A428 Black Cat to Caxton Gibbet improvements

TR010044

Volume 6

6.3 Environmental Statement

Appendix 13.4 Flood Risk Assessment

Annex B: Ordinary Watercourse Modelling Report

Planning Act 2008

Regulation 5(2)(e)

Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

26 February 2021

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

A428 Black Cat to Caxton Gibbet improvements
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Appendix 13.4 Flood Risk Assessment
Annex B: Ordinary Watercourse Modelling Report

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Rev 1	26 February 2021	DCO Application

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1 Introduction

1.1 Background

1.1.1 The purpose of this report is to detail the hydraulic modelling undertaken to assess the impact of the A428 Black Cat to Caxton Gibbet Improvements Scheme, herein referred to as the 'Scheme', upon flood risk associated with ten local ordinary watercourses that are intersected by the Scheme. This assessment forms an Annex to the Flood Risk Assessment (FRA) for the Scheme. A map showing the location of these watercourses with respect to the Scheme is provided in **Figure 1-1**. The catchment characteristics vary for each ordinary watercourse catchment at the point they interact with the Scheme. These differences lead to a range of peak flow design estimates (**Table 1-1**). Catchment areas range from <1km^2 (Wintringham Brook) up to 47km^2 (Hen Brook). The Fox Brook and other smaller ordinary watercourses such as Nill Well Brook Tributary and Caxton Gibbet drain are not considered to have any significant impact on flood risk with respect to the Scheme and therefore no further assessment is required for the purpose of this report.

Table 1-1: Ordinary Watercourses - Hydrology and Catchment Area Summary

Ordinary Watercourse	1% AEP FEH Statistical Peak (m^3/s)	1% AEP ReFH Peak (m^3/s)	Catchment Area (km^2)
West Brook	0.9	1.7	1.7
Wintringham Brook	1.5	2.5	3.30
Wintringham Brook Tributary	0.4	0.8	0.6
Hen Brook	13.1	24.3	46.7
Rectory Farm Brook	0.8	1.2	0.9
Gallow Brook	1.6	3.1	3.6
Begwary Brook	*	1.7	4.8
South Brook	8.6	12.2	27.2
Rockham Ditch	1.1	1.2	2.9
Top Farm Ditch	*	1.9	1.8
River Great Ouse (Main River)	274.0	*	2300.0

1.1.2 *Indicates that peak flow estimate from this method is not available

1.1.3 All ten ordinary watercourses ultimately drain to the River Great Ouse which is designated as an Environment Agency operated Main River which flows northwards through St. Neots. The catchment area and estimated peak flow for the River Great Ouse at St Neots is included within **Table 1-1** for context. The 1% AEP peak flow estimate for the River Great Ouse at St Neots is demonstrated to be appreciably much larger than those of the individual and contributing ordinary watercourses. This is predominantly related to the significant difference in upstream catchment area.

1.1.4 Through consultation with the Environment Agency and Lead Local Flood Authorities (LLFA) over the course of the project, it has been established that St. Neots and surrounding communities are vulnerable to fluvial flooding from the River Great Ouse and its tributary watercourses. It is thought that in addition to the discrete risks posed by individual watercourses, that raised levels in the River Great Ouse may exacerbate flooding on the tributary watercourses through a locking effect.

1.1.5 Given the vulnerability of St. Neots to flooding from the River Great Ouse and its tributary watercourses, the primary driver of this assessment is to ensure that the Scheme results in no increase in flood risk to people and property (aligning with national planning policy), in particular, in St. Neots. The intersection of the Scheme and the ordinary watercourses are generally in rural areas that are remote from vulnerable receptors such as properties and businesses.

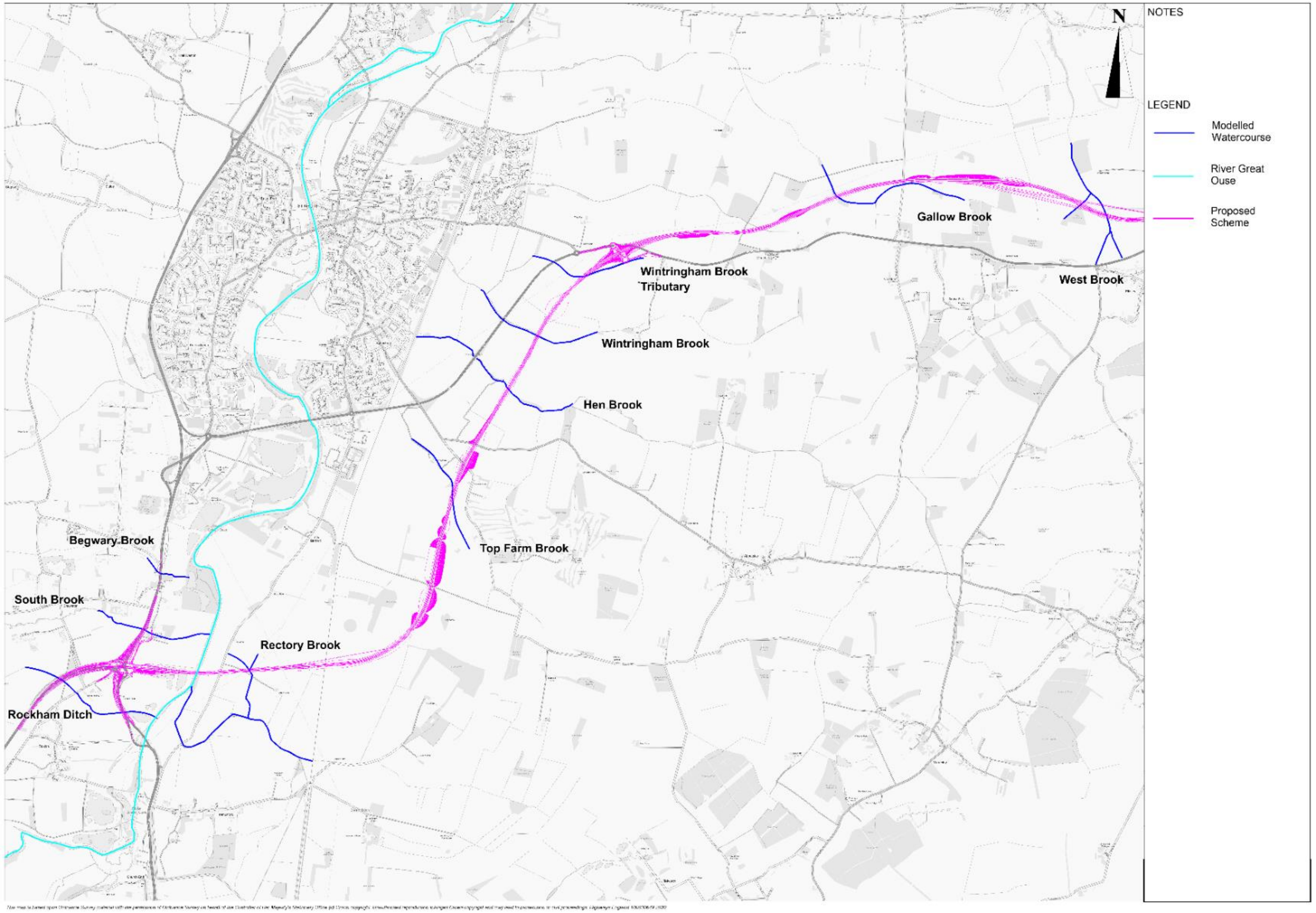


Figure 1-1: Modelled Watercourses

1.1.6 The ordinary watercourses that form part of this assessment are all intersected by the realigned highway and associated development. Hence the Scheme design includes culverts beneath the realigned highway, in order to maintain conveyance of the watercourses. Compensatory storage has been included within the Scheme design where appropriate, in order to provide level for level compensation where the Scheme is shown to displace floodwater. Hydraulic modelling has been used within the design development of these Scheme elements and will be used to demonstrate their compliance with relevant design standards and requirements.

1.1.7 As detailed in Section 1.1.2 and Table 1-1, the ordinary watercourses are characterised by substantial variation in catchment size and estimated peak flows. As such, at the location of the Scheme crossings the characteristics of the watercourse channels vary substantially from drainage ditches approximately 1-2 metres (m) in width with minimal out of bank flooding in modelled design events (Wintringham Brook Tributary), to moderately sized river channels with a typical width of 8-10m (Hen Brook) exhibiting substantial out of bank flows.

1.1.8 Given the substantial variation in characteristics of the ordinary watercourses at the location of the Scheme crossing, it was not deemed appropriate to apply the same methodology to the modelling of all watercourses. Rather, the approach adopted for the hydraulic modelling assessment for each watercourse has been selected according to a number of factors including the watercourse characteristics and required outcomes for the assessment. Modelling approaches adopted for the watercourses are detailed further in Sections 2 to 12 of this report.

1.1.9 This Hydraulic Modelling Report forms Annex B of the FRA, and the reader is referred to the main FRA document for further context and key details of the proposed Scheme.

1.2 Objectives

1.2.1 Based upon the Scheme background presented in Section 1.1, the primary aim of the hydraulic modelling documented within this report is to provide an appropriate assessment of the flood risk impact of the A428 Black Cat to Caxton Gibbet Improvements Scheme upon the local ordinary watercourses. To achieve this the following primary objectives have been undertaken;

a. Assess fluvial flood risk within the existing (baseline) scenario for the ordinary watercourses.

b. Assess fluvial flood risk to/from the proposed development scenario for the ordinary watercourses.

c. Ensure that, where required, proposed compensatory areas function correctly to offer level for level, volume for volume compensation for the Scheme.

d. Assess freeboard within the Scheme culverts, where required.

1.3 Design simulations and climate change

1.3.1 To meet the objectives outlined in Section 1.2, and to ensure compliance with relevant planning policy[1], the fluvial hydraulic modelling for the ordinary watercourses has been undertaken for the baseline and proposed scenarios for design events with the following Annual Exceedance Probabilities (AEPs); 5% AEP, 1% AEP and 0.1% AEP.

1.3.2 In line with Environment Agency guidance[2], the 1% AEP design event including an allowance for climate change (1% AEP + 35% increase in peak flows) has also been simulated for the baseline and proposed permanent scenarios. The allowance of + 35% corresponds to the 'Higher Central' allowance for the Anglian river basin district. Based upon planning guidance[1,2] the 'Higher Central' allowance is recommended to be used as the design event, with mitigation measures usually being designed to accommodate this event.

1.3.3 In order to consider the worst case, fluvial modelling for the ordinary watercourses was undertaken for the 1% AEP design event, inclusive of an uplift in peak flow of + 65%. This corresponds to the 'Upper' climate change allowance for the Anglian river basin district. Planning guidance generally dictates that the 'Upper' allowance is used as a sensitivity test to assess the flood risk to and from a development in the worst case, however in the context of this project, it has been designed to the 'Upper' allowance to maximise the resilience of the Scheme. The hydraulic modelling undertaken can therefore be considered conservative and this should be taken when considering the modelling results contained within this report and the associated provision of mitigation and Scheme assessment.

1.4 Report structure

a. Section 2 of this report details general aspects of the hydraulic modelling approach applied across all watercourses modelled within this study. Significantly this section provides justification for the choice of modelling approach for the different ordinary watercourses. It is suggested that the reader refers to this section in conjunction with sections on the individual watercourses.

b. Sections 3 to 9 detail the specific model set up, results, limitations and conclusions for each of the 1D watercourse models.

c. Section 10 to 12 detail the specific model set up, results, limitations and conclusions for each of the 1D-2D watercourse models.

[1] HM Government (2018) Revised National Planning Policy Framework. https://www.gov.uk/government/publications/national-planning-policy-framework--2 . Accessed 05/05/2020.
[2] Environment Agency (2016) Adapting to Climate Change: Advice for Flood and Coastal Management Authorities.

d. Section 13 provides a summary of the work undertaken and key conclusions, for each watercourse.

2 Hydraulic modelling approach

2.1 Overview

2.1.1 This section provides a brief summary of the hydrological analysis undertaken to provide time varying design hydrographs for hydraulic modelling of the ordinary watercourses. This is followed by a justification of the modelling approach applied (either 1D or linked 1D-2D) for the watercourses.

2.1.2 The remainder of the section details the key general aspects of the hydraulic modelling approach and methodology applied within this hydraulic modelling assessment. The aspects detailed within this section are universal across the watercourses modelled. Specific details of the setup of individual models are included within each of the Sections 3-12. This structure has been chosen to minimise duplication of general methodological information within sections for the individual watercourse models.

2.2 Hydrological analysis and inflows

2.2.1 A detailed account of the hydrological analysis undertaken to provide design inflow hydrographs has been documented within the Ordinary Watercourses Hydrology Report, and associated FEH Calculation Record, which forms Annex C of the FRA.

2.2.2 Initial flow estimates were undertaken in 2017 at the outset of this project using the FEH statistical method and the ReFH2.2 rainfall runoff model. These methods represented the most up to date, industry standard approaches, at the time of the analysis and were undertaken in accordance with Environment Agency Flood Estimation Guidelines3. The aforementioned report considers updates in methods and data since the initial flow estimates were made and provides a justification for the use of these flow estimations for this ordinary watercourse modelling assessment. The report concludes that update to available methods and data are unlikely to lead to significant changes in peak flows, and that the original estimated flows can be considered conservative for the purposes of this assessment. The reader is referred to this report for further information and justification.

2.2.3 Due to the variation in catchment size between the different ordinary watercourses that form part of this assessment, two different flow estimation methods have been used to produce the final design inflows for the hydraulic models.

[3] Environment Agency (2015) Flood Estimation Guidelines- Technical Guidance 197_08

2.2.4 Hen Brook (46.71km^2) and South Brook (27.16km^2) are both characterised by a catchment area of greater than 5km2. As such, for catchments greater than 5km2, best practice dictates that final peak design flows for these watercourses are considered appropriate to have been estimated using the FEH statistical method. FEH statistical peak flows have been used to scale ReFH2.2 hydrograph shapes in order to produce time varying inflow hydrographs for the hydraulic model.

2.2.5 The remaining watercourses are all characterised by catchment areas of less than 5km2. For these watercourses time varying inflow hydrographs have been estimated using ReFH2.2, with both the peak flows and hydrograph shape estimated within this software. ReFH2.2 was the preferred method for these catchments over the FEH statistical method as justified in the Ordinary Watercourses Hydrology Report (FRA, Annex C).

2.3 Justification of modelling approach

2.3.1 Two different hydraulic modelling approaches were used within this ordinary watercourse assessment. All watercourses were initially modelled using a 1D only Flood Modeller Pro (FMP) approach. Some of these models were subsequently updated to a linked 1D-2D FMP-TUFLOW approach, based upon results of the initial modelling and other considerations highlighted later within this section. An overview of both modelling approaches, along with a justification of the approach adopted, is included within the remainder of this section.

2.3.2 In general, a 1D only FMP modelling approach facilitates an accurate assessment of within bank channel flows, simple floodplain flows, and flows through hydraulic structures such as weirs, bridges and culverts. Importantly, a 1D only hydraulic model provides a simple representation of hydraulic flows, directly representing flows in the streamwise direction only. Whilst 1D only modelling approaches cannot accurately reproduce complex floodplain flows, simple floodplain flows and storage can be represented through inclusion of extended cross sections and reservoir units. Data requirements are modest, with the primary data input being constituted by a cross sectional survey including significant structures, in order to represent the geometry of the river channel and floodplain. 1D models are able to provide key outputs such as levels, flows, flow volumes and velocities.

2.3.3 A linked 1D-2D FMP-TUFLOW hydraulic model allows a more detailed assessment of the interaction of the channel (1D) and inundation on the floodplain (2D). The 1D model provides a representation of hydraulics within the river channel, and associated outputs, as stated within 2.3.2. When the capacity of the 1D channel is exceeded, water spills out into the 2D model. The grid based 2D model allows water to propagate across the floodplain according to complex topography and other factors such as roughness. This facilitates a more accurate calculation of flood depths and extents that are used to generate map outputs. A 1D-2D model requires more input data and setup time than a 1D only model. Furthermore, a 1D-

2D approach is more computationally intensive than a 1D only model and therefore simulation times are commonly much longer with model outputs files larger and requiring more processing time.

2.3.4 The choice between the two previously outlined approaches was a function of the watercourse characteristics such as catchment area and peak flow, along with the complexity of hydraulics in close proximity to the Scheme elements. In addition, the flood hazard posed by the watercourse along with the presence of vulnerable receptors close to the modelled reach, and therefore the overall risk to people and property, was also factored into the selection of approach for each model.

2.3.5 Hen Brook and South Brook have substantially larger catchments and peak flows than the other ordinary watercourses included within the Scheme assessment (Table 1-1). Initial 1D hydraulic modelling of these watercourses demonstrated that both watercourses were characterised by substantial volumes of out of bank flow around the location of the new Scheme crossing within the 1% AEP + 65% climate change event. As such, these out of bank flows require compensatory areas to mitigate the impacts associated with the Scheme crossing through the floodplain. Subsequently, the Hen Brook and South Brook were modelled using a 1D-2D FMP-TUFLOW to enable calculations of level for level and volume for volume compensatory areas.

2.3.6 The Fox Brook and other smaller ordinary watercourses such as Nill Well Brook Tributary and Caxton Gibbet drain were assessed separately to this report using a MicroDrainage approach, as a detailed hydraulic assessment was not required. These watercourses are not considered to have any significant impact on flood risk with respect to the Scheme and they are not addressed further within this report.

2.4 1D Model - River channel survey

2.4.1 Cross sectional survey for the ordinary watercourses was undertaken by internal AECOM surveyors through 2017 and 2018. The detail of the cross sections surveyed confirmed the geometry of the channel cross sections, including important structures such as bridges, culverts and weirs.

2.4.2 The extent of the surveyed reach upstream and downstream of the A428 Scheme crossing point, and spacing between cross sections, also reflected the characteristics of each watercourse. Model reach lengths are tabulated within **Table 2-1**.

2.4.3 Cross sectional and structure survey were utilised to build the 1D FMP models for the ordinary watercourse channels.

Table 2-1: Ordinary Watercourse Reaches

Watercourse	Reach length (km)
West Brook	2.0
Wintringham Brook	1.5
Wintringham Brook Tributary	1.3
Gallow Brook	2.0
Begwary Brook	0.5
Rockham Ditch	1.7
Top Farm Ditch	1.2
Hen Brook	1.8
Rectory Farm Brook	3.9
South Brook	1.2

2.5 2D Model - floodplain topography

2.5.1 Where a 2D model was required, topographical data consisted of a composite 2m Digital Terrain Model (DTM) with a 2m grid resolution.

2.5.2 The DTM was obtained from the Environment Agency LiDAR data portal in February 2020. Supporting metadata shows that for the majority of the study area, the LiDAR survey was undertaken in 2017 and is considered to be the most current available data.

2.5.3 In some instances, the 2m LiDAR DTM was used to supplement cross sectional survey information within the 1D FMP models to extend surveyed cross sections to cover a wider area of the floodplain. The DTM was also utilised to create level-volume curves for application within reservoir units within the 1D models, where these were required.

2.6 Software

2.6.1 1D channels for all the ordinary watercourses have been represented in FMP. FMP is an industry standard 1D hydraulic modelling package.

2.6.2 All hydraulic models were simulated using FMP version 4.4 or later.

2.6.3 Where a 2D model was required to represent the floodplain, TUFLOW software was used. TUFLOW is an industry standard two-dimensional hydraulic modelling package.

2.6.4 TUFLOW version 2018-03-AD or later was used for all 1D-2D model simulations undertaken.

2.7 Roughness

2.7.1 Channel and floodplain friction was represented within the hydraulic models by defining a varying Manning's Roughness Coefficient across the 1D, and where present, 2D domains.

2.7.2 Within 1D FMP models, Manning's Roughness Coefficients ('n') were assigned within cross sections, and to structures based upon survey information and photographs.

2.7.3 Within 2D TUFLOW models, OS Mastermap data was used to define floodplain land cover, allowing Manning's Roughness Coefficients to be spatially distributed across the domain.

2.7.4 Industry standard values were applied based upon relevant literature, values are summarised in **Table 2-2**[4].

Table 2-2: Manning's 'n' Roughness Coefficients

Surface	'n'
2D	
Building	0.30
Roads and Paved areas	0.025
Grass	0.06
1D	
Smooth channel bed	0.035
Rough Grass	0.06
Short Grass	0.05
Concrete	0.025
Brick Walls	0.03

[4] Chow (1959) Open Channel Hydraulics

2.8 Model boundary conditions

2.8.1 Model inflows were applied at the primary watercourse upstream boundary. The design hydrographs included catchment areas to the downstream model boundary. As the modelled reach lengths were relatively short, this approach provided a conservative estimate of flows at the A428 crossing for the purposes of the Scheme assessment. Any exceptions to this approach are detailed within individual watercourse sections with additional information about the modelling hydrology found in Annex C: Ordinary Watercourse Hydrology Report.

2.8.2 As highlighted within Section 1.1, the ordinary watercourses all ultimately drain into the River Great Ouse. For a number of the watercourses, the downstream model boundary coincides with the confluence with the River Great Ouse (RGO). However, for most of the modelled watercourses the downstream boundary is located upstream of the confluence. A summary of the downstream boundary locations is provided within **Table 2-3**.

Table 2-3: Downstream Boundary Locations

Watercourse	Downstream Boundary Location
West Brook	~ 8km upstream of RGO confluence
Wintringham Brook	~ 2km upstream of RGO confluence
Wintringham Brook Tributary	~ 2km upstream of RGO confluence
Gallow Brook	~ 5km upstream of RGO confluence
Begwary Brook	~ 500m upstream of RGO confluence
Rockham Ditch	At confluence with RGO
Top Farm Ditch	~ 2km upstream of RGO confluence
Hen Brook	~ 2km upstream of RGO confluence
Rectory Farm Brook	At confluence with Stone Brook, 1.5km upstream of RGO
South Brook	At confluence with RGO

2.8.3 In order to adopt a consistent approach across all watercourse models and to retain model stability, a normal depth boundary has been applied at the downstream boundary of the 1D models. A normal depth boundary calculates outflow based upon the gradient of the channel bed and assumes outflow is unrestricted. For 1D-2D models a head flow (HQ) boundary was applied at the downstream limit of the 2D model domain, reflecting the slope of the floodplain.

2.8.4 Where the downstream boundary of a watercourse model is located at, or in close proximity to, the confluence with the River Great Ouse, sensitivity testing has been used to assess the potential impact of raised levels within the River Great Ouse upon the assessment of the Scheme. For these sensitivity tests head time (HT) boundaries have been applied within both the 1D FMP, and 2D TUFLOW models where required, with water levels set to bank full level for the River Great Ouse at the location of the confluence. Bank full levels were obtained from the 1D-2D River Great Ouse hydraulic model, which forms Annex A of the FRA.

2.8.5 For all ordinary watercourse models, the upstream and downstream model boundaries are located sufficiently far from the proposed A428 Scheme elements to enable all impacts of the Scheme to be captured within the domain.

2.9 Compensatory storage

2.9.1 As part of this assessment results from each of the hydraulic models have been used to determine the need for compensatory storage to be provided as part of the scheme, and to inform the calculations of required volumes.

2.9.2 To determine whether compensatory storage was required for a watercourse peak in-channel flood levels were extracted from the baseline scenario model for the 1% AEP + 35% climate change design event at the location of the proposed Scheme. These modelled levels were interpolated within Civils 3D software to create a representation of the maximum water surface elevation, which was then intersected with a surface generated from topographical survey, in order to determine the presence of out of bank flow that would be displaced by the Scheme embankment. The outcome of this assessment was confirmed by checking of maximum levels within 1D model cross sections.

2.9.3 Where the above comparison indicated the presence of out of bank flow, the modelled levels and topographical surface were used along with scheme designs to calculate the required compensatory storage on a level for level, volume for volume basis. These calculations were also undertaken in Civils 3D software, using layers with a maximum thickness of 200mm. For watercourses where the initial level comparison indicated flows remained within bank, compensatory storage was not required and further assessment was not undertaken.

2.9.4 Further details relating to compensatory storage are included within each of the watercourse sections. Detailed calculations relating to floodplain volume compensation are provided in Appendix D.

2.9.5 It should be noted that this methodology utilises maximum modelled water levels from each of the watercourse models, and therefore will reflect uncertainties associated with the models, detailed within section 2.10 and within each individual watercourse section. Nevertheless, the hydraulic models are considered to provide an appropriate representation of hydraulics within each of the watercourses, commensurate with their size and associated level of risk. Therefore the overall methodology for calculation of compensatory volumes is considered conservative.

2.10 General Limitations

2.10.1 Hydraulic modelling has been used to underpin the assessment of flood risk for the ordinary watercourses. It is important that limitations and uncertainties of hydraulic models are taken into account when considering the results and any changes in flood risk associated with the proposed Scheme. Modelling uncertainties should be considered as a cascade and several key overarching uncertainties associated with the ordinary watercourse hydraulic modelling are described below.

2.10.2 Hydraulic models are a numerical representation of complex natural systems, and thus hydraulic models are associated with inherent assumptions and simplifications. These vary according to the model complexity and specific software packages, and are detailed within Section 2.3.2 and 2.3.3.

2.10.3 Uncertainties associated with hydrological inflows generated through FEH methods are typically the largest source of uncertainty associated with hydraulic modelling. For ungauged catchments, such as those included within this report, peak flows estimated through the best available FEH methods are associated with an uncertainty of +/-40%. Please refer to the Ordinary Watercourse Hydrology Report and FEH Calculation Record, Annex C to the FRA, for further information relating to hydrological uncertainties and limitations.

2.10.4 For each watercourse model hydrological inflows were calculated for the entire catchment to the downstream model boundary. For all watercourses presented within this report the entire flow hydrograph was input into the model at the upstream boundary, no lateral flows were used to represent the intervening catchments. Input of all flows at the upstream model boundary will mean that the assessment of the Scheme is conservative.

2.10.5 Another significant source of uncertainty within hydraulic modelling is the data used to define floodplain topography. The 1m LiDAR DTM data used within this study is associated with a stated vertical accuracy of +/-0.15m. Based upon past experience in the use of similar LiDAR data, the data may be less accurate than the stated tolerance within areas characterised by a large number of surface features which require the data to be filtered. For example, in areas of dense vegetation, DTM levels may vary from actual ground elevations by more than 1m.

2.10.6 Roughness values are fixed within each model and therefore do not account for a variation with regards to time of year (change in vegetation density) or depth of flooding.

2.10.7 The hydraulic models for the ordinary watercourses created and documented as part of this modelling report have not been quantitatively calibrated or verified. Formalised calibration and verification of models relies upon the availability of hydrometric data or other sources of observed data relating to flooding, which can be used to compare with and assess the performance of the hydraulic models. No hydrometric data, or other quantitatively observed flood data, were readily available for utilisation within this commission, likely due to the fact that these are ordinary watercourses and of a relatively small size. In lieu of observed data, model proving has been based around sensitivity analysis. Sensitivity analysis has been completed for all watercourse models, addressing model parameters and inputs namely roughness, inflows and downstream boundary configuration. These sensitivity analyses provide an indication of the model response to variation in key parameters and inputs and increase confidence in modelling outputs, and the assessment of the A428 scheme.

2.10.8 Specific limitations for each of the watercourse models are provided within each of the watercourse sections.

3 West Brook (1D FMP)

3.1 Overview

3.1.1 West Brook is a small watercourse located east of St Neots between Croxton and Eltisley. The watercourse begins in Eltisley and flows north towards Yelling and is located predominantly in agricultural fields. The head of the watercourse is located downstream of the existing A428 and is joined by one small tributary from the west before joining Gallow Brook which then outfalls to the River Great Ouse (**Figure 3-1**). The upstream tributary also originates south of the A428 and flows north before joining the main West Brook after flowing beneath the A428. The typical cross section channel width is approximately 5m while the peak flow estimate for the 1% AEP event is 1.70m^3/s.

3.1.2 This section details the development and outcome of the baseline and proposed model results for West Brook. The criteria for assessing the model comparison for West Brook are that:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

3.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the water level in the proposed model is not greater than in the baseline.

3.1.4 Additionally, this section details whether compensatory storage is required, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

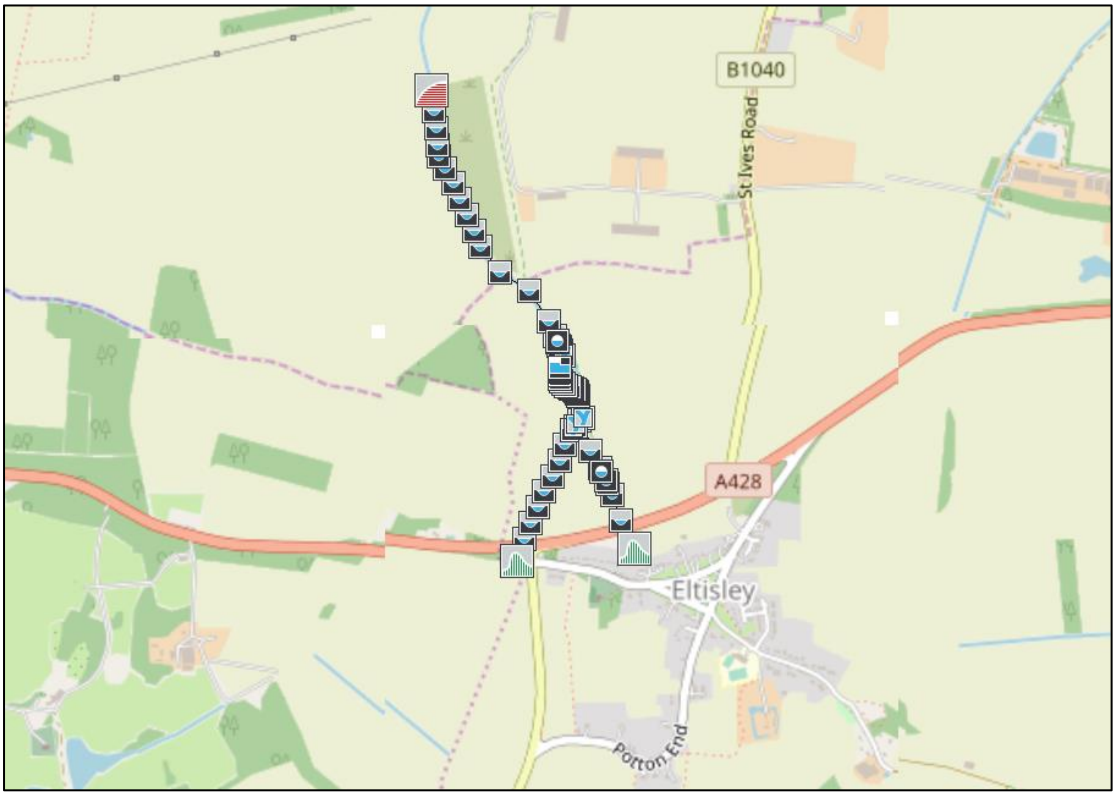


Figure 3-1: West Brook Model Location in Flood Modeller Pro

3.2 Model setup - baseline scenario

3.2.1 **Table 3-1** includes all key information regarding the setup of the West Brook baseline model.

Table 3-1: Baseline Model Setup

Model Setup	Comments
Simulation time	25 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 2.0km
Upstream boundary	Flow-time boundary located immediately downstream of the existing A428 (526908, 259898)
Downstream Boundary – 1D	Normal Depth boundary located 1.5km downstream of existing A428 carriageway (526356, 261154)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

3.2.2 There is one tributary joining West Brook in the model, with an upstream boundary located south of the A428. The hydrology of the tributary is unknown so a small flow has been assumed for the flow time boundary.

3.2.3 There is an existing structure connecting the second tributary to the main watercourse, which is a circular culvert with a diameter of 450mm.

3.2.4 A normal depth boundary has been applied as there is not expected to be any backwater effects as the nearest downstream watercourse connection is 4.5km away from the current downstream boundary of the West Brook model. The baseline model contains 52 nodes over the 2.0km modelled reach of West Brook watercourse.

3.2.5 Additional information about the modelling hydrology can be found in Section 2.2 and in Annex C: Hydrology Report.

3.3 Model setup - Scheme scenario

3.3.1 The proposed Scheme design was incorporated into the hydraulic model downstream of the existing A428 crossing, which was unchanged in the proposed model. The new A428 crossing of West Brook is located approximately 530m downstream of the existing crossing. As baseline modelling indicated no out of bank flows at the location of the Scheme crossing, there was no requirement for floodplain compensation storage for West Brook.

3.3.2 The proposed Scheme model includes a realigned channel upstream of the A428 crossing and one culvert of 39.8m in length, including a raised pedestrian footway, under the A428. The asymmetrical culvert cross section shown in Figure 3-2 (not to scale) was simplified to a symmetrical culvert in the model to retain stability. The symmetrical culvert was modelled with an equivalent opening area to the design shown in Figure 3-3. The proposed channel is approximately 2.2m by 1.0m, whilst the raised pedestrian walkway is approximately 3.3m by 4.0m. Therefore, the maximum width of the modelled culvert is 5.5m and the maximum height is 5.0m.

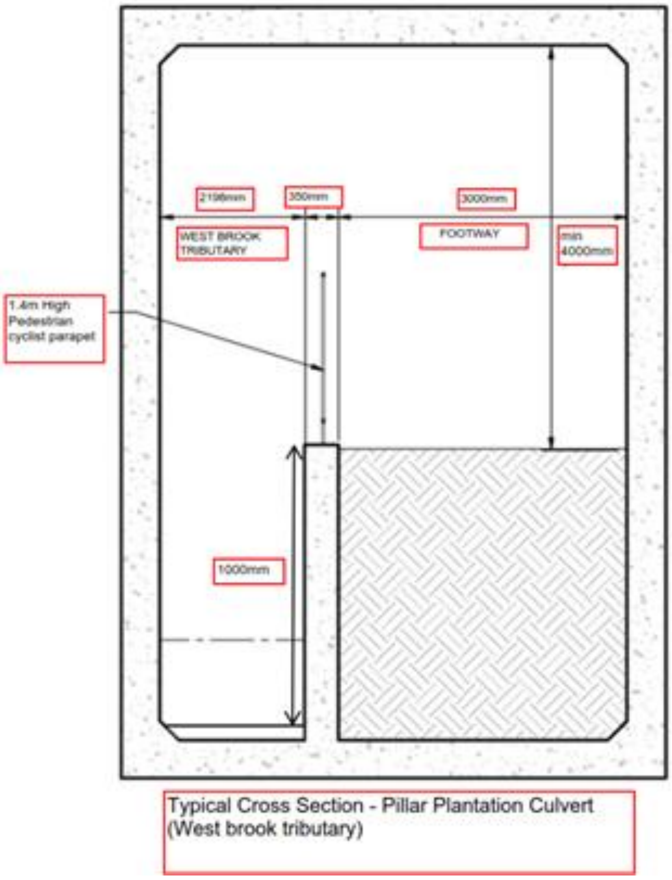


Figure 3-2: West Brook Proposed A428 Culvert (dimensions not to scale)

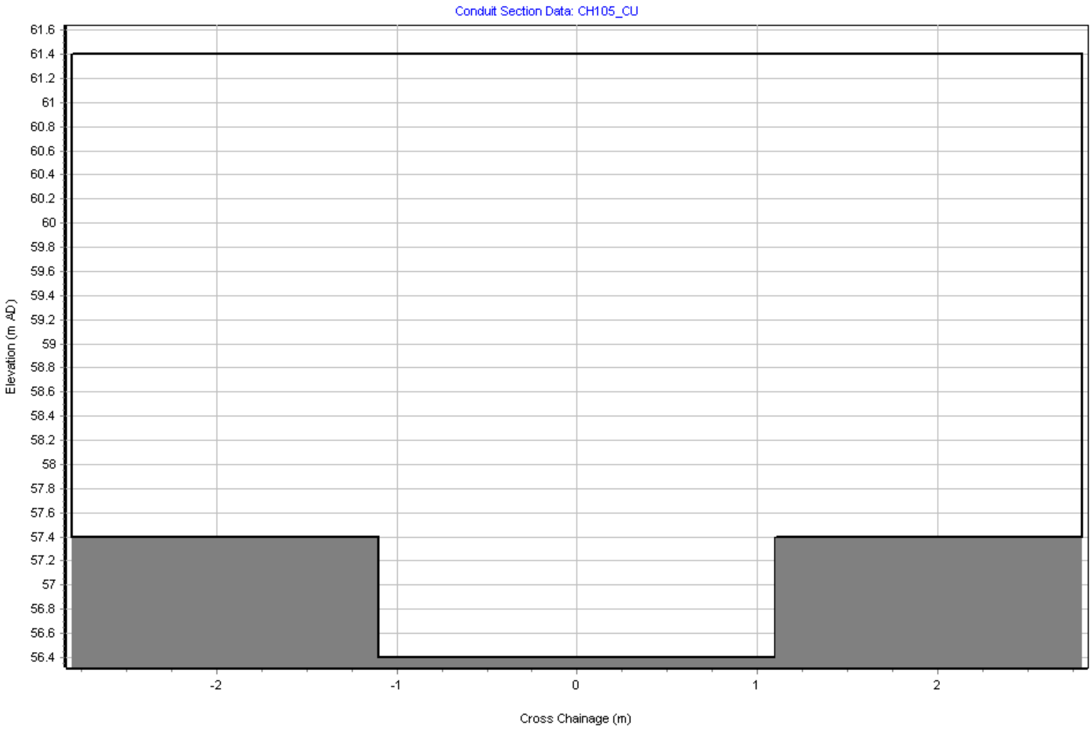


Figure 3-3: West Brook Proposed A428 Modelled Culvert (dimensions not to scale)

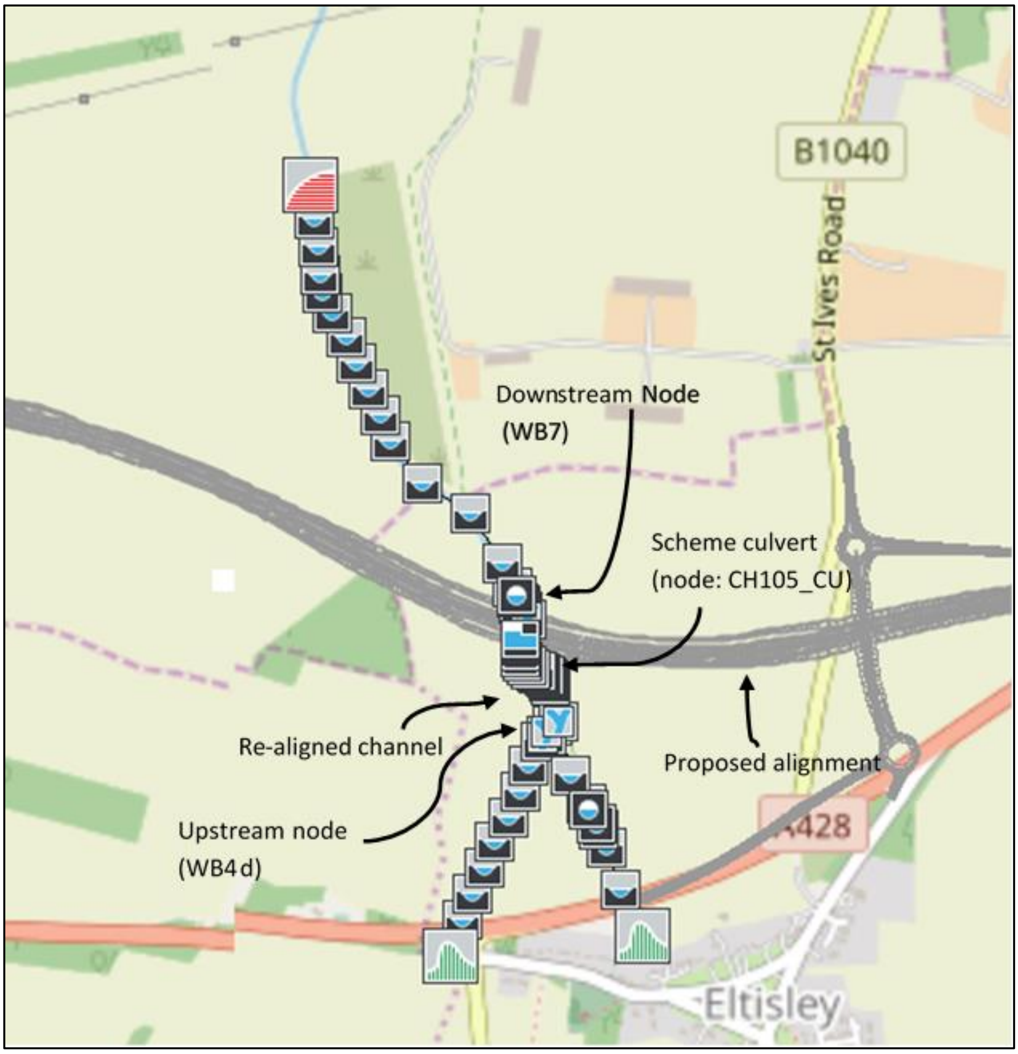


Figure 3-4: West Brook Proposed Scheme Model Schematic in Flood Modeller Pro

3.4 Results

Downstream peak flow

3.4.2 **Table 3-2** shows that the modelled peak flow of the proposed Scheme is the same as the baseline modelled peak flow for all simulated events. The node selected is the first point downstream of the A428 culvert that is not connected to a structure (labelled on **Figure 3-4**).

Table 3-2: Comparison of Peak Flow Results Downstream of A428 Culverts (Node WB7)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	1.19	1.19	0.0
1%	1.82	1.82	0.0
1% + 35%CC	2.42	2.42	0.0
1% + 65%CC	2.94	2.94	0.0
0.1%	3.13	3.13	0.0

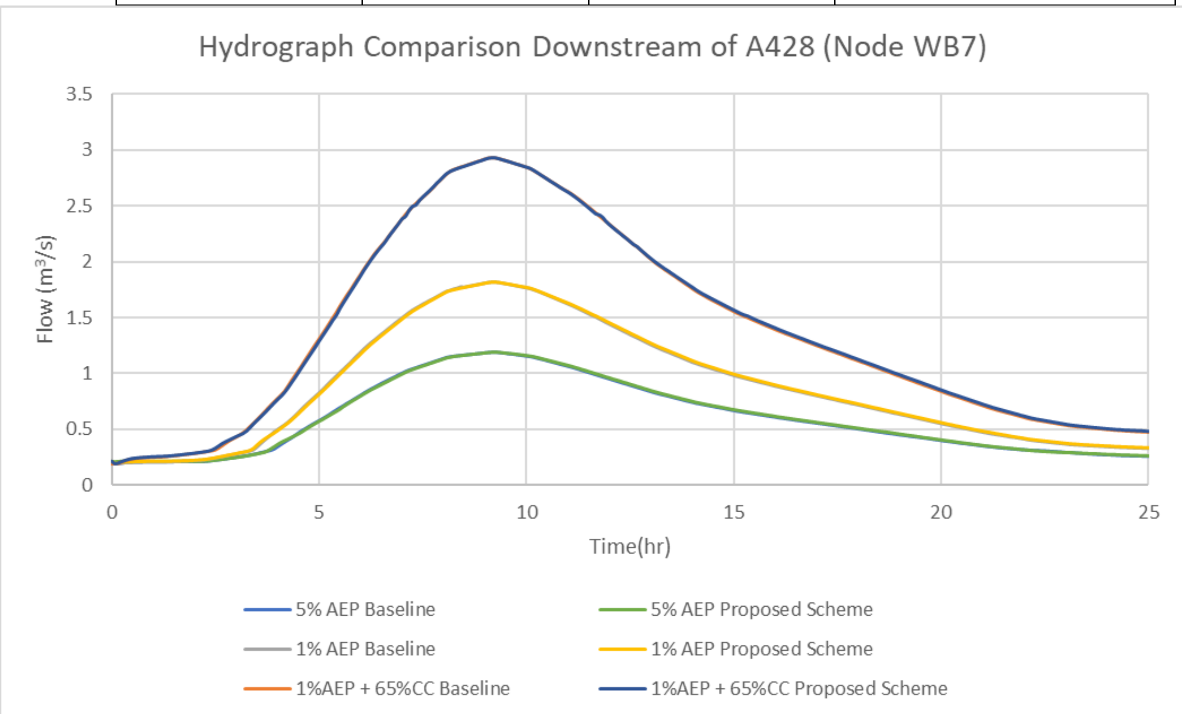


Figure 3-5: Hydrograph of Baseline and Proposed Scheme Downstream of A428 Culverts (Node WB7) for the 5% AEP, 1% AEP and 1% AEP + 65% climate change event for the West Brook model

3.4.3 **Figure 3-5** displays the modelled flow for the baseline and proposed Scheme downstream of the new A428 crossing. The hydrograph for 5% AEP, 1% AEP and 1% AEP + 65% climate change event for the proposed Scheme follows the hydrograph for the baseline scenario. For 1% AEP + 65% climate change event, the baseline and proposed Scheme both reach the same peak flow of 2.94m^3/s. Modelling results demonstrate that including the proposed A428 bridge culvert in the model does not create a negative impact on the peak flow downstream of the proposed A428.

Scheme culvert peak water level

3.4.4 **Figure 3-6** assesses the modelled water level in the proposed A428 culvert, as the peak water level during the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable. **Figure 3-6** also displays the level of the pedestrian walkway to demonstrate if floodwater will overtop the channel onto the adjoining footpath. **Figure 3-6** displays the water level in the A428 crossing culvert (CH105_CU) with an invert level of 57.40m AOD and soffit level of 60.10m AOD.

3.4.5 The model results shown in **Figure 3-6** indicate that the minimum freeboard of 300mm and desirable freeboard of 600mm, between the soffit of the culverts and peak water level for the 1% AEP + 65% climate change event is achieved for the proposed A428 culvert. The pedestrian walkway level is 57.40m AOD and the modelled peak water level in the culvert is 57.55m AOD. The model shows that the water level in the culvert is greater than the invert level of the pedestrian walkway so the footpath would flood during the peak of the 1% AEP + 65% climate change event.

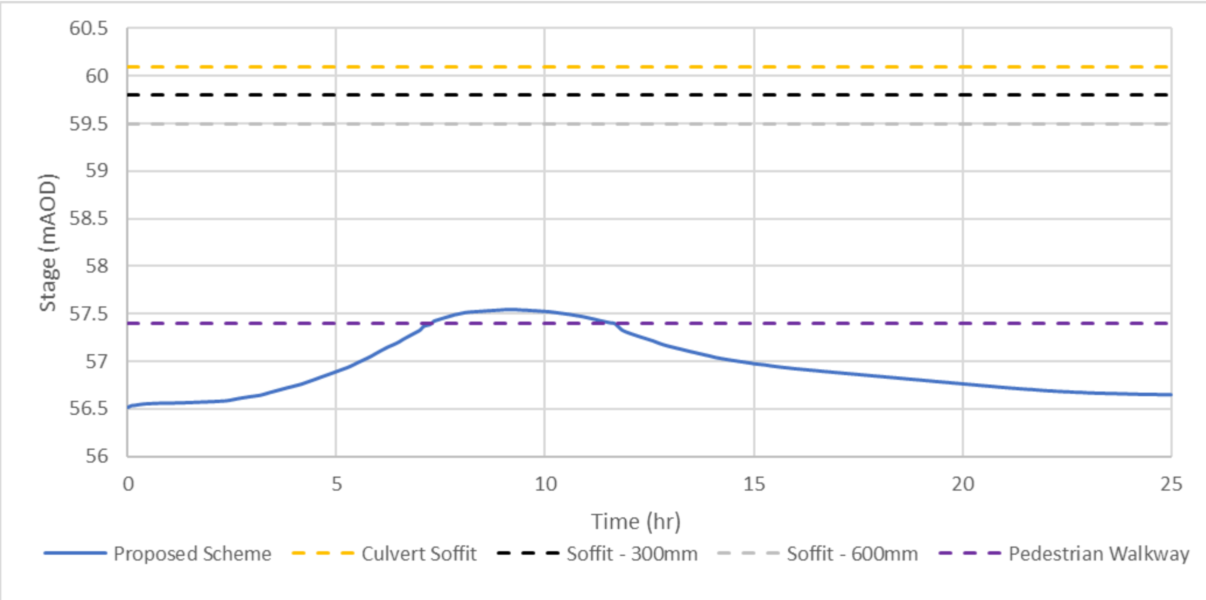


Figure 3-6: Stage Plot of A428 Culvert for the 1% AEP + 65% Climate Change Event for the West Brook model

Upstream peak water level

3.4.6 **Figure 3-7** displays the water level of the node at the upstream end of the model, approximately 0.4km upstream of the A428 culverts, as sections immediately upstream of the culvert reflect the channel realignment and thus are not directly comparable for the purpose of the Scheme assessment.

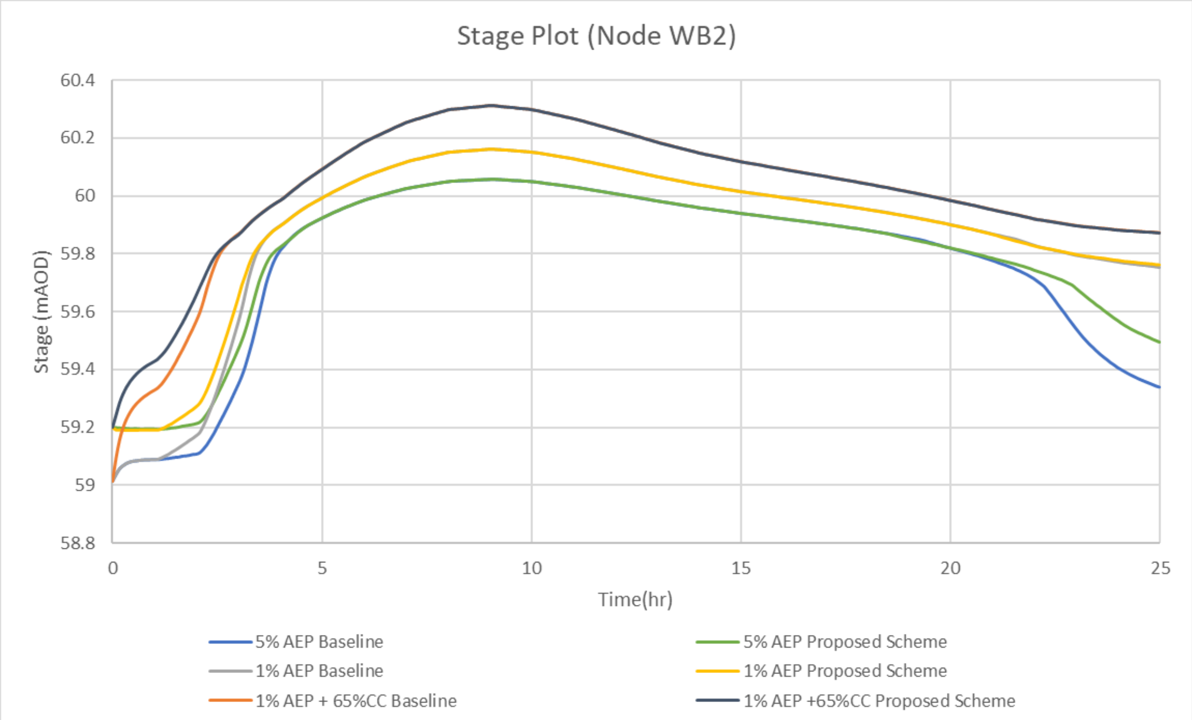


Figure 3-7: Stage Plot of Baseline and Proposed Scheme Upstream of A428 Culverts for the 5% AEP, 1% AEP and 1% AEP + 65% Climate Change event for the West Brook model

3.4.7 Model results show that the peak water level for the baseline and proposed Schemes are the same at 60.31m AOD during the 1% AEP + 65% climate change design event upstream of the A428 culverts. For both the 5% AEP and 1% AEP the model results show the peak water level is the same for the baseline and proposed Scheme. The small differences in water level at the beginning of the baseline and proposed Scheme models is due to the difference in initial water level in the model only, and is not reflective of a difference in watercourse hydraulics as a result of the Scheme. This indicates that the A428 culverts are not restricting flow upstream in the proposed model.

Compensatory Storage

3.4.8 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Wintringham Brook, with a maximum level of 57.45 mAOD at node WB5, located upstream of the proposed Scheme crossing. Therefore, compensatory storage is not required.

3.5 Sensitivity Analysis

3.5.1 Sensitivity analysis has been performed on the West Brook proposed model to verify that the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event included:

a. ± 20% Upstream Boundary Inflow.

b. ± 20% Manning's Roughness Coefficient.

3.5.2 **Table 3-3** displays the peak water level upstream, downstream and at the A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. Figure 3-8 displays the water level at the proposed A428 culvert for 1% AEP + 65% climate change event and the four sensitivity tests undertaken.

Table 3-3: Sensitivity Analysis Results

	Peak Water Level m AOD		
	Upstream (Wb4d)	A428 Culvert (CH105_CU)	Downstream (WB7)
Proposed Scheme	58.20	57.55	56.71
Flow +20%	58.28 (+0.08m)	57.66 (+0.11m)	56.82 (+0.11m)
Flow -20%	58.10 (-0.10m)	57.32 (-0.23m)	56.60 (-0.11m)
Roughness +20%	58.26 (+0.06m)	57.59 (+0.04m)	56.80 (+0.09m)
Roughness -20%	58.13 (-0.07m)	57.50 (-0.05m)	56.61 (-0.10m)

3.5.3 An increase and decrease of 20% was applied to the flow hydrograph at the upstream boundary of West Brook model. A 20% increase in flow at the upstream boundary has produced an increase of +0.11m in water level at the A428 culvert. When the flow is decreased by 20%, the water level at the A428 culvert falls by -0.23m compared to the proposed model results.

3.5.4 Manning's roughness analysis was performed on the proposed model to determine how the model responds when the main model parameters were varied. A 20% increase and decrease were applied globally in the model to all Manning’s Roughness Coefficients in the 1D channel and banks. Model results show that a 20% increase globally to Manning’s Roughness Coefficients in channel and on the bank have produced an increase of +0.04m in water level in the culvert and a 20% decrease produces a fall of -0.05m in the water level.

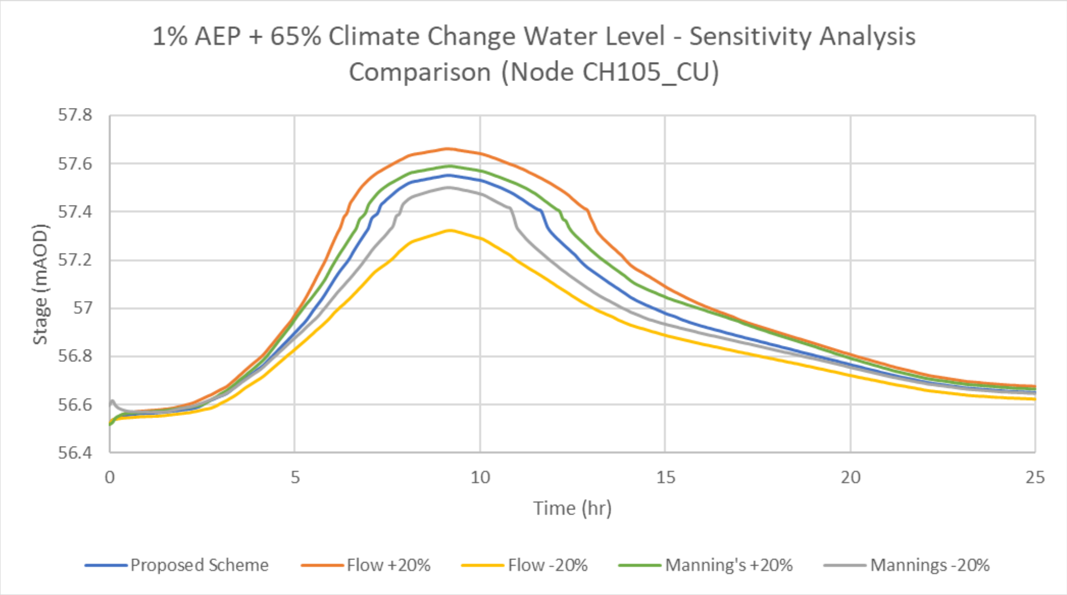


Figure 3-8: Sensitivity Analysis of A428 Culvert for the 1% AEP + 65% Climate Change event for the West Brook model

3.6 Limitations

3.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

3.6.2 The upstream model boundary for the main West Brook watercourse is located immediately downstream of a culvert beneath the existing A428, and therefore this structure and its potential attenuating impact upon flood flows is not accounted for in the model. Ideally, the existing A428 culvert would be included within the model to account for its hydraulic impact, however the fact that this culvert is not modelled will result in a more conservative approach to the assessment of the Scheme.

3.6.3 Out of bank storage has been represented through inclusion of extended 1D channel sections. This approach to the representation of floodplain flow is simple and assumes flow is one dimensional in the same direction as the channel. Given the small size of the watercourse and limited occurrence of out of bank flows on West Brook it is not expected that the simplified representation of floodplain flow will impact upon the assessment of the Scheme. Furthermore, there are no vulnerable receptors within the area, and therefore detailed flood mapping is not required.

3.6.4 A simplified approach was used to apply a Manning's Roughness Coefficient of 0.035 (n) within river sections throughout the model. This assignment of Manning's Roughness Coefficient 'n' values was supported by observations of the survey team, who noted that the channel was characterised by a smooth bed through the surveyed reach. Sensitivity analysis testing the roughness produced little variation in the water level in the channel so this has been deemed as an acceptable assumption in the model.

3.6.5 Overall, the specific limitations stated within this section are thought to be relatively small contributors to the overall model uncertainty, particularly in light of uncertainties relating to hydrological inflows. Given that West Brook is an ungauged catchment, hydrological peak flow estimates can be associated with an error of +-40%.

3.7 Conclusions

3.7.1 In the West Brook model, the flow downstream of the A428 crossing is the same in the proposed model and baseline model for the 1% AEP + 65% climate change scenarios. For all return periods tested, the peak flow in the baseline and proposed model were the same indicating there is no increase in peak or volumetric flow downstream of the A428 crossing.

3.7.2 The water level in the culvert under the proposed A428 is lower than the minimum freeboard of 300mm and desired freeboard of 600mm for the 1% AEP + 65% climate change event. It is noted that the peak water level is greater than the invert level of the pedestrian walkway indicating that footpath would flood during the peak of the 1% AEP + 65% climate change event.

3.7.3 There is no increase in peak water level at the upstream end of the modelled reach during the 1% AEP + 65% climate change event in the proposed model compared to the baseline. Modelled results presented demonstrate that the A428 culverts do not restrict flow upstream of the crossing in the proposed model.

3.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed indicates that flow is contained within bank, and compensatory storage is not required.

4 Wintringham Brook (1D FMP)

4.1 Overview

4.1.1 Wintringham Brook is a small watercourse located east of St Neots. The head of the watercourse is located in the fields east of the A428 near Lower Wintringham Farm and flows west under the A428 towards St Neots (Figure 4-1). The confluence of Wintringham Brook Tributary and Wintringham Brook is located beyond the downstream boundaries of both hydraulic models. The typical cross section channel width is approximately 5m, while the peak flow estimate for the 1% AEP event is 2.50m^3/s.

4.1.2 This section details the development and outcome of the baseline and proposed model results for Wintringham Brook. The criteria for assessing the model comparison are stated below:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Peak water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

4.1.3 Additionally, the impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the water level in the proposed model is not greater than in the baseline.

4.1.4 Additionally, this section details whether compensatory storage is required for Wintringham Brook, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

Figure 4-1: Wintringham Brook Model Location in Flood Modeller Pro

4.2 Model setup- baseline scenario

4.2.1 **Table 4-1** includes all key information regarding the setup of the Wintringham Brook baseline model.

Table 4-1: Baseline Model Setup

Model Setup	Comments
Simulation time	40 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.5km
Upstream boundary	Flow-time boundary located in fields east of the existing A428 near Lower Wintringham Farm (521126, 259072)
Downstream Boundary – 1D	Normal Depth boundary located 0.4km downstream of existing A428 carriageway (519929, 259535)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

4.2.2 Existing structures within the baseline model include the existing A428 crossing (2.8m by 2.0m) and two small bridge culverts representing field crossings upstream of the A428.

4.2.3 A normal depth boundary has been applied as there is not expected to be any backwater effects from areas downstream of the Wintringham Brook model. The confluence of Wintringham Brook Tributary and Wintringham Brook is located beyond the downstream boundaries of both hydraulic models and interaction between the two is not expected to impact model results. The effect of an inflow from Wintringham Brook Tributary on Wintringham Brook has been included in the sensitivity analysis in **Figure 4-8**. The baseline model contains 50 nodes over the 1.5km modelled reach of Wintringham Brook watercourse.

4.2.4 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

4.3 Model setup- Scheme scenario

4.3.1 The proposed Scheme design was incorporated into the hydraulic model. The Wintringham Brook proposed Scheme model includes two additional culverts; one under the access road for the attenuation ponds (also known as attenuation basins) and one under the proposed A428. As baseline modelling indicated no out of bank flows at the location of the Scheme crossing, there was no requirement for floodplain compensation storage for Wintringham Brook. The proposed A428 crossing of Wintringham Brook is located approximately 380m upstream of the existing crossing. The existing A428 crossing is being retained so no changes were made to this culvert in the model.

4.3.2 Amendments were made to the cross-sections at the road crossing locations to create the culverts. The culvert under the proposed A428 is a 2.4m by 2.4m square culvert, shown in **Figure 4-2**, and 45m in length. Upstream of the A428 crossing is a road, inclusive of culvert beneath, which provides maintenance access to the attenuation ponds. This culvert was modelled as a 2.1m by 2.1m culvert, 7.5m in length.

Figure 4-2: Wintringham Brook Proposed A428 crossing culvert (dimensions not to scale)

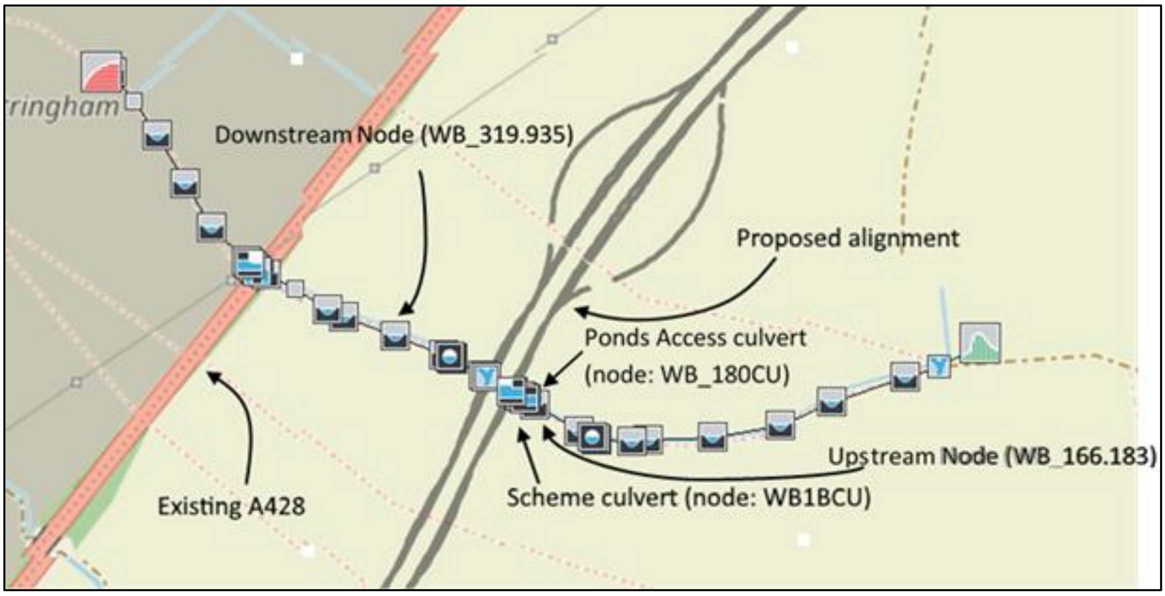


Figure 4-3: Wintringham Brook Proposed Scheme Model Schematic in Flood Modeller Pro

4.4 Results

Downstream peak flow

4.4.2 **Table 4-2** below shows that the modelled peak flow of the proposed Scheme is the same as the baseline peak flow for all simulated events. The node selected is the first downstream point from the A428 culvert that is not connected to a structure (labelled on Figure 4-3).

Table 4-2: Comparison of Peak Flow Results Downstream of A428 Culverts (Node WB_319.935)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (proposed vs Baseline)
5%	1.59	1.59	0.0
1%	2.46	2.46	0.0
1% + 35%CC	2.91	2.91	0.0
1% + 65%CC	3.55	3.55	0.0
0.1%	4.25	4.25	0.0

4.4.3 **Figure 4-4** displays the modelled flow for the baseline and proposed Scheme downstream of the proposed A428 crossing. The hydrograph for 1% AEP + 65% climate change event for the proposed Scheme follows the hydrograph for the baseline Scheme, with both reaching the same peak flow of 3.55m^3/s. This is also the case for the modelled 1% and 5% events. Modelling results indicate that including the A428 culvert in the model does not create a negative impact on the peak flow downstream of the proposed A428.

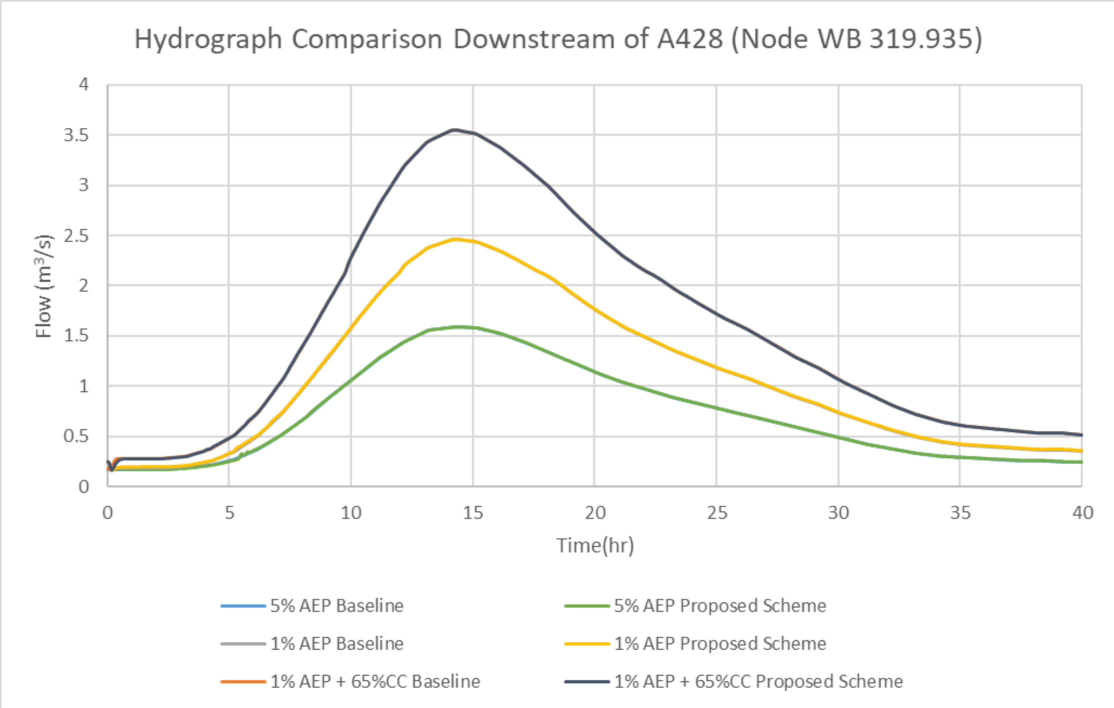


Figure 4-4: Hydrograph of Baseline and Proposed Scheme Downstream of A428 Culvert (Node WB_319.935) for the Wintringham Brook Model

Scheme culvert peak water level

4.4.4 **Figure 4-5 and 4-6** assess the modelled water level in the proposed A428 culvert. The peak water level during the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428 crossing. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (also included on the figure).

4.4.5 **Figure 4-5** displays the water level at the proposed A428 culvert (WB1BCU) which has an invert level of 25.05m AOD and a soffit level of 27.45m AOD. **Figure 4-6** displays the water level in the access track culvert which has an invert level of 25.15m AOD and a soffit level of 27.25m AOD. This is located upstream of the proposed A428 crossing.

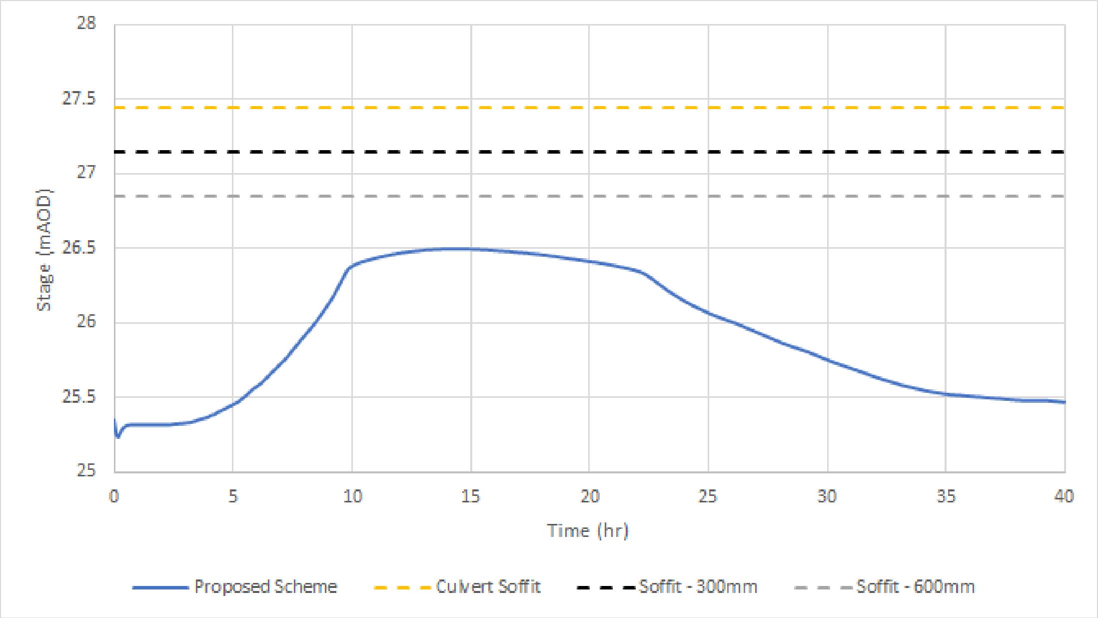


Figure 4-5: Stage Plot of the Proposed A428 Culvert for 1% AEP + 65% Climate Change Event for the Wintringham Brook model

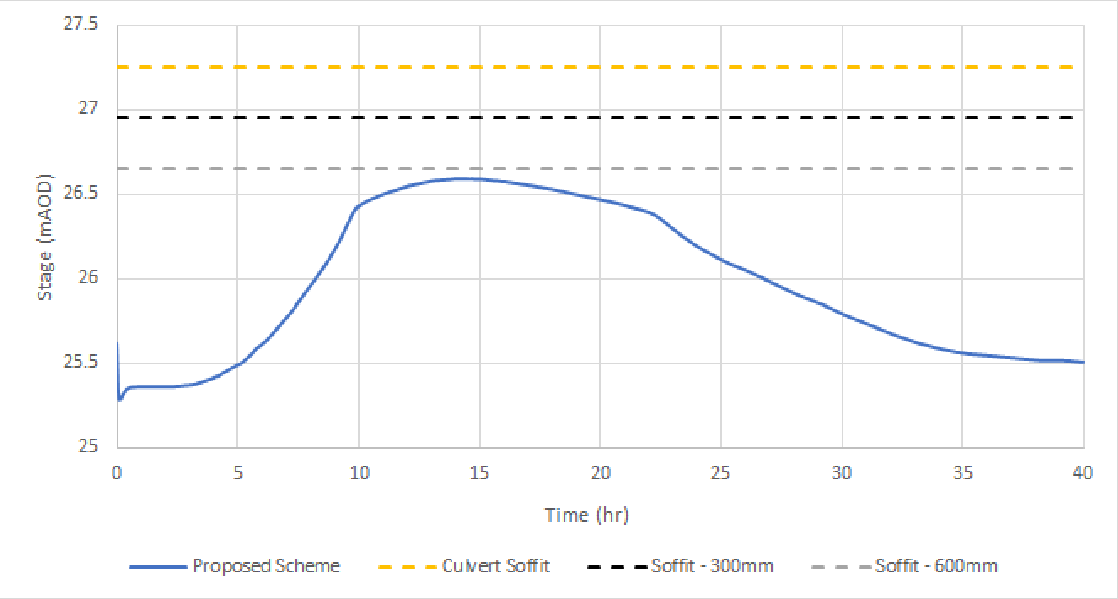


Figure 4-6: Stage Plot of Access Track Culvert for 1% AEP + 65% Climate Change Event for the Wintringham Brook model

4.4.6 **Figure 4-5 and 4-6** indicate that the minimum freeboard of 300mm and desirable freeboard of 600mm between the soffit of the culverts and peak water level for the 1% AEP + 65% climate change event is achieved for both the proposed A428 culvert and maintenance access track culvert.

Upstream peak water level

4.4.7 **Figure 4-7** displays the water level of the first node upstream of the proposed A428 culvert that occurs in both the baseline and proposed model (WB_166.183), shown on Figure 4-3.The modelled 1% AEP + 65% climate change peak water level for the proposed Scheme is 26.69m AOD which is the same as the baseline. For the 1% AEP and 5% AEP modelled events, peak flood levels upstream of the Scheme in the proposed scenario are lower than for the baseline.

4.4.8 Based upon the stage plot in **Figure 4-7**, modelling results suggests that there is no increase in peak water level within Wintringham Brook upstream of the A428 crossing. Furthermore, other supporting modelling results presented within this section suggest that the Scheme exerts a minimal overall impact upon conveyance within Wintringham Brook.

Compensatory Storage

4.4.9 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Wintringham Brook, with a maximum level of 26.61 mAOD at node WB_166.183, located upstream of the proposed Scheme crossing. Therefore, compensatory storage is not required for this watercourse.

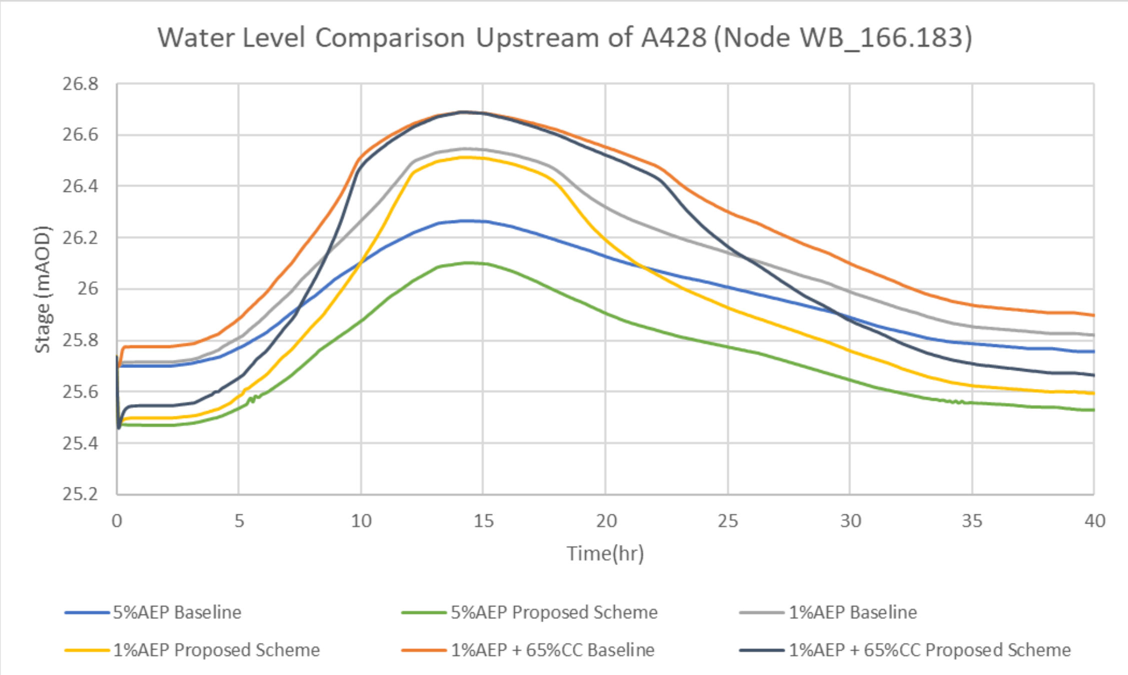


Figure 4-7: Stage Plot of Baseline and Proposed Scheme Upstream of the Proposed A428 Culvert for the Wintringham Brook model

4.5 Sensitivity Analysis

4.5.1 Sensitivity analysis has been performed on the Wintringham Brook model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were:

a. ± 20% Upstream Boundary Inflow.

b. ± 20% Manning's Roughness Coefficient.

c. Wintringham Brook Tributary Inflow.

4.5.2 **Table 4-3** displays the peak water level upstream, downstream and at the A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. Figure 4-8 displays the water level at the proposed A428 culvert for 1% AEP + 65% climate change event and the five sensitivity tests undertaken.

Table 4-3: Sensitivity Analysis Results

	Water Level m AOD		
	Upstream (WB_166.183)	A428 Culvert (WB1BCU)	Downstream (WB_319.935)
Proposed Scheme	26.69	26.50	25.78
Flow +20%	26.82 (+0.13m)	26.55 (+0.05m)	25.88 (+0.10m)
Flow -20%	26.58 (-0.11m)	26.44 (-0.06m)	25.66 (-0.12m)
Roughness +20%	26.73 (+0.04m)	26.52 (+0.02m)	25.87 (+0.09m)
Roughness -20%	26.56 (-0.13m)	26.48 (-0.02m)	25.67 (-0.11m)
Wintringham Brook Tributary Inflow	26.69 (+0.00m)	26.50 (+0.00m)	25.78 (+0.00m)

4.5.3 An increase and decrease of 20% was applied to the flow hydrograph at the upstream boundary of Wintringham Brook model. Increasing the inflow at the upstream boundary by 20% has resulted in a +0.05m increase to peak water level at the proposed A428 culvert. A 20% decrease in the total inflow produces a -0.06m decrease in peak water level at the node WB1BCU.

4.5.4 Manning's Roughness Coefficient analysis was performed on the proposed model to determine how the model responds when the main model parameters were varied. A 20% increase and decrease were applied globally in the model to all Manning's Roughness Coefficients in the 1D channel and banks. Model results show a 20% increase globally to Manning's Roughness Coefficients in channel and on the bank have produced an increase of +0.02m in water level at the culvert and a 20% decrease produces a fall of -0.02m in the water level.

4.5.5 The flow hydrograph at the downstream boundary of Wintringham Brook Tributary model has been extracted for the 1% AEP + 65% climate change event and applied to the Wintringham Brook model. This inflow was applied at the approximate location of the confluence with Wintringham Brook Tributary, with the aim of demonstrating the impact of this additional inflow on the Wintringham Brook Scheme assessment. Model results in Table 4-3 and **Figure 4-8** show that the inclusion of the inflow from Wintringham Brook Tributary has no effect on the water level in channel at the proposed Scheme culvert, demonstrating that the Scheme assessment using the current model configuration is robust.

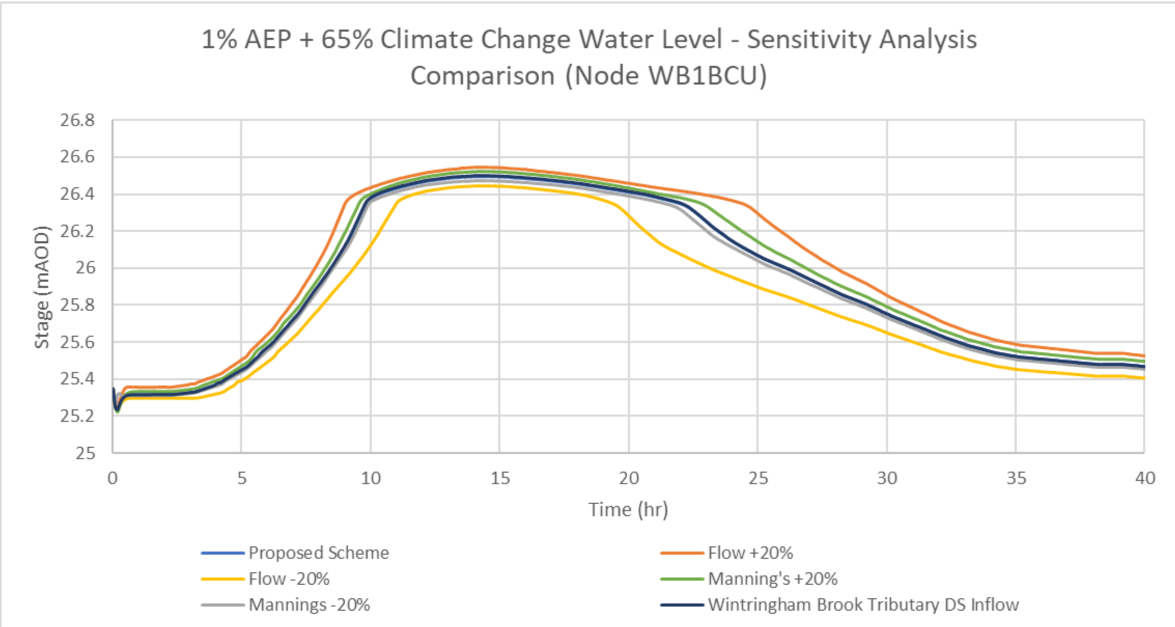


Figure 4-8: Sensitivity Analysis of the Proposed A428 Culvert for the 1% AEP + 65% Climate Change Event for the Wintringham Brook model

4.6 Limitations

4.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

4.6.2 The attribution of Manning's Roughness Coefficient 'n' values remains consistent through the reach, with values of 0.035 being applied within the channel and 0.05 being applied for top of banks and floodplain. These roughness coefficients were assigned based upon observations by the survey team, the modelled reach is relatively short and there were no clear changes in channel morphology, therefore the consistent application of Manning's Roughness Coefficient values was considered appropriate.

4.6.3 The downstream model boundary is configured as a normal depth boundary, which calculates outflow according to channel bed slope, assuming no other downstream influences. this boundary type has been selected as the downstream limit of the model is located within an open channel section of Wintringham Brook. Wintringham Brook ultimately confluences with Fox Brook, which then confluences with Hen Brook and finally the River Great Ouse more than 2km downstream of the downstream boundary of the Wintringham Brook model. Given the distance of the downstream model boundary from the River Great Ouse, along with the numerous watercourse connections, it is considered unlikely that raised levels within the River Great Ouse would impact upon the Scheme assessment for Wintringham Brook.

4.6.4 Wintringham Brook and Wintringham Brook Tributary have been modelled separately, not accounting for any interactions between these watercourses. Modelling results demonstrate that the Scheme does not result in any increase in peak or volumetric flow downstream from either watercourse, with conveyance being retained as per the baseline. This provides confidence that separate modelling of the tributaries is appropriate, as there are no significant changes in conveyance within one watercourse that might impact upon the other. A sensitivity test has been undertaken where the inflow from Wintringham Brook tributary has been included in the Wintringham Brook model at the approximate location of the confluence between the two watercourses. This sensitivity test suggests that the set-up of the model, and Scheme assessment, are robust.

4.6.5 Overall, the specific limitations stated within this section are thought to be relatively small contributors to the overall model uncertainty, particularly in light of uncertainties relating to hydrological inflows. Given that Wintringham Brook is an ungauged catchment, hydrological peak flow estimates can be associated with an error of +-40%.

4.7 Conclusions

4.7.1 In the Wintringham Brook model, the peak flow downstream of the proposed A428 culvert is the same in the proposed Scheme model as it is in the baseline model during the 1% AEP + 65% climate change event.

4.7.2 The water level in the Scheme culverts in the Wintringham Brook model do not exceed the minimum freeboard of 300mm or desired freeboard of 600mm. The peak water level for the access track culvert is 60mm below the 600mm freeboard level and the peak water level for the proposed A428 crossing culvert is 350mm below the 600mm freeboard level, for the 1% AEP + 65% climate change event.

4.7.3 The water level upstream of the A428 crossing culverts remains the same during the proposed scenario (when compared with the baseline) for the 1% AEP + 65% climate change event.

4.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed indicates that flow is contained within bank, and compensatory storage is not required.

5 Wintringham Brook Tributary (1D FMP)

5.1 Overview

5.1.1 Wintringham Brook Tributary is located east of St Neots and north of Wintringham Brook (**Figure 5-1**). The confluence of Wintringham Brook Tributary and Wintringham Brook is located beyond the downstream boundaries of both hydraulic models. The typical cross section channel width is approximately 3.50m while the peak flow estimate for the 1% AEP event is $0.80m^3/s$.

5.1.2 This section details the development and outcome of the baseline and proposed model results for Wintringham Book Tributary. The criteria for assessing the model comparison are stated below:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

5.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the water level in the proposed model is not greater than in the baseline.

5.1.4 Additionally, this section details whether compensatory storage is required for Wintringham Brook Tributary, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

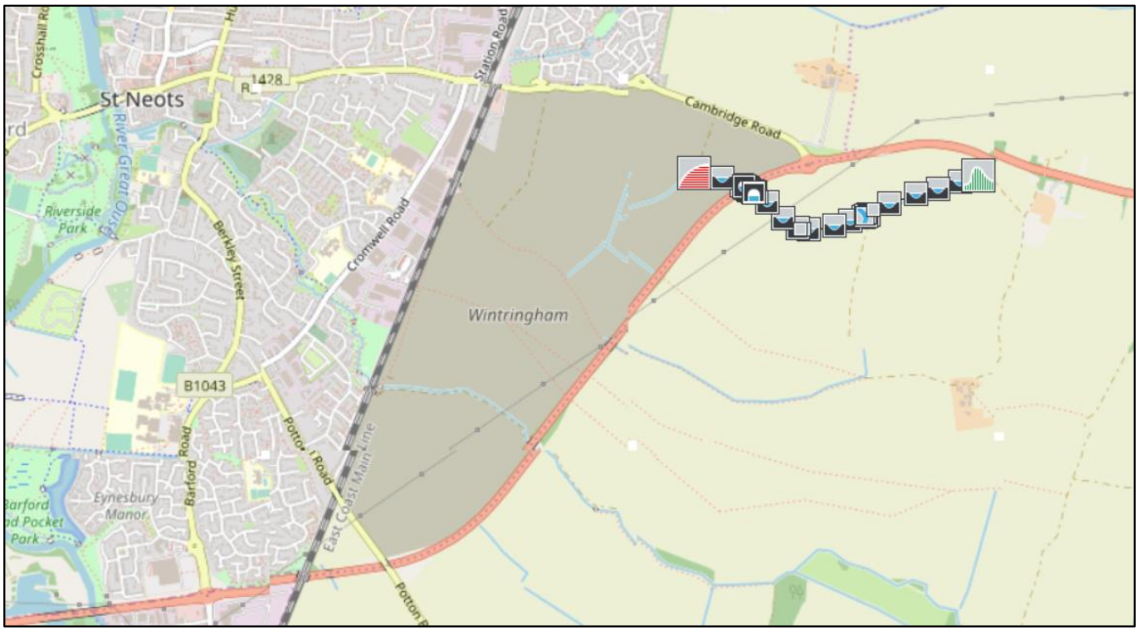


Figure 5-1: Wintringham Brook Tributary Model Location in Flood Modeller Pro

5.2 Model Setup- Baseline Scenario

5.2.1 **Table 5-1** includes all key information regarding the setup of Wintringham Brook Tributary model.

Table 5-1: Baseline Model Setup

Model Setup	Comments
Simulation time	20 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.3km
Upstream boundary	Flow-time boundary located in fields south of the existing A428 (521669, 259901)
Downstream Boundary – 1D	Normal Depth boundary located in fields 0.2km downstream of existing A428 carriageway (520505, 259912)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

5.2.2 The baseline model contains 41 nodes over the 1.3km modelled reach of the Wintringham Brook Tributary. There are three structures in the baseline model, the existing A428 crossing is a 1.0m diameter culvert and there are two small footpath crossings between fields.

5.2.3 A normal depth boundary has been applied within the model to reflect the fact that there are not expected to be any backwater effects from downstream of the Wintringham Brook Tributary model. The confluence of Wintringham Brook and Wintringham Brook Tributary is located beyond the downstream boundary of the Wintringham Brook Tributary model and interaction between the two is not expected to impact model results.

5.2.4 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

5.3 Model setup- Scheme scenario

5.3.1 The proposed Scheme model includes a realigned channel upstream of the proposed A428 and one rectangular 2.1m by 1.65m culvert (46.3m in length) under the proposed A428, as shown in **Figure 5-2 and Figure 5-3**. As baseline modelling indicated no out of bank flows at the location of the Scheme crossing, there was no requirement for floodplain compensation storage for Wintringham Brook Tributary.

5.3.2 The proposed scenario model contains a hydraulic attenuation area, approximately 130m x 36m, within the reach of realigned channel upstream of the proposed A428. Directly downstream of the hydraulic compensatory area, a 300mm diameter orifice plate limits pass on flow and encourages the hydraulic compensatory area to be utilised.

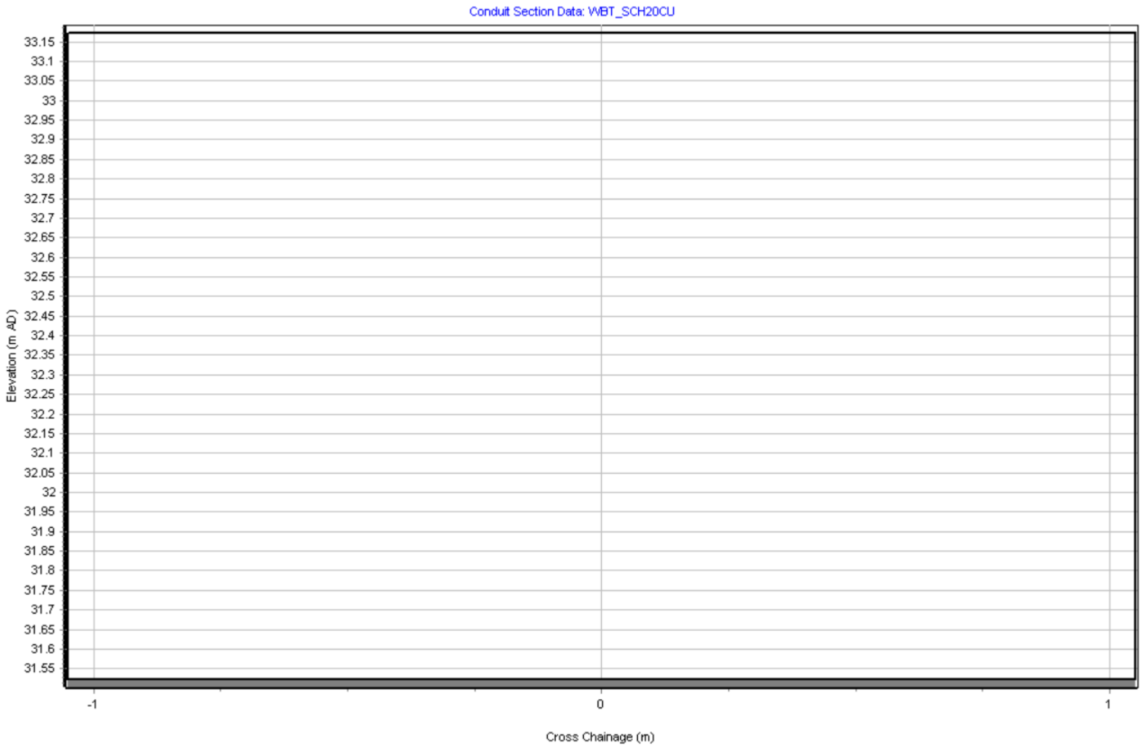


Figure 5-2: Wintringham Brook Tributary Proposed A428 crossing culvert (dimensions not to scale)

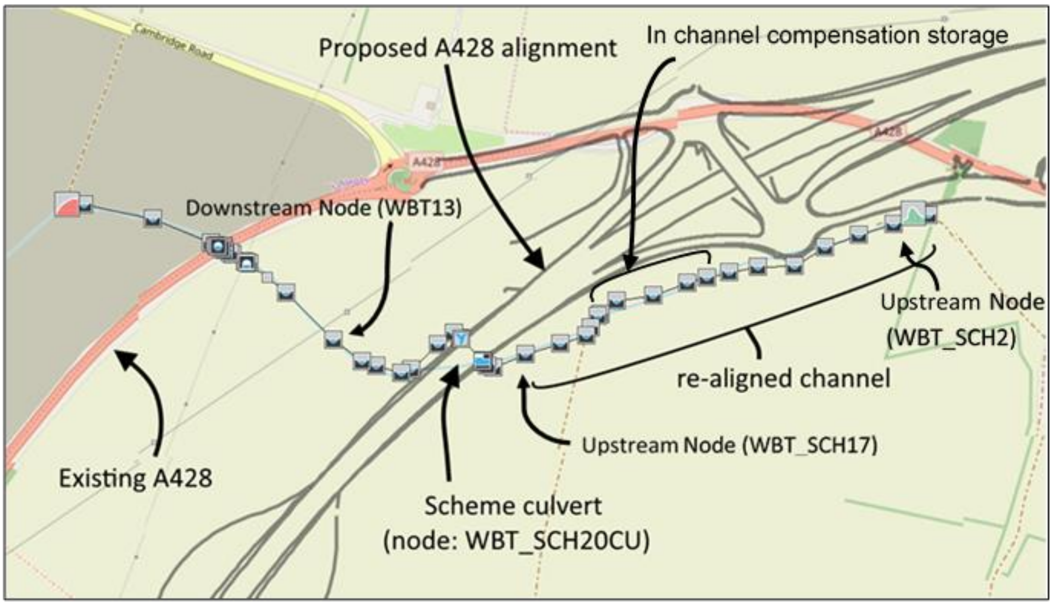


Figure 5-3: Wintringham Brook Tributary Proposed Scheme Model Schematic in Flood Modeller

5.4 Results

Downstream peak flow

5.4.2 **Table 5-2** below shows that the modelled peak flow downstream of the Scheme is greater in the baseline than the proposed Scheme for 5% AEP, 1% AEP, 1% AEP + 35% climate change. The modelled peak flow is the same in the baseline and proposed scenarios for 1% AEP + 65% climate change, and greater in the proposed scenario for 0.1% AEP by +0.03m3/s. The node selected is the first downstream of the A428 culverts that is not part of the reprofiled channel and not connected to a structure (labelled on **Figure 5-2**).

Table 5-2: Comparison of Peak Flow Results Downstream of A428 Culvert (Node WBT13)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	0.52	0.50	-0.02
1%	0.80	0.78	-0.02
1% + 35%CC	1.08	1.07	-0.01
1% + 65%CC	1.32	1.32	0.00
0.1%	1.40	1.43	+0.03

5.4.3 **Figure 5-4** displays the modelled flow for the baseline and proposed Scheme downstream of the proposed A428 and reprofiled channel sections. The model demonstrates that flow within the 1% AEP + 65% climate change event for the proposed Scheme scenario downstream of the proposed A428 is delayed by 1-2 hours when compared with the baseline.

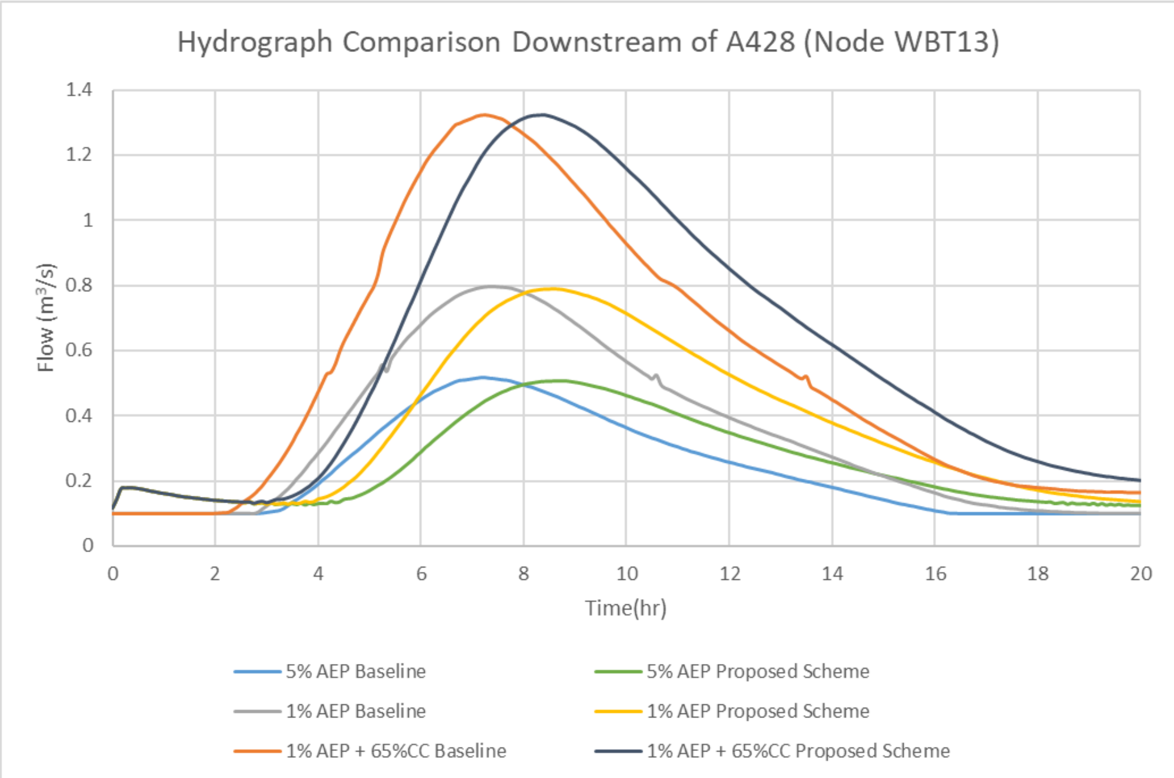


Figure 5-4: Hydrograph of Baseline and Proposed Scheme Downstream of A428 Culvert (Node WBT13) for the Wintringham Brook Tributary model

5.4.4 The delay in the hydrograph is due to the impact of the orifice plate, which constricts flow and forces water to utilise the hydraulic compensatory area located upstream of the proposed A428. It should be noted however that peak flow of 1.32m^3/s is experienced during both the baseline and proposed Scheme scenarios. Comparison of the baseline and proposed results have indicated that including the proposed A428 culvert and channel reprofiling in the model does not create a negative impact on the peak flow downstream.

Scheme culvert peak water level

5.4.5 **Figure 5-5** assesses the water level in the proposed A428 culvert. The peak water level during the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428 crossing. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (also included on the figure). Figure 5-4 displays the water level at the proposed A428 culvert (WBT_SCH20CU) which has an invert level of 31.52m AOD and soffit level of 33.17m AOD.

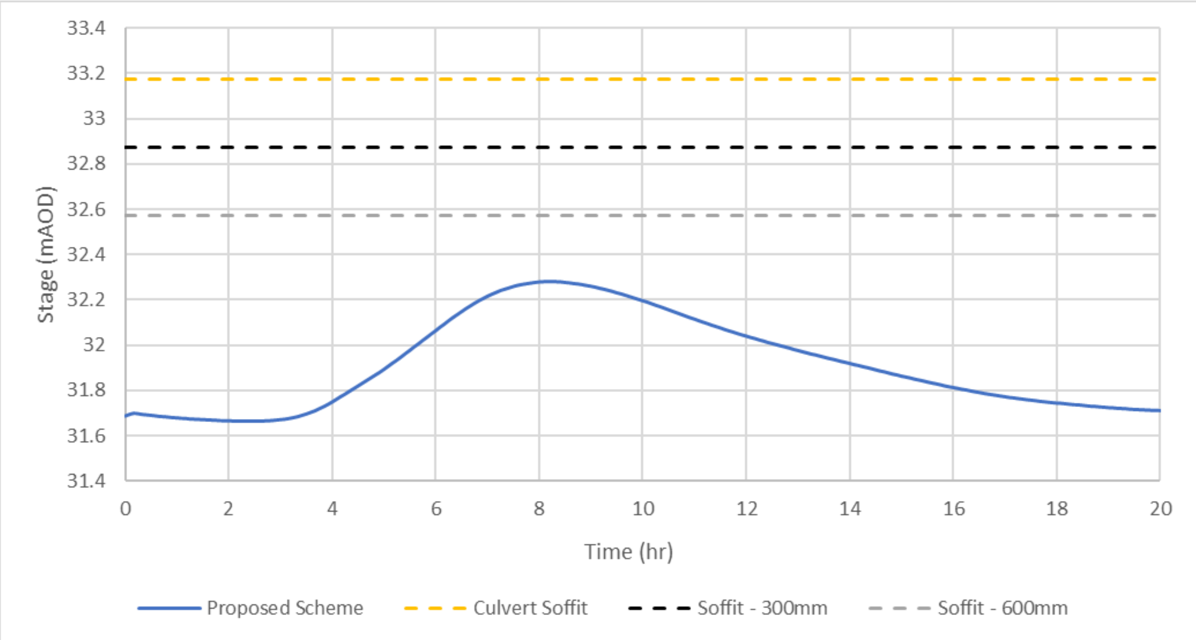


Figure 5-5: Stage Plot of A428 Culvert for 1% AEP + 65% Climate Change for Wintringham Brook Tributary model

5.4.6 As shown in **Figure 5-5**, the minimum freeboard and desirable freeboard of 600mm between the soffit of the culverts and peak water level for the 1% AEP + 65% climate change event is achieved at the A428 crossing culvert.

Upstream peak water level

5.4.7 Due to the channel reprofiling upstream of the A428 crossing, there are no identical nodes upstream in both the baseline and proposed models to allow for a direct comparison of the effects of the proposed A428 culvert, when considering the water level. Different nodes in similar locations have therefore been used for a comparison of upstream water depths (WBT2 in the baseline model and WBT_SCH2 in the proposed model). It should be noted that the bed level of the channel is 38.85m AOD in the baseline and 38.64m AOD in the proposed Scheme.

Compensatory Storage

5.4.8 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Wintringham Brook Tributary, with a maximum level of 32.89 mAOD at node WBT9, located upstream of the proposed Scheme crossing. Therefore compensatory storage is not required for this watercourse. It should be noted that the hydraulic attenuation area detailed within 5.3 has been provided in order to retain downstream pass on flows in line with the baseline. This was required due to the removal of a small culvert that acted as a throttle to flow within the baseline scenario, and was not related to compensatory storage requirements.

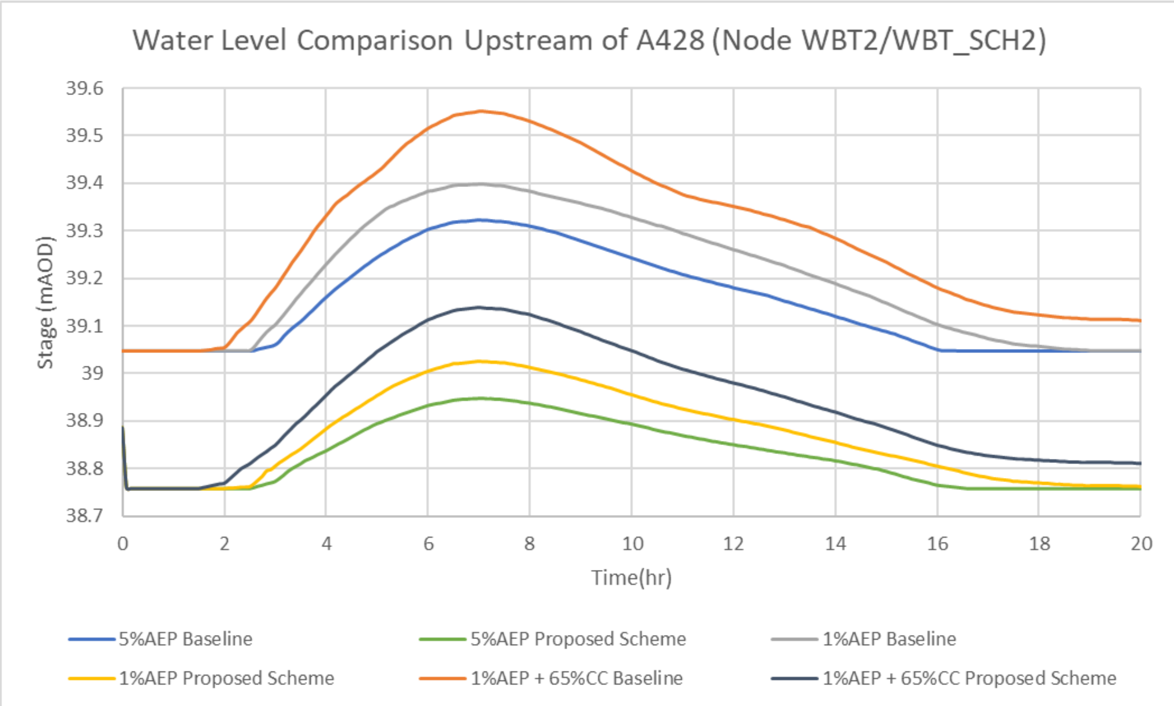


Figure 5-6: Stage Plot of Baseline and Proposed Scheme Upstream of A428 Culverts for Wintringham Brook Tributary model

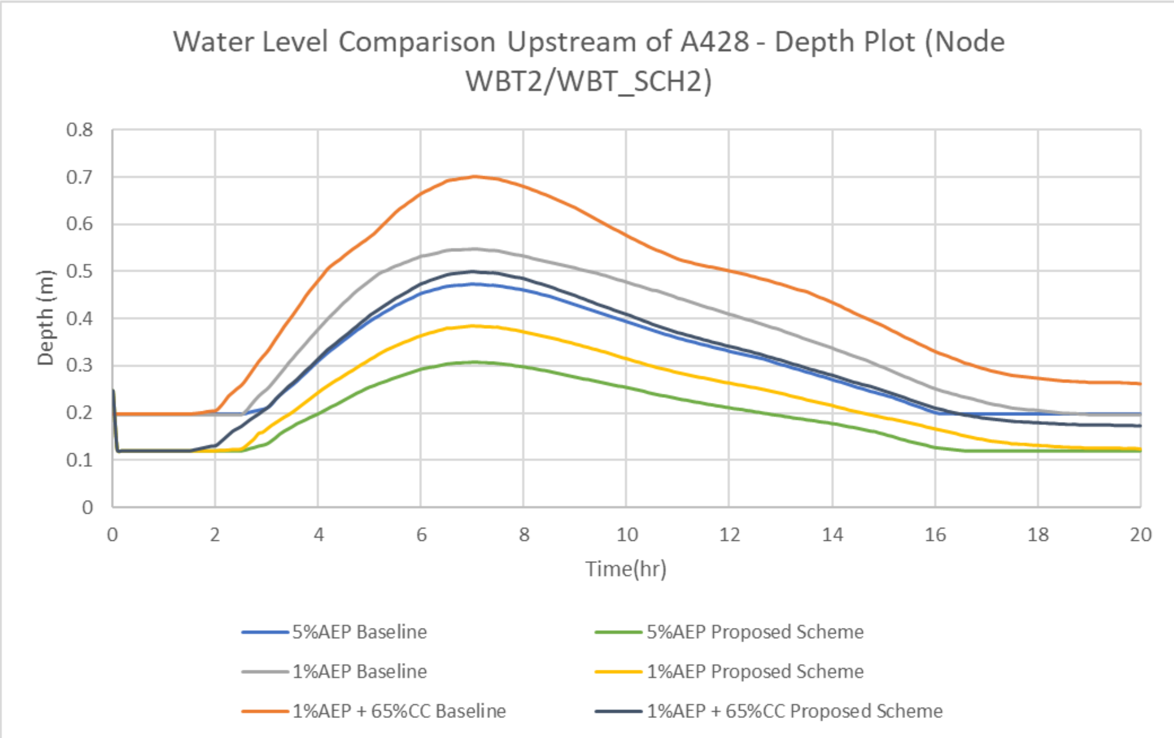


Figure 5-7: Depth Plot of Baseline and Proposed Scheme Upstream of A428 Culverts for Wintringham Brook Tributary model

5.4.9 **Figure 5-6** displays the modelled water level upstream of the A428 crossing for the baseline and reprofiled proposed cross-sections. The modelled peak water level for the baseline design is 39.55m AOD and the peak water level for the proposed design is 39.29m AOD. **Figure 5-7** displays the depth of water within the channel for the 1% AEP + 65% climate change design simulation. The peak depth for the proposed Scheme is 0.65m and the peak depth for the baseline is 0.70m. Peak depths and water levels are also higher within the baseline than the proposed conditions for the 1% AEP and 5% AEP events. The change in depth can be attributed to the reprofiling of the channel upstream of the proposed A428.

5.5 Sensitivity Analysis

5.5.1 Sensitivity analysis has been performed on the Wintringham Brook Tributary model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were:

a. ± 20% Upstream Boundary Inflow.

b. ± 20% Manning’s Roughness Coefficient.

5.5.2 **Table 5-3** displays the peak water level upstream, downstream and at the proposed A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. **Figure 5-8** displays the water level at the A428 culvert for 1% AEP + 65% climate change event and the four sensitivity tests undertaken.

Table 5-3: Sensitivity Analysis Results

	Water Level (m AOD)		
	Upstream (WBT_SCH17)	A428 Culvert (WBT_SCH20CU)	Downstream (WBT13)
Proposed Scheme	33.07	32.28	29.53
Flow +20%	33.13 (+0.06m)	32.43 (+0.15m)	29.58 (+0.05m)
Flow -20%	33.03 (-0.04m)	32.15 (-0.13m)	29.45 (-0.09m)
Roughness +20%	33.12 (+0.04m)	32.34 (+0.06m)	29.66 (+0.12m)
Roughness - 20%	33.03 (-0.05m)	32.23 (-0.05m)	29.43 (-0.11m)

5.5.3 An increase and decrease of 20% was applied to the flow hydrograph at the upstream boundary of Wintringham Brook Tributary model. A 20% increase in flow at the upstream boundary has produced an increase of +0.15m in water level at the proposed A428 culvert. When the flow is decreased by 20%, the water level at the proposed A428 culvert falls by -0.13m.

5.5.4 Manning's Roughness Coefficient analysis was performed on the proposed model to determine how the model responds when the main model parameters were varied. A 20% increase and decrease were applied globally in the model to all Manning's Roughness Coefficients in the 1D channel and banks. Increasing the Manning's Roughness Coefficients by 20% has resulted in an increase of +0.06m in water level in the culvert and a 20% decrease produces a fall of -0.05m in the water level.

Compensatory Storage

5.5.5 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Wintringham Brook Tributary, with a maximum level of XX mAOD at node XX, located upstream of the proposed Scheme crossing. Therefore, compensatory storage is not required.

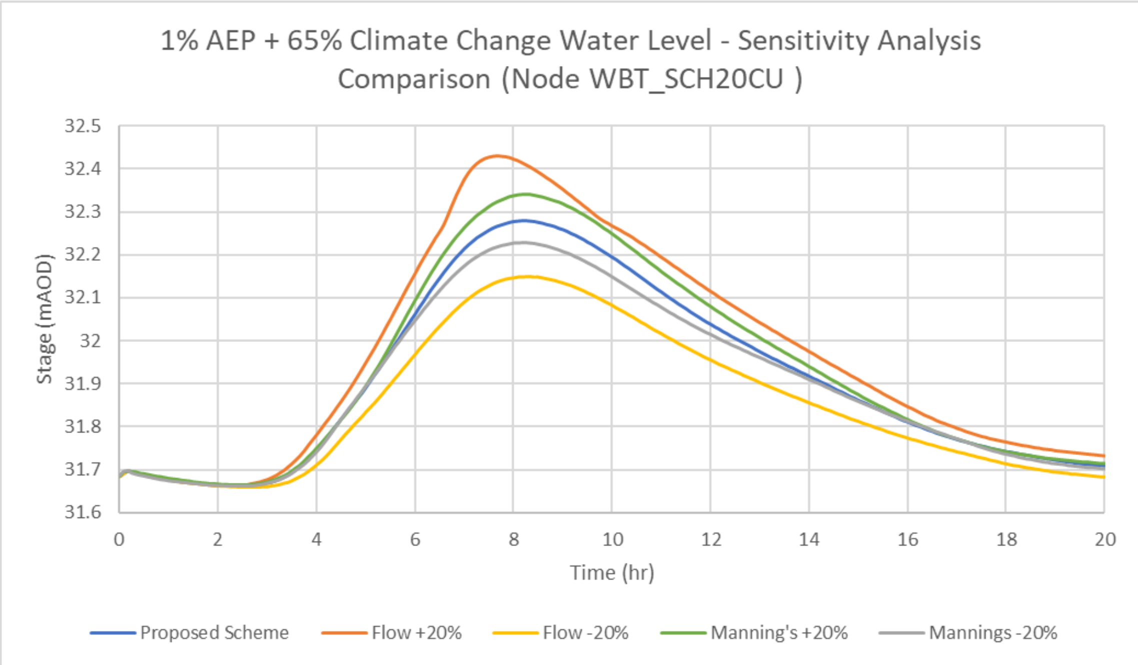


Figure 5-8: Sensitivity Analysis of Proposed A428 Culvert for 1% AEP + 65% Climate Change Event for the Wintringham Brook Tributary model

5.6 Limitations

5.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

5.6.2 The attribution of Manning's Roughness Coefficient 'n' values remain consistent through the reach, with values of 0.035 being applied within the channel and 0.05 being applied for top of banks and floodplain. These roughness coefficients were assigned based upon observations by the survey team, who noted that morphology was similar to Wintringham Brook. The modelled reach is relatively short and there were no clear changes in channel morphology, therefore consistent application of Manning's Roughness Coefficient values was considered appropriate.

5.6.3 The downstream model boundary is configured as a normal depth boundary, which calculates outflow according to channel bed slope, assuming no other downstream influences. this boundary type has been selected as the downstream limit of the model is located within an open channel section of Wintringham Brook Tributary. Wintringham Brook Tributary ultimately confluences with Wintringham Brook which then confluences with Fox Brook, Hen Brook and finally the River Great Ouse more than 2km downstream of the downstream boundary of the Wintringham Brook model. Given the distance of the downstream model boundary from the River Great Ouse, along with the numerous watercourse connections, it is considered unlikely that raised levels within the River

Great Ouse would impact upon the Scheme assessment for Wintringham Brook Tributary.

5.6.4 Wintringham Brook and Wintringham Brook Tributary have been modelled separately, not accounting for any interactions between these watercourses. This approach can be partially attributed to data availability, as the Wintringham Brook Tributary survey does not extend all the way to the confluence with Wintringham Brook. Nevertheless, based upon model results and a consideration of key features of the watercourses, the Scheme assessment can be considered robust. It should be noted that the peak water level in Wintringham Brook at the confluence with Wintringham Brook tributary is 23.07mAOD for the 1%AEP +65% climate change event. This level is substantially lower than the bed level of 26.28mAOD at the downstream node of Wintringham Brook Tributary.

5.6.5 Given the substantial difference in elevations between the Wintringham Brook flood level and the bed level at the downstream end of the Wintringham Brook tributary model, it is considered unlikely that levels on Wintringham Brook would exert a significant backwater effect on Wintringham Brook tributary. A sensitivity test has been undertaken on Wintringham Brook model, by applying the flow from the downstream of the Wintringham Brook Tributary model to the confluence location in the Wintringham Brook model demonstrating there is no effect on the water level in channel at the proposed Scheme culvert, see Section 4.5. Modelling results demonstrate that the Scheme does not result in any increase in flow downstream from either watercourse, with conveyance being retained as per the baseline. This provides confidence that separate modelling of the tributaries is appropriate, as there are no significant changes in conveyance within one watercourse that might impact upon the other.

5.6.6 Out of bank storage, including the hydraulic compensatory area, has been represented through inclusion of extended 1D channel sections in the model. This approach to the representation of floodplain flow is simple and assumes flow is one dimensional in the same direction as the channel. Given the small size of the watercourse and limited occurrence of out of bank flows on West Brook it is not expected that the simplified representation of floodplain flow will impact upon the assessment of the Scheme. Furthermore, there are no vulnerable receptors within the area, and therefore detailed flood mapping is not required.

5.7 Conclusions

5.7.1 In the Wintringham Brook Tributary model, the peak flow downstream of the proposed A428 culvert reaches the same flow of 1.32m^3/s as during the baseline scenario for the 1% AEP + 65% climate change event. The baseline peak flow is greater than the proposed Scheme for the three lower magnitude events of 5% AEP, 1% AEP and 1% AEP + 35% climate change. For the 0.1% AEP event, peak flow during the proposed scenario is greater than the baseline by +0.03m^3/s.

5.7.2 The water level at the proposed A428 culvert is lower than the minimum and desired freeboard level, of 300mm and 600mm respectively, for the 1% AEP + 65% climate change event.

5.7.3 The water depth in the realigned channel upstream of the proposed A428 was compared to the existing upstream channel for 1% AEP + 65% climate change event. There is a decrease in water depth of -0.04m in the proposed Scheme model. It should be noted that the profile of the cross sections compared are different, so it is not a direct comparison.

5.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed indicates that flow is contained within bank, and compensatory storage is not required. A hydraulic attenuation area has been provided as part of the scheme, but this is to mitigate the removal of a small culvert as part of the Scheme, and retain downstream pass on flows in line with the baseline scenario.

6 Gallow Brook (1D FMP)

6.1 Overview

6.1.1 Gallow Brook is a small 7.5km watercourse located east of St Neots and north of Croxton and the A428. The head of the watercourse is located in the fields north of Croxton, flowing west towards St Neots before joining the River Great Ouse (Figure 6-1). It should be noted that the stretch of the watercourse which joins the River Great Ouse is located a significant distance from the proposed Scheme and has not been modelled. The typical cross section channel width is approximately 4.5m while the peak flow estimate for the 1% AEP event is 3.10m^3/s.

6.1.2 This section details the development and outcome of the baseline and proposed model results for Gallow Brook. The criteria for assessing the model comparison are stated below:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Water level is below the soffit and required freeboard of 300mm of the main Scheme crossing culvert.

6.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the water level in the proposed model is not greater than in the baseline.

6.1.4 Additionally, this section details whether compensatory storage is required for Gallow Brook, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

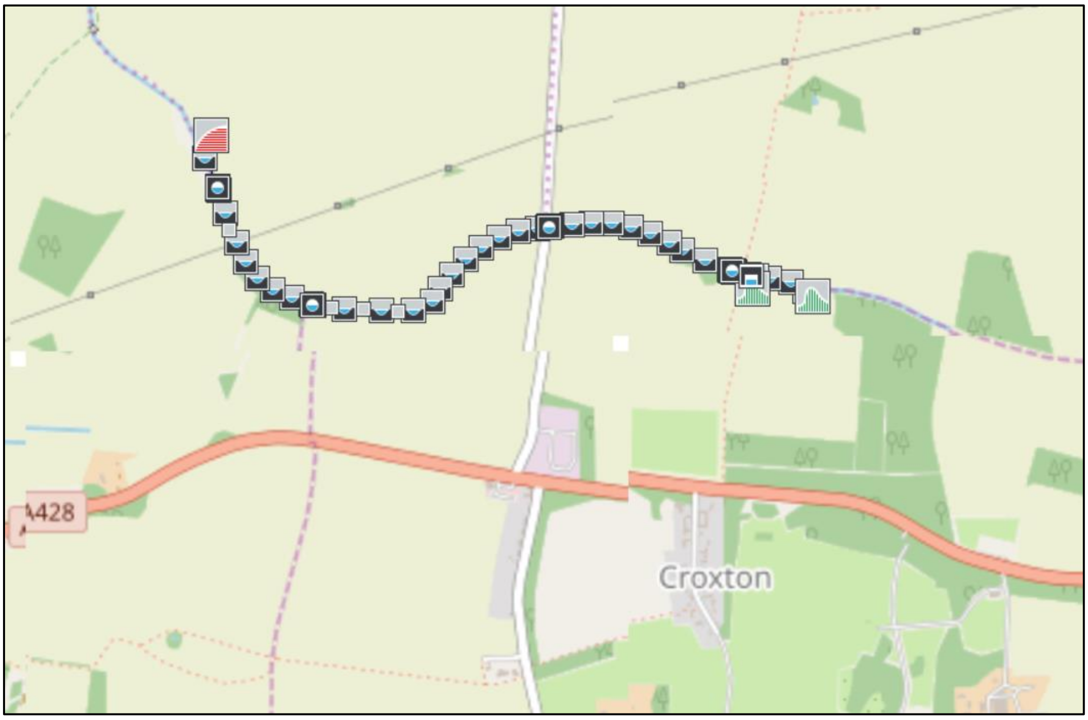


Figure 6-1: Gallow Brook Model Location in Flood Modeller Pro

6.2 Model Setup - Baseline Scenario

6.2.1 **Table 6-1** includes all key information regarding the setup of the Gallow Brook baseline model.

Table 6-1: Baseline Model Setup

Model Setup	Comments
Simulation time	50 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 2.0km
Upstream boundary	Flow-time boundary located north of Croxton and the existing A428 (525155, 260541)
Downstream Boundary – 1D	Normal Depth boundary located north of the existing A428 (523659, 260872)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

6.2.2 There are four existing structures within the baseline model, which includes field crossings and an unnamed road from Croxton to Toseland.

6.2.3 A normal depth boundary has been applied as there is not expected to be any backwater effects from downstream as the nearest watercourse connection is 1.4km away. The baseline model contains 80 nodes over the 2km modelled reach of Gallow Brook.

6.2.4 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

6.3 Model Setup- Scheme Scenario

6.3.1 The proposed Scheme model includes a realigned channel upstream of the proposed A428. The watercourse is conveyed beneath the new A428 carriageway by a rectangular culvert 3m by 1.8m (63.8m in length). A cross section of the culvert is shown in **Figure 6-2** and a schematic shown in Figure 6-3. As baseline modelling indicated no out of bank flows at the location of the Scheme crossing, there was no requirement for floodplain compensation storage for Gallow Brook.

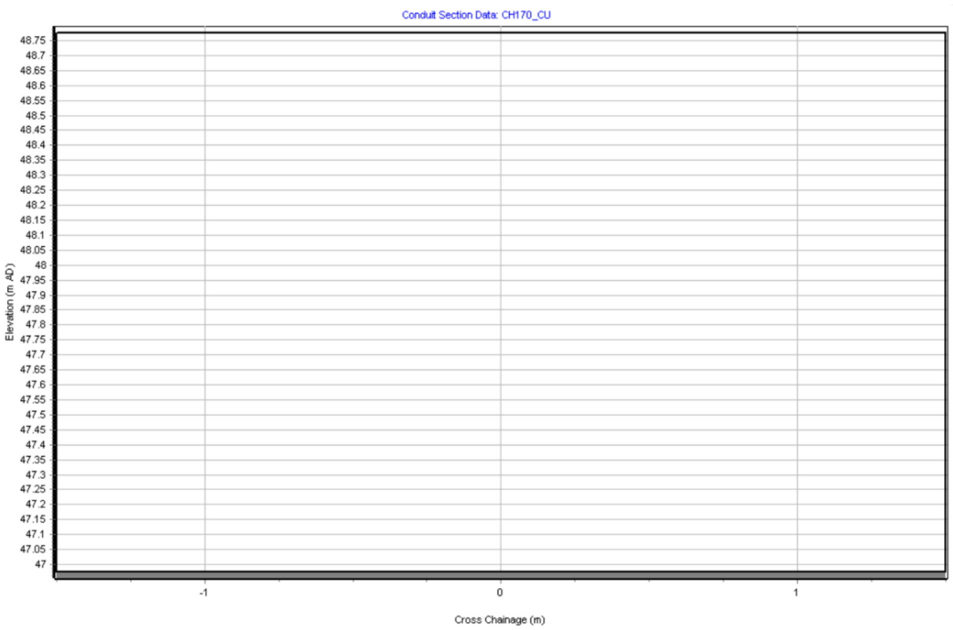


Figure 6-2: Gallow Brook Tributary Proposed A428 crossing culvert (dimensions not to scale)

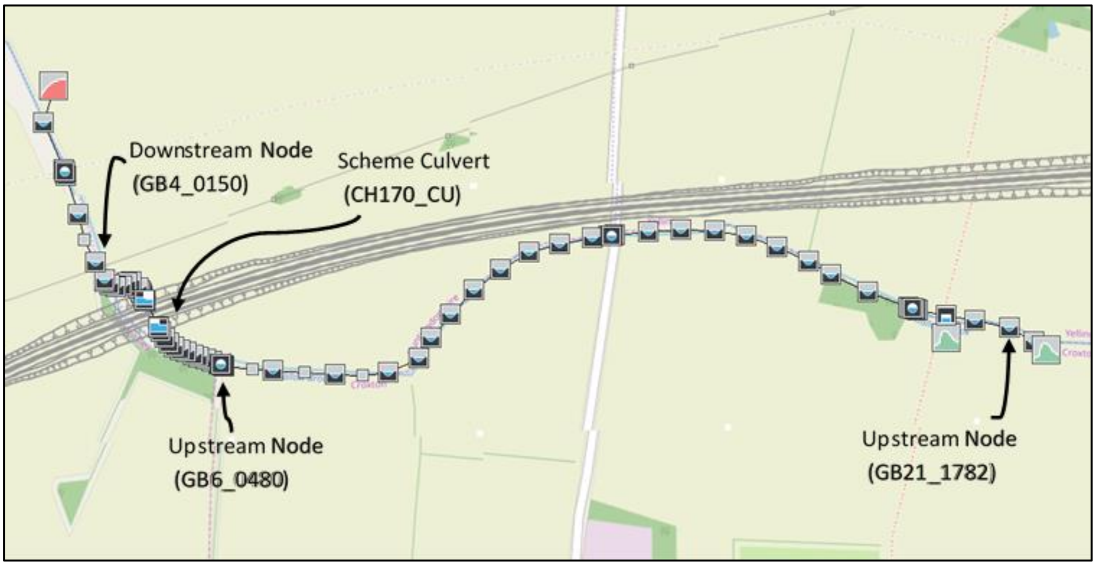


Figure 6-3: Gallow Brook Proposed Scheme Model Schematic in Flood Modeller

6.4 Results

Downstream peak flow

6.4.2 **Table 6-2** below shows the peak modelled flow is greater in the baseline when compared to the proposed scenario for the 1% AEP + 65% climate change design event by <0.1%, and is the same in the baseline and proposed scenarios for 1% and 0.1% AEP. The peak flow downstream of the Scheme is greater in the proposed Scheme scenario than baseline by <0.1% for 5% AEP and 1% AEP + 35% climate change events. These changes are not considered significant and therefore, when considered in combination with **Figure 6-4** it can be concluded that the Scheme does not have a detrimental impact in terms of pass on flows downstream. The node selected is the first downstream of the A428 culverts that is not part of the reprofiled channel and not connected to a structure (labelled on **Figure 6-2**).

Table 6-2: Comparison of Peak Flow Results Downstream of A428 Culvert (Node GB4_0150)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	1.97	1.98	<+0.1
1%	3.08	3.08	+0.0
1% + 35%CC	4.16	4.17	<+0.1
1% + 65%CC	5.10	5.08	<-0.1
0.1%	5.33	5.33	+0.0

6.4.3 **Figure 6-4** displays the hydrograph for the baseline and proposed Scheme downstream of the proposed A428 fo 5%, 1% and 1% . The hydrographs for the baseline and proposed are very similar with the modelled peak flow for the proposed Scheme reaching 5.08m3/s and the peak flow for the baseline Scheme reaching 5.10m^3/s.

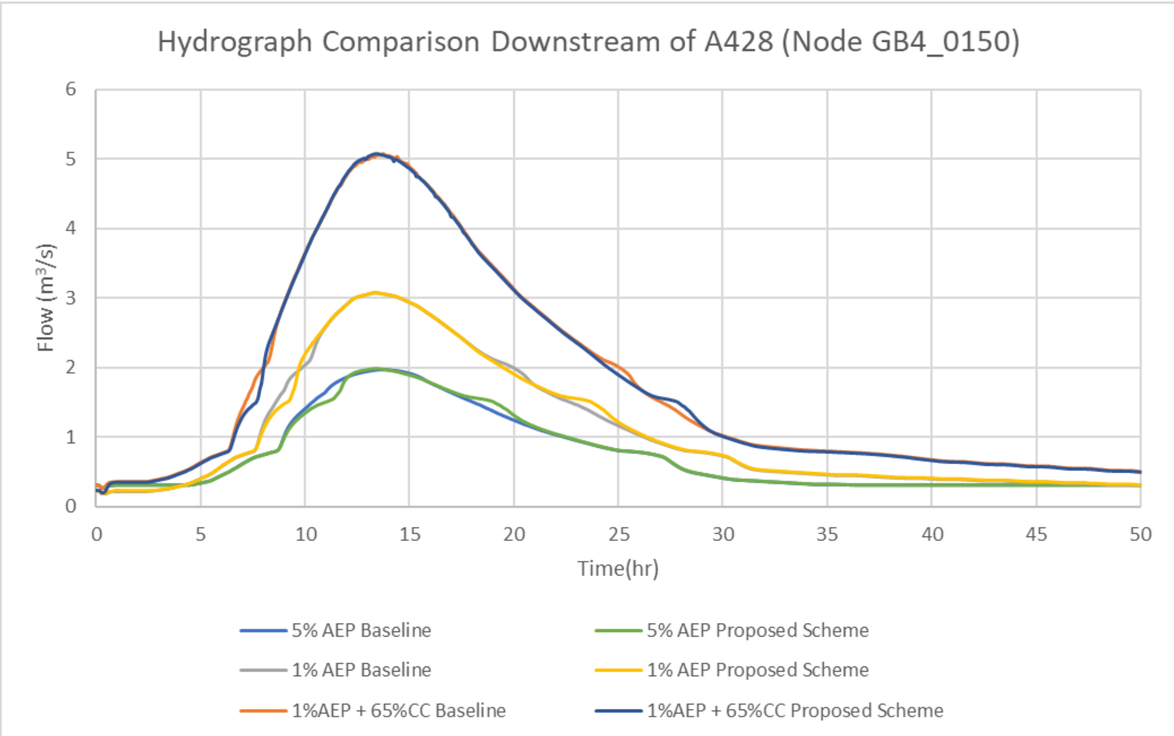


Figure 6-4: Hydrograph of Baseline and Proposed Scheme Downstream of A428 Culvert (Node GB4_0150) for the Gallow Brook model

6.4.4 **Figure 6-5** assesses the water level at the proposed A428 culvert. The peak water level during the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (also included in **Figure 6-4**).

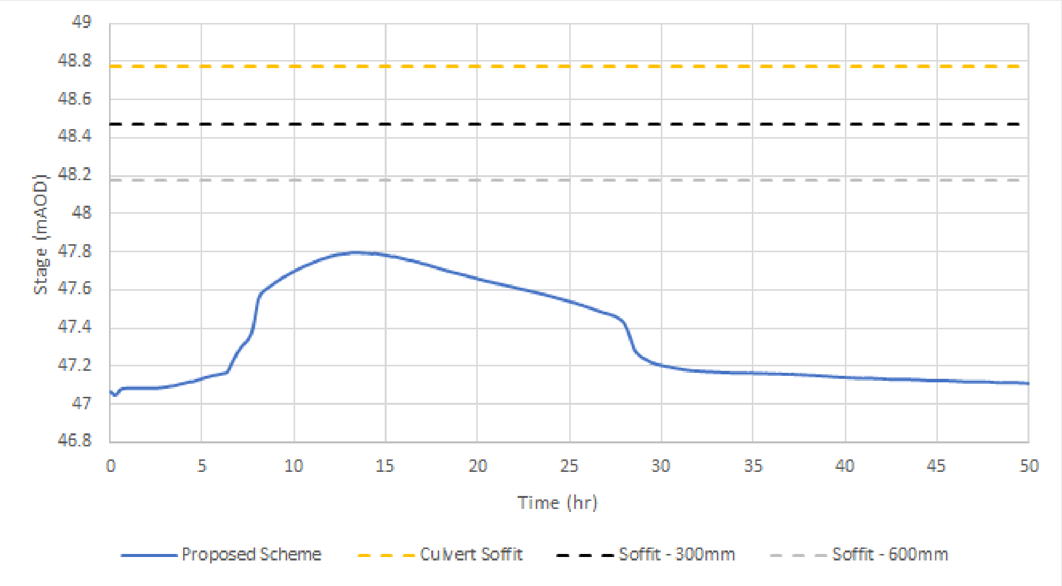


Figure 6-5: Stage Plot of A428 Culvert for the 1% AEP + 65% Climate Change Event for the Gallow Brook model

6.4.5 The invert of the proposed culvert is 46.98m AOD while the soffit is 48.78m AOD. **Figure 6-5** indicates that the minimum freeboard of 300mm and desirable freeboard of 600mm between the soffit of the culvert and peak water level for the 1% AEP + 65% climate change event is achieved at the proposed A428 culvert.

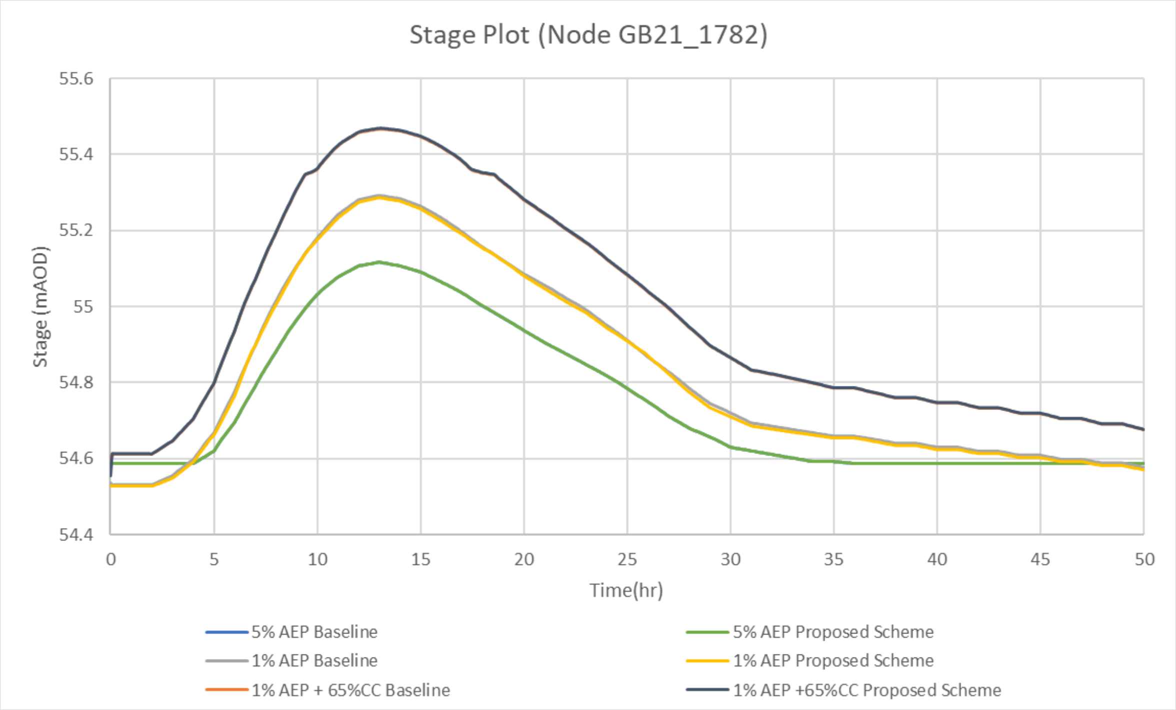


Figure 6-6: Stage Plot of Baseline and Proposed Scheme Upstream of A428 Culvert for the Gallow Brook model

6.4.6 **Figure 6-6** displays the modelled water level of the node at the upstream reach of the modelled watercourse. The results show that the proposed Scheme water level is lower than the baseline water level, indicating that the A428 culvert does not create a negative impact on upstream water levels during the 1% AEP + 65% climate change event. This reduction in level upstream can be attributed to reprofiling of channel sections within the proposed Scheme condition.

Compensatory Storage

6.4.7 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Gallow Brook, with a maximum level of 48.23 mAOD at node GB5c_0380, located upstream of the proposed Scheme crossing. Therefore compensatory storage is not required.

6.5 Sensitivity Analysis

6.5.1 Sensitivity analysis has been performed on the Gallow Brook model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were:

a. ± 20% Upstream Boundary Inflow.

b. ± 20% Manning’s Roughness Coefficient.

6.5.2 **Table 6-3** displays the peak water level upstream, downstream and at the proposed A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. Figure 6-7 displays the water level at the A428 culvert for 1% AEP + 65% climate change event and the four sensitivity tests undertaken.

Table 6-3: Sensitivity Analysis Results

	Water Level (m AOD)		
	Upstream (GB6_0480)	A428 Culvert (CH170_CU)	Downstream (GB4_0150)
Proposed Scheme	48.17	47.79	47.65
Flow +20%	48.29 (+0.12m)	47.87 (+0.08m)	47.69 (+0.04m)
Flow -20%	48.04 (-0.13m)	47.73 (-0.06m)	47.62 (-0.03m)
Roughness +20%	48.23 (+0.06m)	47.86 (+0.07m)	47.67 (+0.02m)
Roughness -20%	48.11 (-0.06m)	47.76 (-0.03m)	47.63 (-0.02m)

6.5.3 An increase and decrease of 20% was applied to the flow hydrograph at the upstream boundary of the Gallow Brook model. Increasing the inflow at the upstream boundary by 20% has resulted in a +0.08m increase to peak water level at A428 culvert. A 20% decrease in the total inflow produces a -0.06m decrease in peak water level at the node CH170_CU.

6.5.4 A 20% increase and decrease were applied globally in the model to all Manning's Roughness Coefficients in the 1D channel and banks. Increasing the Manning's Roughness Coefficients by 20% has resulted in an increase of +0.07m in water level in the culvert and a 20% decrease produces a fall of -0.03m in the water level.

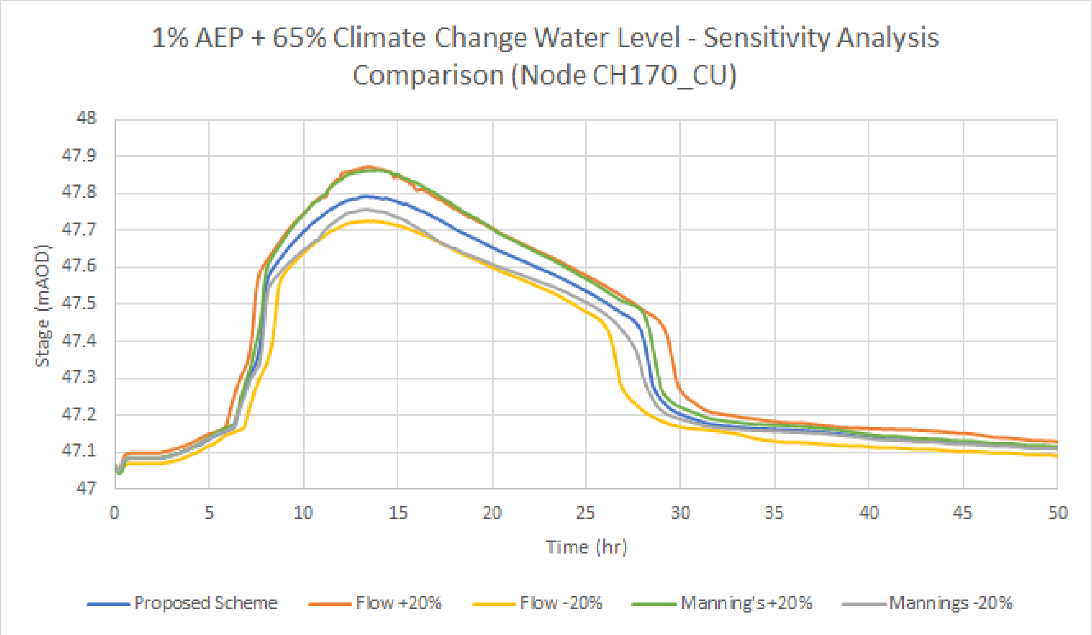


Figure 6-7: Sensitivity Analysis of the Proposed A428 Culvert for the 1% AEP + 65% Climate Change Event for the Gallow Brook model

6.6 Limitations

6.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

6.6.2 The downstream model boundary is configured as a normal depth boundary, which calculates outflow according to channel bed slope, assuming no other downstream influences. The downstream boundary is located within a reach of open channel and is located more than 5km upstream of the confluence with the River Great Ouse. Given the distance between the River Great Ouse and the downstream boundary of the Gallow Brook model, along with the presence of a number of structures such as bridges and culverts in between, it is considered unlikely that raised levels within the River Great Ouse would exert significant impacts upon flood flows within the modelled reach of Gallow Brook.

6.6.3 A small sweetening flow is included within the model downstream of the bridge at GB19_BrU, this has been added to the model to retain convergence at this bridge and does not impact upon modelled results or conclusions.

6.6.4 Out of bank storage has been represented through inclusion of extended 1D channel sections. This approach to the representation of floodplain flow is simple and assumes flow is one dimensional in the same direction as the channel. Given the small size of the watercourse and limited occurrence of out of bank flows on Gallow Brook it is not expected that the simplified representation of floodplain flow will impact upon the assessment of the Scheme. Furthermore, there are no vulnerable receptors within the area, and therefore detailed flood mapping is not required.

6.6.5 Overall, the specific limitations stated within this section are thought to be relatively small contributors to the overall model uncertainty, particularly in light of uncertainties relating to hydrological inflows. Given that West Brook is an ungauged catchment, hydrological peak flow estimates can be associated with an error of +-40%.

6.7 Conclusions

6.7.1 In the Gallow Brook model, the flow downstream of the proposed A428 is $0.02m^3/s$ less in the proposed model than the baseline model for 1% AEP + 65% climate change events. For the 5% AEP and 1% AEP + 35% climate change events the proposed Scheme peak flow is $0.01m^3/s$ greater than the baseline and the peak flow is the same for 1% AEP and 0.1% AEP. Overall these changes equate to a difference of <0.1% compared to the baseline and are not considered significant, it can be concluded that the Scheme does not exert a negative impact upon downstream flows.

6.7.2 The water level at the culvert under the proposed A428 is lower than the minimum freeboard of 300mm and desired freeboard of 600mm for the 1% AEP + 65% climate change event.

6.7.3 The water level upstream of the proposed A428 culvert is lower (by 0.58m) in the proposed model than in the baseline for the 1% AEP + 65% climate change event, indicating that the proposed A428 culvert does not create a negative impact on water levels upstream.

6.7.4 An assessment of maximum flood levels for the 1% AEP + 35% CC event indicates that flow is contained within bank, and compensatory storage is not required.

7 Begwary Brook (1D FMP)

7.1 Overview

7.1.1 Begwary Brook is a small watercourse located in Wyboston, south of St Neots. The head of the watercourse is located in the fields around residential houses on The Lane and flows east (Figure 7-1). The watercourse flows beneath the A1 and towards the River Great Ouse. The typical cross section channel width is approximately 6m while the peak flow estimate for the 1% AEP event is 1.70m^3/s.

7.1.2 This section details the development and outcome of the baseline and proposed model results for Begwary Brook. The criteria for assessing the model comparison for Begwary Brook are stated below:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

7.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the water level in the proposed model is not greater than in the baseline.

7.1.4 Additionally, this section details whether compensatory storage is required for Begwary Brook, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

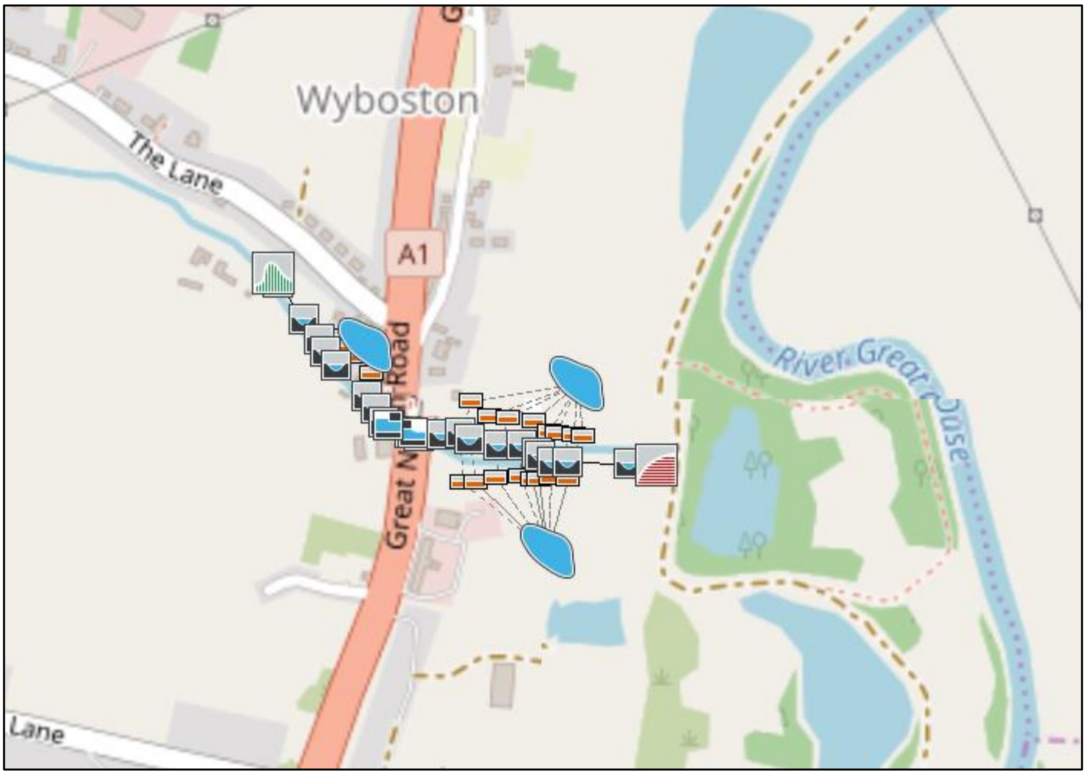


Figure 7-1: Begwary Brook Proposed Scheme Model Schematic in Flood Modeller

7.2 Model setup- baseline scenario

7.2.1 **Table 7-1** includes all key information regarding the setup of the Begwary Brook baseline model.

Table 7-1: Baseline Model Setup

Model Setup	Comments
Simulation time	50 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 0.5km
Upstream boundary	Flow-time boundary located west of the existing A1 (516261, 256592)
Downstream Boundary – 1D	Normal Depth boundary located 0.25km downstream of existing A1 carriageway (516629, 256411)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

7.2.2 The baseline model contains 50 nodes over the 0.5km modelled reach of Begwary Brook watercourse. There is a structure under the existing A1 in the baseline model and floodplain compensation areas upstream of the A1.

7.2.3 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

7.2.4 The downstream boundary, located east of the A1 crossing, has been modelled as a Normal Depth boundary. The model assumes that there is free outfall flow from the boundary as the end of the Begwary Brook is set back from the River Great Ouse and outflows into a wetland area. Analysis was carried out on the downstream boundary, testing a range of normal depth boundary gradients as using levels from the River Great Ouse caused instabilities in the model; the most representative gradient was applied.

7.3 Model Setup- Scheme Scenario

7.3.1 The Begwary Brook proposed Scheme model includes a rectangular culvert with dimensions of 2.0m by 1.8m and (length of 17.35m) beneath the proposed Roxton Link Road. This culvert has been included within the model as a rectangular conduit, along with appropriate culvert inlet and outlet losses (**Figure 7-2 and 7-3**).

7.3.2 As baseline modelling displayed out of bank flows at the location of the Scheme crossing, the Scheme also includes two floodplain compensation areas, the first is located upstream of the Scheme culvert on the left bank and is approximately 40m in length and 20m in width. The second compensation area is located downstream of the Scheme culvert on the right bank and is 20m in length and approximately 30m in width. These compensation areas are created by lowering floodplain levels, including the river banks, and therefore constitute online storage. Floodplain compensation areas were represented within the model through extended cross sections, a combination of new sections and modifications to existing sections within the baseline.

7.3.3 The assessment of the floodplain storage compensation is based on EA’s climate change guidance. The affected land uses define the level of allowance with the higher central allowance (35%) being indicated for most cases, whilst ensuring no flooding affects sensitive receptors with the upper end allowance (65%). Floodplain storage compensation volumes and cross-sections for Begwary Brook can be seen in Appendix D1.

Figure 7-2: Begwary Brook Tributary Proposed Roxton Link Road crossing culvert (dimensions not to scale)

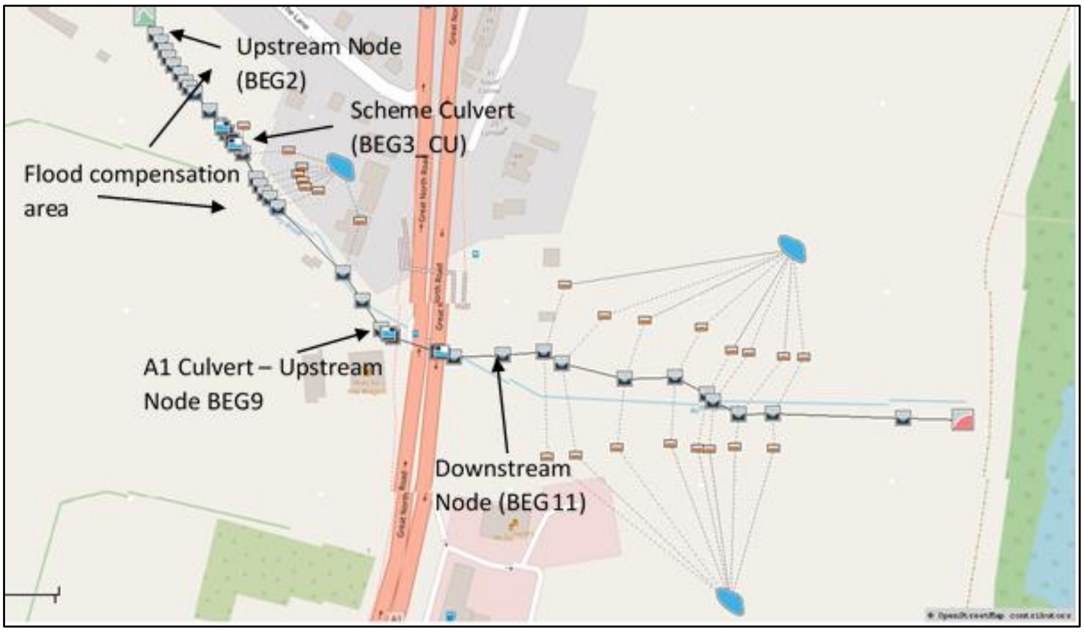


Figure 7-3: Begwary Brook Proposed Scheme Model Schematic in Flood Modeller Pro

7.4 Results

Downstream peak flow

7.4.2 **Table 7-2** below shows that the peak flow downstream of the Scheme is greater in the baseline than the proposed Scheme for 1% AEP + 65% climate change and 0.1% AEP events. The peak flow is the same in the baseline and proposed scenarios for the 5% AEP and 1% AEP events, and greater in the proposed scenario for 1% AEP + 35% climate change. The node selected is the first point downstream of the proposed Roxton Link Road and A1 culverts that is not connected to a structure (labelled on **Figure 7-3**).

Table 7-2: Comparison of Peak Flow Results Downstream of Proposed Roxton Link Road and A1 Culverts (Node BEG_11)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	1.07	1.07	0.0
1%	1.65	1.65	0.0
1% + 35%CC	2.22	2.23	<+0.1
1% + 65%CC	2.71	2.70	<-0.1
0.1%	2.83	2.82	<-0.1

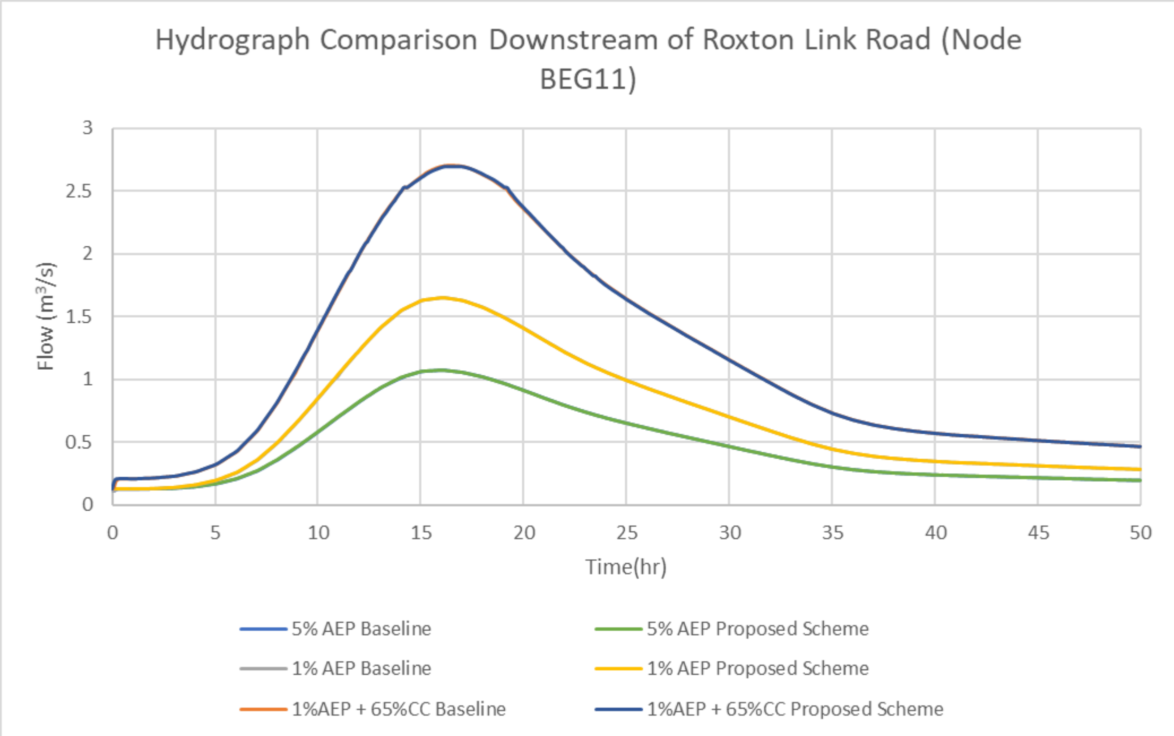


Figure 7-4: Hydrograph of Baseline and Proposed Scheme Downstream of Proposed Roxton Link Road and A1 Culverts (Node BEG11) for Begwary Brook Model

7.4.3 **Figure 7-4** displays the flow for the baseline and proposed Scheme downstream of the proposed Roxton Link Road and A1 crossing. The hydrograph for 1% AEP + 65% climate change event for the proposed Scheme follows the hydrograph for the baseline scenario, with the baseline reaching a peak flow of 2.71m^3/s and the proposed reaching a peak flow of 2.70m^3/s. Similarly, both 5% AEP and 1% AEP baseline and proposed models reach the same peak flow value of 1.07m^3/s and 4.65m^3/s respectively. This suggests that the proposed Scheme exerts no impact upon conveyance within the watercourse.

Scheme culvert peak water level

7.4.4 **Figure 7-5 and 7-6** assesses the water level in the proposed Roxton Link Road culvert as the peak water level within the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed Scheme culvert. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (also included in **Figure 7-5**).

7.4.5 **Figure 7-5** indicates that the minimum freeboard of 300mm the soffit of the culverts and peak water level for the 1% AEP + 65% climate change event is achieved for the proposed Roxton Link Road crossing culvert.

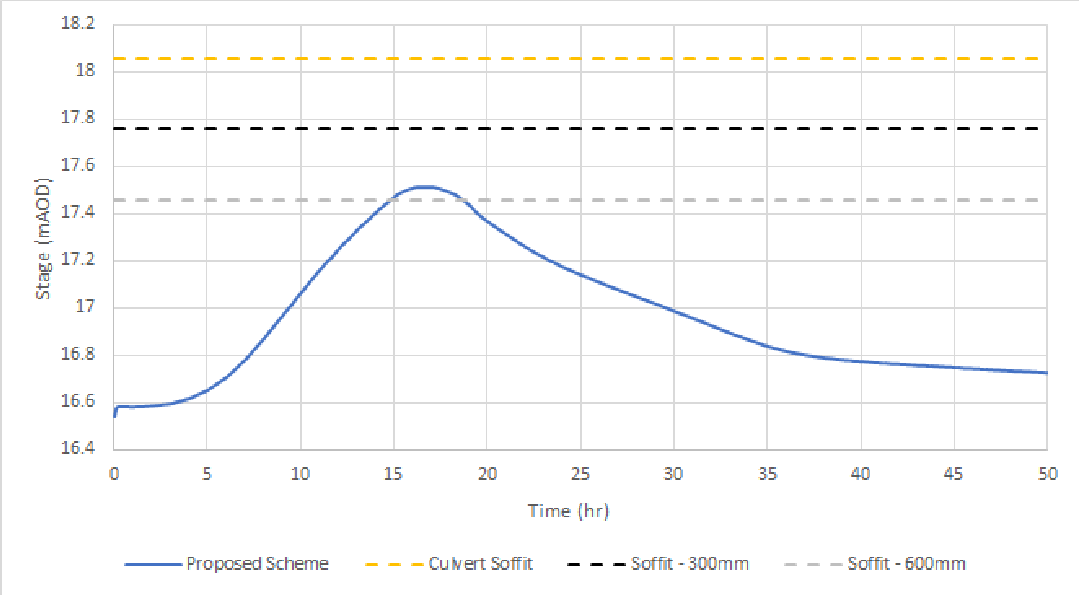


Figure 7-5: Stage Plot of Proposed Roxton Link Road Culvert for the 1% AEP + 65% Climate Change Event for Begwary Brook Model

Upstream peak water level

7.4.6 The peak water level for the proposed Scheme is 17.54m AOD and the peak water level for the baseline is 17.56m AOD, for the 1% AEP + 65% climate change event. The peak water level for the 5% AEP and 1% AEP are 17.08mAOD and 17.26mAOD respectively, which is reached in both the baseline and proposed Scheme. The Roxton Link Road culvert has not restricted the flow of Begwary Brook as the peak water level upstream (Node BEG2, Figure 7-3) for the proposed scenario is lower than the water level in the baseline model.

Compensatory Storage

7.4.7 In-channel maximum baseline water levels have been extracted from the model at the location of the proposed Scheme in order to assess if flow is out of bank. The maximum levels extracted show that flow is out of bank, demonstrating that compensatory storage is required for Begwary Brook.

7.4.8 Compensatory storage volumes have been calculated according to the methodology outlined in section 2.9, and associated results are provided within Appendix D1. It should be noted that for Begwary Brook, the quoted maximum flood level of 17.4 mAOD has been calculated through interpolation of maximum levels between model nodes, as the watercourse is intersected by the scheme at more than one location.

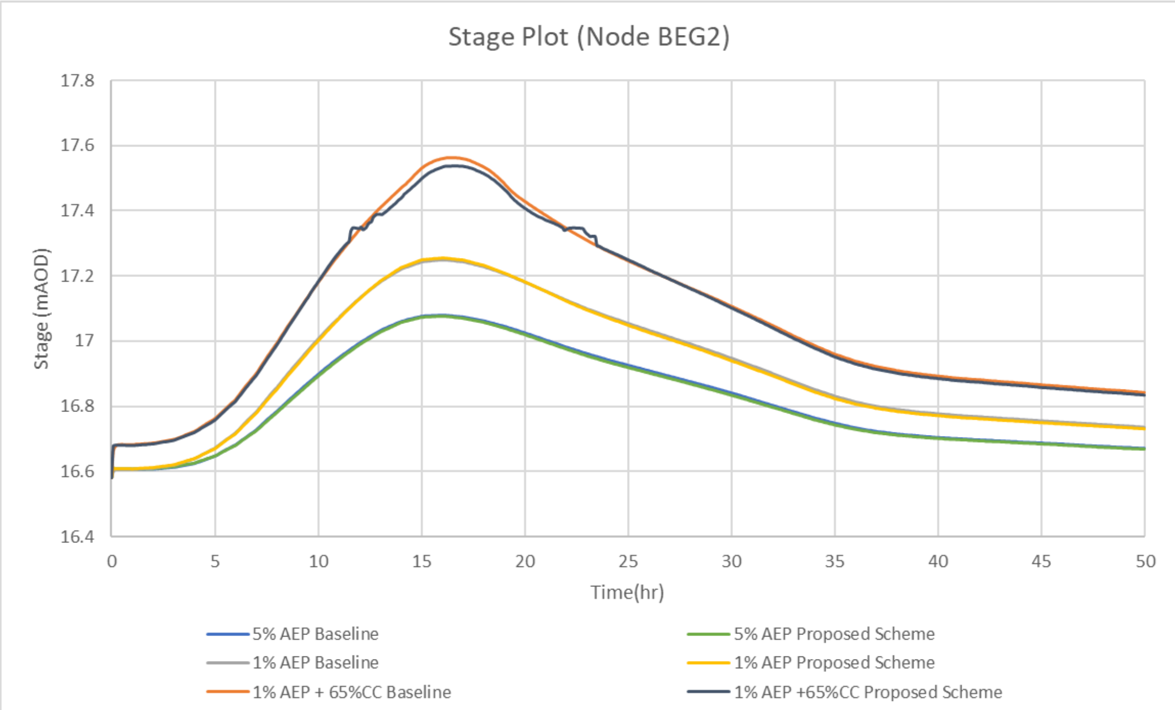


Figure 7-6: Stage Plot of Baseline and Proposed Scheme Upstream of Proposed Roxton Link Road Culvert for Begwary Brook Model

7.5 Sensitivity Analysis

7.5.1 Sensitivity analysis has been performed on the Begwary Brook model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were:

a. ± 20% Manning's Roughness Coefficient.

b. River Great Ouse downstream boundary water level set to bank full at 16.30m AOD.

7.5.2 For the roughness sensitivity tests a 20% increase and decrease were applied globally in the model to all Manning's Roughness Coefficients in the 1D channel and banks.

7.5.3 The downstream boundary of the Begwary Brook model is configured as a normal depth boundary, located within a section of open channel as it crosses a wetland area on the River Great Ouse floodplain. Given the proximity of the boundary to the River Great Ouse, a sensitivity test on the downstream boundary has been undertaken in order to analyse the effect of raised levels on the River Great Ouse on Begwary Brook. For the sensitivity simulation the downstream boundary has been set as a constant Head-Time (HT) boundary at the bank full level of the River Great Ouse of 16.30m AOD, as extracted from the model used for the River Great Ouse assessment (Annex A to the FRA).This downstream boundary configuration will provide an indication of the impact of restricted outflow upon levels within Begwary Brook.

7.5.4 **Table 7-3** displays the peak water level upstream, downstream and at the A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. Figure 7-7 displays the water level in the Roxton Link Road culvert for 1% AEP + 65% climate change event and the four sensitivity tests undertaken.

Table 7-3: Sensitivity Analysis Results

	Water Level (m AOD)		
	Upstream (BEG2)	**Roxton Link Road Culvert (BEG3_CU)**	**Downstream (BEG11)**
Proposed Scheme	17.54	17.51	16.91
Roughness +20%	17.57 (+0.03m)	17.53 (+0.02m)	16.95 (+0.04m)
Roughness -20%	17.51 (-0.03m)	17.50 (-0.01m)	16.78 (-0.13m)
River Great Ouse DS Boundary (Constant HT at 16.3m AOD)	17.54 (+0.00m)	17.51 (+0.00m)	16.91 (+0.00m)

7.5.5 Model results show a 20% increase globally to Manning's Roughness Coefficients in channel and on the bank have produced an increase of +0.02m in water level in the culvert and a 20% decrease produces a fall of -0.01m in the water level which is a reasonable response to a ±20% change to Manning's Roughness.

7.5.6 Simulating the model with a HT downstream boundary at the bank full level of the River Great Ouse of 16.30m AOD has not impacted the peak water level at the locations where water levels have been extracted from the model, including at the Roxton Link Road culvert which is the same as the proposed Scheme simulation at 17.51m AOD. This lack of change in modelled peak water levels can be attributed to the fact that the downstream boundary of the model is located more than 500m upstream of the confluence with the River Great Ouse, diminishing the impact of raised levels within the main river.

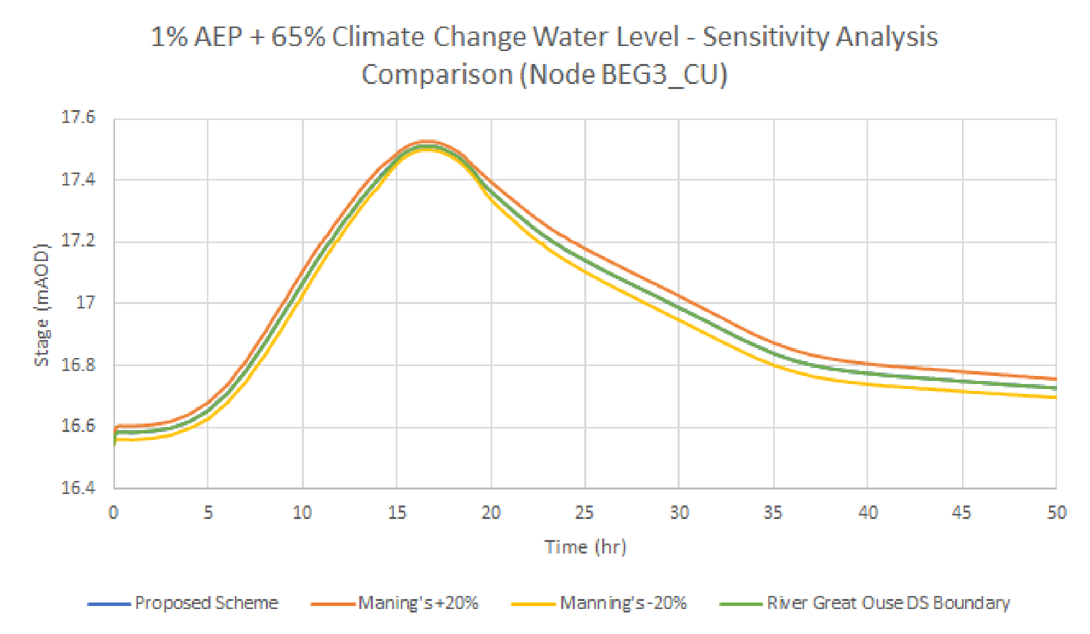


Figure 7-7: Sensitivity Analysis of A428 Culvert for the 1% AEP + 65% Climate Change Event for Begwary Brook Model

7.6 Limitations

7.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

7.6.2 The attribution of Manning's Roughness Coefficient 'n' values remains consistent through the reach, with values of 0.030 being applied within the channel and 0.050 being applied for top of banks and floodplain. These roughness coefficients were assigned based upon observations by the survey team, who noted that the channel bed was smooth and the floodplain was generally characterised by short grass. The modelled reach is relatively short and there were no clear changes in channel morphology, therefore consistent application of Manning's Roughness Coefficients was considered appropriate.

7.6.3 The model reach is relatively small, with just over 250m of the river channel upstream and downstream of the existing A1 included. The modelled reach length was restricted by the extent of the survey acquired. Despite the relatively short reach of watercourse modelled, all changes attributable to the Scheme are captured within this reach, providing justification that the modelled reach length is sufficient for the assessment of the Scheme.

7.6.4 The downstream model boundary is configured as a normal depth boundary for the design simulations, which calculates outflow according to channel bed slope, assuming no other downstream influences. This boundary configuration was selected to retain a good level of convergence within the model. The downstream boundary of the Begwary Brook model is located within an open channel section on the left bank floodplain of the River Great Ouse. Given the proximity of the downstream boundary of the River Great Ouse a sensitivity test was undertaken to assess the impact of raised levels within the main river on hydraulics. This sensitivity test suggested that the configuration of the downstream boundary will facilitate a robust assessment of the Scheme.

7.7 Conclusions

7.7.1 In the Begwary Brook model, the flow downstream of the proposed Scheme culvert and existing A1 culvert is within $0.01m^3/s$ (when compared with the baseline) for the 1% AEP + 65% climate change events, as well as the other return period events. This demonstrates that there is no significant change in pass on flow downstream.

7.7.2 The peak water level in the proposed culvert under the proposed Roxton Link Road meets the required freeboard of 300mm and exceeds the desired freeboard of 600mm by 0.05m for the 1% AEP + 65% climate change event.

7.7.3 Upstream of the proposed Roxton Link Road culvert, model results show that there are small decreases in peak water level of -0.02m within the proposed model for 1% AEP + 65% climate change event, when compared to the baseline scenario. This suggests that the proposed culvert and Scheme elements do not lead to increases in water levels within Begwary Brook upstream of the new carriageway.

7.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is required. Details of the compensatory storage calculations are included within Appendix D1.

8 Rockham Ditch (1D FMP)

8.1 Overview

8.1.1 Rockham Ditch is a small watercourse located south of St Neots in Roxton. The head of the watercourse is located west of Roxton and flows north-east to join the River Great Ouse (**Figure 8-1**). The watercourse flows under the A421, Bedford Road and A1. The typical cross section channel width is approximately 5m while the peak flow estimate for the 1% AEP event is 1.20m^3/s.

8.1.2 This section details the development and outcome of the baseline and proposed model results for Rockham Ditch. The criteria for assessing the model comparison are stated below:

- Flow downstream of the Scheme is not greater in the proposed model than in the baseline; and,
- Water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

8.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the flow in the proposed model is not greater than in the baseline.

8.1.4 Additionally, this section details whether compensatory storage is required for Rockham Ditch, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

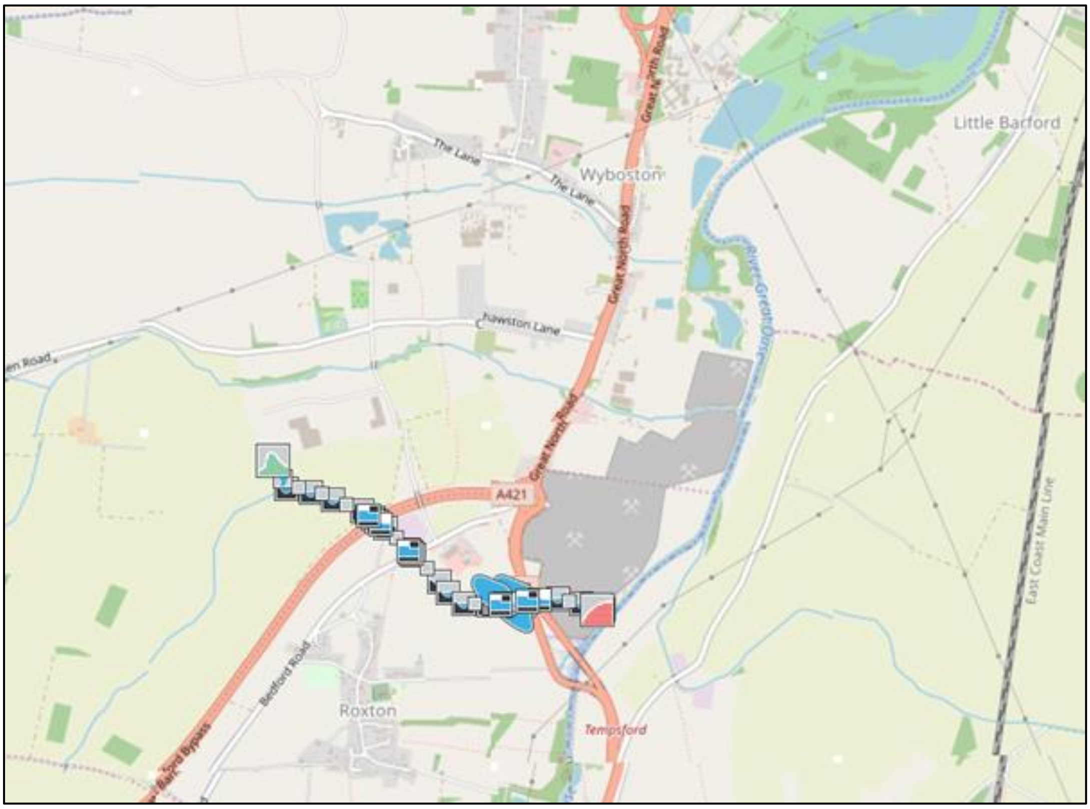


Figure 8-1: Rockham Ditch Model Location in Flood Modeller Pro

8.2 Model Setup- Baseline Scenario

8.2.1 **Table 8-1** includes all key information regarding the setup of the Rockham Ditch baseline model.

Table 8-1: Baseline Model Setup

Model Setup	Comments
Simulation time	60 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.7km
Upstream boundary	Flow-time boundary located west of the existing A421 (514920, 255431)
Downstream Boundary – 1D	Normal Depth boundary located at the convergence with the River Great Ouse (516311, 254890)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

8.2.2 There are three existing structures in the baseline model representing the crossings of the A421, Bedford Road and A1.

8.2.3 A normal depth boundary has been applied as there is not expected to be any backwater effects from downstream. As the downstream boundary is located within a section of open channel as it crosses a wetland area on the River Great Ouse floodplain, a sensitivity analysis has been performed to confirm the effect the of the peak water level at the downstream boundary of the Rockham Ditch model as detailed in Section 8.5. The baseline model contains 70 nodes over the 1.7km modelled reach of Rockham Ditch.

8.2.4 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

8.3 Model Setup- Scheme Scenario

8.3.1 The proposed Scheme design was incorporated into the model downstream of the existing A421 and Bedford Road culverts. These structures remain unchanged and are shown on **Figure 8-3**.

8.3.2 The proposed Scheme model includes the new culverts under the Kelpie Marina Access Road and A1, the openings of which are both 1.5m by 1.8m, shown in Figure 8-2, and are 17.0m and 77.8m in length respectively. As baseline modelling displayed out of bank flows at the location of the Scheme crossing, there are also new floodplain compensation areas defined upstream and downstream of Kelpie Marina Access Road.

8.3.3 The assessment of the floodplain storage compensation is based on EA's climate change guidance. The affected land uses define the level of allowance with the higher central allowance (35%) being indicated for most cases, whilst ensuring no flooding affects sensitive receptors with the upper end allowance (65%). Floodplain storage compensation volumes and cross-sections for Rockham Ditch can be seen in Appendix D1.

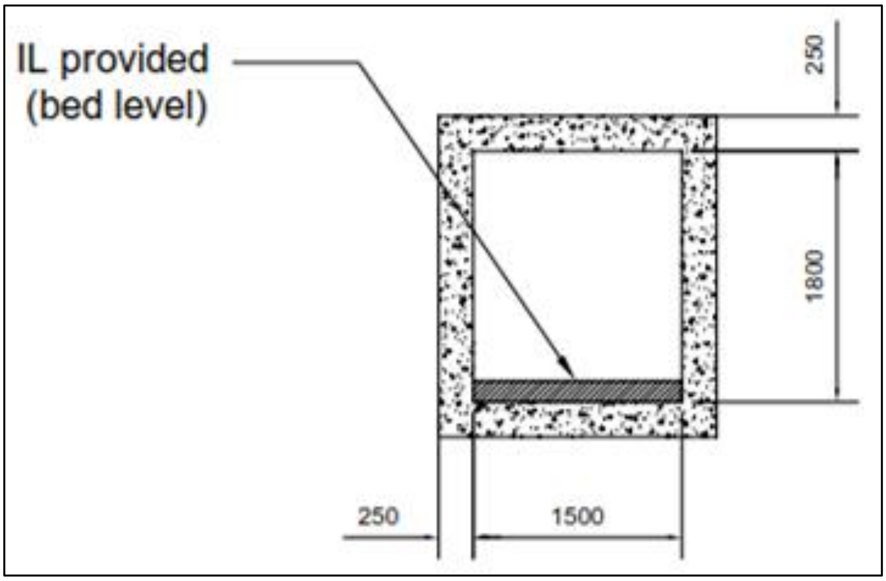


Figure 8-2: Rockham Ditch Proposed Kelpie Marina Access Road and A1 Culvert (dimensions not to scale)

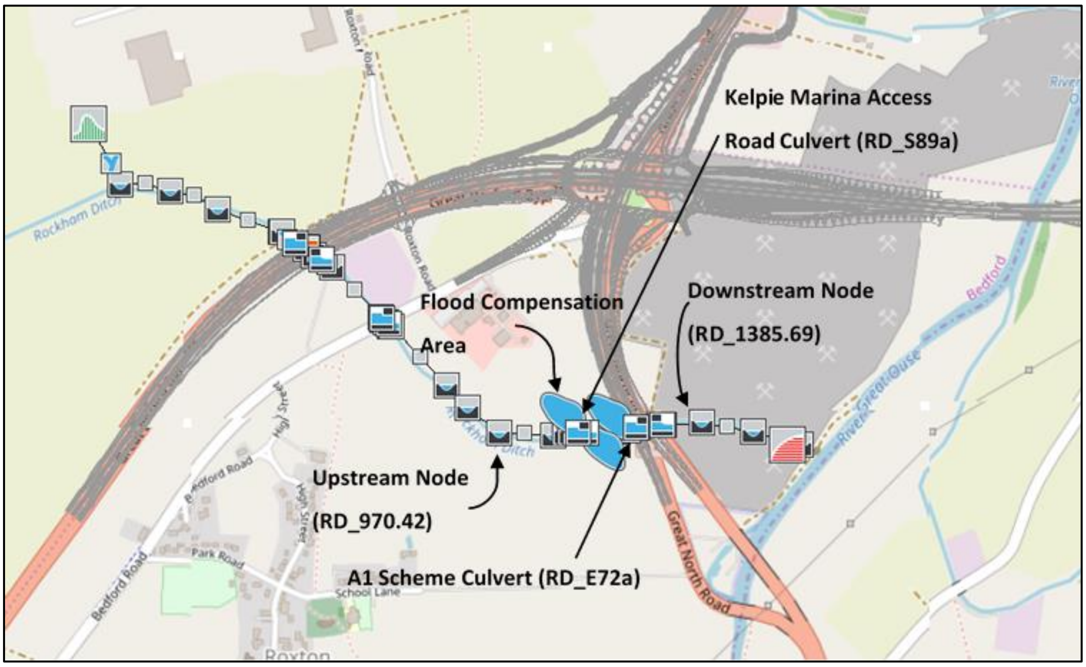


Figure 8-3: Rockham Ditch Proposed Scheme Model Schematic in Flood Modeller Pro

8.4 Results

Downstream peak flow

8.4.2 **Table 8-2** below shows that the modelled peak flow downstream of the proposed Scheme is less than the baseline peak flow for 1% AEP + 65% climate change and 0.1% AEP events. The other modelled events show an increase of 0.01m^3/s in the proposed Scheme, with respect to the baseline. The node selected is the first point downstream of the A41 culvert that is not connected to a structure (labelled on **Figure 8-3**).

Table 8-2: Comparison of Peak Flow Results Downstream of A1 Culvert (Node RD_1385.69)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	0.77	0.77	+0.0
1%	1.19	1.20	<+0.1
1% + 35%CC	1.61	1.62	<+0.1
1% + 65%CC	1.97	1.95	<-0.1
0.1%	2.11	2.07	<-0.1

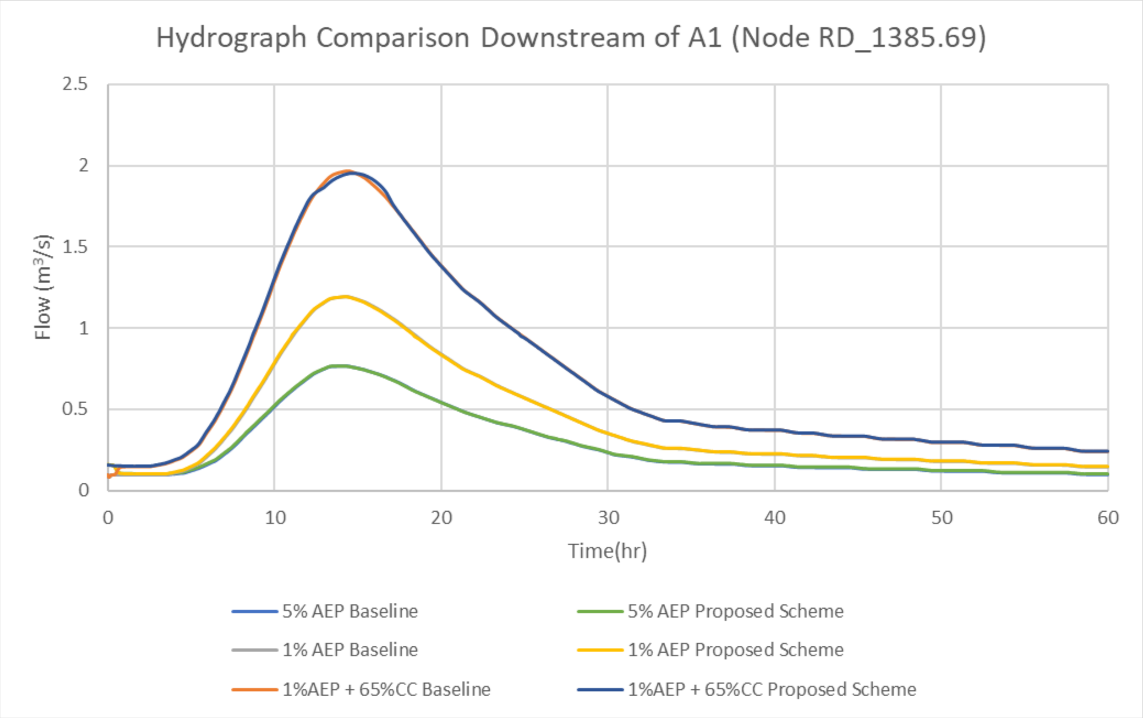


Figure 8-4: Hydrograph of Baseline and Proposed Scheme Downstream of A1 Culvert (Node RD_1385.69) for Rockham Ditch model

8.4.3 **Figure 8-4** displays the modelled flow for the baseline and proposed Scheme downstream of the A1 crossing. The hydrograph for the 1% AEP + 65% climate change event for the proposed Scheme is similar to the hydrograph for the baseline Scheme, with the baseline reaching a peak of 1.97m^3/s and the proposed model reaching a peak of 1.95m^3/s. Similarly, for 5% AEP and 1%AEP both reach peaks within 0.01m^3/s comparing the baseline and proposed Scheme. Modelling shows that the proposed Scheme maintains conveyance in line with existing and does not lead to an increase in the peak flow downstream of the A1 culvert.

Scheme culvert peak water level

8.4.4 **Figure 8-5** assesses the water level in the proposed A1 culvert, as the peak water level within the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428 crossing. Furthermore, as specified in Design Manual for Roads and Bridges CD 356, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (included within **Figure 8-5**). **Figure 8-5** displays the water level in the A1 crossing culvert (RD_E72a) which has an invert level of 16.95m AOD and a soffit level of 18.75m AOD.

8.4.5 **Figure 8-5** indicates that the minimum freeboard of 300mm and desirable freeboard of 600mm between the soffit of the culverts and peak water level for the 1% AEP + 65% climate change event is achieved for the A1 crossing culvert.

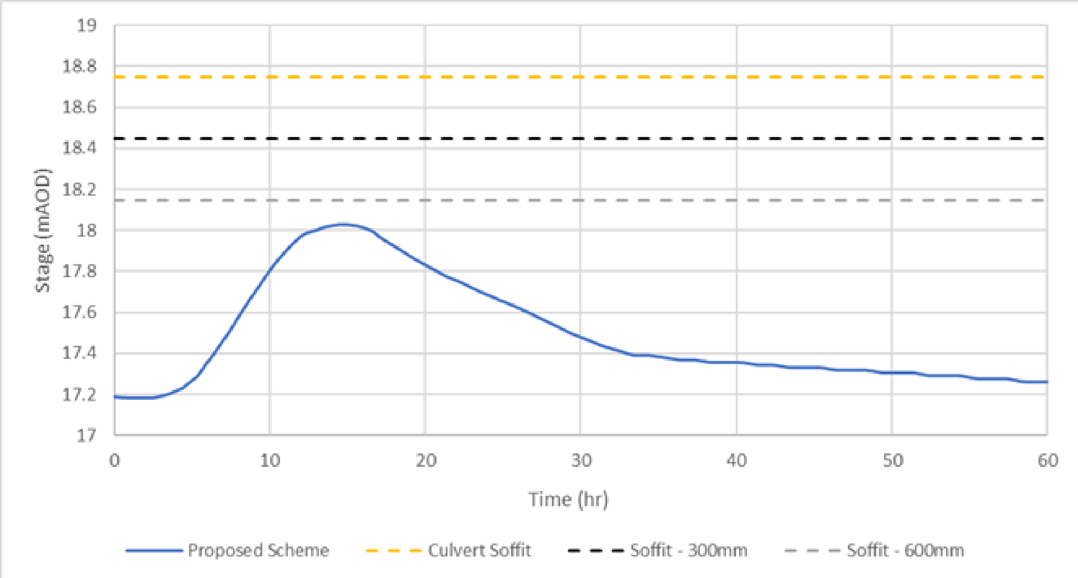


Figure 8-5: Stage Plot of A1 Culvert for the 1% AEP + 65% Climate Change Event for Rockham Ditch Model

Upstream peak water level

8.4.6 **Figure 8-6** displays the modelled water level of the first node upstream of the A1 and Kelpie Marina Access Road culvert (RD_970.42) that is common between both models. The stage plots show the same profile through the modelled event, although there is a small decrease in the peak water level of 0.03m in the proposed Scheme in comparison to the peak water level in the baseline. The peak water level for the proposed Scheme for 5% AEP and 1% AEP are both 0.01m lower than the baseline Scheme for the same event. This indicates that the Scheme results in no increase in water level upstream of the Scheme.

Compensatory Storage

8.4.7 In-channel maximum baseline water levels have been extracted from the model at the location of the proposed Scheme in order to assess if flow is out of bank. The extracted maximum water level shows that flow is out of bank, demonstrating that compensatory storage is required for Rockham Ditch.

8.4.8 Compensatory storage volumes have been calculated according to the methodology outlined in section 2.9, and associated results are provided within Appendix D1. It should be noted that for Begwary Brook, the quoted maximum flood level of 18.2 mAOD has been calculated through interpolation of maximum levels between model nodes, as the watercourse is intersected by the scheme at more than one location.

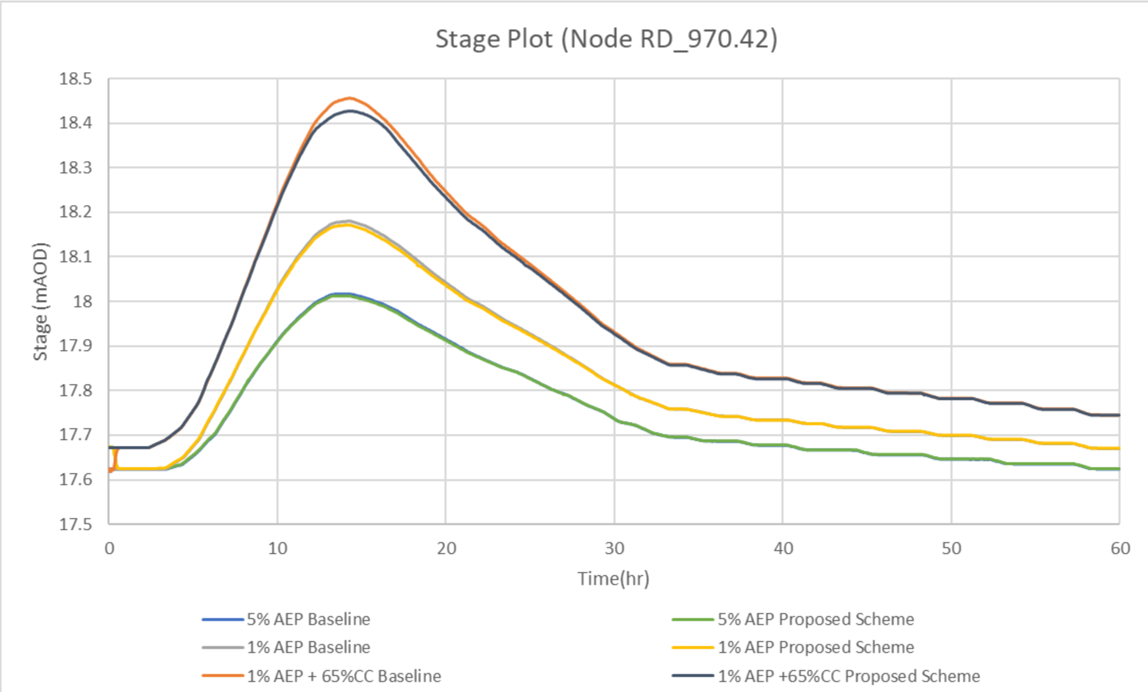


Figure 8-6: Stage Plot of Baseline and Proposed Scheme Upstream of A1 Culvert for Rockham Ditch Model

8.5 Sensitivity Analysis

8.5.1 Sensitivity analysis has been performed on the Rockham Ditch model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were:

a. ± 20% Upstream Boundary Inflow.

b. River Great Ouse downstream boundary water level set to bank full at 15.95m AOD (constant HT).

8.5.2 **Table 8-3** displays the peak water level upstream, downstream and at the A1 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. **Figure 8-7** displays the water level in the A1 culvert for 1% AEP + 65% climate change event and the three sensitivity tests undertaken.

Table 8-3: Sensitivity Analysis Results

	Water Level m AOD		
	Upstream (RD_970.42)	A1 Culvert (RD_E72a)	Downstream (RD_1385.69)
Proposed Scheme	18.43	18.03	17.44
Roughness +20%	18.49 (+0.06m)	18.05 (+0.02m)	17.51 (+0.07m)
Roughness -20%	18.36 (-0.07m)	18.00 (-0.03m)	17.36 (-0.08m)
River Great Ouse DS Boundary HT at 15.95m AOD	18.43 (+0.00m)	18.02 (-0.01m)	17.50 (+0.06m)

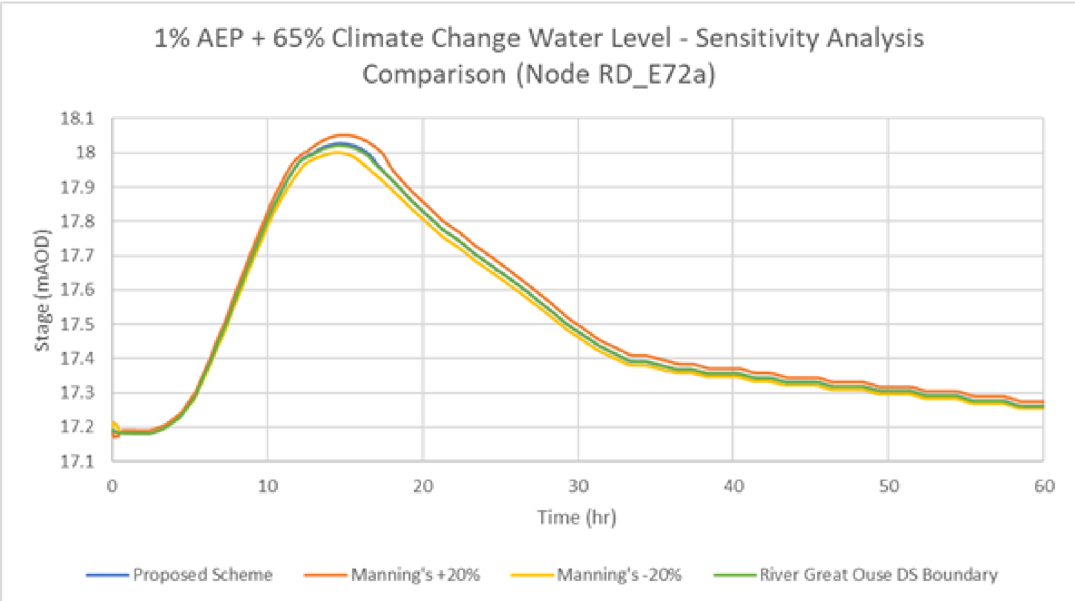


Figure 8-7: Sensitivity Analysis of A1 Culvert for the 1% AEP + 65% Climate Change Event for Rockham Ditch Model

8.5.3 A 20% increase and decrease were applied globally in the model to all Manning's Roughness Coefficients in the 1D channel and banks. Model results show a 20% increase globally to Manning's Roughness Coefficients in channel and on the bank have produced an increase of +0.02m in water level in the culvert and a 20% decrease produces a fall of -0.03m in the water level. This model response appears reasonable based upon the change in parameters.

8.5.4 The downstream boundary of the Rockham Ditch model is configured as a normal depth boundary, located within a section of open channel as it crosses a wetland area on the River Great Ouse floodplain. This sensitivity test examines the effect on the model when the downstream boundary is at the bank full level of the River Great Ouse of 15.95m AOD preventing free outflow. Simulating the model with a HT downstream boundary at the bank full level of the River Great Ouse of 15.95m AOD has increased the water level through the downstream stretch and by 0.06m at node RD_1385.69.

8.6 Limitations

8.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

8.6.2 The downstream model boundary is configured as a normal depth boundary for the design simulations, which calculates outflow according to channel bed slope, assuming no other downstream influences. This boundary configuration was selected to retain a good level of convergence within the model. The downstream boundary of the Rockham Ditch model is located at the confluence with the River Great Ouse. Given that the downstream boundary is located at the confluence with the River Great Ouse, a sensitivity test was undertaken to assess the impact of raised levels within the main river on hydraulics within Begwary Brook. This sensitivity test suggested that raised levels within the River Great Ouse did not affect the Scheme assessment, and therefore it was concluded that the configuration of the downstream boundary facilitates a robust assessment of the Scheme.

8.6.3 Out of bank flow has been represented through inclusion of extended 1D channel sections within the baseline model, whilst a number of 1D reservoir units have been added to account for compensatory area provided within the proposed Scheme scenario. This approach to the representation of floodplain flow is simple and assumes flow is one dimensional in the same direction as the channel. Given the small size of the watercourse and limited occurrence of out of bank flows, the simplified approach will facilitate an appropriate assessment of the Scheme.

8.6.4 Overall, the specific limitations stated within this section should be considered in light of uncertainties relating to hydrological inflows. Given that Rockham Ditch is an ungauged catchment, hydrological peak flow estimates can be associated with an error of +-40%.

8.7 Conclusions

8.7.1 In the Rockham Ditch model, the flow downstream of the A1 crossing is $0.02m^3/s$ less in the proposed model than the baseline model for 1% AEP + 65% climate change event and $0.04m^3/s$ less for the 0.1% AEP event. The peak flow is the same for 5% AEP and for 1% AEP and 1% AEP + 35% climate change events the proposed Scheme peak flow is $0.01m^3/s$ greater than the baseline. These differences equate to a change of less than 0.1%, and therefore based upon modelling results it can be concluded that the Scheme doesn't exert a significant impact upon conveyance within Rockham Ditch.

8.7.2 The modelled water level in the culvert under the A1 crossing meets requirements for the minimum freeboard of 300mm and desired freeboard of 600mm for the 1% AEP + 65% climate change event.

8.7.3 The stage plots upstream of the A1 culvert are similar within the baseline and proposed scenarios, with a small decrease in peak level observed in the proposed model for the 1% AEP + 65% climate change event. In combination with other reported results, this indicates that the A1 culvert does not lead to an increase in water level upstream.

8.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is required. Details of the compensatory storage calculations are included within Appendix D1.

9 Top Farm Brook (1D FMP)

9.1 Overview

9.1.1 Top Farm Brook is located south-east of St Neots. The head of the watercourse is located in the fields south of St Neots Road and flows north-west towards St Neots (**Figure 9-1**). The typical cross section channel width is approximately 4.5m while the peak flow estimate for the 1% AEP event is 1.9m^3/s.

9.1.2 This section details the development and outcome of the baseline and proposed model results for Top Farm Brook. The criteria for assessing the model comparison are stated below:

a. Flow downstream of the Scheme is not greater in the proposed model than in the baseline.

b. Water level is below the soffit with a required freeboard of 300mm for the main Scheme culvert.

9.1.3 The impact on water level upstream of the main Scheme crossing culvert has been assessed to confirm that the flow in the proposed model is not greater than in the baseline.

9.1.4 Additionally, this section details whether compensatory storage is required for Top Farm Brook, based upon whether modelled maximum baseline water levels indicate that flow is out of bank at the location of the proposed Scheme crossing.

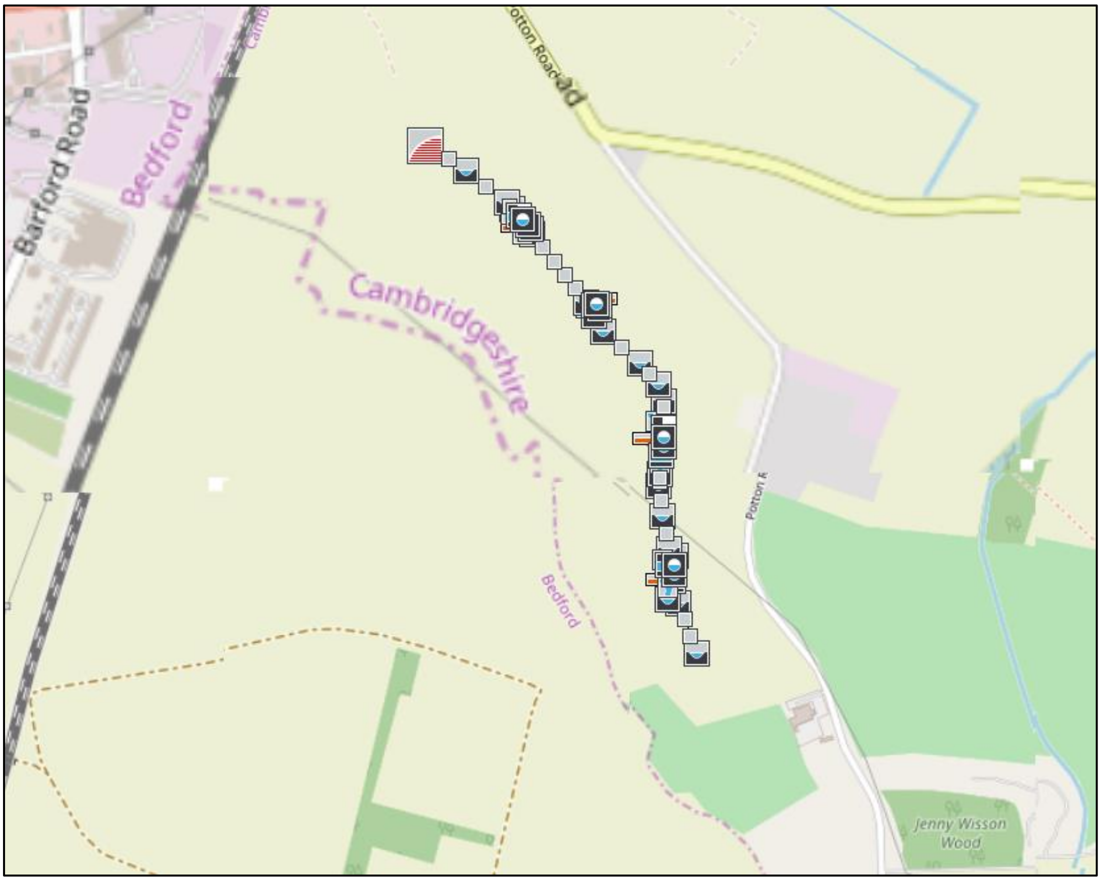


Figure 9-1: Top Farm Brook Proposed Scheme Model Schematic in Flood Modeller Pro

9.2 Model setup- baseline scenario

9.2.1 **Table 9-1** includes all key information regarding the setup of the Top Farm Brook baseline model.

Table 9-1: Baseline Model Setup

Model Setup	Comments
Simulation time	25 hours
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.2km
Upstream boundary	Flow-time boundary located in fields south of the existing A428 (519649, 256968)
Downstream Boundary – 1D	Normal Depth boundary located in fields south of the existing A428 (519147, 257907)
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients

9.2.2 There are four existing structures in the baseline model, two field crossings and two culverts under farm access tracks.

9.2.3 A normal depth boundary has been applied as there is not expected to be any backwater effects from downstream. Slope has been calculated based on the bed of the upstream node. The baseline model contains 67 nodes over the 1.2km modelled reach of Top Farm Brook.

9.2.4 Additional information about the modelling hydrology used can be found in Section 2.2 and in Annex C: Hydrology Report.

9.3 Model Setup- Scheme Scenario

9.3.1 The Top Farm Brook proposed Scheme model includes reprofiling of the channel and a culvert at the proposed A428 crossing which is located approximately 1.2km south-east of the existing A428 crossing. The reprofiled channel cross-sections retain the similar cross-sectional area to the baseline with lowered bed levels. As baseline modelling indicated no out of bank flows at the location of the Scheme crossing, there was no requirement for floodplain compensation storage for Top Farm Brook.

9.3.2 The proposed Scheme model includes amendments to the cross-section at the proposed culvert location (17.3m in length). The modifications include a raised animal crossing ledge within the culvert, and minor reprofiling to river channel bed level immediately upstream and downstream of the culvert. The Scheme also includes a hydraulic attenuation area, upstream of the A428 culvert and is approximately 170m in length and 50m in width. The asymmetrical culvert cross section shown in **Figure 9-2** (not to scale) was simplified to a symmetrical culvert in the model to retain stability (Figure 9-3). The outer dimensions of the modelled culvert are 2.3m by 1.5m.

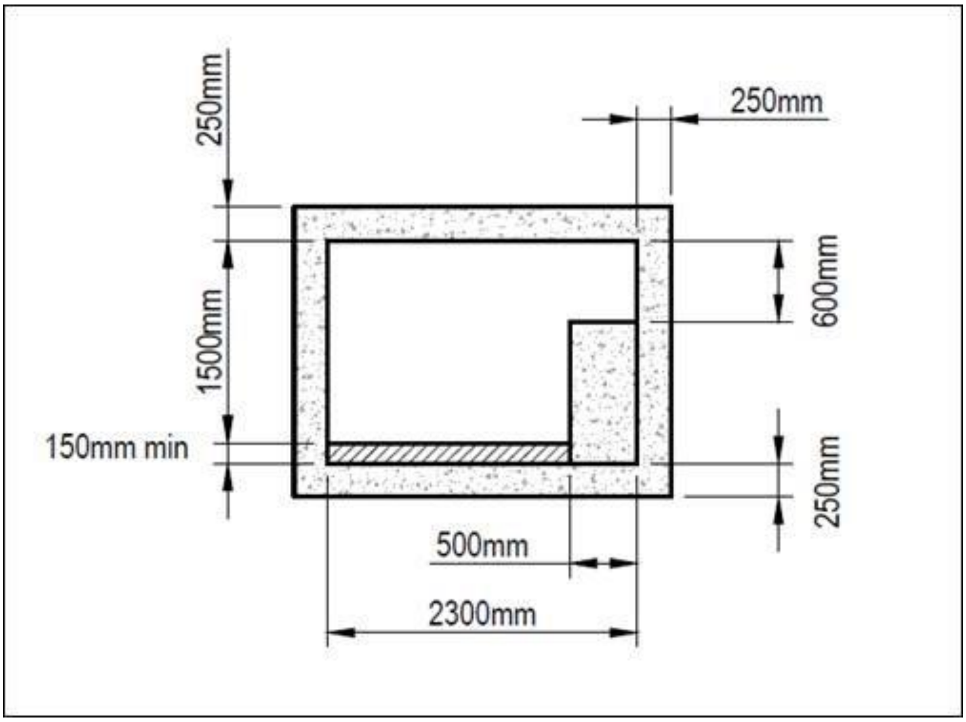


Figure 9-2: Top Farm Brook Proposed A428 Culvert (dimensions not to scale)

Figure 9-3: Top Farm Brook Proposed A428 Modelled Culvert

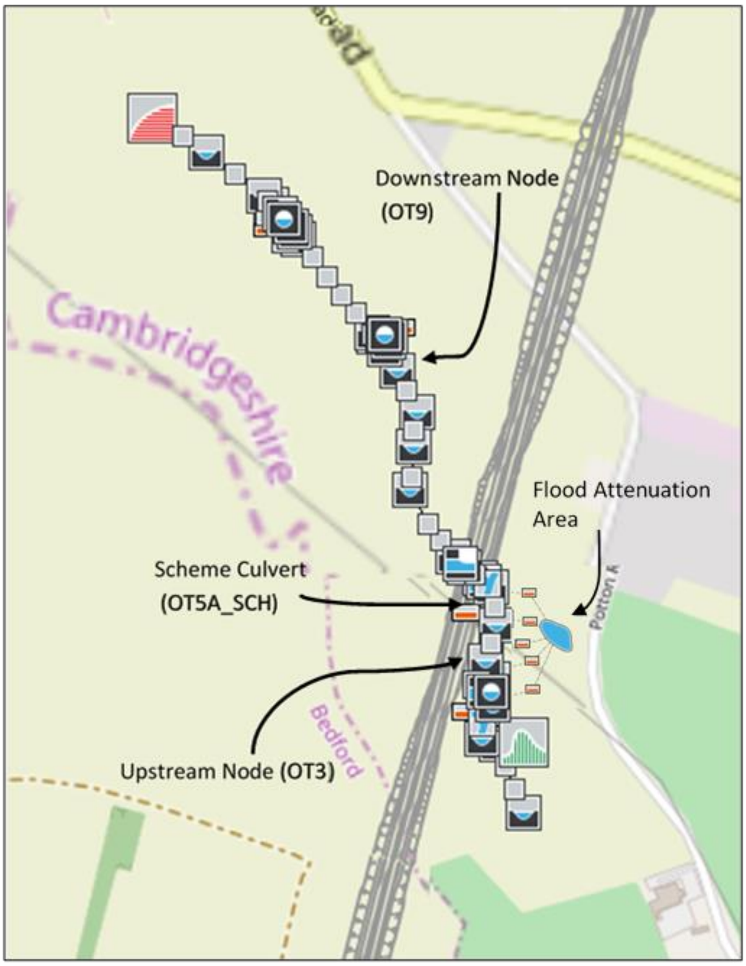


Figure 9-4: Top Farm Brook Proposed Scheme Model Schematic in Flood Modeller

9.4 Results

Downstream peak flow

9.4.2 **Table 9-2** below shows that the peak flow downstream of the Scheme is the same in the baseline and proposed Scheme model for all simulated events. The node selected is the first point downstream of the proposed A428 culvert that is not connected to a structure and is labelled on **Figure 9-4**.

Table 9-2: Comparison of Peak Flow Results Downstream of A428 Culvert (Node OT9)

AEP	Baseline Flow (m3/s)	Proposed Scheme (m3/s)	% Change (Proposed vs Baseline)
5%	1.21	1.20	<-0.1
1%	1.87	1.82	<-0.1
1% + 35%CC	2.53	2.51	<-0.1
1% + 65%CC	3.07	3.05	<-0.1
0.1%	3.29	3.27	<-0.1

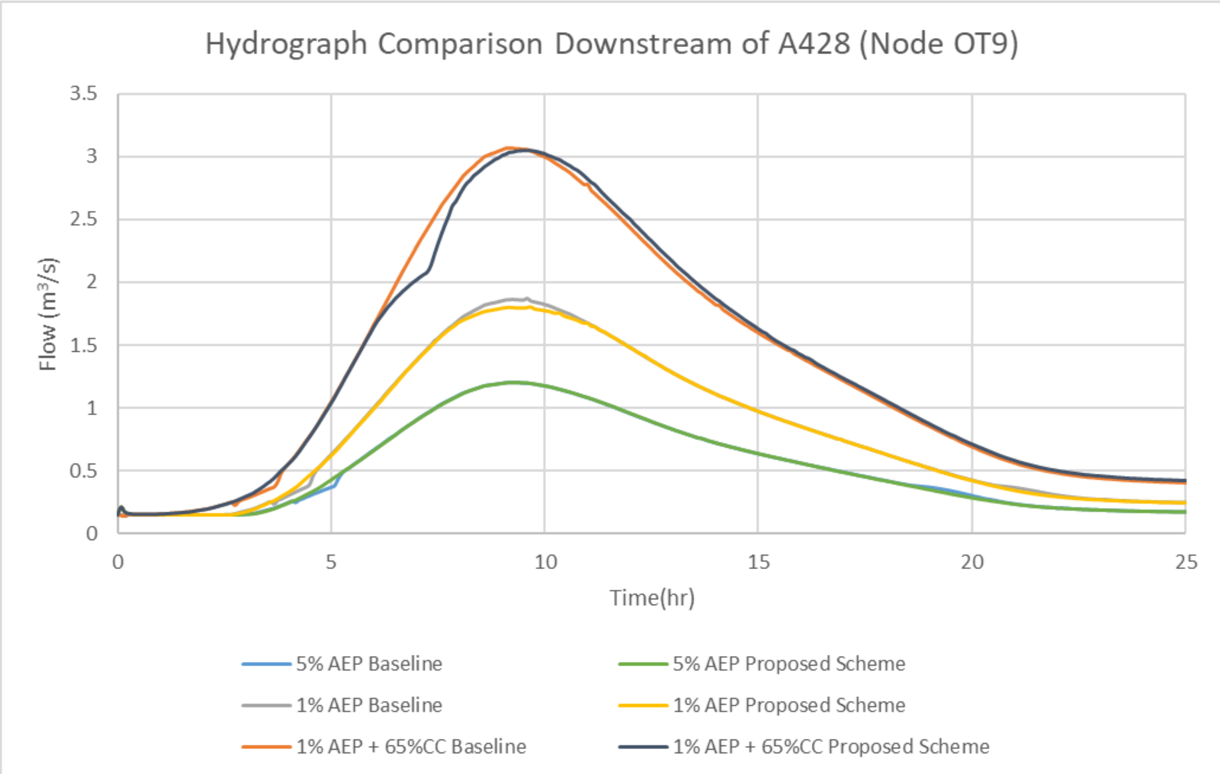


Figure 9-5: Hydrograph of Baseline and Proposed Scheme Downstream of Proposed A428 Culvert (Node OT9) for Top Farm Brook Model

9.4.3 **Figure 9-5** displays the flow for the baseline and proposed Scheme downstream of the proposed A428 crossing. The hydrograph for the 1% AEP + 65% climate change event for the proposed Scheme follows the hydrograph for the baseline Scheme, with the baseline reaching a peak of 3.07m^3/s and proposed Scheme reaching a peak of 3.05m^3/s. Hydrographs are also similar for the 1% and 5% AEP events, with peak flows in the proposed scenario being equivalent or lower than the baseline scenario.

Scheme culvert peak water level

9.4.4 **Figure 9-6** assesses the water level in the proposed A428 culvert as the peak water level during the 1% AEP + 65% climate change event must not exceed the level of the culvert soffit beneath the proposed A428. Furthermore, the design team require a minimum of 300mm freeboard between the culvert soffit and peak water level for the 1% AEP + 65% climate change event, however a 600mm freeboard would be desirable (also included in **Figure 9-6**).

9.4.5 Model results shown in **Figure 9-6** indicate that the minimum freeboard of 300mm and desirable freeboard of 600mm between the soffit of the culvert and peak water level for the 1% AEP + 65% climate change event is achieved for the proposed A428 culvert.

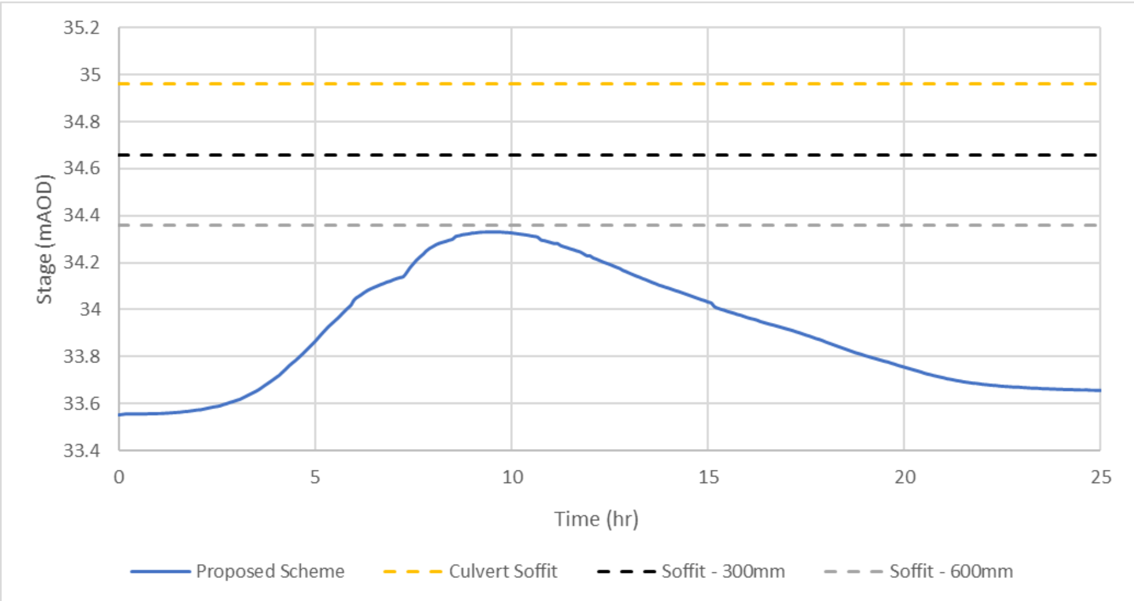


Figure 9-6: Stage Plot of A428 Culvert for 1% AEP + 65% Climate Change for Top Farm Brook Model

Upstream peak water level

9.4.6 The peak water level for the proposed Scheme is 36.26m AOD and the peak water level for the baseline is 36.34m AOD, for the 1% AEP + 65% climate change event (**Figure 9-7**). Peak upstream water levels are also lower within the proposed scenario, when compared to the baseline, for the 1% AEP and 5% AEP events. These results demonstrate that the proposed A428 culvert has not restricted the flow of Top Farm Brook as the peak water level upstream (at Node OT3) for proposed has decreased compared to the water level in the baseline model.

Compensatory Storage

9.4.7 Comparison of baseline maximum flood levels for the 1% AEP + 35% CC event showed that flows were not out of bank on Top Farm Brook, with a maximum level of 35.41 mAOD at node OT4, located upstream of the proposed Scheme crossing. Therefore, compensatory storage is not required.

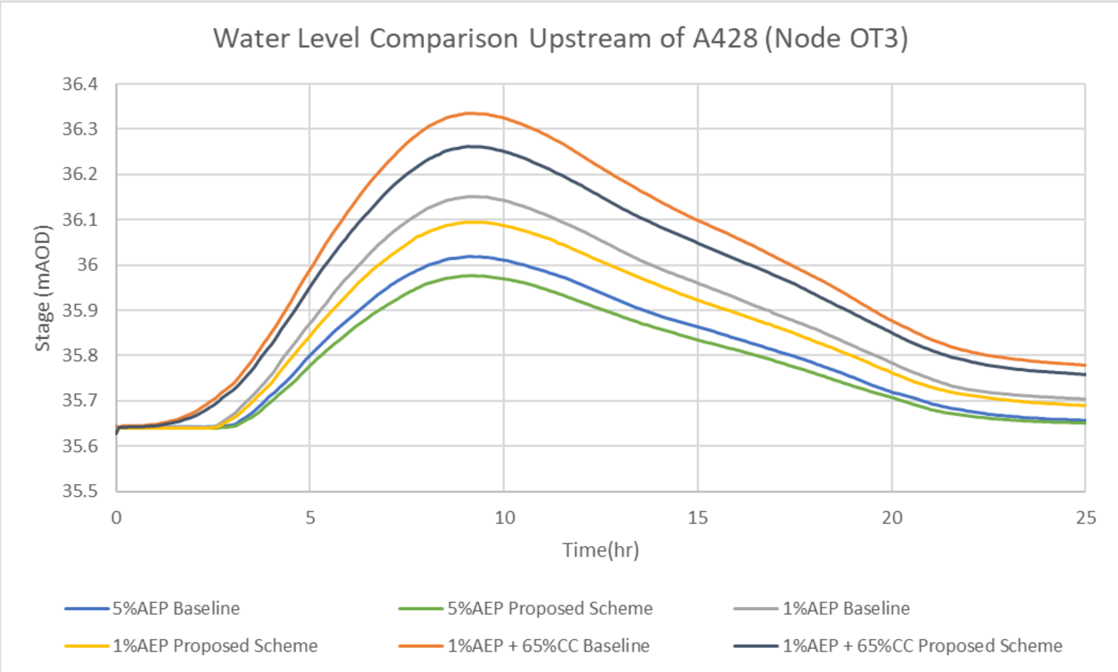


Figure 9-7: Stage Plot of Baseline and Proposed Scheme Upstream of Proposed A428 Culvert for Top Farm Brook Model

9.5 Sensitivity Analysis

9.5.1 Sensitivity analysis has been performed on the Top Farm Brook model to verify the hydraulic model was functioning appropriately and to test the parameter assumptions. The sensitivity checks performed on the 1% AEP + 65% climate change event were;

a. Anglian Water inflow of 0.06m^3/s.

b. ± 20% Manning's Roughness Coefficient.

c. ± 20% Upstream Boundary Inflow.

9.5.2 **Table 9-3** displays the peak water level upstream, downstream and at the A428 culvert for the 1% AEP + 65% climate change event for the proposed Scheme and sensitivity analysis. **Figure 9-8** displays the water level in the A428 culvert for 1% AEP + 65% climate change event and the four sensitivity tests undertaken.

Table 9-3: Comparison of Sensitivity Analysis

	Water Level (m AOD)		
	Upstream (OT3)	A428 Culvert (OT5A_SCH)	Downstream (OT9)
Proposed Scheme	36.26	34.33	29.09
Proposed Scheme with Anglian Water inflow	36.27 (+0.01m)	34.34 (+0.01m)	29.09 (+0.00m)
Roughness+20%	36.31 (+0.05m)	34.40 (+0.07m)	29.11 (+0.02m)
Roughness -20%	35.19 (-0.07m)	34.26 (-0.07m)	29.06 (-0.03m)
Flow +20%	36.33 (+0.07m)	34.43 (+0.10m)	29.15 (+0.06m)
Flow -20%	36.18 (-0.08m)	34.22 (-0.11m)	29.01 (-0.08m)

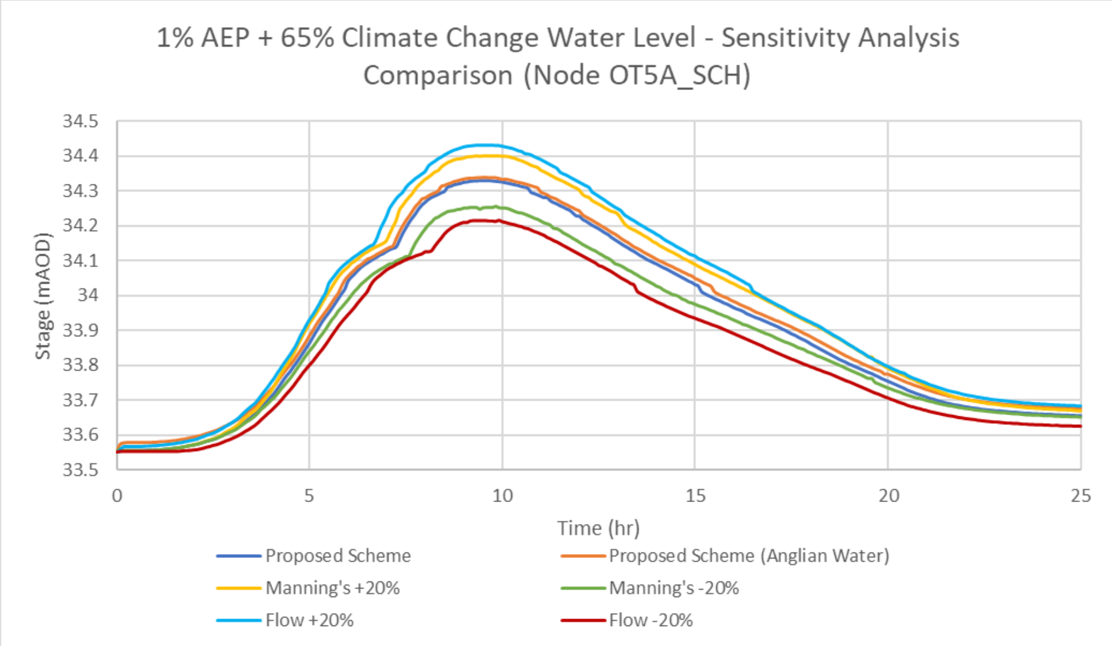


Figure 9-8: Sensitivity Analysis of Proposed A428 Culvert for the 1% AEP + 65% Climate Change Event for Top Farm Brook Model

9.5.3 A constant inflow of 0.06m^3/s was applied immediately downstream of the upstream boundary in the Top Farm Brook model to represent the potential inflow from Anglian Water overflow ponds which is an increase in peak flow of <0.1%. The Anglian Water additional inflow of 0.06m^3/s has increased the peak water level at the proposed A428 culvert by +0.01m, upstream of the culvert by +0.01m and downstream of the culvert by +0.01m. The Anglian Water additional inflow has not led to large increases in water level and flow remains in bank.

9.5.4 A 20% increase and decrease were applied globally in the model to all Manning’s Roughness Coefficients in the 1D channel and banks. Manning's Roughness Coefficient analysis was performed on the proposed model to determine how the model responds when the main model parameters were varied. Increasing the Manning’s Roughness Coefficients by 20% has resulted in an increase of +0.07m in water level in the culvert and a 20% decrease produces a fall of -0.07m in the water level for 1% AEP + 65% climate change event without Anglian Water inflow.

9.5.5 An increase and decrease of 20% was applied to the flow hydrograph at the upstream boundary of the Top Farm Brook model. Increasing the inflow at the upstream boundary by 20% has resulted in a +0.10m increase to peak water level at A428 culvert. A 20% decrease in the total inflow produces a -0.11m decrease in peak water level at the node OT5A_SCH.

9.6 Limitations

9.6.1 General limitations that affect all 1D models can be found in Section 2.10, such as uncertainties from generated hydrological inflows.

9.6.2 It is noted that the Top Farm Brook hydraulic model extends only 300m upstream of the proposed Scheme crossing. Based upon satellite imagery and topographical survey the model captures the majority of the channelised reach of the Brook upstream, and it doesn't appear that the watercourse extends further. The modelled reach captures all changes in flow and level related to the Scheme and so the reach length modelled is considered adequate.

9.6.3 The attribution of Manning's Roughness Coefficient 'n' values remains consistent through the reach, with values of 0.035 being applied within the channel and 0.050 being applied for top of banks and floodplain. These Manning's Roughness Coefficients were assigned based upon observations by the survey team and reflect the presence of a smooth channel bed, and short grass within agricultural fields upon the floodplain. The modelled reach is relatively short and there were no clear changes in channel morphology, therefore consistent application of Manning's Roughness Coefficient values was considered appropriate.

9.6.4 Out of bank flow has been represented through inclusion of extended 1D channel sections. This approach to the representation of floodplain flow is simple and assumes flow is one dimensional in the same direction as the channel. Given the small size of the watercourse and limited occurrence of out of bank flows on Top Farm Brook it is expected that the simplified representation of floodplain flow will facilitate an adequate assessment of the Scheme.

9.6.5 Overall, the specific limitations stated within this section are thought to be relatively small contributors to the overall model uncertainty, particularly in light of uncertainties relating to hydrological inflows. Given that Top Farm Brook is an ungauged catchment, hydrological peak flow estimates can be associated with an error of +-40%.

9.7 Conclusions

9.7.1 Within the Top Farm Brook modelling, the peak flow downstream of the proposed A428 culvert is the same in the proposed Scheme model and baseline model for the 1% AEP + 65% climate change event, along with all other design events. This demonstrates that the Scheme does not lead to an increase in pass on flow and flood risk downstream.

9.7.2 The water level in the Scheme culvert in the Top Farm Brook model does not exceed the minimum freeboard of 300mm or desired freeboard of 600mm. The modelled peak water level for the proposed A428 culvert is 0.03m below the 600mm freeboard level for the 1% AEP + 65% climate change event.

9.7.3 The modelled water level upstream of the proposed A428 culvert has decreased by -0.08m in the proposed model compared to the baseline model for the 1% AEP + 65% climate change event. Results therefore demonstrate that the Scheme does not lead to an increase in flood levels upstream.

9.7.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required. A hydraulic attenuation area is included as part of the scheme, although this is included in order to retain downstream pass on flows in line with the baseline, and is not related to requirements for floodplain compensation storage.

10 Hen Brook (1D-2D FMP-TUFLOW)

10.1 Overview

10.1.1 Hen Brook is a watercourse located to the south-east of St Neots. The head of the watercourse is located within agricultural fields located to the north of the B1046 near Abbotsley, receiving flow from other minor watercourses and land drains. Hen Brook flows in a north-west direction towards St Neots (Ordinary Watercourse) and after flowing beneath the existing A428 carriageway the watercourse reaches the rail line where it then becomes a Main River. The size of the catchment of Hen Brook is approximately 47km^2 with a peak flow estimate of ~13m^3/s for the 1% AEP event (FEH statistical method).

10.1.2 Beyond the downstream boundary of the model, the Hen Brook flows through Eynesbury before confluencing with the Fox Brook prior to its final discharge to the River Great Ouse in St Neots. The Ordinary Watercourse section of the Hen Brook which has been modelled is shown in Figure 10-1.

10.2 Model setup - baseline Scenario

10.2.1 **Table 10-1** includes all the key information relating to the set-up of the Hen Brook baseline model. This includes information about model boundaries and how the floodplain was represented.

Model Setup	Comments
Simulation time	60 hours (18 hour critical storm duration)
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.8km
Upstream boundary	Located within agricultural fields approximately 1.2km upstream of the existing A428 carriageway (520775, 258230)
Downstream Boundary – 1D	Located 0.6km downstream of the existing A428 carriageway (519360, 259090). Normal Depth boundary with slope calculated based on gradient of channel bed to the upstream node
Downstream Boundary – 2D	Water level–flow boundaries (HQ) added at the location of the 1D downstream boundary, perpendicular to floodplain flow.
Cell size	2m cell size
LiDAR	1m LiDAR data captured in 2017 used to establish the 2D model extent
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients. No buildings included within the model domain

Table 10-1: Baseline Model Setup

10.2.2 A topographical survey for the Hen Brook channel has been used to create the baseline channel throughout the modelled reach. The only structure located along the watercourse is at the existing A428 where a 4.50m by 1.90m rectangular culvert (50m in length) is located. This has been represented in the 1D model using a rectangular conduit unit which has been designed based on the provided survey information. It should be noted that immediately adjacent to the location of this culvert there is also a 12m by 5m underpass beneath the A428 carriageway which provides vehicular access to the agricultural land either side of the raised carriageway. Consequently, any out of bank floodwater on the upstream side of the carriageway flows through this opening (represented within the 2D model) as shown within the results section below.

10.2.3 As can be seen within **Figure 10-1**, other than the existing A428 highway there are no other sensitive receptors such as residential and commercial property within close proximity to the watercourse with the floodplain largely undeveloped within this area. The cover level of the existing A428 carriageway is elevated more than 3m above the surrounding floodplain and results have demonstrated that this highway is not at risk of inundation from the watercourse. Beyond the downstream boundary there is a railway line, however this is raised more than 5m above the surrounding floodplain.

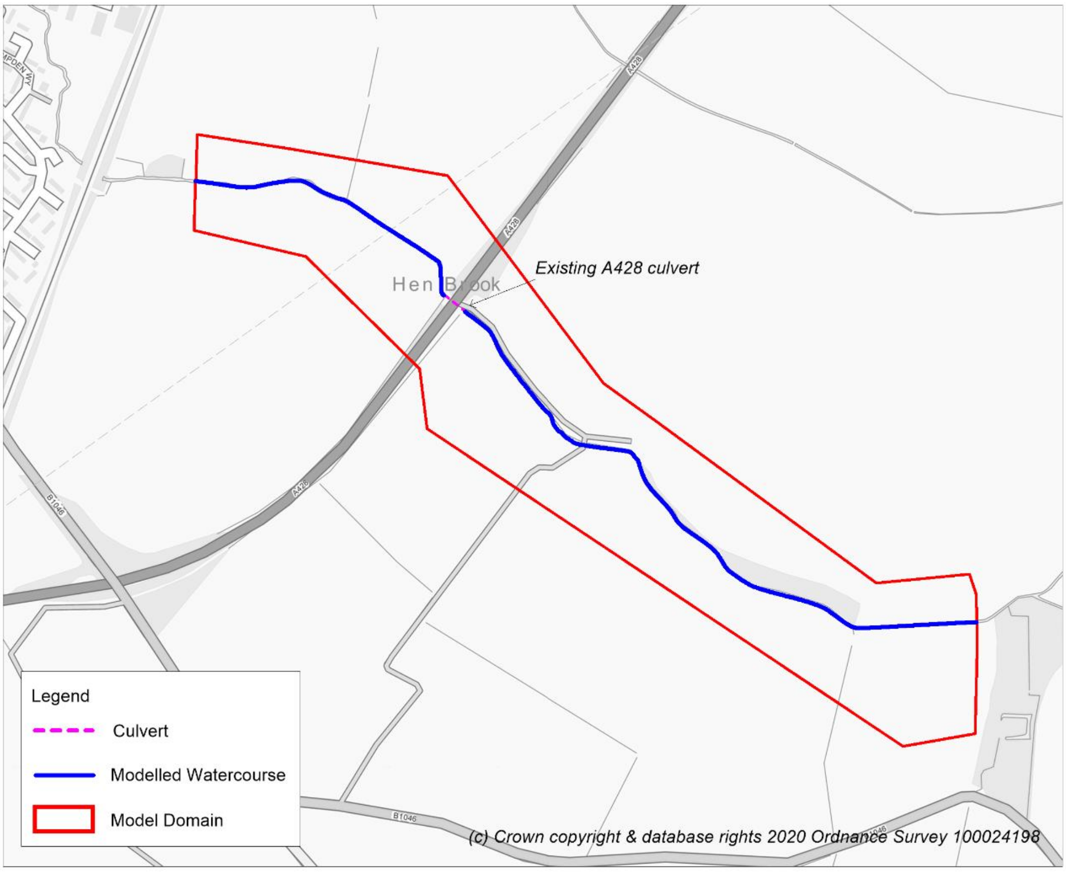


Figure 10-1: Baseline Model Extents

10.3 Model setup - proposed scenario

10.3.1 The proposed Scheme is located approximately 0.5km upstream of the existing A428 carriageway and comprises a new embanked carriageway with a culvert to convey the watercourse beneath the carriageway and a further six high flow culverts through the embankment to maintain conveyance of the Hen Brook (**Figure 10-2**). As baseline modelling displayed out of bank flows at the location of the Scheme crossing, a floodplain compensation area has been proposed to compensate for the displacement of floodwater as a result of the proposed Scheme. The individual Scheme elements, and their representation within the model are described further below.

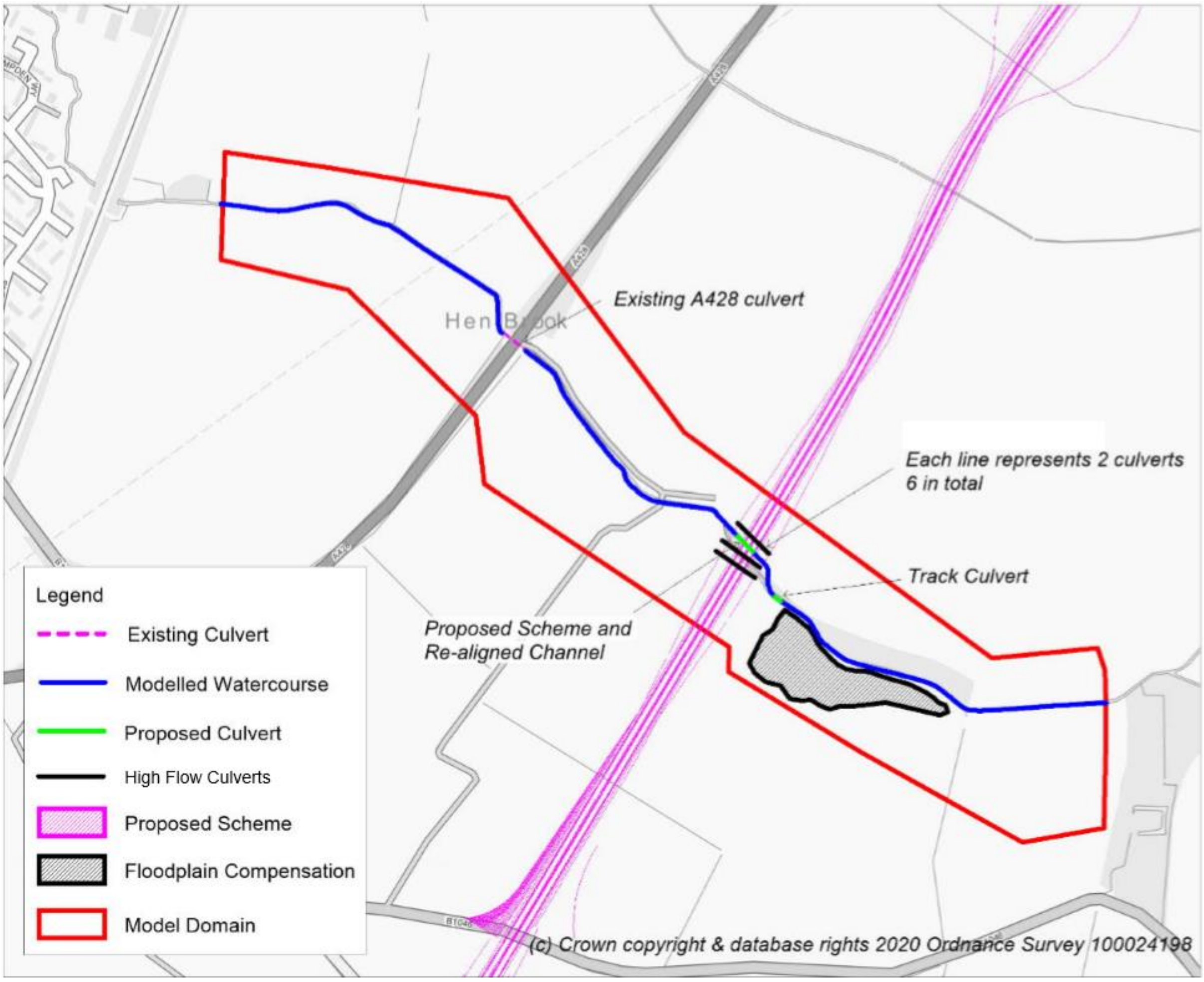


Figure 10-2: Proposed Model Extents

1D Model

10.3.2 The 1D FMP proposed Scheme model includes a realigned channel (over a stretch of approximately 250m) and one 32.66m long culvert under the proposed A428 highway). Scheme designs show that this proposed culvert conveys the realigned Hen Brook channel and also contains a pedestrian walkway with a separating raised wall. Given the asymmetrical shape of this culvert, and to promote model convergence, this culvert has been represented using a symmetrical conduit unit, with an equivalent opening area to the provided asymmetrical design. **Figure 10-3** displays the modelled culvert.

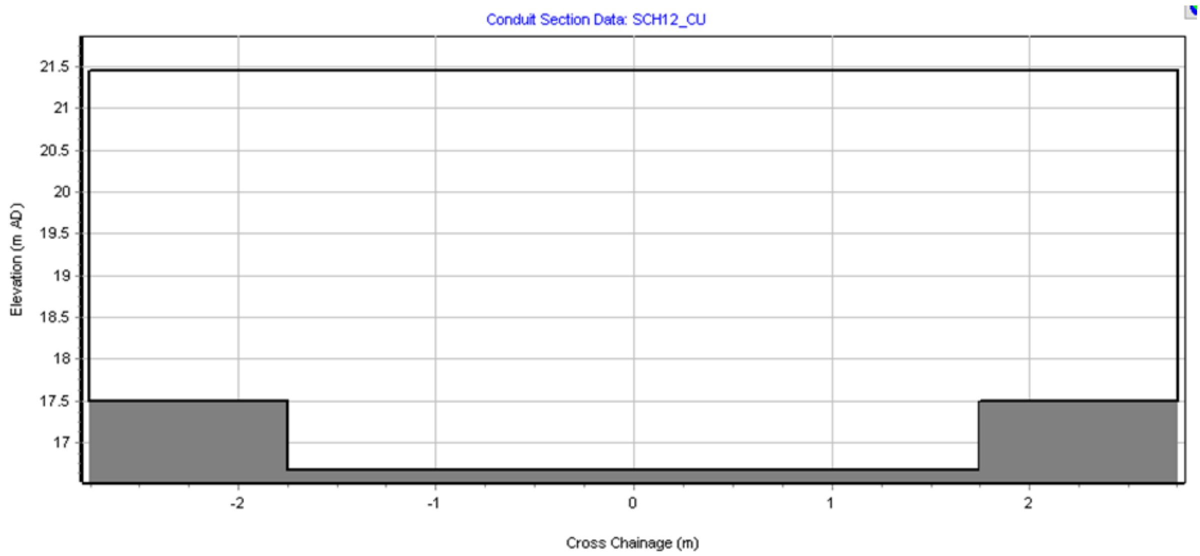


Figure 10-3: Hen Brook Proposed A428 Modelled Culvert (dimensions not to scale)

10.3.3 Six high flow culverts each 3.0m by 1.5m (approximately 75m in length) have been modelled as ESTRY culverts through the new dual carriageway embankment to provide additional conveyance (**Figure 10-2**).

10.3.4 There is also a 7.54m long culvert located 80m upstream of the proposed Scheme which represents an access track crossing designed for maintenance access. This has been represented in the 1D FMP model using a symmetrical culvert unit and modelled a single T-shaped culvert unit to allow conveyance of greater flow volumes at high water levels. **Figure 10-4** displays the modelled culvert.

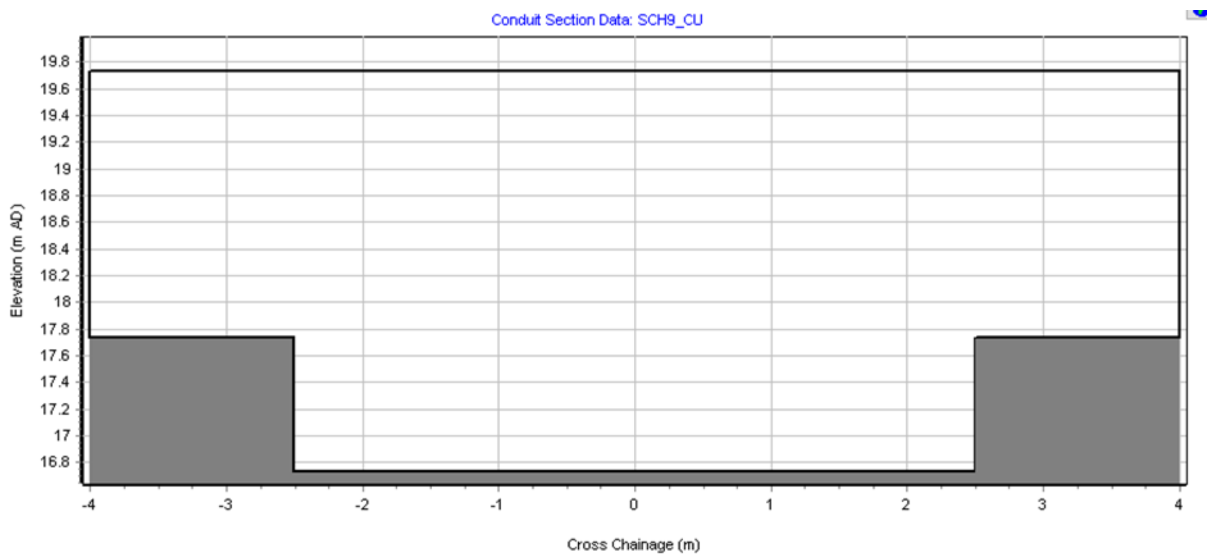


Figure 10-4: Hen Brook Modelled Access Track Culvert (dimensions not to scale)

10.3.5 The realigned channel has been created based on information provided by the project design team. Generally, the channel has been designed so that the bed is approximately 5m wide with a 1:3 slope applied to the banks. The area of realignment occurs from node HB1C to SCH12a within the 1D model.

2D Model

10.3.6 Modelling files within the 2D model were updated to reflect the changes to the 1D model i.e. location of 1D nodes to reflect the realigned channel, bank heights and 1D-2D boundaries. The proposed Scheme also includes floodplain compensation located 110m upstream of the new highway. This has been designed as a two-stage channel, providing more capacity during the 1% AEP + 65% climate change event and compensates for the displacement of the floodplain as a result of the proposed Scheme. This has been represented within the 2D model (**Figure 10-2**) with bank levels adjusted accordingly within the 1D model.

10.3.7 The assessment of floodplain storage compensation is based on EA's climate change guidance. The affected land uses define the level of allowance with the higher central allowance (35%) being indicated for most cases, whilst ensuring no flooding affects sensitive receptors with the upper end allowance (65%). Floodplain storage compensation volumes and cross-sections for Hen Brook can be seen in Appendix D2.

10.3.8 A z-shape has also been used within the 2D model to raise the levels of the floodplain to represent the proposed highway. This approach has also been applied to represent the proposed access track, located approximately 80m upstream of the new A428 carriageway.

10.4 Results

Overview

10.4.2 The results presented within the main body of the report are for the 1% AEP + 65% climate change scenario. For the other AEP events, results are provided in Appendix A. The flooding mechanisms shown and described for the 1% AEP + 65% climate change scenario are similar across all modelled AEPs, however the magnitude of flood depths and extents are shown to vary with peak flow.

Baseline Results

10.4.3 Out of bank flooding is largely contained within the surrounding agricultural fields with flood depths reaching a maximum of approximately 0.75m in low lying areas (**Figure 10-5**). There are areas where flood depths are greater than this, but these occur within low lying field ditches. At the existing A428, the highway presents a barrier to flow and therefore once out of bank flow occurs, floodwater backs up against the road. Flood depths within the vehicular underpass beneath the A428 at this location are approximately 0.64m.

10.4.4 The modelled 1% AEP flood extent has been compared with the corresponding EA flood extents to assess how they correlate. Generally, the flood extents are similar in that they are both fairly narrow around Hen Brook however the EA's flood extents are greater in size and represent areas of overtopping which do not occur during the modelling undertaken as part of this study. It should be noted that the EA's flood extents were produced using localised 2D modelling which contains a simplified representation of the river channel and hydraulic structures. This difference in methodology is likely to account for the differences in flooding observed.

Compensatory Storage

10.4.5 In-channel maximum baseline water levels have been extracted from the model at the location of the proposed Scheme in order to assess if flow is out of bank. The maximum level of 18.87 mAOD at node HB1B is out of bank, demonstrating that compensatory storage is required for Hen Brook.

10.4.6 Compensatory storage volumes have been calculated according to the methodology outlined in section 2.9 and results are provided within Appendix D2.

Proposed Scheme Results

10.4.7 The proposed Scheme represents a significant obstruction across the floodplain and results in the displacement of floodwater (Figure 10-6). Consequently, additional floodplain compensation is required for this displacement, to ensure that there are no significant increases in flood risk to third party land. This floodplain compensation is shown immediately upstream of the proposed Scheme in **Figure 10-2** and involves increasing the width of the channel to provide more capacity. This functions as a two-stage channel and becomes online when the water level within the Hen Brook reaches 10.35m AOD. Floodplain loss between 10.2m AOD and 10.4m AOD is less than 100m3 with 1600m3 compensation provided (see Table D2-2 in Annex D below), along with the additional capacity of the new culvert at the lower floodplain levels it is considered that sufficient flood compensation is provided.

10.4.8 Below summarises the key results from the proposed Scheme simulations:

a. **Figure 10-7** shows a depth difference map which compares the baseline and proposed model results. This figure does not show the entire flood extent, but instead shows areas where differences in depth have occurred within the model.

b. Increases and decreases in flood depth are depicted within this figure by red/pink/yellow and green colours respectively.

c. This figure clearly demonstrates a significant increase in flood depth in the area where floodplain compensation is provided and a significant reduction in flood depth in the location of the proposed Scheme where floodwater has been displaced, as expected.

d. Within the wider floodplain the model demonstrates that there are generally decreases in flood depth (up to -600mm) immediately upstream and downstream of the proposed Scheme which is attributable to the designated area of floodplain compensation.

e. There is a small increase in flood depth (up to +10mm) immediately upstream of the proposed A428 highway adjacent to the left bank, however this is located in an undeveloped agricultural area that will be Highway England permanent land and therefore does not impact on any sensitive receptors. This is also located within the Order Limits of the Scheme.

10.4.9 There are other areas shown in ‘pink’ and ‘red’ as areas where flood depths have increased, however these coincide with the proposed realignment of the new channel (i.e. where no flood extent is shown in the 2D floodplain in the baseline) therefore naturally this area will be shown to have significant increases in flood depth. It is also important to note that these areas of flood depth increase already experience flooding during the baseline scenario and are within the Order Limits for the Scheme.

Figure 10-5: Baseline Maximum Flood Depth Map – 1% AEP + 65% Climate Change

Figure 10-6: Proposed Maximum Flood Depth Map – 1% AEP + 65% Climate Change

Figure 10-7: Depth Difference Map (Baseline vs Proposed) – 1% AEP + 65% Climate Change

Downstream Flows

10.4.10 To understand how the proposed Scheme has impacted downstream flows, results have been extracted from both the 1D model and 2D model in the area located between the proposed Scheme and the existing A428 (node HB_391.598 on **Figure 10-8**). Model results suggest that there is significant out of bank flow within the design event and therefore consideration of flows in both the 1D and 2D models is necessary to provide an overall assessment of the impact of the Scheme upon flow downstream.

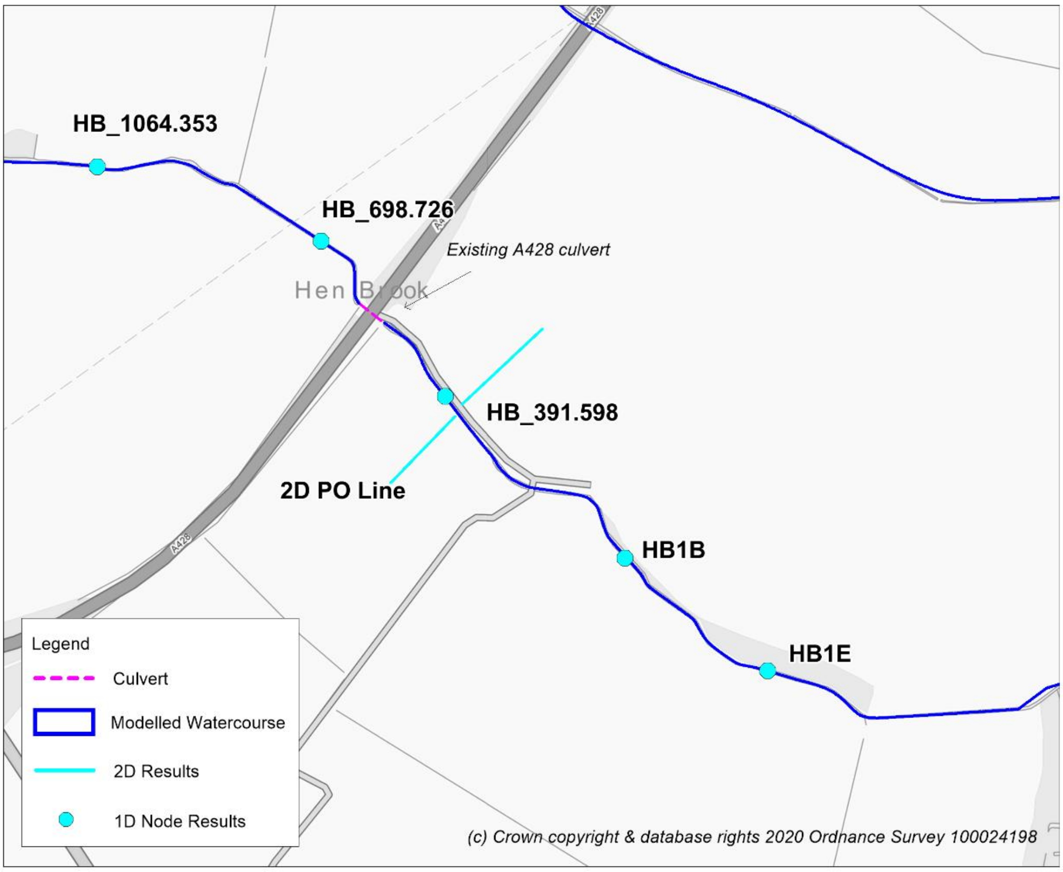


Figure 10-8: Location of 1D Nodes

10.4.11 **Table 10-2** shows that for the 1% AEP +65% climate change event the 1D flows during the proposed are greater than those during the baseline. The peak flow within the proposed scenario is 14.02m^3/s while the baseline peak is 13.79m^3/s.

10.4.12 However, when the 2D flows are assessed (extracted from the floodplain perpendicular to the 1D channel node HB_391.598) the opposite occurs. During the proposed scenario, the peak flow rises to 10.23m^3/s while the peak flow for the baseline scenario rises to 10.46m^3/s.

Table 10-2: Flow Comparison (1% AEP +65% climate change)

Label	NGR	Scenario	1D Peak Flow (m3/s)	2D Peak Flow (m3/s)	Total (m3/s)
HB_391.598	519940, 258690	Baseline	13.79	10.46	24.25
		Proposed	14.02	10.23	24.25

10.4.13 These results demonstrate that during the baseline scenario, flows are greater across the floodplain (when compared with the proposed), however in-channel flows are greater during the proposed (when compared with the baseline). This suggests that further upstream, the proposed Scheme causes more water to be contained/redirected into the channel as it can no longer flow across the floodplain at the Scheme location. This is also being impacted by the upstream area of floodplain compensation where additional channel capacity is provided.

10.4.14 When the 1D flows and 2D flow hydrographs are combined and compared (**Figure 10-9**), the results are very similar with the same peak flow for the baseline and proposed. Essentially, these modelling results show that the proposed Scheme leads to no increase in flow downstream, which is likely to be attributable to the upstream area of floodplain compensation.

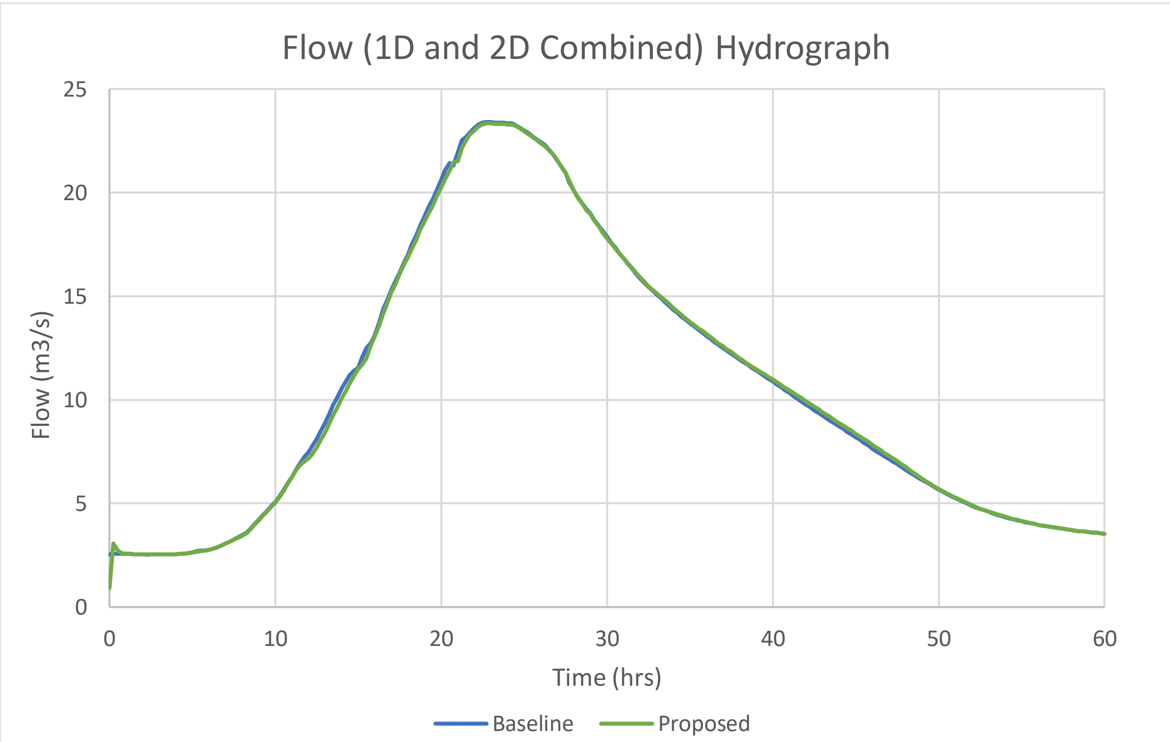


Figure 10-9: Flow (1D and 2D Combined) Hydrograph

10.4.15 The final area of analysis focuses on the proposed Scheme culvert. During the proposed scenario the maximum water level within the culvert for the 1% AEP + 65% climate change event is 18.81m AOD. The soffit level for this culvert is 21.45m AOD, indicating that there is sufficient freeboard during this event.

10.5 Sensitivity Analysis

10.5.1 Sensitivity testing of the model was undertaken to assess the influence of parameter assumptions made during the model development in order to understand confidence in the model results. It also helps to understand variations between summer and winter with regards to vegetation coverage. The following elements have been examined to assess the model sensitivity and therefore the potential impact on maximum flood depths and extents:

a. ± 20% change to 1D and 2D channel roughness values (undertaken for baseline 1% AEP + 65% climate change).

b. ± 20% to peak flow (undertaken for baseline 1% AEP).

c. Downstream Boundary slope increased and decreased (undertaken for 1% AEP + 65% climate change).

10.5.2 A 20% increase and decrease was applied to all Manning's Roughness Coefficients in the 1D channel and 2D model to assess how sensitive the model is to assumptions made in this parameter. Comparison of 1D results (**Table 10-3**) show that within the Hen Brook there are small differences from the baseline when increasing and decreasing Manning's Roughness, but this is in line with the expected response to changes in the roughness coefficients. These results have been extracted from the nodes shown in **Figure 10-6**.

Table 10-3: 1D In-Channel Maximum Stage Hen Brook Roughness Sensitivity Results - 1% AEP + 65% Climate Change

	Maximum Stage + change of in-channel water depth compared to baseline					
Label	**NGR**	**Baseline (m AOD)**	**+20% n (m AOD)**	**Difference (m)**	**-20% n (m AOD)**	**Difference (m)**
HB1E	520495, 258260	19.34	19.35	+0.01	19.32	-0.02
HB1B	520200, 258450	18.90	18.90	0.00	18.90	0.00
HB_391.598	519940, 258690	18.38	18.35	-0.03	18.34	-0.04
HB_698.726	519760, 258915	17.72	17.74	+0.02	17.70	-0.02
HB_1064.353	519430, 259020	17.17	17.17	0.00	17.15	-0.02

10.5.3 A 20% increase and decrease was applied to the peak flow on Hen Brook to assess how sensitive the model is to changes in flow. Comparison of 1D results (**Table 10-4**) show levels vary between +0.10m (increase in flow) and -0.12m (decrease in flow), showing an intuitive response to changes in flow. These results have been extracted from the nodes shown in **Figure 10-6**.

Table 10-4: 1D In-Channel Maximum Stage Hen Brook Flow Sensitivity Results - 1% AEP

	Maximum Stage + change of in-channel water depth compared to baseline					
Label	**NGR**	**Baseline (m AOD)**	**+20% Q (m AOD)**	**Difference (m)**	**-20% Q (m AOD)**	**Difference (m)**
HB1E	520495, 258260	19.12	19.20	+0.08	19.01	-0.11
HB1B	520200, 258450	18.80	18.84	+0.04	18.69	-0.11
HB_391.598	519940, 258690	18.02	18.09	+0.05	17.90	-0.12
HB_698.726	519760, 258915	17.52	17.58	+0.06	17.45	-0.07
HB_1064.353	519430, 259020	16.98	17.08	+0.10	16.86	-0.12

10.5.4 To assess sensitivity of the model to the downstream boundary condition, the slope of the boundary was increased from a 1:300 slope in the baseline, to a 1:100 slope and also decreased to a 1:1000 slope. Comparison of 1D results (Table 10-5) show that the model is not sensitive to changes in downstream boundary slope. There are no changes in water levels/depths through the area of the proposed Scheme which demonstrates that the Scheme assessment is robust. These results have been extracted from the nodes shown in Figure 10-6.

Table 10-5: In-Channel Maximum Stage Hen Brook Downstream Boundary Slope Sensitivity Results - 1% AEP

	Maximum Stage + change of in-channel water depth compared to baseline					
Label	NGR	Baseline (m AOD)	1:100 DSBDY (m AOD)	Difference (m)	1:1000 DSBDY (m AOD)	Difference (m)
HB1E	520495, 258260	19.34	19.34	0.00	19.34	0.00
HB1B	520200, 258450	18.90	18.90	0.00	18.90	0.00
HB_391.598	519940, 258690	18.38	18.38	0.00	18.38	0.00
HB_698.726	519760, 258915	17.72	17.72	0.00	17.72	0.00
HB_1064.353	519430, 259020	17.17	17.09	-0.08	17.17	0.00

10.6 Assumption/Limitations

10.6.1 It is noted that the Hen Brook confluences with Fox Brook prior to draining into the River Great Ouse, and there is currently no model data to provide an understanding of potential backwater effects to support the use of an alternative boundary setup. Sensitivity testing on the downstream boundary has been undertaken and documented in Section 10.5, demonstrating that the representation of the downstream boundary and Scheme assessment is robust.

10.6.2 There is a railway line located 180m beyond the downstream boundary of the model and due to insufficient survey, the model has not been extended to include this feature. However, given the railway line is raised more than 5m above the surrounding floodplain, it is not considered to be at risk of flooding from the Hen Brook. It is important to note that floodplain attenuation and backwater effects associated with this raised structure is currently unknown. With this feature located 1.2km downstream of the proposed Scheme, and based on the current results (i.e. negligible difference between the baseline and proposed results at the location of the current downstream boundary) it is not considered that the railway will have an effect on the results.

10.6.3 Given the asymmetrical shape of the culvert beneath the proposed Scheme, it was not possible to represent this within the model whilst retaining model stability. The culvert was therefore represented with symmetrical geometry, however the culvert opening area has been retained in line with designs and will provide an acceptable representation of conveyance for the structure.

10.6.4 The proposed attenuation (highways drainage) have not been considered as part of this assessment. As a general requirement by Highways England and Lead Local Flood Authorities, highways drainage should be considered in isolation and not in combination with the fluvial regime.

10.7 Summary and Conclusions

a. The proposed scenario along the Ordinary Watercourse Hen Brook, comprises a new culvert to convey the watercourse beneath the proposed A428 highway, 6 high flow culverts through the new dual carriageway embankment, a new culvert for a maintenance access bridge upstream of the new highway and channel realignment (0.25km) in the location of proposed Scheme. There is also additional floodplain compensation being proposed to account for the displacement of floodplain volume associated with the Scheme.

b. An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is required. Details of the compensatory storage calculations are included within Appendix D2.

c. Results from this modelling exercise have shown that by providing floodplain compensation upstream of the proposed Scheme, there is no significant detriment to third party land.

d. Where modelling shows an area characterised by a small increase in depth, located upstream of the new A428 highway on the right bank. This small area of increased flood depths is restricted to undeveloped agricultural land, with no sensitive receptors affected, and is located within the Order Limits for the Scheme. The aforementioned increase in flood depth occur in an area which already floods within the baseline scenario.

e. Overall, the modelling results have shown that with mitigation in place through floodplain compensation, the proposed Scheme does not have a significant impact on channel flow downstream or flood depths and levels on the floodplain.

11 Rectory Farm Brook (1D-2D FMP-TUFLOW)

11.1 Overview

11.1.1 Rectory Farm Brook is a small watercourse located to the south of St Neots. Rectory Farm Brook has a catchment area of 0.90km^2 and has an estimated peak flow of 0.80m^3/s for the 1% AEP event (FEH statistical method). Rectory Farm Brook originates as two tributaries (Barford and Spinney branches) located in agricultural fields approximately 1.6km south of Little Barford as seen in **Figure 11-1**.

11.1.2 These tributaries confluence approximately 0.045km upstream of a farm access track where the watercourse flows through an existing culvert. Rectory Farm Brook flows in a southerly direction until it confluences with the Stone Brook which flows in a westerly direction flowing beneath Barford Road until it outfalls into the River Great Ouse. The distance from the Rectory Farm Brook and Stone Brook confluence to the River Great Ouse is approximately 1.46km.

11.2 Model setup- baseline scenario

11.2.1 **Table 11-1** includes all key information regarding the setup of the Rectory Farm Brook baseline model.

Table 11-1: Baseline Model Setup

Model Setup	Comments
Simulation time	30 hours (6.5-hour critical storm duration)
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 3.1km
Upstream Boundary setup	Barford boundary located within agricultural fields approximately 0.17km upstream of Barford and Spinney confluence (517454, 255558) Spinney boundary located within agricultural fields approximately 0.24km upstream of the Barford and Spinney confluence (517136, 255577) Stone Brook boundary located within agricultural fields 70m east of the West Coast Main Line (518137, 254410) with inflow set at approximately bank full on Stone Brook (5% AEP event)
Downstream Boundary setup – 1D	Downstream Boundary located at confluence with River Great Ouse. Normal Depth boundary with slope calculated based on gradient of channel bed to the upstream node (516730, 255182)
Downstream Boundary setup – 2D	An SX link was added along Barford Road where the Dummy Downstream Boundary was located to connect the 2D and 1D domains to allow water to flow into the remaining 1D model to the River Great Ouse
Cell size	1m cell size
LiDAR	1m LiDAR data captured in 2017 used to establish the 2D model extent
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients An elevated roughness value of 1.0 was assigned to represent the building in the model domain

11.2.2 As the proposed Scheme is located upstream of the farm track culvert, it was not deemed necessary to include the total modelled reach within the 2D domain. Therefore, the 2D model domain extends to include the right bank of the Stone Brook with the left bank being represented in the 1D domain as extended sections as seen in **Figure 11-1**. The 2D domain extends to Barford Road on the west and the remaining reach of the Stone Brook outside of the 2D domain to the River Great Ouse was modelled in 1D only (approximately 0.65km reach).

11.2.3 A topographical survey for the Rectory Farm Brook channel has been used to create the baseline channel throughout the modelled reach. The baseline model includes a 0.45m diameter circular culvert (21m in length) on the Rectory Farm Brook beneath the farm access track road. This has been represented in the 1D model using a circular conduit unit. There is a 3.21m by 1.79m pipe arch culvert (9.44m in length) located beneath Barford Road on the Stone Brook. This is represented in the 1D model using a sprung arch conduit. There is a footbridge located 0.65km downstream of Barford Road. This has been represented in the model as a USBPR bridge. Each structure in the model has been designed based on the provided survey information.

11.2.4 As seen in **Figure 11-1** other than the farm track road, there are is one outbuilding partially present within the model domain to the west, with the floodplain being largely undeveloped within this area. Results have shown that this building is not at risk of inundation from the watercourse. The farm track road is potentially at risk of inundation from the watercourse with the lowest level of the farm track only elevated 0.5m above the surrounding floodplain.

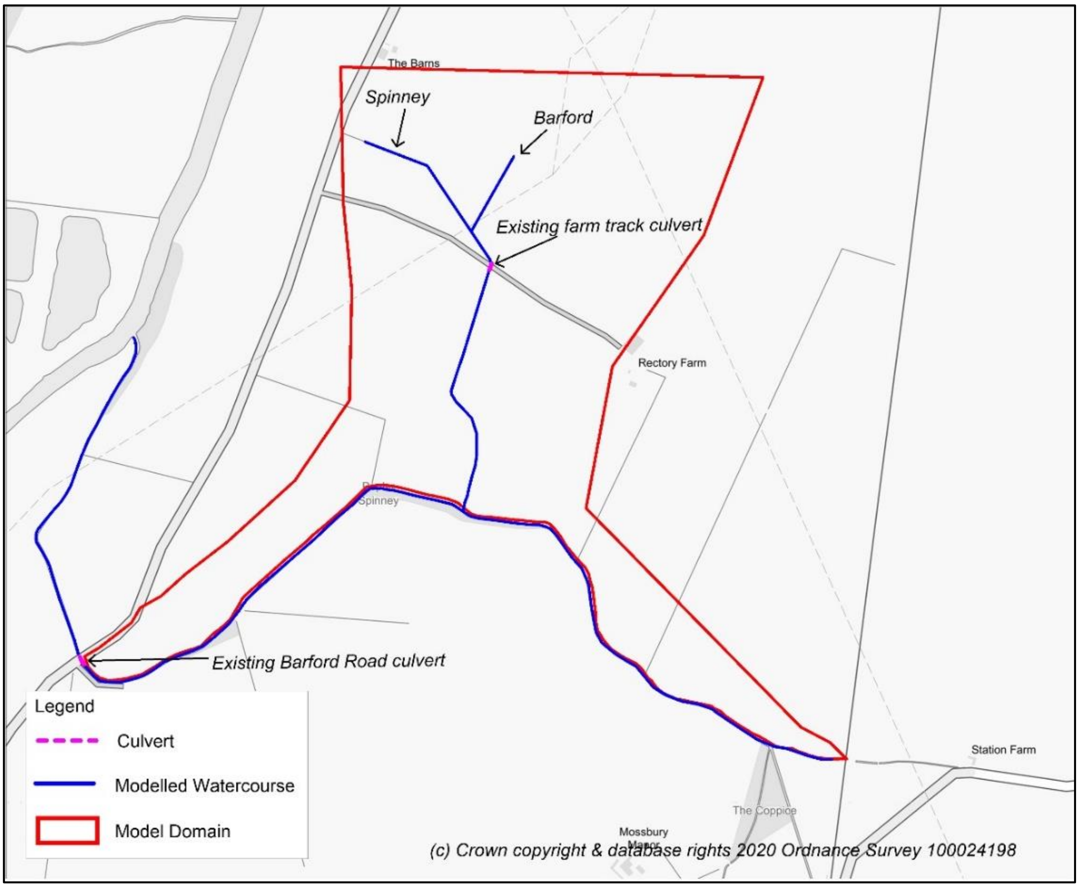


Figure 11-1: **Baseline Model Extents**

11.3 Model setup- Scheme scenario

11.3.1 The proposed Scheme design was incorporated into the hydraulic model which features the proposed A428 highway and access track located upstream of the farm track crossing where the channel is realigned with two proposed culverts located where the Scheme crosses the watercourse (**Figure 11-2**). As baseline modelling displayed out of bank flows at the location of the Scheme crossing, floodplain compensation areas are proposed to compensate for the displacement of floodwater as a result of the proposed Scheme.

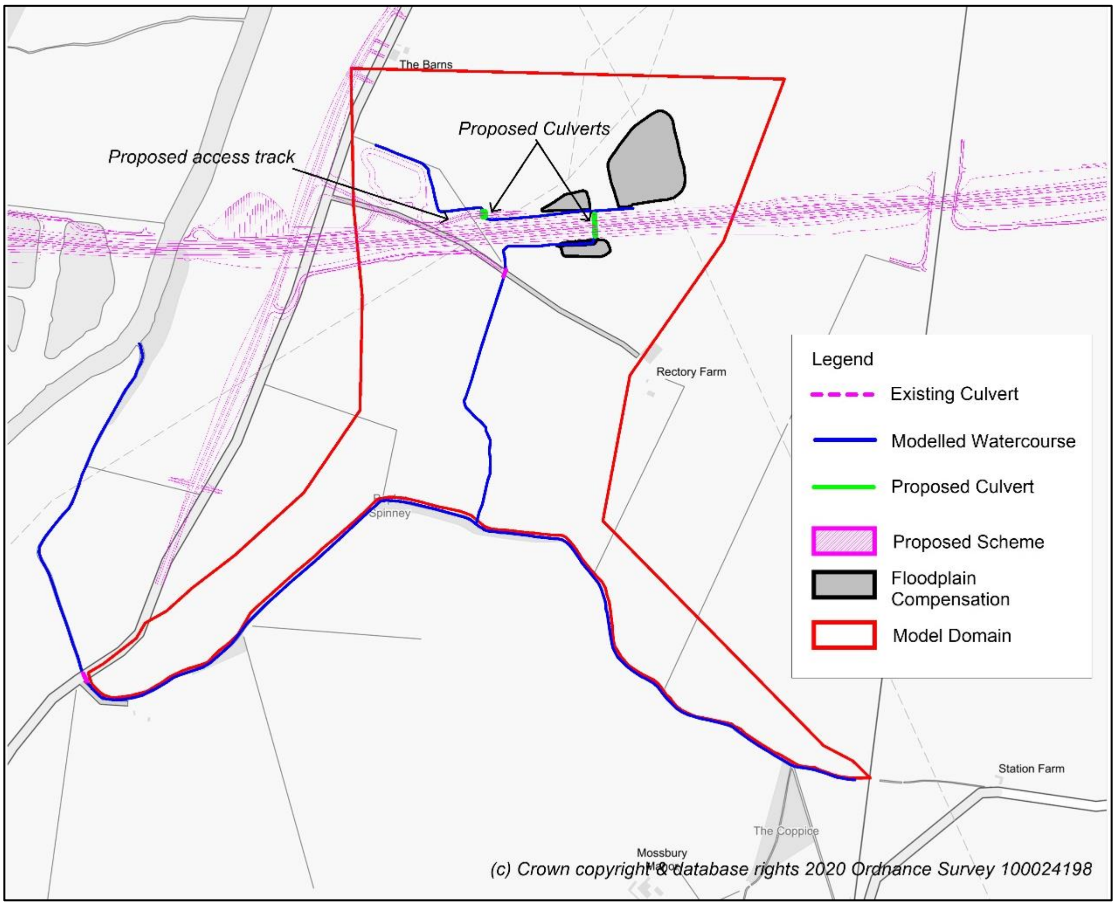


Figure 11-2: Proposed Model Extents

1D Model

11.3.2 The proposed Scheme includes a realigned channel (over a stretch of approximately 0.80km) and two new culverts under the proposed highway located in the realigned channel reach. There is a new dual carriageway culvert with dimensions of 2.4m by 2.0m (31.1m in length) beneath the main proposed A428 highway. There is also a culvert with dimensions of 2.4m by 1.8m (5.5m in length) beneath the access track. Both of these proposed culverts have been represented in the 1D model using rectangular culvert units. **Figures 11-3** displays the modelled proposed A428 culvert and 11-4 displays the access track culvert.

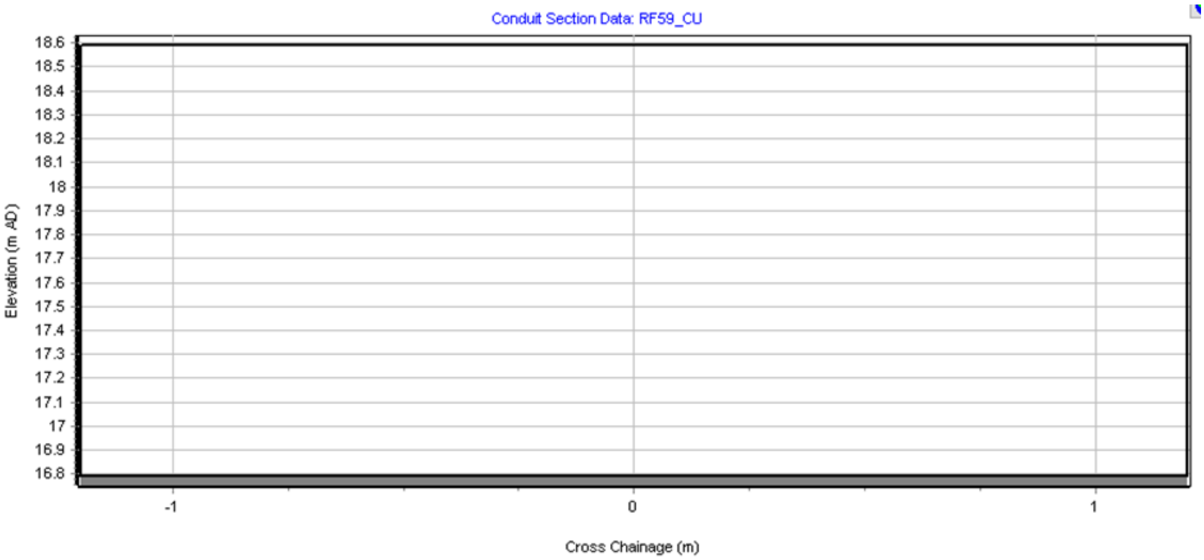


Figure 11-3: Rectory Brook Modelled Proposed A428 Culvert (dimensions not to scale

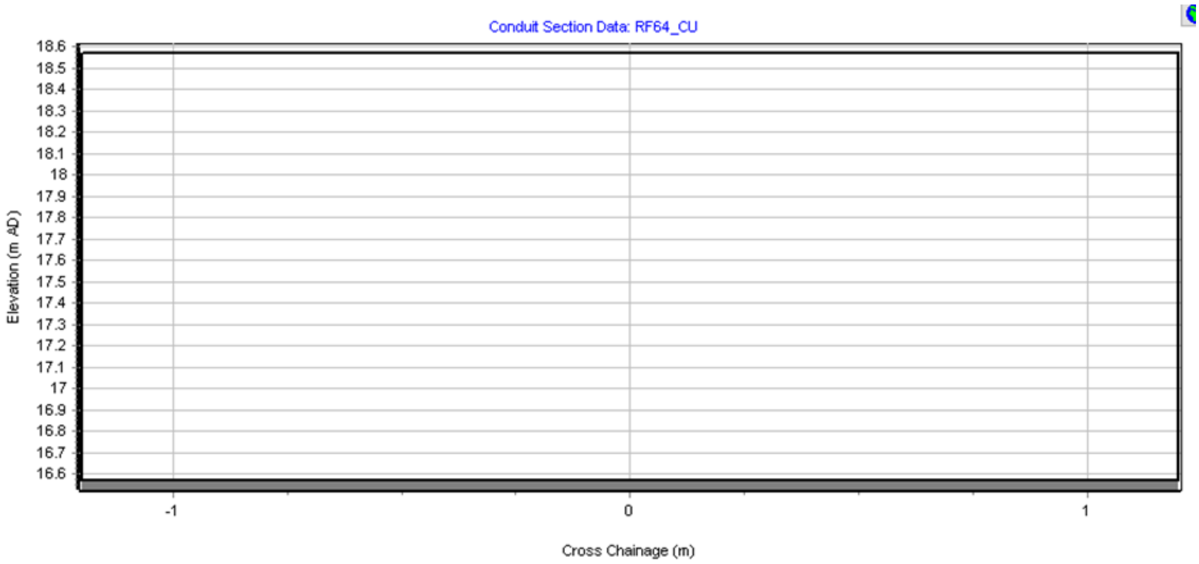


Figure 11-4: Rectory Brook Modelled Access Track Culvert (dimensions not to scale)

11.3.3 Generally, the realigned channel has been designed so that the bed is approximately 0.4m wide which is a similar width to the existing channel. The area of realignment occurs from nodes RF33_757.492 and RF36 on the Spinney and Barford branches respectively to RF28_458D upstream of the farm track crossing when looking at the 1D model.

2D Model

11.3.4 Modelling files within the 2D model were updated to reflect the changes to the 1D model i.e. location of 1D nodes to reflect the realigned channel, bank heights and 1D-2D boundaries. The proposed Scheme also contains floodplain compensation areas located in multiple locations alongside the realigned channel as shown in **Figure 11-2**. These have been represented in the 2D model with bank levels adjusted accordingly within the 1D model.

11.3.5 The assessment of floodplain storage compensation is based on EA's climate change guidance. The affected land uses define the level of allowance with the higher central allowance (35%) being indicated for most cases, whilst ensuring no flooding affects sensitive receptors with the upper end allowance (65%). Floodplain storage compensation volumes and cross-sections for Rectory Farm Brook can be seen in Appendix D3. Also, an offtake channel was modelled in the 2D domain to allow water to utilise the largest compensation area to the north east during high flow events.

11.3.6 Topographical amendments have been used within the 2D model to raise the levels of the floodplain to represent the new dual carriageway. Further topographical amendments have been made to raise the levels of the floodplain to represent the proposed access track which has been graded down to the floodplain to represent the verges along the sides of the road.

11.4 Results

Overview

11.4.2 The results are presented for the 1% AEP + 65% climate change scenario. Results relating to the other AEP events are presented within figures in Appendix B. It should be noted that the flood mechanism for these AEP events are similar to the 1% AEP + 65% climate change event, however the magnitude of flood depths and extents are shown to vary with peak flow.

Baseline

11.4.3 The modelled 1% AEP flood extent has been compared with the corresponding EA flood extents to assess the level of the agreement between the two. This has not been included as a figure in this report. The modelled 1% AEP flood extent displays increased extents of flooding compared to the EA flood zone map. It should be noted that the EA’s flood extents were produced using National Generalised Modelling and it is therefore likely that these models will not contain detailed, site-specific survey. This is likely to account for the differences observed.

11.4.4 Out of bank flooding is largely contained upstream of the farm track crossing with a maximum depth of approximately 0.68m in low-lying areas (**Figure 11-5**). This is due to the small farm track culvert constricting flow and causing floodwater to back up behind the raised track. Some floodwater overtops the farm track road at the lowest lying part of the road and propagates downstream on the left floodplain. Flood depths downstream of the farm track road generally reach up to 0.20m with a small area reaching up to 0.28m where there is a small depression in the ground.

Compensatory Storage

11.4.5 In-channel maximum baseline water levels have been extracted from the model at the location of the proposed Scheme in order to assess if flow is out of bank. The maximum level of 18.09 mAOD at node RF29i_493.5 is out of bank, demonstrating that compensatory storage is required for Rectory Brook.

11.4.6 Compensatory storage volumes have been calculated according to the methodology outlined in section 2.9 and results are provided within Appendix D3.

Scheme Results

11.4.7 The Scheme represents a significant obstruction across the floodplain and results in the displacement of floodwater (Figure 11-6). Consequently, additional floodplain compensation is required for this displacement, to ensure that there are no significant increases in flood risk to third party land. This floodplain compensation is shown along the re-aligned channel in **Figure 11-2**.

11.4.8 The key results from the proposed Scheme simulations are summarised below:

a. A visual comparison of Figures 11-5 and 11-6 show that the flood extents for the 1% AEP + 65% climate change design event remain largely consistent within the baseline and proposed scenarios, despite the inclusion of the proposed Scheme embankment and associated engineering works.

b. Figure 11-7 shows a depth difference map which compares the baseline and proposed model results for the 1% AEP + 65% climate change design event. This figure does not show the entire flood extent, but instead shows where differences have occurred within the model.

c. Increases and decreases in flood depth are depicted within this figure by red/pink/yellow and green colours respectively.

d. This figure clearly demonstrates a significant increase in flood depth in the areas where floodplain compensation is provided and a significant reduction in flood depth in the location of the proposed Scheme where floodplain has been displaced, as expected.

e. Within the wider floodplain, the model demonstrates that there are generally decreases in flood depths (up to -70mm) immediately upstream of the proposed Scheme which is attributable to the designed areas of floodplain compensation.

f. There are several areas where model results show small increases in flood depths (up to +36mm), however these are generally located in undeveloped agricultural areas. There is one isolated area at the end of the proposed access road (~8m reach) which experiences slight increases of flood depths (up to +60mm).

g. Areas experiencing minor increases in flood depths are all located within the Order Limits for the Scheme and the proposed access road is not considered a key access route that is frequently used. It is also important to note that these areas of flood depth increase already experience flooding during the baseline scenario.

Figure 11-5: Baseline Maximum Flood Depth Map – 1% AEP + 65% Climate Change

Figure 11-6: Proposed Maximum Flood Depth Map – 1% AEP + 65% Climate Change

Figure 11-7: Depth Difference Map – 1% AEP + 65% Climate Change

Downstream Flows

11.4.9 To understand how the proposed Scheme has impacted downstream flows, results have been extracted from the 1D model as no overbank flow occurred downstream of the existing track culvert. Figure 11-8 displays a flow hydrograph from the 1D channel node RF25_329.336 (labelled on **Figure 11-5**) located downstream of the proposed Scheme and the existing farm track culvert. The peak flow during the baseline is 0.55m^3/s and during the proposed scenario is 0.52m^3/s. Therefore, modelling demonstrates that the proposed Scheme results in a small reduction in peak flow downstream, but does not have a significant impact on pass on flow.

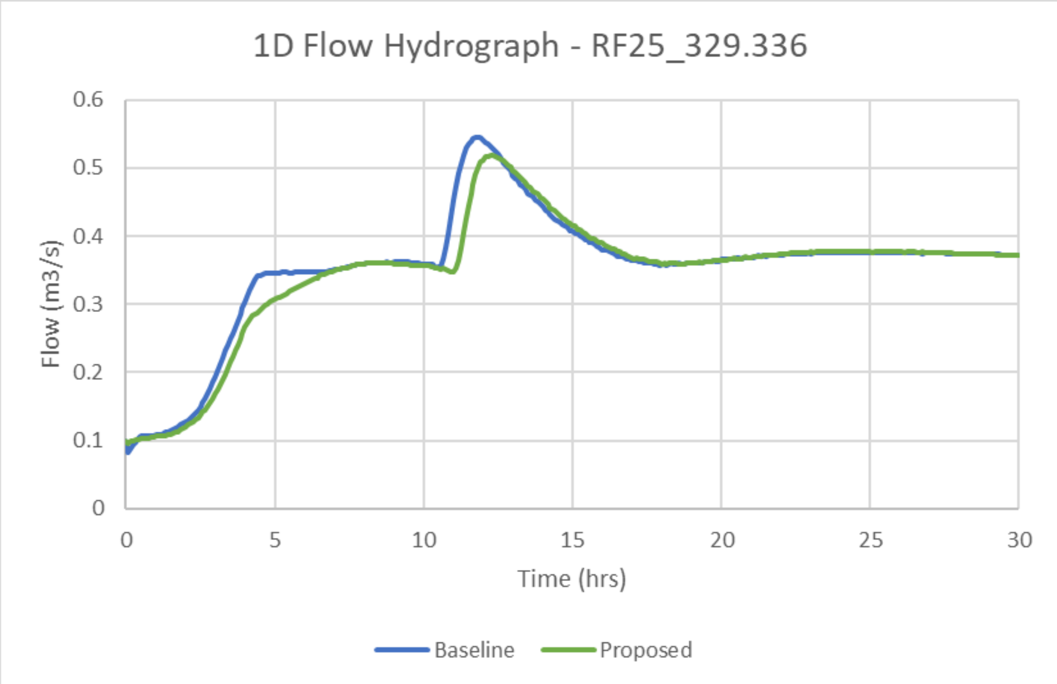


Figure 11-8: 1D Flow Hydrograph (RF25_329.336)

11.4.10 The final area of analysis focuses on the proposed Scheme culverts. During the proposed scenario the maximum water level within the access track culvert for the 1% AEP + 65% climate change event is 18.15m AOD. The soffit level for this culvert is 18.59m AOD. The maximum water level during the proposed scenario within the new dual carriageway culvert is 18.10m AOD with the soffit level for the culvert at 18.57m AOD. These levels indicate that there is sufficient freeboard in these culverts during this event.

11.5 Sensitivity analysis

11.5.1 Sensitivity testing of the model was undertaken to assess the influence of parameter assumptions made during the model development in order to understand uncertainties in the model results. The following elements have been examined to assess the model sensitivity and therefore the potential impact on maximum flood depths and extents for the 1% AEP + 65% climate change event during the baseline scenario:

a. 20% decrease and 15% increase to 1D and 2D channel roughness values.

b. Inflow on Stone Brook modelled with 2% AEP and 1% AEP events.

c. Inflow on Stone Brook modelled with 1% AEP event and the Downstream Boundary modelled as an HT boundary with water level set at peak 10% AEP event on the River Great Ouse.

11.5.2 A 15% increase to roughness values was selected as an increase of 20% caused poor model convergence within the culvert unit beneath Barford Road. As this is located at the downstream end of the Stone Brook and a significant distance away from the proposed Scheme, it is considered appropriate to use a 15% increase to roughness as this will still provide an indication on the model's sensitivity to roughness.

11.5.3 Table 11-2 shows the change in the 1D channel water level through the model compared to the baseline for the roughness sensitivity tests at the model nodes labelled on **Figure 11-5**. The maximum in-channel water level does not increase or decrease by more than +/-0.13m. Within the 2D model results have shown that when roughness values are increased by 15%, flood depths across the floodplain generally do not change, with a small area experiencing increased flood depths of up to +0.20m. When roughness values are decreased by 20%, generally across the floodplain, flood depths do not change. There is a small area where flood depths decrease by up to -0.02m. These results suggest that there is a low level of sensitivity to changes in roughness with changes within acceptable tolerances.

Table 11-2: 1D In-Channel Maximum Stage Roughness Sensitivity Results - 1% AEP + 65% Climate Change

	Maximum Stage + change of in-channel water depth compared to baseline					
Label	NGR	Baseline (m AOD)	+15% n (m AOD)	Difference (m)	-20% n (m AOD)	Difference (m)
RF32_703.161	517269, 255507	18.11	18.11	0.00	18.10	-0.01
RF36	517414, 255483	18.10	18.10	0.00	18.10	0.00
RF29i_502	517378, 255353	18.10	18.11	+0.01	18.10	0.00
RF25_329.336	517350, 255785	17.16	17.24	+0.08	17.04	-0.12
RF20_0.00	517346, 245878	17.14	17.22	+0.08	17.01	-0.13

11.5.4 The confluence of Rectory Farm Brook and Stone Brook is located approximately 500m downstream of the location of the proposed A428 Scheme. Stone Brook is a larger watercourse than Rectory Farm Brook, with a potential to exert backwater effects that may impact upon the Scheme. To assess the potential impact of raised levels in the Stone Brook on the Scheme, the inflow of the Stone Brook was set using the 2% AEP and 1% AEP events. **Table 11-3** shows a maximum in-channel water level change of +0.29m in the channel at the downstream end of Rectory Farm Brook, at the confluence with the Stone Brook. Significantly, no water level changes occur upstream of the farm track culvert in the location of the Scheme when using the 1% AEP event as the inflow on Stone Brook.

11.5.5 **Figure 11-9** displays a depth difference map when the 1% AEP event inflow on Stone Brook is applied, rather than the 5% AEP hydrograph used within the design events. There are increases in flood depths downstream as expected, as the Stone Brook experiences out of bank flooding when using the 1% AEP event inflow hydrograph. The changes in depth were limited to the downstream end of Rectory Farm Brook and importantly no changes in depth were present on the floodplain upstream of the farm track, in the location of the proposed Scheme.

Table 11-3: 1D In-Channel Maximum Stage Stone Brook Inflow Sensitivity Results - 1% AEP + 65% Climate Change

	Maximum Stage + change of in-channel water depth compared to baseline					
Label	NGR	Baseline (m AOD)	2% AEP Stone Brook (m AOD)	Difference (m)	1% AEP Stone Brook (m AOD)	Difference (m)
RF32_703.161	520495, 258260	18.11	18.11	0.00	18.11	0.00
RF36	520200, 258450	18.10	18.10	0.00	18.10	0.00
RF29i_502	519940, 258690	18.10	18.10	0.00	18.10	0.00
RF25_329.336	519760, 258915	17.16	17.32	+0.16	17.43	+0.27
RF20_0.00	519430, 259020	17.14	17.32	+0.18	17.43	+0.29

Figure 11-9: Depth Difference Map (Stone Brook Inflow 1% AEP Sensitivity) - 1% AEP + 65% Climate Change

11.5.6 The Stone Brook ultimately confluences with the River Great Ouse approximately 1.5km downstream of the Rectory Farm Brook confluence. To assess the potential impact of raised levels in the Stone Brook and the River Great Ouse the inflow on the Stone Brook was set at a 1% AEP event and the downstream boundary was modelled as a HT boundary with water level set to the peak 10% AEP event on the River Great Ouse. Levels were obtained from the 1D-2D River Great Ouse hydraulic model, which forms Annex A of the FRA. It was considered that this would represent a conservative scenario for the purposes of assessing model sensitivity.

11.5.7 **Table 11-4** shows that stage increases downstream of the Proposed A428 Scheme, with the maximum increase of 0.41m at the confluence of Rectory Farm Brook and Stone Brook. However, importantly there are no significant increases upstream of the farm track crossing in the location of the proposed Scheme with a small increase in stage of 0.01m.

11.5.8 **Figure 11-10** displays a depth difference map when modelling the Stone Brook and River Great Ouse in flood conditions, showing that flood depths increase downstream as expected when levels are raised in the Stone Brook and the River Great Ouse. The changes in depth were contained to the downstream end of Rectory Farm Brook and importantly no changes in depth were present on the floodplain upstream of the farm track, in the location of the proposed Scheme. Results presented within this sensitivity analysis demonstrate that the Scheme assessment is robust and for a range of downstream conditions on the Stone Brook and River Great Ouse.

Table 11-4: 1D In-Channel Maximum Stage Stone Brook & River Great Ouse Sensitivity Results - 1% AEP + 65% Climate Change

	Maximum Stage + change of in-channel water depth compared to baseline			
Label	**NGR**	**Baseline (m AOD)**	**Stone Brook 1% AEP & RGO 10% AEP (m AOD)**	**Difference (m)**
RF32_703.161	517269, 255507	18.11	18.11	0.00
RF36	517414, 255483	18.10	18.11	+0.01
RF29i_502	517378, 255353	18.10	18.11	+0.01
RF25_329.336	517350, 255785	17.16	17.56	+0.40
RF20_0.00	517346, 245878	17.14	17.55	+0.41

Figure 11-10: Depth Difference Map (Stone Brook 1% AEP & River Great Ouse 10% AEP Sensitivity) - 1% AEP + 65% Climate Change

11.6 Assumptions/limitations

11.6.1 General limitations that affect all 1D-2D models can be found in Section 2.10, such as uncertainties generated from hydrological inflows.

11.6.2 The current representation of the downstream boundary of the Stone Brook within the design simulations, as a normal depth boundary, assumes free discharge and does not account for any backwater effects from the River Great Ouse that may occur when levels are raised in the Main River. Results from the sensitivity tests whereby the inflow on Stone Brook was set using a 2% AEP and 1% AEP event, along with implementation of a boundary condition to represent raised levels on the River Great Ouse, indicate that any raised levels within this watercourse exert a localised impact upon levels within the Rectory Farm Brook channel and on the floodplain. The increase in levels observed within the sensitivity test propagate approximately 300m upstream on Rectory Farm Brook and no change is observed through the Scheme area. This suggests that the model set up for design events is robust, and resulting Scheme assessment, are robust.

11.6.3 The section of Stone Brook from Barford Road downstream to the River Great Ouse is a simplified representation, as this is represented in 1D only. The 2D model domain ends upstream of Barford Road and is connected to 1D extended cross sections downstream. It is thought that this reach provides an acceptable representation of flow conveyance on the Stone Brook, which is sufficient to support the Scheme assessment for Rectory Farm Brook.

11.6.4 All inflow for the Rectory Farm Brook catchment is applied at the upstream boundary, however an analysis of the catchment suggests that approximately 25% of the total flow would be received downstream of the proposed Scheme. This results in a conservative assessment of the Scheme and can be partially attributed as a reason for the small increases in flood depths shown within the Order Limits.

11.6.5 The inflow on the Stone Brook uses the Rectory Farm Brook critical duration of 6.5hrs and does not use the longer Stone Brook critical duration of 15hrs. Although no testing has been undertaken using the Stone Brook critical duration, the Rectory Farm Brook critical duration results in a greater peak flow as the hydrograph is shorter and therefore it is considered that an appropriately conservative approach has been adopted.

11.7 Summary and conclusions

11.7.1 The proposed scenario along Rectory Farm Brook comprises of a realigned channel and two new culverts beneath the access road and beneath the new dual carriageway. Floodplain compensation areas are proposed to compensate for the displacement of floodwater associated with the proposed Scheme.

11.7.2 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is required. Details of the compensatory storage calculations are included within Appendix D3.

11.7.3 Results have shown that by providing floodplain compensation, there is no significant detriment to third party land and no increase in pass on flow downstream.

11.7.4 Where modelling shows areas characterised by small increases in depth, these are all within the Order Limits and are mostly undeveloped agricultural land. The access track is not considered a key access route and therefore the small increase in depth along the small section at the end of the road is considered acceptable. The aforementioned increases in flood depth occur in areas which already flood during the baseline scenario.

11.7.5 Overall, a conservative approach has been adopted whereby the flood mitigation measures have been designed to account for the 1% AEP + 65% climate change event. With mitigation in place, the proposed Scheme does not have a significant impact on channel flow or flood depths on the floodplain.

12 South Brook (1D-2D FMP-TUFLOW)

12.1 Overview

12.1.1 South Brook is a small watercourse located to the south of St Neots. South Brook has a catchment area of 27.16km^2 and has an estimated peak flow of 8.60m^3/s for the 1% AEP event. The head of the watercourse is located within agricultural fields in Chawston and flows in an easterly direction towards the River Great Ouse. The watercourse flows beneath the existing A1 Great North Road before reaching its outfall to the River Great Ouse. Sensitive flood risk receptors are present around the modelled reach including the A1 Great North Road. There are commercial properties at the upstream extent of the model on the left bank floodplain and outbuildings downstream of the A1 Great North Road on the right bank floodplain.

12.2 Model setup- baseline scenario

12.2.1 **Table 12-1** includes all key information regarding the setup of the South Brook baseline model.

Table 12-1: Baseline Model Setup

Model Setup	Comments
Simulation time	60 hours (22-hour critical storm duration)
AEPs simulated	5%, 1%, 1% + 35% climate change, 1% + 65% climate change, 0.1%
Modelled length	Approximately 1.2km
Upstream Boundary setup	Located within agricultural fields in Chawston approximately 0.5km upstream of the A1 Great North Road (515744, 256048)
Downstream Boundary setup – 1D	Located 0.7km downstream of A1 Great North Road at confluence with River Great Ouse. Normal Depth boundary with slope calculated based on gradient of channel bed to the upstream node (516910, 255779)
Downstream Boundary setup – 2D	Water level – flow boundaries (HQ) added perpendicular to floodplain flow direction along drainage ditches on left and right floodplains (Figure 12-1). HQ boundaries added at the location of the 1D downstream boundary, perpendicular to floodplain flow. This boundary assumes free discharge into the River Great Ouse not accounting for any backwater effects that may occur when levels are raised in the main river.
Cell size	2m cell size
LiDAR	1m LiDAR data captured in 2017 used to establish the 2D model extent.
Roughness	Section 2.7 states the general methodology for assigning Manning's 'n' Roughness Coefficients applied for South Brook using photographs and survey information. An elevated roughness value of 1.0 was assigned to represent buildings in the model domain.

12.2.2 Topographical channel survey[5] has been used to create the channel within the 1D FMP baseline model. The baseline model includes a bridge located approximately 0.05km upstream of the A1 Great North Road. This is represented in the 1D model as a USBPR bridge unit based on the provided survey information[6]. Beneath the A1 Great North Road is a 3.17m by 1.87m rectangular culvert (28.16m in length). This is represented in the 1D model using a rectangular conduit, which has been based on the provided survey information[8].

[5] 'A428 BC to CG_South Brook_Structure Locations_1250 Scale_A1 Sheet' (September 2017)
[6] 'A428 BC to CG_South Brook_Structure Elevations_1250 Scale_A1 Sheet' (September 2017)

12.2.3 **Figure 12-1** displays a schematic of the baseline model setup. There are commercial properties present approximately 0.1km from the watercourse at the upstream extent of the model domain on the left bank floodplain represented in the materials layer using OS Mastermap data and setting appropriate Manning's Roughness Coefficient values. Downstream of the A1 Great North Road, outbuildings are present in the model domain approximately 0.06km from the watercourse on the right floodplain.

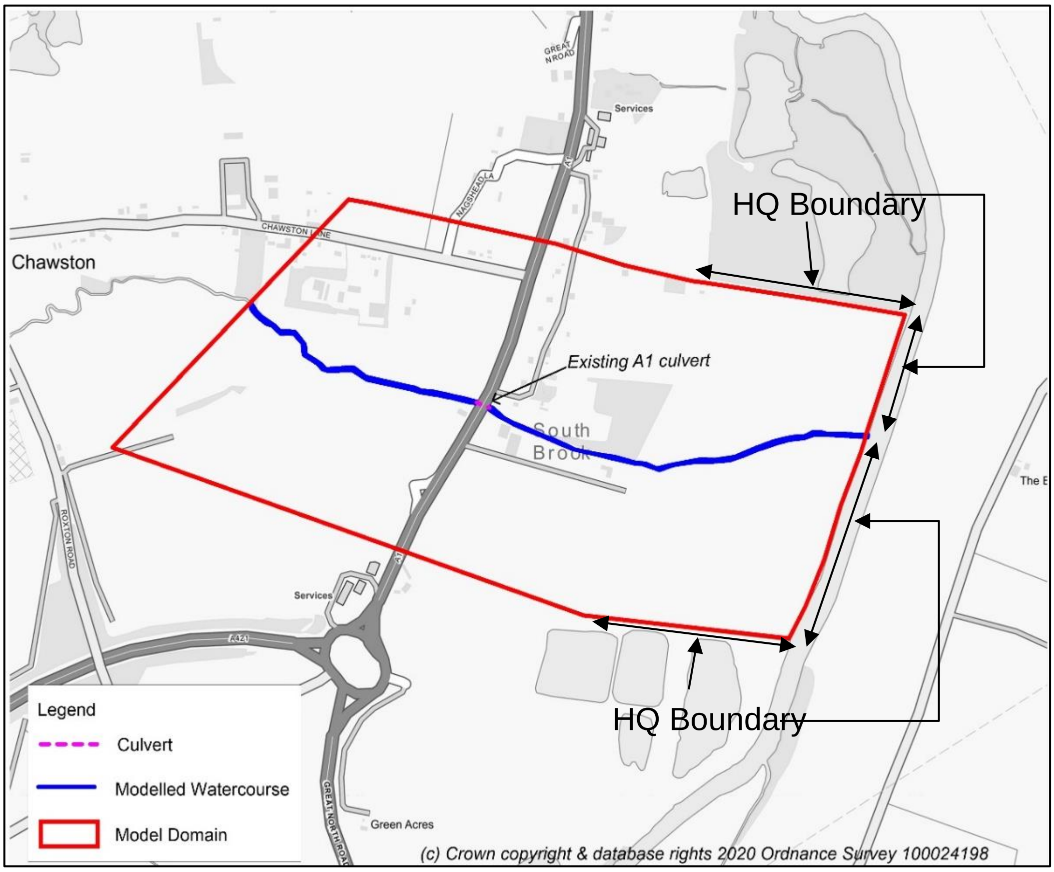


Figure 12-1: Baseline Model Extents

12.3 Model setup- Scheme scenario

12.3.1 The proposed Scheme design was incorporated into the hydraulic model which features Roxton Link Road with a new culvert running beneath and alterations to the existing A1 Great North Road with a new longer culvert to take account of this. As baseline modelling displayed out of bank flows at the location of the Scheme crossing, floodplain compensation areas are proposed to compensate for the displacement of floodwater as a result of the proposed Scheme. **Figure 12-2** displays the proposed Scheme model extents.

12.3.2 The proposed culvert beneath Roxton Link Road has replaced the bridge present in the baseline model and has been represented in the 1D model using a rectangular conduit unit (4.0m by 2.8m and 18m in length). The modelled culvert is displayed in Figure 12-3. The proposed culvert beneath the A1 Great North Road has been updated and has been represented in the 1D model using a rectangular culvert unit (3.1m by 2.7m and 56m in length). The modelled culvert is displayed in **Figure 12-4**.

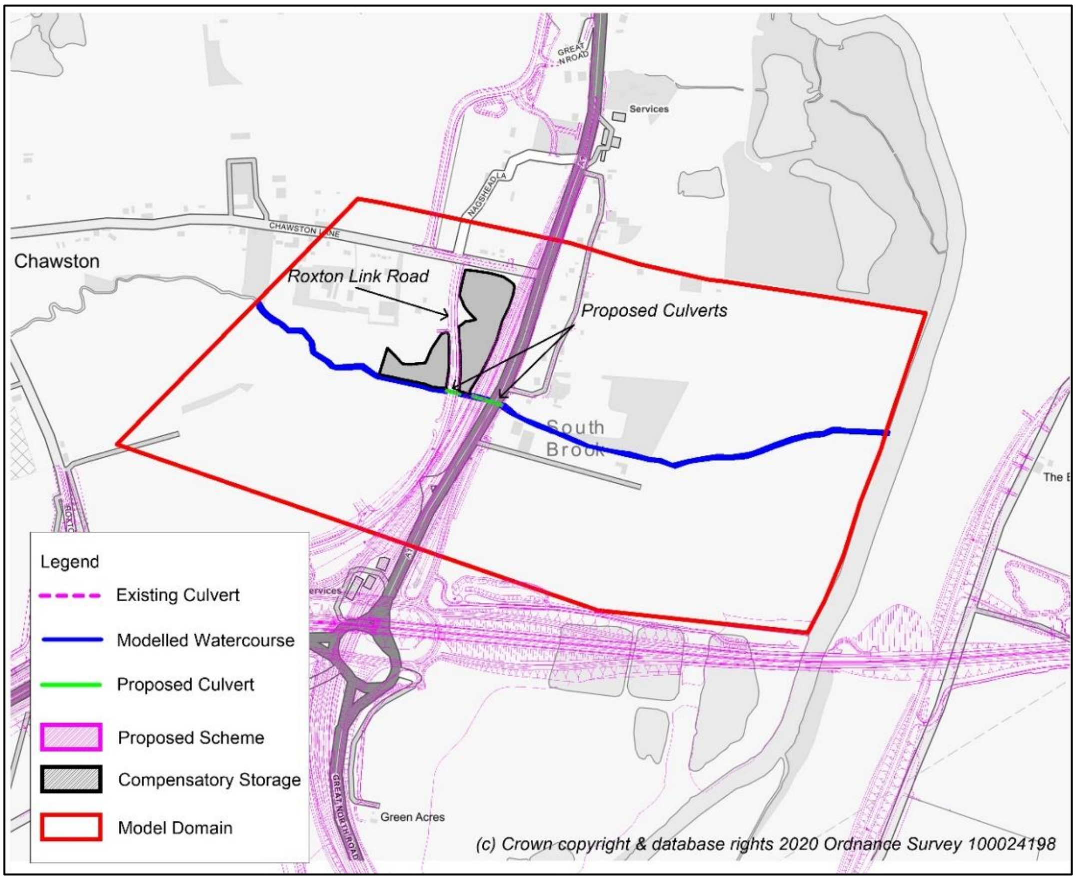


Figure 12-2: Proposed model extents

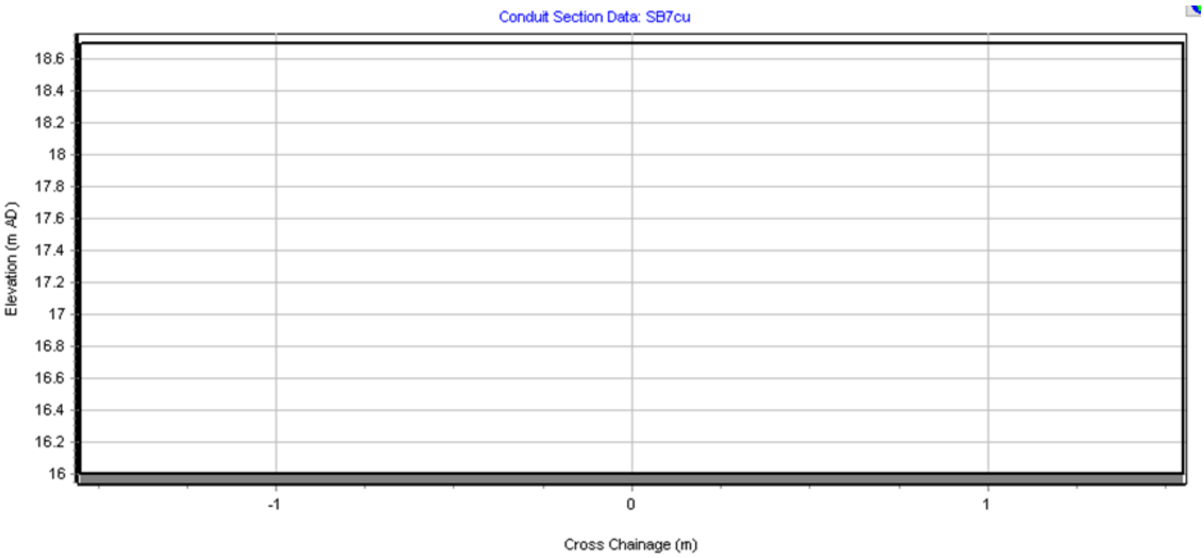


Figure 12-3: South Brook Modelled Proposed A428 Culvert (dimensions not to scale)

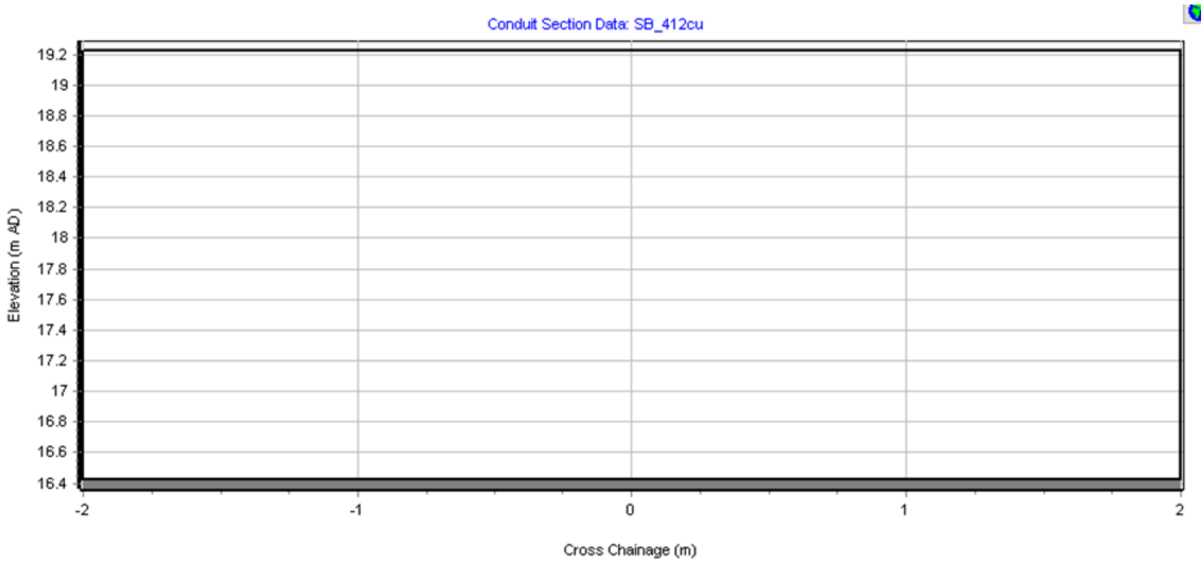


Figure 12-4: South Brook Modelled Proposed A428 Culvert (dimensions not to scale)

12.3.3 In addition to the proposed culverts, the proposed Scheme also features online floodplain compensation areas marked on **Figure 12-2** to increase the capacity of the channel. These have been modelled in the 2D domain by altering the floodplain topography and making associated changes to the 1D cross-sections and 2D bank levels.

12.3.4 The assessment of floodplain storage compensation is based on EA's climate change guidance. The affected land uses define the level of allowance with the higher central allowance (35%) being indicated for most cases, whilst ensuring no flooding affects sensitive receptors with the upper end allowance (65%). Floodplain storage compensation volumes and cross-sections for South Brook can be seen in Appendix D4.

12.4 Results

Overview

12.4.2 As highlighted in Section 1.3, a conservative approach has been adopted whereby the 1% AEP + 65% climate change event has been considered when designing flood mitigation for the Ordinary Watercourses which coincide with the alignment of the proposed Scheme. This is therefore the event which is discussed throughout this results section, however all results relating to the other AEP events are presented within figures in Appendix C. It should be noted that the flood mechanism for these AEP events are similar to the 1% AEP + 65% climate change event, however the magnitude of flood depths and extents are shown to vary with peak flow.

12.4.3 Baseline

12.4.4 The modelled 1% AEP results were compared to the corresponding Environment Agency Flood Zone 3 outline. The modelled 1% AEP flood extent varied from the Flood Zone 3 extent with the modelled flood extent displaying only a very small amount of overtopping towards the downstream extent, whereas the Flood Zone 3 extent was larger with flooding across the whole floodplain towards the downstream end. These variations are likely due to varying scales of modelling undertaken; this modelling exercise is a detailed site-specific study compared to the Flood Zone 3 extent being generated from National Generalised Modelling which is not likely to include detailed, site-specific survey.

12.4.5 During the 1% AEP + 65% climate change event, the model shows that out of bank flooding occurs on the floodplain to the north and south of South Brook upstream of the A1 Great North Road. Maximum depths typically reach up 0.75m in this event (**Figure 12-5**). The A1 Great North Road acts as a barrier to flow, with floodwater pooling on the floodplain upstream of the embankment. Some floodwater overtops the road on the southern side, with depths up to 0.15m. There is no property flooding present as properties are located approximately 40m from the maximum modelled flood extent and 0.4m above the maximum flood level.

12.4.6 Out of bank flooding is also present downstream of the A1 Great North Road where floodwater depths typically reach up to 0.10m. There is a small area of floodwater adjacent to the channel where depths reach up to 0.50m where the land elevation is lower than the surrounding floodplain. The model demonstrates that floodwater flows out of bank and spreads across the floodplain on both the north and south side of the watercourse as the area is generally very flat. Out of bank flow on both the north and south of the channel eventually propagates to the model boundaries at the northern and southern limit of the model, where it flows out of the model. Outflow of water from the model at these locations is representative of flow into the ditches which bound the modelled floodplain to the north and south of South Brook downstream of the A1 crossing.

Compensatory Storage

12.4.7 In-channel maximum baseline water levels have been extracted from the model at the location of the proposed Scheme in order to assess if flow is out of bank. The maximum level of 18.53 mAOD at node SB_340 is out of bank, demonstrating that compensatory storage is required for South Brook.

12.4.8 Compensatory storage volumes have been calculated according to the methodology outlined in section 2.9 and results are provided within Appendix D4.

Proposed Scheme

12.4.9 During the 1% AEP + 65% climate change event, modelling results show that the proposed Scheme represents a significant obstruction across the floodplain and results in the displacement of floodwater (**Figure 12-6**). Consequently, additional online features are required within the floodplain to compensate for this displacement, to ensure that there are no significant increases in flood depths to third party land or increases in pass on flow downstream. The floodplain compensation areas are shown in Figure **12-2,** both compensation areas are located on the left bank floodplain with one area located upstream of the A1 Great North Road and one located upstream of the Roxton Link Road.

12.4.10 **Figure 12-7** shows a depth difference map which compares the baseline and proposed results. It should be noted that this figure does not show the entire modelled flood extent but shows areas where differences in depth have occurred that are attributable to the proposed Scheme. Increases and decreases in flood depth are depicted by red/pink/yellow and green colours respectively. The figure clearly demonstrates increased flood depths are confined to the area where floodplain compensation areas are being provided and a significant reduction in flood depth in the location of the proposed Scheme where floodwater has been displaced. Within the wider floodplain, model results show that there are decreases in flood depths of up to 250mm upstream of the proposed Scheme which can be attributed to the designed floodplain compensation areas.

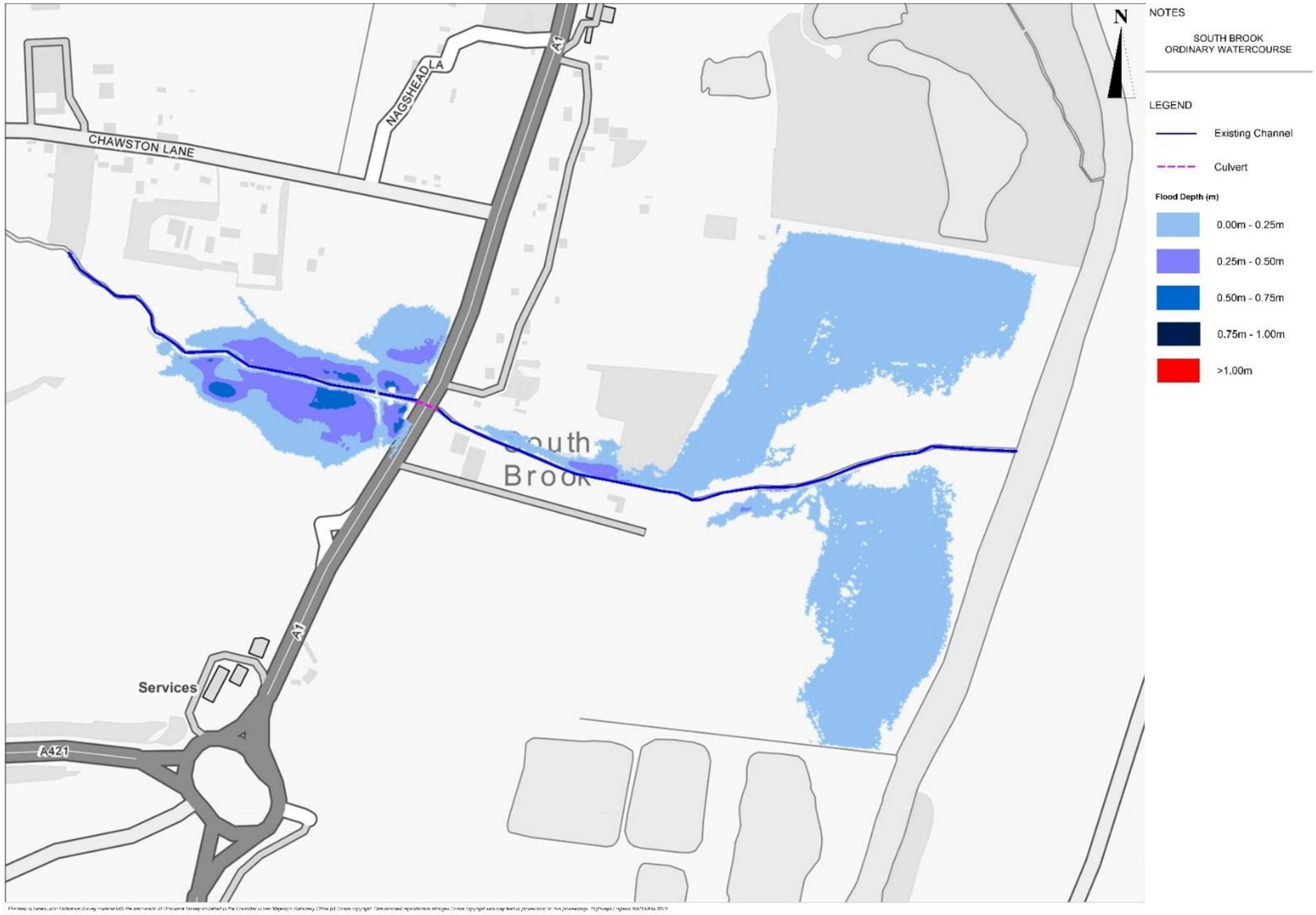


Figure 12-5: Baseline Maximum Flood Depth Map – 1% AEP + 65% Climate Change

Figure 12-6: Proposed Maximum Flood Depth Map - % AEP + 65% Climate Change

Figure 12-7: Depth Difference Map (Baseline vs Proposed) – 1% AEP + 65% Climate Change

Downstream Flows

12.4.11 To understand how the proposed Scheme has impacted downstream flows, results have been extracted from the 1D model in the area located downstream of the proposed Scheme. **Figure 12-8** displays a flow hydrograph from the 1D channel node SB8 (Figure 12-7) located immediately downstream of the proposed Scheme for the 1% AEP + 65% climate change event. The peak flow during the baseline is 14.1m^3/s, and during the proposed scenario is 14.1m^3/s. Therefore, modelling demonstrates that the proposed Scheme does not have a significant impact on the downstream flow.

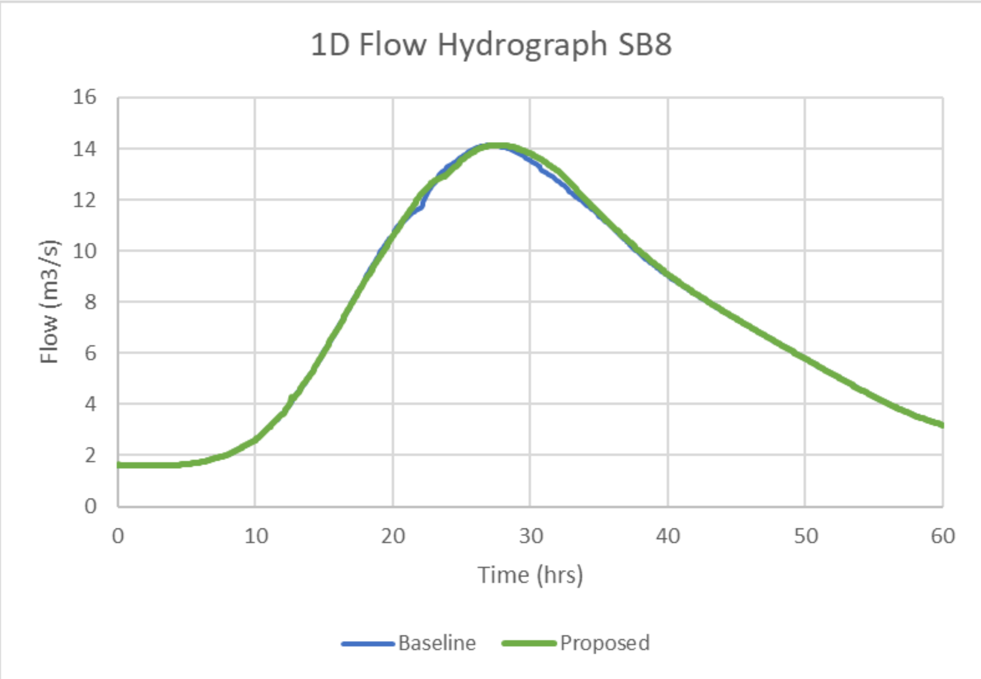


Figure 12-8: 1D Flow Hydrograph (SB8)

12.4.12 The final area of analysis focuses on the proposed Scheme culverts. The required freeboard is displayed in **Table 12-2** and shows that for both proposed culverts, the required freeboard was met. In the A1 Great North Road culvert, there was no required freeboard level set and the objective was to meet the existing freeboard level. At present, the A1 Great North Road culvert does not provide any freeboard with the maximum water level above the soffit level. Figure 12-7 displays the existing and proposed culvert designs for the A1 Great North Road culvert and maximum water level during the 1% AEP + 65% climate change event. Despite the increase in freeboard in the A1 Great North Road culvert, Figure 12-9 displays no detrimental impact on downstream flows, this is likely to be because this culvert is not the most significant throttle to flow within the reach.

Table 12-2: Proposed Scheme Culverts Freeboard

Proposed Culvert	Required Freeboard (m)	Modelled Freeboard (m)	Meets Criteria?
Roxton Link Road	0.75	0.83	Yes
A1 Great North Road	Meet baseline freeboard level (no freeboard)	0.59	Yes

Figure 12-9: A1 Great North Road Culvert Design for Baseline (Top) and Proposed (Bottom) Scenarios

12.5 Sensitivity analysis

12.5.1 Sensitivity testing of the model was undertaken to assess the influence of parameter assumptions made during the model development in order to understand uncertainties in the model results. The following elements have been examined to assess the model sensitivity and therefore the potential impact on maximum flood depths and extents for the 1% AEP + 65% climate change event:

a. ± 20% change to 1D and 2D roughness values.

b. Downstream Boundary modelled as a HT boundary with water level set at bank full level on the River Great Ouse.

c. Downstream Boundary modelled as a HT boundary with water level set at peak 10% AEP event on the River Great Ouse.

d. Downstream Boundary modelled as a HT boundary with water level set at peak 5% AEP event on the River Great Ouse.

12.5.2 A 20% increase and decrease was applied to all Manning's Roughness Coefficients in the 1D channel and 2D model. **Table 12-3** shows the change in the 1D channel water level through the model compared to the baseline scenario for each sensitivity test at the model nodes shown in Figure 12-5. It can be seen that the maximum in-channel water level through the model does not increase or decrease by more than 0.30m for the roughness sensitivity testing. There is a low level of sensitivity to changes in roughness with changes of water levels within acceptable tolerances.

12.5.3 To assess the interaction between the South Brook and the River Great Ouse, the Downstream Boundary was modelled as a HT boundary with water level set at bank full on the River Great Ouse. Bank full levels were obtained from the 1D-2D River Great Ouse hydraulic model, which forms Annex A of the FRA. **Table 12-3** shows a maximum water level change of +0.70m in the channel at the downstream end of the model associated with the drainage ditches, and no water level change further upstream in the location of the Scheme.

12.5.4 **Figure 12-10** displays a depth difference map showing an increase of flood depths at the downstream end of the model across the floodplain up to +0.20m. Small localised areas of flood depths increased up to +0.34m. The changes in depth were generally contained to the downstream end of the model and little variations in depth were present on the floodplain in the location of the proposed Scheme. This suggests that whilst the model is sensitive to the downstream boundary representation locally around the boundary, there are no significant impacts around the proposed Scheme.

Table 12-3: 1D In-Channel Maximum Stage Sensitivity Results - 1% AEP + 65% Climate Change

		Maximum Stage + change of in-channel water depth compared to baseline						
Label	NGR	Baseline (m AOD)	+20% n (m AOD)	Difference (m)	-20% n (m AOD)	Difference (m)	DSBDY (m AOD)	Difference (m)
SB_0	515722, 256021	19.11	19.23	+0.12	18.99	-0.12	19.11	0.00
SB_430	516139, 255850	18.60	18.65	+0.05	18.60	0.00	18.60	0.00
SB_588	516278, 255789	17.61	17.70	+0.09	17.46	-0.15	17.61	0.00
SB_913	516593, 255735	16.73	16.77	+0.04	16.60	-0.13	16.73	0.00
SB_1243	516913, 255782	15.67	15.67	0.00	15.57	-0.10	16.37	+0.70

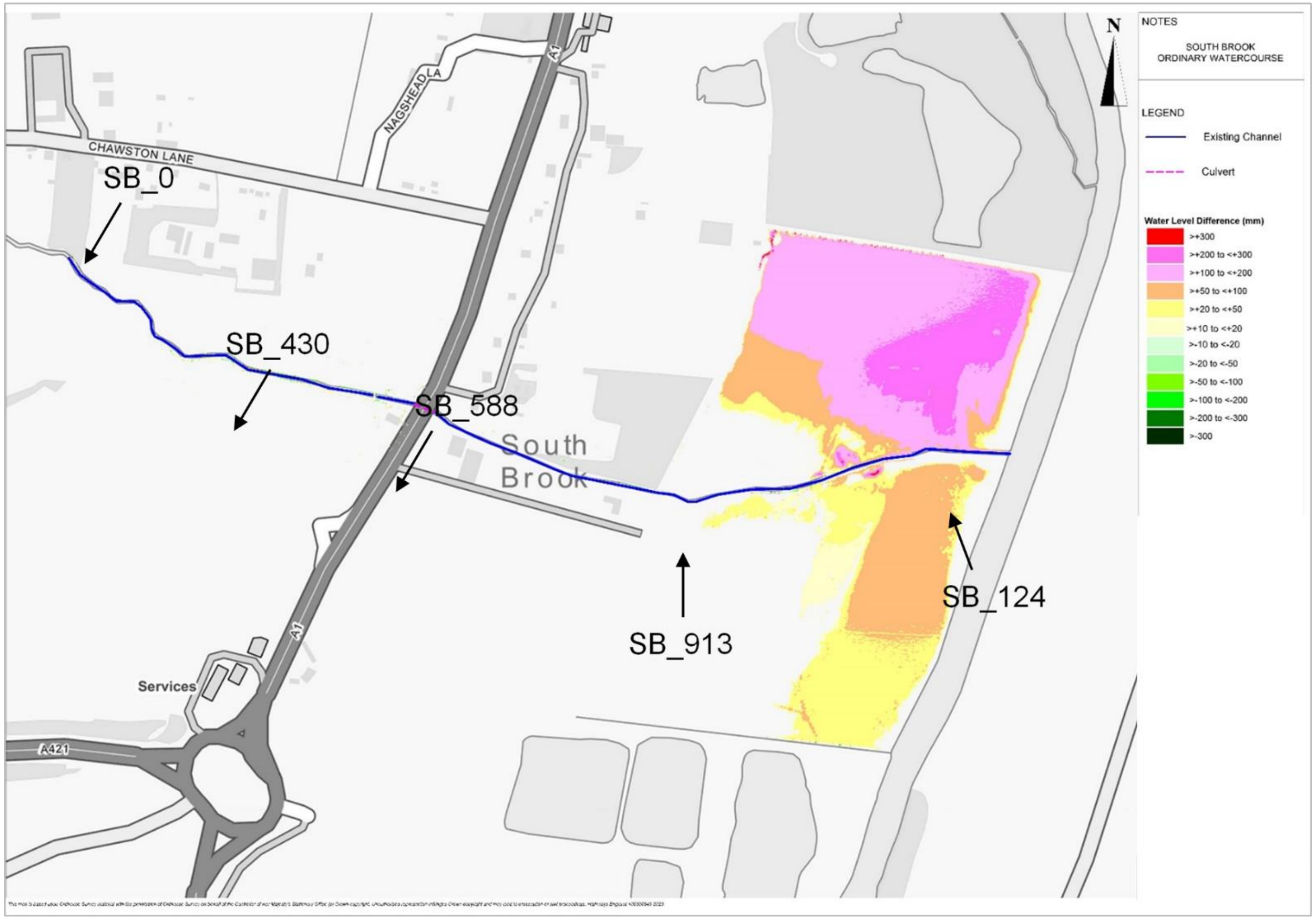


Figure 12-10: Depth Difference Map (Downstream Boundary Sensitivity) – 1% AEP + 65% Climate Change

12.5.5 To further understand the interaction between South Brook and the River Great Ouse in flood condition, additional simulations were undertaken in which the Downstream Boundary was modelled as a HT boundary with water level set at the peak 10% AEP event and the peak 5% AEP event on the River Great Ouse. The peak 10% AEP and 5% AEP levels were obtained from the 1D-2D River Great Ouse hydraulic model. Modelling of a 5% AEP and 10% AEP event on the River Great Ouse, in combination with a 1% AEP plus 65% climate change design event on South Brook, was considered appropriately conservative for the purposes of this sensitivity testing.

12.5.6 Table 12-4 shows a maximum water level change of +0.93m and +1.06m in the channel at the downstream end of the model associated with the drainage ditches during the 10% AEP and 5% AEP events respectively. Very minimal increases in water level occurred at SB_913 with no water level change further upstream. Figures 12-11 and 12-12 display depth difference maps showing an increase of flood depths at the downstream end of the model across the floodplain up to +0.55m and +0.70m during the 10% AEP and 5% AEP events respectively. The changes in depth were generally contained to the downstream end of the model and little variations in depth were present on the floodplain in the location of the proposed Scheme. When the South Brook and River Great Ouse are modelled in flood conditions, there are no significant impacts around the proposed Scheme, demonstrating that the Scheme assessment is robust.

Table 12-4: 1D In-Channel Maximum Stage Sensitivity Results in Flood Conditions- 1% AEP + 65% Climate Change:

		Maximum Stage + change of in-channel water level compared to baseline				
Label	NGR	Baseline (m AOD)	10% Ouse DSBDY (m AOD)	Difference (m)	5% Ouse DSBDY (m AOD)	Difference (m)
SB_0	515722 , 256021	19.11	19.11	0.00	19.11	0.00
SB_430	516139 , 255850	18.60	18.60	0.00	18.60	0.00
SB_588	516278 , 255789	17.61	17.61	0.00	17.61	0.00
SB_913	516593 , 255735	16.73	16.76	+0.03	16.77	+0.04
SB_1243	516913 , 255782	15.67	16.60	+0.93	16.73	+1.06

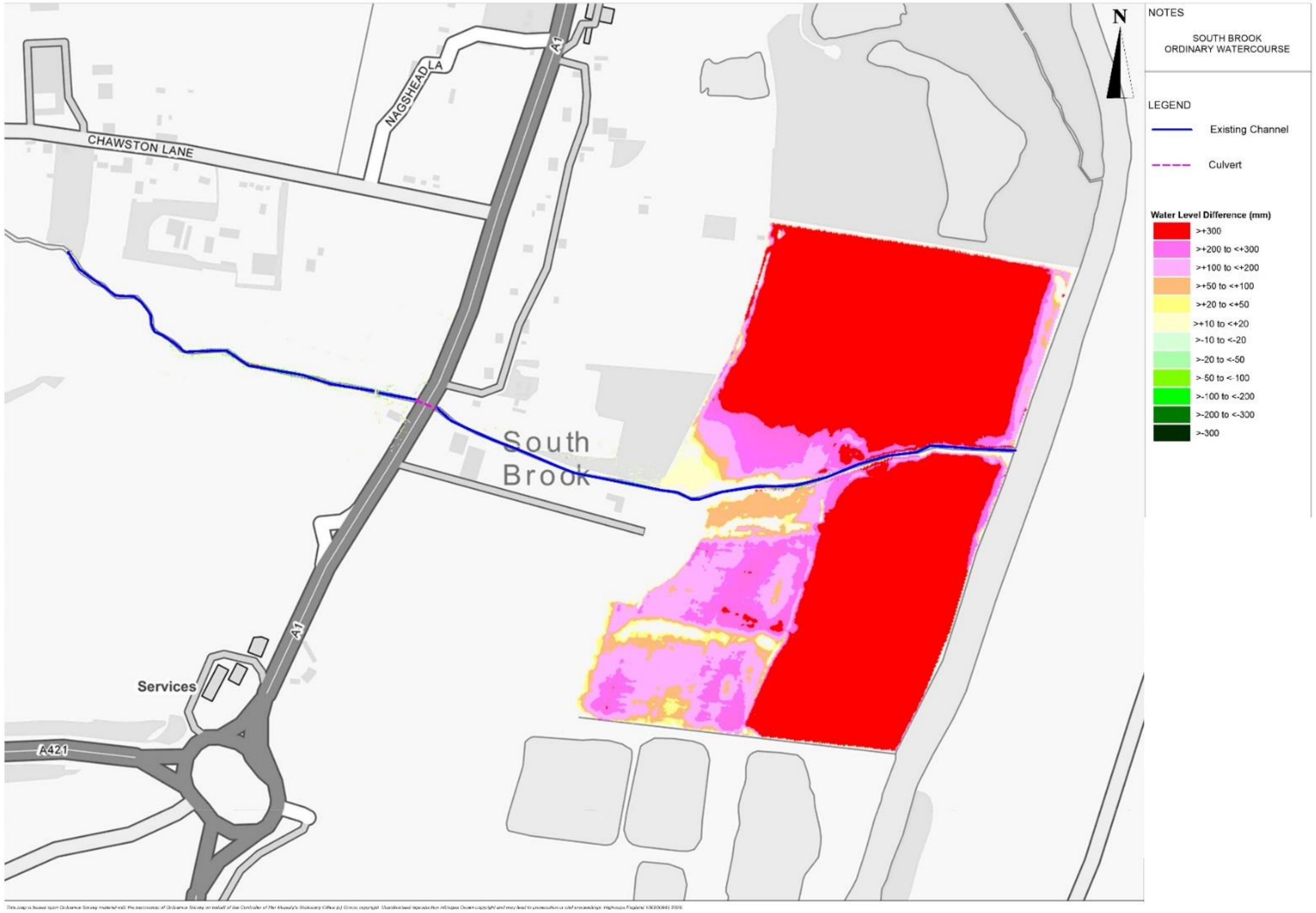


Figure 12-11: Depth Difference Map (10% AEP River Great Ouse Sensitivity) – 1% AEP + 65% Climate Change

Figure 12-12: Depth Difference Map (5% AEP River Great Ouse Sensitivity) – 1% AEP + 65% Climate Change

12.6 Assumptions/limitations

12.6.1 General limitations that affect all 1D-2D models can be found in Section 2.10, such as uncertainties generated from hydrological inflows.

12.6.2 The current representation of the downstream boundary within the design simulations, as a normal depth boundary, assumes free discharge and does not account for any backwater effects from the River Great Ouse that may occur when levels are raised in the main river. Results from the downstream boundary sensitivity tests demonstrate that raised levels on the River Great Ouse exert a localised impact upon levels within the channel and floodplain of South Brook. The increase in levels observed within the sensitivity tests propagate approximately 350 m upstream on the South Brook, although no significant change is observed through the Scheme area, even within the extreme 1% AEP + 65% climate change event. This suggests that the model set up for the design events, and resulting Scheme assessment, are robust.

12.6.3 The length of the available survey was limited and only extended approximately 0.43km upstream of the proposed Scheme. An increased length of survey is generally preferable; however, results have shown that the current extent of the model captures all impacts of the Scheme.

12.7 Summary and conclusions

12.7.1 The proposed scenario along South Brook comprises of a new culvert beneath the proposed Roxton Link Road and a new culvert beneath the proposed A1 Great North Road. Online floodplain compensation areas are proposed to increase channel capacity to compensate for the displacement of floodwater associated with the proposed Scheme.

12.7.2 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is required. Details of the compensatory storage calculations are included within Appendix D4.

12.7.3 Results have shown that the floodplain compensation areas provide adequate compensation for the loss of floodplain; therefore, there are no significant impacts upon downstream channel low and no detriment to third party land or vulnerable receptors.

12.7.4 A conservative approach has been adopted whereby the flood mitigation measures have been designed to account for the 1% AEP + 65% climate change event.

13 Summary and conclusions

13.1 West Brook

13.1.1 West Brook is located to the east of St Neots between Croxton and Eltisley. It has a peak flow of 1.7m^3/s for the 1% AEP event. The modelled reach of 1.5km is mainly located in agricultural fields to the north of the existing A428 carriageway, with the downstream boundary being located approximately 8km upstream of the River Great Ouse confluence. Based upon aerial imagery and available mapping there is one property located to the east of the watercourse, although baseline modelling show that's that this is not at risk of flooding. The watercourse has been modelled as a 1D only using FMP.

13.1.2 During the 1% AEP + 65% climate change modelled event for West Brook, the flow downstream of the A428 proposed crossing is equivalent for the baseline and proposed scenarios. Upstream of the proposed A428 Scheme and associated channel reprofiling peak water level is the same within the baseline and Scheme scenarios for the design event. Furthermore, the minimum and desired freeboard is achieved for 1% AEP + 65% climate change event at the proposed A428 crossing.

13.1.3 Modelling results therefore demonstrate that the A428 Scheme retains conveyance of the West Brook watercourse in line with existing conditions, leading to no increase in flood risk upstream or downstream.

13.1.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required.

13.2 Wintringham Brook

13.2.1 Wintringham Brook is located to the east of St Neots, and ultimately flows into the River Great Ouse via Fox Brook and Hen Brook. The length of the modelled reach is approximately 1.5km, beginning in agricultural fields and ending approximately 2km upstream of the River Great Ouse to the east of the railway line. It should be noted that there are no properties or vulnerable elements located along the modelled reach. The estimated peak flow for Wintringham Brook is 2.5m^3/s for the 1% AEP event. The watercourse has been modelled as 1D only using FMP.

13.2.2 Model results presented in Section 4 demonstrate that peak flow downstream and peak water level upstream of the A428 crossing are equivalent for the baseline and proposed Scheme scenarios for Wintringham Brook for the 1% AEP + 65% climate change design event. The minimum and desired freeboard is achieved for the proposed A428 crossing culvert.

13.2.3 Modelling results therefore demonstrate that the A428 Scheme retains conveyance of the Wintringham Brook watercourse in line with existing conditions, leading to no increase in flood risk upstream or downstream.

13.2.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required.

13.3 Wintringham Brook Tributary

13.3.1 Wintringham Brook Tributary is located to the east of St Neots and to the north of Wintringham Brook. The modelled reach of 1.3km is located in agricultural fields and flows beneath the existing A428, with the downstream boundary being located upstream of the confluence with Wintringham Brook. The watercourse has an estimated peak flow estimate of 0.8m^3/s for the 1% AEP event. There are no vulnerable elements such as properties and businesses located through the modelled reach. The watercourse has been modelled in 1D only using FMP.

13.3.2 In the 1% AEP + 65% climate change event simulated for Wintringham Brook Tributary the peak flow downstream of the proposed A428 culvert remains equivalent in the proposed and baseline models. Upstream of the proposed A428 crossing modelling results show that there is a decrease in both peak flow and depth within the proposed Scheme model, when compared to the baseline. Due to reprofiling of the channel upstream of the Scheme peak water levels are not directly comparable, however based upon analysis of model results it can be concluded that the decreases in water level and depth can be attributed to the reprofiling of the channel, along with the presence of an online compensatory storage area. The minimum and desired freeboard is achieved for 1% AEP + 65% climate change event at the proposed A428 crossing.

13.3.3 Overall, results demonstrate that the A428 Scheme retains conveyance of the Wintringham Brook Tributary watercourse in line with existing conditions, leading to no increase in flood risk upstream or downstream.

13.3.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required. A hydraulic attenuation area is included as part of the scheme, although this is included in order to retain downstream pass on flows in line with the baseline, and is not related to requirements for floodplain compensation storage.

13.4 Gallow Brook

13.4.1 Gallow Brook is located to the east of St Neots and to the north of the existing A428 carriageway. Available mapping shows that the 2km modelled reach flows through agricultural fields, with the downstream boundary being located approximately 5km upstream of the River Great Ouse confluence. The watercourse has an estimated peak flow of 3.1m^3/s for the 1% AEP event. It should be noted that there are no properties located within the modelled floodplain for Gallow Brook. The watercourse has been modelled in 1D only using FMP.

13.4.2 Within the 1% AEP + 65% climate change design event, flow downstream of the proposed A428 crossing in the Gallow Brook model is 0.02m^3/s lower in the proposed results compared to the baseline, although this is not considered a significant change. Whilst reprofiling of the channel upstream of the A428 Scheme limits comparability of water levels between the baseline and Scheme models upstream, extraction of water level results close to the upstream boundary demonstrates that the Scheme results in no change in peak water level for the modelled design event. For 1% AEP + 65% climate change event, the minimum and desired freeboard is achieved at the proposed A428 crossing.

13.4.3 Overall, results demonstrate that the A428 Scheme retains conveyance of the Gallow Brook watercourse in line with existing conditions, leading to no increase in flood risk upstream or downstream.

13.4.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required.

13.5 Begwary Brook

13.5.1 Begwary Brook is located close to Wyboston south of St Neots, the modelled reach is approximately 0.5km in length. The watercourse has an estimated peak flow of 1.7m^3/s for the 1% AEP event. The modelled reach of Begwary Brook is primarily located within agricultural fields and flows through the residential area of Wyboston and beneath the A1. The modelled reach ends approximately 500m upstream of the River Great Ouse. The watercourse has been modelled in1D only using FMP.

13.5.2 For the 1% AEP + 65% climate change modelled design event for Begwary Brook, the peak flow downstream of the A1 crossing is 0.01m^3/s lower within the proposed Scheme scenario, when compared to the baseline flow. Upstream of the proposed A1 culvert model results show that there is a small decrease in peak water level of 0.02m within the proposed Scheme scenario when compared to the baseline. Furthermore, the minimum freeboard is achieved for the 1% AEP + 65% climate change design event within the A1 crossing culvert.

13.5.3 Overall, results demonstrate that the A428 Scheme retains conveyance of the Begwary Brook watercourse in line with existing conditions, leading to no increase in flood risk upstream or downstream.

13.5.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is provided as part of the Scheme.

13.6 Rockham Ditch

13.6.1 Rockham Ditch is located to the south of St Neots and intersects the A421, Bedford Road, Kelpie Marina Access Road and the A1. The modelled reach is approximately 1.7km in length and ends at the River Great Ouse confluence. It should be noted that there are several vulnerable elements located along the modelled reach including a garden centre and several properties, however model results demonstrate that these elements are located outside the floodplain. Rockham Ditch has an estimated peak flow of 1.2m^3/s for the 1% AEP event. The watercourse has been modelled as 1D only using FMP.

13.6.2 For the 1% AEP + 65% climate change design event simulated within the model, the peak flow downstream of the A1 culvert is 0.02m^3/s less in the proposed scenario when compared to the baseline. Upstream of the proposed A1 culvert there is a small decrease in peak water level of 0.03m within the proposed scenario, when compared to the baseline scenario. It should be noted that the minimum and desired freeboard is achieved for the proposed A428 crossing culvert for the 1% AEP + 65% climate change event .

13.6.3 Overall, results demonstrate that the A428 Scheme retains conveyance of the Rockham Ditch watercourse broadly in line with existing conditions, the small decreases in peak flow downstream and peak water level upstream of the Scheme do not represent a significant change. Therefore, based on modelling results it can be concluded that there is no increase in flood risk upstream or downstream of the Scheme.

13.6.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is provided as part of the Scheme.

13.7 Top Farm Brook

13.7.1 Top Farm Brook is located to the south-east of St Neots, the drainage channel flows in a north westerly direction adjacent to Potton Road, intersecting the existing A428 carriageway and railway line prior to its confluence with the River Great Ouse. The modelled reach of 1.2km is located predominantly in agricultural fields with the downstream boundary 2km from the River Great Ouse confluence, upstream of the existing proposed A428 crossing. A single farm, located immediately adjacent to the watercourse, represents the only vulnerable receptor within the modelled reach. Top Farm Brook is characterised by an estimated peak flow of 1.9m^3/s for the 1% AEP event. The watercourse has been modelled as 1D only using FMP.

13.7.2 For the 1% AEP + 65% climate change modelled design event for Top Farm, the peak flow downstream of the A428 crossing is 0.02m^3/s lower within the proposed Scheme scenario, when compared to the baseline flow. Peak water level upstream of the A428 Scheme culvert is 0.08m lower in the proposed Scheme model, when compared to the baseline model for the 1% AEP + 65% climate change event. For the 1% AEP + 65% climate change event, the minimum and desired freeboard is achieved within the proposed A428 culvert.

13.7.3 A sensitivity test was undertaken to demonstrate the impact of the discharge of a small flow from an Anglian Water storage pond to the Top Farm Brook. It is proposed that the storage pond be connected into Top Farm Brook within the post Scheme scenario. Downstream of the proposed A428 carriageway, inclusion of this additional 0.06m^3/s flow led to an increase in peak water level of 0.01m.

13.7.4 Overall, modelling results demonstrate that the A428 Scheme retains conveyance of the Top Farm Brook in line with existing conditions, leading to no increase in flood risk upstream or downstream of the Scheme.

13.7.5 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is contained within bank, and compensatory storage is not required. A hydraulic attenuation area is included as part of the scheme, although this is included in order to retain downstream pass on flows in line with the baseline, and is not related to requirements for floodplain compensation storage.

13.8 Hen Brook

13.8.1 Hen Brook is located to the south-east of Neots. It has a catchment size of ~47km^2 with a peak flow estimate of ~13m^3/s for the 1% AEP event. The section of ordinary watercourse modelled (~1.8km) is located within agricultural fields to the north of the B1046 near Abbotsley, which includes the existing A428 carriageway. Based on the watercourse characteristics and complexity of hydraulics in close proximity to the proposed Scheme, a 1D-2D FMP-TUFLOW model has been produced.

13.8.2 During the 1% AEP + 65% climate change event for Hen Brook, maximum water elevations increase (as intended) within the floodplain compensatory areas and intuitively, flooding is removed where the new dual carriageway embankment crosses the floodplain. There is a decrease in maximum flood depths immediately upstream and downstream of the Scheme (-600mm) which is attributable to the compensation areas. There is no increase in flow downstream of the proposed Scheme and freeboard requirements are met for the Scheme culvert.

13.8.3 There is a small area where the maximum flood depth increases as a result of the Scheme however this is located within the Order Limits, already floods within the baseline scenario; and is located away from sensitive receptors.

13.8.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is provided as part of the Scheme.

13.9 Rectory Farm Brook

13.9.1 Rectory Farm Brook is located to the south of St Neots with a catchment area of $0.9km^2$ and an estimated peak flow of $0.8m^3/s$ for the 1% AEP event. Rectory Farm Brook flows in a southerly direction until it confluences with the Stone Brook which flows in a westerly direction to its outfall at the River Great Ouse. The approximately 3.1km reach modelled is located within agricultural fields with a farm access track road intersecting Rectory Farm Brook. Based on the watercourse characteristics and complexity of hydraulics in close proximity to the proposed Scheme, a 1D-2D FMP-TUFLOW model has been produced with a small reach represented in 1D only.

13.9.2 During the 1% AEP + 65% climate change event, maximum flood depths increase within the compensatory areas (as intended) and intuitively, flooding is removed where the proposed Scheme crosses the floodplain. There is a decrease in maximum flood depth in an area upstream of the proposed Scheme (-70mm) which is attributable to the floodplain compensation areas. There is no increase in flow downstream of the proposed Scheme and the proposed culverts have sufficient freeboard.

13.9.3 There are several areas where maximum flood depths increase by up to 0.036m as a result of the Scheme, however these areas are located within the Order Limits which already flood during the baseline and impact upon undeveloped agricultural land. An area to note is the small section at the end of the proposed access track road which experiences a small increase in flood depths of 0.060m, however this is not considered a key access route and is within the Order Limits.

13.9.4 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is provided as part of the Scheme.

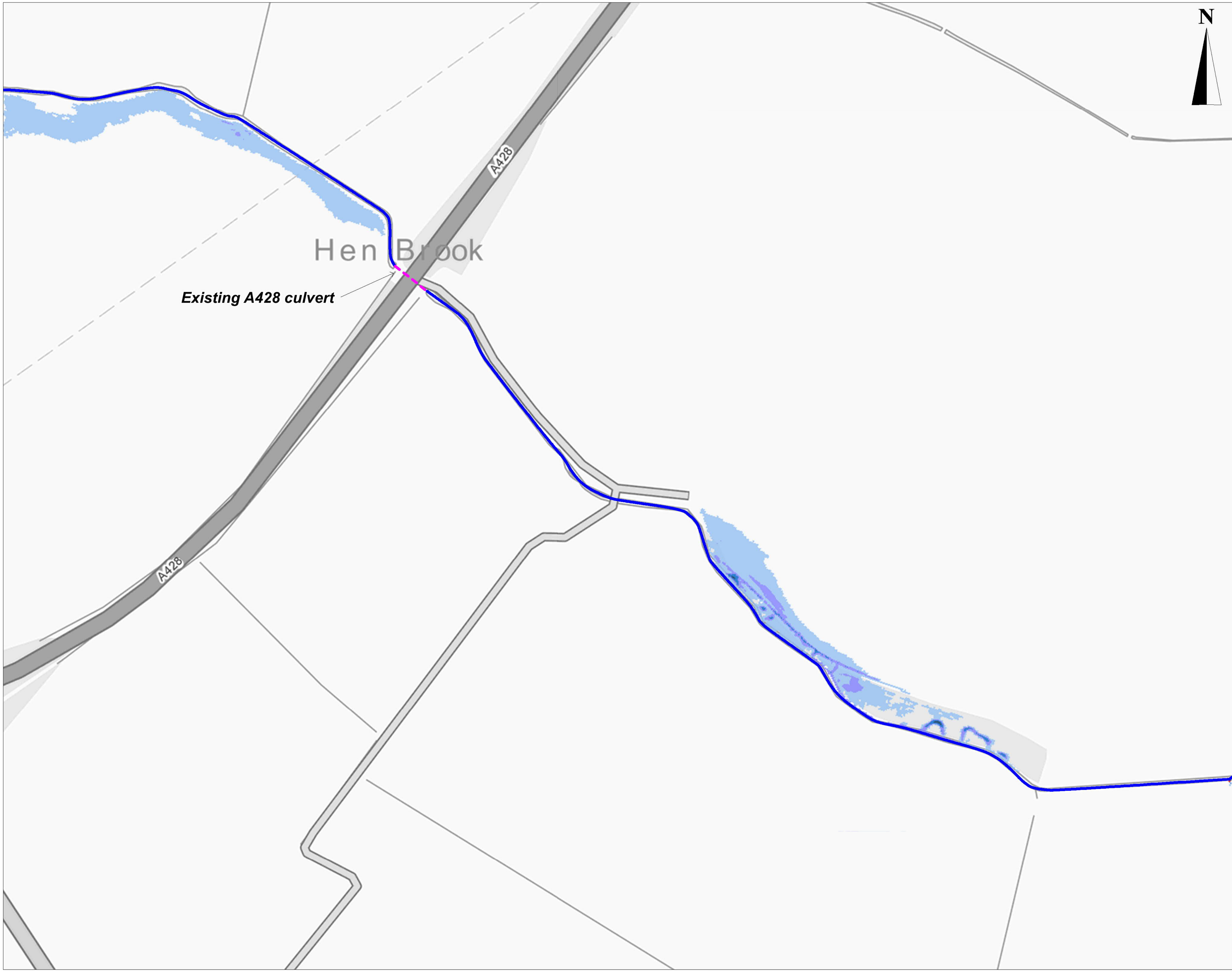
13.10 South Brook

13.10.1 South Brook is located to the south of St Neots with a catchment area of $27.16km^2$ and an estimated peak flow of $8.6m^3/s$ for the 1% AEP event. South Brook flows in an easterly direction to its outfall at the River Great Ouse. The approximately 1.2km reach modelled is located within agricultural fields in Chawston, which has the existing A1 Great North Road intersecting the channel. Based on the watercourse characteristics and complexity of hydraulics in close proximity to the proposed Scheme, a 1D-2D FMP-TUFLOW model has been produced.

13.10.2 During the 1% AEP + 65% climate change event, flood depths exclusively increase (as intended) within the compensation areas and intuitively, flooding is removed where the proposed Scheme crosses the floodplain. There is a decrease of flood depths immediately upstream of the proposed Scheme (-250mm) which is attributable to the floodplain compensation areas. There is no increase in flow downstream of the proposed Scheme or detriment to third party land and the freeboard requirements are met for the proposed culvert.

13.10.3 An assessment of baseline maximum flood levels for the 1% AEP + 35% CC event at the location of the proposed Scheme indicates that flow is out of bank, and compensatory storage is provided as part of the Scheme.

Appendix A- Hen Brook Flood Mapping



NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

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Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

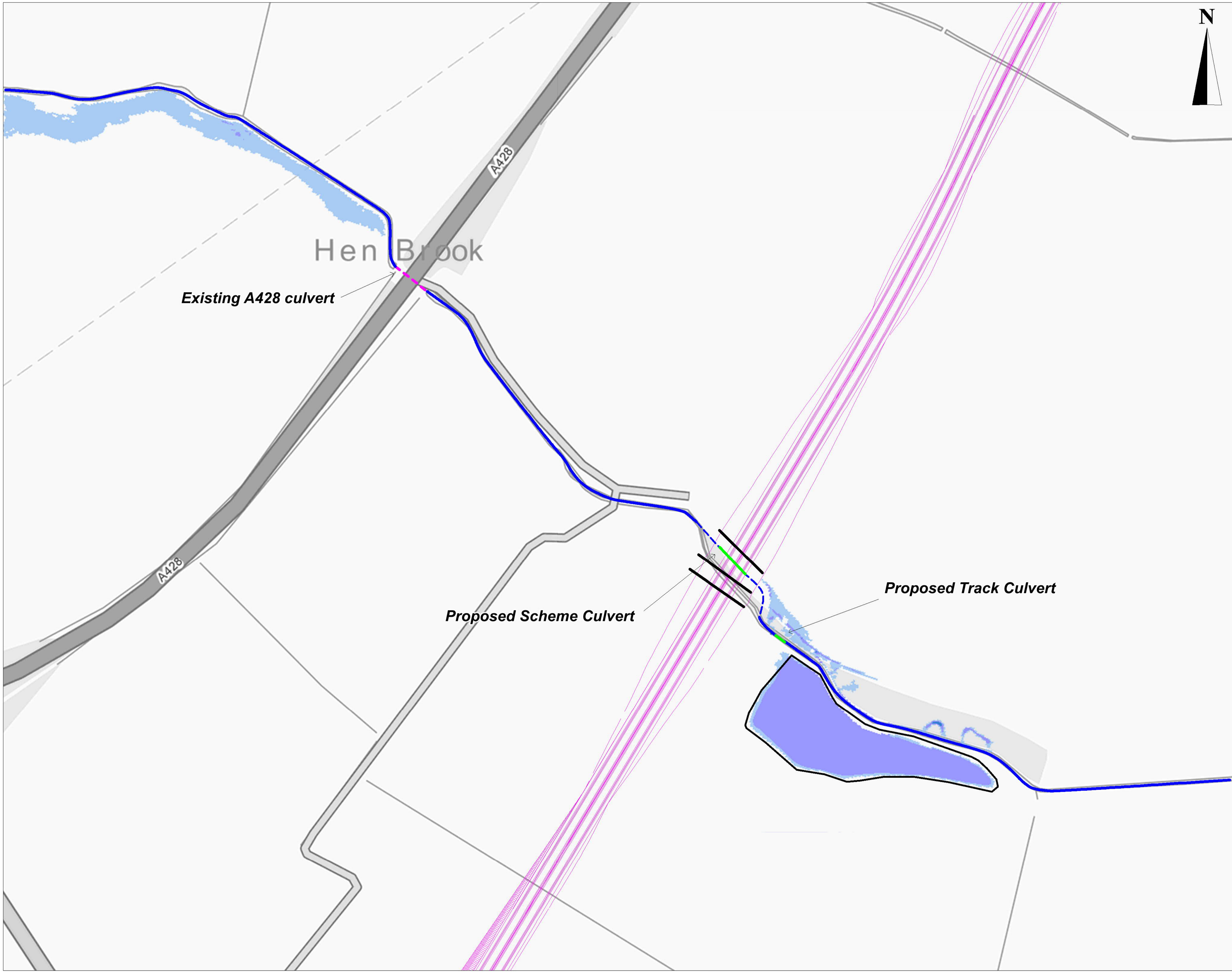
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
RM	RM	SB	MD	23/11/20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Flood Relief Culvert*
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

**Each Flood Relief Culvert represents two culvert (6 in total)*

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Project Title
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ORDINARY WATERCOURSES
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Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
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Internal Project No.	Suitability
60541541	S2
Scale @ A3	**Zone**
1: 4,100	General

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HE551495 -ACM -GEN-
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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel
Proposed Channel
Existing Culvert
Proposed Culvert
Proposed FRC
Proposed Scheme
Floodplain Compensation Area

Water Level Difference (mm)

>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+10 to <+20
>-10 to <-20
>-5 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300

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A428 BLACK CAT
TO CAXTON GIBBET
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HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
20% AEP

Designed	Drawn	Checked	Approved	Date
RM	RM	SB	MD	23/11/20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

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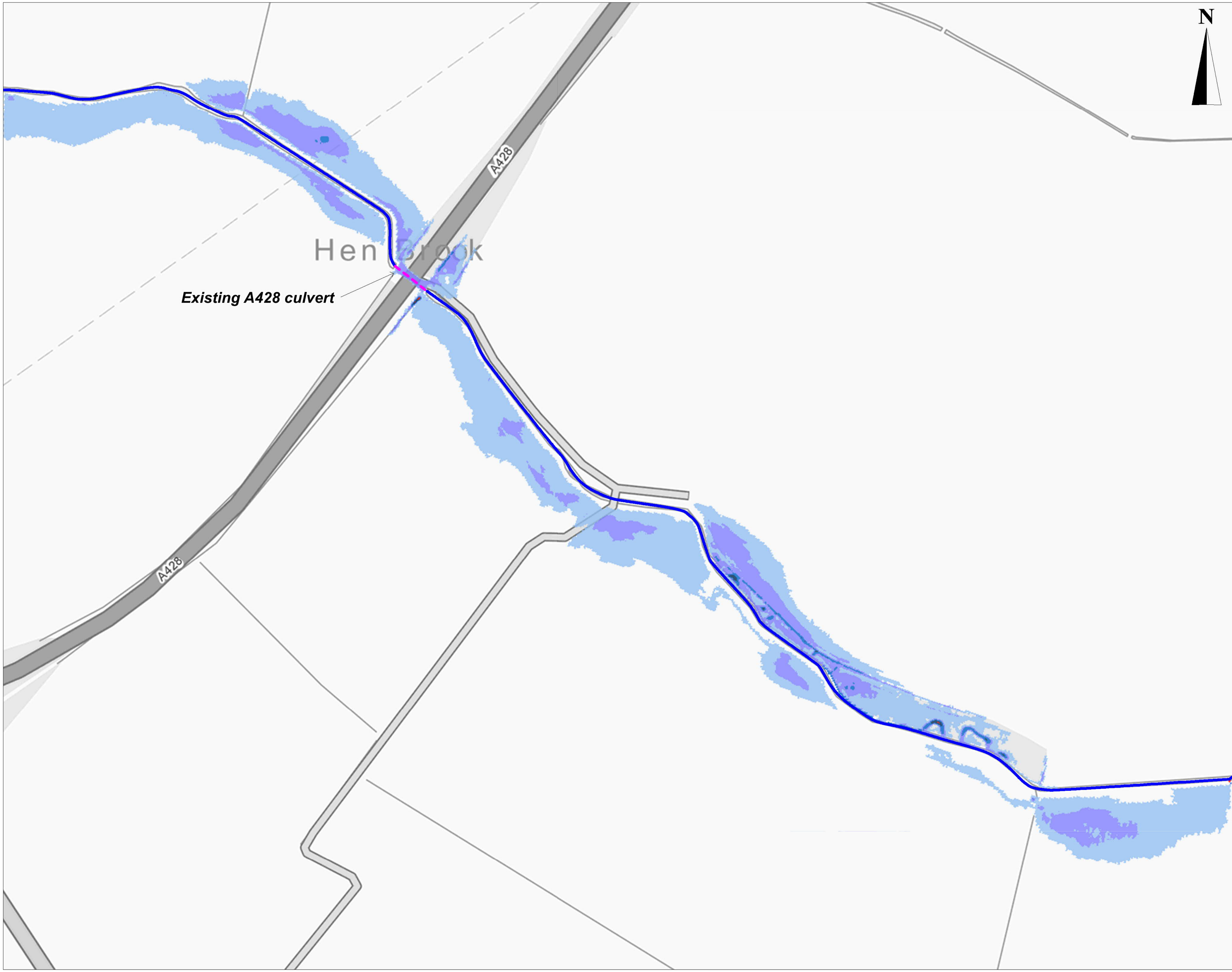

NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Culvert

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

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A428 BLACK CAT
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HYDRAULIC MODELLING REPORT

Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
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Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
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Location | Type | Role | Number

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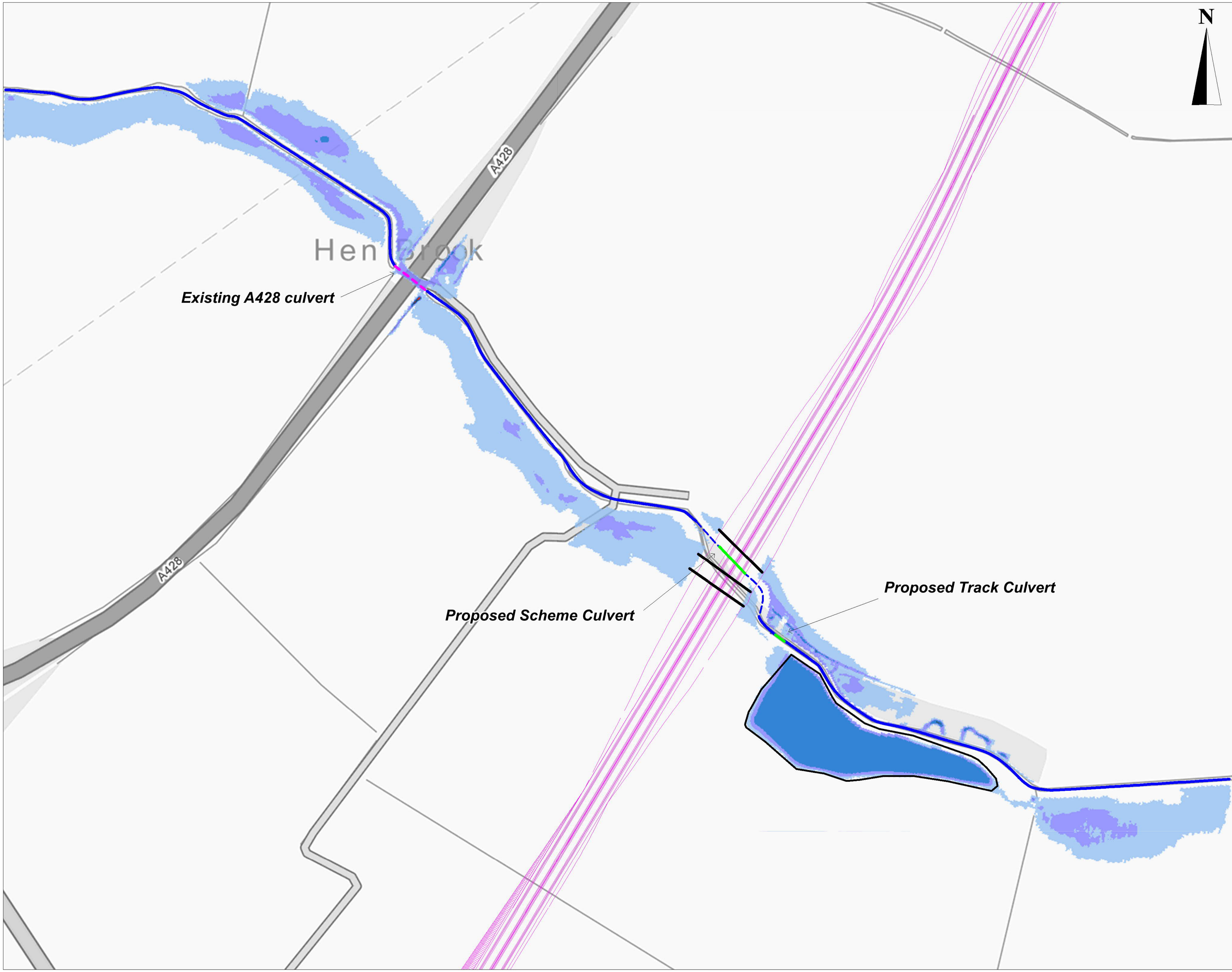
P01



NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel
Proposed Channel
Existing Culvert
Proposed Culvert
Proposed Flood Relief Culvert*
Proposed Scheme
Floodplain Compensation Area

Flood Depth (m)

0.00m - 0.25m
0.25m - 0.50m
0.50m - 0.75m
0.75m - 1.00m
>1.00m

**Each Flood Relief Culvert represents two culvert (6 in total)*

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HYDRAULIC MODELLING REPORT

Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
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Internal Project No.	Suitability
60541541	S2
Scale @ A3	**Zone**
1: 4,100	General

Drawing Number
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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed FRC
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+10 to <+20
- >-10 to <-20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

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Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP

Designed	Drawn	Checked	Approved	Date
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Internal Project No.	Suitability
60541541	S2
Scale @ A3	**Zone**
1: 4,100	General

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

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Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP +35%CC

Designed	Drawn	Checked	Approved	Date
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Scale @ A3 1: 4,100	Zone General

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Flood Relief Culvert*
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

**Each Flood Relief Culvert represents two culvert (6 in total)*

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Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP +35%CC

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1: 4,100	General

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed FRC
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+10 to <+20
- >-10 to <-20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

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Drawing Title

DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP +35%CC

Designed	Drawn	Checked	Approved	Date
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60541541	S2
Scale @ A3	**Zone**
1: 4,100	General

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GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

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HYDRAULIC MODELLING REPORT

Drawing Title

BASELINE
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
RM	RM	SB	MD	23/11/20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Flood Relief Culvert*
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

**Each Flood Relief Culvert represents two culvert (6 in total)*

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Project Title
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TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
RM	RM	SB	MD	23/11/20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
Highways England PIN | Originator | Volume | Location | Type | Role | Number
HE551495 -ACM -GEN-GEN_Z_Z_ZZ -DR -HF

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NOTES

HEN BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed FRC
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+10 to <+20
- >-10 to <-20
- >-5 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

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Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
0.1% AEP

Designed	Drawn	Checked	Approved	Date
RM	RM	SB	MD	23/11/20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 4,100	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

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Appendix B- Rectory Brook Flood Mapping

NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

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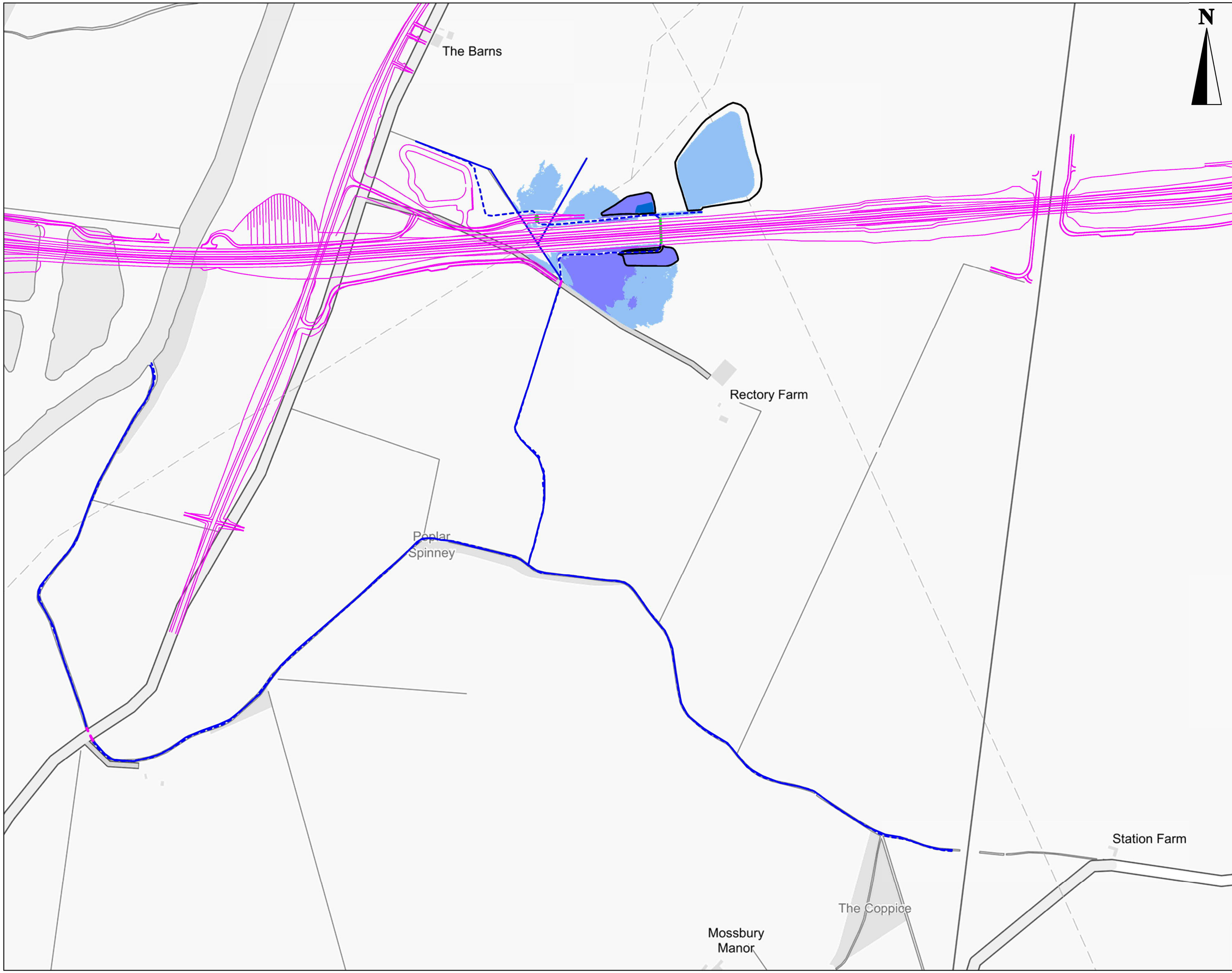
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

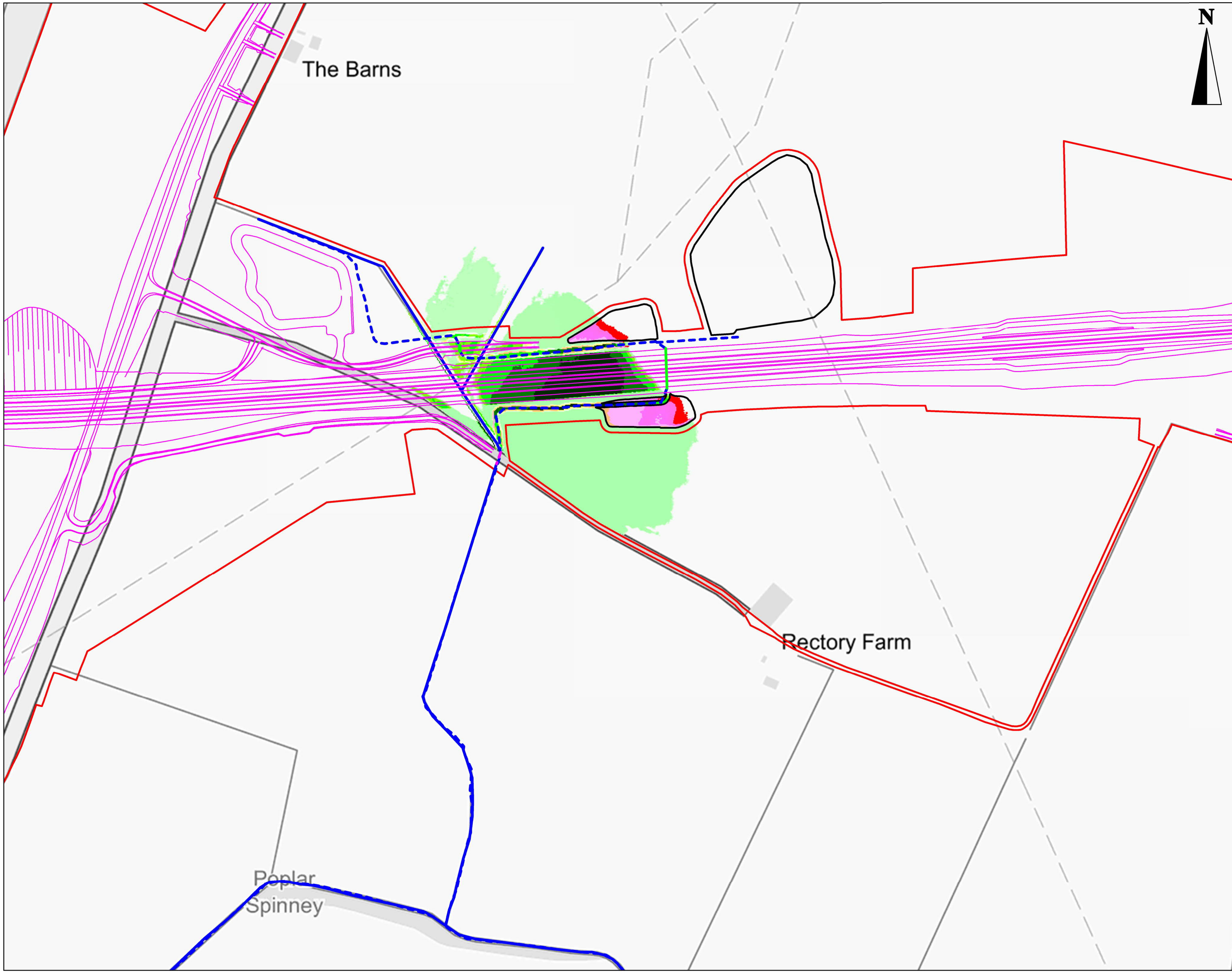
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area
- Red Line Boundary

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- :>+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 3,462	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01

NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

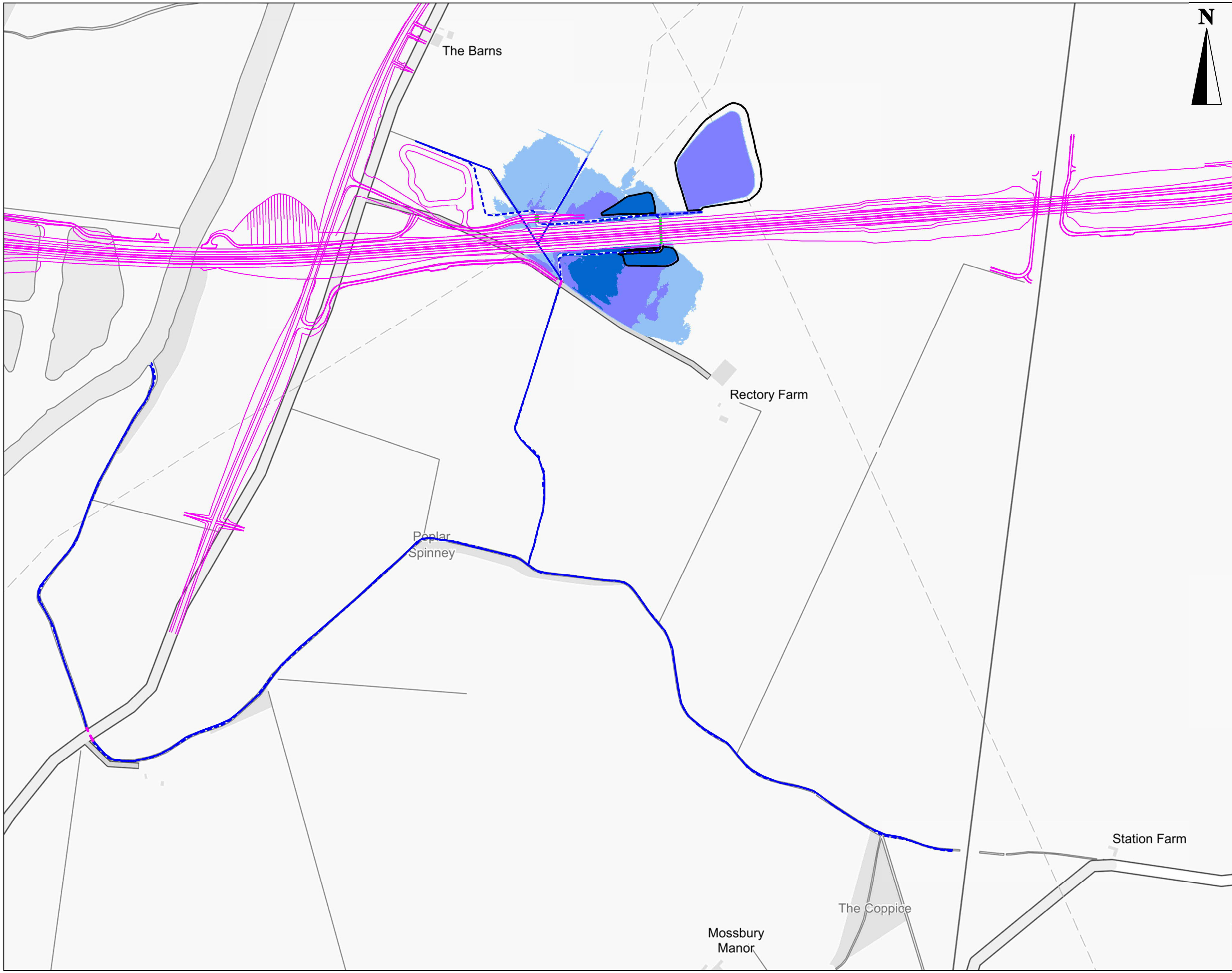
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

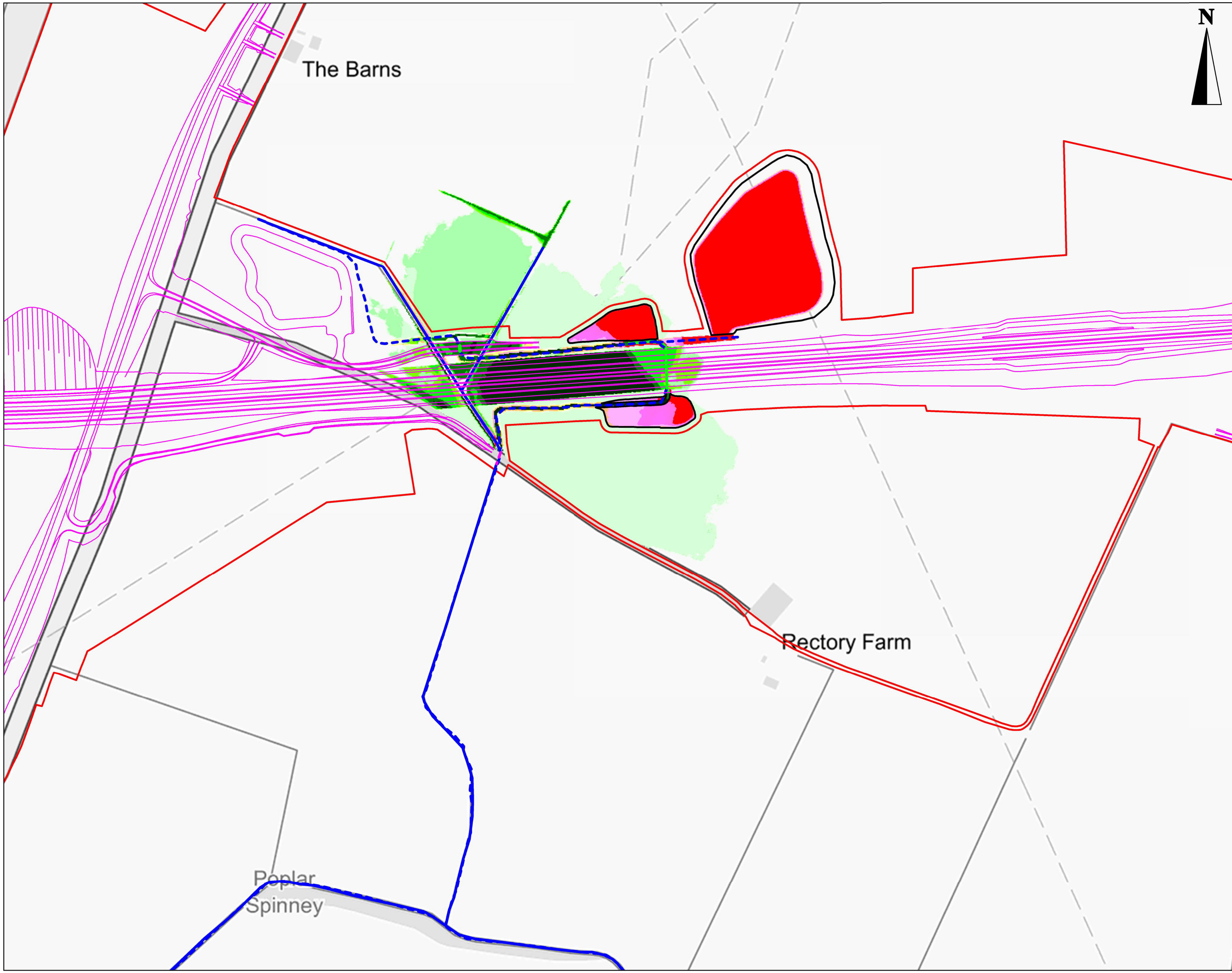
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel
Proposed Channel
Existing Culvert
Proposed Culvert
Proposed Scheme
Floodplain Compensation Area
Red Line Boundary

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
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highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 3,462	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01

NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

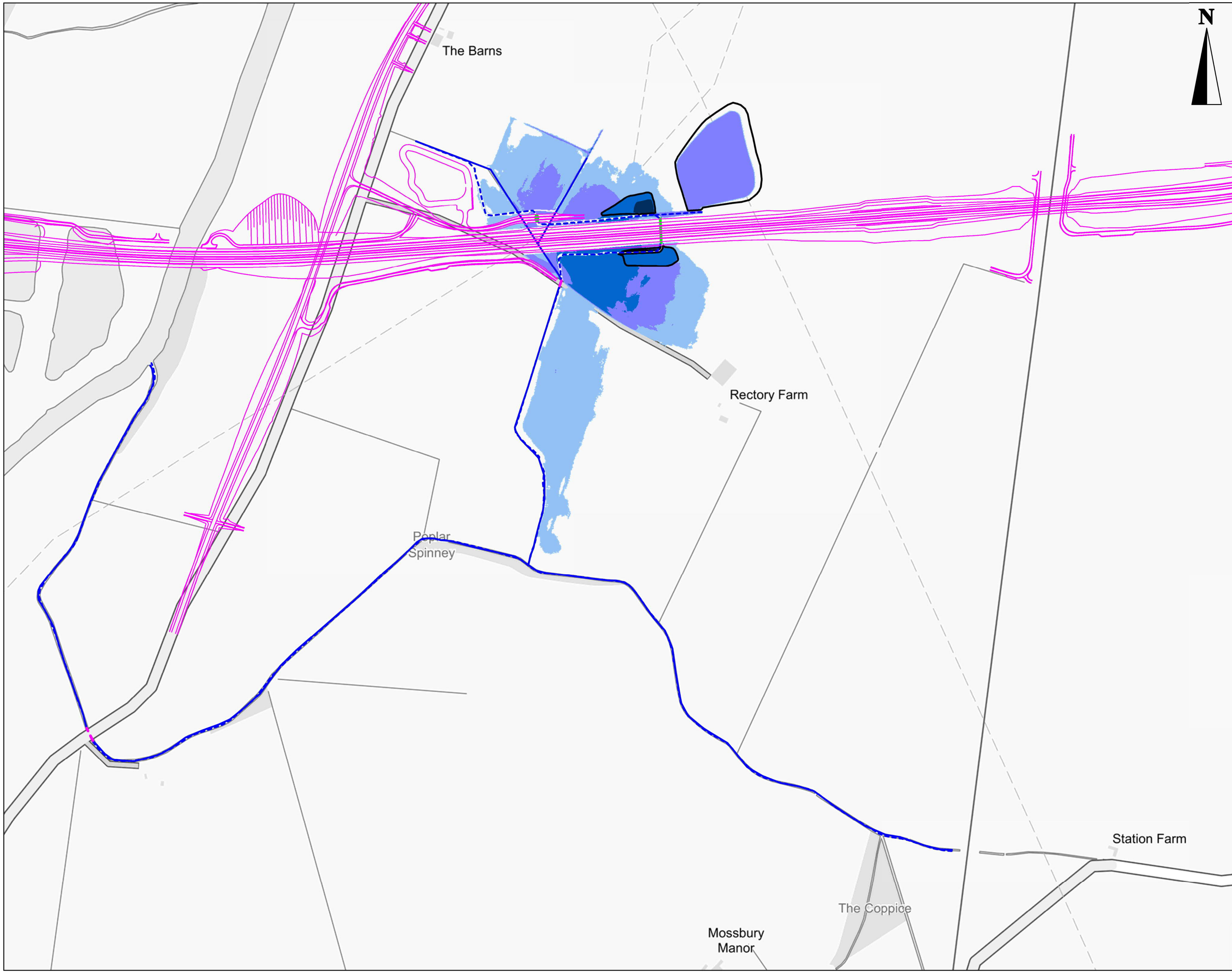
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP + 35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1:5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

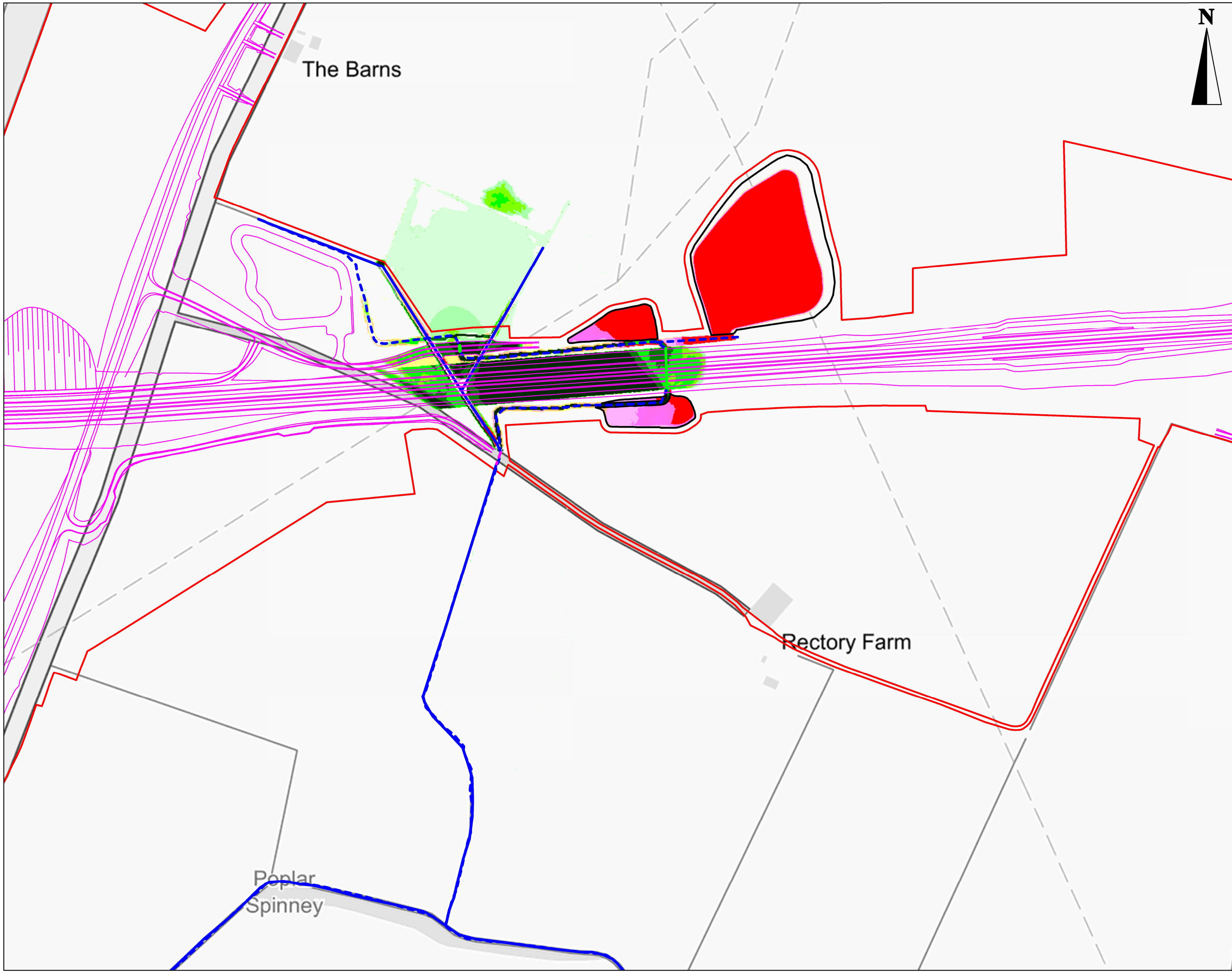
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP + 35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1: 5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area
- Red Line Boundary

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP +35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 3,462	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01

NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

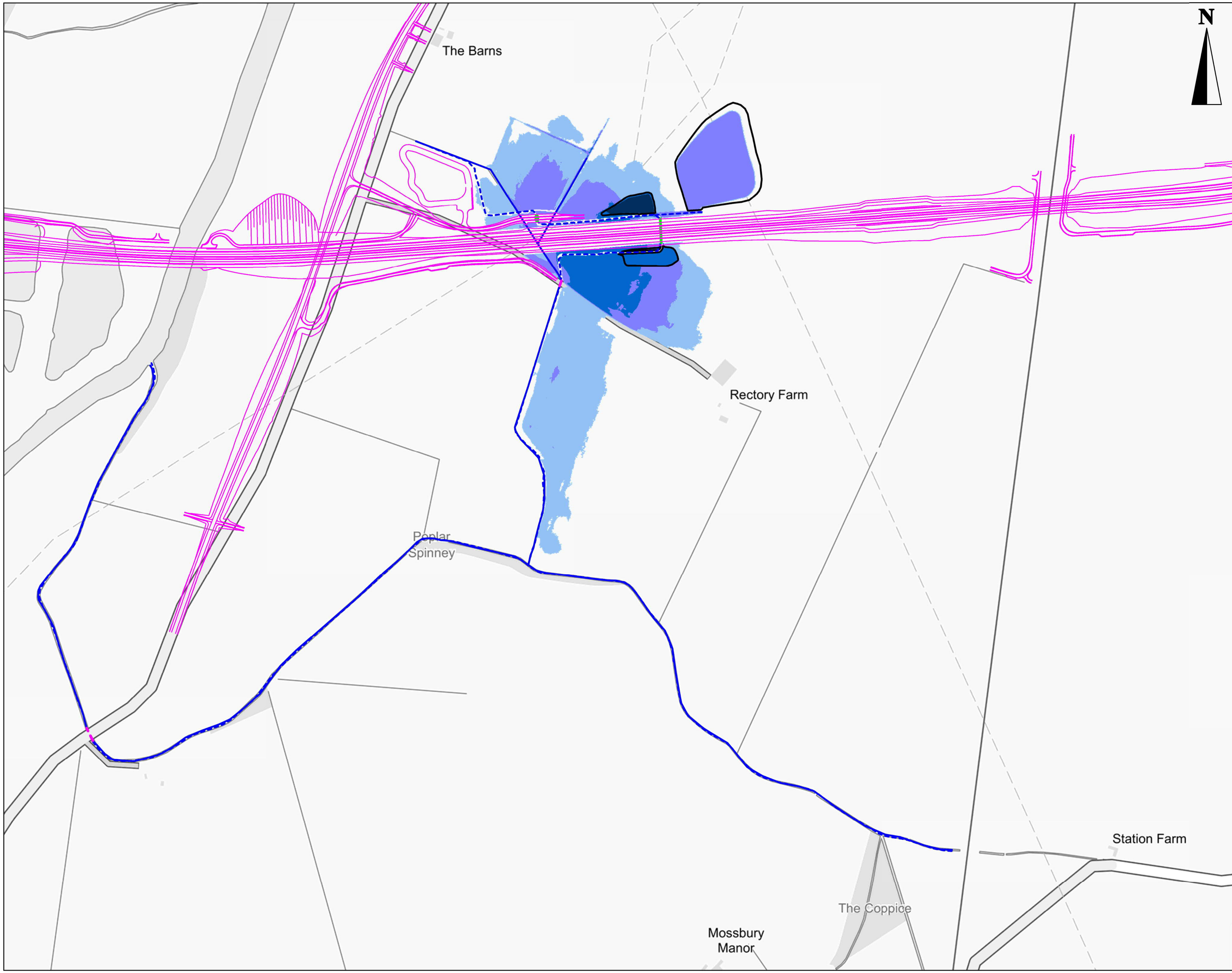
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

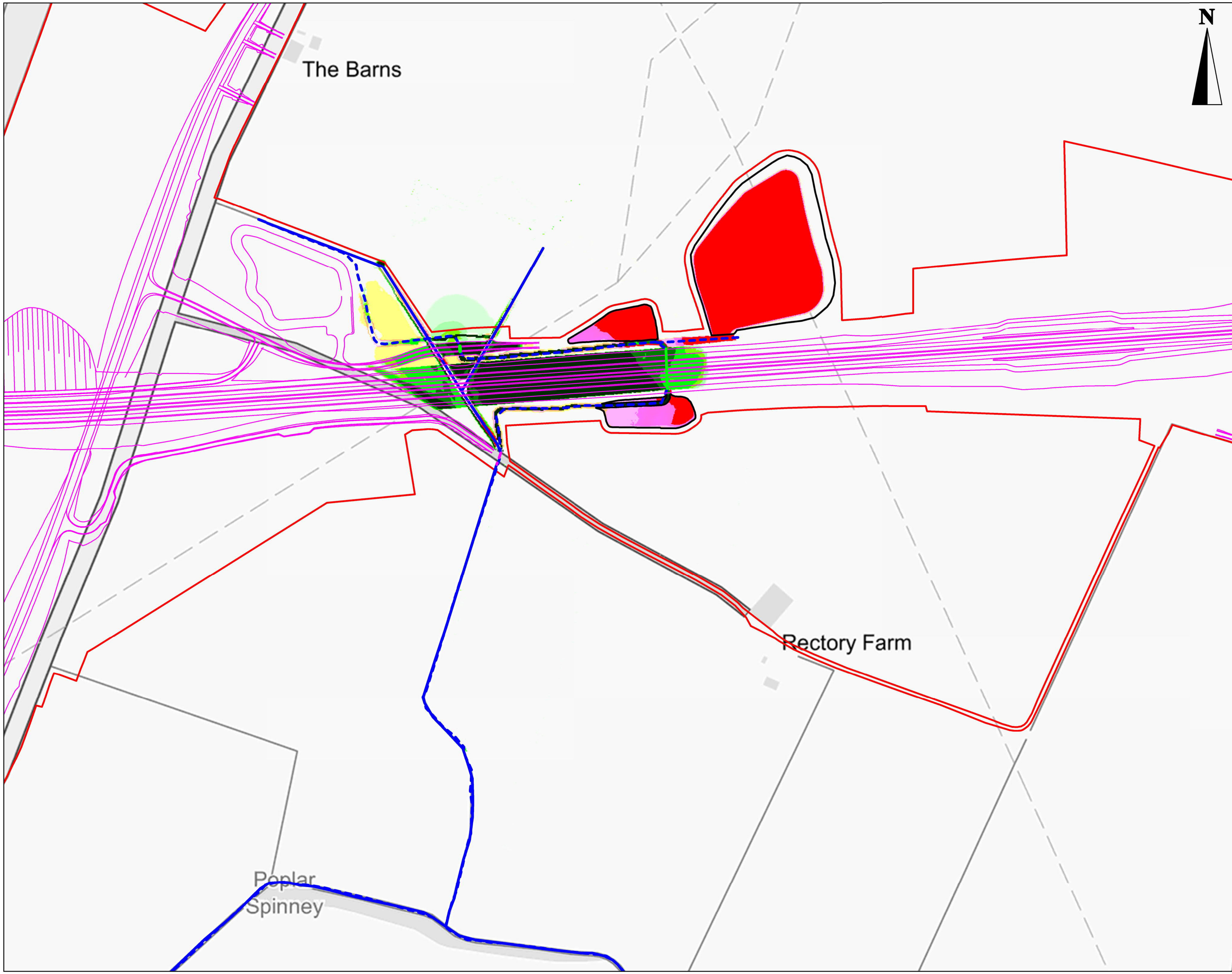
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 5,770	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

RECTORY BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area
- Red Line Boundary

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
0.1% AEP

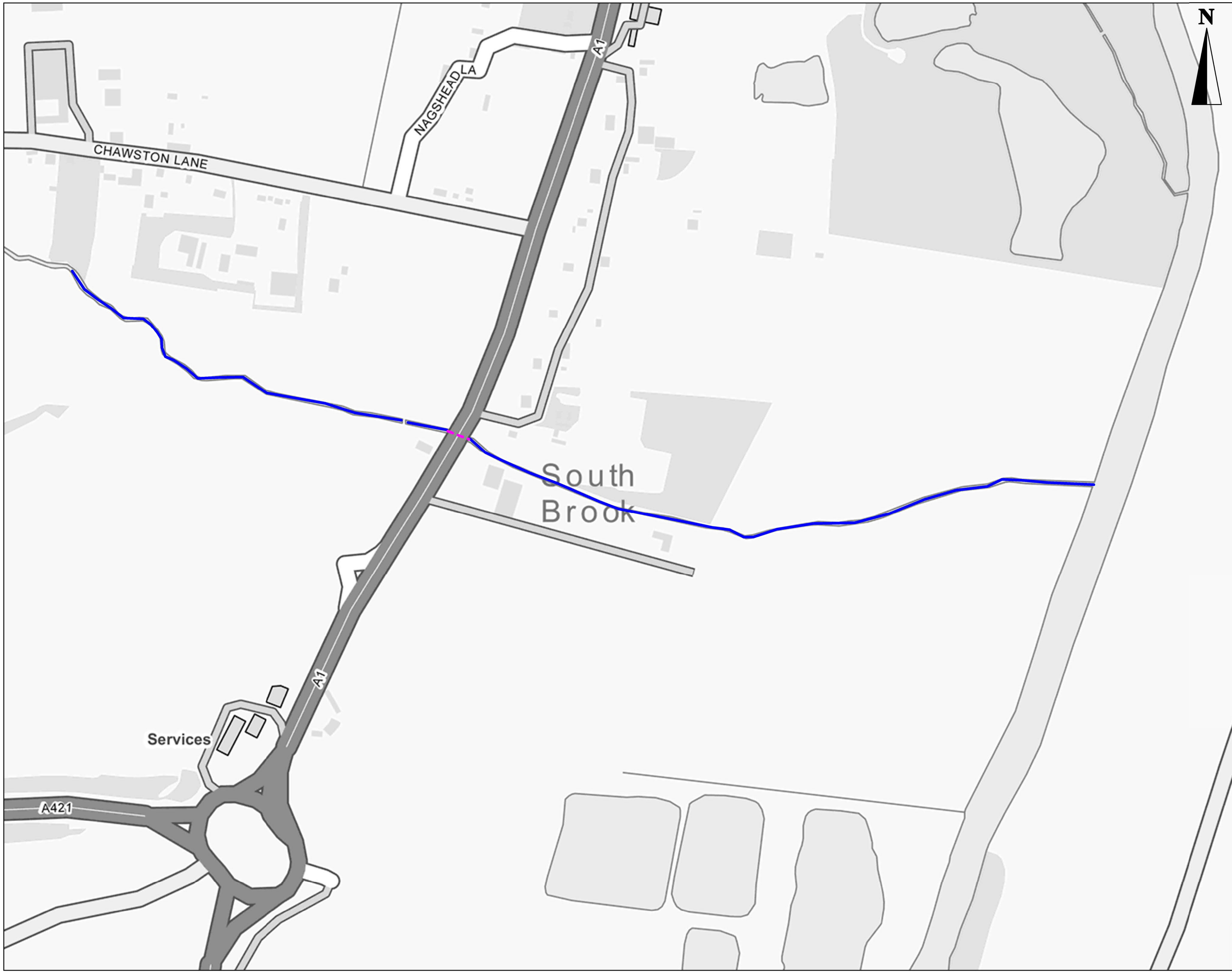
Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	JUNE 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1: 3,462	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01

Appendix C- South Brook Flood Mapping



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

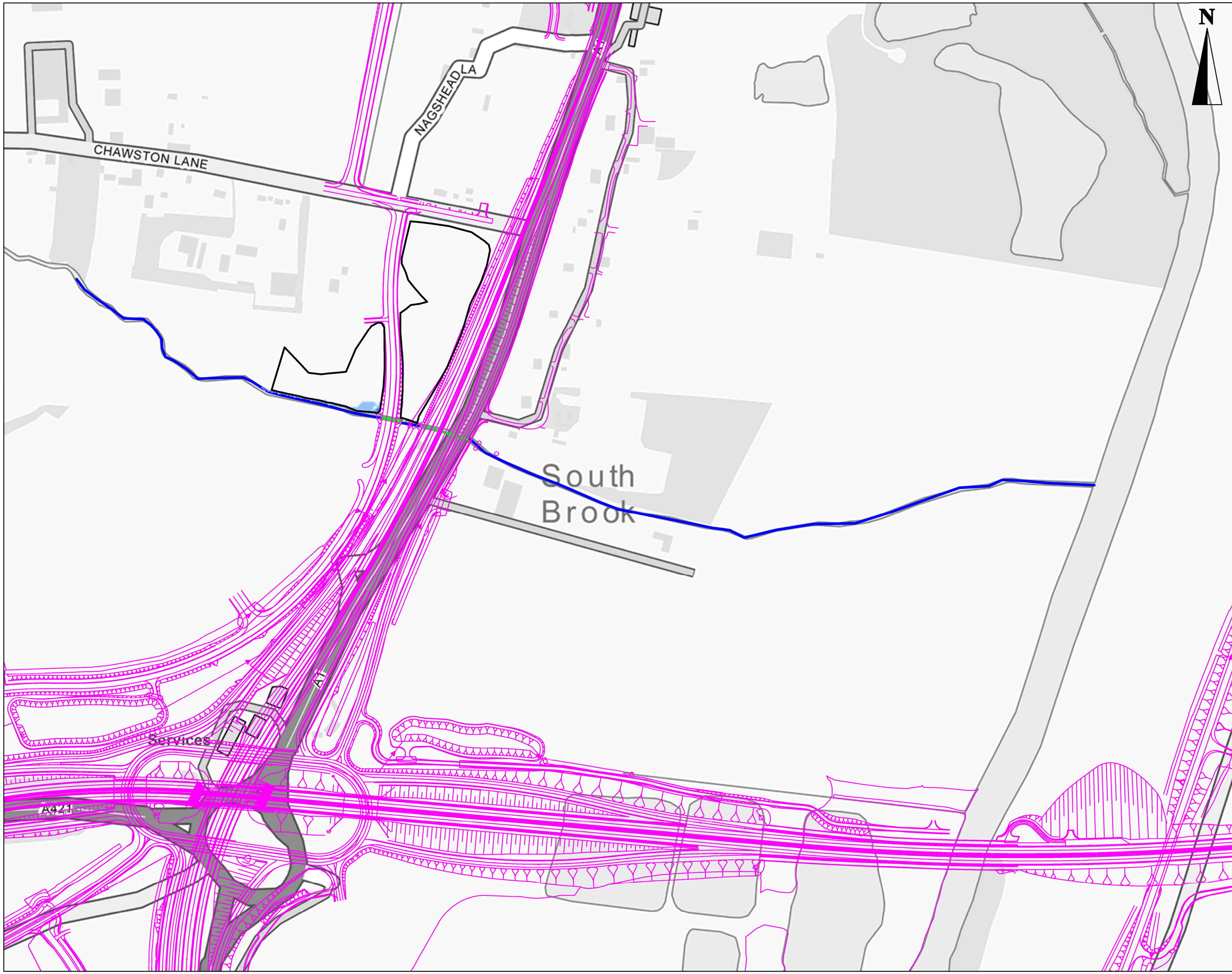
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

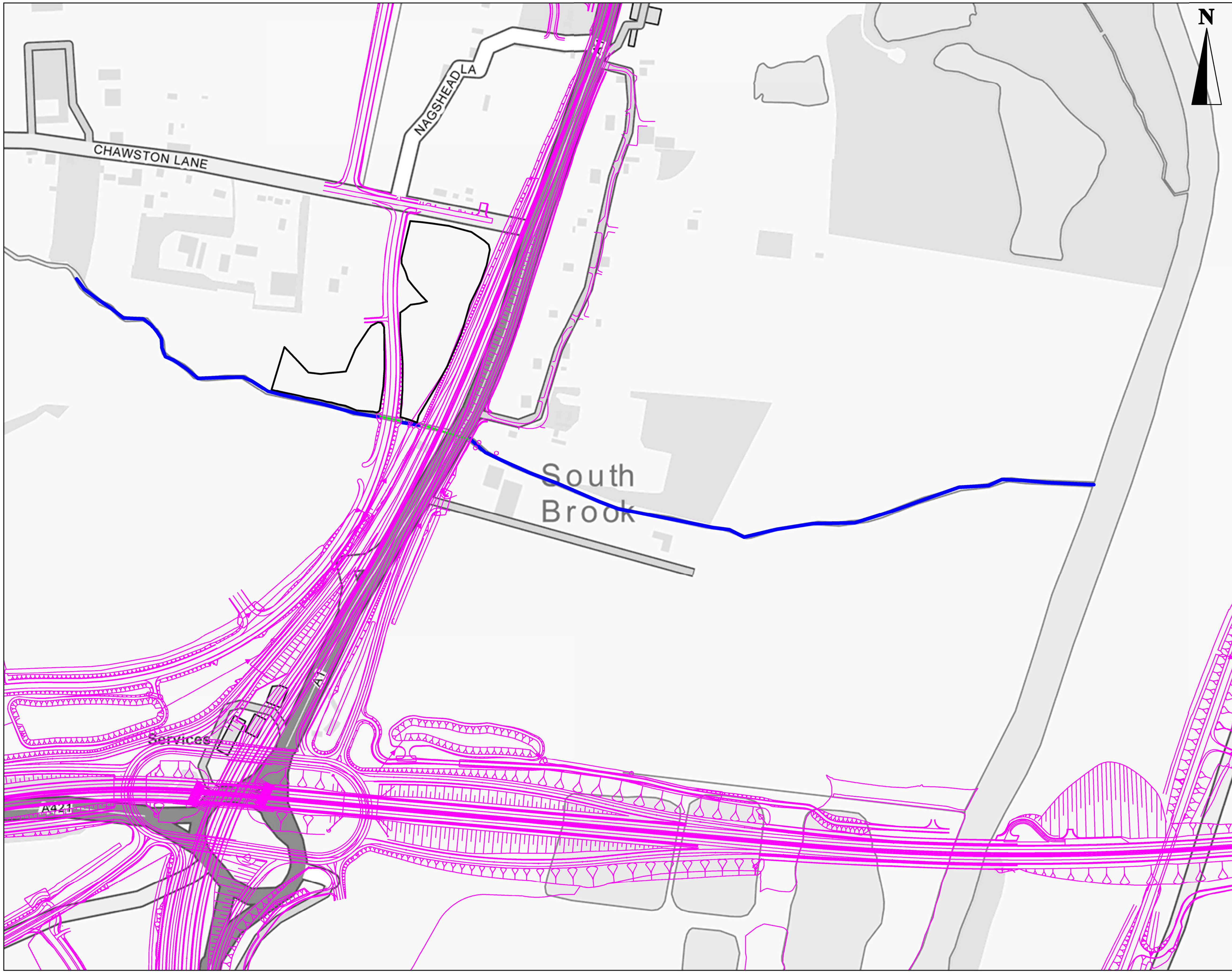
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

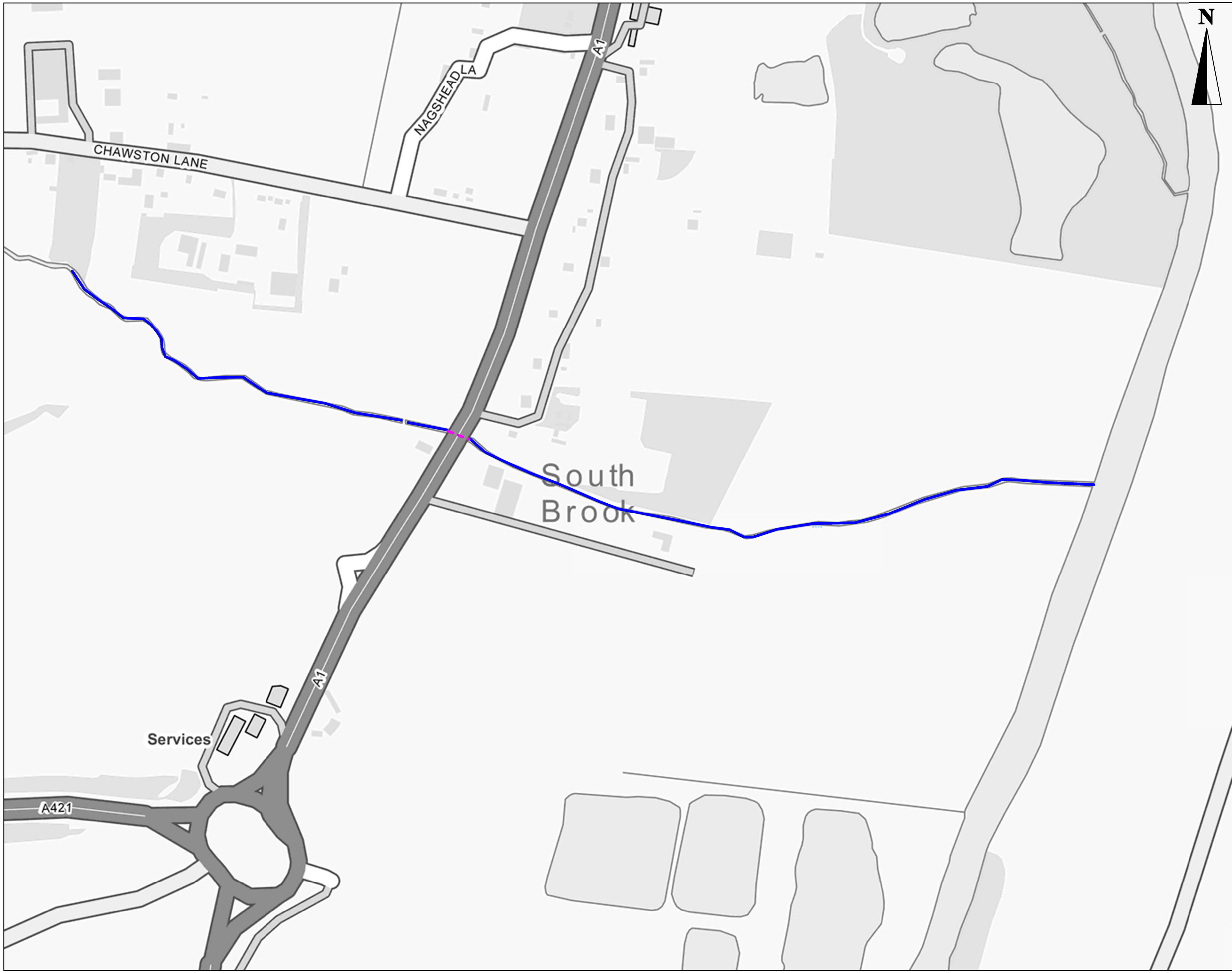
Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
5% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

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Purpose of Issue
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Client
Highways England
Woodlands
Manton Lane
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highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

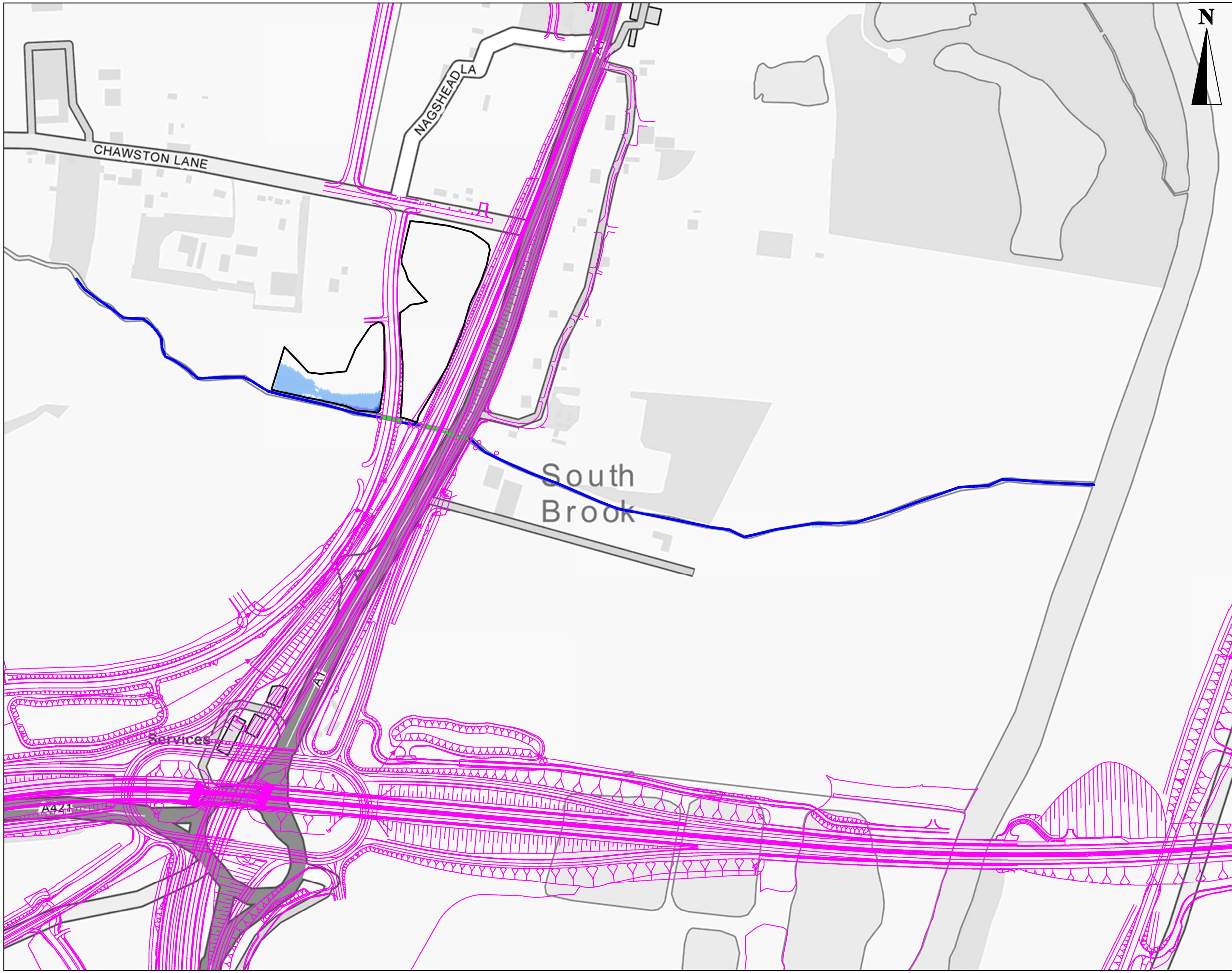
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

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Purpose of Issue
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Manton Industrial Estate
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Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

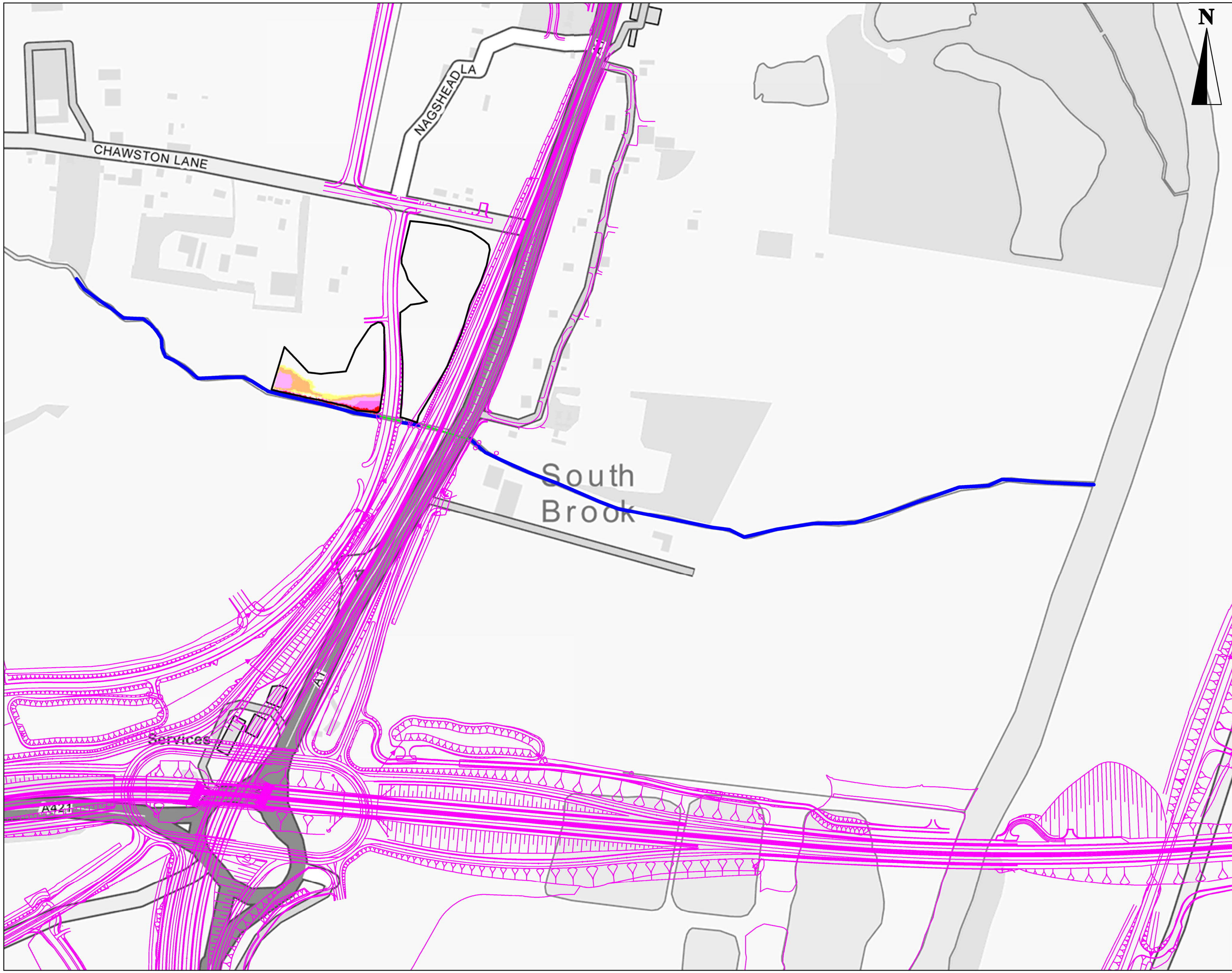
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

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Purpose of Issue
FOR INFORMATION

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Woodlands
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highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

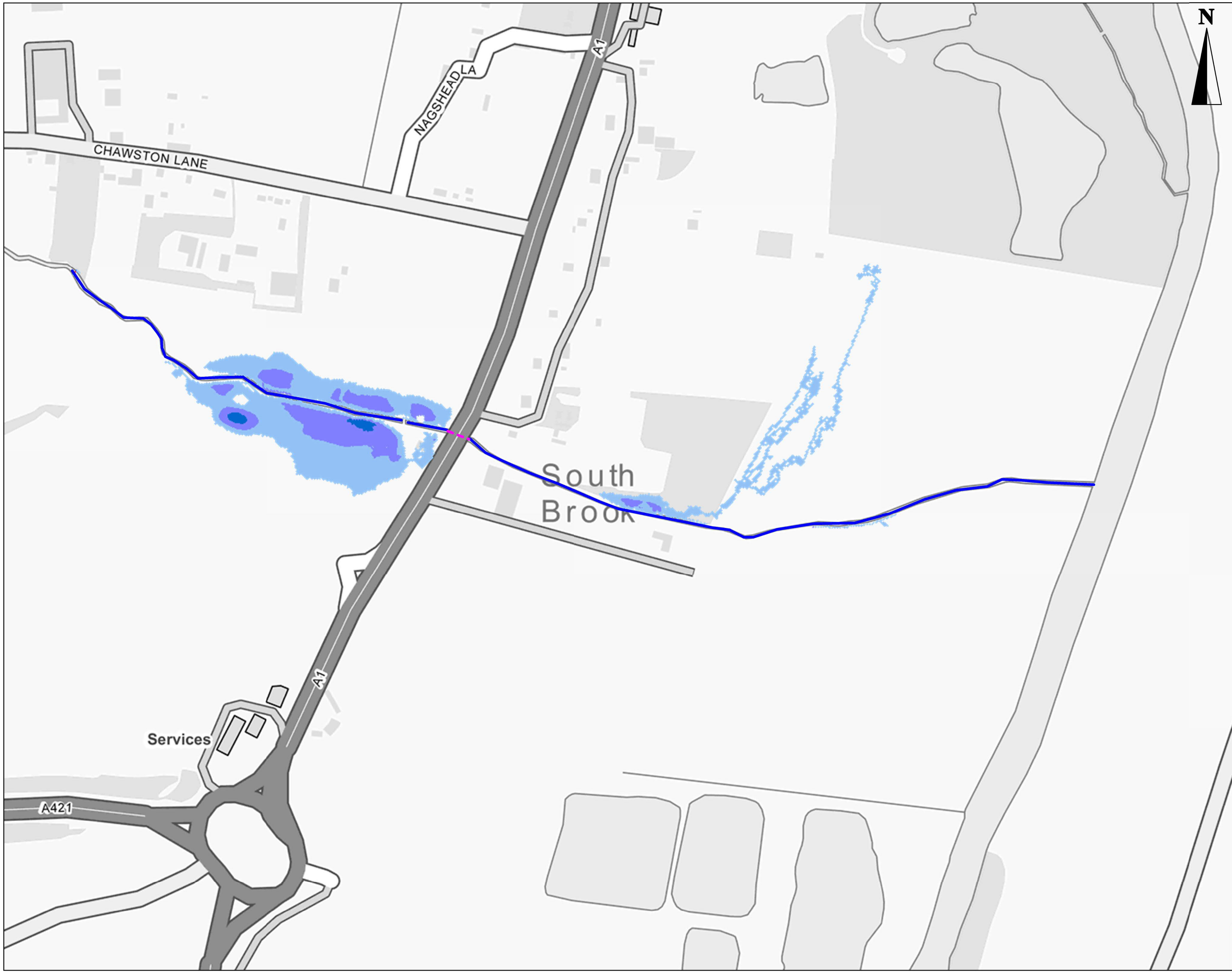
Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE			
Revision Details			

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

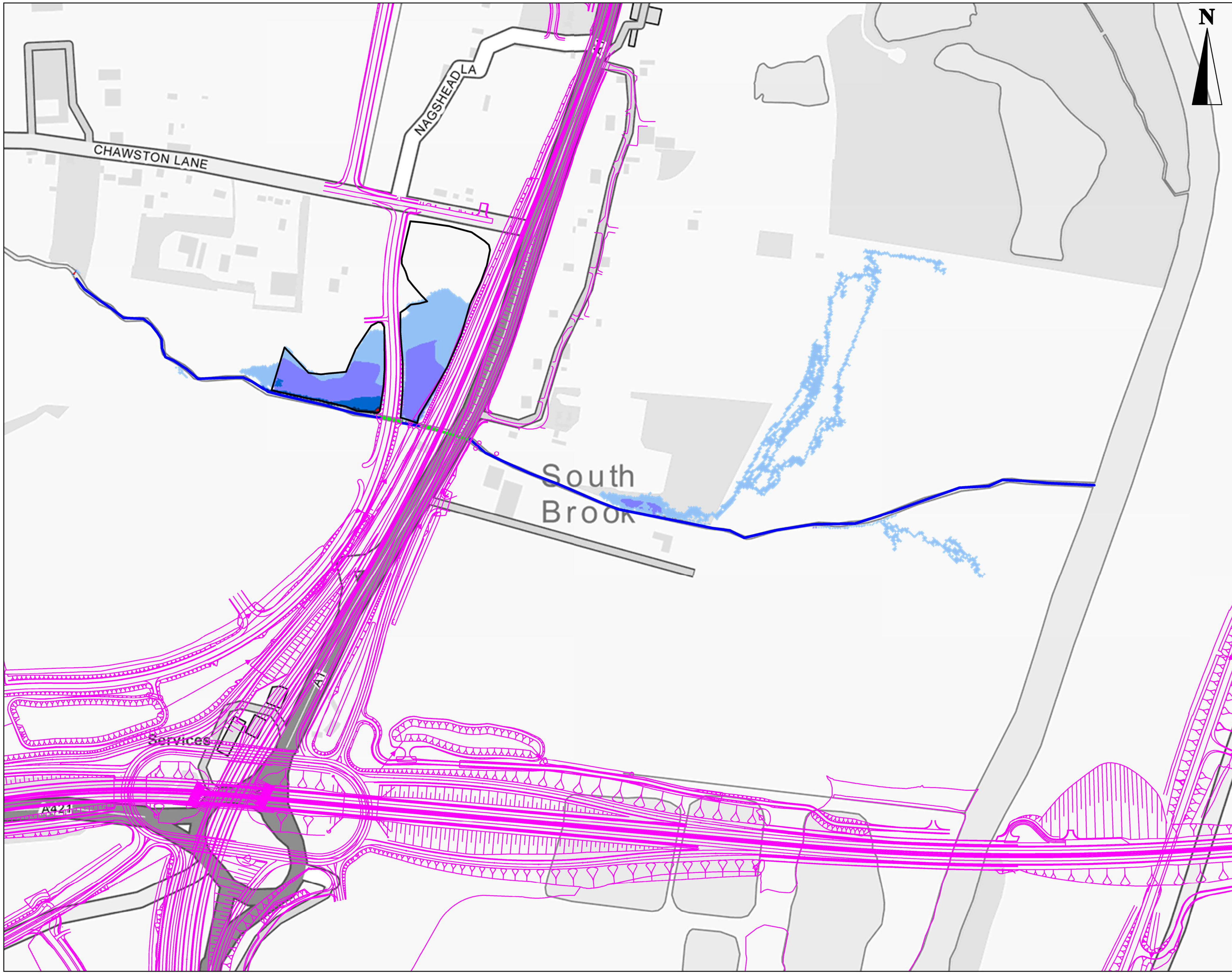
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
1% AEP + 35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

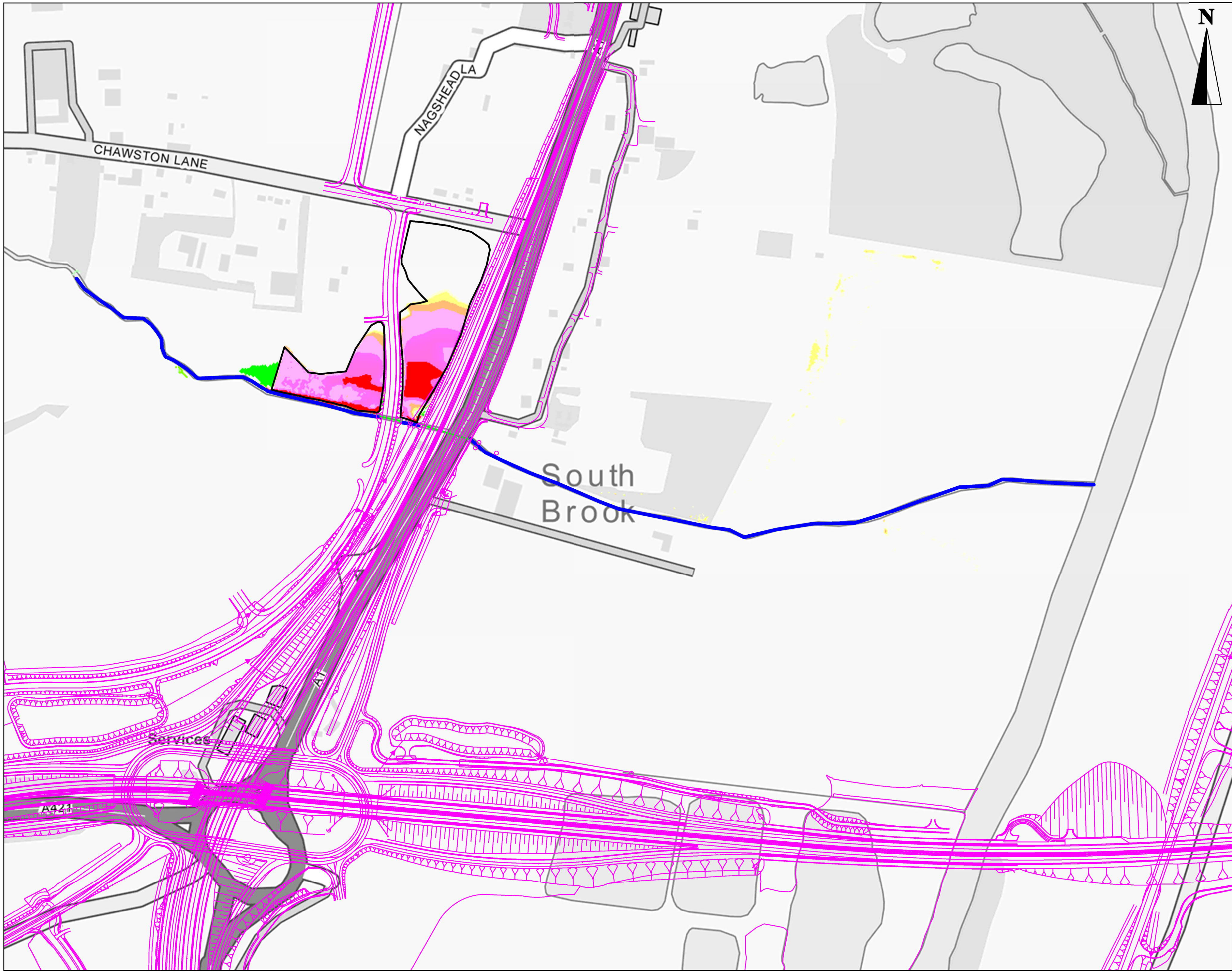
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
1% AEP + 35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

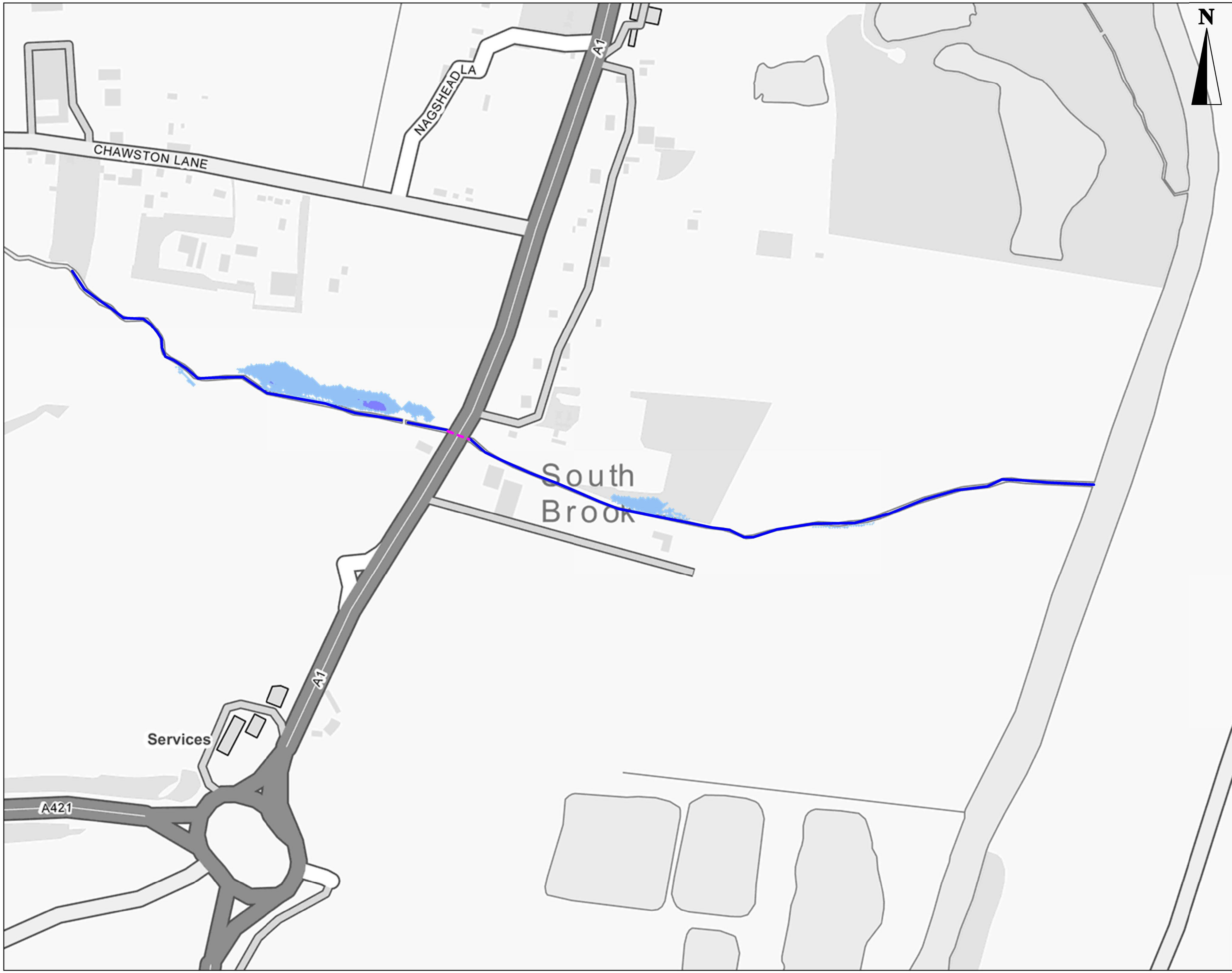
Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
1% AEP + 35% CLIMATE CHANGE

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

Existing Channel

Culvert

Flood Depth (m)

0.00m - 0.25m

0.25m - 0.50m

0.50m - 0.75m

0.75m - 1.00m

>1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

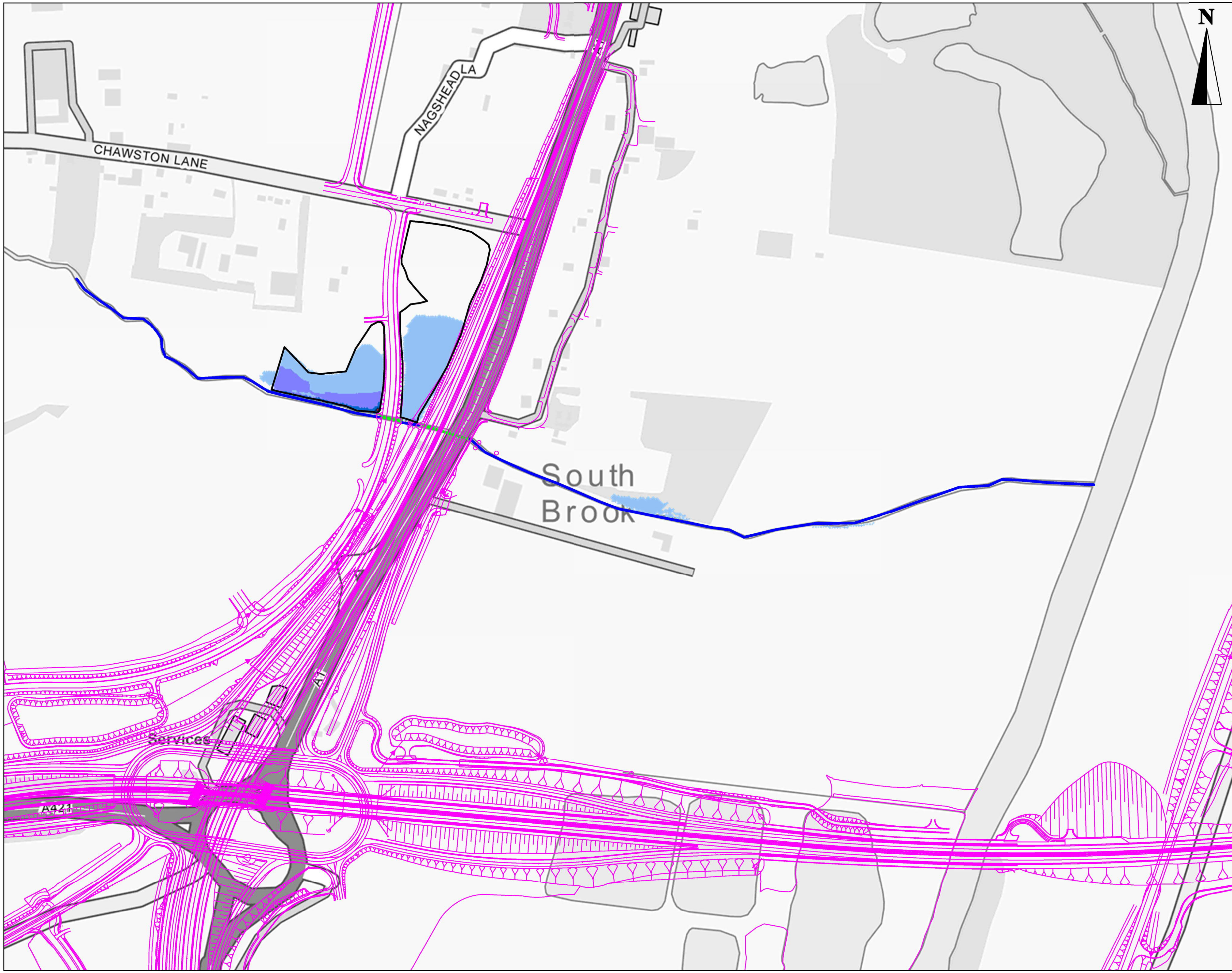
Drawing Title
BASELINE
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Flood Depth (m)

- 0.00m - 0.25m
- 0.25m - 0.50m
- 0.50m - 0.75m
- 0.75m - 1.00m
- >1.00m

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

highways england

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

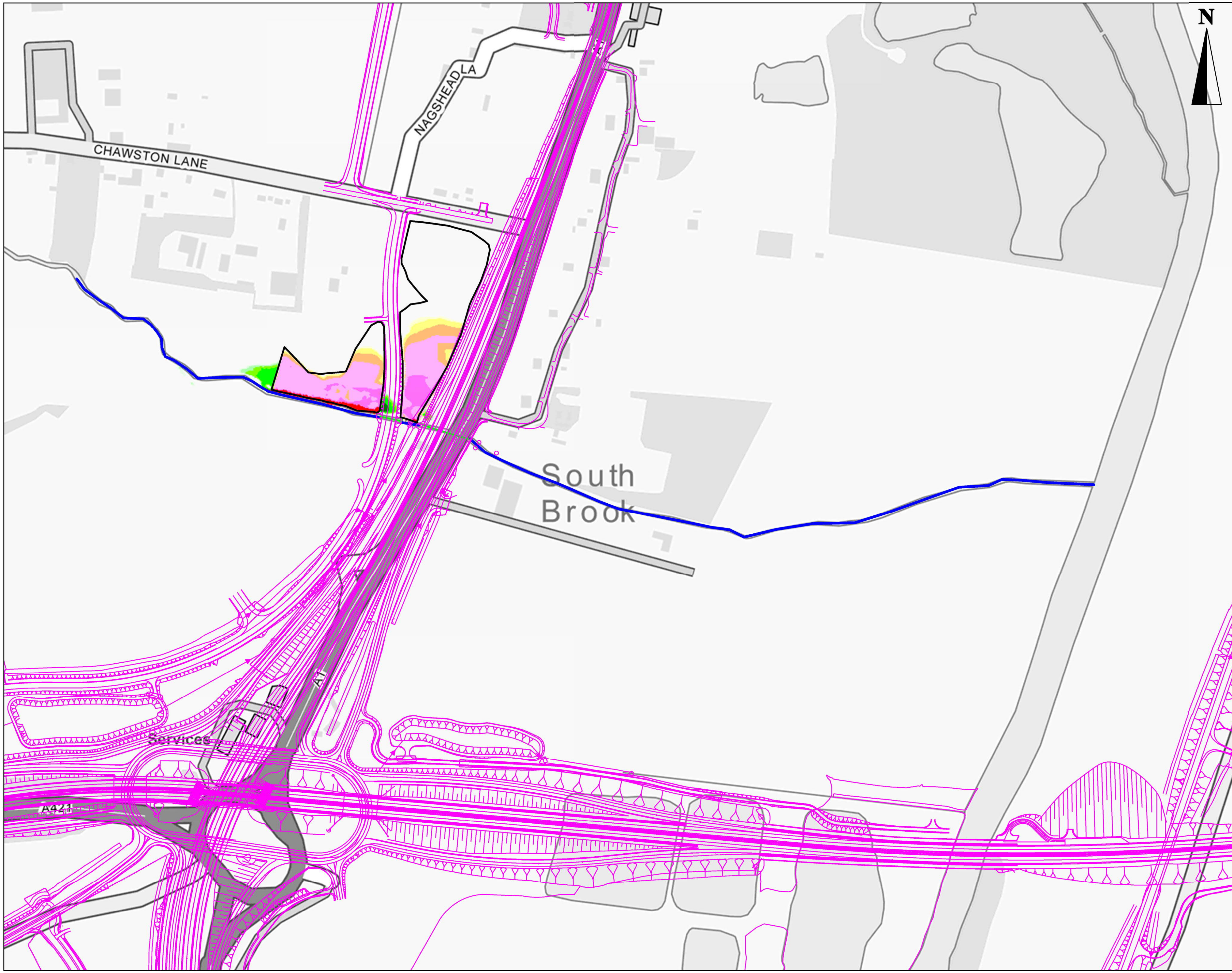
Drawing Title
PROPOSED
MAXIMUM FLOOD DEPTH MAP
0.1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No.	Suitability
60541541	S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01



NOTES

SOUTH BROOK
ORDINARY WATERCOURSE

LEGEND

- Existing Channel
- Proposed Channel
- Existing Culvert
- Proposed Culvert
- Proposed Scheme
- Floodplain Compensation Area

Water Level Difference (mm)

- >+300
- >+200 to <+300
- >+100 to <+200
- >+50 to <+100
- >+20 to <+50
- >+10 to <+20
- >-10 to <-20
- >-20 to <-50
- >-50 to <-100
- >-100 to <-200
- >-200 to <-300
- >-300

FIRST ISSUE

Revision Details

Purpose of Issue
FOR INFORMATION

Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW

Development Consent Order Number
TR010044

Project Title
A428 BLACK CAT
TO CAXTON GIBBET
ORDINARY WATERCOURSES
HYDRAULIC MODELLING REPORT

Drawing Title
DEPTH DIFFERENCE MAP
BASELINE VS PROPOSED
0.1% AEP

Designed	Drawn	Checked	Approved	Date
SB	SB	SB	MD	MAY 20

Internal Project No. 60541541	Suitability S2
Scale @ A3 1:4000	Zone General

Drawing Number
Highways England PIN | Originator | Volume
HE551495 -ACM -GEN-
GEN_Z_Z_ZZ -DR -HF
Location | Type | Role | Number

Rev
P01

Appendix D – Floodplain Compensation

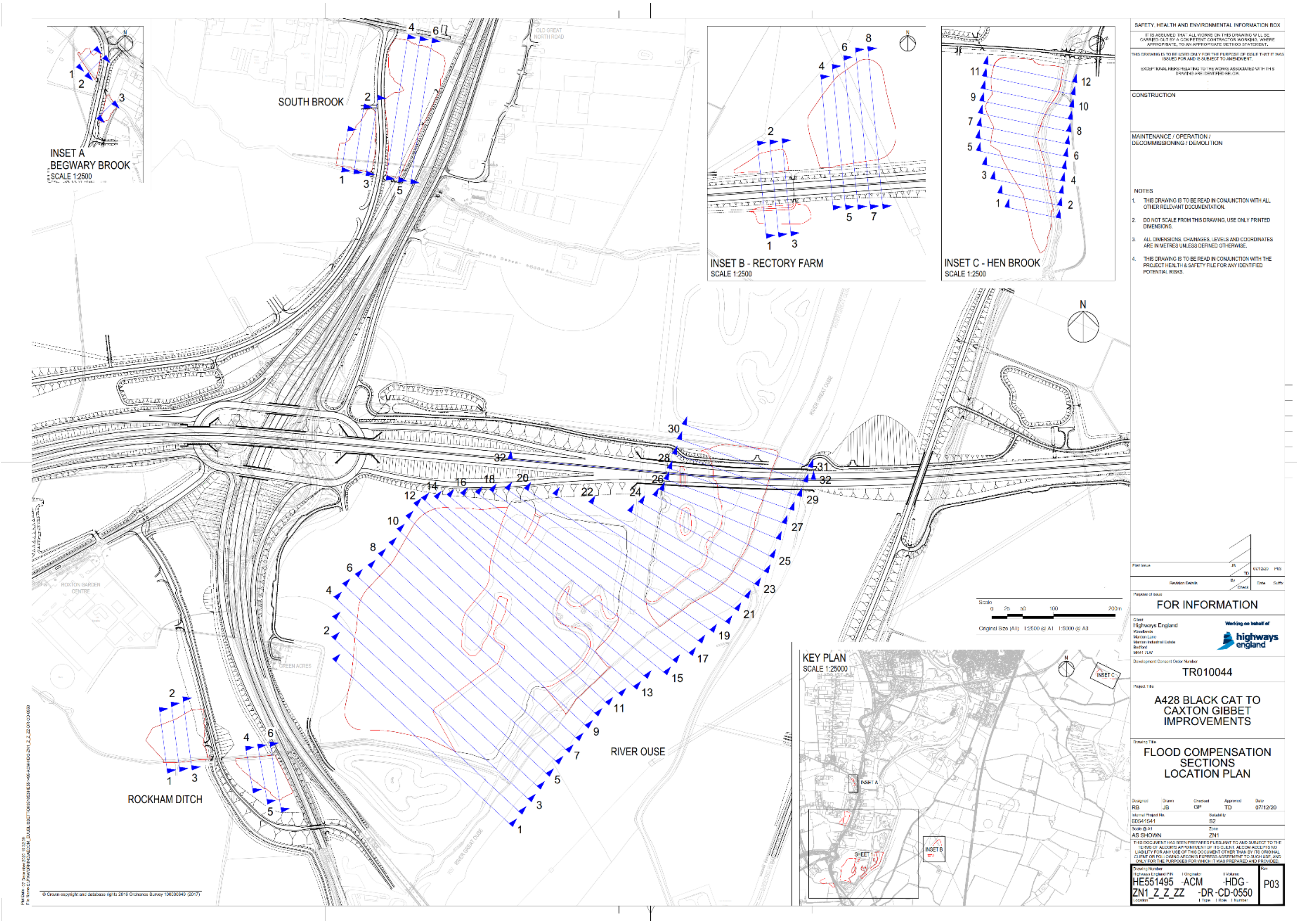


Figure A-1: Location of Floodplain Compensation

Appendix D1 – Begwary Brook and Rockham Ditch Floodplain Compensation

Table D1-13-1: Begwary Brook Flood Level (1% AEP + 35% Climate Change)

Watercourse	Flood Level (mAOD)
	1% AEP + 35% CC
Begwary Brook	17.40

Table D1-13-2: Begwary Brook Floodplain Volume Losses and Gains (1% AEP + 35% Climate Change)

Begwary Brook			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Loss	Gain
FL	17.20	50	75

** All volumes are approximated by a multiple of 100m^3 for volumes of at least 100m^3 and by a multiple of 25m^3 for volumes lower than 100m^3*

Table D1-13-3: Rockham Ditch Flood Level (1% AEP + 35% Climate Change)

Watercourse	Flood Level (mAOD)
	1% AEP + 35% CC
Rockham Ditch	18.20

Table D1-13-4: Rockham Ditch Floodplain Volume Losses and Gains (1% AEP + 35% Climate Change)

Rockham Ditch			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Loss	Gain
FL	18.00	100	200

** All volumes are approximated by a multiple of 100m^3 for volumes of at least 100m^3 and by a multiple of 25m^3 for volumes lower than 100m^3*

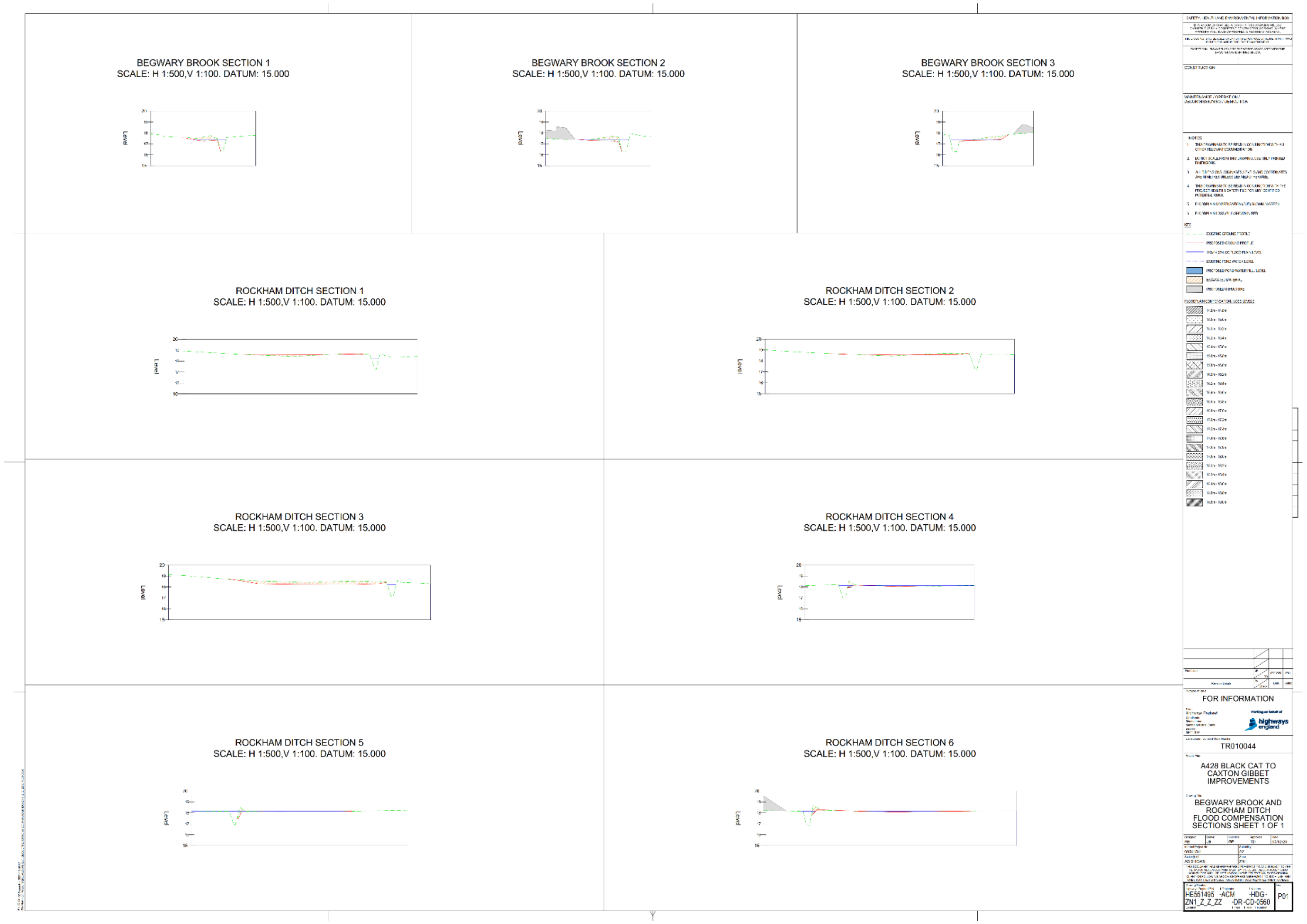


Figure D1-1: Begwary Brook and Rockham Ditch Floodplain Compensation Cross-Sections

Appendix D2 – Hen Brook Floodplain Compensation

Table D2-1: Hen Brook Flood Level (1% AEP + 35% Climate Change)

Watercourse	Flood Level (mAOD)
	1% AEP + 35% CC
Hen Brook	18.87

Table D2-2: Hen Brook Floodplain Volume Losses and Gains (1% AEP + 35% Climate Change)

Hen Brook			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Loss	Gain
FL	18.80	600	1600
18.80	18.60	1300	3200
18.60	18.40	500	3300
18.40	18.20	100	1600
Total		2500	9700

** All volumes are approximated by a multiple of 100m^3 for volumes of at least 100m^3 and by a multiple of 25m^3 for volumes lower than 100m^3*

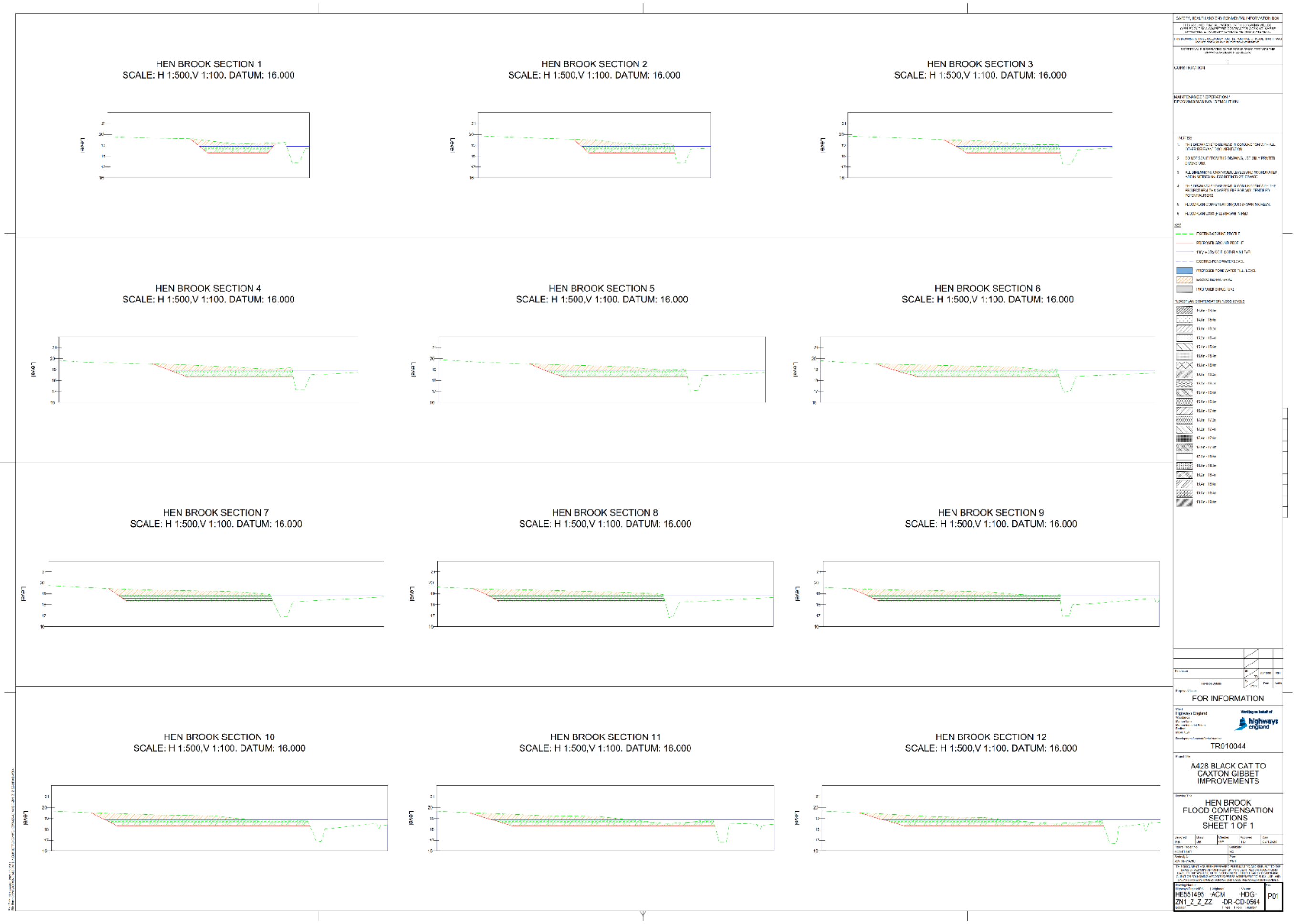


Figure D2-1: Hen Brook Floodplain Compensation Cross-Sections

Appendix D3 – Rectory Farm Brook Floodplain Compensation

Table D3-1: Rectory Farm Brook Flood Level (1% AEP + 35% Climate Change)

Watercourse	Flood Level (mAOD)
	1% AEP + 35% CC
Rectory Farm Brook	18.09

Table D3-2: Rectory Farm Brook Floodplain Volume Losses and Gains (1% AEP + 35% Climate Change)

Rectory Farm Brook			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Loss	Gain
FL	18.00	1000	1500
18.00	17.80	1900	2800
17.80	17.60	1400	1700
17.60	17.40	600	700
Total		4900	6700

** All volumes are approximated by a multiple of 100m^3 for volumes of at least 100m^3 and by a multiple of 25m^3 for volumes lower than 100m^3*

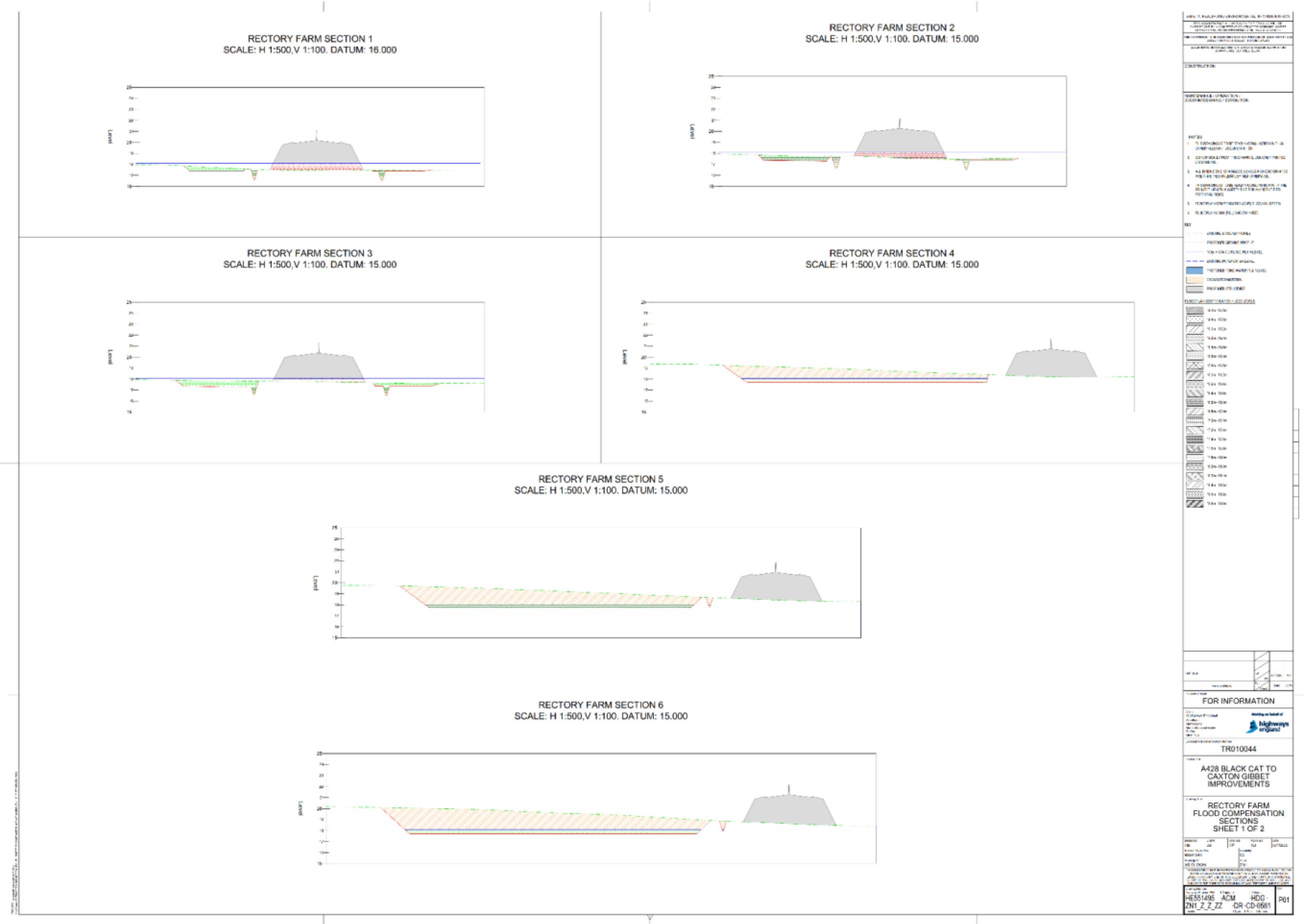


Figure D3-1: Rectory Brook Floodplain Compensation Cross-Sections (Sheet 1 of 2)

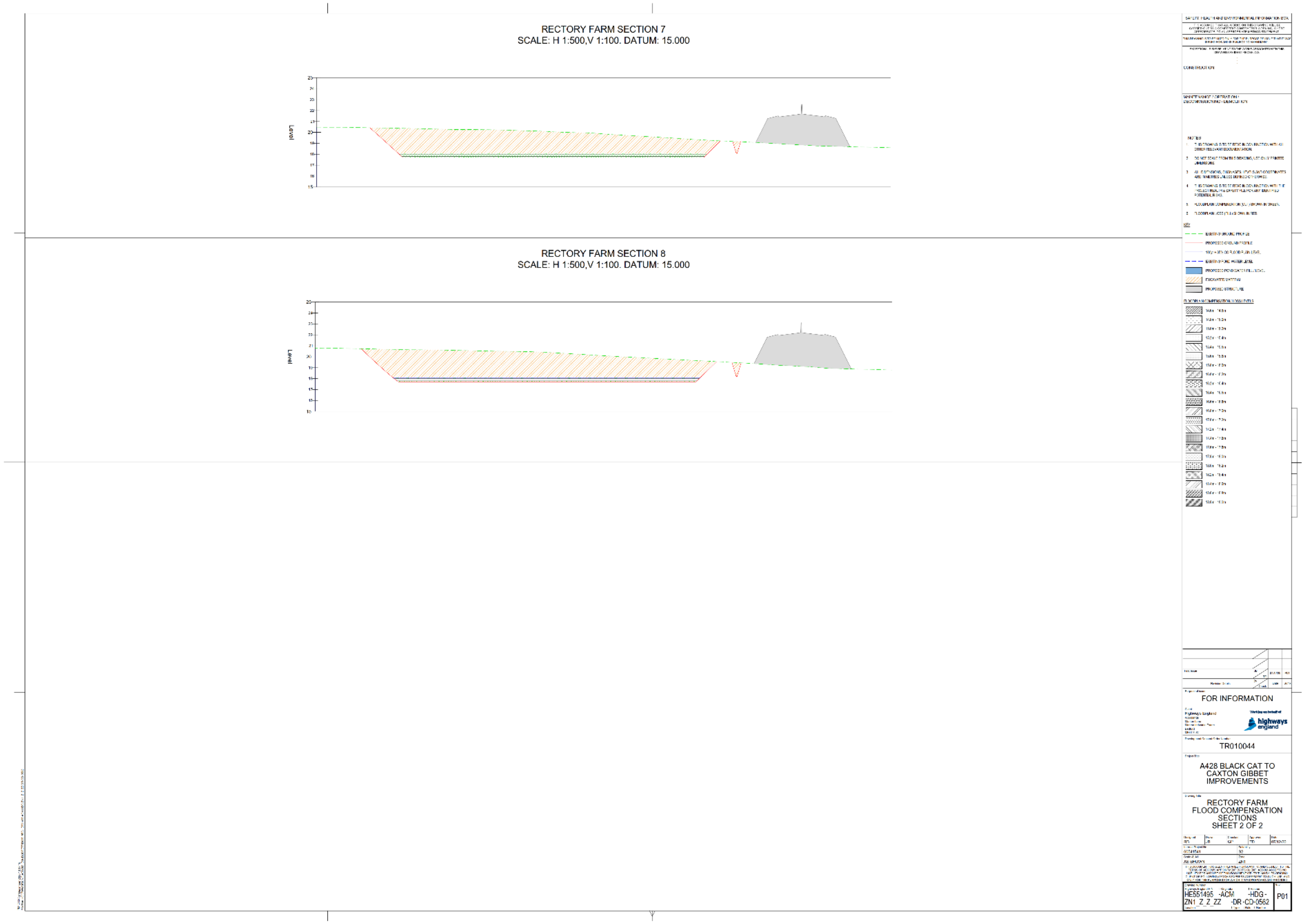


Figure D3-2: Rectory Brook Floodplain Compensation Cross-Sections (Sheet 2 of 2)

Appendix D4 – South Brook Floodplain Compensation

Table D4-1: South Brook Flood Level (1% AEP + 35% Climate Change)

Watercourse	Flood Level (mAOD)
	1% AEP + 35% CC
South Brook	18.53

Table D4-2: South Brook Floodplain Volume Losses and Gains (1% AEP + 35% Climate Change)

South Brook			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Loss	Gain
FL	18.40	900	1100
18.40	18.20	700	800
18.20	18.00	100	300
Total		1700	2200

** All volumes are approximated by a multiple of 100m^3 for volumes of at least 100m^3 and by a multiple of 25m^3 for volumes lower than 100m^3*

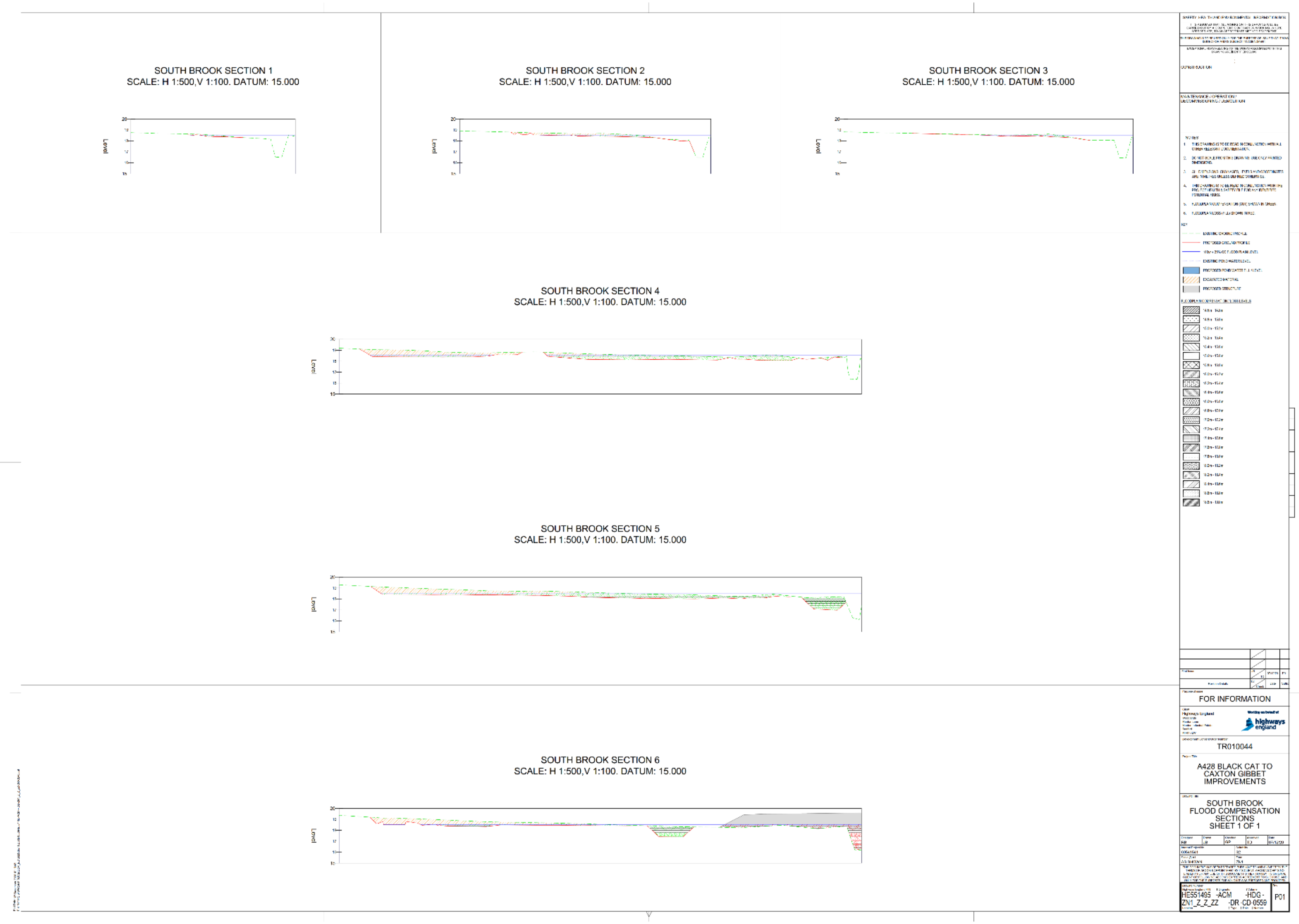


Figure D4-1: South Brook Floodplain Compensation Cross-Sections