A are shown below in Figure 4.

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Figure 4 – Site A Baseline Model Results

6.4 POST DEVELOPMENT

6.4.1. The modelling software used to develop the Environment Agency's 2015 hydraulic model and subsequently this model is ICM which uses a flexible grid approach to representing the ground surface. This means that there will be differences in the location of the triangles which are used to represent the ground surfaces for different iterations of the model, which manifest in the flood difference maps as areas that show large fluctuations between positive and negative differences in adjacent triangles. These differences mean that the flood difference maps (a comparison of the flood depths for the baseline and post development scenarios) are not as comparable as those developed using a fixed grid approach, this is a recognised limitation with this type of modelling. However, these maps demonstrate the overall modelled changes in flood risk.

6.4.2. To the south east of the site, the flood difference map, shows that the flood risk is increased (red colour) within the site extents, due to the formalisation / change in flow path, this results in a decrease in flood risk (green colour) on Golf Links Road / Shirley Drive. It also identifies areas which further interpretation is required, these are shown on the extract of the flood impact map in Figure 5 below, which is followed by the additional interpretation.

6.4.3. The reduction in the displayed depth of the flooding is to reveal any shallow flow paths that may cause an increase in flood risk in the south east of the site. The post development flood depth map

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is shown in Figure 6 to provide a greater level of context to the understanding of flood risk in the area.



Figure 5 – Site A Flood Impact Map Extract

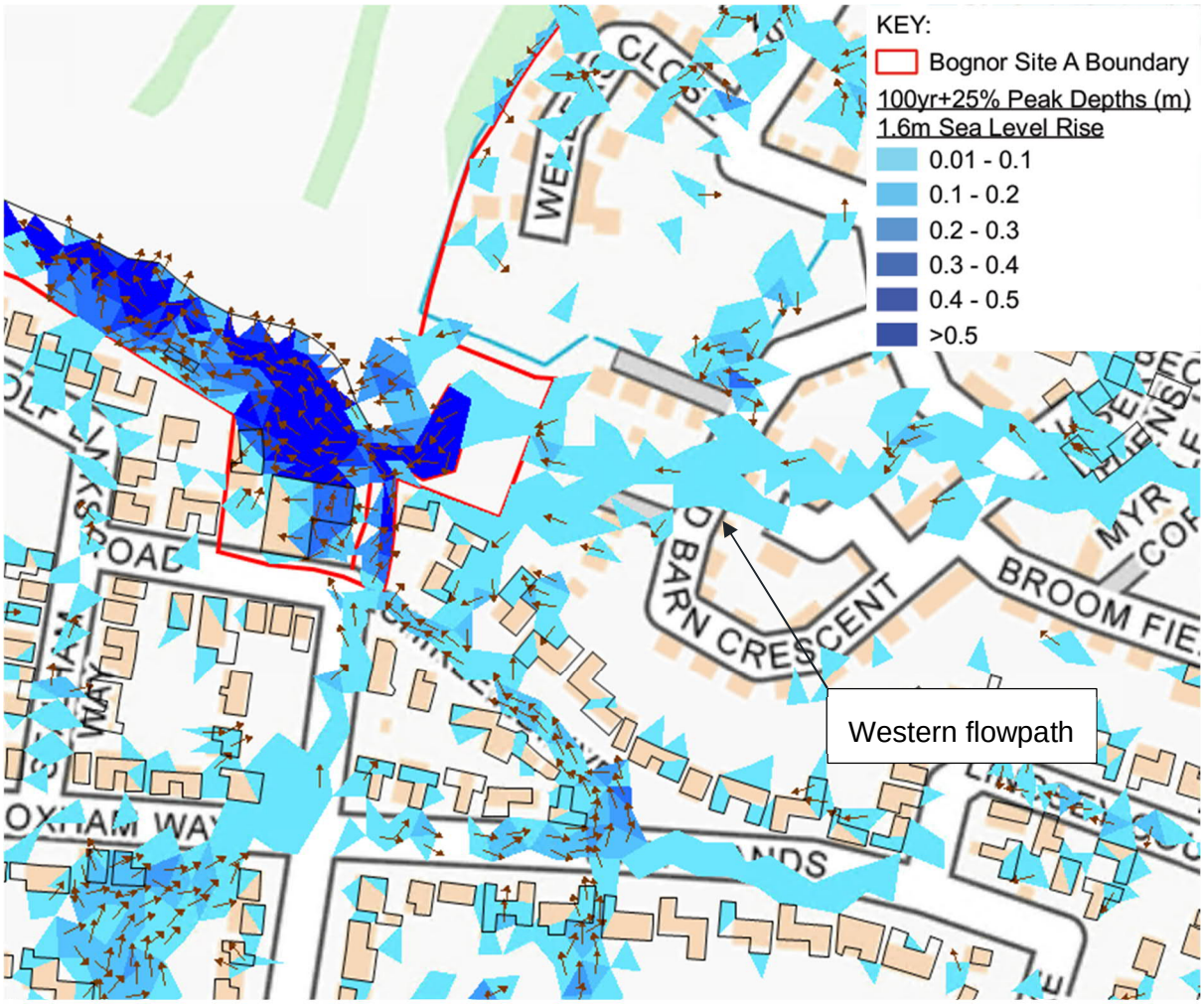


Figure 6 - Flood Depths and Flowpaths

AREA 1

6.4.4. Area 1 covers the modelled flooding in the vicinity of the junction between Shirley Drive, Downview Road and Golf Links Road. The depth increases in the post-development model at range between approximately 20mm and 120mm in the 1 in 100 year +25% climate change and 1.6m sea level rise, as the worse-case scenario.

6.4.5. The overall depths in along Downview Road and Golf Links Road remains less than 125mm which is the standard UK kerb height, thus the flood extents will be contained within the highway and are not likely to spill toward adjacent properties.

6.4.6. The depths exceed 125mm in some places along Shirley Drive, however, this is not shown to be an increase from the baseline flood depths.

AREA 2

6.4.7. The offsite impacts in Area 2 are associated with a shallow surface water flowpath (<50mm depth), flowing in a western direction towards Site A. This is the flow route which will be altered by the development which has recently been constructed. The overland flow route will be less than

modelled, given that the development incorporates surface water sewers and other means of rainfall management. On this flow route, the model shows an overall reduction in flood risk in the area closest to the site boundary, whilst within the recently constructed development the flood differences are considered to be the model tolerance (a result of the differences in the model mesh), given that there are green (betterment) and red / orange triangles (adverse changes) adjacent to each other.

AREA 3

6.4.8. The model demonstrates that this area is a small catchment which drains into these properties, behind which the model shows the water becomes stuck (red flow arrows in Figure 6). Given that no changes are being made in these areas the flood differences are considered to be a result of the model tolerance, as described in Area 2.

DEVELOPMENT PLATFORMS

6.4.9. The Scheme requires the construction of raised development platforms to facilitate gravity based surface water drainage. The modelling demonstrates that there are no adverse impacts on the existing adjacent properties and surface water runoff implications are fully assessed within the design of the platforms and associated surface water drainage strategy. The raised platforms are surrounded by a network of surface water ditches, as such there is no potential for elevated groundwater levels.

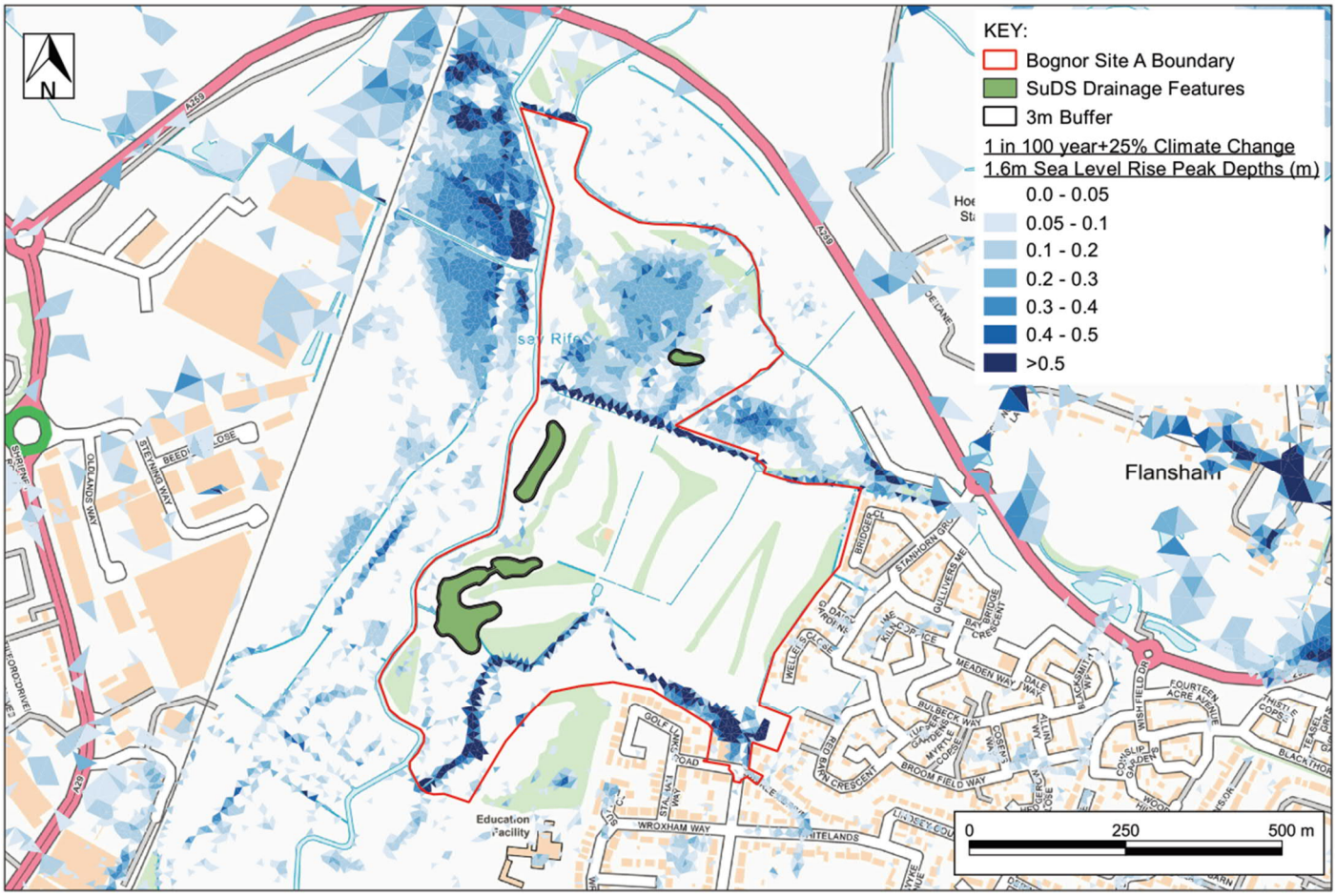
SUMMARY

6.4.10. The model therefore demonstrates that the Scheme does not lead to adverse impacts off site, rather the Scheme leads to an improvement to flood risk on Golf Links Road / Shirley Drive. The western flowpath shown to the south east of the site is likely to be altered by the recent development which is not included in the model; due to this and the result of model tolerances, the Scheme is not considered to cause an impact on flood depths in Areas 2 and 3. These changes in flood risk consider the impacts of the proposed development platforms.

6.5 SURFACE WATER DRAINAGE

6.5.1. The hydraulic model demonstrates that the surface water drainage features are located outside of the modelled flood extents for the 1 in 100 year +25% climate change and 1.6m sea level rise scenario, this is shown in Figure 7. This figure also shows that

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Figure 7 - Drainage Features

6.5.2. A 3m buffer can be provided alongside all water features, in line with the Arun District Council Drainage Engineers comment to provide suitable access for maintenance. This is shown in the Design and Access Statement, the relevant pages of which are provided in Appendix E.

7 SUMMARY

7.1.1. A hydraulic modelling study has been undertaken to determine the impact that the proposed development at Bognor Site A and Site B has on flood risk.

7.1.2. The baseline model has been based on the Environment Agency 2015 Aldingbourne Rifes model. This is a 1D-2D, direct rainfall ICM model, which was commissioned by the Environment Agency for the Aldingbourne Flood Risk Mapping Study. Updates have been made to Environment Agency model to make it suitable for the purposes of site-specific assessment of flood risk at the site, including the hydrology and enhancement of the ground model through topographic survey.

7.1.3. A post-development model has been created to simulate the impact of the proposed development on flood risk at the site. This has been created through the use of updated ground models, mesh resolution refinements, inflows and sub-catchments with the results presented in the FRA.

7.1.4. An additional level of assessment has been provided for Site A, in light of the Arun District Council Drainage Engineers comments. This assessment of the impact that the post-development model has on flood depth indicates that there are some limited offsite impacts to the south east of Site A. These impacts have been assessed and determined that they will not cause significant detriment to the offsite areas, as the flooding with either be contained in the roadway or would be mitigated by the new residential development to the south east of the site.

Appendix A

MODELLING METHODOLOGY

MODELLING METHODOLOGY

DATE:	08 November 2019	**CONFIDENTIALITY:**	Public
SUBJECT:	Flood Risk Position Statement		
PROJECT:	Bognor Regis Golf Course	**AUTHOR:**	Dave Turner
CHECKED:	Dean Ward	**APPROVED:**	Andy Smith

BACKGROUND

WSP has been appointed by Hallam Land Management to work with the Environment Agency to provide comfort to Arun District Council (ADC) as the LPA with comfort that Bognor Regis Golf Course is a suitable location for a residential led development scheme to enable allocation within the local plan. Following this we are to agree the approach to site specific flood modelling for Bognor Regis Gold Course to allow them to gain a deeper understanding of the overall constraints on development from a flood risk perspective. It is understood at this stage that the site is at risk from fluvial, pluvial and tidal sources, all of which will need to be understood in greater detail.

The potential development site is located at Bognor Regis Golf Club, north east of Bognor Regis (at NGR SU 95116 01137), as shown in Figure 1. The topography varies across the wider allocated site from over 5mOD (west toward Felpham) to approximately 1.2mOD (along the Lidsey Rife). A number of ordinary watercourse flow eastwards through the site, towards the Lidsey Rife on the western boundary.

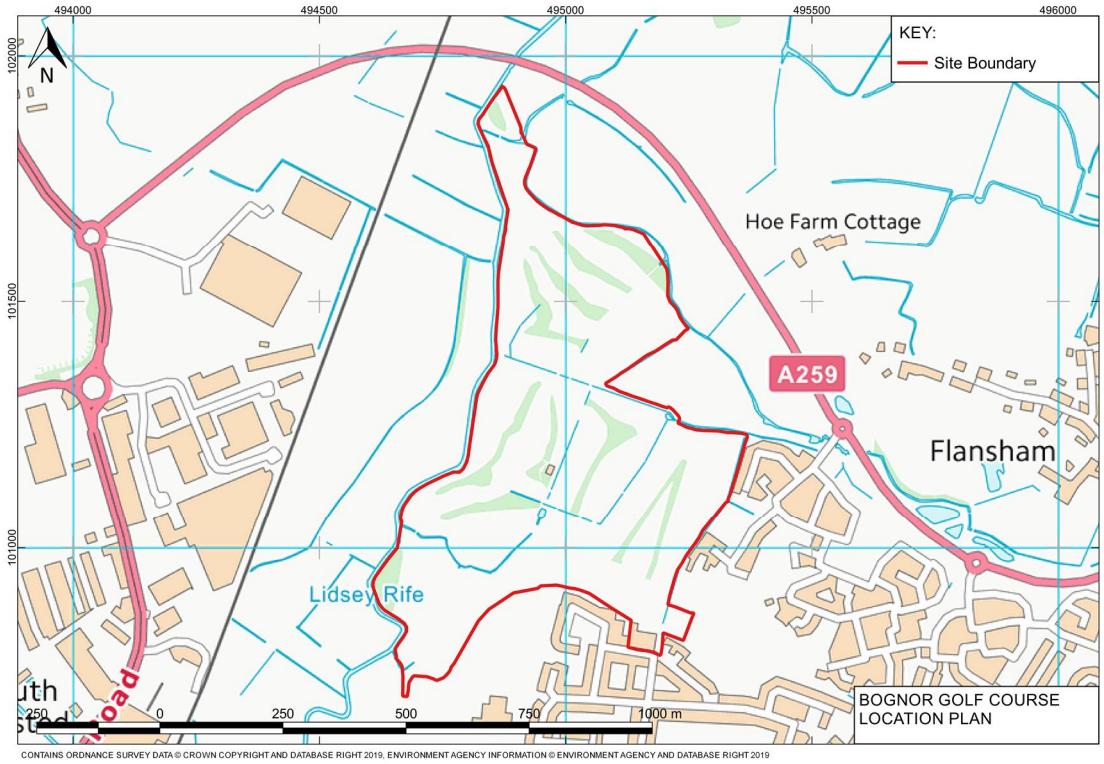


Figure 1 – Site Extents

An initial review of the existing Environment Agency Infoworks ICM model of Aldingbourne Rife which was previously supplied for this site has been undertaken, from our involvement in sites in the local vicinity we understand that no changes have been recently made to this model. This note provides brief summary of the findings from the review, and sets out the proposed modelling methodology for the site.

MODELLING APPROACH AND METHODOLOGY

Existing MODELS

A 1D/2 hydraulic model is available for the site, which was commissioned by the Environment Agency for Aldingbourne Flood Risk Mapping Study which was completed in 2015. The hydraulic model includes fluvial systems, as well as surface water systems and flow paths.

We have also reviewed the Emsworth to Littlehampton Coastal model outputs and consider that whilst they provide a good baseline understanding, taking this forward we will include the tidal boundary within our proposed model. We do not consider any need to remodel the wave overtopping, given the findings of this scenario.

An initial review has been undertaken of the model to inform the proposed modelling approach, a number of deficiencies have been identified which will require addressing to ensure the model is suitable to inform a site specific flood risk assessment:

1. Runoff parameters incorrectly defined for buildings, resulting in nil runoff from buildings roofs in the model
2. It has been attempted to apply roughness to 1D elements with 2D roughness polygons
3. Poor digitised 1D elements have created voids within the 2D domain around river reaches
4. Manholes have been used as breakpoints between River Reaches and culverts
5. 2D roughness equivalent to light brush and trees in summer has been applied across the 2D domain, including urban areas, and roads
6. Use of stored flood type within the 2D domain, and with poorly defined flood cones
7. Discharge coefficients left as default for flap valves, screens, and other ancillary structures
8. Roughness equivalent to a foul sewer applied to surface water systems
9. Headloss coefficients not calculated for all 1D links
10. Joint probability of MHWS and rainfall events has not been considered
11. Antecedent conditions have been applied equivalent to 100% saturation of all soils within the catchment

Proposed Modelling Approach

In order to manage the extent, and scale of work required to bring the model up to a suitable standard for assessing the flood risk to the site, it is proposed to limit the model boundary as shown in the model schematic in Appendix A with inflow hydrographs calculated based on FEH methods in accordance with Environment Agency Flow Estimation Guidelines and detailed within the Calculation Record.

The modelling within the area of interest will then be updated to:

1. Calculate contributing area for modelled subcatchments from mapping, with fixed runoff characteristics
2. Remove redundant 2D roughness zones
3. Enhance the model representation across the site, to include the ditch network based upon a site specific topographical survey, and improve digitisation around existing river reaches
4. Adjust nodes at breakpoints between river reaches and culverts to break nodes
5. 2D roughness zones defined from OS mastermap
6. Apply appropriate flood types to all modelled nodes
7. Calculate and discharge coefficients to ancillary structures based on the available information (existing reports / photos etc)
8. 1D roughness from channel characteristics and system type
9. Calculate and apply headloss to all 1D links
10. Undertake simplified joint probability analysis and apply suitable tidal boundary conditions
11. Rainfall direct to the 2D domain outside of subcatchments, with infiltration based on soil type within permeable areas, and fixed runoff coefficient for impermeable areas
12. Include inflow hydrographs at four locations to represent runoff from the wider catchment
13. Produce climate change scenarios based on current Environment Agency guidelines, with pump rates uplifted to maintain the present standard of protection as per the adopted policy and plans.
14. Undertake a sensitivity test for an undefended scenario, with the pumping station and seawall removed.

Breach and Overtopping

We note that coastal modelling undertaken by the Environment Agency included a drawn down beach scenario but the risks were not significant. In light of this and the distance upstream of the site we are not proposing to undertake these model scenarios.

Summary

The site is covered by an existing 1D/2D Infoworks ICM model commissioned by the Environment Agency as part of the Aldingbourne Flood Risk Mapping Study. A number of errors and deficiencies have been identified within the model that require addressing prior to ensure it is fit for the intended purpose of assessing flood risk to Bognor Regis Golf Club.

It is proposed to cut down the model to the area of interest, to ensure that the scope of these works is proportionate to the scale and nature of the development and consider the proposed development site in detail. As part of this, point source inflow hydrographs will be derived from FEH flow estimation methods to simulate the inflows form areas which were previously modelled on a direct rainfall runoff basis.

The model will be simulated for a range of return periods, with flows, rainfall and tides based on the simplified joint probability approach. Mapping will be based on the defended situation both for the present day, and 100 years into the future (the lifetime of the proposed development). For the future scenario pump rates will be uplifted in line with current climate change projections as per adopted policy and plans for the area. In addition, a sensitivity test of the undefended with the pumping station and seawall removed as a sensitivity test.

Appendix B

HYDROLOGICAL ASSESSMENT

Public

BOGNOR REGIS DIRECT RAINFALL HYDROLOGY

DATE:	04 October 2021	**CONFIDENTIALITY:**	Public
SUBJECT:	Bognor Regis Direct Rainfall Hydrology		
PROJECT:	70088068 - Bognor Regis Golf Course Planning	**AUTHOR:**	Aidan Wilks Daly
CHECKED:	Rachel Ledger	**APPROVED:**	Andy Smith

DESIGN RAINFALL PARAMETERS

2014 Model

The hydrological approach for the existing model is defined in the 'Aldingbourne and Barnham Rifes Interim Hydrology Report – Direct Rainfall' (JBA, 2014)'. It is noted that when considering hydrological methods for applying inflows to the model, "direct rainfall became the preferred option as there are potential problems with applying standard methods to this catchment. This is due to low gradients in the downstream catchment which makes it difficult to select inflow points that properly represent the contribution of flow in the catchment." This assessment is reasonable and agrees with our understanding, and as such it is considered preferable to retain the direct rainfall nature of the model.

The design rainfall in the 2015 model was based on data from the Flood Estimation Handbook (FEH) CD-ROM (v3). The FEH CD-ROM contains a database of catchment descriptors along with parameters of the FEH (1999) rainfall Depth-Duration-Frequency (DDF) model. The DDF parameters are provided on 1 km^2 grid and the parameters were extracted for each of the 1km^2 grid squares overlapping the catchment extent.

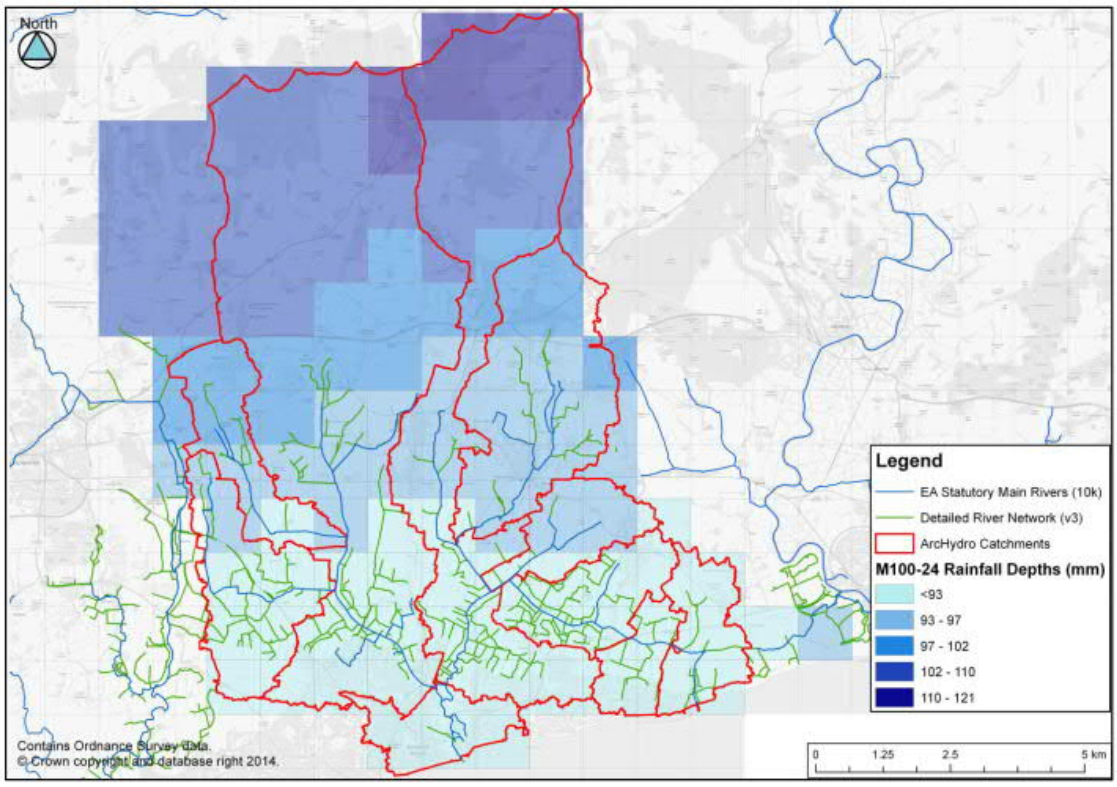


Figure 1 Design rainfall for the 100yr 24-hour storm event

BOGNOR REGIS DIRECT RAINFALL HYDROLOGY

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CHECKED:	Rachel Ledger	**APPROVED:**	Andy Smith

It was found that there was a considerable degree of spatial variation in the rainfall across the catchment, with Figure 1 illustrating the range of rainfall depths for the 100-year 24-hour storm event. Higher rainfall depths were observed in the upstream part of the catchment and the rainfall totals gradually decrease further downstream. There is a large difference between the upstream catchment totals (120.5mm in the north-east) and the downstream catchment total (89mm in the south).

It was decided that different hyetographs should be applied across the catchment in the hydraulic model in order to represent the variability in rainfall totals. To create a hyetograph specific to this area, the DDF parameters from the grid squares covering the modelled 2D domain were amalgamated to create average parameters for each hyetograph. Three hyetographs (low, medium and high) were used within the hydraulic model, these are shown in Figure 2.

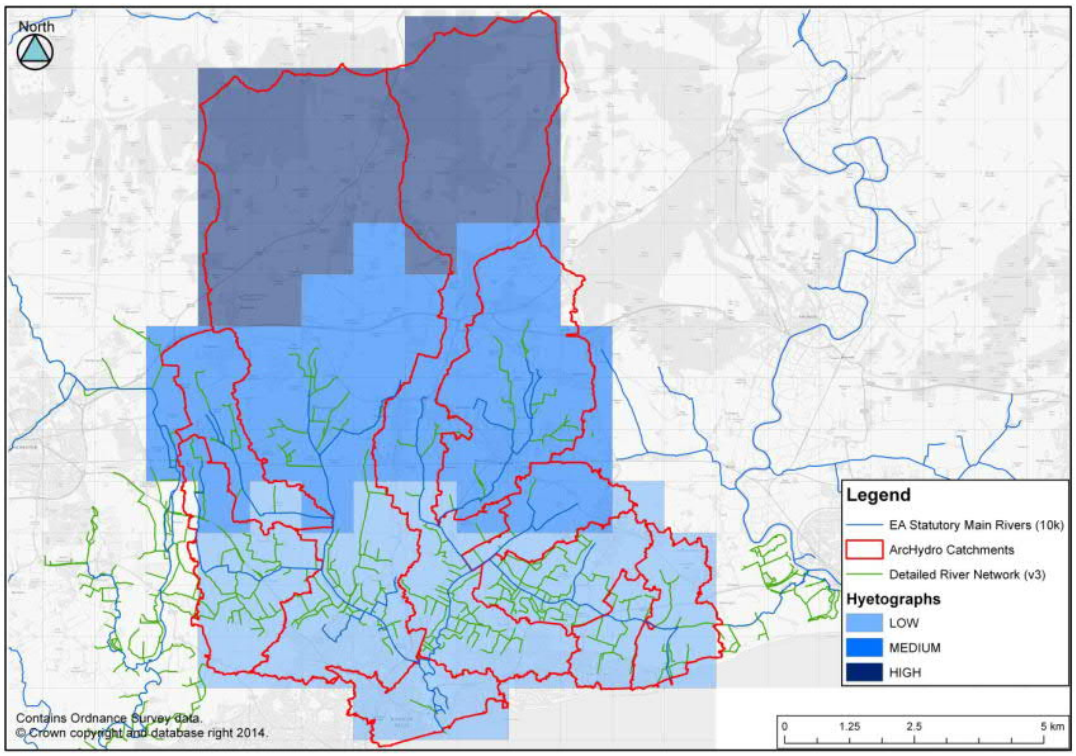


Figure 2: Hyetograph Areas

The DDF parameters averaged for the three hyetograph areas are displayed in Table 1.

BOGNOR REGIS DIRECT RAINFALL HYDROLOGY

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CHECKED:	Rachel Ledger	**APPROVED:**	Andy Smith

Table 1: FEH DDF Rainfall Parameters

Hyetograph Location	Area	FEH RAINFALL PARAMETERS					
		C	D1	D2	D3	E	F
LOW	33.75	-0.026	0.397	0.247	0.410	0.309	2.312
MEDIUM	36.73	-0.026	0.414	0.247	0.379	0.309	2.330
HIGH	26.83	-0.027	0.439	0.270	0.361	0.311	2.368

2021 Model Updates

To bring the hydrology approach in line with the current best-practice guidance, the hydrology will be derived using the FEH 2013 model, which superseded the FEH 1999 rainfall model that was previously utilised. To reflect the spatial variability in rainfall that was noted in the 2014 hydrology report, separate hyetographs will be generated for the high, medium and low areas. FEH 2013 point data (from the FEH Webservice) was purchased for the centroids of each of the low, medium and high hyetograph areas. The locations of these centroids are shown in Figure 3 and listed below.

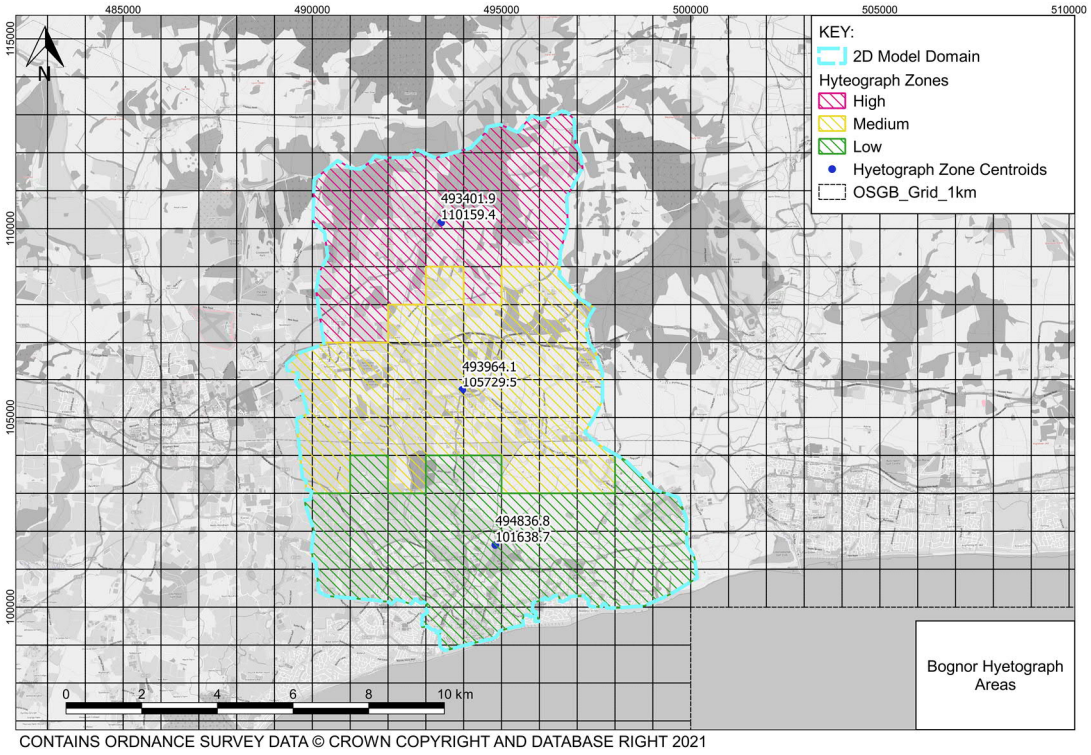


Figure 3: Hyetograph Areas and Centroids

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- 'Low' hyetograph area: Point Data at 494837,101639;
- 'Medium' hyetograph area: Point Data at 493964,105730; and
- 'High' hyetograph area: Point Data at 493402,110159.

FEH 2013 Point Descriptors do not contain The FEH1999 DDF parameters (C, D, E & F) that were amalgamated in the previous hydrology, however the design rainfall depths generated can be compared.

AREAL REDUCTION FACTORS AND SEASONAL DIRECTION FACTORS

When deriving design rainfall depths, Areal Reduction Factors (ARFs) vary based on storm duration and in the 2014 model the 10.25hr duration storm was modelled as the key design event so this has been replicated in the new hydrology. The whole catchment extent (97.3km^2) was used for deriving the ARF as ARFs should be consistent across the hydraulic model even though there are different hyetographs.

Seasonal Correction Factors (SCFs) are dependent on location, season, duration (of rainfall event) and selected return period. The default seasonality for all three hyetograph areas is winter, given the largely rural nature of these areas, however given the different locations of the hyetograph areas, they should have slightly different SCFs. The SCFs derived for each area in ReFH2 is displayed in Table 2 and these are the default values as suggested in ReFH2. As is to be expected, the higher SCF values associated with the 'High' and 'Medium' hyetograph areas, result in higher total rainfall depths, aligning with what was recorded in the 2014 hydrology report, which found that higher rainfall depths occur in the upstream (north) of the catchment.

Table 2: 10.25hr 100yr Design Rainfall Depths

Hyetograph Area	**Seasonal Correction Factor**	**100yr 10.25hr storm event – total rainfall depth (mm)**	
		Existing model hydrology	Revised Hydrology
Low	0.713	56.40	47.08
Medium	0.727	59.74	48.89
High	0.759	65.67	52.80

The revised design rainfall depths are between 16.5% and 19.6% lower than the design rainfall depths from the existing Environment Agency model.

BOGNOR REGIS DIRECT RAINFALL HYDROLOGY

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CHECKED:	Rachel Ledger	**APPROVED:**	Andy Smith

STORM DURATIONS

In the 2014 hydrology report, it is stated that in addition to the 10.25hr storm event, several other storm durations were tested, as it was important to check what was critical for key locations within the catchment, including upstream locations such as Barnham and downstream locations such as Bognor. The storm durations tested were: 2.25hrs, 5.25hrs, 10.25hrs, 17.25hrs, and 27.5hrs based on the critical duration in several locations such as urbanised areas, Westergate, Barnham, and the whole Aldingbourne catchment.

The 27.5 hour storm duration was selected as this duration corresponds with the June 2012 event at the site of the Westergate TBR and it was assessed likely that the Aldingbourne catchment, as a whole, is more responsive to longer duration storm events.

To replicate the approach of the 2014 hydrology, the 2.25rs, 5.25hr, 17.25hr, and 27.5hr storm events will also be tested, along with the 10.25hr event, with hyetographs for all of these events derived using the FEH2013 rainfall profile in ReFH2.

BASEFLOW

A limitation of the direct rainfall hydrology approach is that subsurface flows are not calculated. As a result, the baseflow component of river flow has been considered separately, using the same approach as the 2014 hydrology. In the 2014 hydrological assessment, the baseflow contribution was calculated by analysing flow records to understand typical baseflow levels during winter months. This was applied to the model using a baseflow component within the river reaches. This approach has been retained.

RAINFALL LOSSES

In the 2014 model the rainfall losses were dealt with within the ICM model utilising Horton Infiltration. The catchment at Bognor Regis is highly permeable and in the 2014 hydrology report it is stated that use of the ReFH losses model was discounted due to its known limitation in application to permeable catchments.

The Horton infiltration model was selected as it has the advantages of a time varying infiltration rate, depending on preceding rainfall, and because the Horton equation is physically based, it can be applied in a permeable catchment.

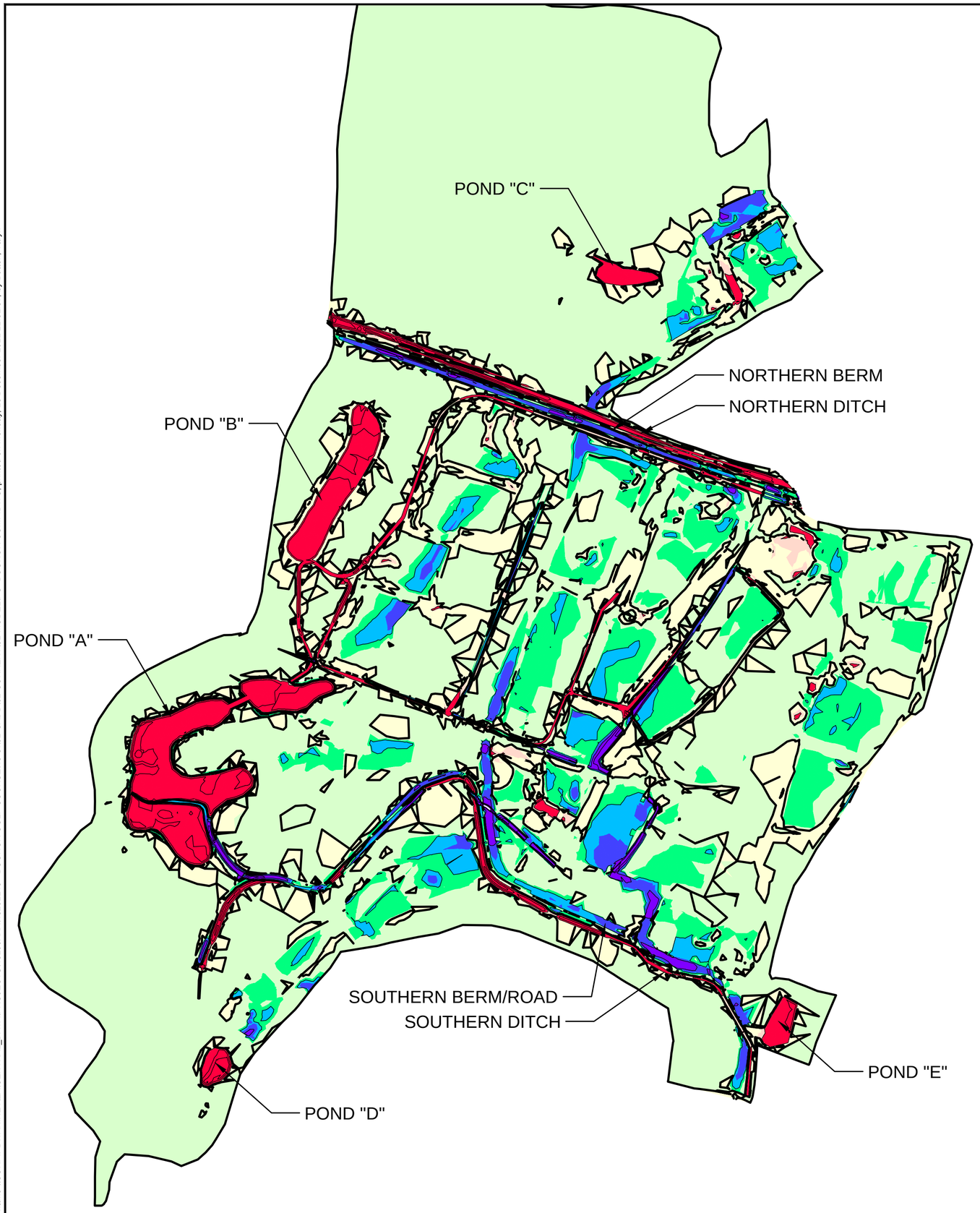
The use of the Horton infiltration model is reasonable and aligns with our understanding of what is appropriate for permeable catchments, therefore the Horton losses model will be retained.

Further details regarding the application of the Horton losses model are outlined in the hydraulic modelling updates report.

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Appendix C

SITE A AND SITE B RE-GRADING PLANS



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1	-2.53	-0.50	
2	-0.50	-0.30	
3	-0.30	0.00	
4	0.00	0.30	
5	0.30	0.50	
6	0.50	0.70	
7	0.70	1.00	
8	1.00	2.65	

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23	3.80	4.00	
24	4.00	4.20	
25	4.20	4.40	
26	4.40	4.60	
27	4.60	4.80	

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LEGEND

GREEN
PROPOSED CONTOURS
SEMI ROUGH
EXISTING CONTOURS
BUNKER
ROUGH
SHOT LINE
FAIRWAY
LAKE EDGE
PATH
TEE

IRRIGATION STORAGE TANK
IRRIGATION PUMP STATION
DRIVING RANGE BUILDING
HALFWAY HOUSE

IRRIGATION STORAGE LAKE
CAR PARK
MAINTENANCE FACILITY
IRRIGATION STORAGE LAKE
PRACTICE RANGE
CLUBHOUSE
CG
PG
Hobbs' New Barn
Drain
Iss
Collects
WATTS LANE WEST
4m
5m
3m
TON-ON-SEA CP
PO
ANCTON DRIVE
ANCTON CL
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Appendix D

FLOOD IMPACT MAPS

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1 in 100 year + 25% Climate Change
1.2m Sea Level Rise
Rainfall Applied on Site + Inflow from SuDS Features
Flood Depth Impact

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1.2m Sea Level Rise
Rainfall Applied on Site
Flood Depth Impact

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PROJECT:
Bognor Regis Golf Course

TITLE:
1 in 100 year + 25% Climate Change
1.2m Sea Level Rise
No Rainfall Applied on Site
Flood Depth Impact

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1.6m Sea Level Rise
No Rainfall Applied on Site
Flood Depth Impact

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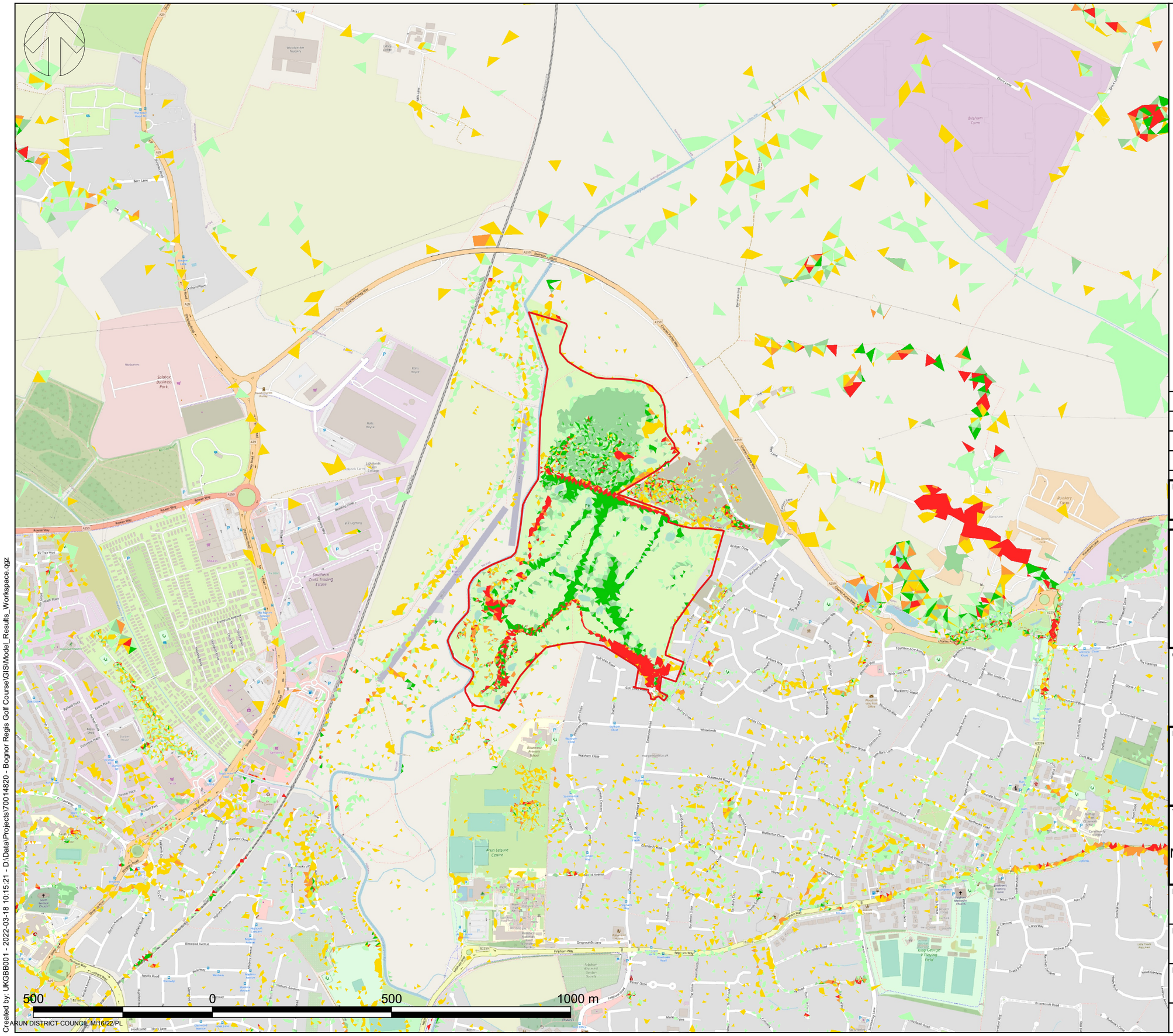
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PROJECT: Bognor Regis Golf Course

TITLE: 1 in 100 year + 25% Climate Change
1.2m Sea Level Rise
No Rainfall Applied on Site + Inflow from SuDS Features
Flood Depth Impact

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PROJECT No:	SCALE @A3:	DATE:
70088068	1:10000	18/03/2022

DRAWING No: 70088068-FLD-IMP-006 REV: A

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Key:

- Bognor Site A Boundary

Depth difference from baseline model (m)

- <0.1
- -0.1 - -0.05
- -0.05 - -0.01
- -0.01 - 0.01
- 0.01 - 0.05
- 0.05 - 0.1
- >0.1

REV	DATE	BY	DESCRIPTION	CHK	APP
A	18/03/22	GBB	FIRST ISSUE	AS	AS

DRAWING STATUS:
S2 - FOR INFORMATION

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wsp.com

CLIENT:
Hallam Land Management Limited

PROJECT:
Bognor Regis Golf Course

TITLE:
1 in 100 year + 25% Climate Change
1.6m Sea Level Rise
Rainfall Applied on Site
Flood Depth Impact

DRAWN:	CHECKED:	APPROVED:
GBB	AS	AS

PROJECT No:	SCALE @A3:	DATE:
70088068	1:10000	18/03/2022

DRAWING No:	REV:
70088068-FLD-IMP-003	A

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500 0 500 1000 m

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Appendix E

EXTRACTS OF THE DESIGN AND ACCESS STATEMENT



KEY

- Application site boundary - 40 ha
- Proposed areas of residential development
- Community facility and services
- Retained and proposed open space within wider green infrastructure
- Existing trees to be retained
- Areas of proposed tree planting
- Proposed singular tree planting
- Key areas of ecological value and enhancement
- Proposed growing areas
- Existing ditch/drainage network
- Proposed ditches and swales
- Proposed SuDS
- Existing Public Rights Of Way (PROWs) to be retained
- Proposed permissive public footpaths
- Proposed road network
- Proposed emergency access
- Safeguarded route for future Felpham - A259 link road
- Potential future vehicular link to the surrounding area
- Potential future pedestrian/ cycle link to the surrounding area
- Proposed car parks

F. 20 | FRAMEWORK PLAN

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NOTES

All dimensions to be verified on site. Do not scale this drawing. All discrepancies to be clarified with project Landscape Architect.

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KEY

Site Boundary: 39.6 Ha

Residential Areas
circa 480 units

Community Hub
Uses to be determined through consultation

Proposed roads

Proposed footpaths / cycleways

Proposed equipped play space

Proposed informal natural play space

GREEN INFRASTRUCTURE

Retained trees

Proposed specimen tree planting

Proposed community growing space

Proposed sustainable drainage features (SuDS) and habitat creation

Proposed drainage/ditch network

1 Proposed parkland area with biodiversity enhancements

2 Western ecological buffer with integrated SuDS

3 Greenways featuring existing mature Category A trees

4 Community Car Park

ACCESS

Proposed vehicular & pedestrian access points

Potential future pedestrian/cycle links to surrounding areas

Public Right of Way

Safeguarded route

Existing telecommunications apparatus

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