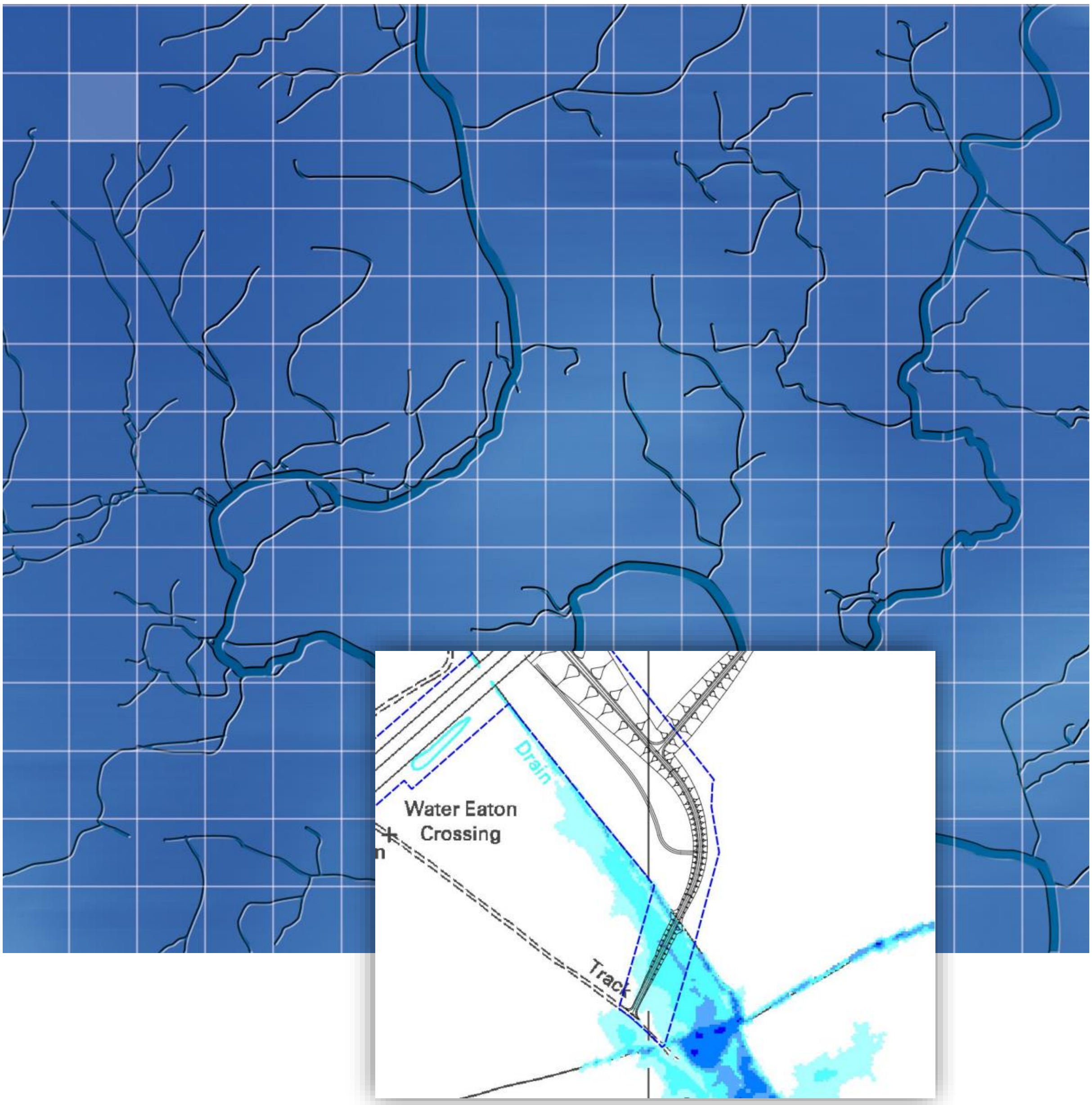
Network Rail and Chiltern Railways

December 2016

EWR-P1- Level 3 FRA: AP13 Northfield Farm



WHS

Wallingford HydroSolutions Limited

Network Rail and Chiltern Railways

EWR P1 – Level 3 FRA: AP13 Northfield Farm

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For and on behalf of Wallingford HydroSolutions Ltd.

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Date **20 December 2016**

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Contents

1 Introduction

1.1 Background

Environmental Resources Management (ERM) and Wallingford HydroSolutions Ltd. (WHS) completed a Level 2 Flood Risk Assessment (FRA) in 2009 (including a revision in July 2010), together with a Technical Paper outlining flood storage mitigation requirements (Chiltern Railways Bicester to Oxford Improvements Level 2 Flood Risk Assessment, July 2010 & Compensatory Storage Technical Paper and Level 3 FRA Specification) in support of an application for an Order under the Transport and Works Act 1992 (TWA) by Chiltern Railways (CRCL). The TWA Order was granted by the Secretary of State for Transport in October 2012. This gives statutory powers to authorise the East West Rail Phase 1 (EWR P1) project, comprising the redevelopment and operation of the railway between Oxford and Bicester. The project seeks to introduce a new, fast service between London and Oxford.

The Level 2 FRA was conducted in accordance with Planning Policy Statement 25: Development and Flood Risk (PPS25), and its Practice Guide companion. The Level 2 FRA document highlighted a number of locations along the railway corridor where proposed developments lie within Flood Zones 2 or 3 and could potentially have impacts upon the incidence of local flooding. The report identified a number of assessment points (AP's) along the route of the EWR P1 that require further consideration in a Level 3 FRA. These assessment points included AP13 – Northfield Farm Overbridge.

1.2 Scope of Level 3 FRA

This document constitutes a Level 3 FRA for the AP13 – Northfield Farm Overbridge, as required by planning condition 12 of deemed planning permission granted alongside the Order under the Transport and Works Act 1992. Although the 2010 Level 2 assessment had initially confirmed that a Level 3 assessment at AP13 was not required, subsequent changes to the Environment Agency (EA) Flood Maps and discussions led to a requirement for a Level 3 assessment.

This document together with the original Level 2 FRA provides the information required by the National Planning Policy Framework (NPPF) and the associated requirements of PPS25.

This FRA document has been commissioned to address the flood risk issues that result from the construction of the Northfield Farm Overbridge. The location of the Northfield Farm Overbridge is shown in Figure 1. The purpose of this FRA is to quantify any adverse impacts on flood risk and provide sustainable and effective mitigation where required to mitigate any impacts.

It should be noted that surface water drainage issues are not dealt with in this FRA, an additional document will be submitted to the LPA which focuses on the surface water runoff issues resulting from the construction of Northfield Farm Overbridge.

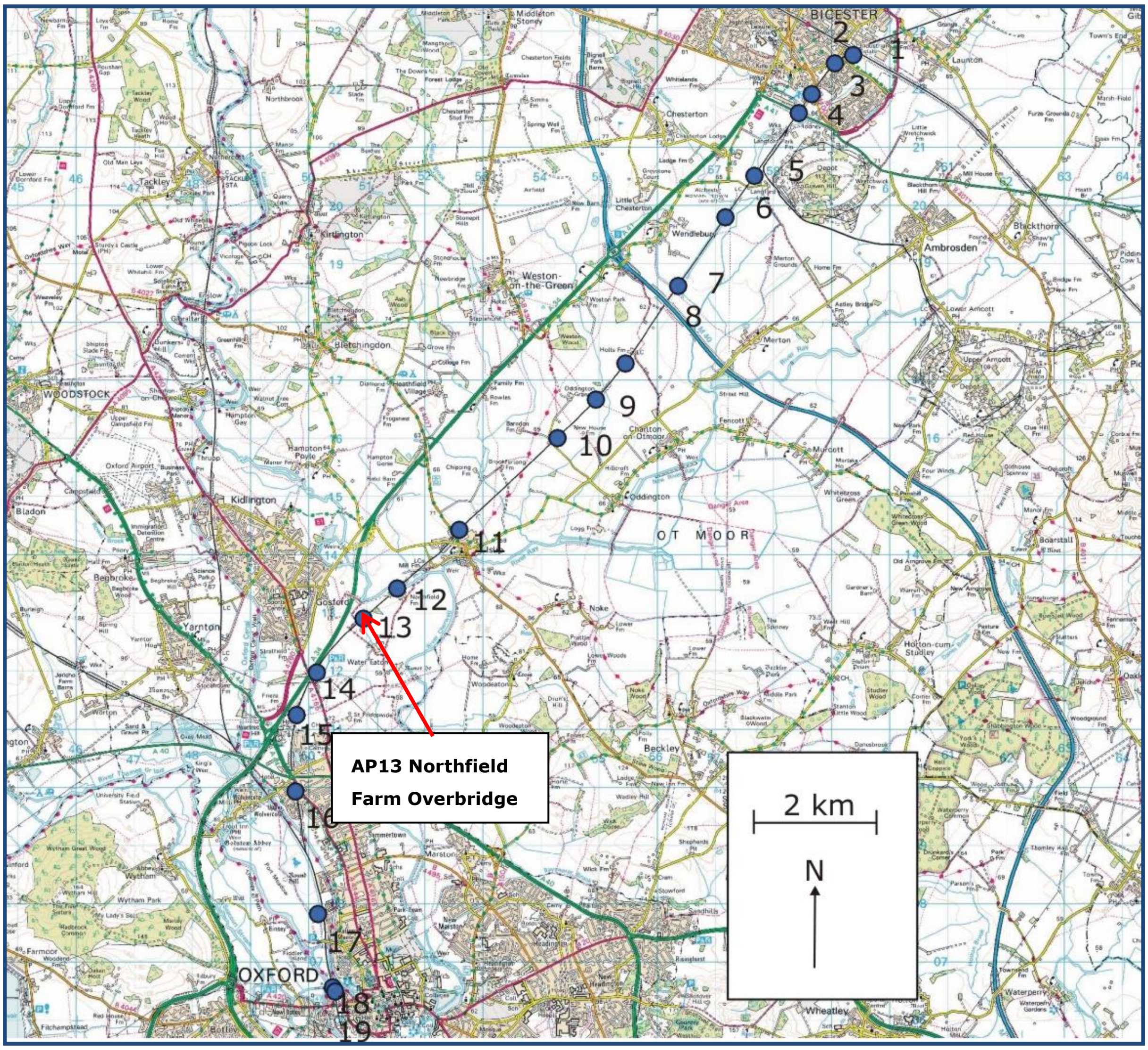

Figure 1 - Scheme Overview Showing Various Assessment Points.

2 Site Description

2.1 Location/ Site Description

The proposed works centre around the existing Water Eaton Crossing located along the railway corridor to the south west of Islip town (NGR: 450905, 212876). The surrounding area, both downstream and upstream of the railway embankment, is predominantly farmland being a mix of pasture and crops.

Two main watercourses are within the study area, the River Cherwell flowing from the north and the River Ray flowing from the east, which joins with the River Cherwell approximately 1.7km to the east of the site.

The current EA flood mapping shows that the area is at risk of fluvial flooding during the 1 in 100 and the 1 in 1000 year flood events, shown in Figure 2. It has been confirmed by the EA that this flood mapping has been based on the 1D modelling work conducted by PBA in 2005[1] that has been provided on licence to be utilised as part of this FRA.

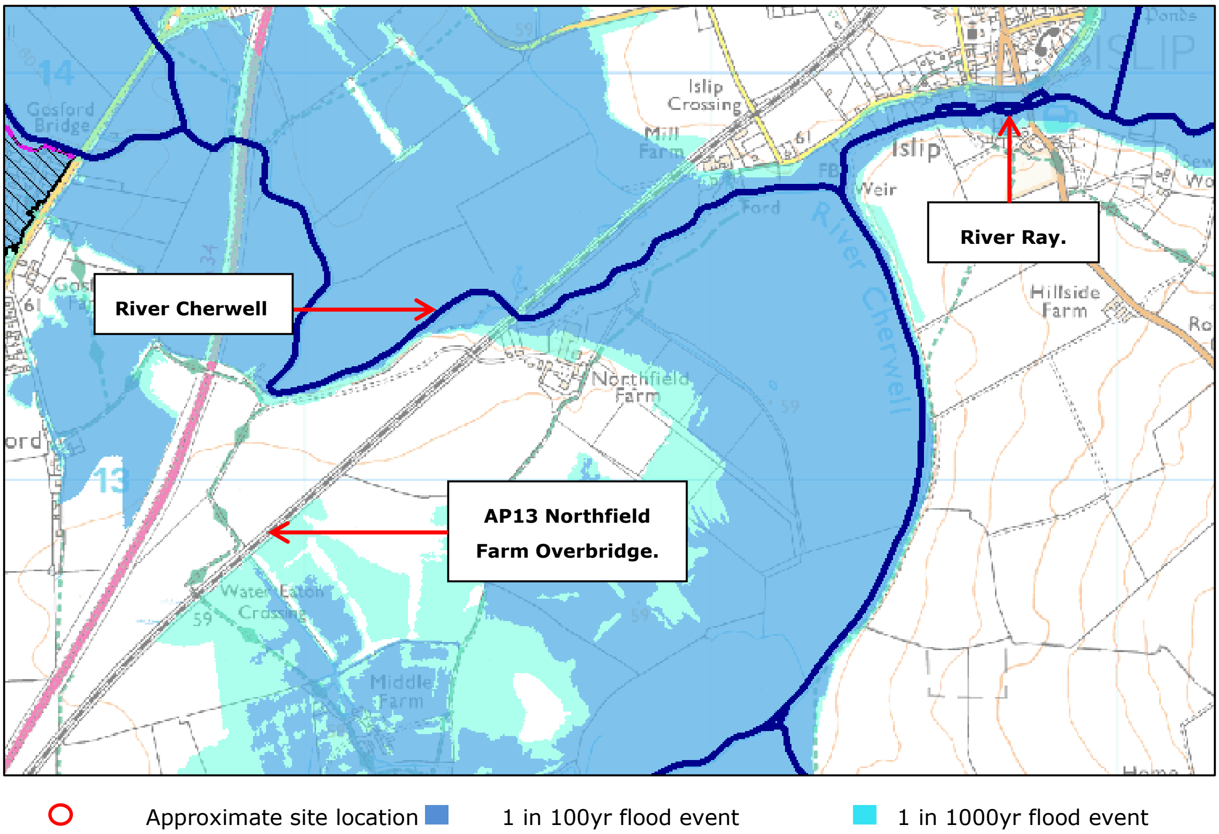

Figure 2 – Extract from the Environment Agency Flood Map (available online) Showing Flood Extent Surrounding the Study Area. (© ENVIRONMENT AGENCY COPYRIGHT AND DATABASE RIGHTS 2013 @ ORDNANCE SURVEY CROWN COPYRIGHT. ALL RIGHTS RESERVED. ENVIRONMENT AGENCY. 100026380).

[1] Peter Brett Associates (2005) *Lower Cherwell Flood Risk Mapping Study,* Final Report and Hydraulic Model.

2.2 Description of the Proposed Works

The existing Northfield Farm overbridge is to be demolished as it is too low for w12+ gauge specifications and the existing Water Eaton No. 5 crossing is to be closed. They are to be replaced by an overbridge close to the location of the current Water Eaton No. 5 crossing, along with additional farm road to enable access. Please see Figure 3 for the layout of the proposed access road and underbridge.

Figure 3 – Design Layout of the Proposed Northfield Farm Overbridge and Access Road (Provided by Atkins).

3 Flood Risk Impacts

3.1 Overview

Part of the proposed AP13 Northfield Farm development is situated within Flood Zone 3 of the EA Flood Maps as defined by the PBA model outputs[1]. Based on the existing PBA model[1] information WHS conducted an initial compensatory storage assessment for the AP13 development that resulted in excess of 1000m^3 of compensatory floodplain storage being required to mitigate flood risk issues. This volume is quite large and following discussions with the Atkins design team it was confirmed that there are numerous constraints at the site including the need to provide surface water attenuation storage and an additional Network Rail access track that could result in land availability issues.

From previous modelling studies conducted by WHS in the area it was judged that refining the model to include a 2D representation of the floodplain would markedly reduce flood levels and extents at the site. This would reduce the requirement to provide compensatory storage as well as providing more space outwith of flood zones for the siting of attenuation ponds required for the surface water drainage.

An updated modelling study was undertaken by WHS to more accurately define flood extents and levels at AP13. This study benefits from updated hydrological inflows (produced by WHS to inform the Islip safe access & egress model[2]) and a more robust modelling methodology utilising a linked 1D – 2D model. It should be noted that the existing PBA model used to define the current flood level is based on conservative roughness coefficients, outdated hydrology and a relatively coarse DTM based on SAR data[3] to define floodplain topography. The updated WHS model provides a more refined assessment that is likely to result in reductions in predicted flood levels and extents which in turn will reduce flood risk constraints at Northfield Farm. Details of the updated WHS modelling are provided in Appendix 1 of this report.

3.2 Sources of data used

The main sources of data used in this modelling study include;

- **LiDAR data** - LiDAR data[4] has been provided by the EA, through the Geomatics Team. LiDAR data[4] at 2m resolution was adopted for this hydraulic model. The vertical accuracy of the LiDAR provided is between ±0.15m.

- **Design Layout drawings**[5] - Design Drawings of the proposed AP13 Northfield Farm Overbridge and access road.

- **Lower Cherwell Hydraulic Model –** An existing 1D hydraulic Model was built by PBA in 2005[1] and has been provided on licence by the EA. This model has been used to define the 1D portion of the updated WHS model and any in channel hydraulic structures.

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[2] WHS. 2013. Islip Hydrology Report

[3] DTM based on Synthetic Aperture Radar (SAR) data and has a 5m horizontal resolution with a vertical accuracy of +/- 0.5m.

[4] LiDAR data purchased from the EA Gemomatics Group website. (2m horizontal resolution with a vertical accuracy of between 0.05 – 0.15m)

[5] Atkins Design Drawing: Northfield Farm Accommodation Track Alignment. (Dwg Ref – 5114534-ATK-DRG-HW-000037)

- **Updated hydrology** – An updated hydrological assessment[2] was prepared by WHS specifically for use in the Islip Safe Access and Egress modelling, which is considered fit for use in this modelling study.

- **10K OS Mapping -** for use in model reporting and land use classification.

- **The Scheme Boundary** - which for the purposes of the flood risk aspects of the Scheme is referred to as the 'blue line' boundary. This boundary incorporates land within the Limits of Deviation (LOD) and those areas of the Limits of Land to be Acquired and Used (LLAU) where Chiltern Railways has the legal powers to install flood mitigation, without further land acquisition.

- **WHS updated Hydraulic model** - outputs from an updated 1D – 2D hydraulic model, built by WHS for use in this FRA, are used to delineate the inundation area and obtain design flood levels for the 1:100 year (plus climate change allowance) event. Further details of the modelling undertaken are found in Appendix 1 of this report.

3.3 Model Results

Flooding at AP13 Northfield farm site is caused by the backing up of floodwaters from the River Cherwell about 1.5km downstream of the site along the minor watercourse adjacent to Middle Farm and flooding the low lying areas of floodplain adjacent to the site. Figure 4 highlights the predicted flood extent during the 1 in 100 year (plus an allowance for climate change) flood event in the vicinity of the proposed AP13 Northfield Farm Overbridge for the baseline scenario. The predicted extent shows that the majority of the proposed alignment is outside of the predicted flood extent. However, the south western section of the access road does flood with flood depths generally around 400mm with isolated depths of up to 800mm in the drainage ditch. The predicted flood level is 58.50mAOD at the western spur of the AP13 access road and will be used in the compensatory storage calculations.

As shown by Figure 4 the predicted flood extent is considerably reduced over that predicted by the EA flood risk mapping. There are a number of reasons for this clear difference in extent. The main factors for this are considered to be the limitations of the PBA 1D modelling (basis of the current EA flood-map) and the simplistic approach of defining a flood extent by extrapolating a flood level over a coarse DTM (based on SAR data[3]). It should be noted that the existing PBA model used to define the current flood level is based on conservative data in terms of a high manning's value of 0.1 being used to define floodplain roughness, which is quite high given the nature of the floodplain, outdated hydrology and course SAR data[3] to define floodplain topography. The updated WHS 1D – 2D model provides a more refined assessment that results in reductions in flood level and extent which in turn reduces constraints at Northfield Farm from a flood risk perspective.

Although the predicted flood extent is reduced, a small proportion of the alignment was shown to be within the flood extent. Therefore, consideration of flood consequence and an analysis of compensatory flood storage was undertaken and this is outlined in sections 3.4 and 3.5.

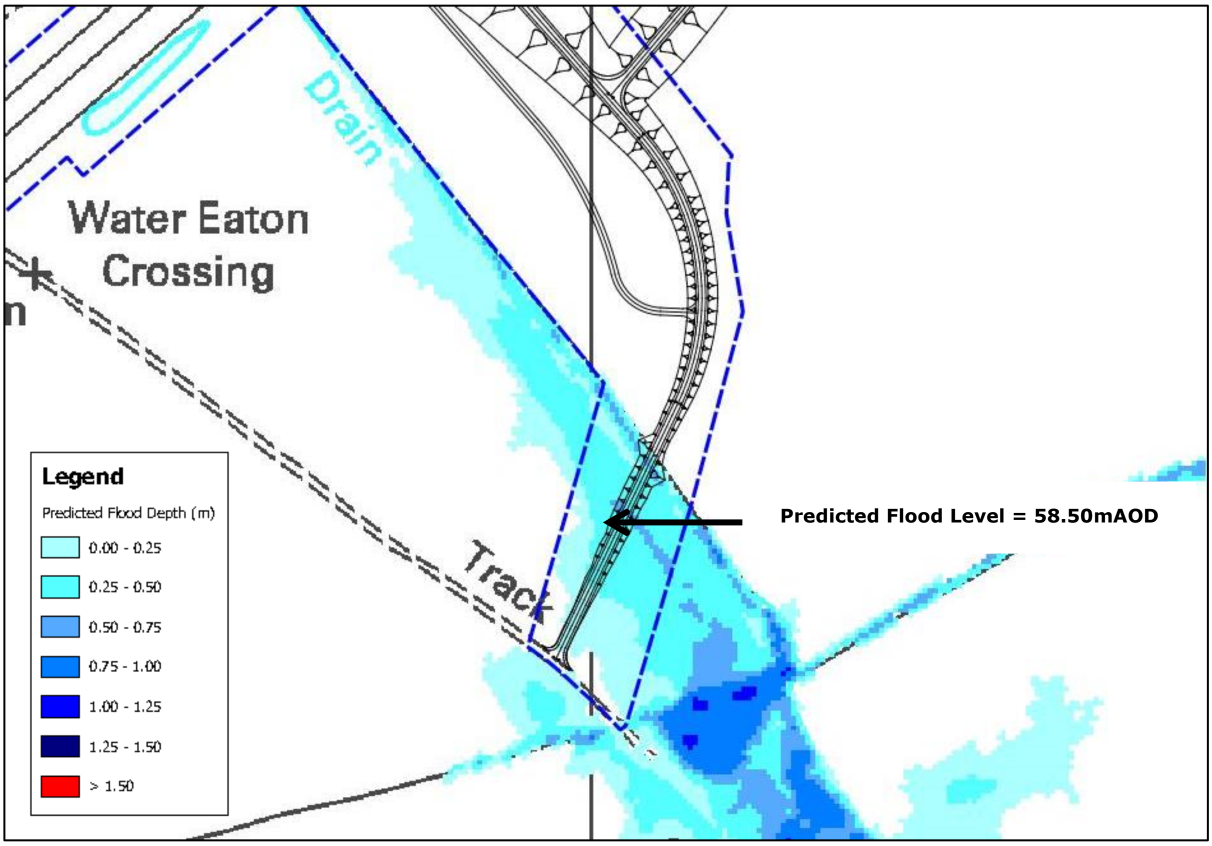

Figure 4 – Predicted 1 in 100 year Plus Climate Change Flood Extent in Relation to the Proposed Road Alignment for the Baseline Scenario.

3.4 Floodplain Storage Loss Analysis

3.4.1 Methodology

This section outlines the methodology used in undertaking the flood impact assessment for the construction of AP13 Northfield Farm Overbridge. This involves an assessment of the floodplain storage volume lost as a result of new road construction and includes recommendations for mitigation measures to provide compensatory floodplain storage. The updated WHS hydraulic model has been used to inform design. The methodology, parameters and working assumptions, together with the results and recommendations for mitigation are all described in the following sections. An outline of the procedure used to calculate floodplain storage loss is presented below:

- Calculation of the predicted flood level adjacent to the proposed Northfield Farm access road using the WHS modelling data.
- Calculation of the subsequent flood storage volume lost at 200mm depth intervals as a result of the embankment widening works.
- Provision of compensatory floodplain storage on a level for level basis as a mitigation measure to ensure flood risk is effectively managed.

The approach used in this assessment has been discussed and agreed with the EA.

3.4.2 Analysis

The volume of floodplain storage lost as a result of the proposed access road has been calculated to inform the design of any compensatory storage provision that is required to ensure flood risk is effectively managed. The loss of floodplain storage volume has been calculated with the aid of GIS design software. The method adopted is outlined below:

- Atkins has provided design layout drawings[5] of the proposed AP13 Northfield farm overbridge which have been used in conjunction with the updated WHS modelled flood extent to define a flooded area for the development as per Figure 4.
- To define the ground profile a GIS point layer has been created with an individual point being generated for each LiDAR cell (2m x 2m) within the flooded area. Each point was then interrogated against the LiDAR data to obtain a ground elevation for each LiDAR cell.
- Predicted flood depths at each cell were calculated by subtracting the associated ground level from the predicted flood level of 58.50mAOD taken from the updated WHS modelling.
- Flood volumes were then calculated by multiplying the predicted flood depth by the plan area of each cell which is 4m^2 (i.e 2m x 2m). This was undertaken in 200mm increments down from the predicted flood level of 58.50mAOD to the associated ground level at each cell.
- The total volume at each 200mm depth band was summed to give the total volume of storage that will be lost as a result of the AP13 access road construction.

Table 1 provides a summary of the level for level storage requirements at 200mm increments. The total storage volume lost due to the access road is 243m^3. However, it should be noted that the lower depth bands between 57.50mAOD and 57.90mAOD are within the existing drainage ditch and a culvert will be installed to ensure conveyance is maintained. Therefore, no compensatory storage will be required at these lower levels and the total compensatory storage volume that needs to be provided is 239m^3 between 57.90mAOD (lowest surrounding ground levels) to 58.50mAOD (1 in 100 year plus CC predicted flood level).

Table 1 – Floodplain Storage Volume Losses at 200mm Increments.

Depth Band	Loss of Storage Volume (m^3)	Land take Area Required (m^2)
57.5 – 57.7	1	5
57.7 - 57.9	3	15
57.9 - 58.1	24	120
58.1 - 58.3	85	425
58.3 – 58.5	130	650
Total Storage volume lost (m^3)	**243**	
Total Compensatory Storage required (m^3)	**239**	

3.5 Compensatory Storage Provision

The EA has confirmed that compensatory storage should be provided on a strict level for level basis to mitigate against the volume of floodplain lost as a result of the construction of the Northfield farm overbridge. To achieve the level for level storage requirement, 239m^3 of compensatory storage volume needs to be provided between 57.90mAOD (lowest ground level) and 58.50mAOD (maximum predicted flood level).

An assessment of suitable land has been undertaken in order to confirm that there are suitable areas in the vicinity of the site to provide the compensatory storage. Throughout the process of identifying suitable locations for storage there are a number of key factors that have been considered that include:

- Where practicable, storage is to be provided within the 'blue line' LOD boundary, as close as possible to the point of impact.
- Ensuring compensatory storage areas can be hydraulically connected to the floodplain.
- Identifying areas that can provide the required storage on a level for level basis. Volume requirements to be assessed at 200mm intervals, based on LiDAR data.
- Reviewing aerial photography to ensure areas are appropriate to be utilised as storage areas and to ensure LiDAR data are accurate. (i.e no tree cover that could influence levels etc.)

From the above assessment it is proposed to provide compensatory floodplain storage via two separate solutions. Firstly the higher level storage (i.e between 58.30mAOD to 58.5mAOD) will be provided via a swale excavation running adjacent to the southern spur of the new overbridge and the lower level storage (i.e between 57.90mAOD to 58.30mAOD) will be provided through a staged shallow excavation of topsoil down to the required levels. Please see Figures 5 for the proposed location and indicative cross section of the compensatory storage areas. Detailed design of these areas will need to be undertaken by Atkins via a ground modelling exercise to inform the detailed design of this scheme and ensure exact volumes and areas are provided.

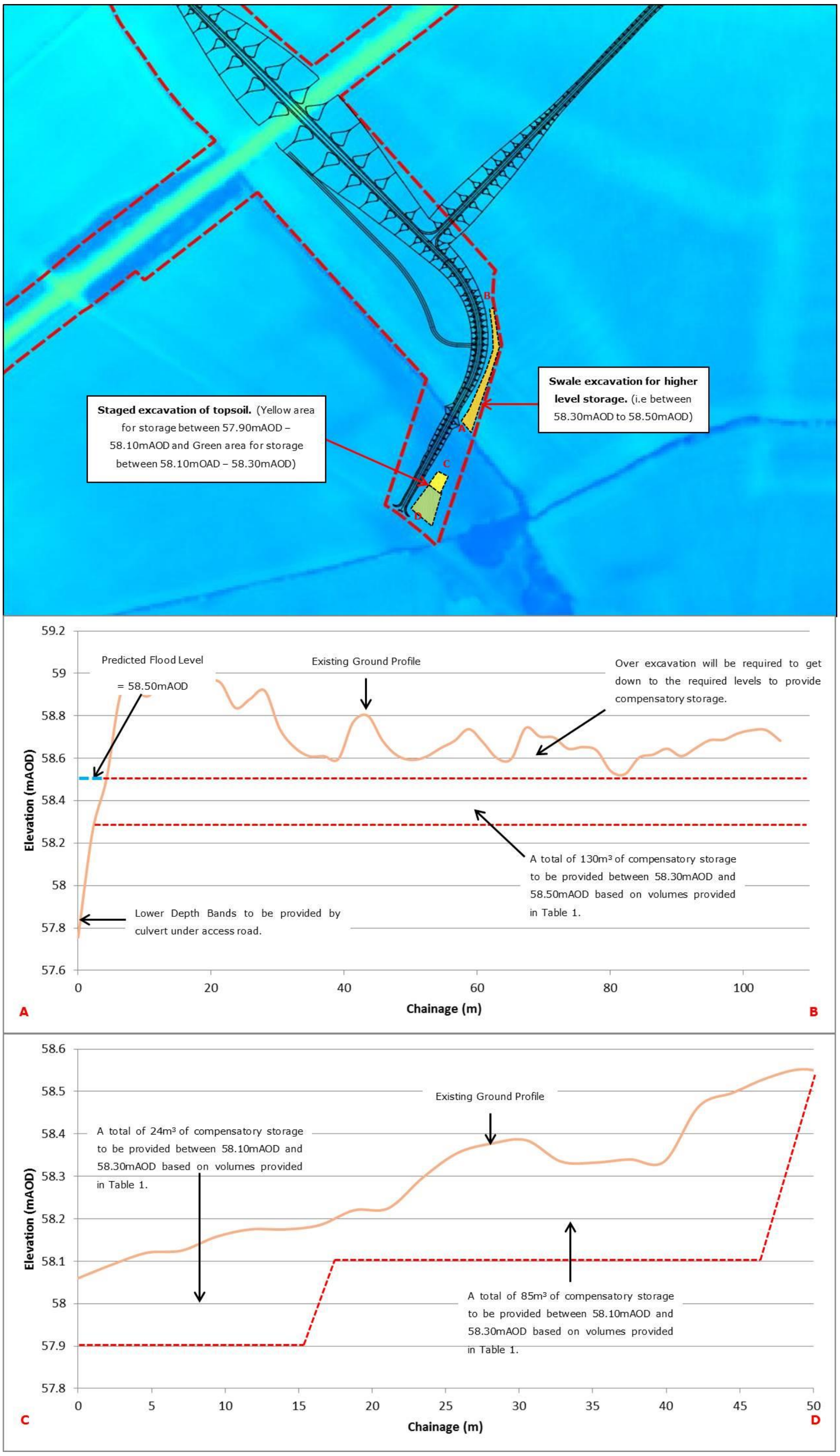

Figure 5 – Location Plan and Cross Sections through the Proposed Storage Areas (Ground Profile taken from LiDAR data).

In summary, the proposed storage option at AP13 has been chosen as the preferred solution and location to provide floodplain compensatory storage for a number of reasons, which include that it:

- is located close proximity to the point of impact;
- can be hydraulically connected to the River Cherwell floodplain;
- provides appropriate topography to achieve the level for level storage requirement including a degree of over compensation at higher levels, and;
- provides potential additional ecological benefits by creating additional habitat and increasing biodiversity in the area.

3.6 Safe Access and Egress

The existing Northfield farm accommodation bridge is to be demolished as part of the scheme as it is too low to allow full clearance for trains with w12+ gauge specifications. The existing Water Eaton No.5 level crossing, located further to the south of the existing bridge, will also be closed in order to improve safety and meet current Network Rail and Office of Rail Regulation guidelines.

The existing accommodation bridge and level crossing are to be replaced by the new Northfield Farm overbridge close to the location of the current Water Eaton No.5 level crossing along with a new access road for the residents of Northfield Farm. The new bridge will provide access across the railway for the residents of Northfield Farm to the north east as well as from Middle Farm and Middle Cottage to the south. The current and proposed access and egress to and from Northfield farm and Middle Farm in relation to the 1 in 100 year (plus a 20% allowance in peak flows to account for climate change) event taken from the updated WHS modelling is shown in Figure 6.

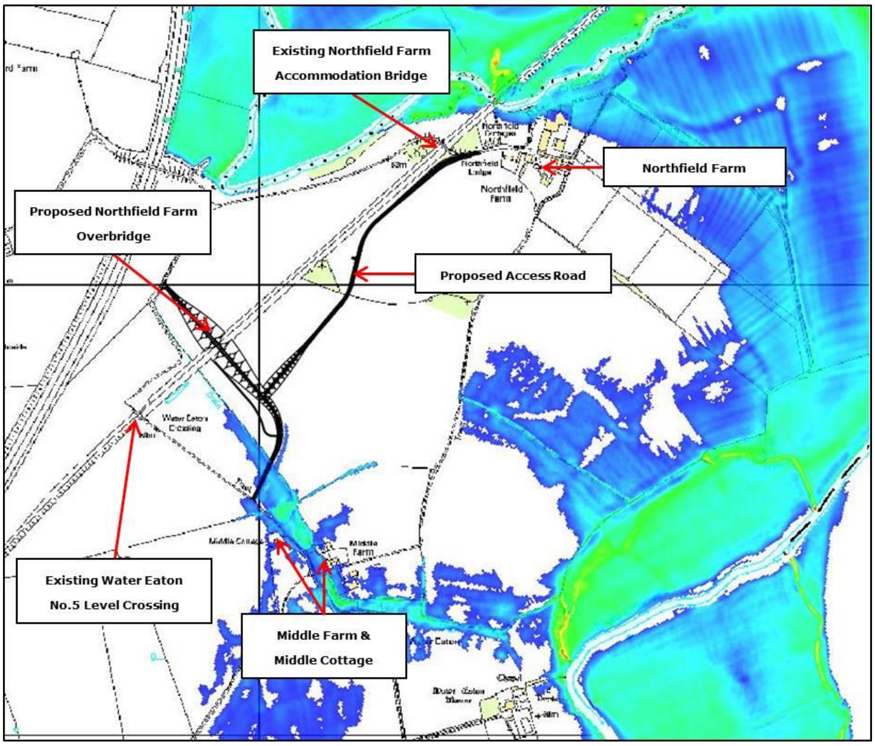

Figure 6 – Locations of Existing and Proposed Structures in Relation to Predicted Post development Flood Extent.

The EA has requested evidence showing that flood impacts and hazards are not increased along the proposed safe access & egress routes to Northfield Farm, Middle Cottage and Middle Farm. It needs to be demonstrated that there is no overall increase in the level of flood hazard along the proposed safe access and egress routes as a result of the development with aspirations to provide an overall reduction in flood hazard.

In regards to Northfield Farm the updated flood modelling work undertaken by WHS for this FRA has shown that the new access road and new Northfield Farm Overbridge is outwith of the 1 in 100 year (plus a 20% allowance in peak flows to account for climate change) flood zone. Therefore, there is no direct flood hazard to the safe access & egress route for residents of Northfield farm.

However, when considering the safe access & egress route used by residents of both Middle Farm and Middle Cottage, which utilises the small track to the north and over the new Northfield Farm Overbridge, this route is located within the extreme floodplain extent of the Cherwell. Figure 7 shows the southern spur of the new access track in relation to the floodplain with the existing and proposed safe access & egress routes identified. The southern spur of the proposed access track is to be constructed within the active floodplain which will potentially influence flood conveyance and reduce the available floodplain storage capacity of the floodplain in this area.

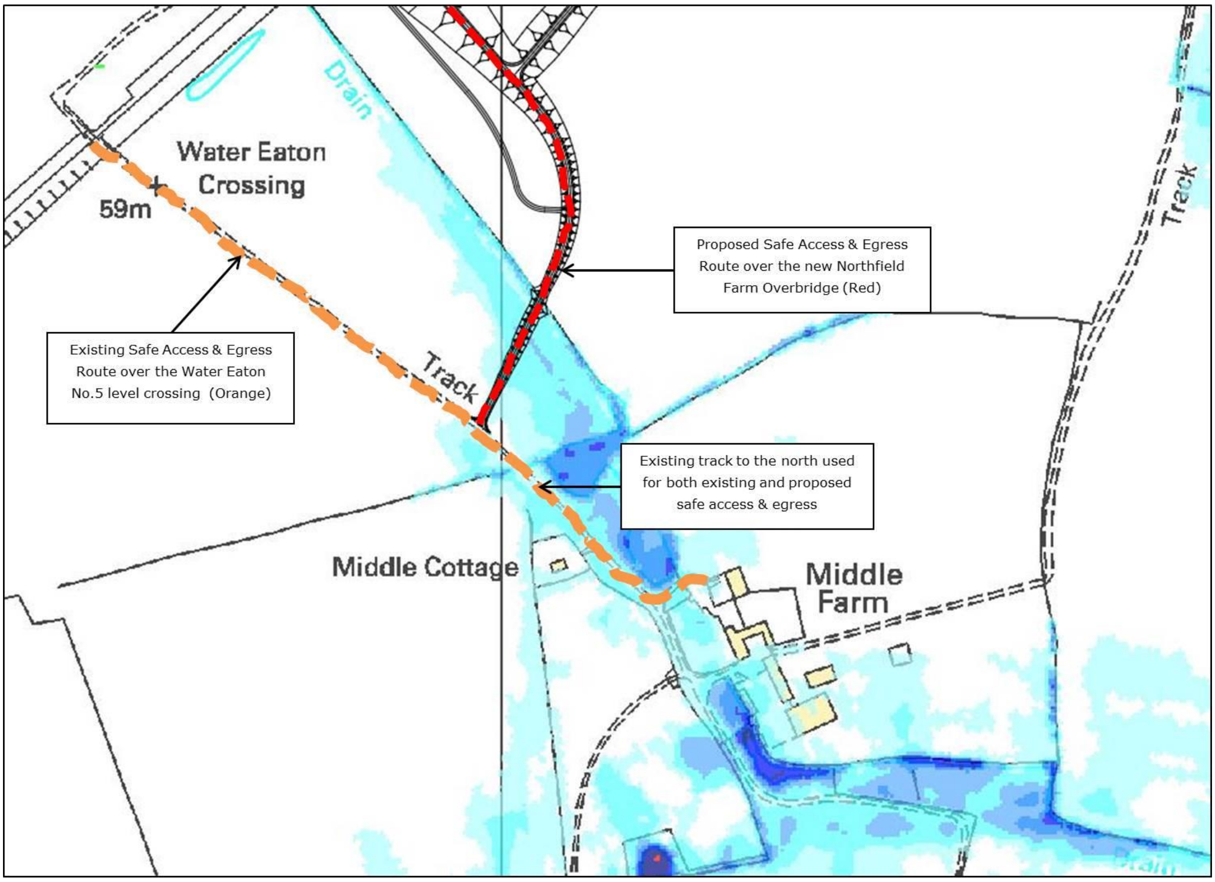

Figure 7 – Existing and proposed safe access & egress routes from Middle Cottage & Farm.

The existing track that runs from Middle Cottage and Middle Farm to the north is predicted to flood to depths of up to 300mm in the pre-development scenario. The EA stipulate that no increase in flood hazard along this route should occur as a result of development and preferably a betterment over the existing flood hazard.

To investigate the flood hazard and provide adequate mitigation measures we have prepared a post-development model. This model includes the Northfield farm overbridge modelled as a raised embankment with a 1m wide x 0.5m high box culvert installed under the new track to maintain a flow path through this structure. The post-development model also includes the provision of the compensatory floodplain storage as per the requirements set out in 3.5 to provide mitigation for the volume of floodplain lost as a result of construction of the access track.

In order to compare the potential flooding impacts associated with the construction of the Northfield Farm overbridge a number of steps were taken to record the modelled flooding impacts for each modelled simulation. These include;

- Assessment of the change in flood extents between the baseline and post-development model flood depth grids.
- Quantitative assessment of the change in flood depths across the 2D domain through creation of a flood depth difference grid (post-development model results – baseline model results = +/- flood depth as a result of the construction of the Northfield Farm Overbridge).
- Quantitative assessment of changing flood depths at a number of key locations within the 2D floodplain.

As shown in Figure 8, there is no significant increase in flood extent as a result of the construction of the Northfield Farm Overbridge. However, there are small localised increases predicted in the maximum flood extent to the south of the new access road. These increases are a result of the modifications made to the ground profile within the post development model where the compensatory floodplain storage has been incorporated leading to the increased flood extent. These increases are not of great significance as they occur within agricultural land and no property or infrastructure is adversely affected. These increases are extremely small in the context of the floodplain where baseline flood extents are predicted to already flood large areas of the Lower Cherwell floodplain.

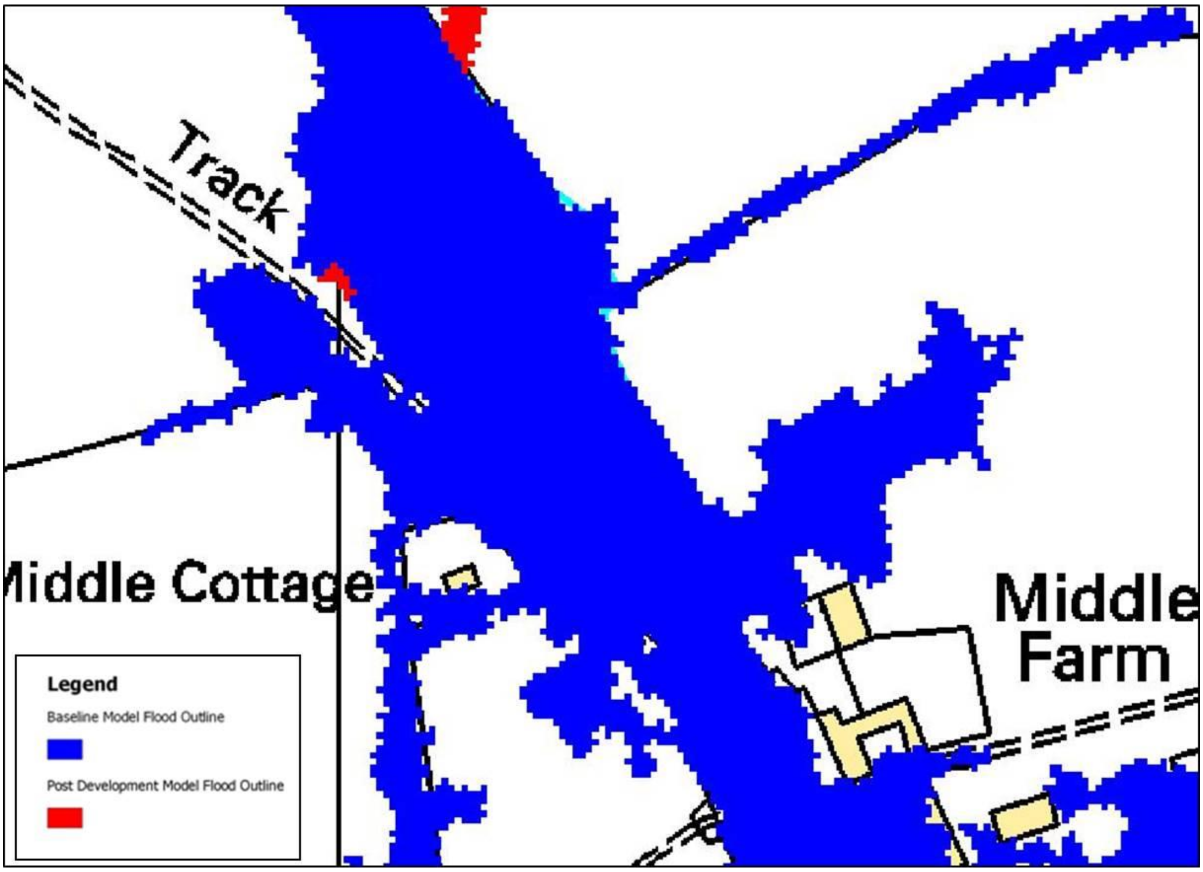

Figure 8 – Flood Extent Mapping for the 1 in 100 year (plus allowance for climate change) Flood Event.

3.6.1 2D Depth Grid Comparison

There is no predicted increase in flood depth along the existing access track from Middle Cottage and Middle Farm as a result of the construction of the Northfield Farm Overbridge. There are no significant changes in flood depth across the wider floodplain although there are minor and local predicted changes in flood depth immediately adjacent to the proposed raised access road. These localised areas are directly to the north and south of the access track where flood depth decreases of more than 100mm are predicted. Additionally there are more significant localised increases in flood depth of up to 100mm to the south of the access track. These are the areas where compensatory storage volume has been modelled and flood depths are inevitably deeper than the baseline model. Please refer to Figure 9 for flood depth mapping showing the distribution of flood depth increases and decreases over the Lower Cherwell floodplain. It should be noted that all the changes in flood depth are confined within the LOD boundary (i.e within networks rail land) and there are no impacts predicted on third party land.

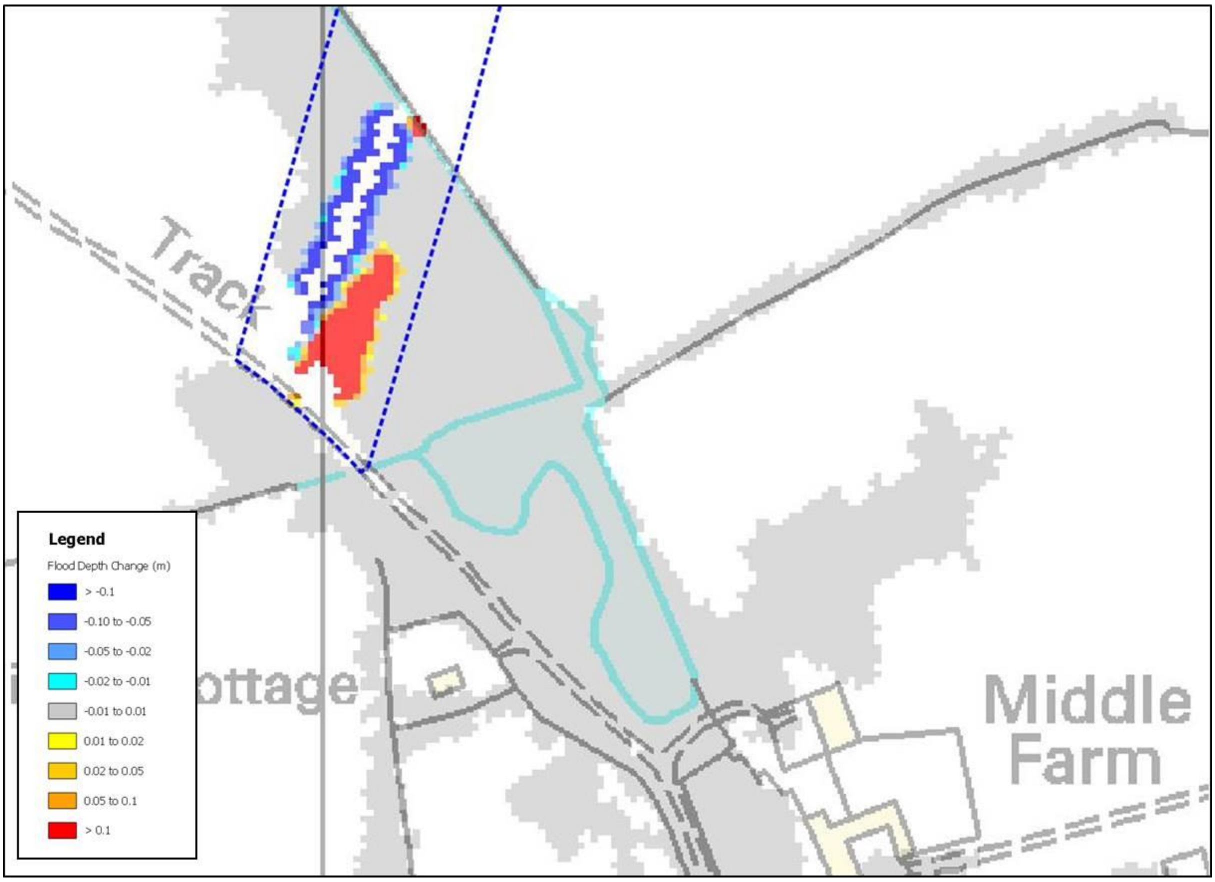

Figure 9 – Change in flood depth map for the 1 in 100 year (plus allowance for climate change) flood event. (LOD Boundary in blue)

A comparison of flood depths has also been recorded during the modelling by the use of PO sample points at strategic locations within the floodplain (presented in Figure 10 below). Table 2 shows the predicted maximum flood depths at each of the assessment points for the baseline and post development models.

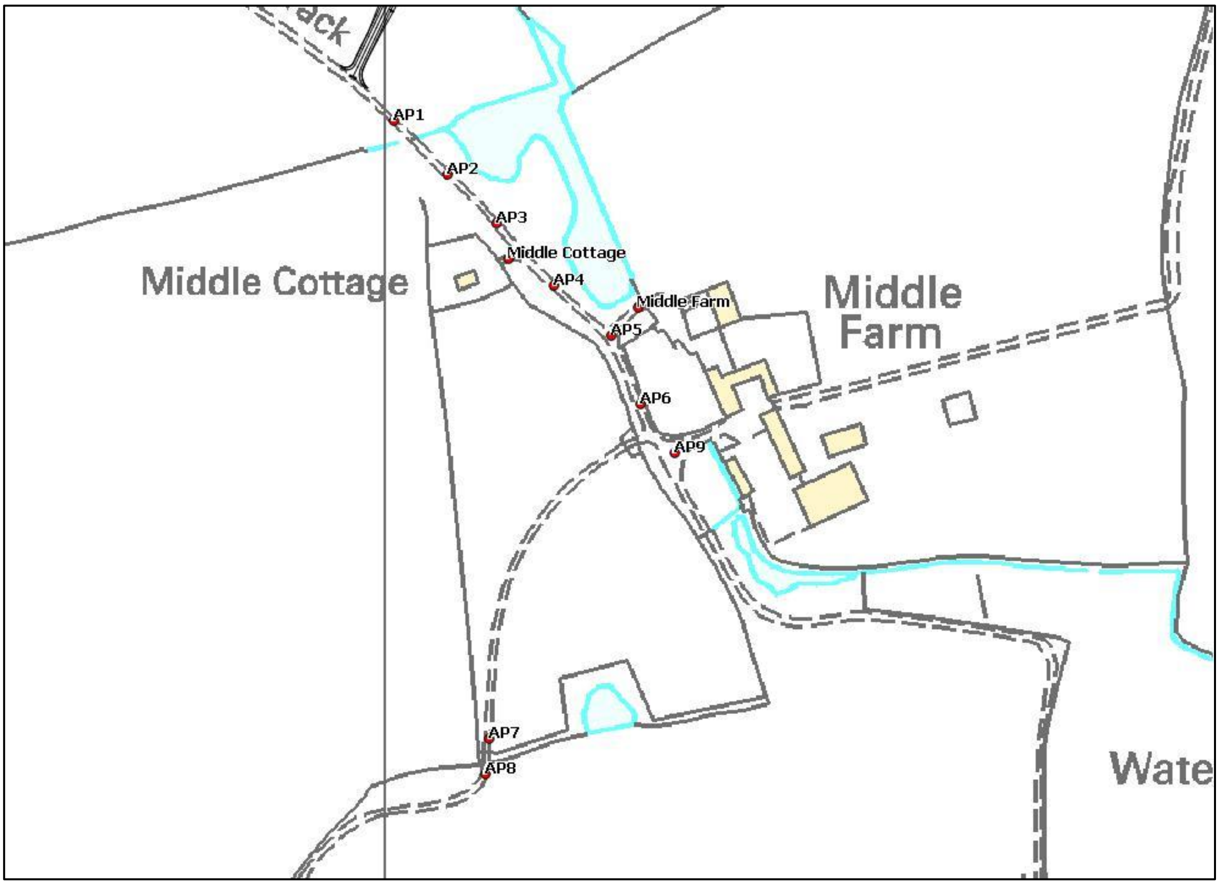

Figure 10 – PO Point Locations within the 2D domain.

Table 2 - Change in maximum 2D flood depths at selected Assessment Points.

Sample Point	Maximum Flood Depth (Baseline Model) (m)	Maximum Flood Depth (Post-development Model) (m)	Difference (m)
AP1	0.00	0.00	0.00
AP2	0.15	0.15	0.00
AP3	0.22	0.22	0.00
AP4	0.13	0.13	0.00
AP5	0.06	0.06	0.00
AP6	0.08	0.08	0.00
AP7	0.04	0.04	0.00
AP8	0.12	0.12	0.00
AP9	0.22	0.22	0.00
Middle Farm	0.42	0.42	0.00
Middle Cottage	0.17	0.17	0.00

Based on the post-development model results, it can be concluded that there is no increase in flood hazard predicted along the proposed safe access & egress route for Middle Cottage and Middle Farm.

4 October 2016 Addendum

4.1 Summary

The previously proposed level for level storage design, shown in Figure 5, has been reviewed within the context of newly available survey data[6] at the location. The previous level for level storage layout, proposed in 2014, suggested the lowering of ground levels at three strategic locations at the southern end of the AP13 Northfield Farm overbridge and access track to provide the required storage of 239m^3 between 57.90m AOD and 58.50m AOD. In light of the new survey data, two critical issues have arisen which make these proposed level for level storage areas unfeasible;

- Detailed survey and design has confirmed that to achieve the required level for level storage in the areas shown in Figure 5, lowering of existing, informal flood protection would be required. This would increase the flooding risk to the landowner at lower return period events.

- Survey data indicates that the topography in the region where compensatory areas C and D and proposed does not match LiDAR levels at this location. Ground levels at this location are generally between 58.0-58.15m AOD with only small areas exceeding the required 58.30m AOD. Consequently, the required 85.3m^3 of storage necessary between 58.10m AOD and 58.30m AOD is not attainable at the proposed location (D).

Based on the above information, two new locations for compensatory storage are offered. Figure 11 shows two potential locations for compensatory storage; Area A and Area B. As in section 3.5 throughout the process of identifying suitable locations for storage there are a number of key factors that have been considered that include:

- Where practicable, storage is to be provided within the 'blue line' LOD boundary, as close as possible to the point of impact.
- Ensuring compensatory storage areas can be hydraulically connected to the floodplain.
- Reviewing available topographic data to ensure ground levels can accommodate the required storage volume.

Based on the above, it is deemed that Area B is not suitable due to the fact that it is upstream of the new culvert under the access road, would not be sufficiently connected to the flood extent and lowering of ground to reach 58.50m AOD may increase flood risk at lower return periods. Conversely, Area A is suitably connected to the flood extent and is downstream of the new culvert. However, Area A is at 58.0m AOD, below the required compensation level and as such would not provide the required 215m^3 of storage at the required depth bands. Consequently, a 50% over compensation is proposed, bringing the compensation volume requirement to 358.5m^3

[6] 161011 NFF Field (OS).dwg

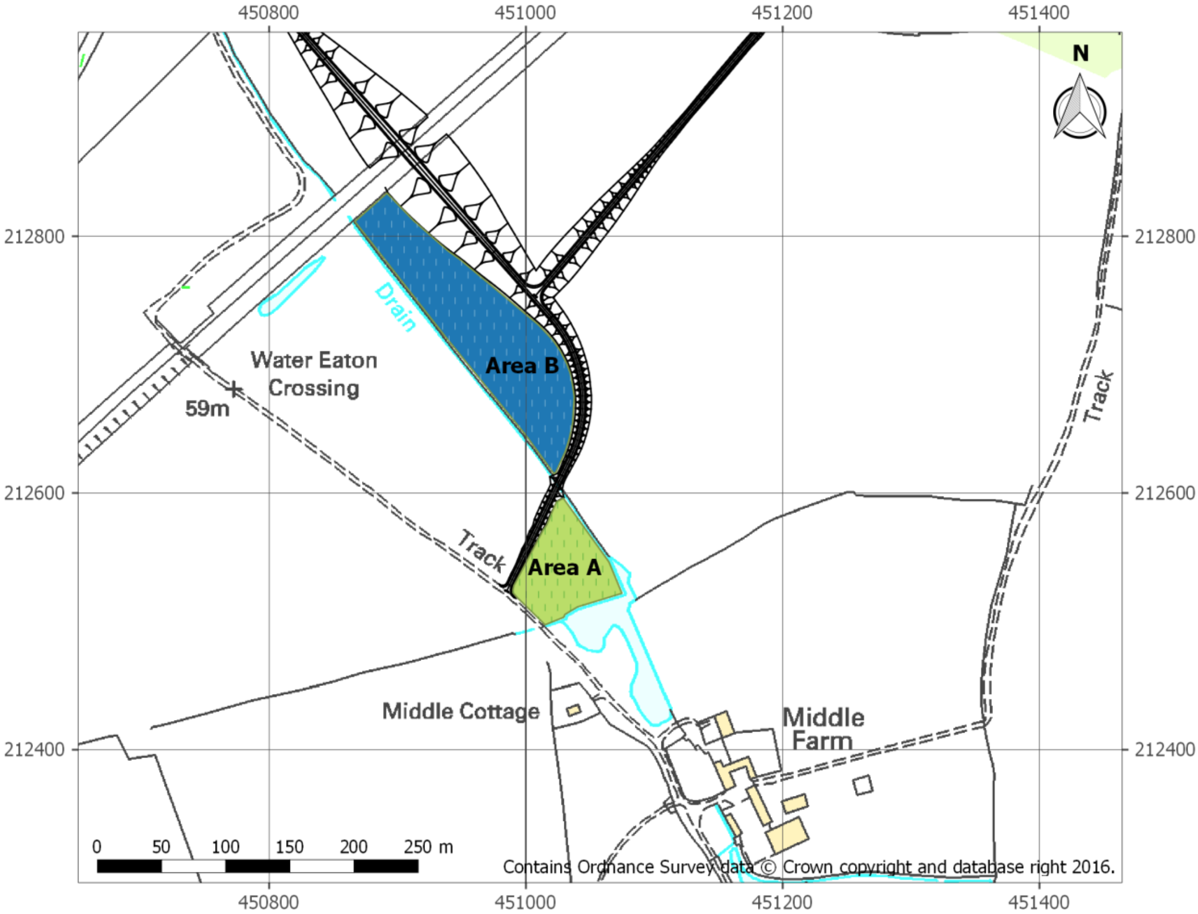

Figure 11 – Two areas identified as potential locations for compensatory flood storage

Area A, which is approximately 4500m^2 in area, has been identified as the preferred location for compensatory storage. In order to achieve the required 358.5m^3 of storage, a shallow scrape, the depth of which is dependent on area used, is required. Table 2 presents the depth requirements for varying areas utilised for storage.

Area Utilised (m^2)	Depth Required (m)
1500	0.239
2000	0.179
3250	0.110
4500	0.080

Table 3 – Area depth requirements for storage

In summary, the proposed storage option at Area A has been chosen as the preferred solution and location to provide floodplain compensatory storage for a number of reasons, which include that it:

- Is located close proximity to the point of impact;
- Can be hydraulically connected to the River Cherwell floodplain;
- Is downstream of the new culvert through the access track, reducing the impact of potential blockage should the storage area be located upstream and;
- Does not require ground lowering which could make the land more prone to flooding at lower return period events.

4.2 2D Modelling of Volume for Volume Storage

To assess the impacts of the proposed volume for volume storage outlined in Section 4.1, topographic changes were applied to the DTM of the original Northfield Farm 2D TuFLOW model to represent Area A shown in Figure 11.

A 2000m^2 polygon of 0.18m depth was applied to Area A. The originally proposed level for level storage areas were removed from the model.

The post development scenario with the volume for volume storage provision assumes the same roughness and floodplain features as the baseline 1 in 100 year event with an allowance for climate change. The proposed access overbridge was included in the post development model scenario along with the proposed storage area. As the assessment is a like for like comparison for flood level change with the new storage area included in the digital terrain model, the climate change value was maintained at 20% as this is the value assigned to the previous baseline scenario.

Figure 12 shows the baseline scenario compared to the post development scenario for the 1 in 100 year event with a 20% allowance for climate change. The image shows depth increases of up to 0.18m at Area A, reflecting the lowered storage area, with betterment in flood levels indicated directly adjacent to the access track. This is a similar pattern of betterment as shown in Figure 9 which presents the originally proposed level for level storage. No wider impacts as part of the proposed volume for volume storage at Area A are seen in the modelling results.

Figure 13 indicates that the new overbridge access road does not flood during the 1 in 100 year plus climate change event. Additionally, Figure 13 shows the points used to topographically define the feature within the model. This shows that the proposed access track rises from its junction with the existing access track. It is clear that the modelled flood level remains below the access road level as it ascends to towards the northeast and no worsening of hazard along the access and egress routes to Middle Farm is predicted.

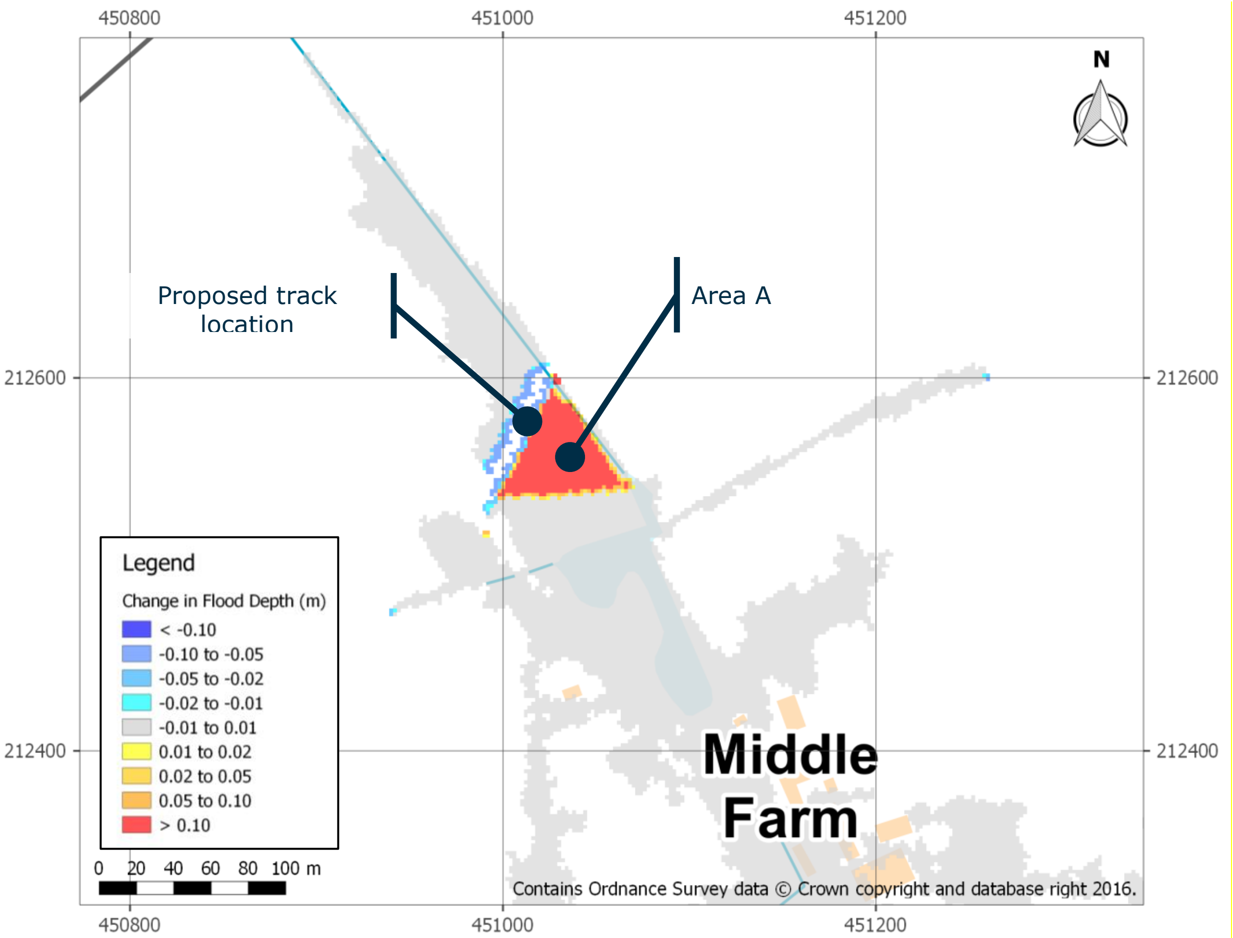

Figure 12 – Depth change comparison for the post development scenario against the baseline scenario

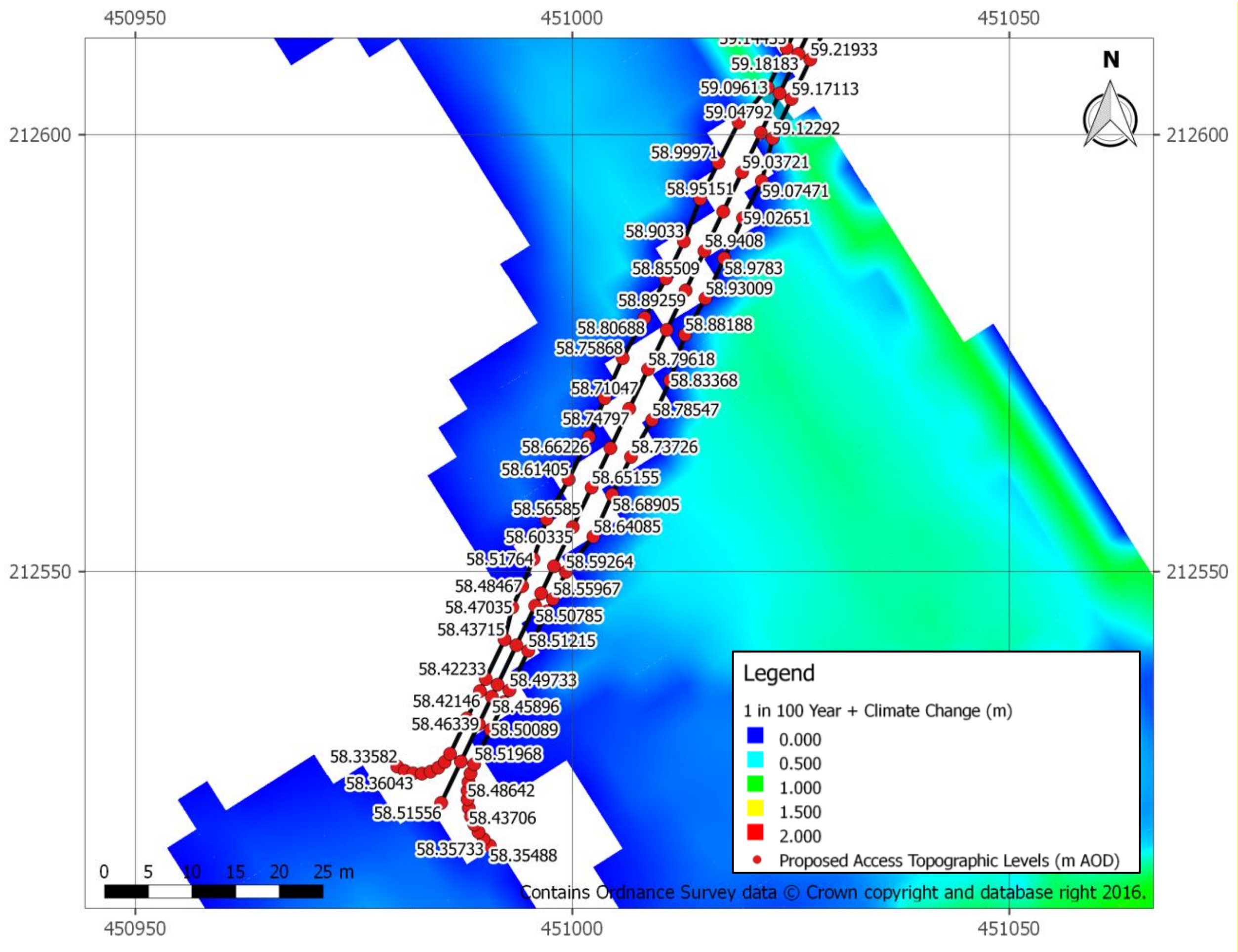

Figure 13 – Access track levels with adjacent flood depth and extent

5 Conclusions

The key conclusions of this FRA are as follows:

- The updated WHS 1D-2D baseline modelling (as per Appendix 1) has predicted a significant reduction in flood extent and depths at AP13 over that shown in the EA Flood Maps, which are based on the existing PBA 1D ISIS model[1].
- Based on flood extents and levels from the updated WHS model the construction of the AP13 Northfield Farm overbridge and access track would lead to a small reduction in floodplain storage and would require 239m^3 of compensatory storage to mitigate flood risk.
- The EA has confirmed that compensatory storage will need to be provided on a strict level for level basis to mitigate against the volume of floodplain lost as a result of the development.
- An assessment of land available to provide compensatory floodplain storage shows that an area of land (Area A) to the south of the proposed access road is suitable but would require overcompensation of 50% up to 358.5m^3 as actual level for level storage is unlikely to be possible.
- A 2000m^2 area of 0.18m depth has been modelled to represent the proposed volume for volume storage at Area A. The model outputs indicate no detriment elsewhere on the floodplain. Additionally, the post development modelling indicates that the proposed access track remains flood free.
- It is proposed that Atkins use the storage volume losses presented in Table 1 and Table 3 of this FRA to inform the detailed design of the final compensatory flood storage option at Area A and ensure that are storage area of 358.5m^3 is achieved.
- A post development modelling scenario has proved that there is no increase in flood hazard along the safe access & egress routes to and from Northfield Farm to the north east and Middle Cottage and Middle Farm to the south as a result of the new construction of the Northfield Farm overbridge.

Based on the analysis undertaken for this FRA, it is concluded that with the provision of 239m^3 (+50%) of compensatory storage there is no significant increase in flood risk as a result of the construction of the AP13 Northfield Farm overbridge.

5.1 Future Considerations

A 'Works Approval' is to be submitted separately in due course for the proposed works in this area, under the provisions of Schedule 15 of the TWA Order. Works Approvals will also be required for any temporary works within 16 metres of the main watercourses or within flood zones 2 and 3.

There are some points that need to be considered by the contractor in relation to the temporary works required during the construction phase of the access road. These include:

- All compounds, stockpiles and other works will need to be kept outside flood zones 2 & 3 and be sited within flood zone 1.
- All temporary haul roads within flood zones 2 and 3 will need to be kept at grade to avoid any requirement for compensatory flood storage.

- All roads should be constructed with a permeable hard-core or stone surface to avoid increasing the impermeable footprint of the site.

Chiltern Railways/ Network Rail will submit applications for the permanent Works Approvals and the Contractor will submit applications for temporary Works Approvals, where necessary.

Appendix 1 – AP13 Hydraulic Modelling Report

1 Introduction and Background

1.1 Purpose of the Report

Wallingford HydroSolutions (WHS) has been contracted to provide flood modelling on behalf of Chiltern Railways and Network Rail, to inform a Flood Risk Assessment (FRA) for proposed essential infrastructure works along the Bicester to Oxford Railway line.

This report assesses flood risk to, and as a result of, development taking place at Northfield Farm and accompanies the above FRA report submitted as a requirement of the conditions of the Transport and Works Act Order. The proposed works include the construction of a new access road and bridge over the existing railway line.

Flood risk to the site needs to be considered in order to assess whether the proposed development will have any impact on third-parties. If significant impact is found, mitigation measures will be considered to reduce this risk.

1.2 Background

1.2.1 Site Description

The proposed works centre around the existing Northfield Farm (also known as Water Eaton) Crossing located along the railway corridor to the south west of Islip town (NGR: 450905, 212876). The surrounding area, both downstream and upstream of the railway embankment, is predominantly farmland being a mix of pasture and crops.

Two main watercourses are within the study area, the River Cherwell flowing from the north and the River Ray flowing from the east which joins with the River Cherwell approximately 1.7km to the east of the site.

Figure 14 presents the current Environment Agency (EA) flood mapping and shows that the area is at risk of fluvial flooding during the 1 in 100 and the 1 in 1000 year flood events. It has been confirmed by the EA that this flood mapping has been based on the 1D modelling work conducted by PBA in 2005 that has been provided on licence to be utilised as part of this modelling study.

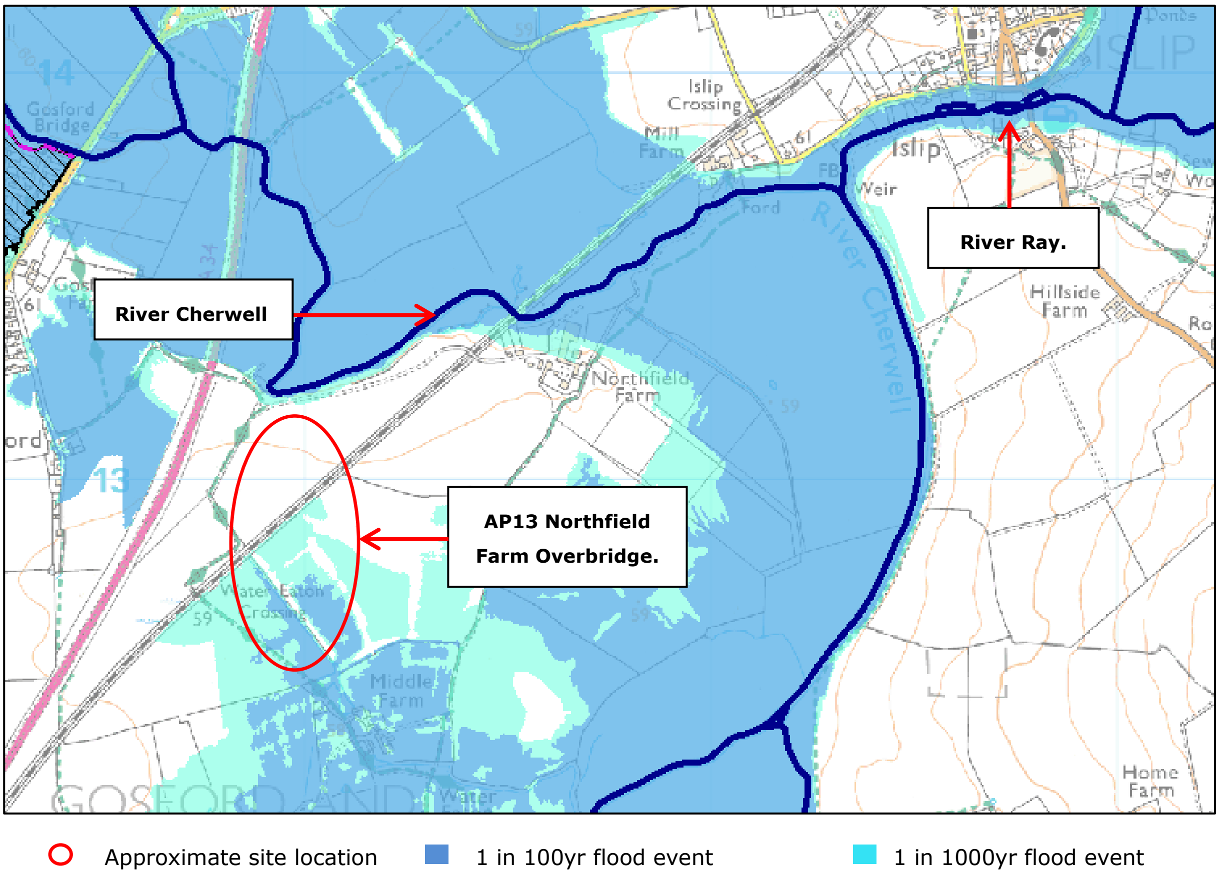

Figure 14 – Extract from the Environment Agency Flood Map (available online) showing flood extent surrounding the study area. **(© ENVIRONMENT AGENCY COPYRIGHT AND DATABASE RIGHTS 2013 @ ORDNANCE SURVEY CROWN COPYRIGHT. ALL RIGHTS RESERVED. ENVIRONMENT AGENCY. 100026380).**

1.2.2 Development Proposal

The existing Northfield Farm overbridge is to be demolished as it is too low for w12+ gauge specifications, and the existing Water Eaton No. 5 level crossing is to be closed. They are to be replaced by an overbridge close to the location of the current Water Eaton No. 5 crossing, along with additional farm road to enable access. Figure 15 shows the location of the proposed access road.

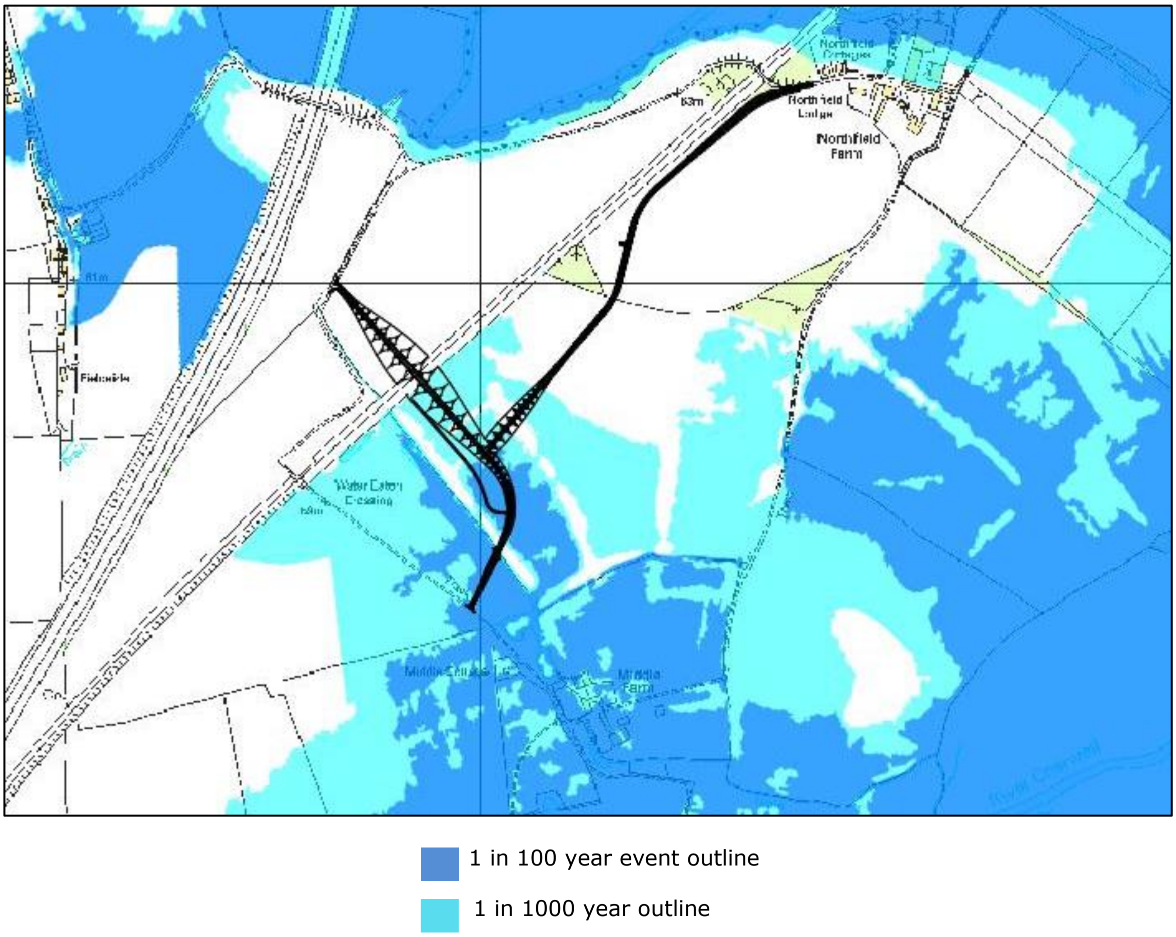

Figure 15 – Proposed Alignment of Northfield Farm Overbridge and Access Track, Following Closure of Existing Level Crossing, (proposed works shown in black).

2 Hydrological Model

An updated hydrological assessment has been conducted by WHS to inform the Islip modelling study and has also been considered fit for use in the AP13 Northfield farm modelling study. The existing PBA modelling hydrology was conducted in 2005, which is now outdated by more up to date methods. Therefore, WHS has conducted an updated hydrological assessment using the current industry standard techniques benefiting from a longer gauged record to estimate peak flood flows. Please refer to the Islip Flood Hydrology Report[2] for further details on the hydrological modelling. The location of the inflow and downstream boundaries are however discussed within section 3.4 of this Appendix.

3 Hydraulic Model Build

3.1 Sources of data used

The main sources of data used in this modelling study include;

- **LiDAR data** - LiDAR data[4] has been provided by the EA, through the Geomatics Team. LiDAR data at 2m[4] resolution was adopted for this hydraulic model. This resolution was considered suitably detailed to model the floodplain features. The vertical accuracy of the LiDAR provided is between ±0.15m.

- **Lower Cherwell Hydraulic Model –** An existing 1D hydraulic Model was built by PBA in 2005[1] and provided on licence by the EA. This model has been used to define the 1D portion of the updated WHS model and any in channel hydraulic structures.

- **Updated hydrology** – An updated hydrological assessment[2] was prepared by WHS specifically for use in the Islip Safe Access and Egress modelling and is considered fit for use in this modelling study.

- **10K OS Mapping -** for use in model reporting and land use classification.

3.2 PBA modelling of the Lower River Cherwell

Peter Brett Associates LLP was commissioned in 2005 by the EA to undertake hydraulic modelling of the Lower River Cherwell that extends from Thrupp railway bridge to the River Thames confluence at Oxford, which also incorporates the town of Kidlington. This modelling was undertaken under the Strategic Flood Risk Mapping framework to create flood risk maps of the area.

The hydraulic modelling assessment was undertaken using ISIS modelling software (Version 2.3) and includes survey data collected by the EA for river channel sections and modified Digital Terrain Model (DTM)[3] data to represent the topography of the floodplain. The entire study reach is modelled as a pure 1D ISIS model which incorporates the river channel, floodplain and any structures within a 1D hydraulic modelling domain.

The model was reviewed by the EA at the time of completion, and was found to be appropriate for use in flood risk mapping. The mapping produced by this model is currently being used by the EA as flood risk mapping for the area.

This model has been provided by the EA for use in this FRA and the model is considered fit for purpose in defining the in-channel hydraulics.

A full copy of the existing PBA model and modelling report is available from the EA on request.

3.3 Modelling Approach

To limit any unnecessary additional costs associated with obtaining new topographic survey data, to reduce timeframes involved in the modelling work and to add value to the scheme the existing PBA model[1] has been utilised as much as practicable in this study to inform the updated WHS model build.

The Lower Cherwell Flood Risk Mapping study used a 1D ISIS model to simulate flooding in the Lower River Cherwell and flood extents at Northfield Farm have been obtained by extrapolating predicted in-channel flood levels across the floodplain. This model has been obtained on licence from the EA and has been used as a starting point for this modelling study. However, the proposed AP13 Northfield Farm Overbridge is located some 1.5km from the main river Cherwell and would benefit from a 2D modelling solution to be developed to enable overland flows to be modelled to more accurately assess flood extents and levels at this location.

WHS has developed a modelling approach that uses ISIS 1D modelling software to simulate the river channel hydraulics which is then dynamically linked to a TuFLOW 2D domain to simulate the floodplain hydraulics. This linked model utilises the existing PBA model[1] for topographic survey data of the river channel and details of hydraulic structures to inform the 1D ISIS model build. The 1D model of the main river is dynamically linked to a 2D domain, which is modelled using TuFLOW modelling software. LiDAR data[4] have been used to represent floodplain topography in the 2D domain and will allow overland flows to be accurately modelled. This approach will allow more accurate definition of flood zones and a more accurate flood level at AP13 to be predicted.

The updated AP13 Northfield Farm hydraulic modelling has been carried out in a number of stages that include;

- Review of PBA modelling data which included the manipulation and extraction of the most appropriate data to inform this updated modelling study. Data extracted from the existing PBA model[1] include:
  - River channel cross sections taken directly from the 1D model have been trimmed to top of bank to aid in the 1D – 2D linking process.
  - The PBA 1D model was trimmed to a location approximately 1.5km upstream and 4km downstream of the site. The extent of the trimmed model is shown in Figure 19.
  - The updated WHS Hydrology[2] has been used as inflows into the trimmed PBA model for both the River Cherwell and River Ray.
- Dynamic linking of the 1D ISIS model of the River Cherwell main channel informed by the PBA model[1] linked to a 2D floodplain modelled in TuFLOW based on LiDAR data[4] to represent the floodplain topography. The 2D domain has then been updated with various structures and roughness coefficients to represent actual ground conditions. For more details please see section 3.5 of this appendix for details of 2D model build.
- Run the model to simulate the 1 in 100 year (plus a 20% increase in peak flow as an allowance for climate change) flood event.
- Sensitivity testing of the hydraulic model.
- Results extraction, analysis and reporting.

3.4 1D Model Build

3.4.1 Model Inflows (River Cherwell and River Ray)

The final design hydrographs for the River Cherwell as calculated by WHS have been used as inflows at the upstream boundary of the ISIS 1D model. Additionally the final design hydrographs for the River Ray have been used as a lateral inflow into the model at Node CHU.024 which is the confluence of the River Cherwell and the River Ray. Please see Figure 16 and Figure 17 for the final inflow hydrographs used.

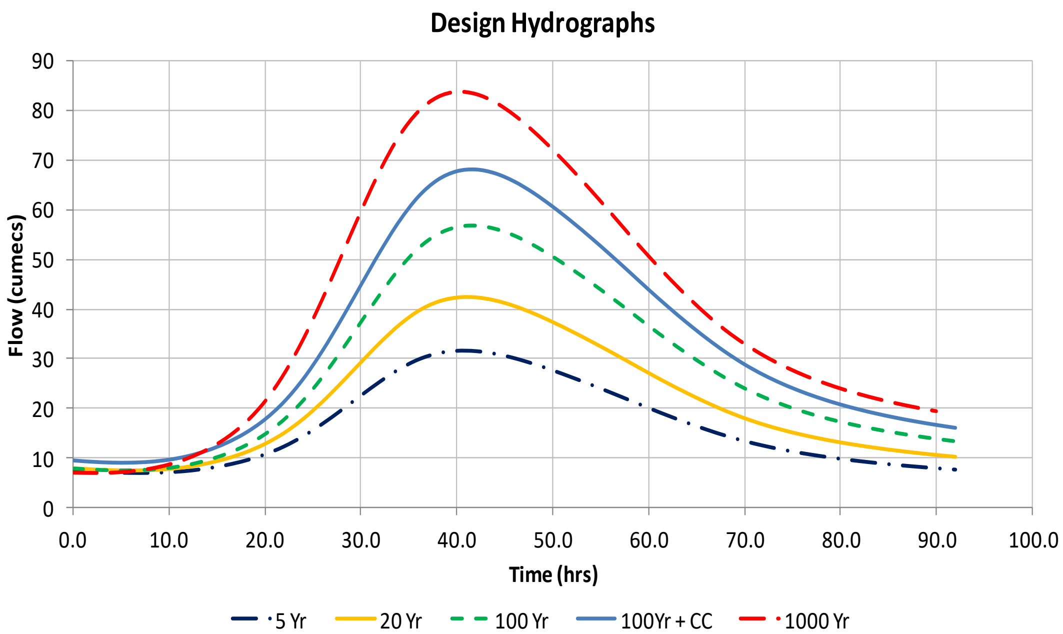

Figure 16 – Final Design Hydrographs for the River Ray.

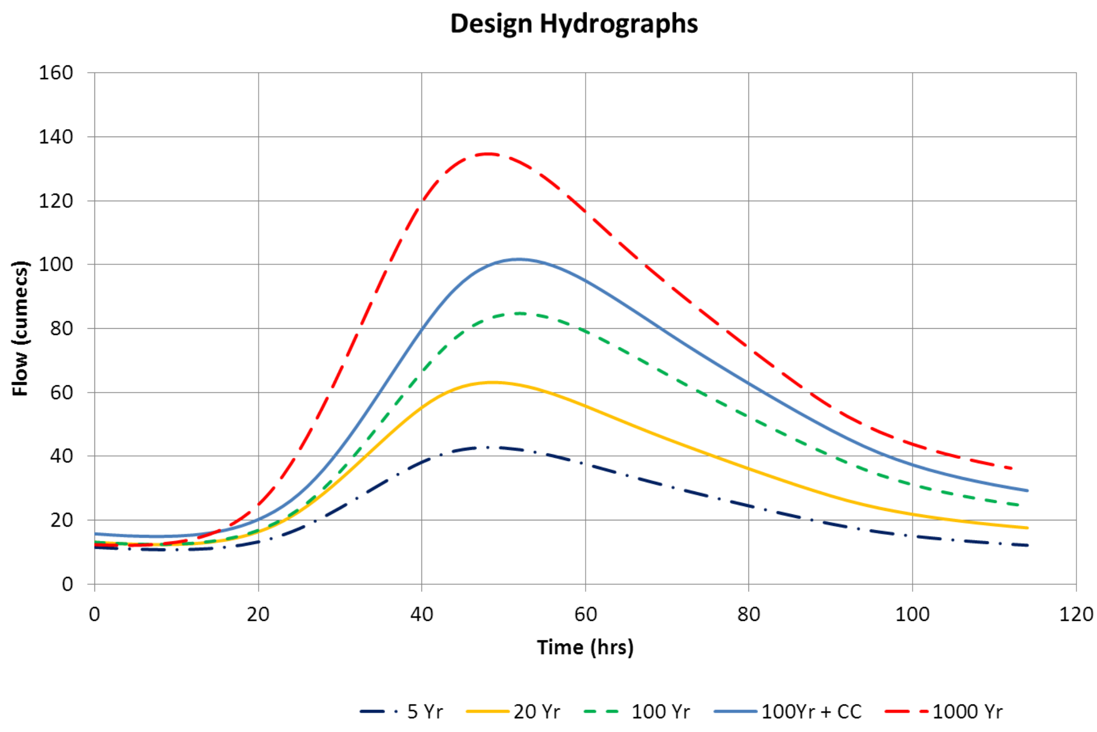

Figure 17 – Final Design Hydrographs for the River Cherwell.

3.4.2 Downstream Boundary Conditions

A normal depth downstream boundary condition has been applied to model node CH.100, which is the new downstream node of the trimmed model. An average bed slope of 2.865×10^{-4} was applied which is calculated as the slope between cross sections CH.113 and CH.100 from the existing PBA model[1]. Sensitivity tests on this boundary slope were conducted to ensure that the results were not sensitive to the boundary condition assumptions.

3.4.3 River Channel Cross sections

The 1D element of the model has been modelled using ISIS 1D modelling software. To inform the 1D element of the model the river channel cross sections have been extracted from the PBA 1D model[1] of the Lower River Cherwell. The river channel sections used in the existing PBA Lower River Cherwell model[1] spaced up to 500m apart around our study area. To aid in the 1D - 2D linking process and improve model stability WHS considered it necessary to manually add a number of interpolated river sections (at 100m spacing) to the 1D element of the model. The reduced spacing between sections will improve model stability when the 1D ISIS model is dynamically linked to the 2D TuFLOW model domain.

3.4.4 In-bank Manning's n

Generally the in-bank Manning's n values used for the in bank river channel sections have been set at 0.05, replicating the existing PBA model[1]. The PBA modelling study[1] uses this value based on observations from site visits. This value represents a relatively clear channel that is affected by vegetation along the banks which from the WHS site visit seems to be a reasonable, if somewhat conservative assumption.

3.4.5 Structures

There are a number of crossing structures within this study reach. The PBA modelling report[1] details what structures have been modelled and provides justification on how these have been modelled in the 1D domain. The WHS updated model has used these existing structures within our updated modelling with the exception of the Cherwell Viaduct (Model Node: CHU.034b_u) that has been modified to represent flows in the 2D domain. Modelling of the Cherwell Viaduct is described in more detail in section 3.5.4 of this appendix.

3.4.6 1D Model Schematic

Figure 18 shows the ISIS 1D model schematic, illustrating the overall construction of the 1D component of the model.

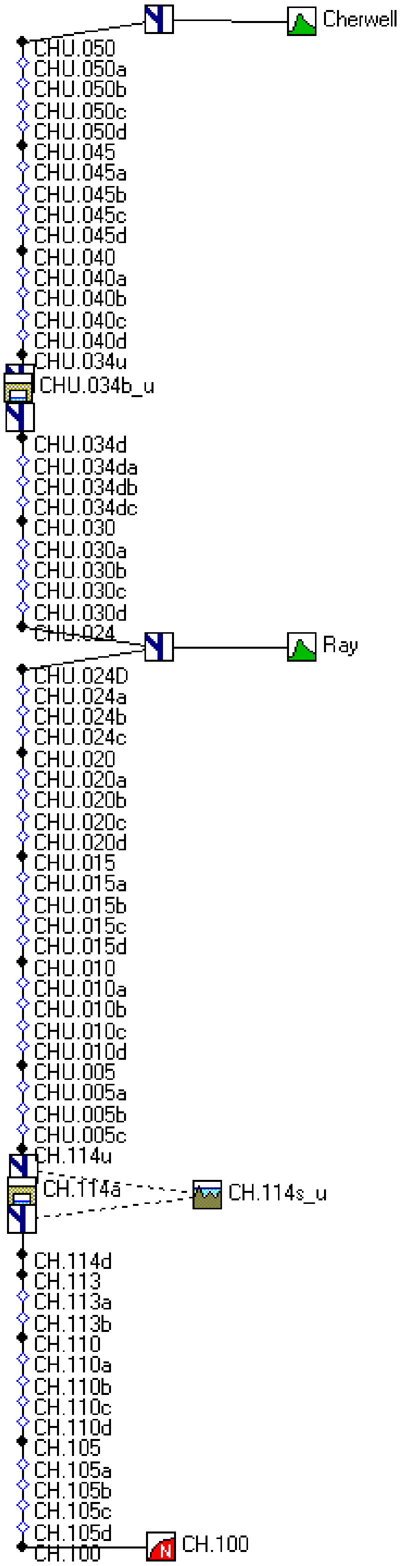

Figure 18 – ISIS Model Schematic.

3.5 2D Model Build

2D modelling allows the dynamic behaviour associated with flow of flood water across the floodplain to be considered. Using 2D modelling, features such as buildings or a change in topography can be incorporated into a DTM (digital terrain model) of the floodplain. This study used 2D modelling in order to more accurately model floodplain hydraulics and predict a more accurate representation of flood extents and levels at the Northfield Farm development to refine the compensatory storage requirements.

TUFLOW was used as the 2D model package. The 2D model component was run using a 4m grid cell size, which is small enough to allow an accurate flood extent to be modelled. The construction of the 2D domain is considered in the following sections.

3.5.1 Model Setup

The TuFLOW model has been developed using version: 2012-05-AC-Isp-W32. The model has been simulated using a 1 second TuFLOW timestep (1 second timestep in 1D ISIS model) and a grid cell size of 4m. Ground levels across the site have been obtained from LiDAR data[4].

Figure 19 shows the extent of the active TuFLOW area, which covers 5.73km^2. It extends from the A34 upstream, which is located just to the north of the railway embankment, down to model node CH.100 from the existing PBA model[1] which is located some 5.5km downstream of the confluence of the River Cherwell and River Ray.

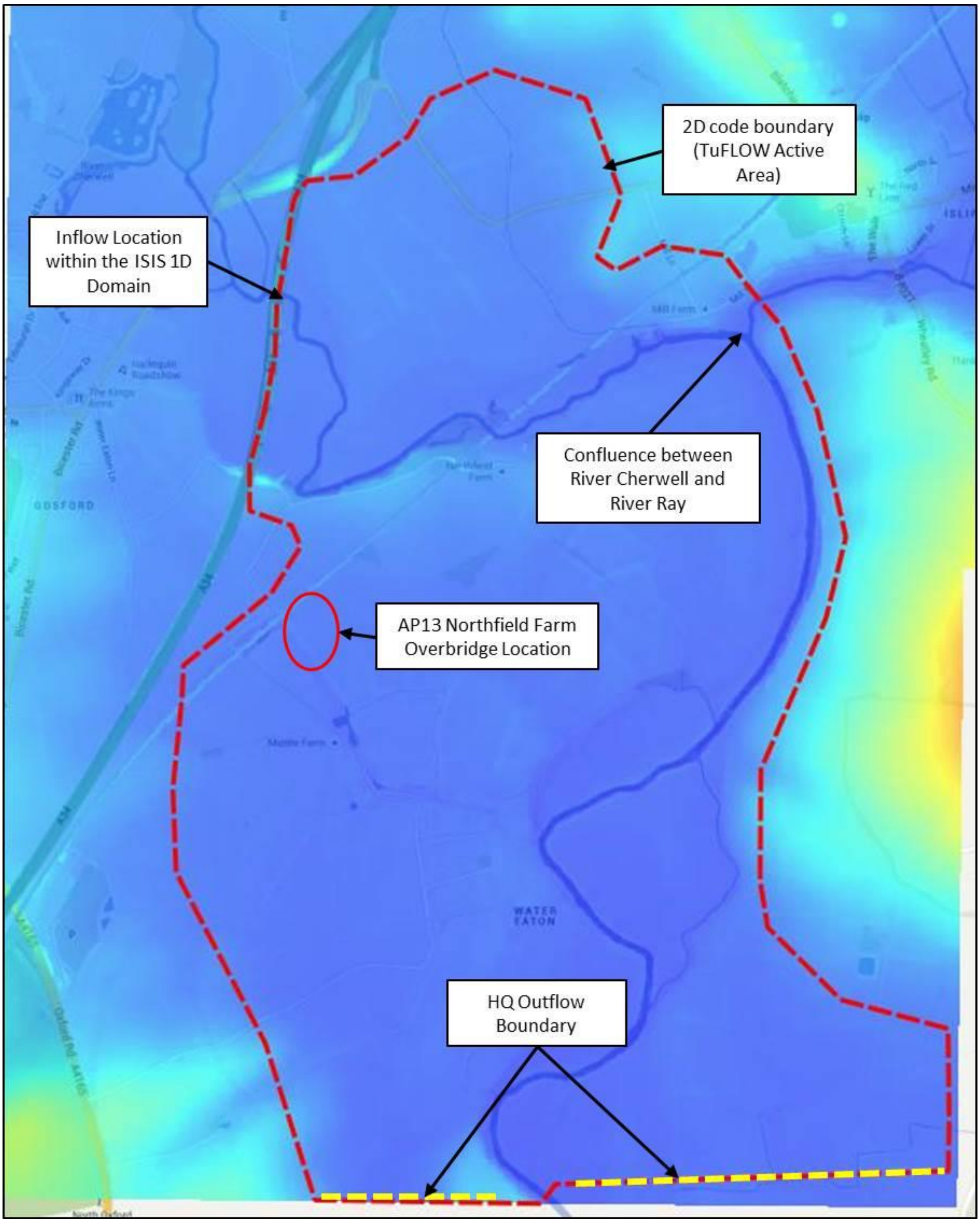

Figure 19 – Tuflow Active Model Area.

3.5.2 Floodplain Topography

LiDAR data[4] was used to define the floodplain topography. A 2m resolution data set was used, and converted to a 4m model grid. Flood plain extent is relatively large in this area, as the topography is very flat. As a result, a large 2D code polygon (defining the active area for modeling) was used. This reduced the risk of glass walling occurring. Figure 19 highlights the area of 2D model extent.

3.5.3 Floodplain Roughness Co-efficient

The influence of hydraulic roughness affects the conveyance capacity of the land or riverbed where flows are occurring. Within the TuFLOW model, hydraulic roughness is defined by the dimensionless Manning's n coefficient.

For broad scale 2D modelling studies the EA recommend a conservative Manning's roughness value of 0.1 is used for floodplain areas. The original PBA model[1] used this recommended value for all areas of the floodplain which would have likely resulted in overly conservative flood extents and depths being predicted.

For the purposes of this assessment a more refined assessment of floodplain roughness has been applied. A number of material roughness classifications have been identified based on engineering judgement and available literature (e.g Chow. 1959)[7]. The distribution of these features has been defined using aerial photography and OS mapping in order to vary the conveyance rates throughout the floodplain. Table 4 presents the key land use types identified along with their corresponding roughness values.

Table 4 – Manning's n Values used in TuFLOW Model.

Manning's n value	Description
0.020	Open water
0.045	Default – Open ground, Fields etc.
0.100	Woodland Areas

3.5.4 Structures

A portion of the Cherwell Viaduct was modelled within the 2D domain. This structure has been jointly modelled in both the 1D and 2D domains given its large expansive nature being both in the main channel and extending out onto the floodplain. The main bridge opening that spans the River Cherwell has been retained within the 1D portion of the model but the 68m section of the viaduct that extends out across the floodplain has been modelled in the 2D domain.

[7] Chow, V T (1959). *Open-channel hydraulics*. McGraw-Hill.

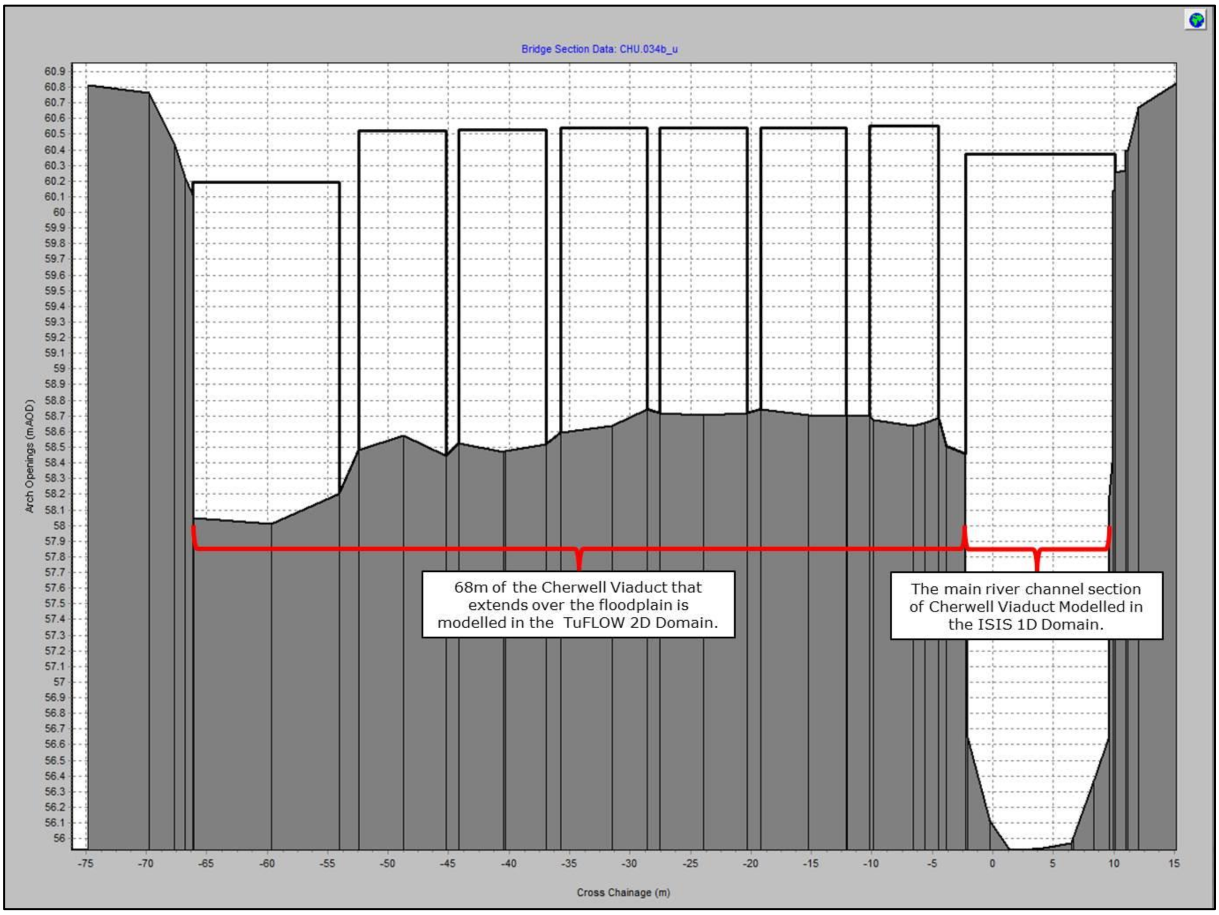

Figure 20 – Cherwell Viaduct ISIS Cross Section.

The Cherwell viaduct has been modelled by applying a single 2D flow constriction unit (2d_fcsh layer) to represent the percentage blockage of the structure and associated losses. This is considered to be the preferred approach to modelling such a structure rather than simply modifying the bridge piers in the 2D domain which would in this case lead to unrealistic blockages given that the pier widths are less than 1m and the cell size used in the modelling is 2m. In this case the floodwater is not predicted to submerge the bridge deck, so only the additional losses and restriction of flow widths parameters were utilised. These parameters have been estimated in line with guidance provided in Hydraulics of Bridge and Waterways, 1978 and a TuFLOW publication on modelling bridge piers[8]. A percentage blockage of 12% and Form Loss Coefficient (FLC) of 0.26 have been modelled.

The Cherwell viaduct bridge deck was represented within the 2D domain at the location identified within Figure 21.

Bridge decks have been modeled as spills within the 2D domain. Standard model convention is that where the bridge deck is greater than 2 model grid cells in width, as is the case here, then 2D representation is appropriate. The bridge decks were represented as Zshapes, with a level assigned equal to the deck level from the PBA model[1].

[8] Document titled: Modelling Bridge Piers and Afflux in TuFLOW.

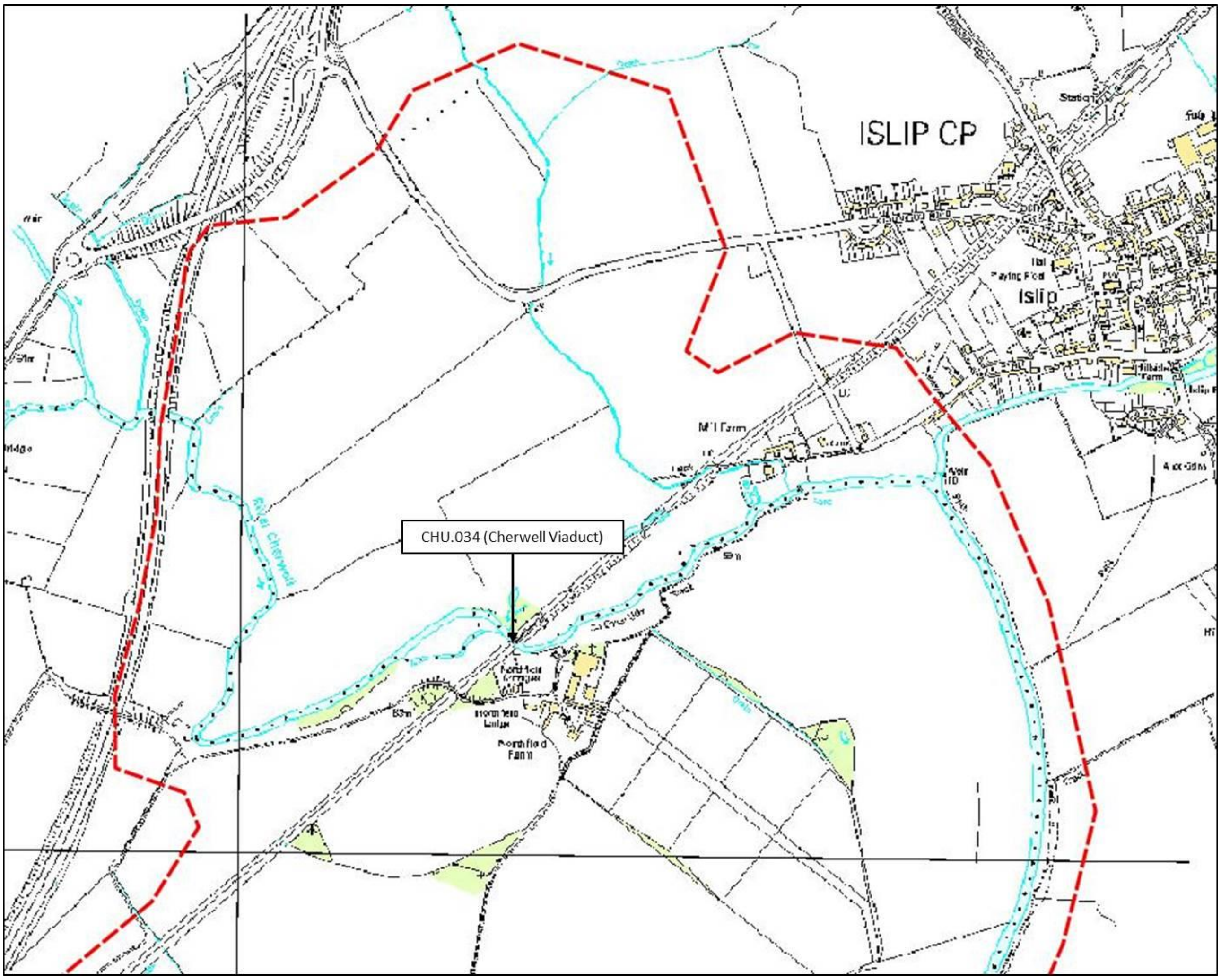

Figure 21 – Locations of the Modified Bridge Deck to be Modelled in the 2D Domain. (This structure had originally been removed during the LiDAR filtering process)

3.5.5 Downstream Boundary

To define water leaving the model at the downstream extent of the 2D domain a number of HQ outflow boundaries have been included. These boundaries are located along the southern edge of the 2D model code boundary defined by the extent of the extended cross section (Node - CH.100) where the existing 1D PBA model[1] has been trimmed. These boundaries provide flow routes out of the model in a downstream direction and replicate the natural overland flow paths that would occur during spate flows in the Lower Cherwell. An approximate ground slope has been applied to each boundary presented in Figure 22 based on LiDAR elevations. The following boundary slopes have been applied;

- Boundary 1 (Orange) = 8.3×10^{-4}
- Boundary 2 (Red) = 8.3×10^{-4}
- Boundary 3 (Yellow) = 1.2×10^{-3}
- Boundary 4 (Purple) = 8.3×10^{-4}
- Boundary 5 (Green) = 5.1×10^{-4}

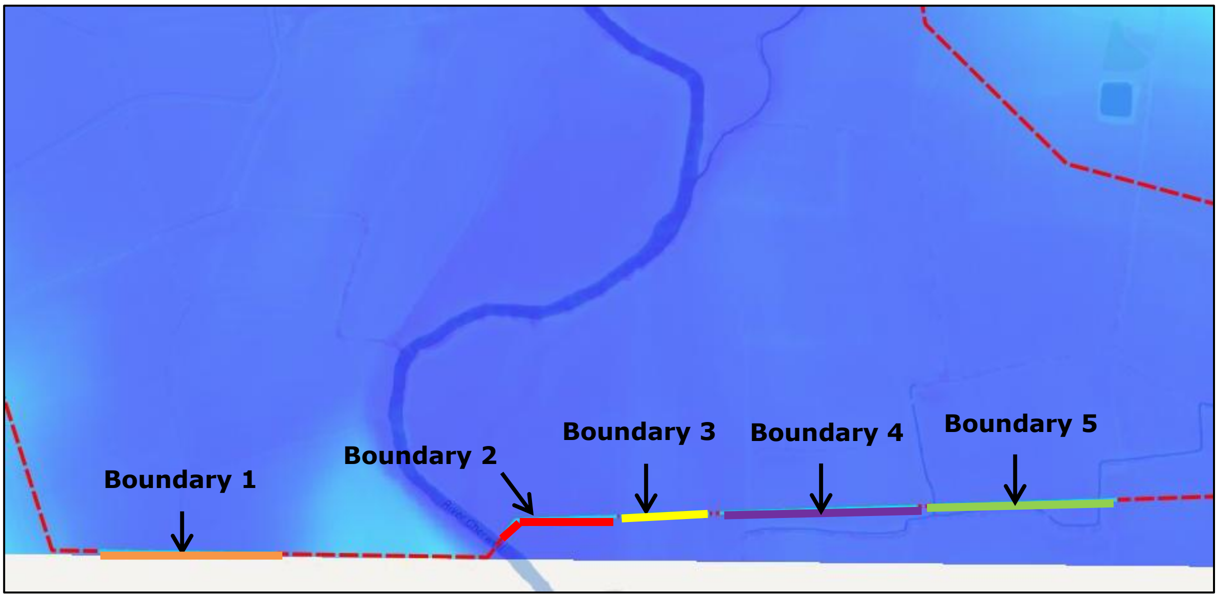

Figure 22 – TuFLOW outflow Boundary Locations.

This boundary has been split into five separate gradients to give a more realistic flow pattern out of the boundary rather than providing a single average slope. A sensitivity analysis will be conducted on these boundary slopes to analyse their impact on flooding at and near Northfield Farm.

No outflow boundary condition has been included on the River Ray at Islip as the floodplain through Islip and upstream on the River Ray is considered to offer no storage during flood conditions and therefore this boundary is being modelled conservatively offering no additional storage.

3.6 Final Model Simulations

A number of simulations were undertaken in order to assess the impacts of the proposed works. The following flow events were simulated:

Baseline Simulations

- 1 in 100 year plus climate change in both the River Cherwell and the River Ray.

Sensitivity (on baseline simulations)

- 1 in 100 year plus climate change in both the River Cherwell and the River Ray. (Manning's values increased globally throughout the model by 20%).
- 1 in 100 year plus climate change in both the River Cherwell and the River Ray. (-10% on Boundary slope in both the 1D and 2D domain).

3.7 Results

Flooding at AP13 Northfield Farm site is caused by the backing up of floodwaters from the River Cherwell about 1.5km downstream of the site along the minor watercourse adjacent to Middle Farm and flooding the low lying areas of floodplain adjacent to the site. Figure 23 highlights the predicted flood extent during the 1 in 100 year plus climate change event on the watercourses in the vicinity of the proposed AP13 Northfield Farm Overbridge for the baseline scenario. The predicted extent shows that the vast majority of the proposed alignment is outside of the predicted flood extent. However, the south western section of the access road does flood with depths generally around

400mm with isolated depths of up to 800mm in the drainage ditch. The predicted flood level is 58.50mAOD at the western spur of the AP13 access road.

As shown by Figure 23 the predicted flood extent is considerably reduced over that predicted by the EA flood risk mapping. There are a number of reasons for this clear difference in extent. The main factors for this are considered to be the limitations of PBA 1D modelling (basis of the current EA flood-map) and the simplistic approach of defining a flood extent by extrapolating a flood level over a course DTM (based on SAR data[3]). It should also be noted that the existing PBA model is based on conservative data in terms of a high manning's value of 0.1 being used to define floodplain roughness, which is quite high given the nature of the floodplain, outdated hydrology and course SAR data[3] to define floodplain topography. The updated WHS 1D – 2D model provides a more refined assessment that results in reductions in flood level and extent which in turn reduces constraints at Northfield Farm from a flood risk perspective.

Although the flood extent predicted is reduced, a small proportion of the alignment was shown to be within the flood extent, therefore consideration of flood consequence, and flood compensatory storage was undertaken and is presented in the main flood risk assessment report.

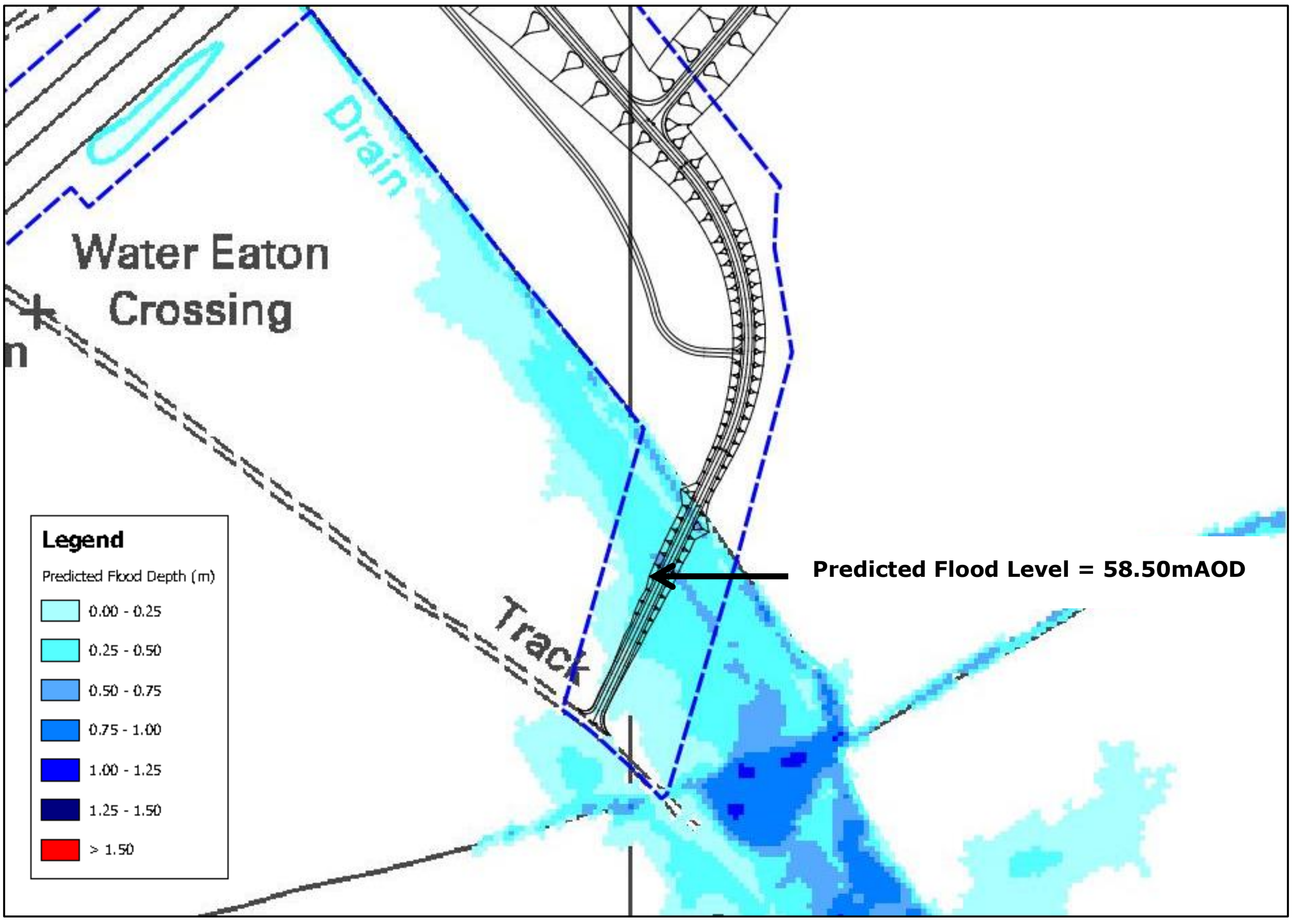

Figure 23 – Predicted 1 in 100 year Plus Climate Change Flood Extent in Relation to the Proposed Road Alignment for the Baseline Scenario.

3.8 Sensitivity Analysis

Sensitivity tests were undertaken to determine the impact of parameter uncertainties on predicted base flood level (1 in 100 year plus climate change) at the AP13 Northfield Farm overbridge site. Our sensitivity testing has focused on the downstream boundary conditions and Manning's n values used to define the roughness coefficient within the model. To aid in the assessment of flooding impacts at the site, a number of assessment points were considered within the 2D domain and these are highlighted in Figure 24. Maximum flood depths at each of the assessment points are highlighted in Table 5 for the baseline scenario and the two sensitivity tests with the relative differences calculated.

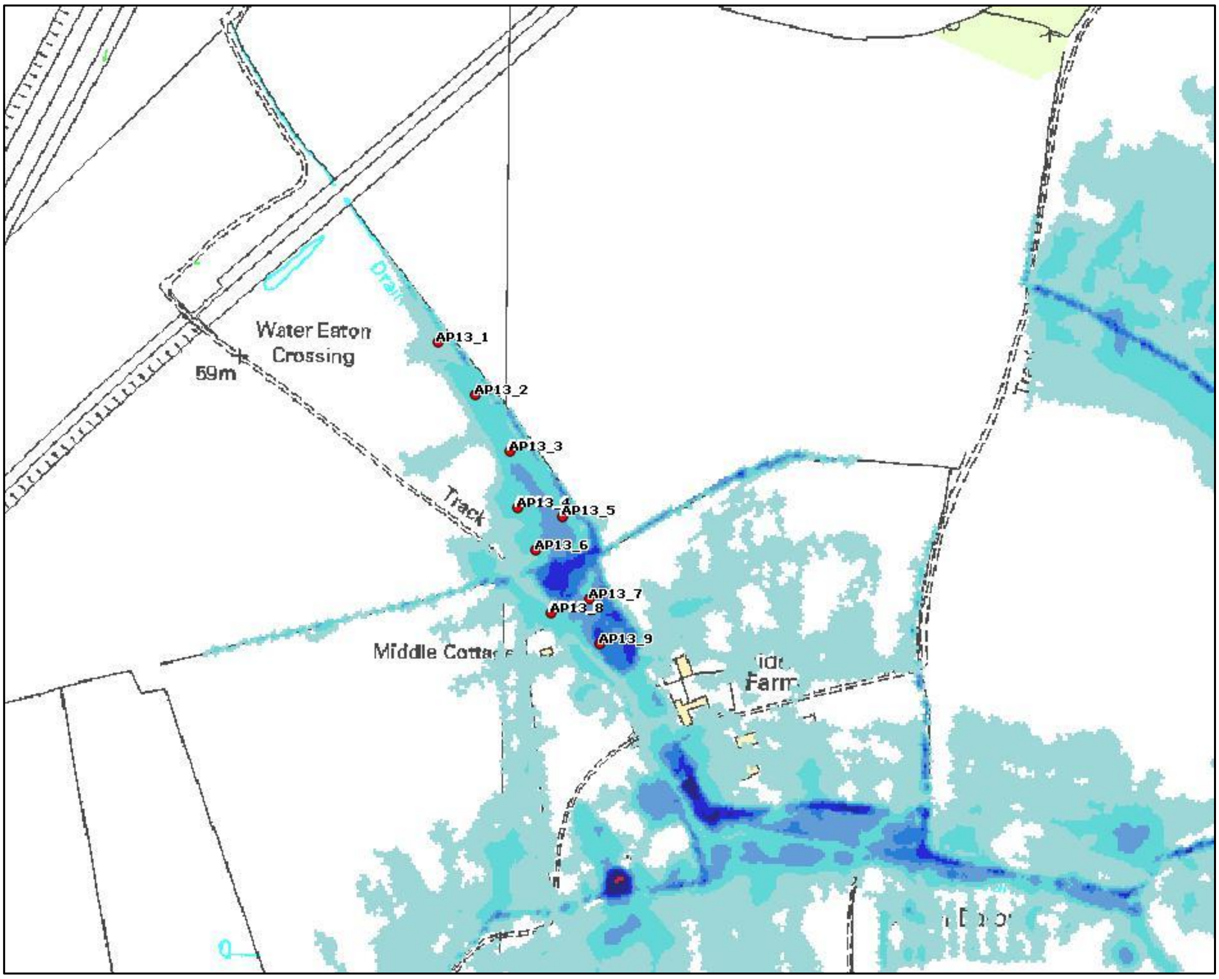

Figure 24 – PO Point Locations.

Table 5 – Sensitivity Comparison.

PO Point reference	Boundary – 10%			Manning's +20%		
	Maximum flood depth (Baseline Model) m	Maximum flood depth (boundary sensitivity model) m	Difference (m)	Maximum flood depth (Baseline Model) m	Maximum flood level (manning's sensitivity model) m	Difference (m)
AP13_1	0.135	0.137	**0.003**	0.135	0.190	**0.055**
AP13_2	0.339	0.342	**0.003**	0.339	0.394	**0.055**
AP13_3	0.422	0.425	**0.003**	0.422	0.477	**0.055**
AP13_4	0.242	0.245	**0.003**	0.242	0.297	**0.055**
AP13_5	0.403	0.406	**0.003**	0.403	0.459	**0.055**
AP13_6	0.299	0.301	**0.003**	0.299	0.354	**0.055**
AP13_7	0.522	0.525	**0.003**	0.522	0.578	**0.055**
AP13_8	0.236	0.239	**0.003**	0.236	0.291	**0.055**
AP13_9	0.941	0.944	**0.003**	0.941	0.996	**0.055**

Sensitivity analysis shows that the model is considered marginally sensitive to an increase in Manning's n values. Increasing manning's by 20% results in an increase in flood depths at the site of 0.055m. This has marginal impacts on compensatory storage volumes with about an additional 40m^3 being required. However, the Manning's n value used for the floodplain in the WHS baseline model of 0.045 is considered to be reasonably conservative for this type of land use. Chow suggests a Manning's value of 0.04 for mature field crops.

Changes in downstream boundary slope both within the 1D and 2D domains of the hydraulic model shows that the model is relatively insensitive to the characterisation of this parameter with only small changes in flood depth of +0.003m predicted.

3.9 Conclusions

The updated WHS 1D - 2D modelling of the Lower Cherwell floodplain has resulted in reduced flood extents and depths at and around the AP13 Northfield Farm development as outlined in section 3.7. The majority of the proposed development alignment is now located outside of the predicted 1 in 100 year plus climate change flood extent. However, there will be a potential requirement for flood mitigation as a result of the development to accommodate the small amounts of flood storage lost. This is assessed within the main flood risk assessment report (included above as the main document).