A428 Black Cat to Caxton Gibbet improvements

TR010044

Volume 6

6.3 Environmental Statement

Appendix 13.4 Flood Risk Assessment

Annex A: River Great Ouse Hydraulic 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

Development Consent Order 202[ ]

Appendix 13.4 Flood Risk Assessment
Annex A: River Great Ouse Hydraulic Modelling Report

Regulation Reference:	Regulation 5(2)(e)
Planning Inspectorate Scheme Reference	TR010044
Application Document Reference	TR010044/APP/6.3
Author	A428 Black Cat to Caxton Gibbet improvements Project Team, Highways England

Version	Date	Status of Version
Rev 1	26 February 2021	DCO Application

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1 Introduction

1.1 Background

1.1.1 In order to robustly assess the impact of the proposed A428 Black Cat to Caxton Gibbet improvements Scheme (the Scheme) on flood risk for the River Great Ouse, hydraulic modelling for this watercourse was undertaken. This Hydraulic Modelling Report has been produced in order to document the technical work undertaken in support of the Scheme Flood Risk Assessment (FRA).

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

1.1.3 The assessment documented within this report has utilised an existing Environment Agency hydraulic model for the River Great Ouse. The hydraulic model was supplied to AECOM in July 2017. Through consultation with the Environment Agency it was determined that the supplied hydraulic model was a strategic scale model with known limitations. It was agreed with the Environment Agency that the received model would be truncated and localised improvements made to the model setup, in order to facilitate a robust assessment of the A428 Scheme.

1.1.4 Further consultation with the Environment Agency has been undertaken throughout the development of the baseline and proposed hydraulic models to improve the suitability of the hydraulic model for this assessment.

1.2 Objectives

1.2.1 In order to provide an appropriate assessment of flood risk from the River Great Ouse in the context of the proposed development, the following primary objectives have been completed;

a. To assess fluvial flood risk as part of the existing (baseline) scenario for the River Great Ouse.

b. To assess fluvial flood risk to/from the proposed permanent development scenario for the River Great Ouse.

c. To assess fluvial flood risk to/from the proposed permanent plus temporary works development scenario during construction for the River Great Ouse.

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 River Great Ouse has been undertaken for the baseline, permanent proposed works for design events with the following Annual Exceedance Probabilities (AEPs); 5% AEP, 1.33% AEP, 1% AEP and 0.1% AEP.

1.3.2 In line with Environment Agency (EA) 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.

1.3.3 In order to consider the worst case, sensitivity fluvial modelling for the River Great Ouse 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 for the baseline and Scheme scenarios.

1.3.4 It should be noted that design simulations for the proposed permanent plus temporary works scenario (Section 1.3, Objective 3) will not be undertaken including an allowance for climate change due to the short term nature of the construction programme.

1.4 Option development

1.4.1 The proposed permanent design outlined in this report is the culmination of an iterative process of design and hydraulic modelling to develop a robust Scheme that meets the requirements of the National Planning Policy Framework[1] and Development Consent Order (DCO). **Table 1-1** shows a timeline of the hydraulic model development and key milestones and consultations within the project.

Table 1-1: Hydraulic Model Development Timeline

Date	Milestone/Consultation
August - September 2017	AECOM Modelling Approach Technical Note and Environment Agency comments and feedback
November 2017	CH2M peer review of baseline hydraulic model
November 2017 – July 2019	AECOM development of baseline hydraulic model and options testing for Scheme
July 2019	AECOM Model and Hydraulic Modelling Technical Note submitted to the Environment Agency which included the assessment of four proposed options.

[1] HM Government (2019) Revised National Planning Policy Framework
[2] Environment Agency (2016) Adapting to Climate Change: Advice for Flood and Coastal Management Authorities.

Date	Milestone/Consultation
September 2019 and February 2020	Environment Agency feedback on AECOM baseline and options modelling, culminating in a meeting 25/02/20.
March 2020	AECOM submit Technical Briefing Note addressing Environment Agency comments on hydraulic model and options development
May 2020	AECOM submission of River Great Ouse Hydraulic Modelling Report to the Environment Agency (this report P01)
July 2020	AECOM submission of revised River Great Ouse Hydraulic Modelling Technical Note Report (P03) detailing previous options development to the Environment Agency
July 2020	Environment Agency feedback on River Great Ouse Hydraulic Modelling Report (P01) culminating in revision of report
December 2020	AECOM complete final version of River Great Ouse Hydraulic Modelling Report (this report P02)

1.4.2 The technical note submitted to the Environment Agency in July 2020[3] provided an assessment of four shortlisted configurations of a Scheme developed during this project. This report provides additional detail to the hydraulic model set up, options development and hydraulic modelling results previously submitted to the Environment Agency in the July 2019[4] technical note. To retain clarity and brevity, this report contains modelling results relating to the final Scheme configuration only. **Table 1-2** provides a brief description of the four shortlisted options and a summary of the outcomes.

[3] AECOM (2020) '*A428 Black Cat to Caxton Gibbet Improvements - River Great Ouse Hydraulic Modelling Technical Note'*
[4] AECOM (2019) '*A428 Black Cat to Caxton Gibbet Improvements Annex A - River Great Ouse Hydraulic Modelling Technical Note'*

Table 1-2: Summary of Shortlisted Proposed Options

Option	Description	Key Outcomes
Option 1[5]	Proposed embankment up to 2050m chainage and viaduct across River Great Ouse (approx. 125m span) with no abutments in the river itself.	Increased flood depths greater than 3km upstream of the Scheme. No flood risk benefits downstream of the Scheme
Option 2[6]	As per Option 1 with the inclusion of flood relief culverts through the proposed embankment.	Increased flood depths greater than 3km upstream of the Scheme but less detrimental impact than Option 1. No flood risk benefits downstream of the Scheme
Option 3[7]	Proposed embankment up to 1960m chainage and viaduct across floodplain and River Great Ouse (approx. 525m span). Proposed culverts through embankment as per Option 2.	Similar to Option 2
Option 4[8]	Proposed embankment up to 1920m chainage and viaduct across floodplain and River Great Ouse (approx. 565m span) with no culverts through embankment and floodplain compensation storage upstream of the Scheme.	Localised increase in flood depths upstream of the Scheme. No change downstream of the Scheme. Option developed further and described in this report

1.4.3 The embankment of the A428 across the floodplain (Option 1) was found to increase flood depths for a distance greater than 3km upstream of the proposed River Great Ouse viaduct whilst providing no flood risk benefits downstream. The detrimental effect upstream was found to be primarily attributable to the impoundment of large volume of floodplain flow through the area of interest. Option 1 was therefore not considered feasible because it did not fulfil the requirements of NPPF and showed no flood risk benefits downstream of the Scheme.

[5] AECOM (2020) Figure 3-1 '*A428 Black Cat to Caxton Gibbet Improvements - River Great Ouse Hydraulic Modelling Technical Note'*
[6] AECOM (2020) Figure 3-3 '*A428 Black Cat to Caxton Gibbet Improvements - River Great Ouse Hydraulic Modelling Technical Note'*
[7] AECOM (2020) Figure 3-5 '*A428 Black Cat to Caxton Gibbet Improvements - River Great Ouse Hydraulic Modelling Technical Note'*
[8] AECOM (2020) Figure 3-7 '*A428 Black Cat to Caxton Gibbet Improvements - River Great Ouse Hydraulic Modelling Technical Note'*

1.4.4 Options 2 and 3 were found to increase flood depths for a distance greater than 3km upstream of the Scheme and provided no flood risk benefits downstream of the Scheme. A further key constraint was that the construction of multiple flood relief culverts through the A428 embankment was considered impractical for the wider design team because of cost, constructability and health and safety concerns. Options 2 and 3 were therefore not considered further because they did not fulfil the requirements of NPPF, showed no benefits downstream of the Scheme and were unacceptable in the context of the wider project disciplines.

1.4.5 Option 4 was found to provide adequate floodplain compensation storage to not cause a significant increase in flood risk upstream or downstream of the proposed River Great Ouse viaduct during the 1% AEP + 35% climate change event. Option 4 forms the basis of the final Scheme design and has been developed further within this report as the proposed option.

1.5 Report Structure

1.5.1 Section 2 of this report details the hydraulic modelling methodology utilised to assess the A428 Scheme. This section begins with a summary of the existing Environment Agency strategic scale model, along with its key limitations. This is followed by a documentation of the key aspects of the localised model setup, including the updates undertaken from the strategic scale model.

1.5.2 Section 3 of this report outlines the baseline, sensitivity, permanent and permanent plus temporary works hydraulic model results.

1.5.3 A statement of the limitations associated with the fluvial hydraulic modelling work undertaken is included within Section 4.

1.5.4 Conclusions based upon the fluvial hydraulic modelling work undertaken are outlined in Section 5.

2 Hydraulic Modelling Methodology

2.1 Existing River Great Ouse Model

2.1.1 The 2015 Lower Ouse Flood Modeller Pro-TUFLOW hydraulic model was commissioned by the Environment Agency to produce strategic scale flood mapping for the River Great Ouse in East Anglia from Great Barford to Stretham (**Figure 2-1**). AECOM undertook an initial model review to understand the suitability of using the hydraulic model for this study.

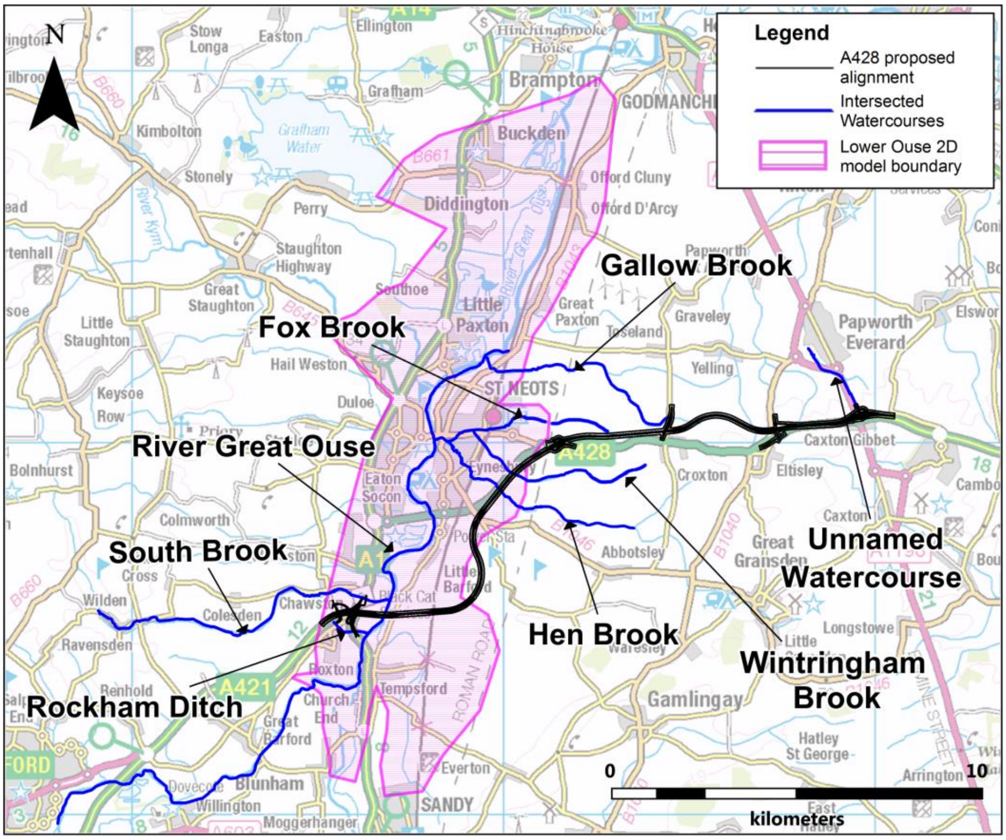


Figure 2-1: 2015 Lower Ouse Model Extent and Location of Proposed A428 Scheme

2.1.2 As a strategic scale model, a key limitation of the received model identified was the coarse representation of the floodplain using a 20m grid which would not provide sufficient resolution to assess the flood risk to and from the Scheme. Furthermore, the topography of the floodplain within the area of interest has altered since the 2015 Lower Ouse model was constructed and therefore required updating.

2.1.3 The hydrological inflows within the 2015 Lower Ouse model are represented using a simplified methodology where only the largest watercourses such as River Ivel are represented as direct inflows. Smaller watercourses that are located within the area of the Scheme such as Rockham Ditch and South Brook are not explicitly modelled, rather forming part of the intervening catchment represented using lateral inflows. This means that the floodplain interaction between the River Great Ouse and tributaries is simplified within the hydraulic model. It is noted that the combined inflows from the tributaries through the area of interest are small compared to the overall flow within the River Great Ouse to this point. Through consultation with the Environment Agency during this study this setup is considered appropriate for assessment of the A428 Scheme crossing on the River Great Ouse.

2.2 Modelling approach

2.2.1 Following the initial review of models received from the Environment Agency and follow up Environment Agency consultation/technical reviews on 15/08/2017, 09/2020 and 25/02/2020, the following approach was agreed with the Environment Agency in adopting the 2015 Lower Ouse model as the 'Baseline' model to assess the risk of flooding to and from the Scheme:

2.2.2 The model has been trimmed just north of the urban area of St Neots in order to improve model performance and focus on the area of interest (Figure 2-2). A normal depth boundary based upon the watercourse gradient has been used as the downstream model limit (Section 2.8);

2.2.3 The hydrological inflows have not been changed from the received model except to reduce the intervening catchment lateral inflows to the revised model limits (Section 2.3);

2.2.4 An additional 10m resolution grid has been nested into the model at the River Great Ouse viaduct location to improve representation of the floodplain (Figure 2-2 – 'Nested Grid');

2.2.5 The LiDAR DTM has been updated with the latest available data to better represent the floodplain topography (Section 2.6);

2.2.6 The proposed Caxton Quarry Restoration ground elevations and water levels have been added to improve the expected topography in and around the proposed River Great Ouse viaduct (Section 2.6) as supplied to A428 modellers;

2.2.7 Three additional river cross sections have been surveyed at the proposed River Great Ouse viaduct location and built into the 1D network (Section 2.5). No further changes were made to the 1D channel network representation.

2.2.8 Details of the changes to the received 2015 Lower Ouse model are highlighted within Sections 2.3 to 2.14.

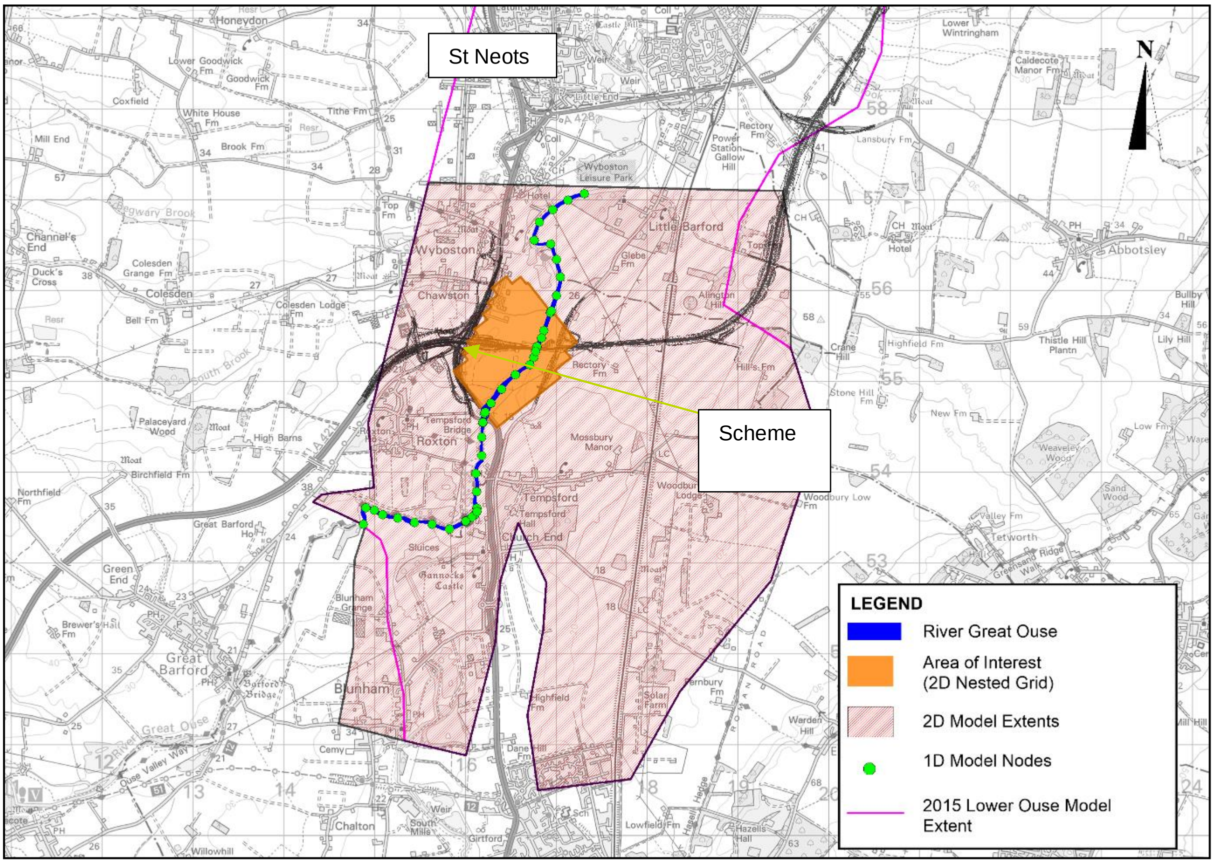


Figure 2-2: Model Extents

2.3 Hydrological analysis

2.3.1 The hydrological analysis undertaken within the 2015 Lower Ouse model is considered to be consistent with current best practice and following the initial review of the hydraulic model and consultation with the Environment Agency on 15/08/17 has been deemed appropriate to use in this study. The hydrological analysis therefore remains unchanged from the 2015 Lower Ouse model. Table 2-1 shows the three hydrological inflows present in the model.

Table 2-1: Hydraulic Model Inflows

Model Inflow	Hydrological Inflow	Adjustment
Roxton	QT Boundary	Great River Ouse US Inflow
IVEL	ReFH	River Ivel
GO_Kym	ReFH	Intervening catchment

2.3.2 A full assessment of the hydrological analysis can be found in the 2015 Lower Ouse model report[9]. Intervening catchment flows from the GO_Kym ReFH inflow have been adjusted to reflect the reduction in catchment size from the received model.

2.3.3 The hydraulic model study reach does not contain any gauging stations on the River Great Ouse. The nearest gauging station is the Bedford Ouse at Offord (NRFA Station 33026) located approximately 13.5km downstream of the study area. This gauge is considered to be a complex site and is not suitable for Hi-Flows data. Given the availability of hydrometric data, the location of the nearest gauge downstream of the study area and unreliable data from the gauge, it was agreed with the Environment Agency at a meeting on 25th February 2020 that calibration of the hydraulic model is not considered appropriate for this model.

2.4 Software

2.4.1 The 1D River Great Ouse channels have been represented in Flood Modeller Pro (FMP). FMP is a one-dimensional (1D) package used for modelling river channels, including bridges, culverts, weirs and other structures. FMP calculates the varying water levels within the channel and associated transference of flow to the floodplain when hydraulically linked to a 2D model (TUFLOW).

2.4.2 TUFLOW is a two-dimensional (2D) hydraulic modelling package that simulates hydrodynamic behaviour of flood waters across the land surface using a grid based approach.

2.4.3 Combining FMP and TUFLOW allows for full hydraulic linking between the channel and the floodplain allowing the water from the channel (1D) to enter the floodplain (2D) and vice versa.

2.4.4 All models were simulated using Flood Modeller Pro (FMP) version 4.5 and TUFLOW version 2018-03-AE.

2.5 1D Model- river channel

2.5.1 Following the initial review of the 2015 Lower Ouse model it was agreed with the Environment Agency that the River Great Ouse 1D model river channel representation was suitable to use in this study. The 1D model river channel representation has therefore primarily been maintained from the 2015 Lower Ouse model. Additional hard bed channel survey was procured to improve the channel representation at the location of the proposed River Great Ouse viaduct (Section 2.5.2). The downstream boundary was truncated to a location approximately 1.6km upstream of the urban area of St. Neots and replaced with a normal depth boundary (**Figure 2-2** and Section 2.9).

[9] Environment Agency (2015) '*Lower Great Ouse Flood Risk Mapping'*, Environment Agency, Brampton.

2.5.2 Prior to additional procured survey, the 1D channel frequency at the proposed River Great Ouse viaduct was 200m within the 2015 Lower Ouse model meaning that the hydraulic representation around the crossing was relatively coarse. Three additional river cross sections were therefore surveyed by AECOM in August 2017 to provide greater detail of the channel geometry and increase the 1D channel frequency around the proposed River Great Ouse viaduct. These sections (GRE44100x, GRE44050x and 43900x) were built into the 1D and 2D model domains (**Figure 2-3**) and increased the accuracy of localised results when building the post development Scheme into the model. All three additional survey sections procured for this study show a good correlation to the 2015 Lower Ouse model and therefore build confidence in the existing channel survey.

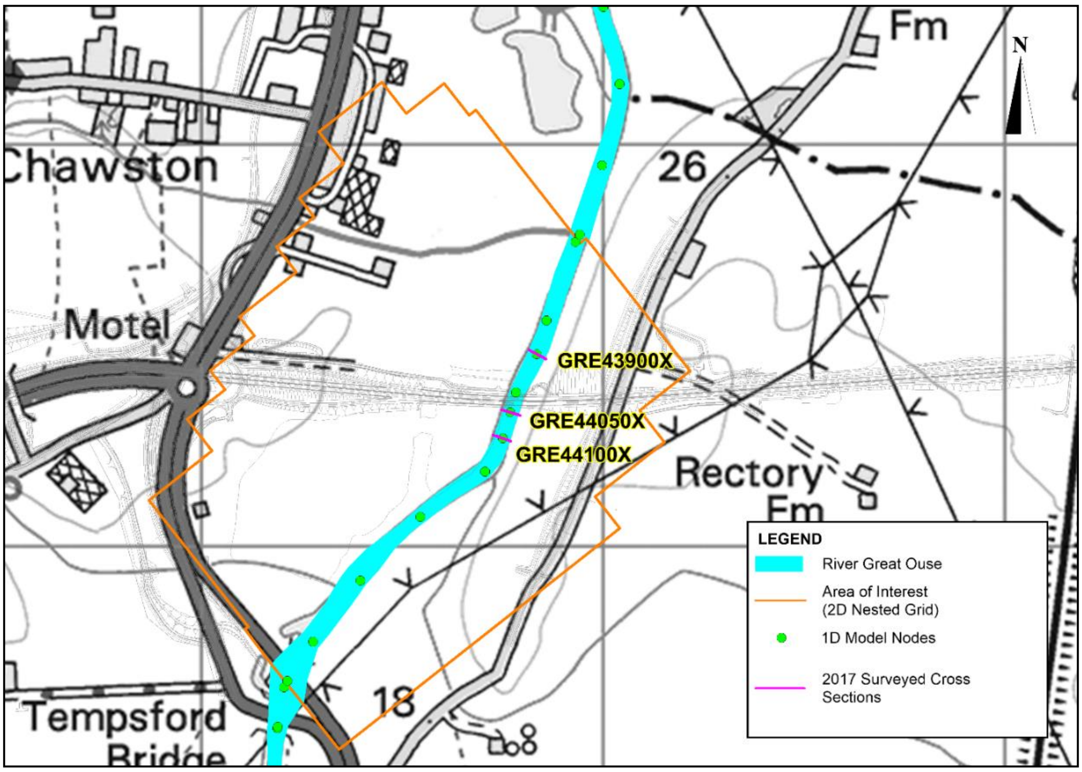


Figure 2-3: Additional Survey Sections

2.5.3 The 2015 Lower Ouse modelling model report[3] does not identify any structures that have been omitted from the watercourse reach in this study. A review of aerial photography shows that there is a footbridge\utilities crossing omitted from the hydraulic model at model node GRE45400. This is located 475m upstream of the study area and appears to be a single span crossing, approximately 2m in streamwise length. Given the size of the crossing and the distance located upstream of the study area it is not considered that this would affect the assessment of the Scheme.

2.6 2D Model- floodplain topography

2.6.1 The topographical data utilised within hydraulic models is a composite Digital Terrain Model (DTM) with a 2m grid resolution. The LiDAR DTM has been updated from the 2015 Lower Ouse model using data that was flown in 2017 to provide the most recent representation of the 2D domain. Figure 2-3 shows the LiDAR DTM through the area of interest.

2.6.2 The 2D TUFLOW model domain of the received 2015 Lower Ouse hydraulic model was represented using a 20m grid. To better represent the 2D flow mechanisms in the area of interest, a higher resolution 10m grid was nested into the model. This was schematised as an entirely nested separate domain within the larger model domain. Figure 2-2 shows the extent of the nested domain within the wider hydraulic model.

2.6.3 The Scheme intersects the Black Cat Quarry site. In 2016, the quarry was granted full planning permission for a restoration project to provide a naturalistic regraded landform, restore agricultural land, improve biodiversity and retain or improve local flood storage capacity. It is anticipated that by the time of construction the quarry restoration will have been completed and it was therefore agreed with the Environment Agency that the proposed quarry restoration should be included within the baseline and proposed model scenarios. Breedon Cement, the landowner, confirmed that the restoration works will be completed by the end of 2020[10] and recent aerial photography of the site shows that a significant amount of restoration works has been completed providing reassurance that the restoration will be completed before the construction of the proposed A428 Scheme.

2.6.4 The proposed quarry restoration elevation and winter water levels included within the hydraulic model have been digitised from the design that was granted planning permission found in Appendix A. Breedon Cement, confirmed that these proposed elevations have not changed[10]. Figure 2-4 shows the quarry restoration ground elevations as represented within the baseline hydraulic model compared to the 2m LiDAR DTM. It is noted that initial water level polygons were used to set the water level of the restored quarry ponds at the outset of the model simulation during the baseline scenario. The standing water level of the quarry ponds in the baseline model, as supplied to the A428 modellers to represent the quarry restoration planning submission level, is 15.5m AOD.

2.6.5 Following the update of the LiDAR DTM a consistency check was carried out between the surveyed channel sections and the LiDAR DTM by subtracting the LiDAR DTM elevations from the modelled bank elevations at each point along the watercourse. The surveyed bank was found to generally show a good agreement with the LiDAR DTM of +/-0.15m which is the standard uncertainty associated with LiDAR data. There are locations characterised by a lower level of agreement between the LiDAR DTM and modelled bank levels, however the accuracy of the LiDAR DTM is restricted by grid resolution and filtering to remove vegetation and other surface features. As the modelled bank lines are mainly drawn from

[10] Ardent 2019 Meeting Minutes GI and discussions on Breedon timescales HE551495-ARD-LLO-GEN_Z_Z_ZZ-MI-LR-0062

surveyed cross section points it is considered that these provide a more accurate representation of the bank levels within the model as opposed to LiDAR data.

2.6.6 **Table 2-2** provides an overview of the key topographic modifications made within the baseline model and the associated model files.

Table 2-2 – Topographic Modifications to Baseline Model

Model File	Topographic Modification
2d_zsh_quarry_restoration_002	Black Cat Quarry site restoration levels shown in Appendix A. This will be completed before the construction of the proposed A428 Scheme and therefore included
2d_zsh_smooth_01	Stability patch retained from 2015 modelling
2d_zsh_loopchannels_008	Amends the LiDAR DTM to provide an overland flow route beneath A1 upstream of the Scheme
2d_zln_bankheights_016	Specifies bank elevations for the River Great Ouse
2d_zln_Roads	Elevation of the roads
2d_zsh_railway	Elevation of the railway

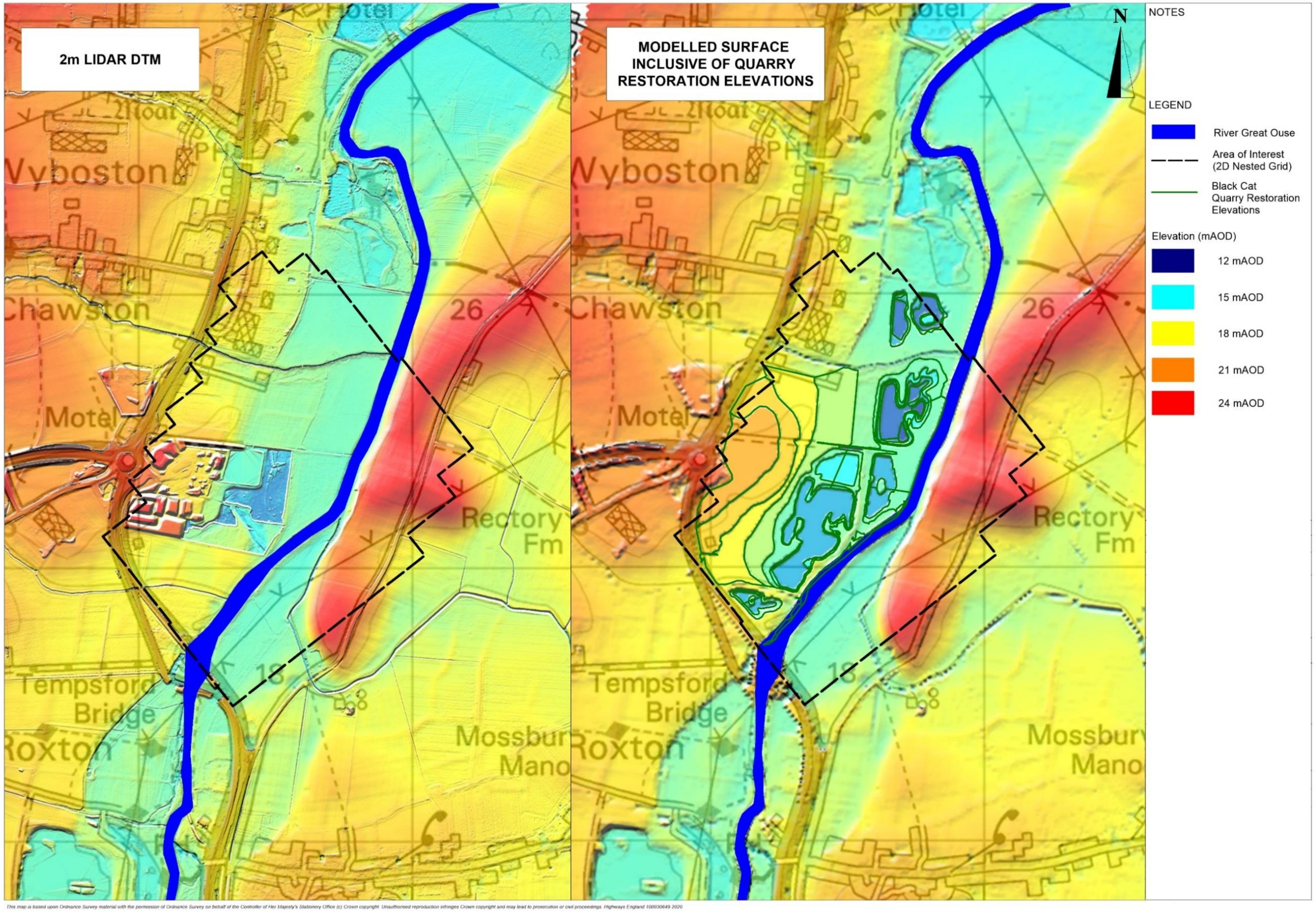


Figure 2-4: Comparison of LiDAR DTM and the Modelled Elevations Inclusive of Quarry Restoration

2.7 Roughness

2.7.1 Channel and floodplain friction was represented in the hydraulic model by defining a varying Manning's Roughness Coefficient across both the 1D and 2D model domain.

2.7.2 The Manning's Roughness Coefficients utilised within the 2015 Lower Ouse model were reviewed alongside images of the watercourse and aerial photography and are considered to provide a suitable representation. Therefore, the Manning's Roughness Coefficients have been maintained from the 2015 Lower Ouse model. To improve confidence in the chosen roughness values a sensitivity assessment has been undertaken and is described further in Section 3.3.

2.7.3 Within the 1D FMP model, the Manning's Roughness Coefficients assigned to the River Great Ouse channel is 0.035 along the entire reach, typically defined within Chow (1957) as a watercourse with 'clean, winding, some pools and shoals'. It is accepted that this is a simplified strategic approach to representing the river channel and therefore to improve confidence in the modelling results a sensitivity analysis has been undertaken on the Manning's Roughness Coefficients described in Section 3.5.

2.7.4 Within the 2D TUFLOW model, OS Mastermap was used to define floodplain land cover, allowing the Manning's Roughness Coefficients to be spatially distributed throughout the domain.

2.7.5 Buildings were represented as areas of elevated roughness, where a Manning's Roughness Coefficient of 0.3 was specified, as per best practice guidance for fluvial hydraulic modelling.

2.7.6 During the model review it was found that large areas of the 2015 Lower Ouse model were covered by a depth varying Manning's Roughness Coefficeint stability patch to improve the functioning of the hydraulic model. This 2D stability patch has been removed from the hydraulic model without impacting upon model stability (Section 1.12). This improves the representation of the floodplain throughout the model.

2.8 Model timestep

2.8.1 The 2D TUFLOW model was simulated with a timestep of 4 seconds for the main 2D domain (20m grid) which is consistent with the 2015 Lower Ouse model. A 2D timestep of 2 seconds was used for the nested grid (10m grid).

2.8.2 The 1D FMP model time step was set to be half of the 2D timestep, at 2 second, which is consistent with 2015 Lower Ouse model.

2.8.3 The 2D timestep differs from the recommended guidance, which suggests that the 2D timestep should be half of the 2D grid cell size (20m & 10m). This is because when the recommended guidance was followed, unacceptable model instabilities were identified that did not exist within the received 2015 Lower Ouse Model. Therefore, it has been decided that using the original model timestep is the most appropriate timestep to use as it shows the most stable simulations.

2.8.4 The model is simulated for 250 hours and takes approximately 2 hours to simulate. The truncation of the 2015 Lower Ouse model greatly reduced the model simulation time from approximately 12hrs to 2hrs.

2.9 Model boundary conditions

2.9.1 The hydraulic model consists of three hydrological inflows, a direct inflow at the River Great Ouse upstream boundary, a direct inflow for the contribution of the River Ivel and a lateral inflow representing inflows from the intervening hydrological catchment. Table 2-1 shows that the upstream boundary is defined as a flow-time boundary and the River Ivel and intervening catchment inflows are represented using ReFH boundaries. These are consistent with the hydrological inflows within the 2015 Lower Ouse model.

2.9.2 The 1D downstream boundary has been truncated from the 2015 Lower Ouse model to a location approximately 1.6km upstream of St Neots. Initial testing found that updating the location of the downstream boundary does not impact upon the hydraulics at the location of the Scheme and therefore would be appropriate for the assessment of flood risk to and from the Scheme.

2.9.3 Given the site specific improvements made to the hydraulic model around the location of the Scheme (Sections 2.3 - 2.13), it was considered inappropriate to apply a downstream boundary based upon head-time (HT) results extracted from the supplied strategic scale model. The 1D downstream boundary is therefore represented by a Normal Depth boundary using a defined gradient for the watercourse of 1:3500 which is an average gradient calculated from the upstream to downstream extent of the model. This configuration is considered appropriate given that the downstream boundary is situated within an open channel reach and is not thought to be hydraulically influenced by any other watercourses.

2.9.4 To improve confidence in the configuration of the downstream boundary for determining the flood risk to and from the Scheme, a sensitivity analysis has been undertaken on the gradient of the downstream boundary and is outlined in Section 3.3. It was found that changes to the Normal Depth boundary do not impinge upon the hydraulics within the area of interest.

2.9.5 Within the 2D TUFLOW model, a stage-flow (HQ) boundary was included across the downstream extent of the 2D domain to represent natural propagation of water across the floodplain according to local topography.

2.9.6 Saliently, the upstream and downstream boundaries are considered remote from the Scheme and the configuration of the boundaries has been proven through assessment of the results to have no impact upon hydraulics at the location of the Scheme.

2.10 Other 1D model improvements

2.10.1 The 1D model parameters have all been improved from the 2015 Lower Ouse model and have been reduced back to the preferred Flood Modeller Pro default software settings, where less ideal custom settings were previously set. This shows a more stable model and increased reliability in the hydraulic model results, reducing the impact of customised settings to aid simulation.

2.11 Other 2D model improvements

2.11.1 The 2D code boundary has been extended at the upstream extent of the hydraulic model to include parts of the River Ivel floodplain to reduce 2D ‘glass walling’ previously observed within the 2015 Lower Ouse model.

2.11.2 It should be noted that some residual ‘glass walling’ observed on the left bank of the River Great Ouse cannot be addressed without significantly extending the hydraulic model upstream. Glass walling in this area occurs in a relatively confined area on the left bank of the River Great Ouse, 2.5km upstream of the study area (**Figure 2-5**). The area of ‘glass walling’ is small compared to the modelled maximum flood extent and may result in a small raising of water levels locally due to a restriction in the floodplain volume.

2.11.3 Given the limited spatial extent of the ‘glass walling’, and that this is occurring in an area that is remote from the area of interest, it can be concluded that the residual impact would have negligible effect on downstream water levels and would not be detrimental to the assessment of the Scheme. Nevertheless, the 2D code boundary has been increased at the upstream extent to minimise the ‘glass walling’ effect.

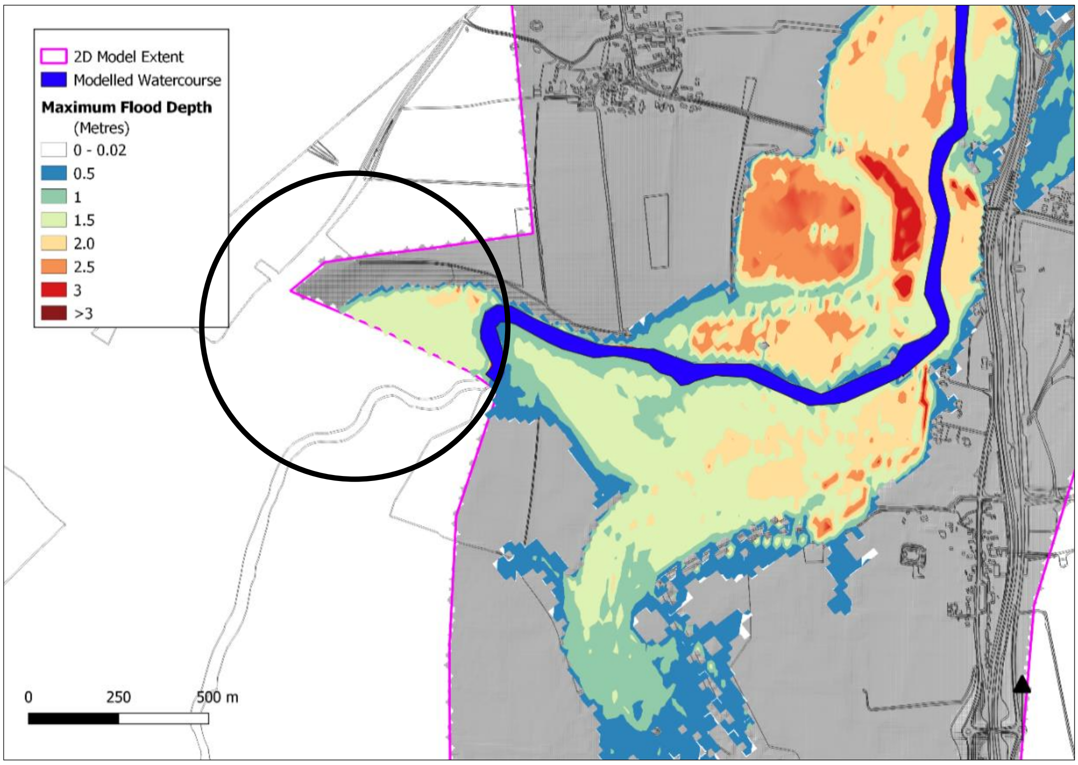


Figure 2-5: Residual Glass Walling in Baseline Model

1% AEP + 35% Climate Change

2.12 Model stability

2.12.1 **Figure 2-6** shows a model convergence output plot from Flood Modeller Pro for the baseline 1% AEP + 35% climate change baseline scenario. **Figure 2-6** demonstrates that the model has been constructed robustly and is exceptionally stable, showing a good level of convergence throughout the simulation with a minor spike at the very beginning. This can be attributed to the large volumes of water entering the hydraulic model and is sufficiently far away from the peak to not impact model results.

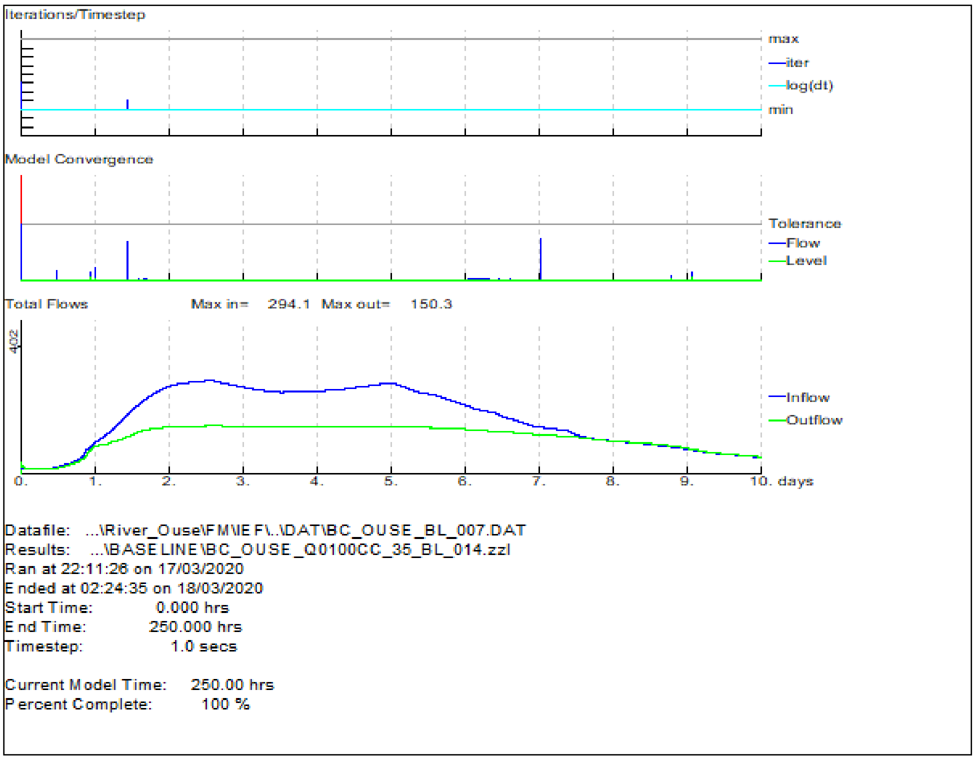


Figure 2-6:Baseline, 1D FMP Convergence Plot

1% AEP + 35% Climate Change

2.12.2 **Figure 2-7** shows the TUFLOW Cumulative Mass Balance output from the 2D model for the 1% AEP + 35% climate change baseline scenario. The cumulative mass balance is well within the recommended tolerances of +/- 1% throughout the simulation indicating a good degree of model stability.

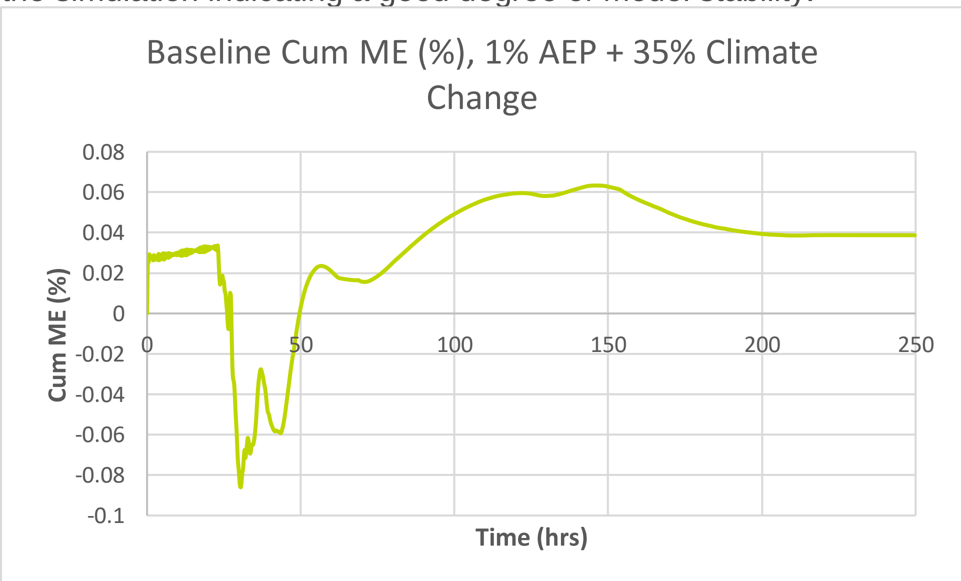


Figure 2-7: Baseline, Cumulative Mass Balance

2.13 Model setup- Scheme permanent scenario

2.13.1 The Scheme design is shown in **Figure 2-8** and was incorporated into the hydraulic model. Modifications to the model set up were made both within the 1D FMP model and 2D TUFLOW model. Further details of the proposed permanent features of the Scheme are included within the main FRA document.

2.13.2 The River Great Ouse viaduct was included within the 1D FMP model and represented using a USPBR unit. This structure is a clear span bridge across the channel at model node (GRE42000) and therefore no pier abutments are present in the 1D model.

2.13.3 Modifications to the topography of the A428 embankments were included within the 2D model domain through topographical amendments. The floodplain storage volume lost as a result of the proposed A428 embankment was calculated on a level by level basis using the 1% AEP plus 35% climate change event. Floodplain compensation storage was included within the design upstream of the River Great Ouse viaduct (Section 2.13.5).

2.13.4 Four bridge piers were specified across the floodplain using flow constriction units, calculated based upon the area of the modelled grid cell reduced by the pier. A maximum elevation of the pier was specified as the proposed elevation of the highway at 21mAOD.

2.13.5 The floodplain compensation area (FCA in **Figure 2-8**) has been represented using topographic amendments to the floodplain. It is assumed that the floodplain compensation storage area contains standing water and therefore a base level of 15.5m AOD for the western pond and 15.1m AOD for the eastern pond is considered to be the standing water level. In the permanent model, the water level has been specified within the model surface rather than using initial water level lines. The floodplain compensation volumes include top banks of the existing quarry ponds. The top banks of the ponds would be lowered, where required, to provide hydraulic connectivity between the compensation area and the watercourse, as a consequence the standing water level of the eastern pond is lowered from 15.5m AOD in the baseline model to 15.1m AOD in the proposed scenario while the western pond standing water is not affected. It is assumed the ponds are at capacity in the proposed scenario and that standing water levels are the same as surrounding ground levels. It is noted that the base of the restored quarry ponds is intended to remain the same as in the baseline scenario. Calculations of the floodplain compensation volumes are described further in Section 2.15. The proposed ground profile lowering along the western bank of the River Great Ouse that ensures the hydraulic connectivity between the River Great Ouse and the floodplain compensation area can be seen in sections 10 to 12 and in sections 18 to 20 (refer to Appendix C).

2.13.6 **Table 2-3** shows the topographic changes made to the Permanent scenario hydraulic model. It is noted that these are made in addition to those described in **Table 2-2**.

Table 2-3: Topographic modifications to Permanent Model

Model File	Topographic Modification
2d_zsh_Embankment_PR_OP4_001	Proposed A428 embankment across the River Great Ouse floodplain elevations
2d_zsh_Bridge_Deck_PR_PERM_001	Bridge deck of the River Great Ouse viaduct
gro_fca_200325_east.txt	Design floodplain compensation storage area levels described in Section 2.15 applied using raster surface.
gro_fca_200325_west.txt	
2d_zsh_TopoFix_PR_PERM_001	Minor topographic smoothing to remove residual low elevations at the edge of floodplain compensation storage area and at the base of the proposed A428 embankment. This is required primarily due to the 10m grid resolution of the nested model domain and the interpolation of the baseline restoration levels causing a small mismatch of levels.
2d_fcsh_Ouse_PR_PERM_001	Flow constriction layer to represent A428 bridge piers

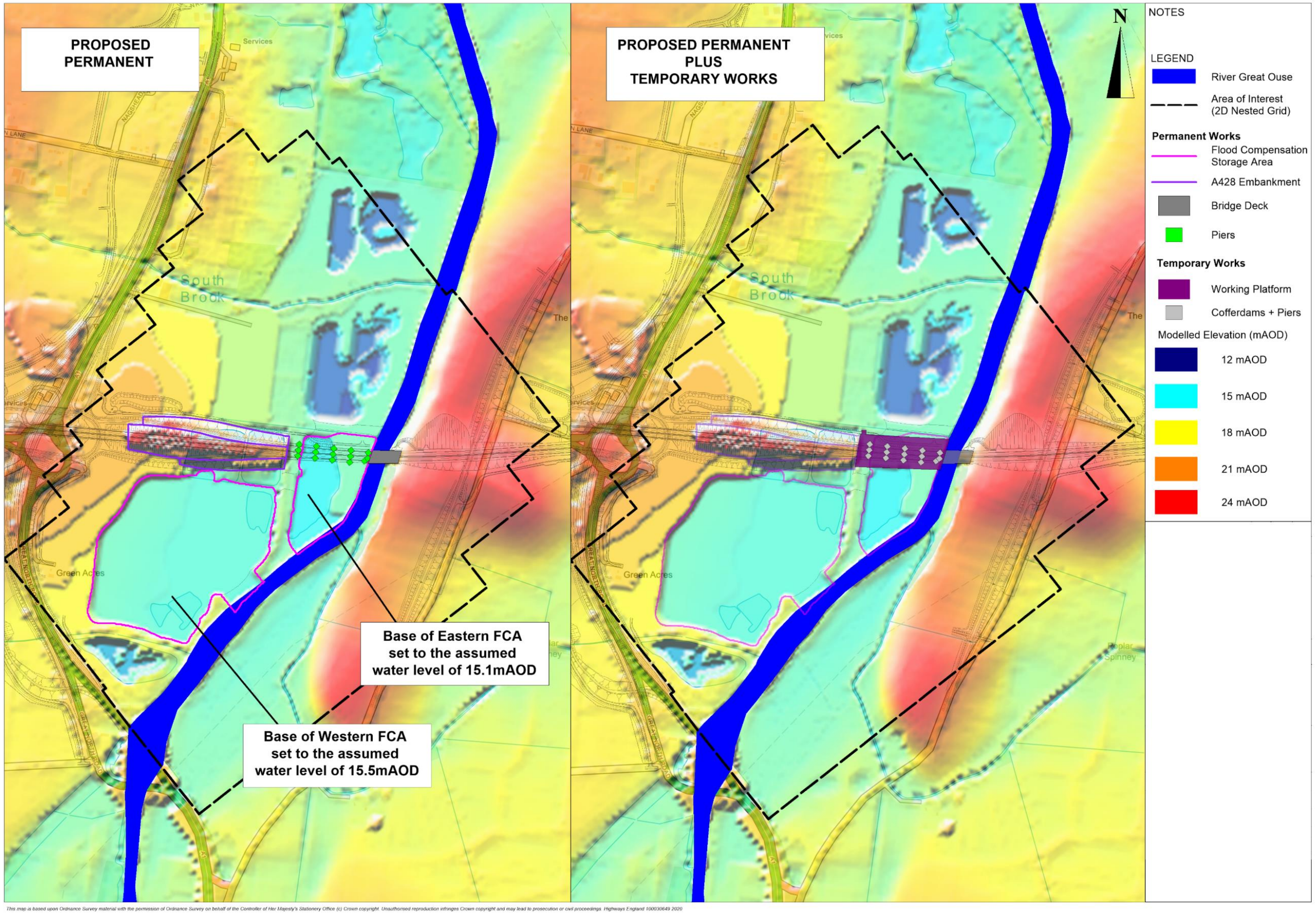


Figure 2-8: River Great Ouse Proposed Permanent and Proposed Permanent Plus Temporary Works Design

2.14 Model setup- Scheme permanent + temporary scenario

2.14.1 To ensure that the impact upon flood risk during the construction phase of the Scheme was fully captured within the assessment, all temporary works were incorporated into the hydraulic model alongside the permanent works and simulated for the present day design events. This configuration was considered to provide a worst case assessment of flood risk impact during the construction phase as a short term assessment. Further details of the proposed temporary features of the Scheme are included within the main FRA document and are summarised in **Figure 2-8**. It should be noted that this approach assumes that the floodplain compensation storage area is constructed prior to any other floodplain construction like the road embankment. If phasing dictates that this is not possible then further hydraulic modelling should be undertaken to assess the flood risk to and from the Scheme during the construction phase.

2.14.2 A working platform set to an elevation of 16m AOD was represented within the hydraulic model using topographic modifications within the 2D hydraulic model.

2.14.3 Cofferdams, used to construct the River Great Ouse viaduct piles, at the same location as the bridge piers in the permanent works are represented using elevation varying flow constriction units. This means that up to an elevation of 17m AOD (top of the cofferdams) there is a 100% flow restriction within the hydraulic model to represent the impermeable barrier. Above this elevation the flow constriction is the same as the permanent works.

2.14.4 The elevations of the working platform and cofferdams have been provided as a precautionary estimate for the construction phase. These should be reviewed again prior to the construction phase and if required further hydraulic modelling should be undertaken to reassess any flood risk impact of altering the temporary works elevations.

2.14.5 **Table 2-4** summarises the topographic modifications made within the proposed hydraulic model for Permanent + Temporary scenario. It is noted that these are in addition to the topographic changes described in Table 2-3.

Table 2-4: Topographic modifications to Permanent + Temporary Model

Model File	Topographic Modification
2d_zsh_PR_TEMP_Platform_001	Temporary works platform set to 16m AOD
2d_lfcsh_Ouse_TEMP_CoffDam_001	Cofferdams represented as flow constriction units with an elevation of 17mAOD

2.14.6 Temporary access to the working platform is proposed on the north side of the A428 embankment. This proposed to be at the existing ground levels and has therefore not been included within the temporary works model as it is not considered to impact the hydraulics of the floodplain or river channel.

2.14.7 Storage of major construction material such as steel beams, pre-cast concrete and fill will be stored outside of the floodplain and have therefore not been included.

2.15 Floodplain compensation storage calculations

2.15.1 This section presents a summary of the methodology followed to calculate flood storage volume loss and compensation volumes for the A428 River Ouse Viaduct within the 1 in 100 year plus 35% climate change floodplain.

2.15.2 Topographic survey data was input into an AutoCAD software file for existing ground elevation levels. Additional topographical sections were interpolated, where topographical survey data was not available along the River Ouse.

2.15.3 Modelled flood water levels, for the 1 in 100 year plus 35% climate change probability storm event, were represented as a flood level surface file in AutoCAD.

2.15.4 Proposed embankment and bridge structure data, in the form of an AutoCAD file containing the surface of the Scheme, was also used to delineate floodplain displacement by the road crossing.

2.15.5 Volume calculations were calculated in the AutoCAD Civil 3D 2018 modelling workspace using the flowing methods;

2.15.6 Floodplain loss volumes were determined by graphically extracting a solid, defined between the topographical surface and Scheme surface, and by intersecting the solid with the floodplain surface. The solid was then divided in 0.2m high layers for determining level for level volumes.

2.15.7 Floodplain compensation volumes to be provided were similarly determined by extracting a solid, defined between the topographical surface and a proposed River Ouse floodplain compensation surface. The solid was also divided in 0.2m high layers for level for level compensation. A visualisation of the compensation volumes for each layer is displayed in **Figure 2-9** for illustrative purposes only.

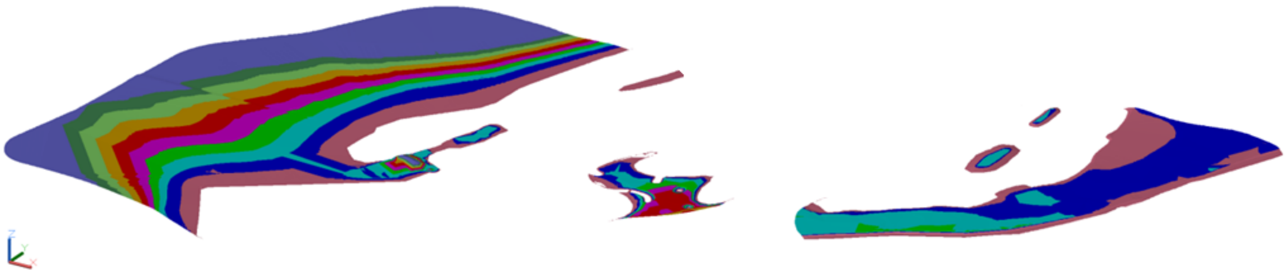


Figure 2-9 Floodplain compensation volume layers

2.15.8 The volume of each solid layer was determined in AutoCAD from the properties of 3D objects.

2.15.9 Software results were checked using an approximated average area method below:

Total Flood storage volume = difference of levels between top and bottom layer surfaces x average area of top and bottom surfaces

2.15.10 Details of volume for volume and level for level compensation quantities extracted from the solids generated and volume checks are indicated in Appendix B.

2.15.11 Spreadsheet results show that proposed compensation volumes are significantly more than compensated floodplain loss volumes; this is due to the nature of the existing ground profile and required compensation volumes at critical levels. Providing additional compensation volumes provides further flood protection at the river crossing.

2.15.12 Floodplain compensation and floodplain loss volume layers are displayed in the cross-section's drawings provided in Appendix C.

3 Hydraulic modelling results

3.1 Overview

3.1.1 The baseline and proposed permanent scenario models were simulated for the 5% AEP, 1.33% AEP, 1% AEP, 1% AEP + 35% climate change, 1% AEP + 65% climate change and 0.1% AEP events. Baseline results are included in Section 3.2 and proposed permanent results are presented in Section 3.3

3.1.2 The proposed permanent plus temporary works scenario was simulated for the 5% AEP and 1% AEP events. No climate change simulations were undertaken in this scenario as the temporary works will only be present during the shorter term construction phase of the project and would therefore not be subject to future hydrological uplift factors associated with climate change. Results from this scenario are presented in Section 3.4.

3.1.3 Sensitivity testing of the baseline hydraulic model was undertaken using the 1% AEP + 35% climate change design event to assess the impact of the chosen Manning's Roughness Coefficients, hydrological inflows and downstream boundary conditions. Results from this sensitivity testing are included within Section 3.5.

3.2 Baseline scenario

3.2.1 A comparison of the baseline modelled flood extents with the corresponding Environment Agency Flood Zones is shown in **Figure 3-1**. The modelled 1% AEP and 0.1% AEP flood extents are broadly similar to Flood Zone 3 and Flood Zone 2 respectively. There is an increase in floodplain storage on the left bank of the River Great Ouse within the area of interest because of the inclusion of the proposed quarry restoration topography in the hydraulic model. There is a corresponding reduction in flood extents when compared to the EA Flood Zone mapping for both modelled events on the right bank due to this increase floodplain storage. The baseline model is considered to be the best representation of local topography as it utilises the restored quarry levels and the latest LiDAR DTM data..

3.2.2 **Figure 3-2** shows a comparison of the 5% AEP, 1% AEP and 0.1% AEP maximum flood extents for the River Great Ouse. It is observed that the maximum flood extents are relatively similar across the range of events with significant floodplain inundation through the area of interest. This indicates that a large proportion of the River Great Ouse floodplain storage is utilised during the 5% AEP event. It is observed that the maximum floodplain flow (Model Node GRE_44450x) ranges from approximately 45m^3/s during the 5% AEP event to 182m^3/s during the 0.1% AEP event showing that a significant volume of water is flowing out of bank at this location.

3.2.3 It is noted that the large area of inundation to the east of the River Great Ouse shown within the Environment Agency Flood Zone mapping is attributable to Stone Brook, a tributary of the River Great Ouse. This watercourse has not been modelled within this study and therefore should not be considered when comparing flood extents. Similarly, the inundation shown within the River Ivel floodplain to the south of the area of interest is attributable to the River Ivel which has not been not been modelled within this study and should therefore not be considered when comparing flood extents.

3.2.4 During the 1% AEP + 35% climate change and 0.1% AEP events there is a great extent of flooding on the left bank, compared to the lower magnitude events, as water levels reach the plateau of the restored quarry.

3.2.5 Figure 3-3 shows the maximum flood depth map for the 1% AEP + 35% climate change event through the area of interest. Floodplain depths are generally observed to be between 1m – 2m with the largest depths of flooding intuitively being observed within the restored quarry ponds where maximum flood depths are over 3m. As noted in Section 2.6.4 the restored quarry ponds are filled at the outset of the simulation using 2D initial water level lines.

3.2.6 There is significant floodplain attenuation upstream of the A1 River Great Ouse crossing where maximum flood depths are consistently between 1m – 2m in the 1% AEP + 35% climate change.

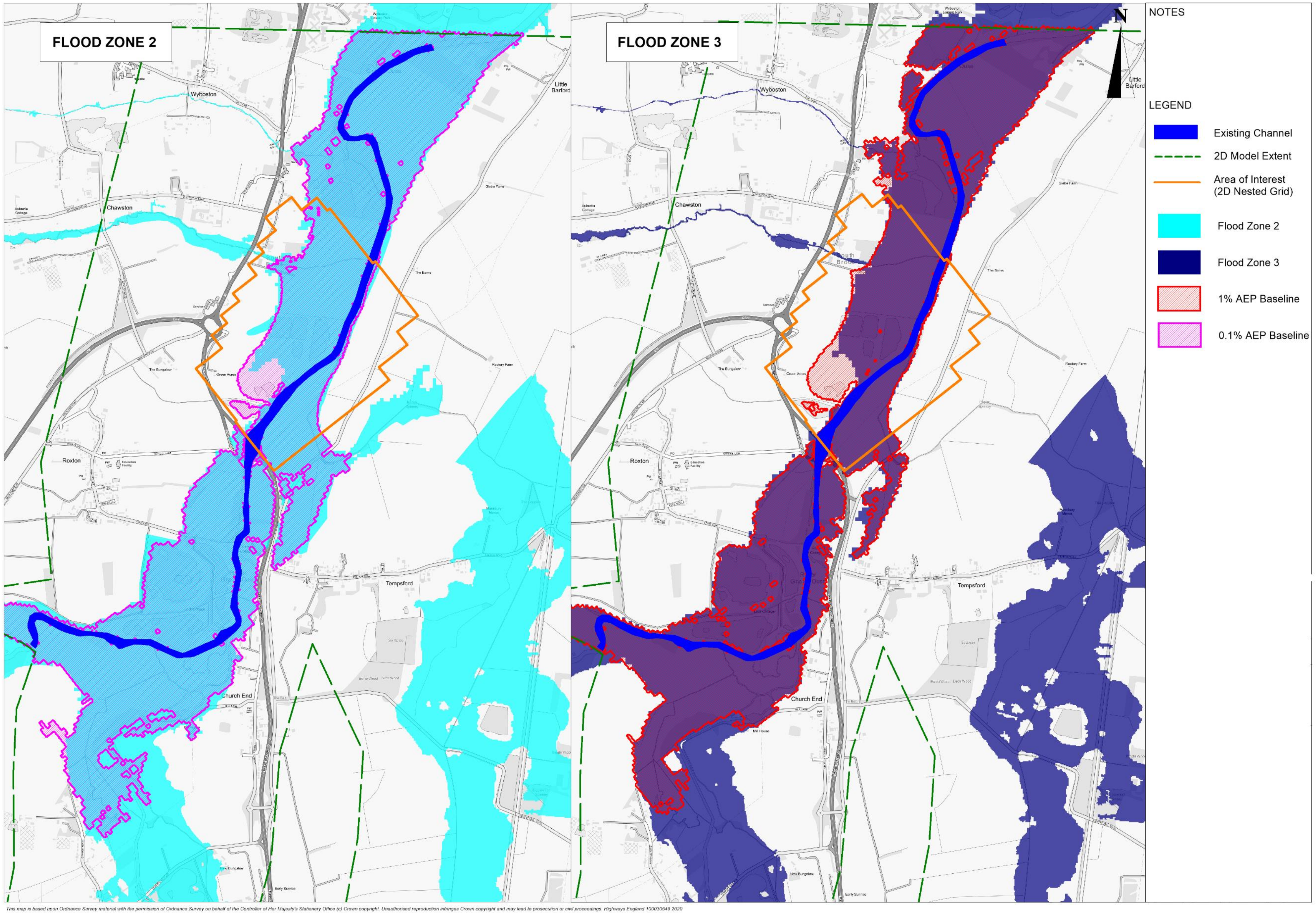


Figure 3-1: Comparison of Baseline vs Environment Agency Flood Zone Mapping

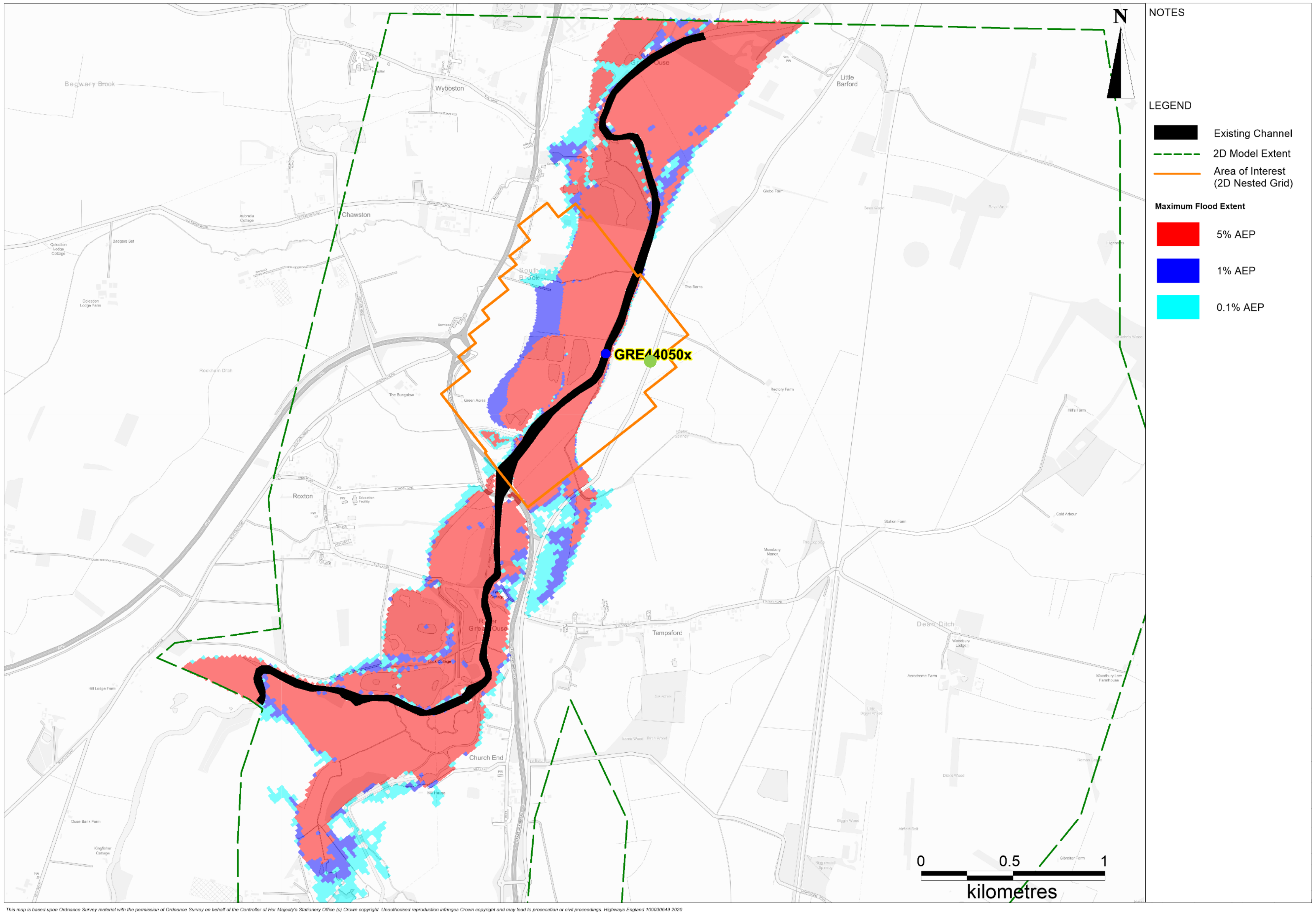


Figure 3-2: Comparison of Baseline Maximum Flood Extents, 5% AEP, 1% AEP and 0.1% AEP

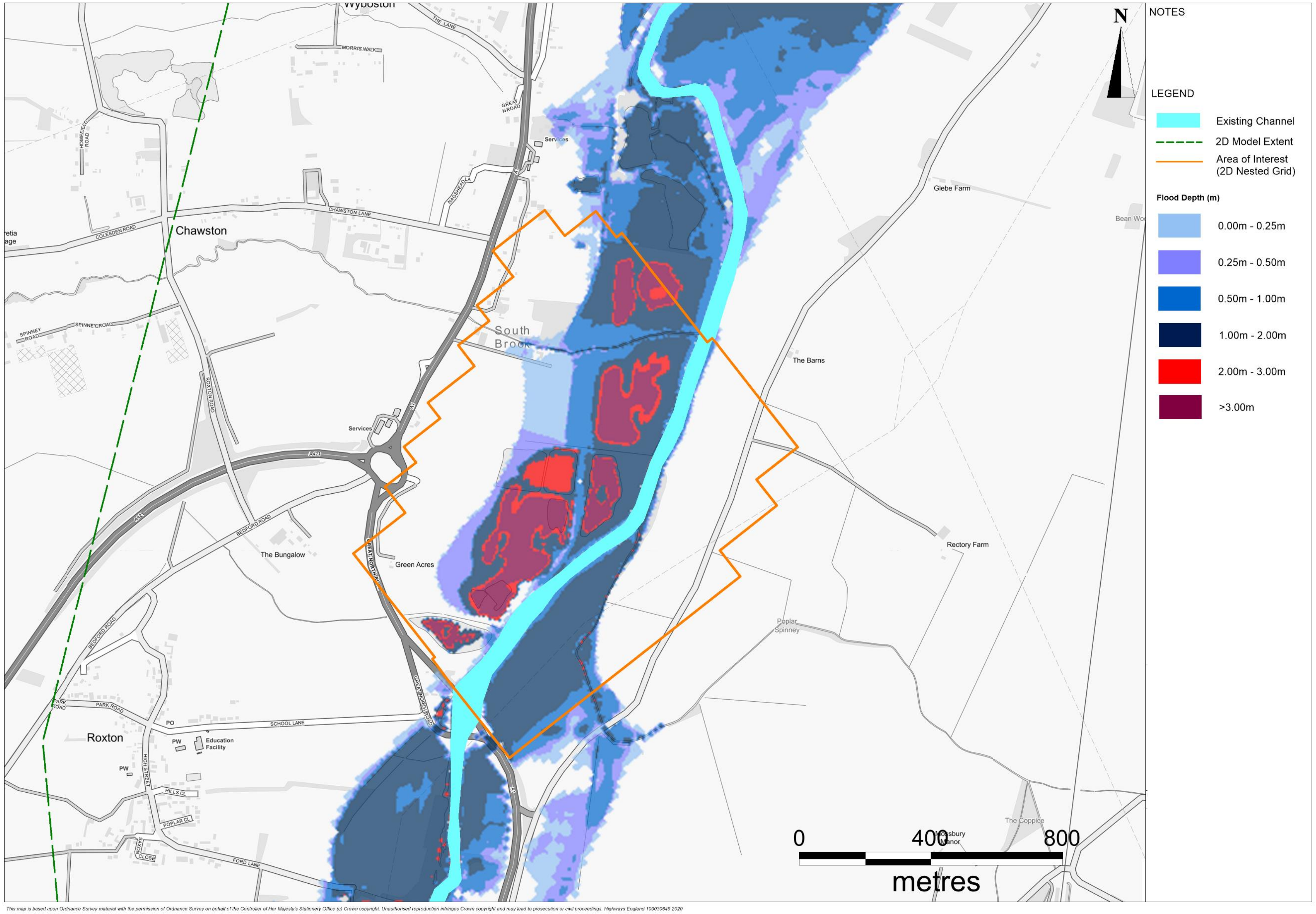


Figure 3-3:Baseline Maximum Flood Depth Map, 1% AEP + 35% Climate Change

3.3 Proposed permanent Scheme scenario

3.3.1 A comparison of the maximum flood depths for the permanent 1% AEP + 35% climate change scenario and baseline scenario are shown in Figure 3-4. Figure 3-5 shows a maximum water level difference plot, which provides a direct comparison of the Scheme and baseline results and therefore shows the increases and decreases in water elevation that are attributable to the Scheme elements. Key elements of the Scheme at this location are highlighted within these figures, and the reader is referred to the main FRA document for further detailed information.

3.3.2 It is observed in **Figure 3-4** that the maximum flood depths and extents are broadly similar to the baseline scenario during the 1% AEP + 35% climate change scenario with maximum flood depths in the area of interest of 1 – 2m. As intended, the flood extents are increased to the south west of the River Great Ouse viaduct within the proposed floodplain compensation storage area where landscaping of the restored quarry has been undertaken to increase the storage capacity of the western pond.

3.3.3 It is noted that the maximum flood depths are shown to be lower around the two restored quarry ponds within the proposed permanent scenario when compared to the baseline. This is because the water level of the floodplain compensation storage area has been represented using a topographic surface and not initial water level polygons as used in the baseline scenario (Section 2.6.4 and Section 2.13.5). Saliently, in both scenarios the ponds are considered full at the outset of the simulation and the actual base level of the restored quarry ponds will not change within the floodplain compensation storage area in the proposed design.

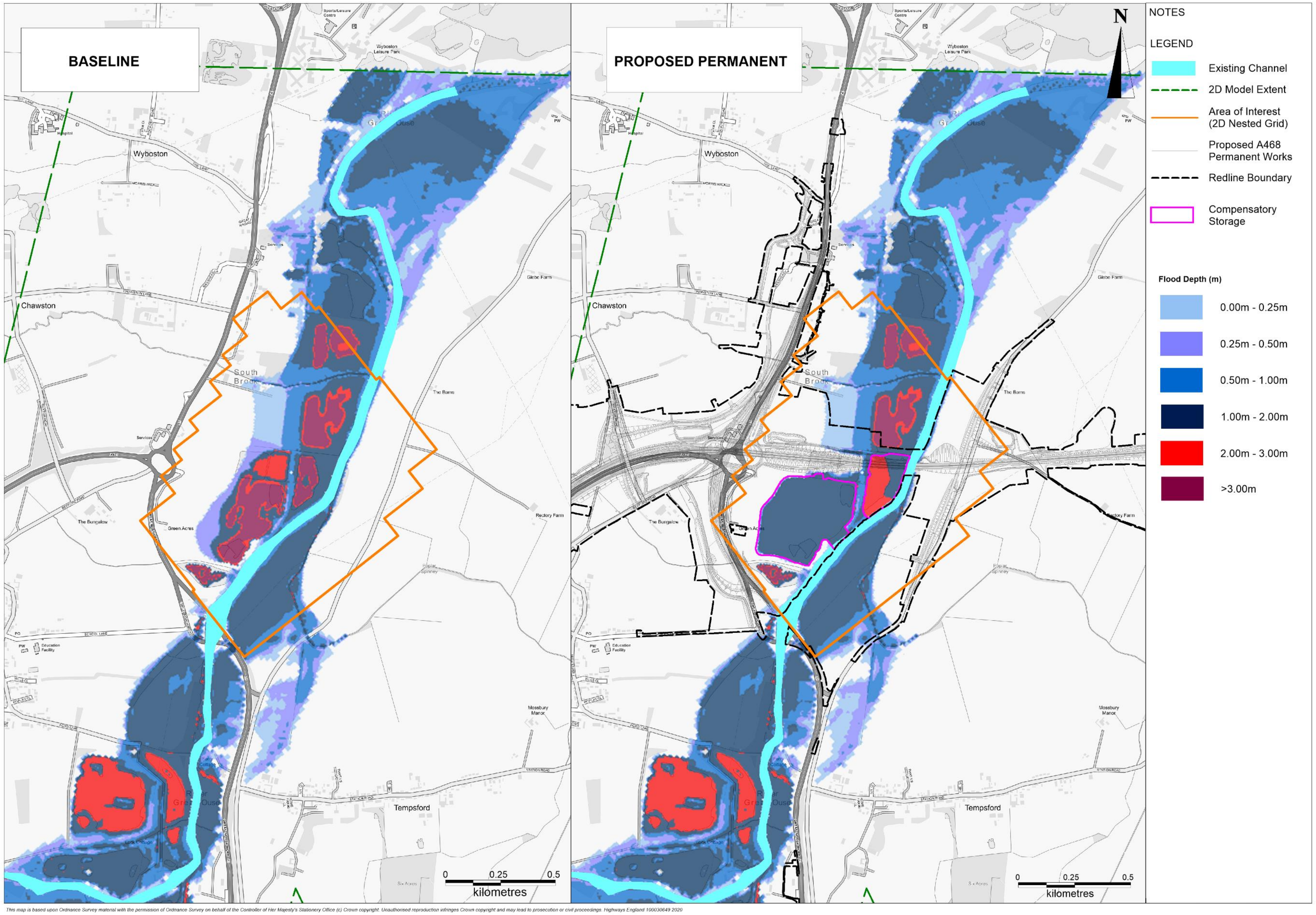


Figure 3-4: Maximum Flood Depth Comparison, Baseline vs Permanent, 1% AEP + 35% Climate Change

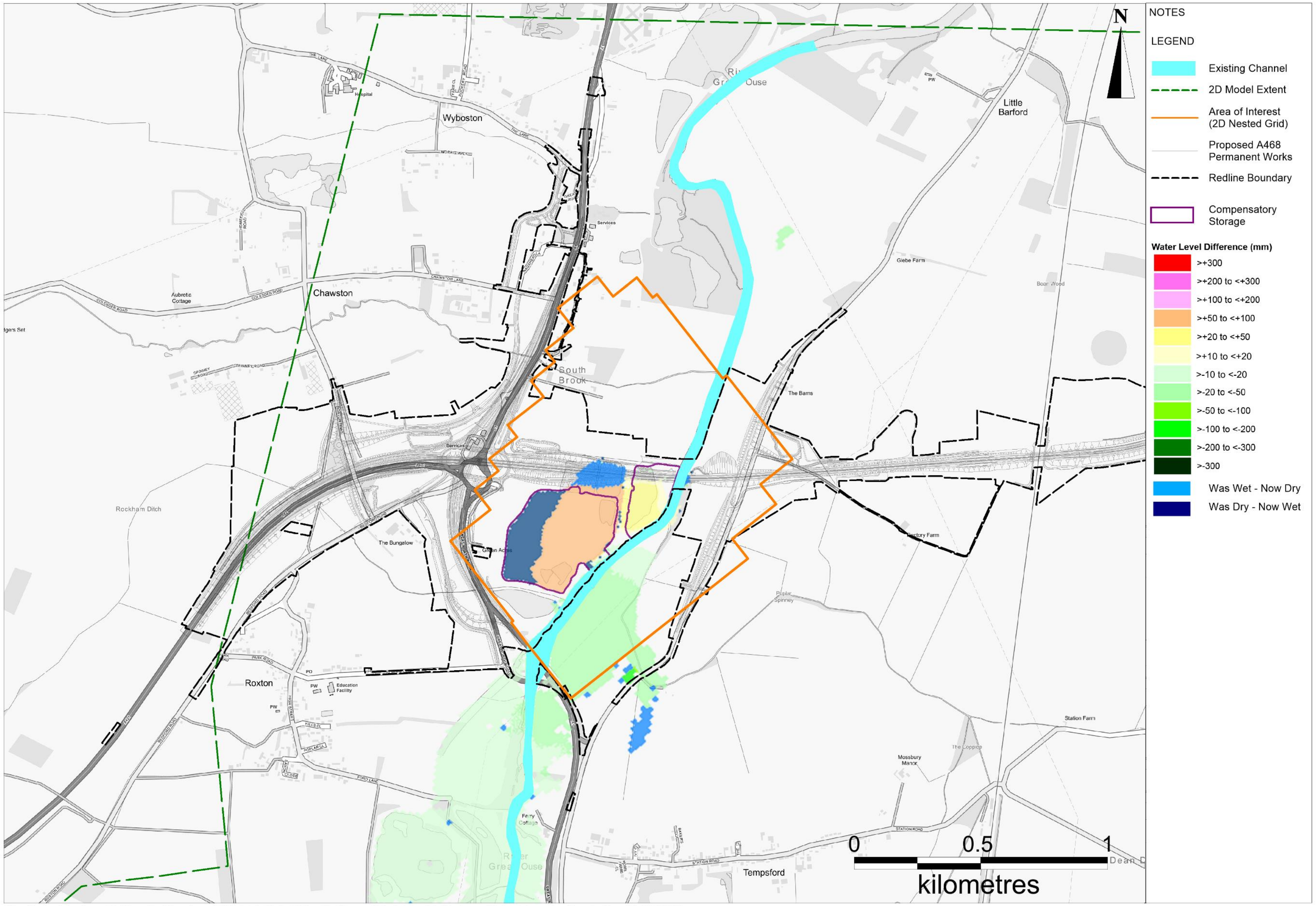


Figure 3-5: Maximum Water Level Difference Map, Permanent vs Baseline, 1% AEP + 35% Climate Change

3.3.4 The results presented in **Figure 3-5** indicate that during the 1% AEP + 35% climate change event there are localised changes in maximum water elevation attributable to the Scheme around the River Great Ouse viaduct and within the proposed compensation storage area. Importantly, there is a general reduction in maximum water elevations of less than 10mm outside of the Order Limits, upstream of the River Great Ouse viaduct and this indicates a net flood risk benefit. This is further demonstrated by the area outside of the Order Limits to the south of the Scheme which was wet in the baseline scenario and is shown to be dry as a result of to the Scheme.

3.3.5 Figure 3-5 shows that there is an increase in maximum water elevation within the proposed floodplain compensation storage area as intended within the design. Maximum floodplain water elevations increase by +50mm to +100mm when compared to the baseline scenario and inundate both ponds. Intuitively flooding is removed where the A428 embankment crosses the floodplain and flooding is increased where the restored quarry has been excavated to create the floodplain compensation storage area

3.3.6 It is noted that there is an increase in maximum flood depths of +10mm to +50mm, within a relatively small area on the right bank of the River Great Ouse upstream of the viaduct immediately outside of the Order Limits. This is within heavily vegetated sloped agricultural fields within the floodplain that already floods to a depth of over 1m during the 1% AEP + 35% climate change event baseline scenario. The flood risk implications of this detrimental effect are discussed in further detail within section 8 of the main FRA report.

3.3.7 The full suite of proposed permanent scenario maximum flood depth and the maximum water elevation difference plots can be viewed in Appendix D. It is noted that the hydraulic model results presented in Appendix D are commensurate across all design events and the same conclusions can be drawn as those described for the 1% AEP + 35% climate change event.

3.3.8 To understand the upstream and downstream impacts of the Scheme, the maximum 1D channel stage results for the baseline and permanent scenario were extracted from the locations along the River Great Ouse shown in Figure 3-6 and tabulated in Table 3-1.

3.3.9 Table 3-1 shows that there is a reduction in the in-channel maximum water level upstream of the A428 floodplain compensation storage area between –10mm to –60mm across the design events which can be attributable to the increase in floodplain storage afforded by the Scheme. Model results indicate that out of bank flooding occurs earlier in the simulation, utilising a greater amount of floodplain storage and hence providing benefit upstream of the floodplain compensation storage area.

3.3.10 For the reach approximately 150m upstream of the River Great Ouse viaduct **Table 3-1** shows that there is an increase in the in-channel maximum water level of +10mm to +20mm. This increase is considered small when considered in the context of the overall volume of water on the floodplain. The depth difference plots in Appendix D show that this is very localised within the River Great Ouse channel and within agricultural fields on the right bank primarily as a result of the constriction of the floodplain at this location.

3.3.11 Table 3-1 shows that downstream of the River Great Ouse viaduct there is no change to the maximum water level indicating that the Scheme has no flood risk impact downstream.

3.3.12 The results show that upstream of the floodplain compensation storage area there is an overall flood risk benefit due to the Scheme however, there are small localised increases in maximum water level immediately upstream of the River Great Ouse viaduct as a result of the floodplain constriction. There is no impact to maximum water levels downstream of the Scheme. It is considered that as the localised increases in maximum water level are small the Scheme provides an overall net flood risk benefit upstream.

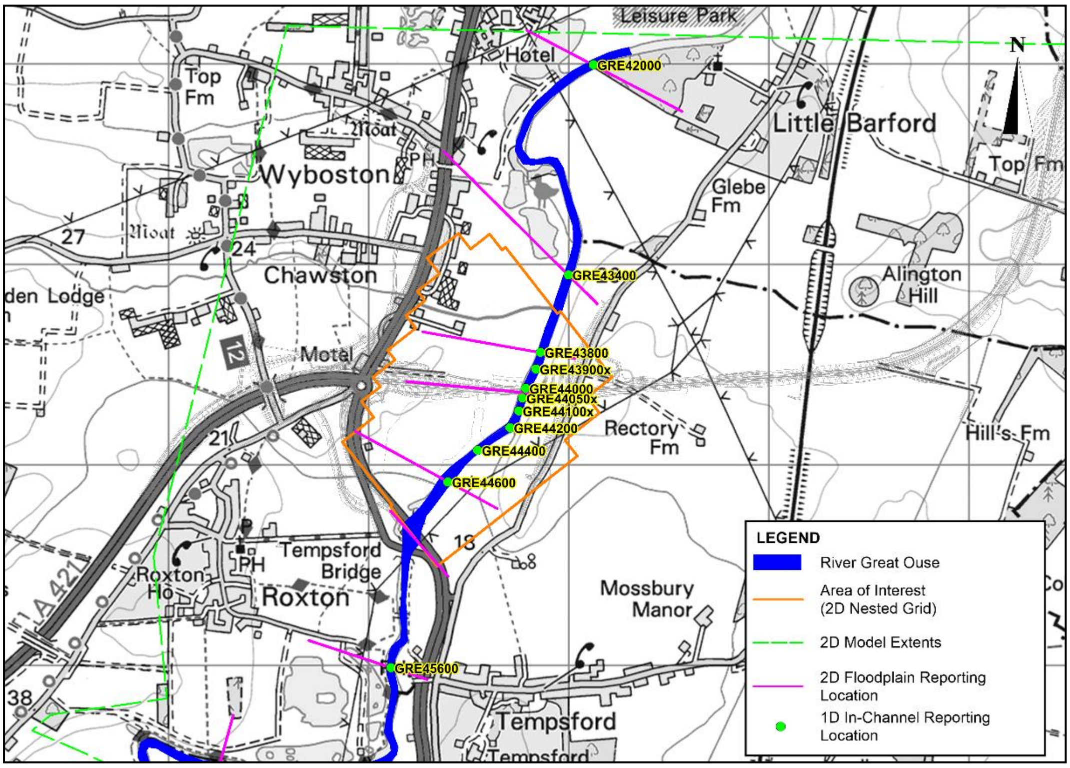


Figure 3-6: Model Reporting Locations

3.3.13 As highlighted in Section 3.2.2 there is significant out of bank flow on the River Great Ouse floodplain in all design events. To ensure that there no increase in pass on flow downstream of the Scheme, the baseline and proposed 1D channel and 2D floodplain flow hydrographs at GRE43400 have been plotted in **Figure 3-7** for the 1% AEP + 35% climate change design event. An additional resilience assessment has been carried out using the 1% AEP + 65% climate change event and is shown in Figure 3-8. Both figures show that there is an overall reduction in the peak flow 650m downstream of the River Great Ouse viaduct and there is no increase in the volume passed on to St. Neot's downstream. Combined with the results shown in Table 3-2, this demonstrates that the Scheme is robust during the extreme 1% AEP + 65% climate change event.

3.3.14 From this assessment it can be concluded that the River Great Ouse viaduct provides some flood risk benefits upstream of the Scheme whilst maintaining the levels and flows as existing downstream. Localised increases in maximum water levels are observed locally 150m upstream of the Scheme but these are considered negligible in the context of the overall volume of water within the floodplain.

Table 3-1: 1D In-Channel Maximum Stage Proposed Permanent vs Baseline

	Maximum Stage (m AOD) (change of in-channel stage compared to baseline (m))									
	5% AEP		1% AEP		1% + 35%CC		1% + 65%CC		0.1% AEP	
Label	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed	Baseline	Proposed
GRE47000	17.78	17.78 (0.00)	17.97	17.96 (-0.01)	18.15	18.14 (-0.01)	18.36	18.35 (-0.01)	18.28	18.27 (-0.01)
GRE45600	17.30	17.28 (-0.02)	17.60	17.58 (-0.02)	17.95	17.93 (-0.02)	18.21	18.20 (-0.01)	18.19	18.18 (-0.01)
GRE44870	17.04	17.01 (-0.03)	17.31	17.27 (-0.04)	17.57	17.54 (-0.03)	17.77	17.75 (-0.02)	17.76	17.74 (-0.02)
GRE44600	16.95	16.91 (-0.04)	17.19	17.13 (-0.06)	17.41	17.36 (-0.05)	17.57	17.51 (-0.06)	17.56	17.51 (-0.05)
GRE44400	16.84	16.81 (-0.03)	17.06	17.05 (-0.01)	17.29	17.29 (0.00)	17.45	17.46 (+0.01)	17.44	17.45 (+0.01)
GRE44200	16.80	16.81 (+0.01)	17.03	17.04 (+0.01)	17.26	17.28 (+0.02)	17.42	17.44 (+0.02)	17.41	17.43 (+0.02)
GRE44100 x	16.79	16.80 (+0.01)	17.02	17.03 (+0.01)	17.25	17.26 (+0.01)	17.41	17.42 (+0.01)	17.40	17.41 (+0.01)
GRE44050 x (US Face of Scheme)	16.78	16.78 ((0.00)	17.01	17.01 (0.00)	17.24	17.24 (0.00)	17.40	17.39 (-0.01)	17.39	17.38 (-0.01)

	Maximum Stage (m AOD) (change of in-channel stage compared to baseline (m))									
	5% AEP		1% AEP		1% + 35%CC		1% + 65%CC		0.1% AEP	
GRE44000	16.77	16.78 (+0.01)	17.00	17.00 (0.00)	17.23	17.23 (0.00)	17.38	17.38 (0.00)	17.37	17.37 (0.00)
GRE43900 x	16.77	16.77 (0.00)	16.99	17.00 (+0.01)	17.22	17.22 (0.00)	17.38	17.37 (-0.01)	17.37	17.36 (-0.01)
GRE43800	16.76	16.76 (0.00)	16.99	16.99 (0.00)	17.22	17.22 (0.00)	17.37	17.37 (0.00)	17.36	17.36 (0.00)
GRE43400	16.67	16.67 (0.00)	16.88	16.88 (0.00)	17.10	17.10 (0.00)	17.25	17.25 (0.00)	17.24	17.24 (0.00)
GRE42000	16.12	16.12 (0.00)	16.33	16.33 (0.00)	16.49	16.49 (0.00)	16.57	16.57 (0.00)	16.56	16.56 (0.00)

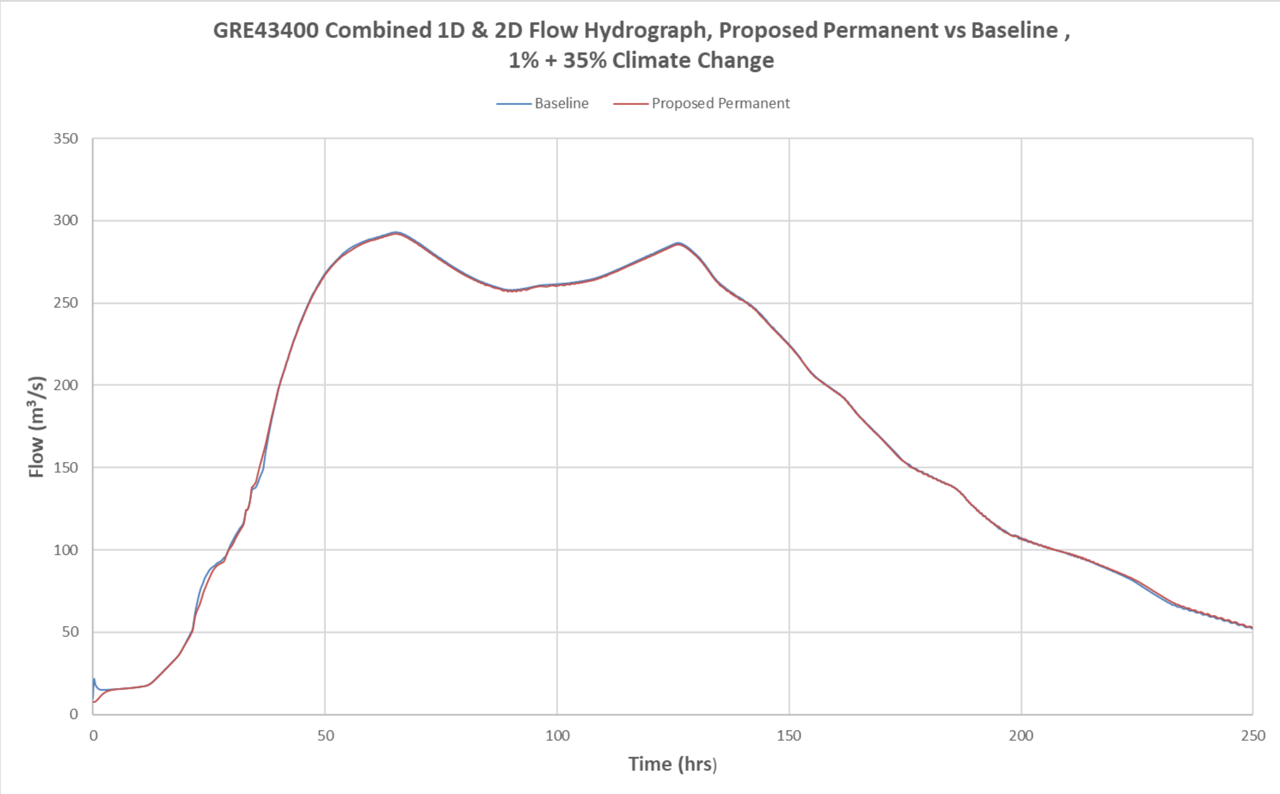


Figure 3-7: Downstream comparison flow hydrograph, Permanent vs Proposed 1% AEP + 35%CC

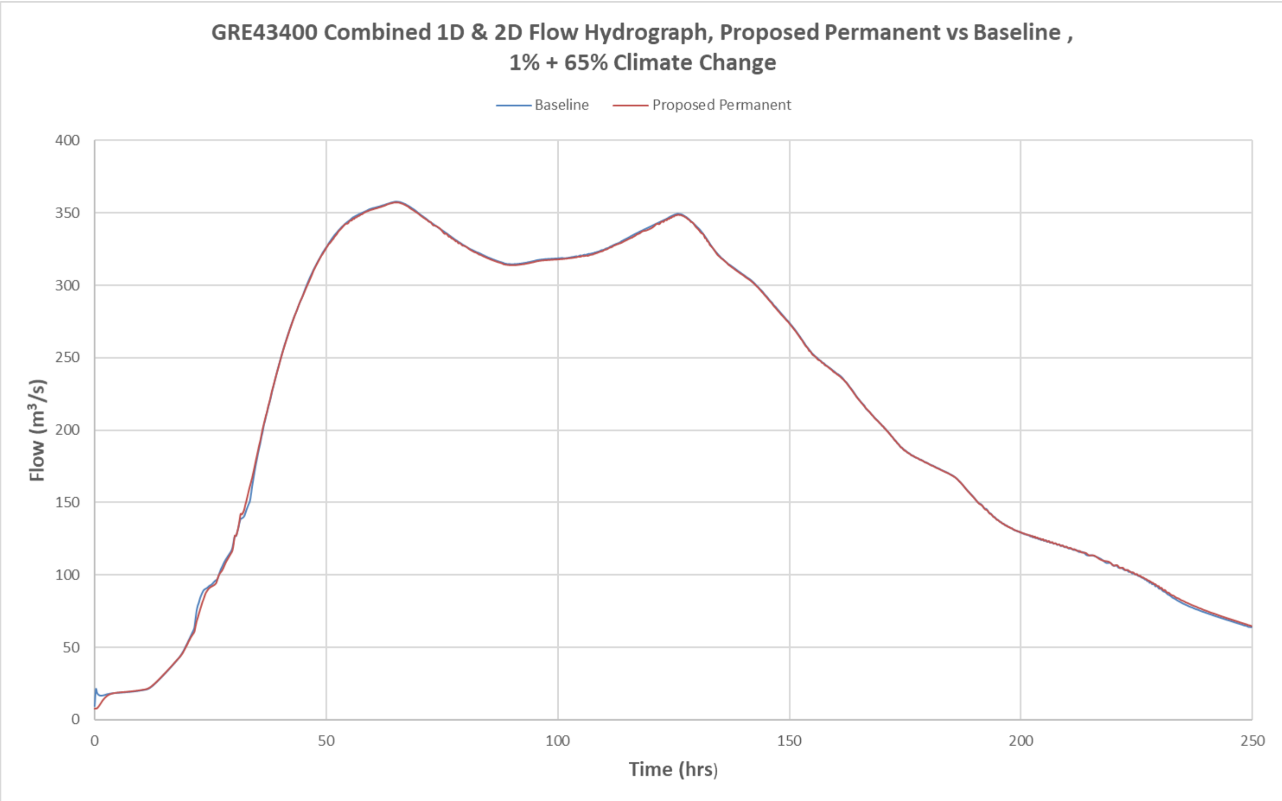


Figure 3-8 Downstream comparison flow hydrograph, Permanent vs Proposed 1% AEP + 65%CC

3.4 Permanent + Temporary Scheme scenario

3.4.1 **Figure 3-9 and Figure 3-10** present the 5% AEP and 1% AEP design events maximum water level difference plots for the permanent plus temporary works scenario respectively. These show the increases and decreases in flood depth that are attributable to the Scheme elements. Maximum flood depths comparison plots are contained within Appendix E.

3.4.2 Both **Figure 3-8 and Figure 3-9** show that the permanent + temporary works scenario is characterised by similar results to the proposed permanent scenario discussed in Section 3.3. There is a general reduction in maximum flood depths upstream of the Scheme outside of the Order Limits of –10mm to -50mm with increase in flood depths confined to the proposed floodplain compensation storage area and River Great Ouse channel 150m upstream of the River Great Ouse viaduct. There is no change in maximum flood depths downstream of the Scheme. There are very localised increases/decreases in maximum flood level of up to 100mm when compared to baseline, as a consequence of the cofferdams and working platforms in the immediate vicinity of the River Great Ouse viaduct, defined as within 50m upstream/downstream of the viaduct. These changes occur in areas that already flood within the baseline scenario and within the

Order Limits and therefore due to the localised impact would not affect any sensitive receptors.

3.4.3 **Table 3-2** shows a comparison of the 1D in channel maximum stage results for the Baseline and permanent plus temporary works scenarios at locations shown in **Figure 3-10**. The model results indicate that there is no change in maximum stage downstream of the Scheme due to the permanent plus temporary works for both the 5% AEP and 1% AEP events. When compared to the Proposed scenario in Table 3-1 there is only a negligible localised change in maximum water level.

3.4.4 It can be concluded that model results show the inclusion of the temporary construction works would not impact flood risk from the Scheme and the conclusions are consistent with those discussed in Section 3.3. There is no increased flood risk upstream or downstream of the Scheme outside of the Order Limits.

Table 3-2: 1D In-Channel Maximum Stage Proposed Permanent plus Temporary Works vs Baseline

	Maximum Stage (m AOD) (change of in-channel stage compared to baseline (m))			
	5% AEP		1% AEP	
Label	Baseline	Proposed	Baseline	Proposed
GRE47000	17.78	17.78 (0.00)	17.97	17.96 (-0.01)
GRE45600	17.30	17.29 (-0.01)	17.60	17.58 (-0.02)
GRE44870	17.04	17.02 (-0.02)	17.31	17.27 (-0.04)
GRE44600	16.95	16.92 (-0.03)	17.19	17.14 (-0.05)
GRE44400	16.84	16.83 (-0.01)	17.06	17.06 (0.00)
GRE44200	16.80	16.82 (+0.02)	17.03	17.05 (+0.02)
GRE44100x	16.79	16.80 (+0.01)	17.02	17.03 (+0.01)
GRE44050x	16.78	16.78 (0.00)	17.01	17.01 (0.00)
GRE44000	16.77	16.77 (0.00)	17.00	17.00 (0.00)
GRE43900x	16.77	16.77 (0.00)	16.99	16.99 (0.00)
GRE43800	16.76	16.76 (0.00)	16.99	16.99 (0.00)
GRE43400	16.67	16.67 (0.00)	16.88	16.88 (0.00)
GRE42000	16.12	16.12 (0.00)	16.33	16.33 (0.00)

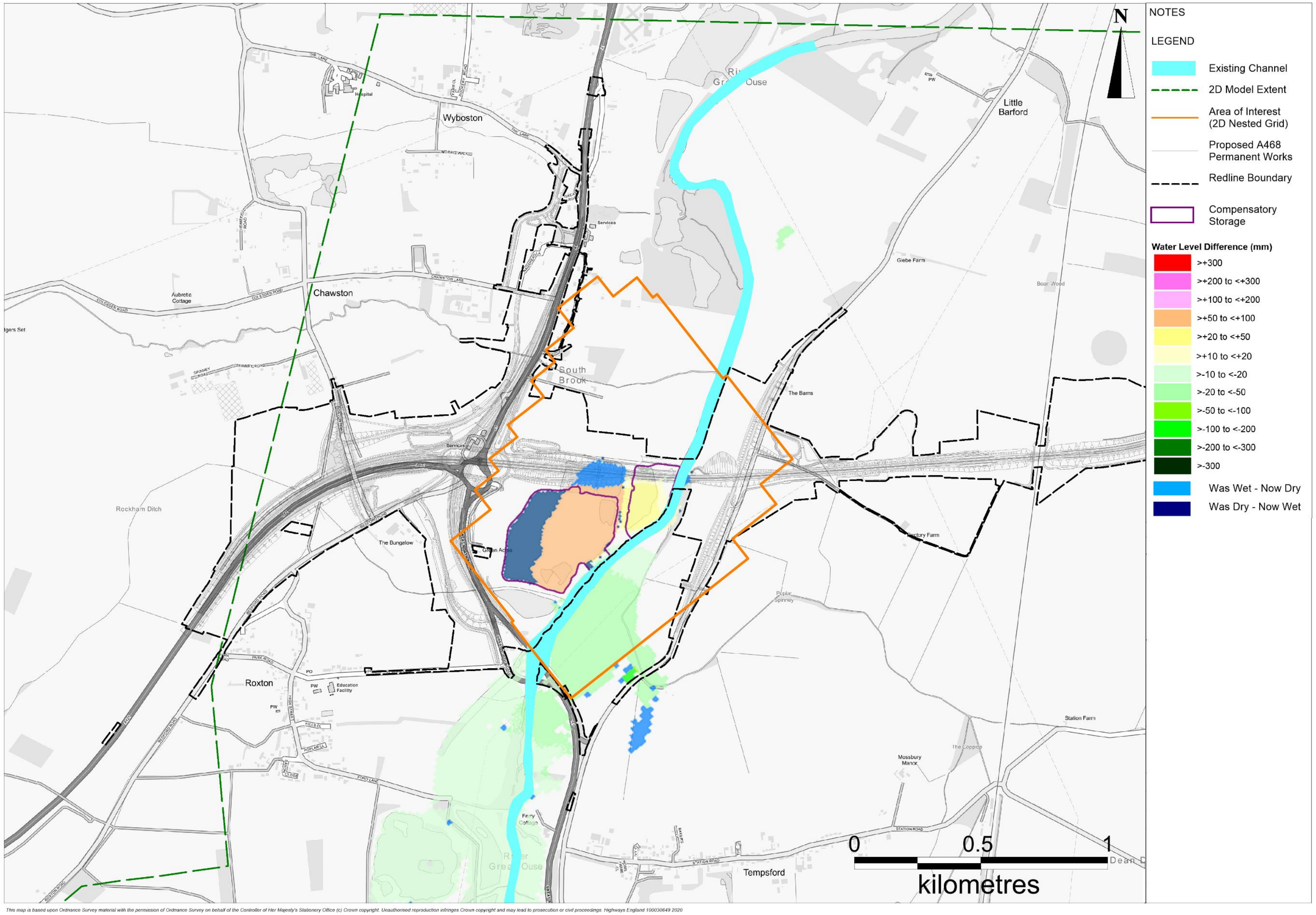


Figure 3-9: Maximum Water Level Difference Map, Permanent Plus Temporary vs Baseline, 5% AEP

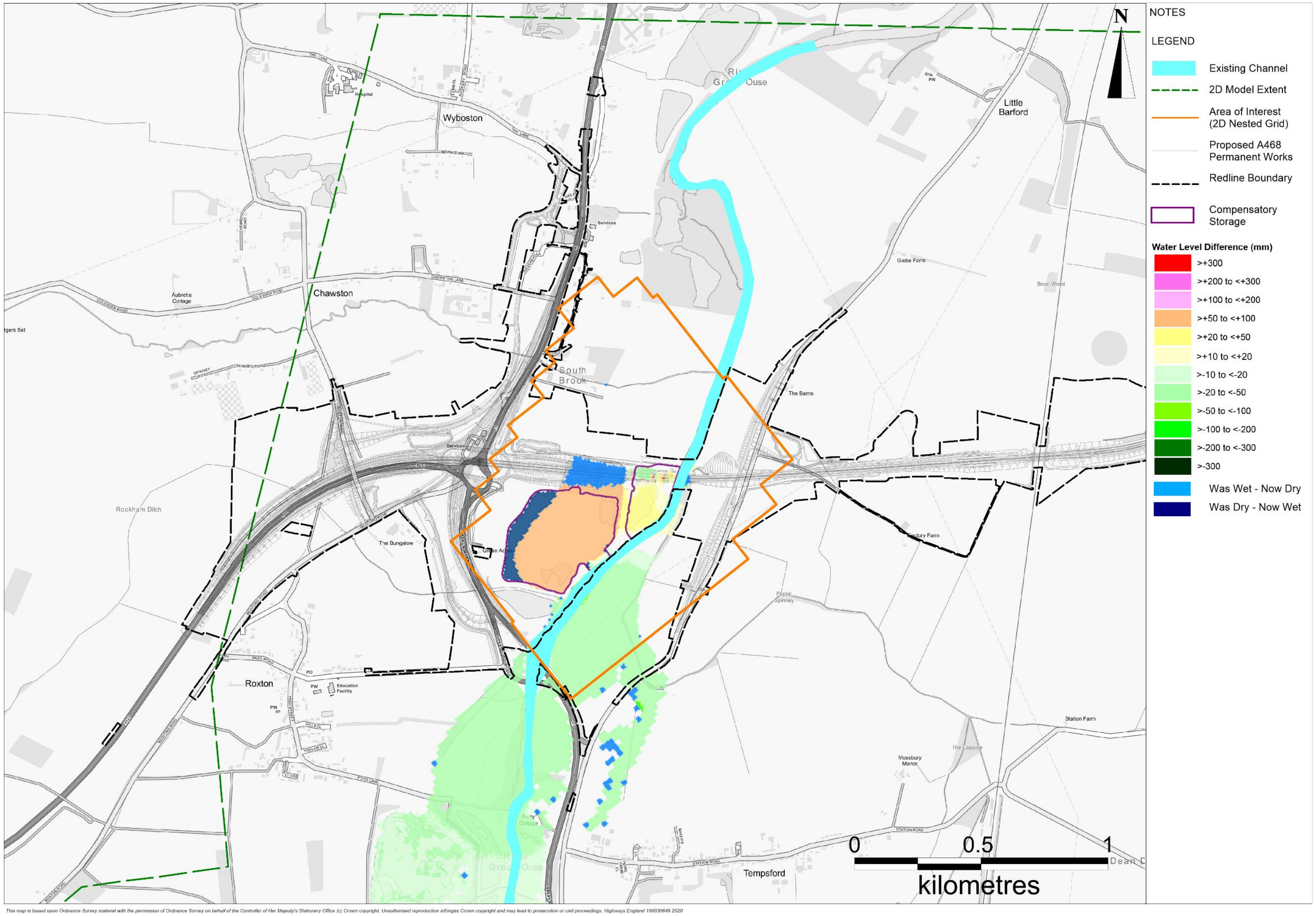


Figure 3-10: Maximum Water Level Difference Map, Permanent Plus Temporary vs Baseline, 1% AEP

3.5 Sensitivity analysis

3.5.1 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. 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 + 35% climate change design event:

+/- 20% 1D channel and 2D floodplain Manning's Roughness Coefficients

+/- 20% Model Inflows; and

+/- 20% downstream boundary gradient.

3.5.2 **Table 3-3** shows the percentage change in 1D channel water level the through the hydraulic model when compared to the baseline scenario for each of the sensitivity scenarios at the model nodes shown in **Figure 3-6**. It can be seen from **Table 3-3** that the maximum in-channel water level through the model does not increase or decrease by +/-5% for any of the sensitivity simulations. This indicates there is an intuitive and reasonable response in maximum water level to changes to the chosen parameters.

3.5.3 Maximum water level difference plots comparing the sensitivity scenarios to the baseline corroborate this conclusion and can be found in Appendix F for reference.

Table 3-3: 1D In-Channel Maximum Stage Sensitivity Results, 1% AEP + 35% Climate Change

		Maximum Stage (m AOD) (% change of in-channel water depth compared to baseline)						
Label	Bed Level (m AOD)	Baseline	-20% DS	-20%n	-20%q	+20% DS	+20%n	+20%q
GRE45600	12.96	17.95	17.95 (0%)	17.75 (-4%)	17.68 (-5%)	17.94 (0%)	18.12 (+4%)	18.19 (+5%)
GRE44600	13.12	17.41	17.41 (0%)	17.26 (-3%)	17.24 (-4%)	17.41 (0%)	17.54 (+3%)	17.56 (+3%)
GRE44050x	12.66	17.24	17.25 (0%)	17.10 (-3%)	17.07 (-4%)	17.24 (0%)	17.37 (+3%)	17.39 (+3%)
GRE43800	12.13	17.22	17.22 (0%)	17.08 (-3%)	17.05 (-3%)	17.22 (0%)	17.34 (+2%)	17.36 (+3%)
GRE43400	12.28	17.1	17.10 (0%)	16.96 (-3%)	16.94 (-3%)	17.10 (0%)	17.22 (+2%)	17.24 (+3%)
GRE42000	12.29	16.49	16.50 (0%)	16.38 (-2%)	16.37 (-3%)	16.47 (0%)	16.56 (+2%)	16.56 (+2%)

3.5.4 It is important to highlight that the adjustment of the downstream boundary has a negligible impact on the peak water levels and peak flows within the study area and therefore indicates that the schematisation of the downstream boundary does not have a significant impact on results within the study area. This builds confidence that the assessment of the flood risk to and from the Scheme is robust.

3.5.5 It can be concluded that the model shows an intuitive and reasonable response to changes to Manning's Roughness Coefficients, Model Inflows and downstream boundary gradient parameters and is suitable to assess the flood risk impacts of the Scheme.

3.6 Summary

3.6.1 The baseline scenario shows a good level of agreement with the Environment Agency Flood Zone Mapping with localised differences primarily resulting from the inclusion of the proposed quarry restoration levels. The baseline modelling completed here is considered the most up to date for this area, and therefore would supersede the EA Flood Zone mapping once reviewed and adopted (in line with methodology agreement with the EA).

3.6.2 Hydraulic model results for the proposed permanent Scheme scenario show that there is a general decrease in maximum flood depths upstream of the Scheme across all design events when compared to the baseline scenario. This is primarily attributable to the increased floodplain storage provided within the quarry restoration area and the inundation of the floodplain earlier in the simulation. Furthermore, the modelling shows that flows and levels downstream of the Scheme are in line with the existing baseline scenario, indicating no downstream flood risk detriment as a result of the Scheme.

3.6.3 Residual increase in maximum flood depths is observed on the right bank of the River Great Ouse immediately upstream of the Scheme where there is an increase of +10mm to +50mm. This area is agricultural land and floods to a depth of greater than 1m in the 1% AEP + 35% climate change event. This area of land is not considered to be a vulnerable receptor. The flood risk implications of this will be discussed in further detail within the main FRA report.

3.6.4 The inclusion of the temporary works, to assess flood risk impact during the construction phase of the project, shows results that are similar to those for the proposed permanent scenario. Therefore, it can be concluded that model results show the inclusion of the temporary works have a negligible impact on flood risk to and from the Scheme and the conclusions are consistent with those discussed in Section 3.3. There is no increased flood risk upstream or downstream of the Scheme outside of the Order Limits.

3.6.5 Sensitivity analysis on the model inflows, Manning's Roughness Coefficient and downstream boundary gradient shows that the hydraulic model reacts in an intuitive and reasonable way to the changes in model parameters. This provides additional confidence in the modelling results and outcomes of the assessment.

4 Limitations

4.1 Hydrology limitations

4.1.1 Uncertainties associated with hydrological inflows generated through FEH methods are typically the largest source of uncertainty associated with hydraulic modelling. Ungauged catchments peak flows estimated through the best available FEH methods are associated with an uncertainty of +/- 40%, this level of uncertainty is generally lower where the catchments are gauged. Saliently, the Scheme has been demonstrated to have only a small localised detrimental effect upstream and no downstream detrimental effects across all design events, including the 1% AEP + 65% climate change event, improving confidence that the assessment of the Scheme is robust to uncertainties associated with hydrological inflows.

4.1.2 Hydrological inflows within model have been simplified to represent smaller watercourses such as Rockham Ditch and South Brook using lateral inflows. It is expected that the magnitude of these inflows would be small compared to total River Great Ouse flow through the area of interest and therefore this is considered an acceptable assumption for the purposes of the Scheme assessment.

4.2 Hydraulic model limitations

4.2.1 A coarse grid cell size of 20m has been used for the majority of the hydraulic model and a grid cell size of 10m used within the area of interest. This means that any topographical features that are smaller than this size may not be fully represented within the model. Given the scale of the River Great Ouse along with the key Scheme elements, model grid cell size is nevertheless considered acceptable for the Scheme assessment as per the agreed methodology with the Environment Agency.

4.2.2 The hydraulic representation of the A1 crossing has been simplified through the floodplain to allow free flow under the road. This is considered to be conservative approach for the assessment of the Scheme because the existing culvert arrangement beneath the A1 roadway would likely to restrict overland flow into the area of interest. Without this restriction a greater peak flow is likely to reach the proposed River Great Ouse viaduct. It is recommended that future local hydraulic modelling studies review this representation of the A1 crossing.

4.2.3 The supplied elevations and water levels for the proposed restored quarry are assumed to be the local ground levels at the beginning of construction for this project. If the proposed elevations are changed through planning prior or during construction of the A428, then the hydraulic model should be updated and any topographic changes included within the model.

4.3 Data limitations

4.3.1 All channel survey data has been retained from the existing 2015 Lower Ouse model. This channel survey was predominately completed in 1991. The original survey was not available for review and therefore the quality of the survey could not be assessed. The three additional survey sections procured for this study show a good correlation to the 2015 Lower Ouse model and therefore build confidence in the existing survey.

4.3.2 Another large source of uncertainty commonly associated with hydraulic modelling is attributable to the data utilised to define floodplain topography. The composite DTM utilised here comprises a combination of 2m resolution EA LiDAR flown across a range of dates. The accuracy of the LiDAR DTM is restricted by grid resolution and filtering to remove vegetation and other surface features and therefore has a stated accuracy of +/- 150mm.

5 Summary and conclusions

5.1 Permanent Scheme scenario

5.1.1 Hydraulic modelling of the River Great Ouse has been completed for a range of design flood events and changes in flood risk attributable to the proposed A428 Scheme assessed.

5.1.2 Within the proposed permanent scenario, for the 1% AEP + 35% climate change design event, changes in flood depth attributable to the Scheme are localised around the Scheme elements. Inclusion of the proposed floodplain compensation storage area successfully offset the loss in floodplain volume associated with the Scheme embankment, whilst their capacity results in a reduction in peak water levels immediately upstream of the Scheme. Modelling results demonstrate that flows and levels downstream of the Scheme are maintained in line with the baseline, showing that there is no downstream flood risk detriment associated with the Scheme.

5.1.3 Small increases in peak water level (+10mm to +50mm) occur on agricultural land on the right bank immediately upstream of the Scheme. Importantly, these increases in water level occur at a location that floods to depth greater than 1m and does not coincide with any vulnerable receptors. The flood risk implications for this are discussed in further detail within the main FRA report.

5.1.4 A resilience assessment using the extreme 1% AEP + 65% climate change event shows that the proposed permanent Scheme is robust and shows a similar response to the 1% AEP + 35% climate change design event. Flood risk mapping demonstrates that the Scheme is also robust for the other simulated AEPs.

5.1.5 It can be concluded that, from a fluvial flood risk perspective, the River Great Ouse viaduct and accompanying mitigation measures do not cause a significant increase in flood risk upstream or downstream.

5.2 Permanent + temporary Scheme scenario

5.2.1 Hydraulic modelling of the River Great Ouse has been completed for the 5% AEP and 1% AEP present day design flood events and changes in flood risk attributable to the Scheme assessed. This modelling provides an assessment of the worst-case scenario for the construction phase of the Scheme.

5.2.2 Modelling results demonstrate that there is no significant increase or decrease in flood levels upstream or downstream of the Scheme as a result of the temporary works. Results from the permanent plus temporary Scheme scenario are consistent with the permanent Scheme scenario, and the same conclusions can therefore be drawn.

Appendix A Black Cat Quarry Restoration Elevations

Restoration aims

- Preservation of the 'best and most versatile' soil resource and restoration of an equivalent area of Grade 3A agricultural land.
- Achieve an acceptable naturalistic regraded landform.
- Avoid disturbances to existing areas of ecological interest and provide a significant long term improvement in biodiversity.
- Retain or improve local flood storage capacity.

Planting specification for all woody plants

All planting material used will be cell grown 1+1 stock, sized 40-60cm (or nearest available), with moist, fibrous roots systems and will comply with the BS 3936 Part 1 for Nursery Stock and Part 4 for Forest Trees. The plants will be notch planted with the original root collar at ground level. Roots will be spread out in the planting notch before firming soil around the plant.

Woodland planting will be carried out in a staggered spacing of 2 x 2 metres. All main tree species will be planted in single species group sizes of 5-12 throughout all the compartments. Minor tree species and woody shrubs will be planted along the compartment edges to approximately 4m wide, in small mixed species of 5-12. The boundary between the main trees and the surrounding shrubs will be irregular to avoid a stepped effect.

Willow carr will be planted in a random pattern of approximately 10m centres over 80% of the total area. Goat willow and Guelder rose are the shrub species to be planted at 5m centres over 20% of the total area. All species would be planted in single species group sizes of 3 to 5.

Hedgerow planting will be on a pre-prepared cam, in 2 staggered rows at 25cm apart with plants at 50cm spacing. The closest row of the hedge should be positioned approximately 60cm from the fence. The hedgerow trees will be the same sized stock but planted frequently, at random intervals equating to 1 per 20m run of hedge. The plant protection will promote the growth of the hedgerow trees.

Plant protection

All woody plants will be protected by 0.6m guards to be Tubex (or equal approved), apart from holly which will have a mesh guard. These would be fitted on the day of planting. The guards will be pushed into the ground around the tree and fixed to the supporting tree stake by 1 ratchet tie.

The stakes will be pressure-treated softwood - 32 mm x 32 mm and at least 75 cm in length for all plants apart from the hedgerow trees which will be at least 1.4m in length. The stakes will be driven into the ground at least 15 cm, so that the stake top for hedgerow plants is below the height of the guard. If this is not possible due to ground conditions, then the protruding end of the stake will be sawn off.

The hedgerow tree stakes will be not be sawn off but will be allowed to protrude above the guard. This will highlight where the trees are for management but allow for the higher success rate of smaller plants. The stakes will always be positioned on the west side of the tubes.

Field boundaries to be enclosed by a stock proof fence (refer to Drawing 2296/LS/3). Fences to be set out to follow land ownership boundaries. Each hedgerow will be enclosed by a double row of stock proof fencing, one of which may be the land ownership boundary fence, to protect the hedgerow from grazing stock.

Woodland		%
Alnus glutinosa	Alder	12
Corylus avellana	Hazel	5
Crataegus monogyna	Hawthorn	10
Fagus sylvatica	Beech	10
Ilex aquifolium	Holly	5
Prunus spinosa	Blackthorn	5
Quercus robur	Oak	15
Rosa canina	Dogrose	5
Salix alba	White willow	12
Salix caprea	Goat willow	6
Salix fragilis	Crack willow	10
Viburnum opulus	Guelder rose	5

Hedgerow		%
Corylus avellana	Hazel	25
Crataegus monogyna	Hawthorn	25
Ilex aquifolium	Holly	5
Prunus spinosa	Blackthorn	25
Rosa canina	Dogrose	5
Salix caprea	Goat willow	5
Viburnum opulus	Guelder rose	10

Hedgerow trees		%
Acer campestre	Field Maple	40
Sorbus aucuparia	Rowan	35
Quercus robur	Oak	25

Willow carr		%
Alnus glutinosa	Alder	35
Betula pubescens	Downy birch	20
Salix alba	White willow	13
Salix caprea	Goat willow	16
Salix fragilis	Crack willow	10
Populus nigra	Black poplar	1
Viburnum opulus	Guelder rose	5

Reedbed/aquatic margins

Colonisation by native species would be hastened by translocating rooted plants or mud / silt containing root fragments from suitable accessible local donor sites in the vicinity. The material would be placed in the shallow margins of the newly created ponds. These works would be carried out under the supervision of a competent ecologist to avoid the introduction of undesirable species and to promote colonisation.

No topsoil would be used in the restoration of the proposed aquatic margins to maintain low nutrient levels. In the absence of suitable donor material, as to aid species diversity, overseeding with a suitable mix (such as Emorsgate EP1) would be undertaken.

Agricultural grass seeding and cultivations

Following soils restoration, between May and September when the soils are dry and friable, agricultural spring tine harrows or heavy agricultural discs would be used to open the surface and to expose the stone, allowing it to be picked off. Stone larger than 100mm in any dimension would be picked, as well as any materials that could impede agricultural and drainage operations. In the event that it is not possible to carry out suitable cultivations to establish cereal or oil seed crop in the first year, a grazing / conservation grass seed mix would be established. This would be a typical Ryegrass mix that also includes Timothy, Creeping Red Fescue and White Clover and be sown at a rate of 42kg/ha.

Conservation headlands

Conservation headlands will be developed to the eastern side of the fields as a buffer to the nature conservation area at 15m width. A suitable wild pollen and nectar flowers seed mix such as Emorsgate wildflower seed mix (ESF2) will be incorporated into a native species fine grassland mix (ESG2) at a rate of 1 part to 4. Grass mixtures to be sown at a rate of 20kg/ha and wildflowers at a rate of 2kg/ha. These mixes comprise those species detailed in the *Updated Restoration Chapter 7 (dated 24th March 2016)*.

Wet grassland

A seed mix with a wide variety of species to accommodate both wet grassland and drier patches, and suitable for the reinstatement of any ditches following the removal of crossing points. For example Emorsgate Special General Purpose Meadow Mixture Em3 which incorporates 20% wildflower species and 80% grasses, including those suitable for wet grassland. However an on-site assessment of pH and nutrient levels prior to seeding would be undertaken and changes to the mix made as required. This complete mix would be sown at a rate of 35 kg/Ha.

Cut-off drains

Drains to be sub-surface comprising a 100mm diameter land drainage pipe within a ditch backfilled with a 'drainage envelope' of clean gravel / gravel rejects and no fines to a depth of 0.4m to accommodate the maximum elevation of groundwater expected above base and the remainder back-filled with excavated subsoil and topsoil to match the surrounding profile. A minimum gradient of 0.001 is required to accommodate the anticipated flow rate.

Carrier drains

Drains to be sub-surface comprising a non-perforated 160mm ID plastic land drainage pipe connected to the cut-off drains. Placed within a ditch back-filled with excavated subsoil and topsoil to match the surrounding profile with no gravel fill required. Set to a minimum gradient of 0.001.

This drawing is pursuant to Condition 29 of planning consent 14/0255 1/EIAWM. It supersedes drawing BC/LR 1.4; BC/LR 2.3; 2296/LP/1A. It should be read in conjunction with Updated Restoration Chapter 7 (dated 24th March 2016); 2296/LP/2 'Lake Edge Restoration Profiles' (dated September 2015) and 2296/LP/3 'Typical Detail - Fencing and Gates'.

LEGEND

- Site boundary
- Limit of extraction
- Phase boundary
- Proposed contours
- Existing hedgerow and trees
- Existing grassland
- Proposed hedgerow
- Proposed woodland
- Proposed willow carr
- Reinstated agricultural field with Conservation headland
- Proposed wet grassland
- Proposed cut off drain
- Proposed carrier drain
- Approx base of lake in metres aOD
- Proposed waterbody
- Predicted water level winter (approximately 0.5m lower in summer)
- Proposed reedbed / aquatic margin
- Proposed shingle bank
- Pipeline

Rev A: GEA 09 May 17 amendments following email from Central Beds Council dated 30 March

INFORMATION

N

0 metres 100

CLIENT

BREEDON

ESP
- Chartered Surveyors
- Chartered Landscape Architects
- Environmental Consultants
- Health and Safety Consultants

ESP
The Creative Industries Centre
Glaisher Drive
Wolverhampton
WV10 9TG

Tel: 01902 771311

PROJECT		
Black Cat Quarry		
TITLE		
Restoration Details Phases 1-14		
SCALE	DRAWN BY	DATE
1:2,500 @A1	GEA/TSC	Jan 2017
DRAWING NUMBER		REV
B024_2016_004		A

Appendix B Floodplain compensation Storage Volume Calculations

- 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.
- The flood levels are variable along the watercourse, therefore, the maximum flood level shown in Table B1 is indicative for nodes located upstream of Scheme crossing.
- Floodplain compensation storage area calculations undertaken at a level for level interval of 0.2m and are shown in Table B2.
- Following a conservative approach, in-channel floodplain volumes have not been considered in the calculations.

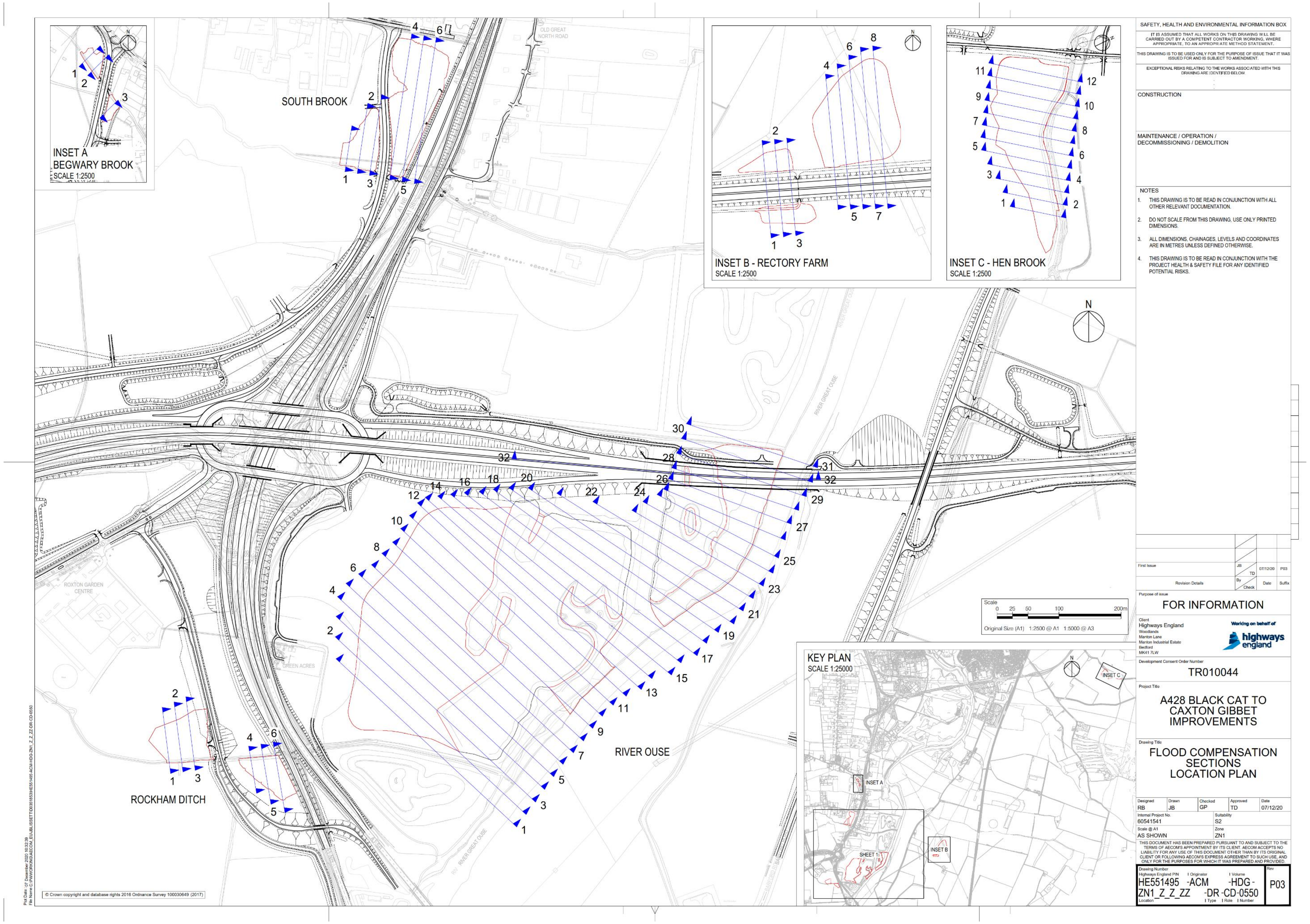
Table B1: Maximum River Great Ouse Flood Level, 1% AEP + 35% Climate Change

Watercourse	Flood level (mAOD)
	1% AEP+35%
River Ouse	17.24

Table B2: Level for Level Floodplain compensation Storage Area Calculations for 1% AEP + 35% Climate Change event

River Great Ouse			
Layer (mAOD)		Floodplain Volumes (m^3) 1% AEP + 35% CC	
Top	Bottom	Floodplain Loss due to Scheme	Floodplain compensation Storage Gain due to Scheme
FL	17.20	800	1100
17.20	17.00	3900	4300
17.00	16.80	3800	5200
16.80	16.60	3700	6100
16.60	16.40	3600	7200
16.40	16.20	3400	8200
16.20	16.00	3100	9200
16.00	15.80	4600	10700
15.80	15.60	3200	6300
15.60	15.40	1500	4100
15.40	15.20	75	3000
15.20	15.00	25	2600
Total		**31700**	**68000 (+36300)**

Appendix C Floodplain compensation Area Cross Sections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SOUTH BROOK
INSET B - RECTORY FARM
SCALE 1:2500
INSET C - HEN BROOK
SCALE 1:2500
ROCKHAM DITCH
RIVER OUSE
KEY PLAN
SCALE 1:25000
INSET A
INSET B
INSET C
SHEET 1
Original Size (A1) 1:2500 @ A1 1:5000 @ A3
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Working on behalf of
highways england
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Designed RB Drawn JB Checked GP Approved TD Date 07/12/20
Internal Project No. 60541541
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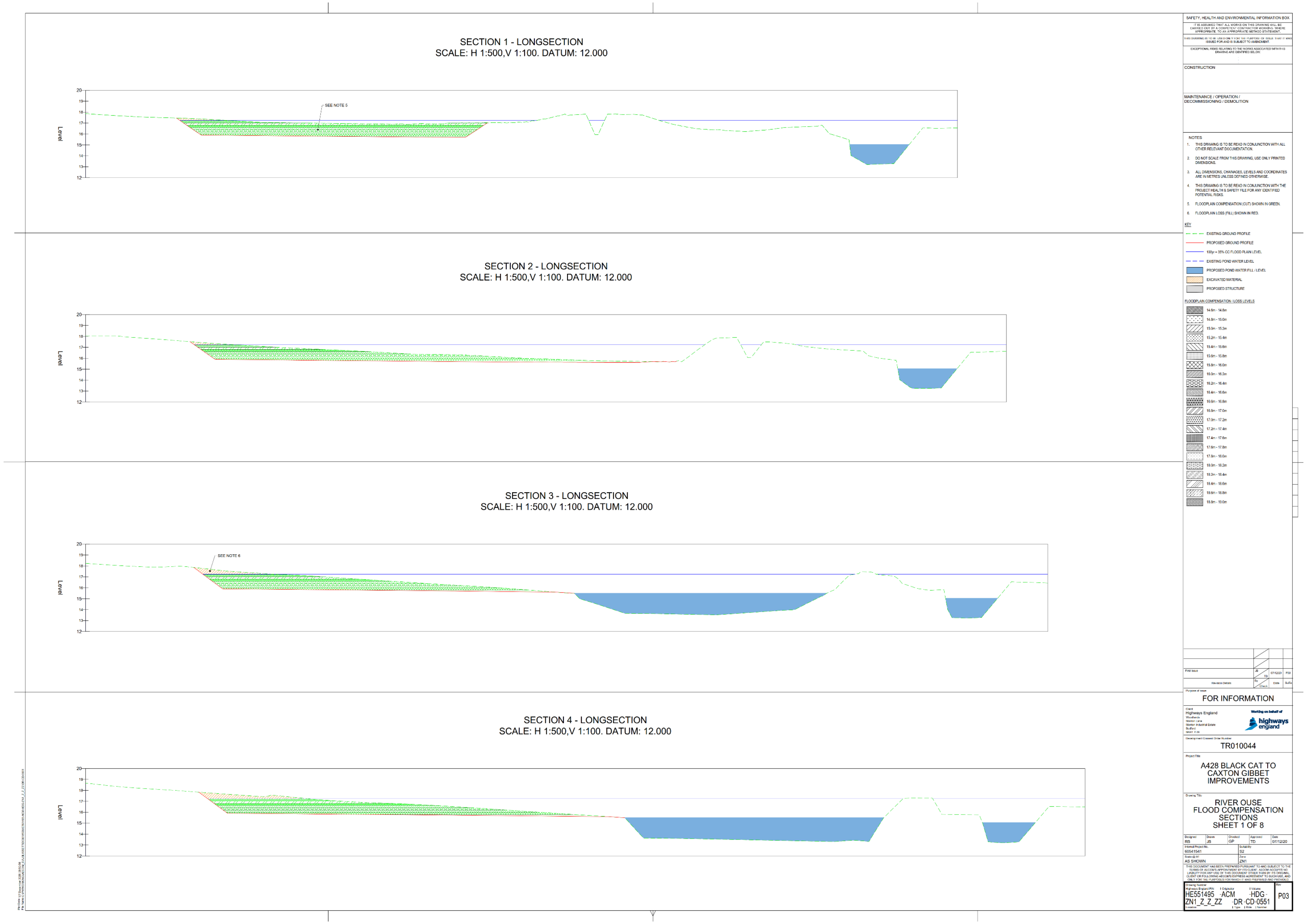
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Manton Industrial Estate
Bedford
MK41 7LW
Working on behalf of
Development Consent Order Number
TR010044
Project Title
A428 BLACK CAT TO CAXTON GIBBET IMPROVEMENTS
Drawing Title
RIVER OUSE
FLOOD COMPENSATION
SECTIONS
SHEET 1 OF 8
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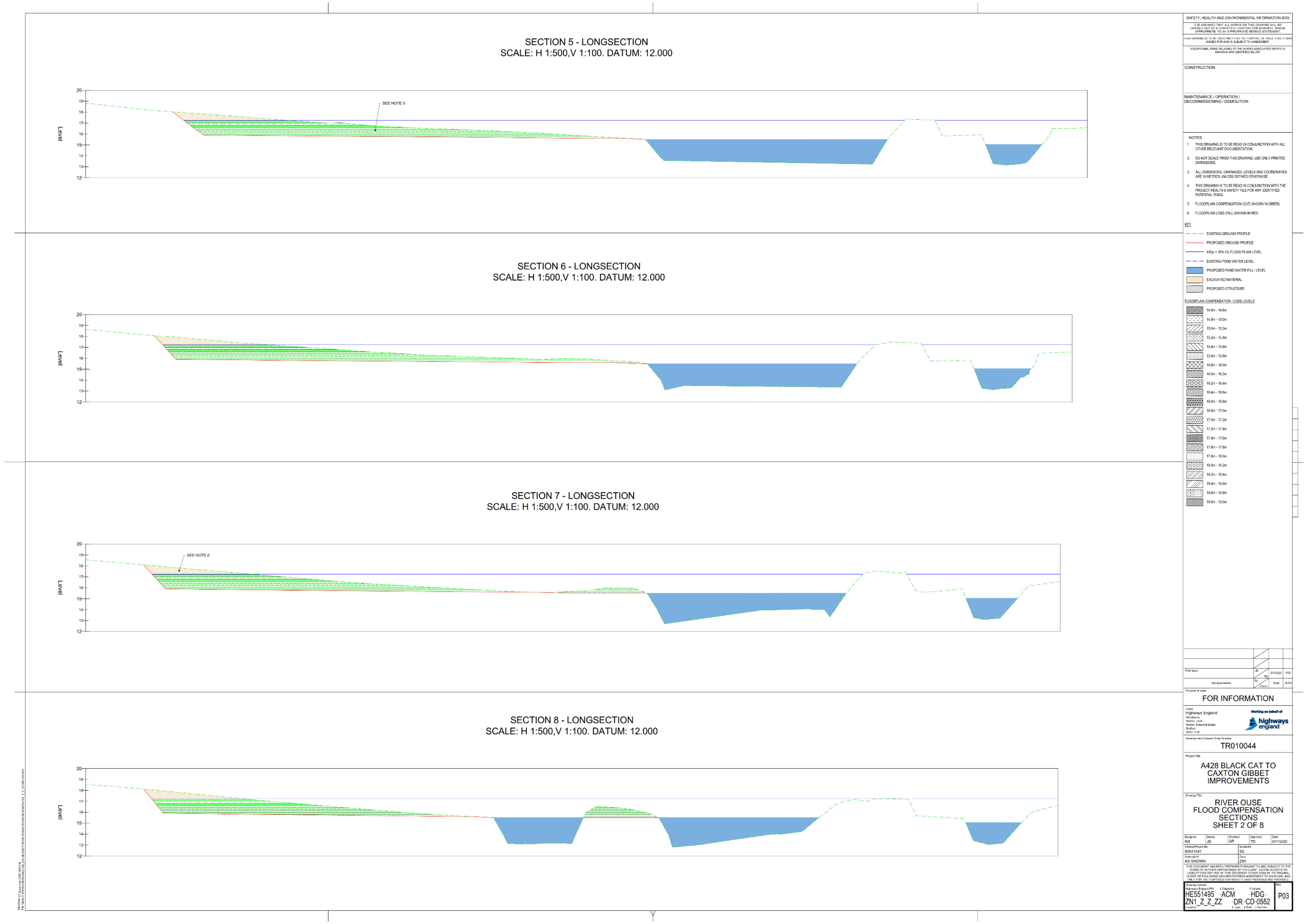
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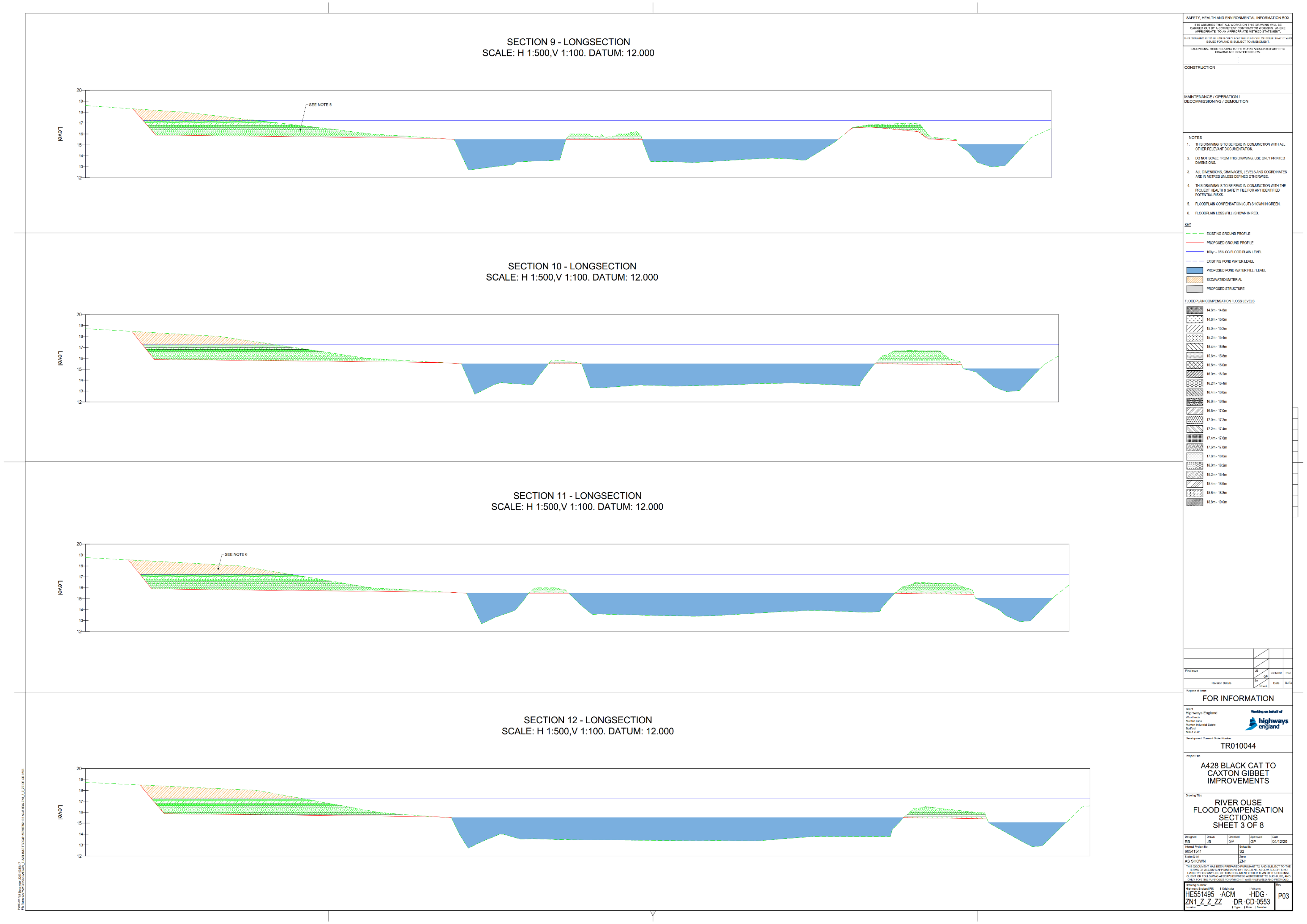
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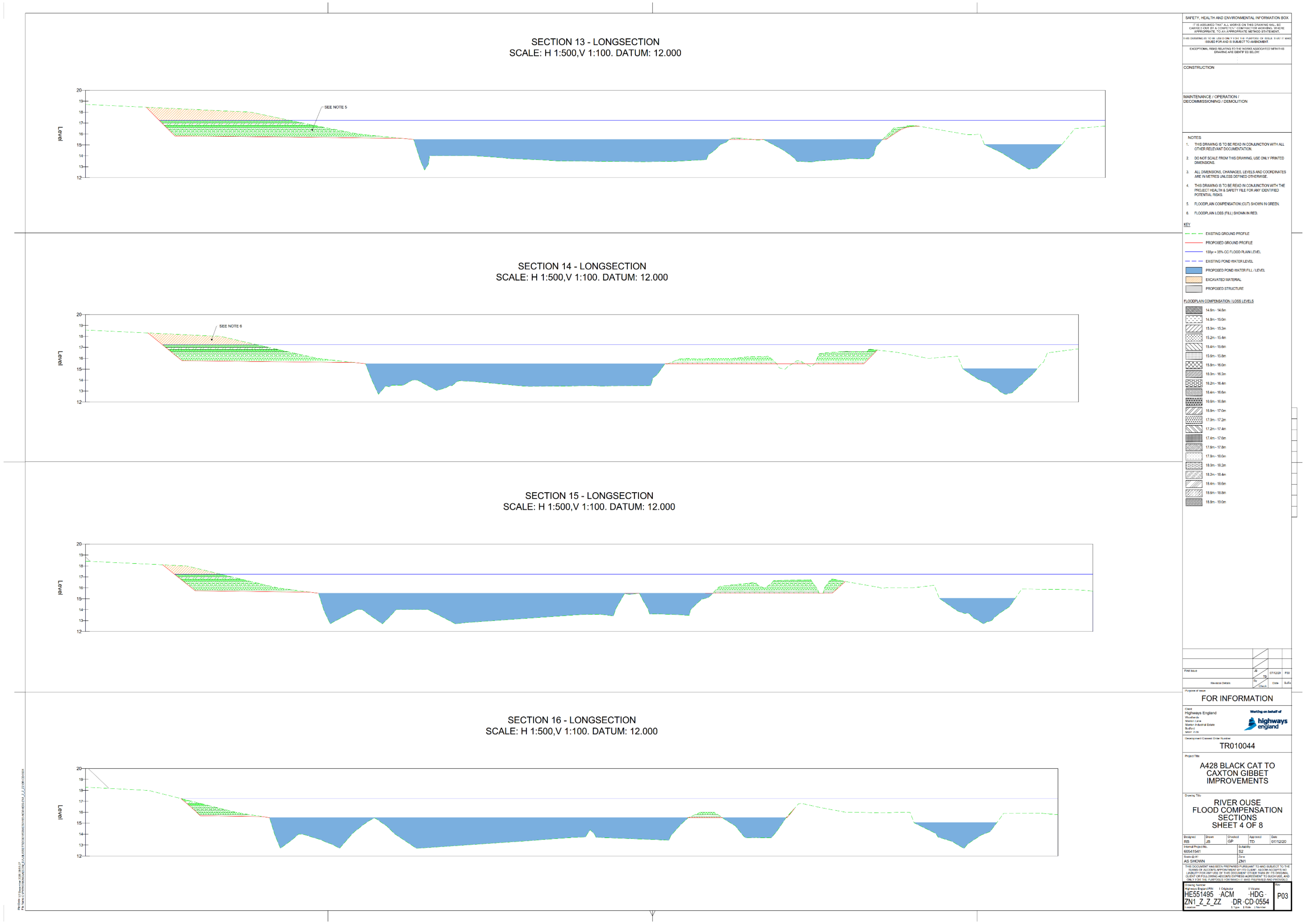
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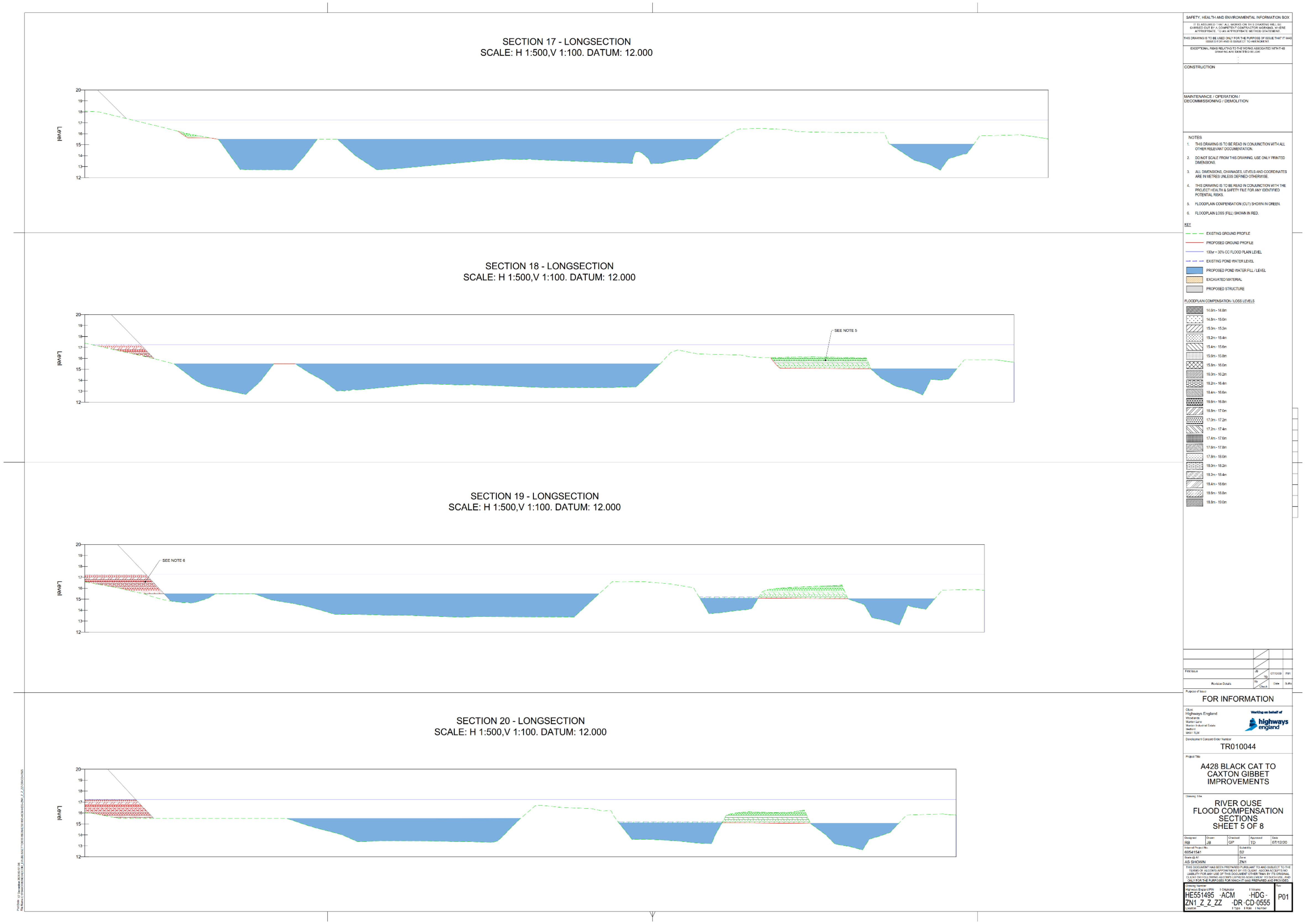
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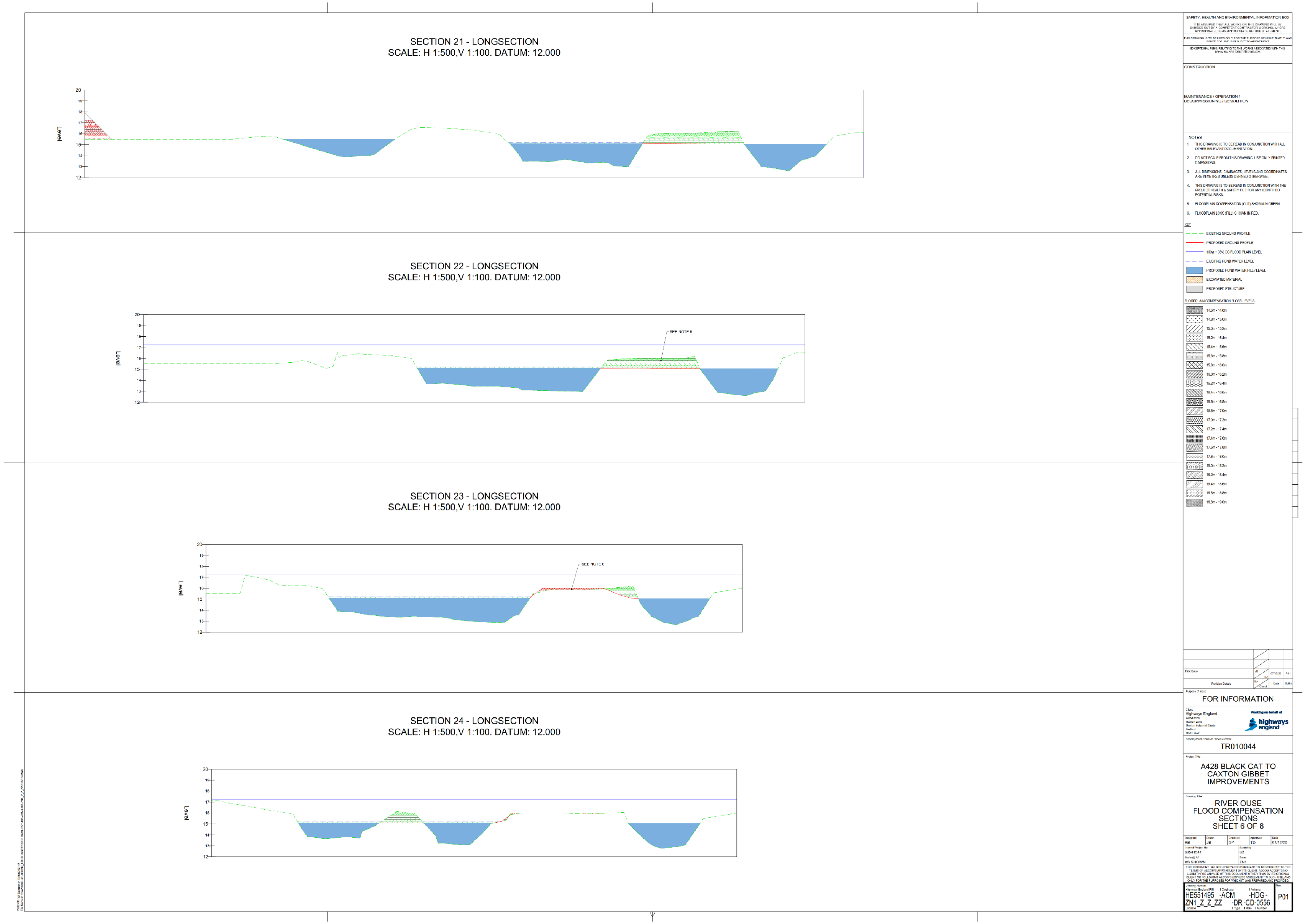
RIVER OUSE FLOOD COMPENSATION SECTIONS SHEET 5 OF 8
P01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SCALE: H 1:500,V 1:100. DATUM: 12.000
SECTION 22 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SEE NOTE 5
SECTION 23 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SEE NOTE 6
SECTION 24 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
Level
First Issue
JB
TD
07/12/20
P01
Revision Details
By
Check
Date
Suffix
Purpose of issue
FOR INFORMATION
Client
Highways England
Woodlands
Manton Lane
Manton Industrial Estate
Bedford
MK41 7LW
Working on behalf of
Development Consent Order Number
TR010044
Project Title
A428 BLACK CAT TO CAXTON GIBBET IMPROVEMENTS
Drawing Title
RIVER OUSE
FLOOD COMPENSATION
SECTIONS
SHEET 6 OF 8
Designed RB
Drawn JB
Checked GP
Approved TD
Date 07/12/20
Internal Project No. 60541541
Suitability S2
Scale @ A1 AS SHOWN
Zone ZN1
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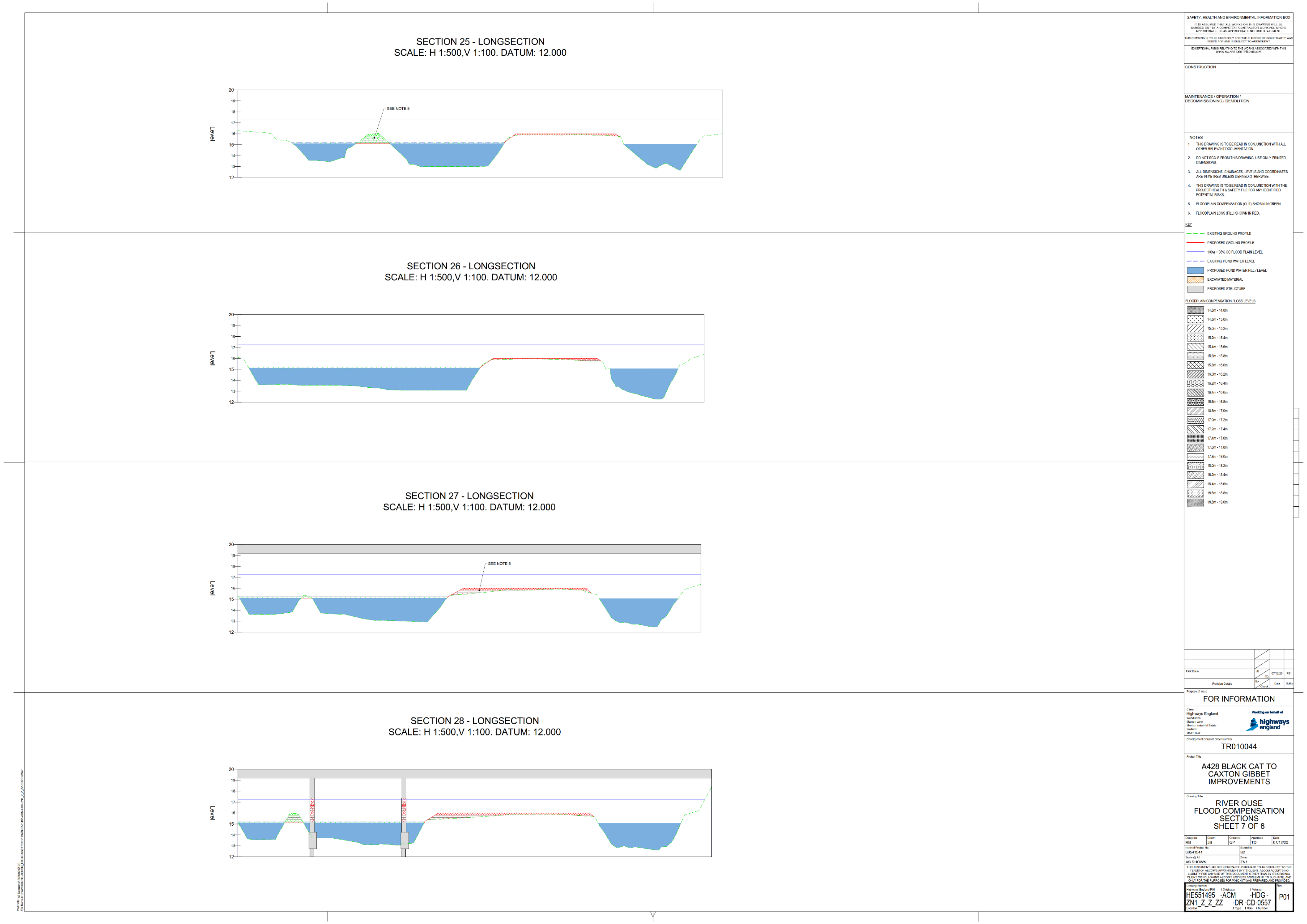
Drawing Number
HE551495 -ACM -HDG -ZN1_Z_Z_ZZ -DR -CD -0556
Rev
P01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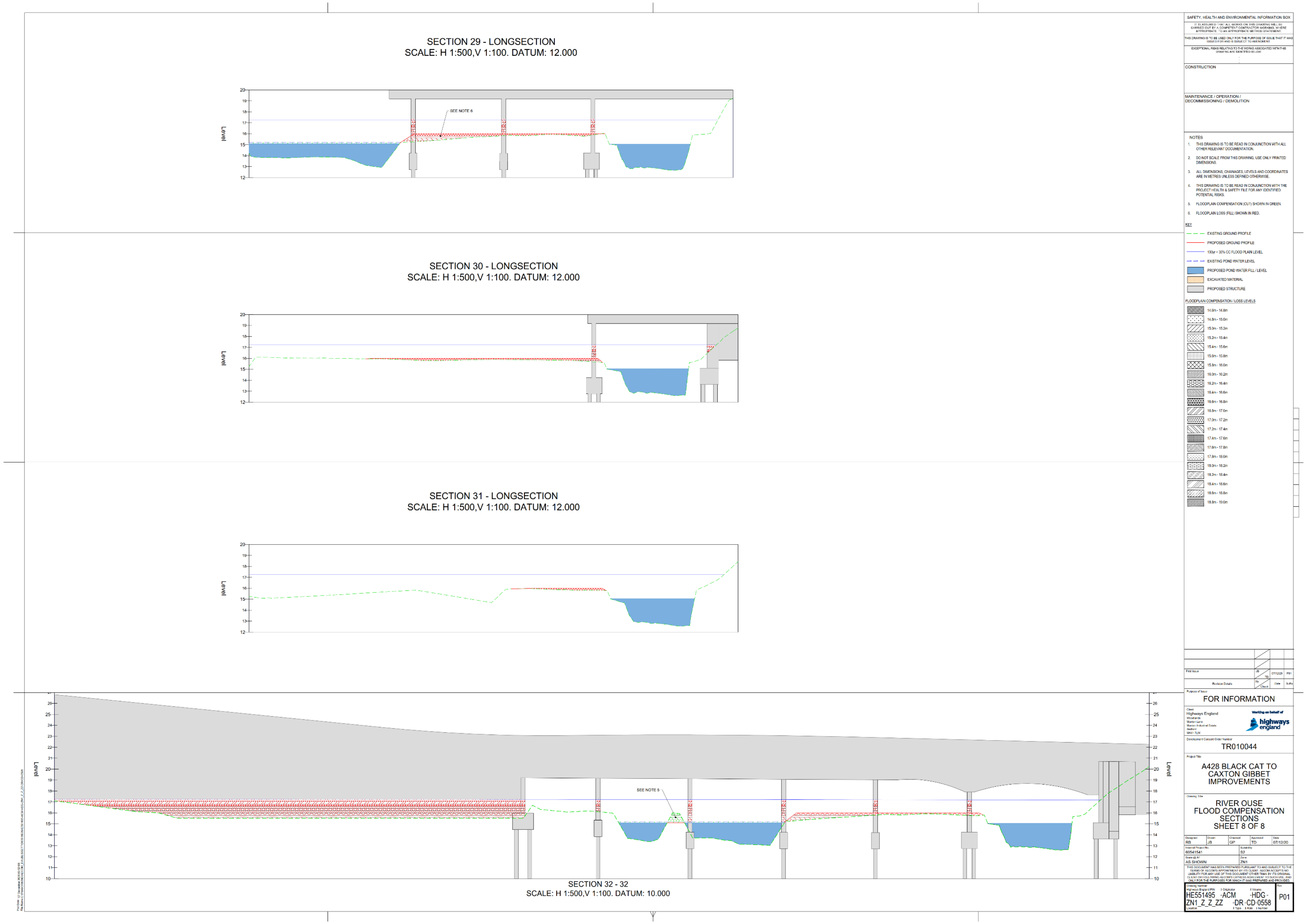
SEE NOTE 5
SECTION 26 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SECTION 27 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SEE NOTE 6
SECTION 28 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
Level
FOR INFORMATION
TR010044
A428 BLACK CAT TO CAXTON GIBBET IMPROVEMENTS
RIVER OUSE FLOOD COMPENSATION SECTIONS SHEET 7 OF 8
HE551495 -ACM -HDG- ZN1_Z_Z_ZZ -DR -CD -0557
P01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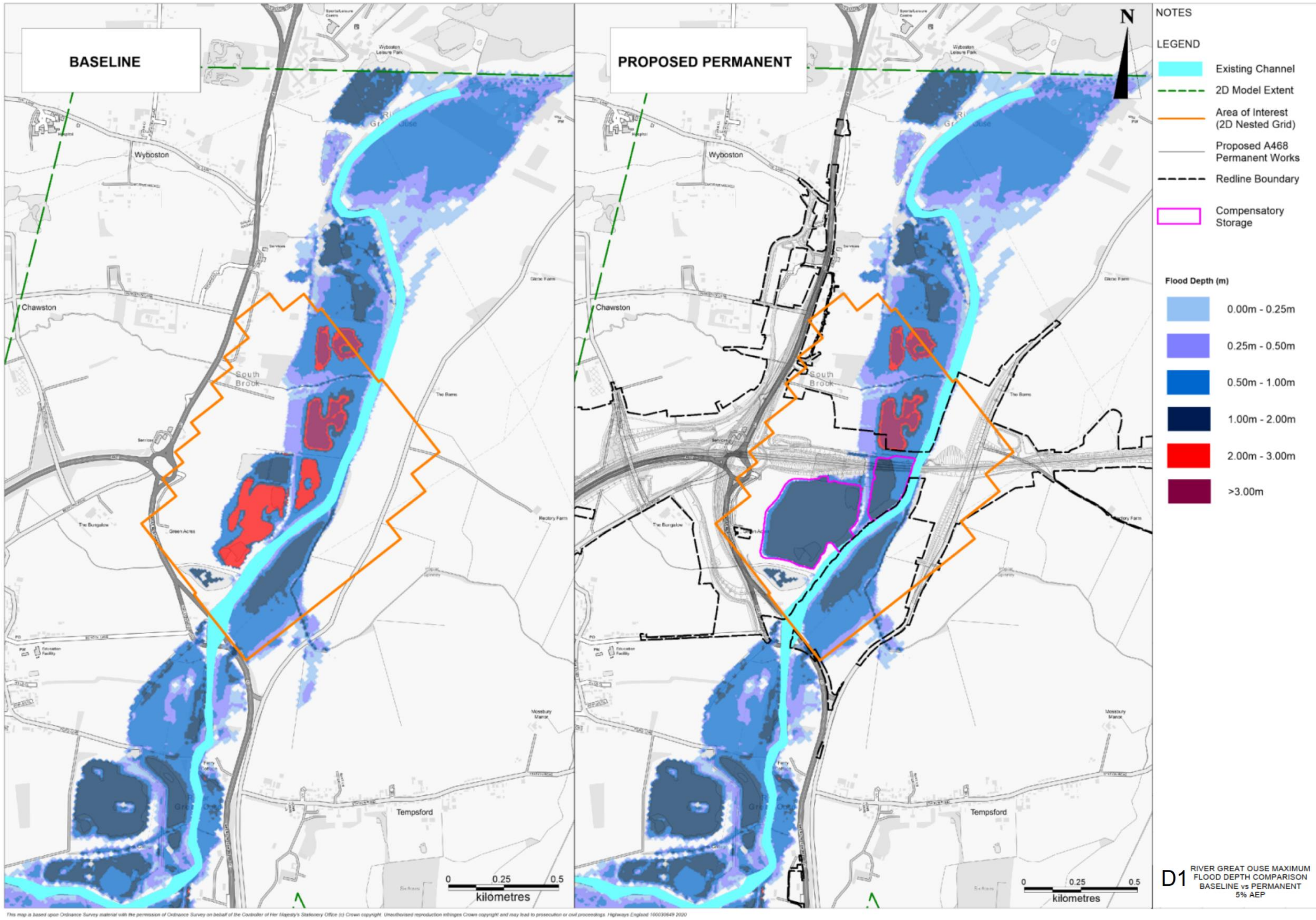
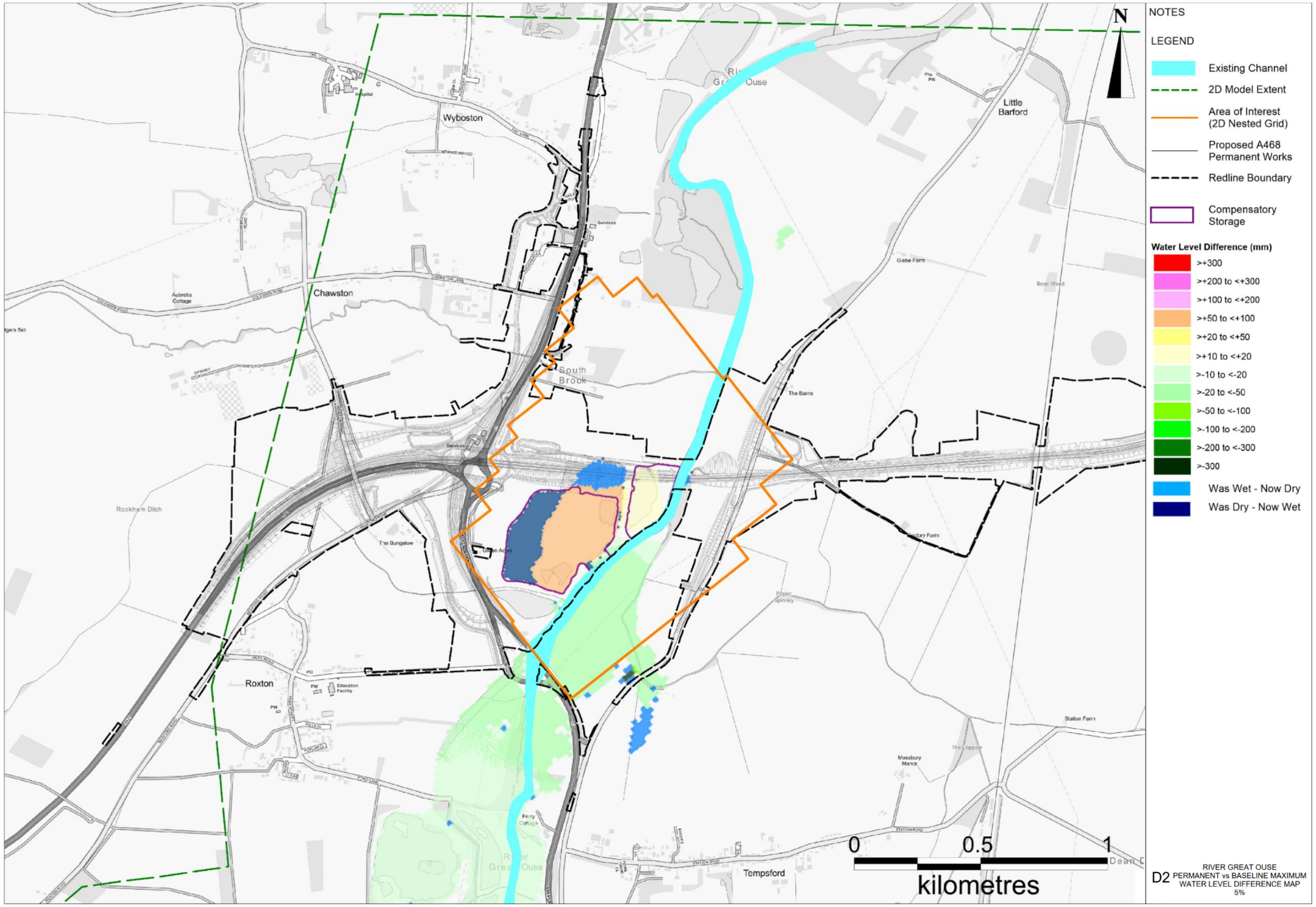
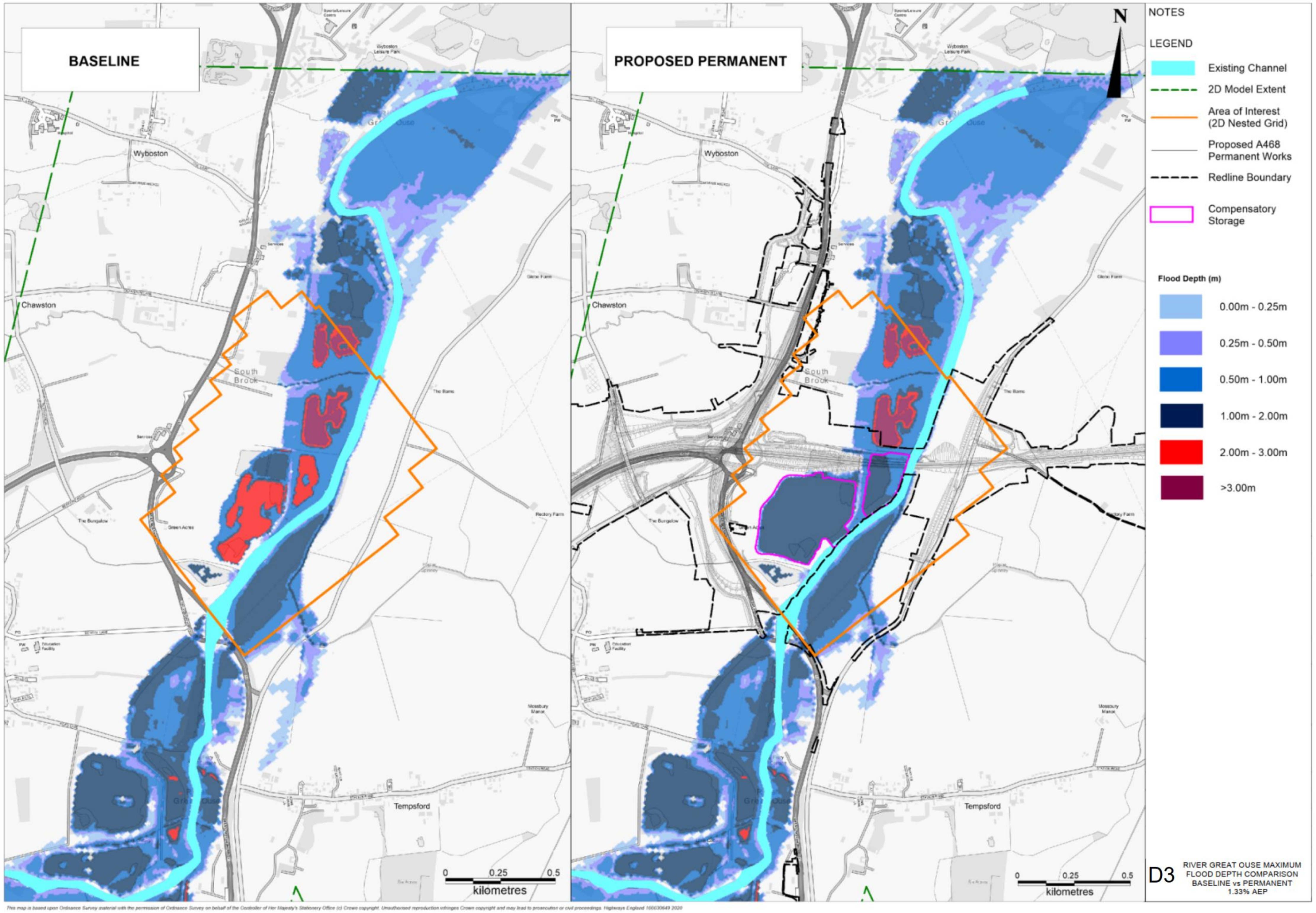
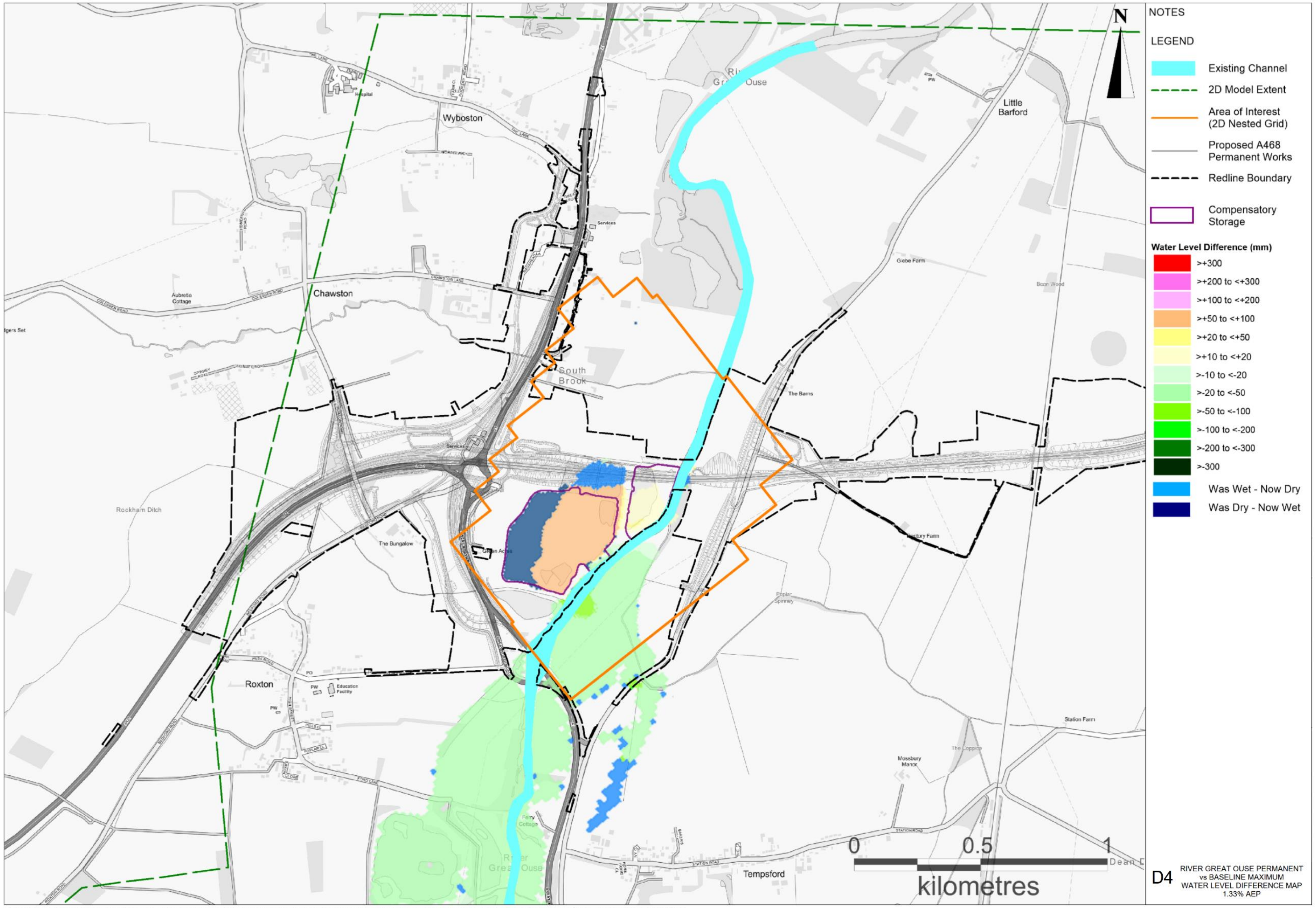
SECTION 30 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SECTION 31 - LONGSECTION
SCALE: H 1:500,V 1:100. DATUM: 12.000
SECTION 32 - 32
SCALE: H 1:500,V 1:100. DATUM: 10.000
FOR INFORMATION
TR010044
A428 BLACK CAT TO CAXTON GIBBET IMPROVEMENTS
RIVER OUSE FLOOD COMPENSATION SECTIONS SHEET 8 OF 8
HE551495 -ACM -HDG-ZN1_Z_Z_ZZ -DR-CD-0558
P01

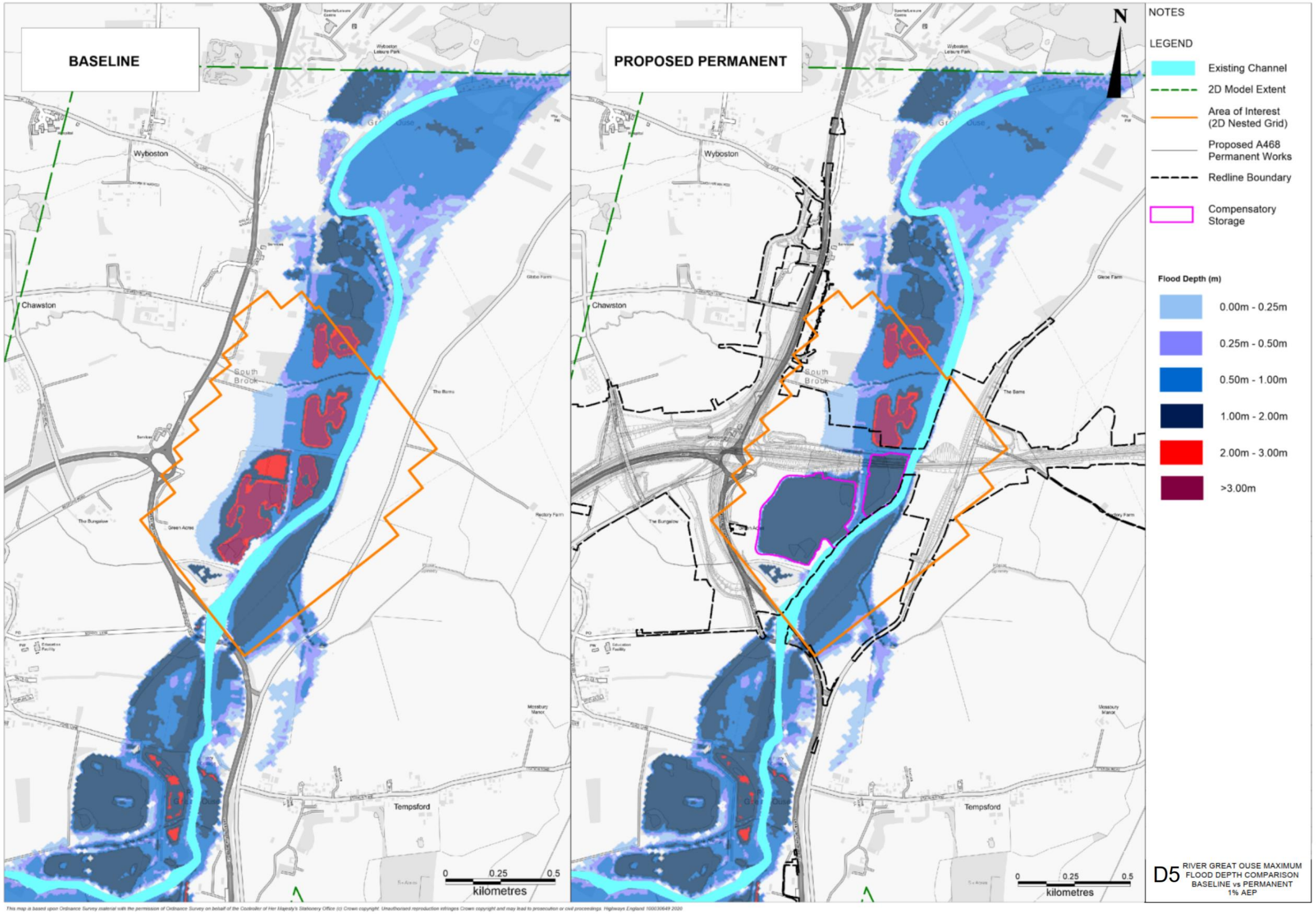
Appendix D Proposed Permanent Model Results

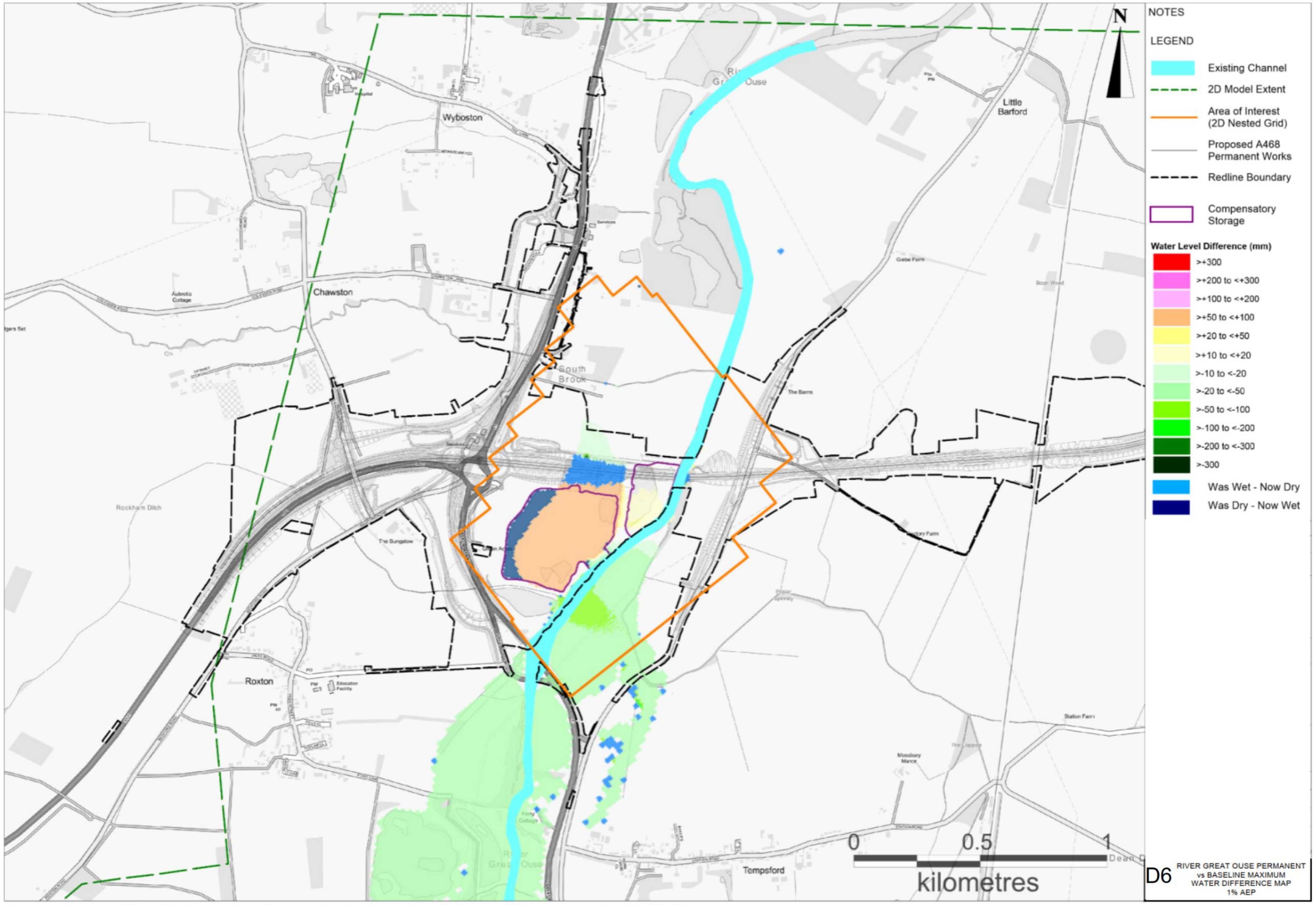

BASELINE
PROPOSED PERMANENT
Wyboston
Chawston
South Brook
Tempsford
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
0
0.25
0.5
kilometres
D1
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT 5% AEP

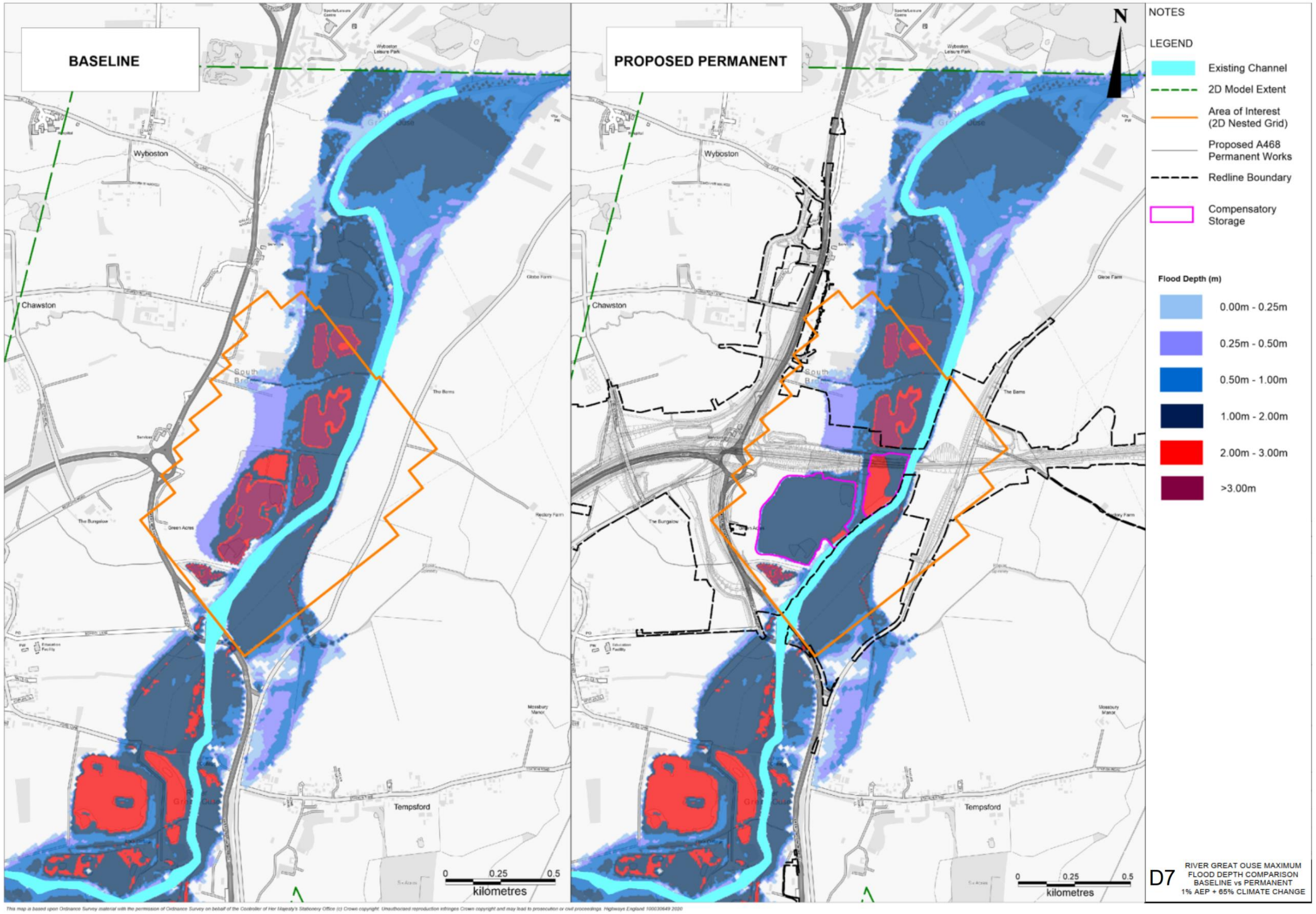

N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Water Level Difference (mm)
>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+20 to <+50
>+10 to <+20
>-10 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Roxton
Tempsford
Little Barford
South Brook
River Great Ouse
0 0.5 1
kilometres
D2
RIVER GREAT OUSE PERMANENT vs BASELINE MAXIMUM WATER LEVEL DIFFERENCE MAP 5%

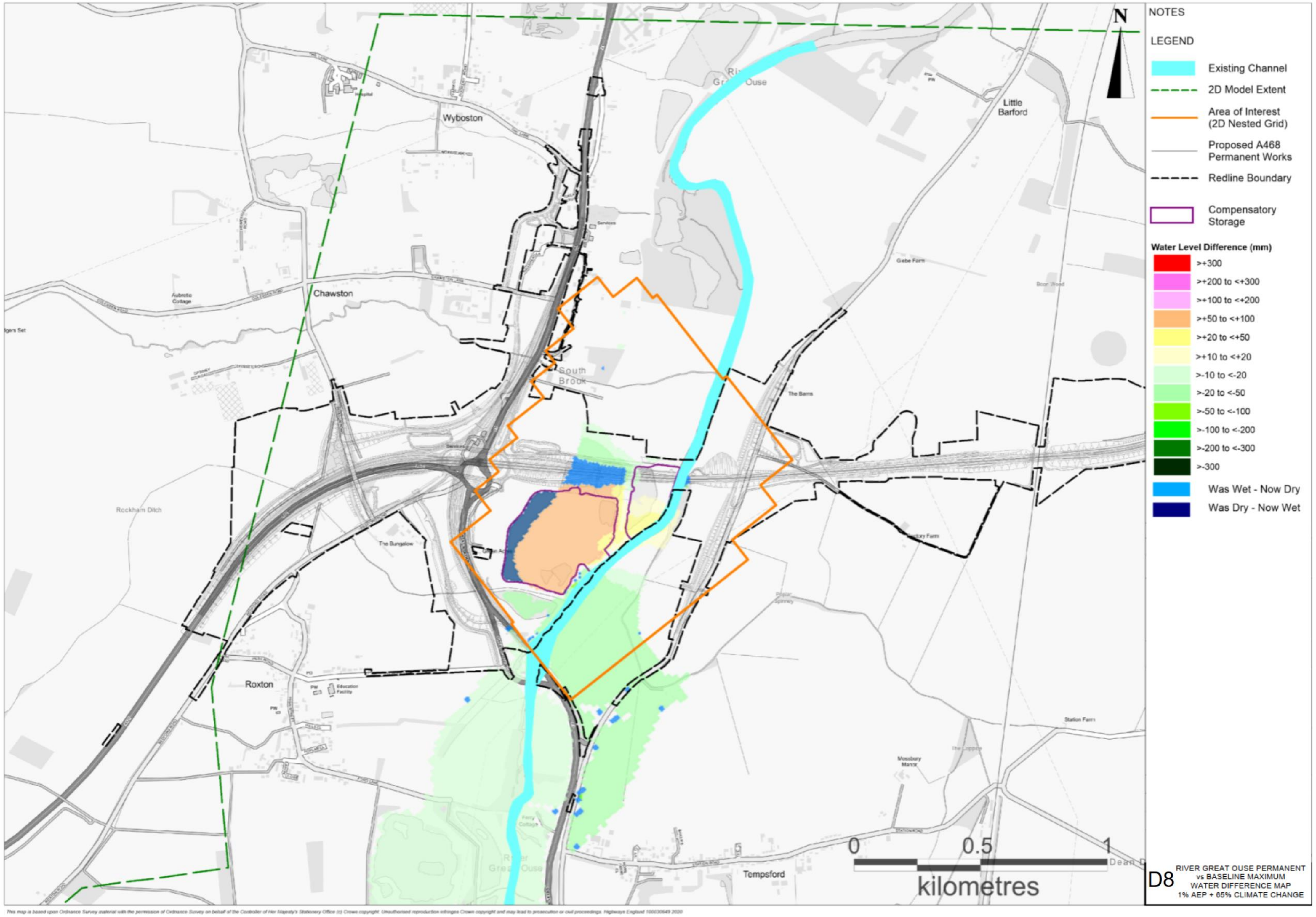

BASELINE
PROPOSED PERMANENT
Wyboston
Chawston
South Brook
Tempsford
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
0
0.25
0.5
kilometres
D3
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT 1.33% AEP

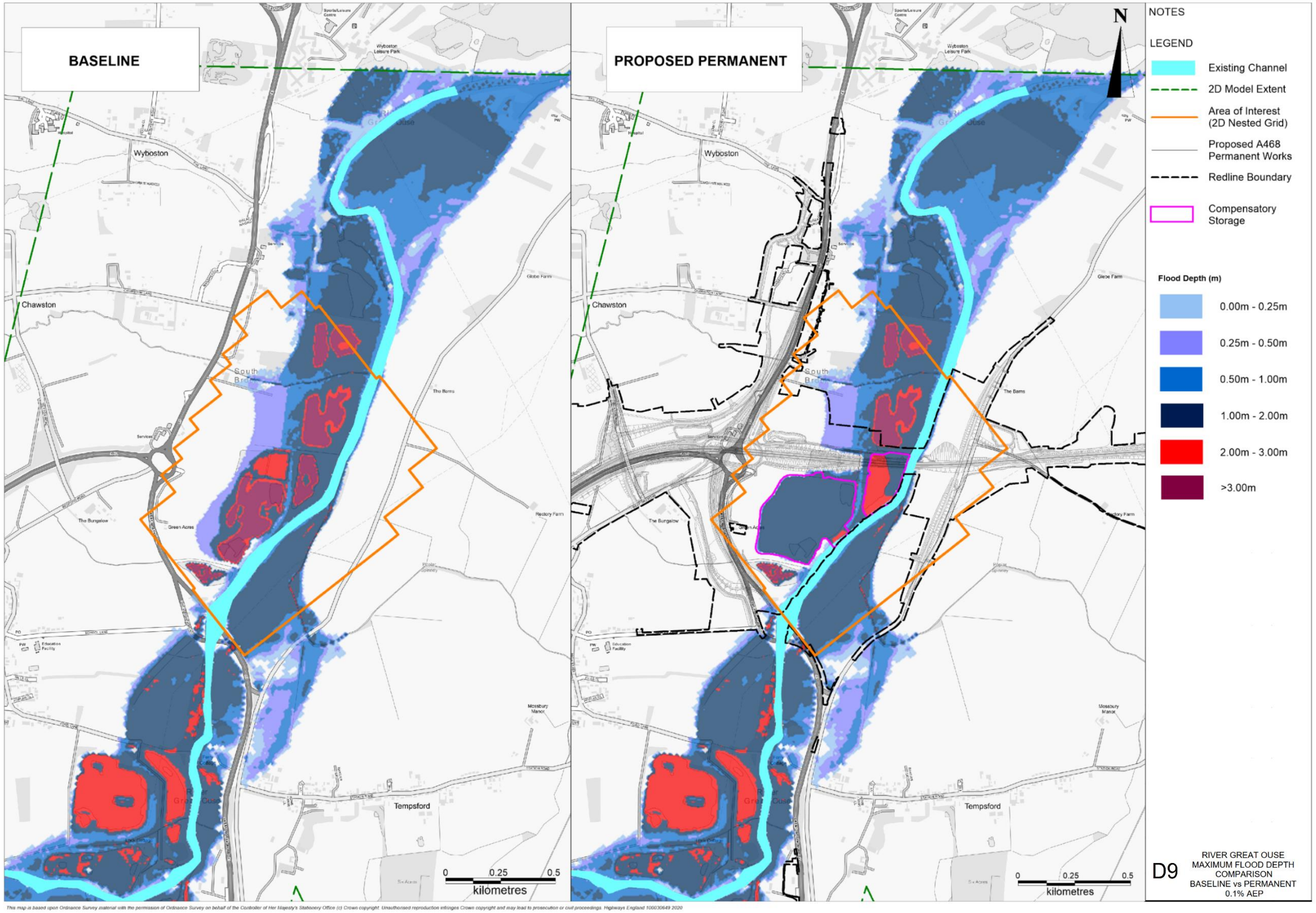

NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Water Level Difference (mm)
>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+20 to <+50
>+10 to <+20
>-10 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300
Was Wet - Now Dry
Was Dry - Now Wet
N
Wyboston
Chawston
South Brook
Roxton
Little Barford
Tempsford
River Great Ouse
0
0.5
1
kilometres
D4
RIVER GREAT OUSE PERMANENT vs BASELINE MAXIMUM WATER LEVEL DIFFERENCE MAP 1.33% AEP

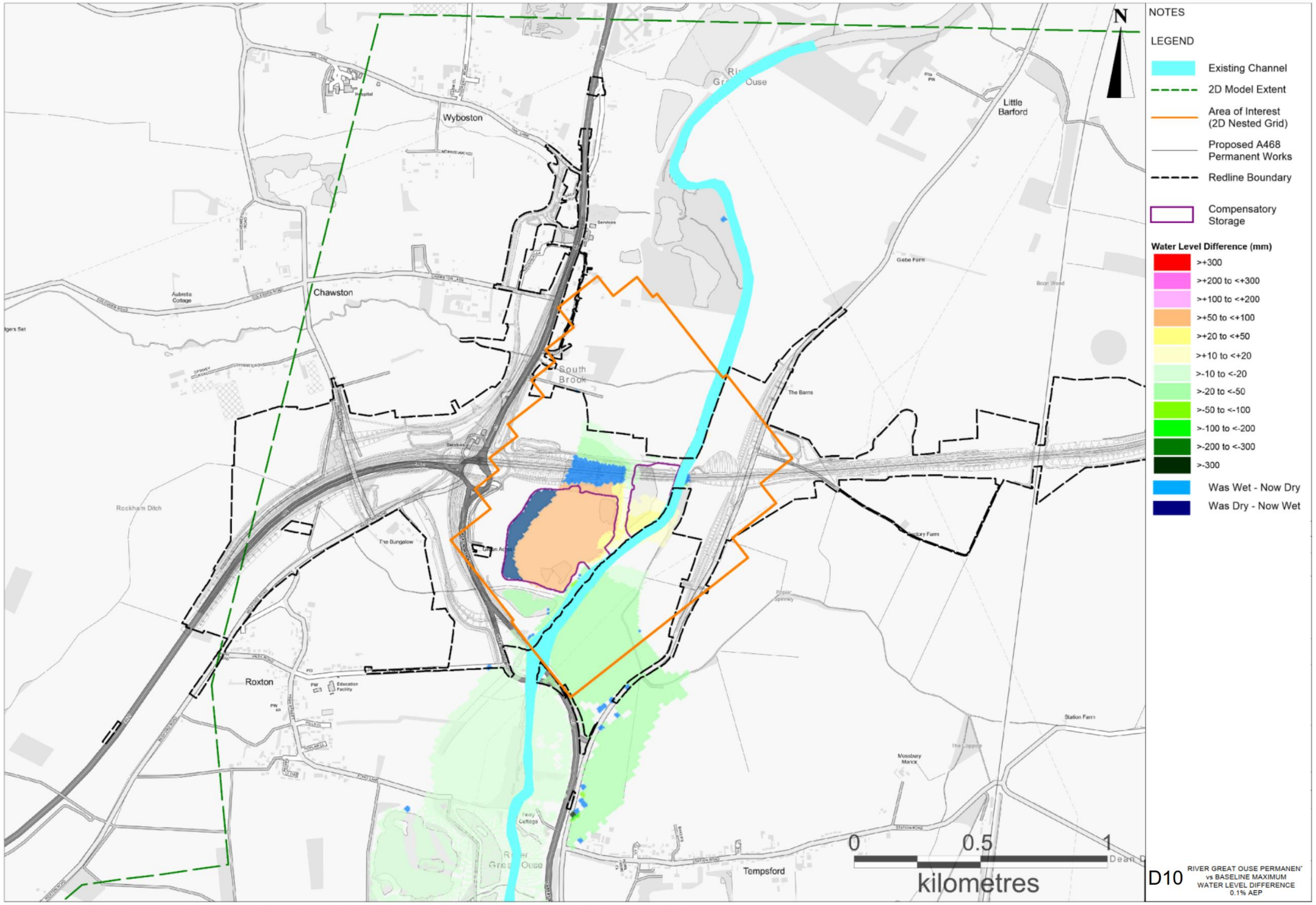

BASELINE
PROPOSED PERMANENT
N
Wyboston
Chawston
South Brook
Tempsford
0
0.25
0.5
kilometres
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
D5
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT 1% AEP


N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
South Brook
Roxton
Tempsford
River Great Ouse
0
0.5
1
kilometres
D6
RIVER GREAT OUSE PERMANENT vs BASELINE MAXIMUM WATER DIFFERENCE MAP 1% AEP

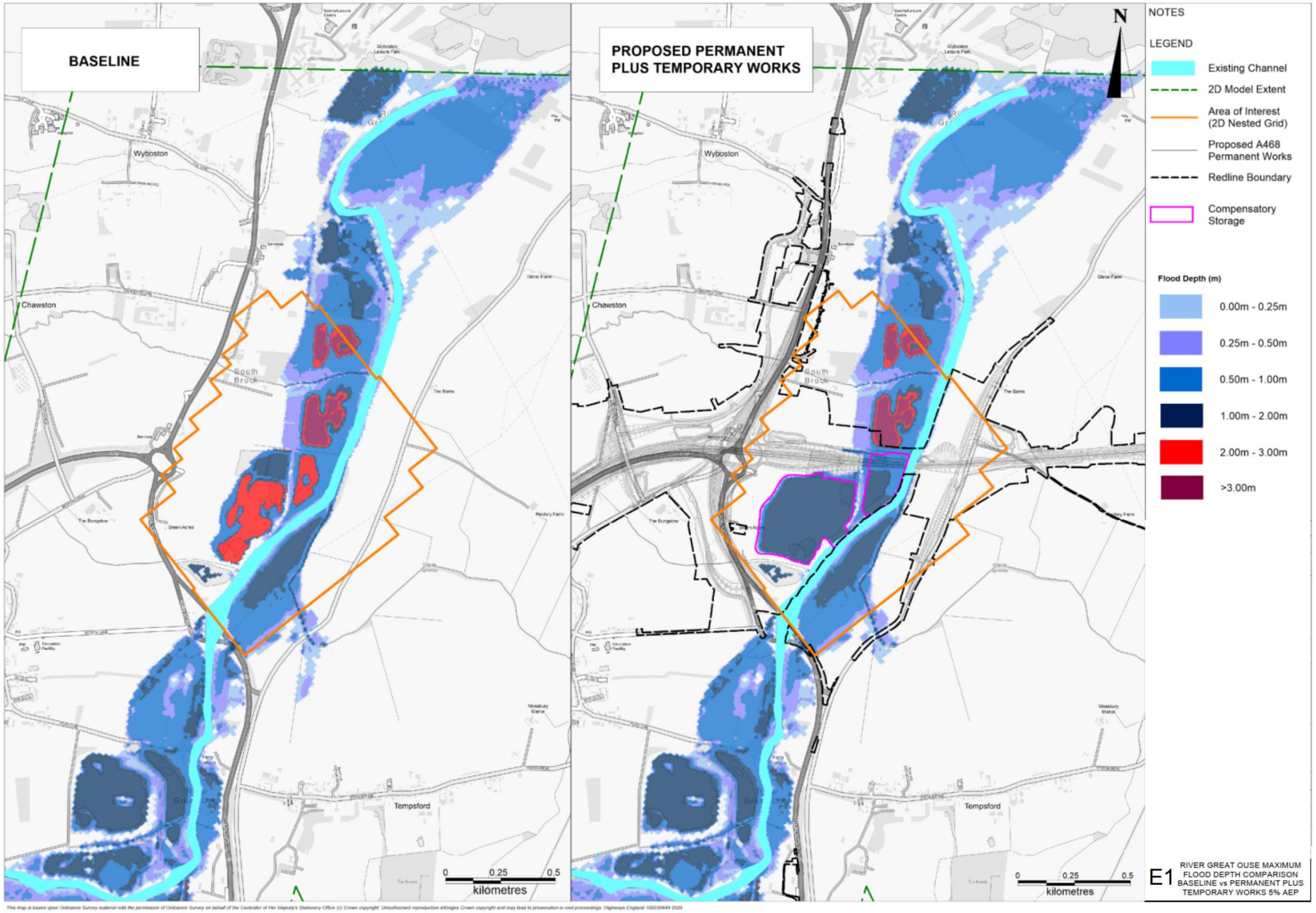

BASELINE
PROPOSED PERMANENT
Wyboston
Chawston
Tempsford
0
0.25
0.5
kilometres
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest
(2D Nested Grid)
Proposed A468
Permanent Works
Redline Boundary
Compensatory
Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
D7
RIVER GREAT OUSE MAXIMUM
FLOOD DEPTH COMPARISON
BASELINE vs PERMANENT
1% AEP + 65% CLIMATE CHANGE

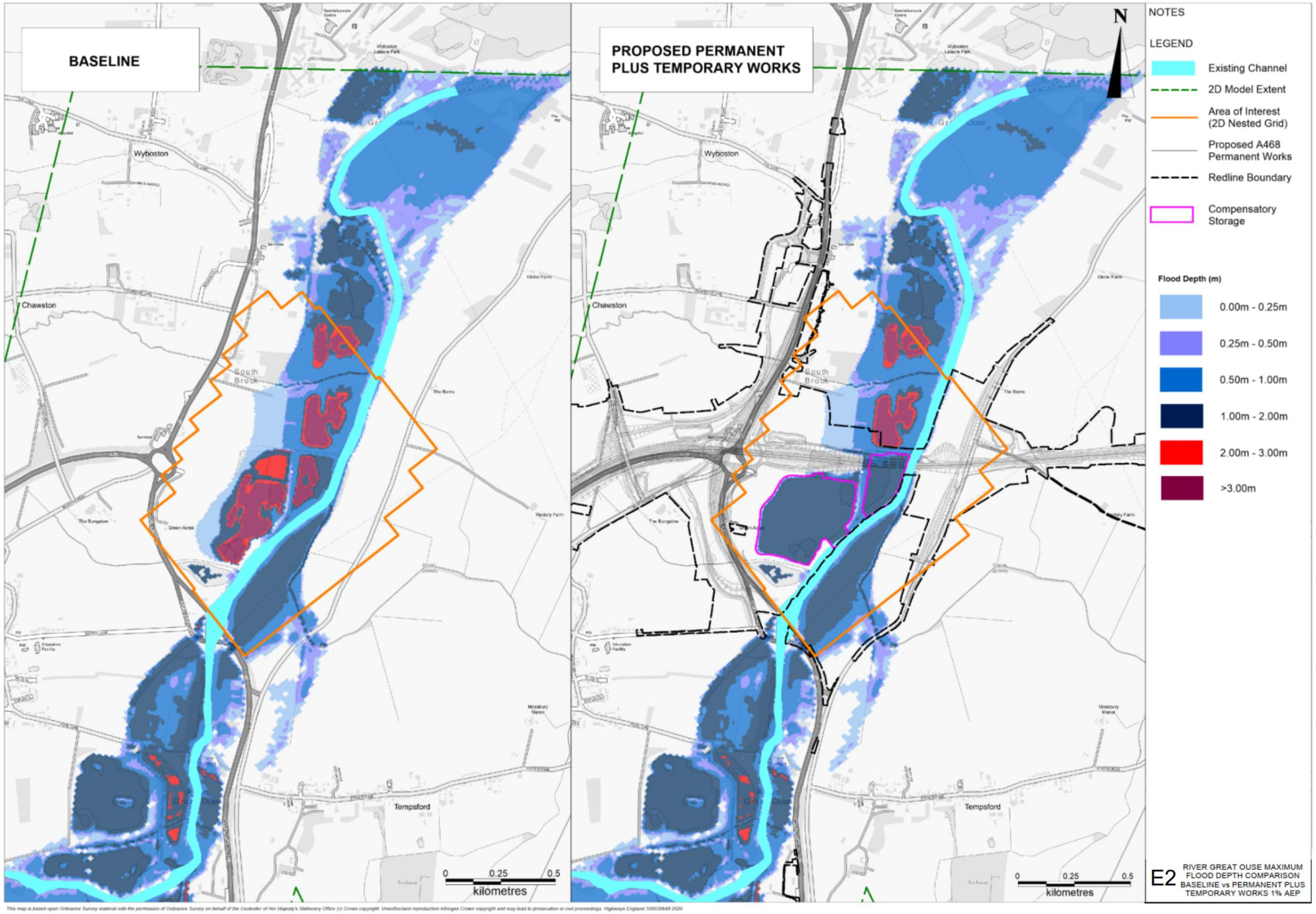

NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Water Level Difference (mm)
>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+20 to <+50
>+10 to <+20
>-10 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300
Was Wet - Now Dry
Was Dry - Now Wet
N
Wyboston
Chawston
Roxton
Tempsford
Little Barford
South Brook
River Great Ouse
0
0.5
1
kilometres
D8
RIVER GREAT OUSE PERMANENT vs BASELINE MAXIMUM WATER DIFFERENCE MAP 1% AEP + 65% CLIMATE CHANGE


BASELINE
PROPOSED PERMANENT
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
Wyboston
Chawston
Tempsford
0
0.25
0.5
kilometres
D9
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT 0.1% AEP

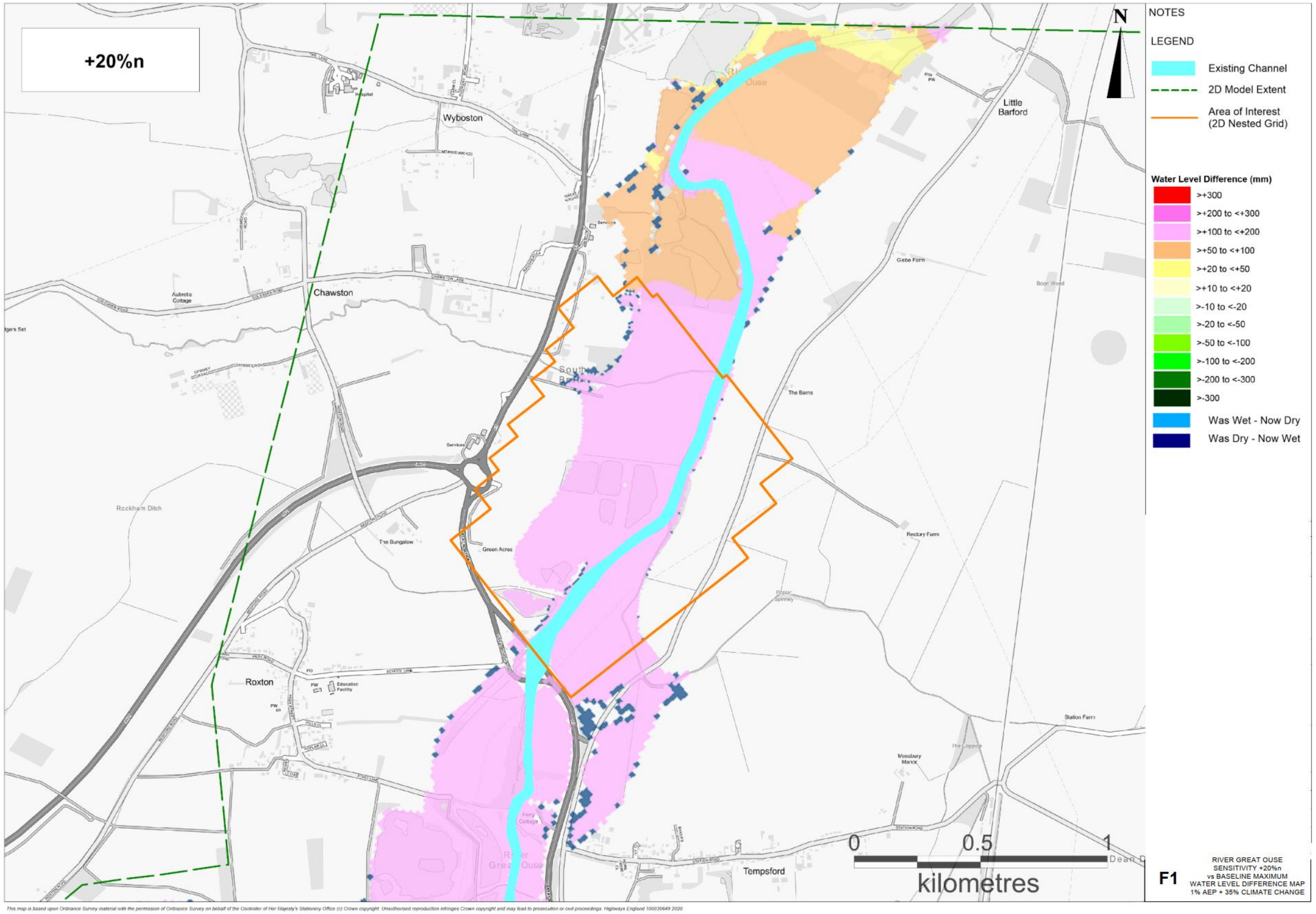

N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Water Level Difference (mm)
>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+20 to <+50
>+10 to <+20
>-10 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
South Brook
Roxton
Tempsford
River Great Ouse
0
0.5
1
kilometres
D10
RIVER GREAT OUSE PERMANENT vs BASELINE MAXIMUM WATER LEVEL DIFFERENCE 0.1% AEP

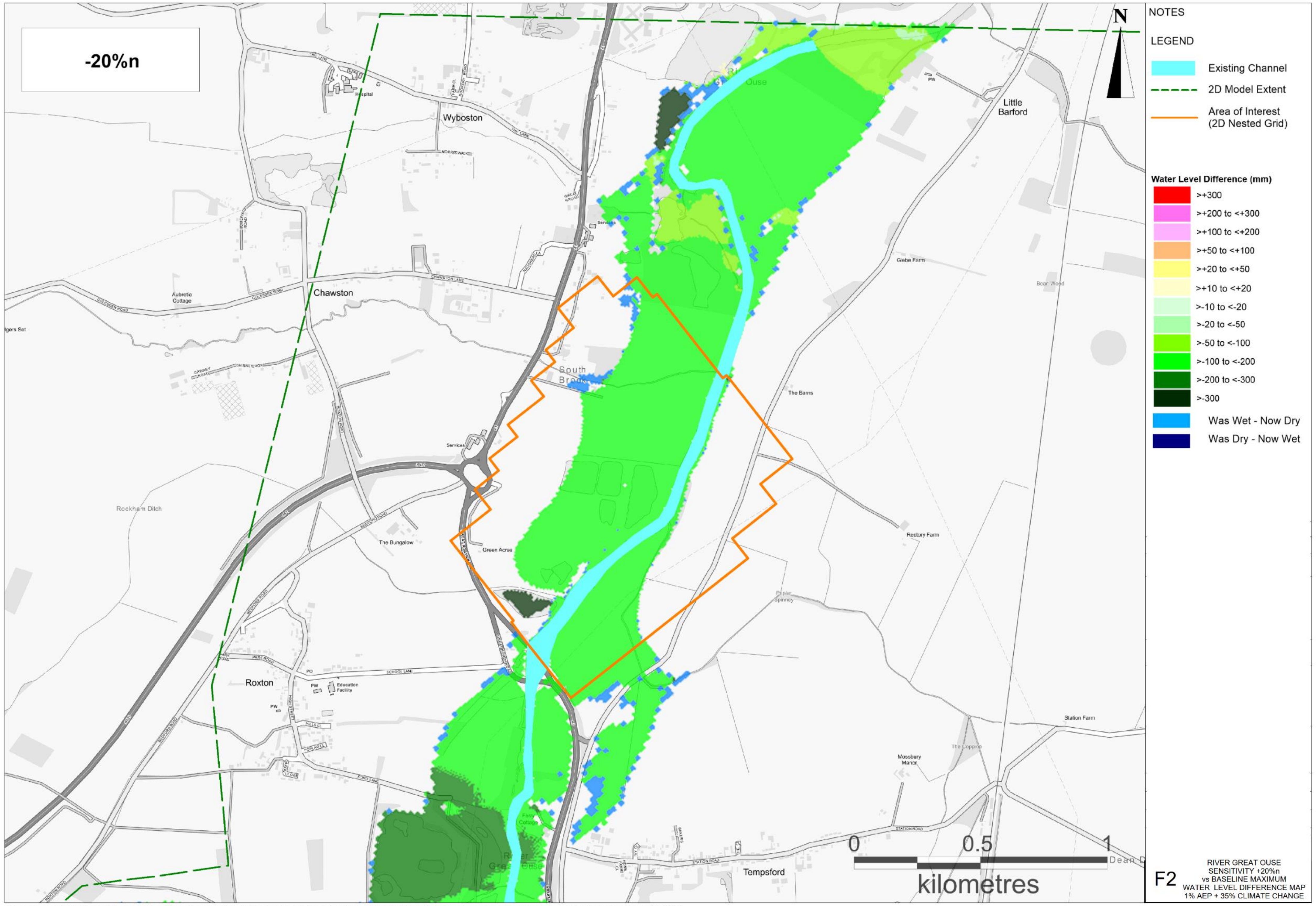
Appendix E Proposed Permanent plus Temporary Works Model Results

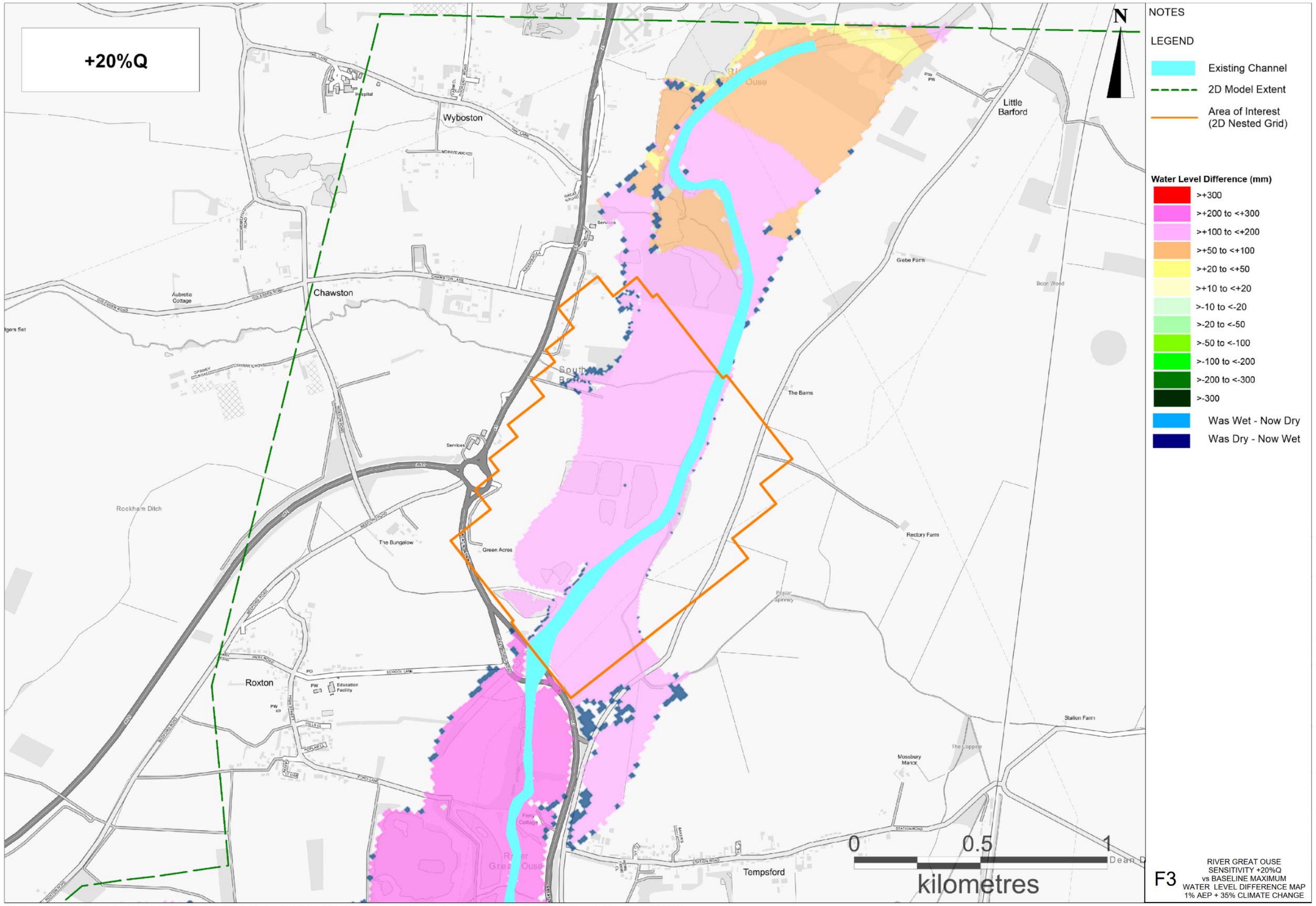

BASELINE
PROPOSED PERMANENT PLUS TEMPORARY WORKS
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
Wyboston
Chawston
Tempsford
0 0.25 0.5
kilometres
E1
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT PLUS TEMPORARY WORKS 5% AEP

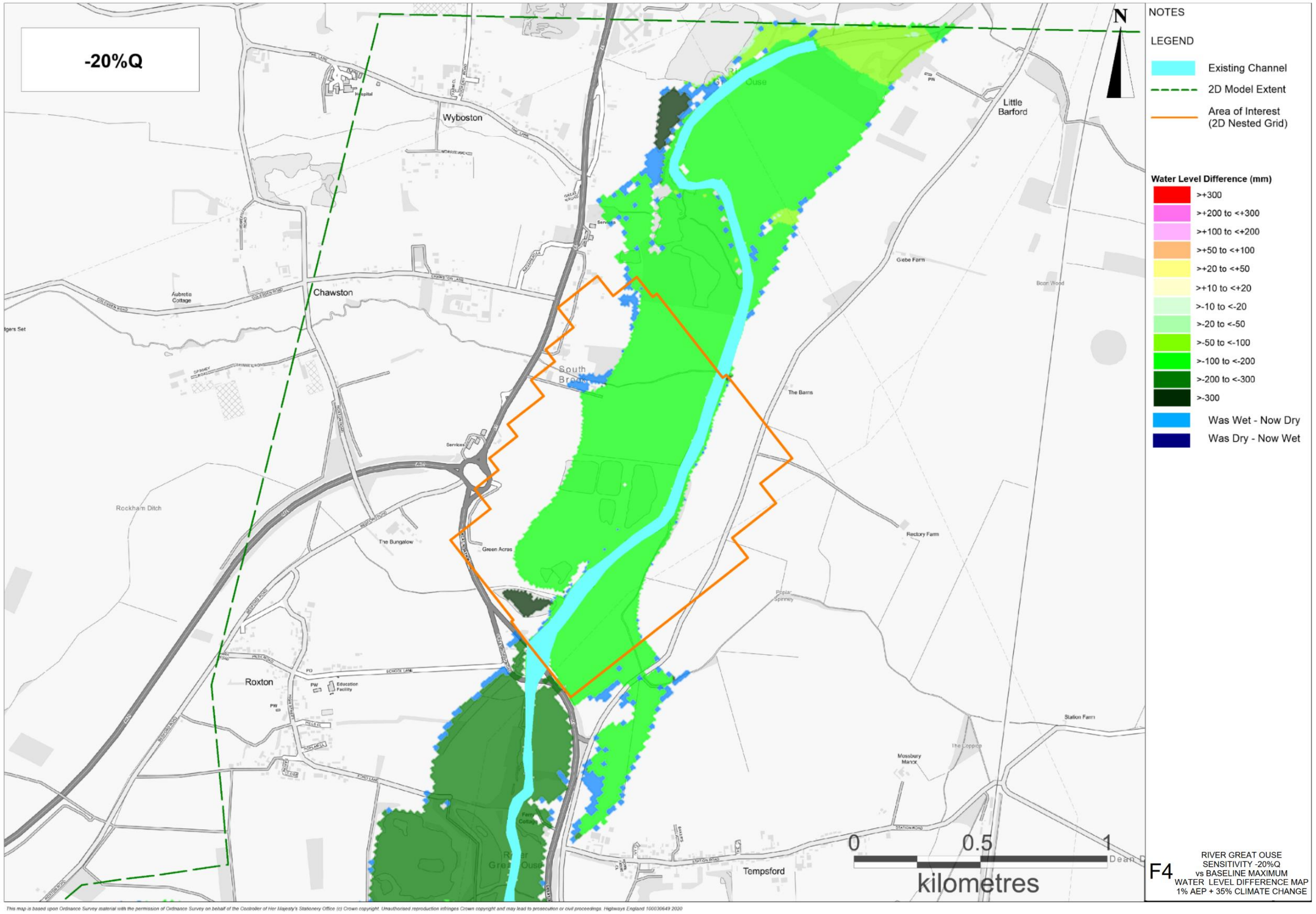

BASELINE
PROPOSED PERMANENT PLUS TEMPORARY WORKS
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Proposed A468 Permanent Works
Redline Boundary
Compensatory Storage
Flood Depth (m)
0.00m - 0.25m
0.25m - 0.50m
0.50m - 1.00m
1.00m - 2.00m
2.00m - 3.00m
>3.00m
Wyboston
Chawston
Tempsford
0
0.25
0.5
kilometres
E2
RIVER GREAT OUSE MAXIMUM FLOOD DEPTH COMPARISON BASELINE vs PERMANENT PLUS TEMPORARY WORKS 1% AEP

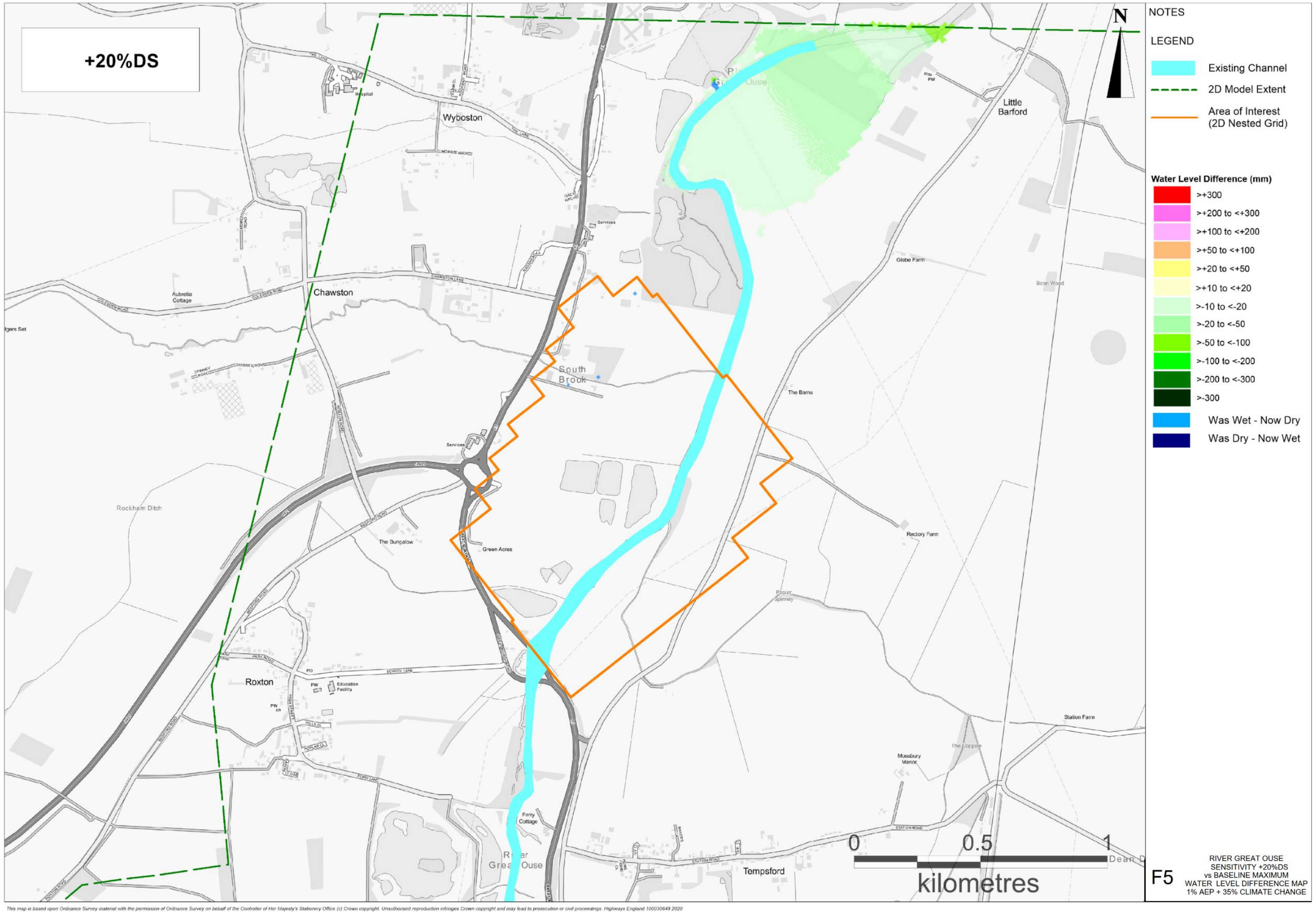
Appendix F Sensitivity Model Results

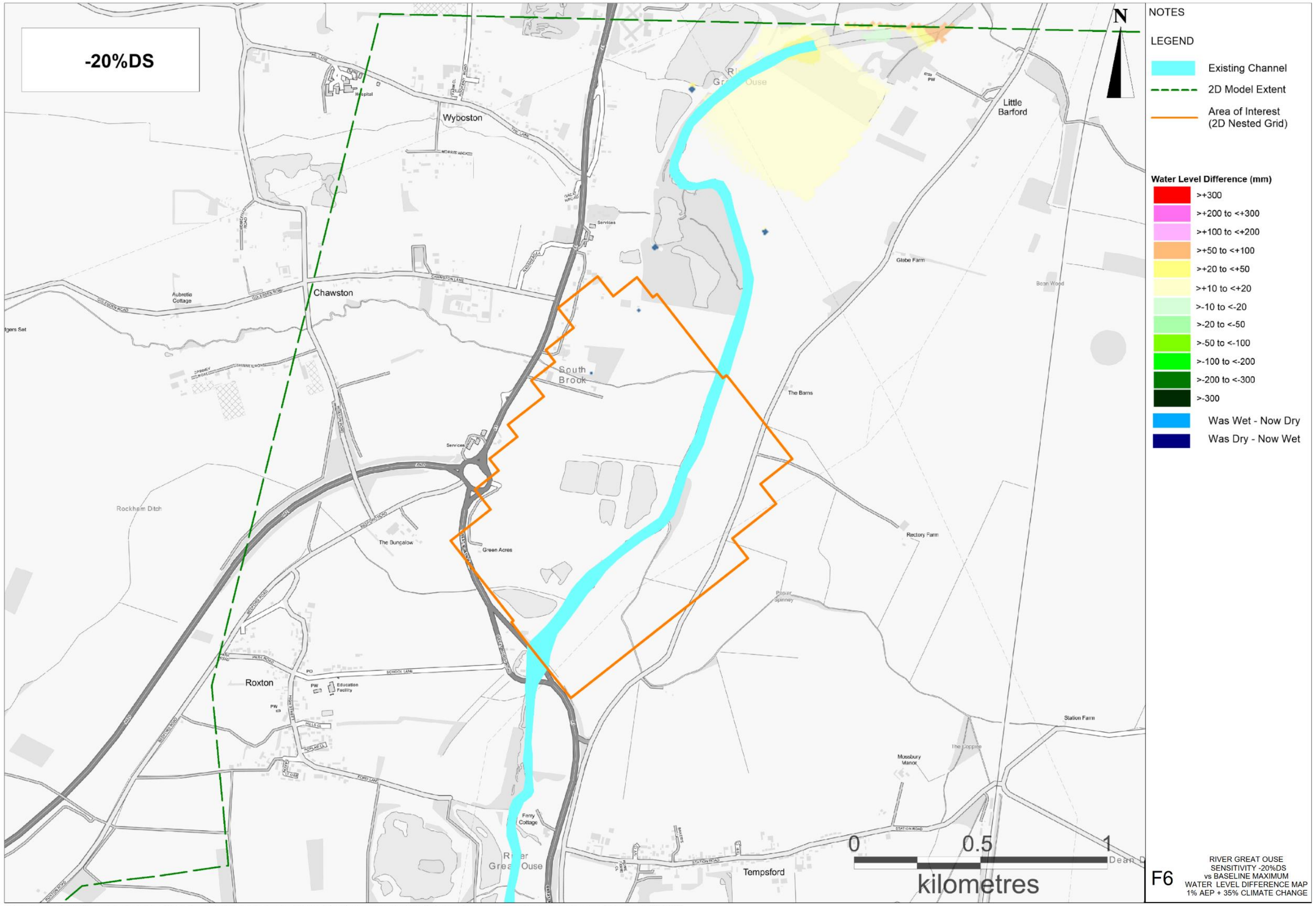

+20%n
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
Water Level Difference (mm)
>+300
>+200 to <+300
>+100 to <+200
>+50 to <+100
>+20 to <+50
>+10 to <+20
>-10 to <-20
>-20 to <-50
>-50 to <-100
>-100 to <-200
>-200 to <-300
>-300
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
Roxton
Tempsford
0
0.5
1
kilometres
F1
RIVER GREAT OUSE
SENSITIVITY +20%n
vs BASELINE MAXIMUM
WATER LEVEL DIFFERENCE MAP
1% AEP + 35% CLIMATE CHANGE


-20%n
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Little Barford
Chawston
South Brook
Roxton
Tempsford
Rockham Ditch
Green Acres
The Bungalow
The Barns
Rectory Farm
Station Farm
Gibbs Farm
Ouse
0
0.5
1
kilometres
F2
RIVER GREAT OUSE
SENSITIVITY +20%n
vs BASELINE MAXIMUM
WATER LEVEL DIFFERENCE MAP
1% AEP + 35% CLIMATE CHANGE


+20%Q
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Little Barford
Chawston
Roxton
Tempsford
0
0.5
1
kilometres
F3
RIVER GREAT OUSE
SENSITIVITY +20%Q
vs BASELINE MAXIMUM
WATER LEVEL DIFFERENCE MAP
1% AEP + 35% CLIMATE CHANGE


-20%Q
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
Roxton
Tempsford
0
0.5
1
kilometres
F4
RIVER GREAT OUSE
SENSITIVITY -20%Q
vs BASELINE MAXIMUM
WATER LEVEL DIFFERENCE MAP
1% AEP + 35% CLIMATE CHANGE


+20%DS
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
Roxton
Tempsford
South Brook
River Great Ouse
0
0.5
1
kilometres
F5
RIVER GREAT OUSE SENSITIVITY +20%DS vs BASELINE MAXIMUM WATER LEVEL DIFFERENCE MAP 1% AEP + 35% CLIMATE CHANGE


-20%DS
N
NOTES
LEGEND
Existing Channel
2D Model Extent
Area of Interest (2D Nested Grid)
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
Was Wet - Now Dry
Was Dry - Now Wet
Wyboston
Chawston
Little Barford
South Brook
Roxton
Tempsford
River Great Ouse
Rockham Ditch
0
0.5
1
kilometres
F6
RIVER GREAT OUSE SENSITIVITY -20%DS vs BASELINE MAXIMUM WATER LEVEL DIFFERENCE MAP 1% AEP + 35% CLIMATE CHANGE