M5 Junction 10 Improvements Scheme

Flood Risk Impacts Technical Note

TR010063 - APP 9.20

Regulation 5(2)(e)

Planning Act 2008

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

Volume 9

October~~March~~ 2024

Gloucestershire County Council

Infrastructure Planning

Planning Act 2008

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

M5 Junction 10 Improvements Scheme

Development Consent Order 202[x]

9.20 Flood Risk Impacts Technical Note (Tracked)

Regulation Number:	Regulation 5(2)(e)
Planning Inspectorate Scheme Reference	TR010063
Application Document Reference	TR010063 – APP 9.20
Author:	M5 Junction 10 Improvements Scheme Project Team

Version	**Date**	**Status of Version**
Rev 0	March 2024	Section 51
Rev 1	October 2024	Deadline 5

Technical Note

Project:	M5 Junction 10 Improvements Scheme
Subject:	Flood risk impacts at the B4634 Old Gloucester Road

1. Background

1.1.1. The M5 Junction 10 Improvements Scheme (the 'Scheme' or M5J10), is being promoted by Gloucestershire County Council (GCC). The Scheme is intended to facilitate and safeguard future development in north-west Cheltenham. GCC submitted a Housing and Infrastructure Funding (HIF) bid to Homes England in March 2019 for funds to improve motorway connectivity in north Cheltenham at Junction 10 of the M5.

1.1.2. The Scheme includes embedded mitigation and controls to alleviate its impact on flood risk. The embedded mitigation is to reduce, as reasonably practicable, any adverse changes in flood risk caused by the Scheme. Detailed flood modelling (see the Flood Risk Assessment (Application document TR010063/APP/6.15)) relates to the primary sources of flood risk, being the River Chelt and Leigh Brook, and demonstrates that the Scheme would displace floodwater and adversely impact the flood risk of third parties if the embedded mitigation was not implemented. With the measures in place, the Scheme has no significant adverse effects on flood risk receptors.

1.1.3. This technical note specifically describes flood risk to and from the M5 Junction 10 Improvements Scheme at the southern end of the West Cheltenham Link Road, off the B4634 Old Gloucester Road. This area is not considered in the hydraulic modelling for the River Chelt and Leigh Brook with the River Chelt model focusing on Main River and other flooding at the primary works site. The results of this note will be included in the Flood Risk Assessment for the Scheme.

1.2. Site description

1.2.1. The site of interest is the farmland both north and south of the Old Gloucester Road, between the M5 motorway and Hayden Hill. The hamlet of Hayden lies to the south of this area. See Figure 1-1~~Figure 1-1~~.

1.2.2. This area is drained by two minor ditches conveying local field runoff north under the Old Gloucester Road. Two separate culverts serve this drainage:

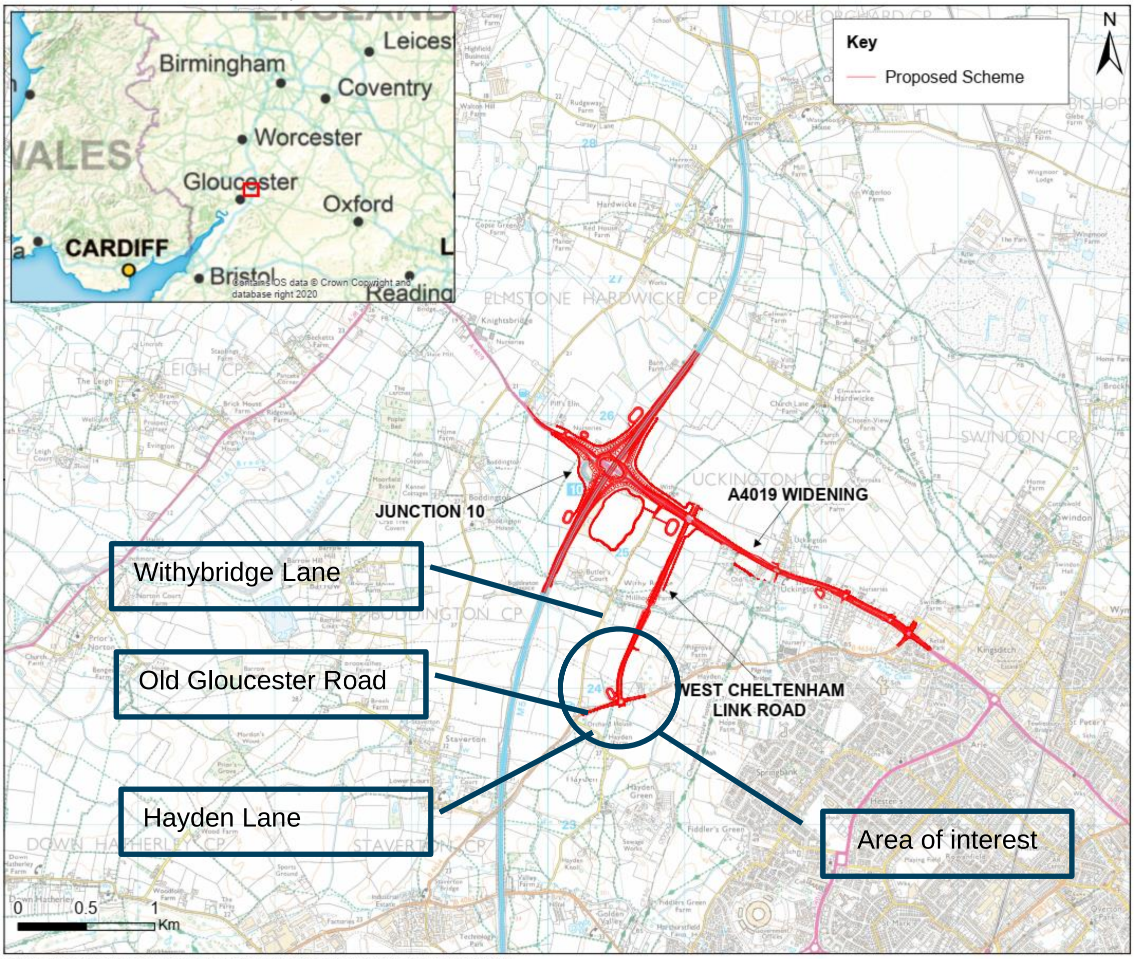
- Western ditch in a 400 mm diameter pipe culvert
- Eastern ditch being a flat roof crossing, similar to a box culvert, approximately 850 mm wide crossing and some 400 mm tall.

1.2.3. The ditches cross open farmland before combining on the immediate east of Withybridge Lane. The watercourse then heads west as a watercourse herein named as the Staverton Stream. That watercourse flows under the M5 motorway before joining the River Chelt upstream of Boddington.

1.2.4. The land between the Old Gloucester Road and the M5 motorway is all agricultural farmland, bisected by Withybridge Lane. There are no built receptors in this area. There are however some dwellings along the Old Gloucester Road, and Hayden Lane.

Figure 1-1: Location plan

This indicates the full extent of the M5J10 improvement Scheme



1.3. Proposed development

1.3.1. The proposed development is indicated in the location plan above. Specifically in the area described by this technical note the proposed development comprises a new road junction between the Old Gloucester Road and the West Cheltenham Link Road being constructed as part of the Scheme. The junction also includes a spur for future access into the development land to the south. Figure 1-2~~Figure 1-2~~ below, illustrates the development at this junction, complete with highway drainage attenuation pond.

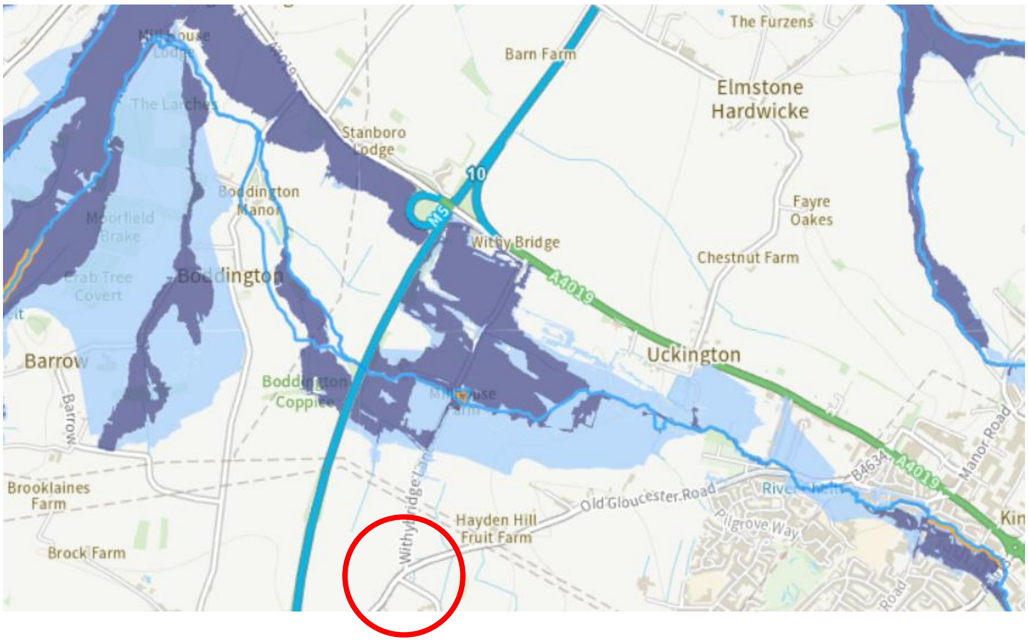
Figure 1-2: proposed development

2. Initial baseline assessment

2.1. Flood map for planning

2.1.1. The published Environment Agency Flood Map for Planning (Figure 2-1Figure 2-1Figure 1-3) indicates no flooding arising from the watercourses in this area. This is of no surprise, with the ditches being designated Ordinary Watercourses, and not Main River.

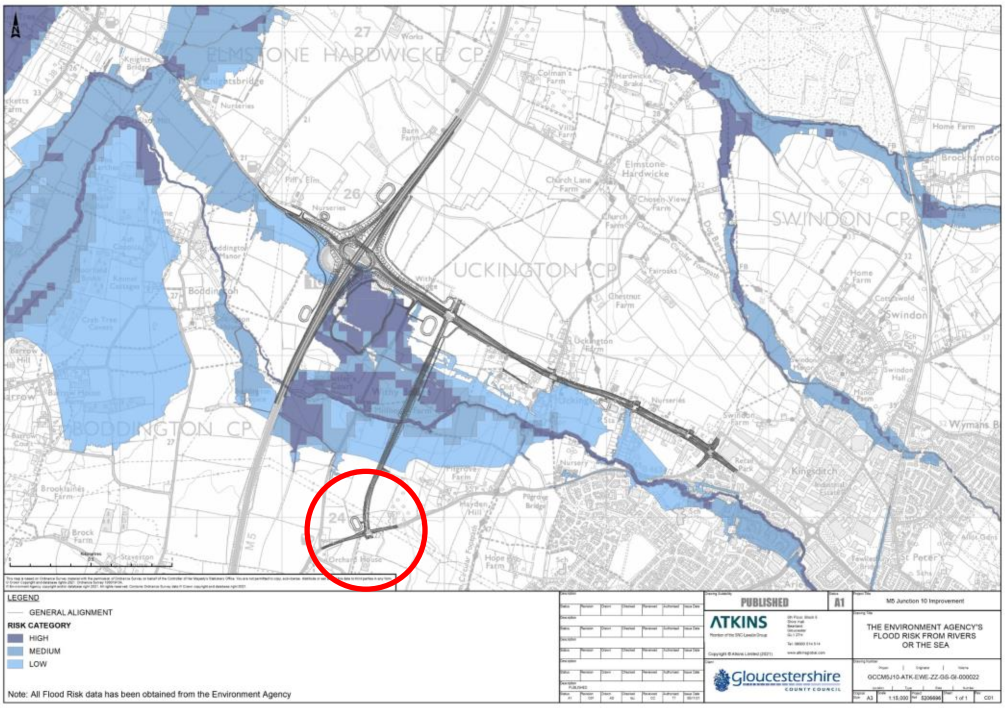
Figure 2-1: Flood Map for Planning



2.2. Flood Risk from Rivers or the Sea mapping

2.2.1. The Environment Agency’s Flood Risk from Rivers or the Sea mapping (Figure 2-2) indicates a similar pattern of flooding, although reflects the risk west of the M5 as per the former Environment Agency flood map for planning.

Figure 2-2: Flood Risk from Rivers or the Sea



2.3. Flooding from surface water

2.3.1. Surface water flooding (sometimes referred to as pluvial flooding) can be caused by overland flow / runoff, and includes water flowing over the ground that has not reached a natural or artificial drainage channel. This can occur when intense rainfall exceeds the infiltration capacity of the ground because rainfall has fallen on ground so highly saturated that it cannot accept any more water.

2.3.2. Surface water flooding can also be caused when intense rainfall exceeds the surface water drainage capacity in an urban area, such that ponding and overland flow occurs. This can also be referred to as surface water sewer flooding. Surface water flooding can be caused by water originating from either on-site or from adjacent sites.

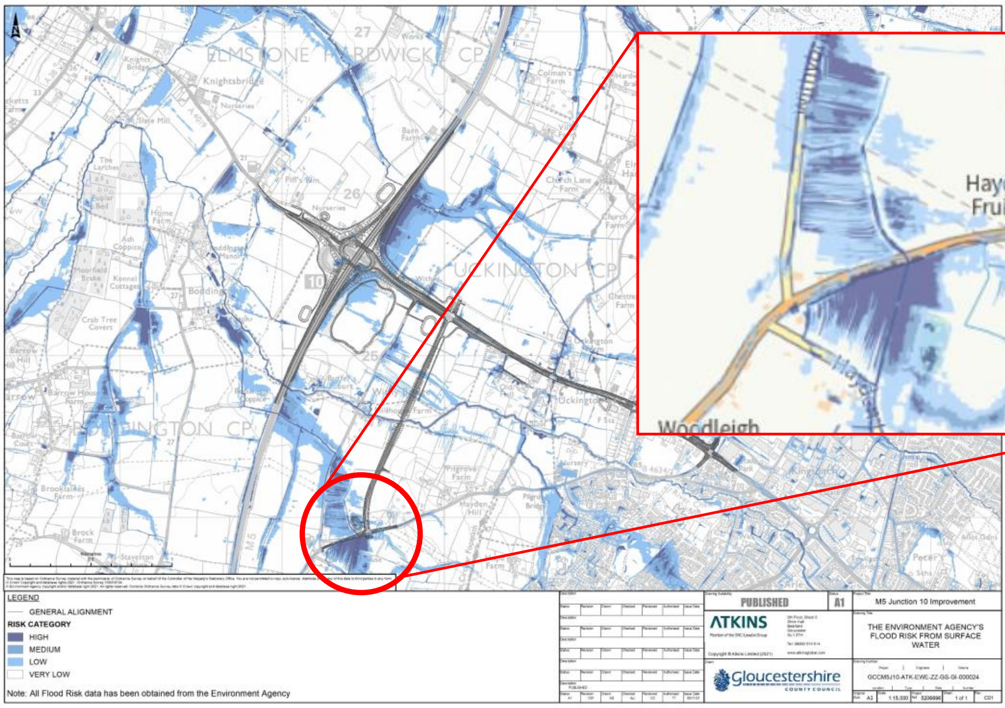
2.3.3. The Environment Agency's map showing the Risk of Flooding from Surface Water (Environment Agency, 2020) categorises it into a Low, Medium and High category.

- Low risk means that each year this area has a chance of flooding of between 0.1% and 1%
- Medium risk means that each year this area has a chance of flooding of between 1% and 3.3%.
- High risk means that each year this area has a chance of flooding of greater than 3.3%.

2.3.4. The mapping, shown on Figure 2-3, indicates medium risk (i.e. from 1% to 3.33% Annual Exceedance Probability (AEP) events) and high risk (i.e. flooding with greater than 3.33% Annual Exceedance Probability (AEP) in areas immediately south of the Old Gloucester Road. This risk reduces with distance from the road, although defines the local drainage ditches as a carrier of floodwater. Overland flow routes are also described in the mapping. To the north of the Old Gloucester Road, the flooding is spread across the fields between the two ditches and Withybridge Lane, with the risk profile a mix of high, medium and low.

2.3.5. The published surface water flooding suggests that several residential properties off the Old Gloucester Road could be affected by flooding in the 0.1% annual exceedance probability event (1 in 1,000-year return period). Furthermore, the mapping indicates that the proposed highway junction could be at risk of flooding and being developed within the existing floodplain.

Figure 2-3 - Environment Agency Risk of Flood from Surface Water mapping



3. Actual baseline flood risk

3.1.1. The study area was defined in an ICM model as supplied by WSP. The model was developed in 2021 (year) to support St Modwen Development's work in the land to the south of the Old Gloucester Road. The model was developed using topographic survey collected by BWB in October 2021 and applied a direct rainfall approach to determine flood risk to the development site.

3.1.2. The model was supplemented by survey collected by Atkins for the M5J10 Scheme during 2021 – referred to as the mobile scanning infill ground survey and aerial survey. Revision 3 of this survey included specific survey of the watercourse in this area, pertinent to the highway drainage design and flood assessment. The model topography then uses a combination of LiDAR and the above topographic surveys.

3.2. Hydrology

3.2.1. The hydrology for the Scheme uses the similar inflows as applied to the wider River Chelt model and estimated in 2021 – based on the catchment of the Staverton Stream to the M5 motorway. It uses FEH assessments (ReFH2). The flow estimates for all design events are provided below in Table 3-1.

3.2.2. The flow estimates were split by ratio of catchment area to derive inflows to the hydraulic model upstream of B4634 Old Gloucester Road. 62% of the catchment was found to drain upstream, with the remaining 38% contributing downstream of the B4634 Old Gloucester Road.Withybridge Lane. The critical storm generating the highest peak runoff was found to be 7½ hours.

3.2.3. The flows applied to the hydraulic model were further split to serve the two minor watercourses serving the drainage in this area, being a ditch on the eastern side (71%) of the upper catchment and another on the western side of the upper catchment (29%).

3.2.4. Climate change has been accounted for in the model testing as applied to the River Chelt modelling, following the Environment Agency's climate change allowance (July 2021)[1]. In summary, the modelling undertaken applies a +53% increase in peak flow for 100-years in the future (defined herein as the Design Event),, in accordance with the Environment Agency guidance (Higher Central allowance for the Severn river basin district and Severn Vale management catchment). This is precautionary and based on an essential infrastructure vulnerability. Reducing to the central allowance (all other vulnerabilities) would see a lower 37% increase in peak flow.

Table 3-1 – Flow estimates

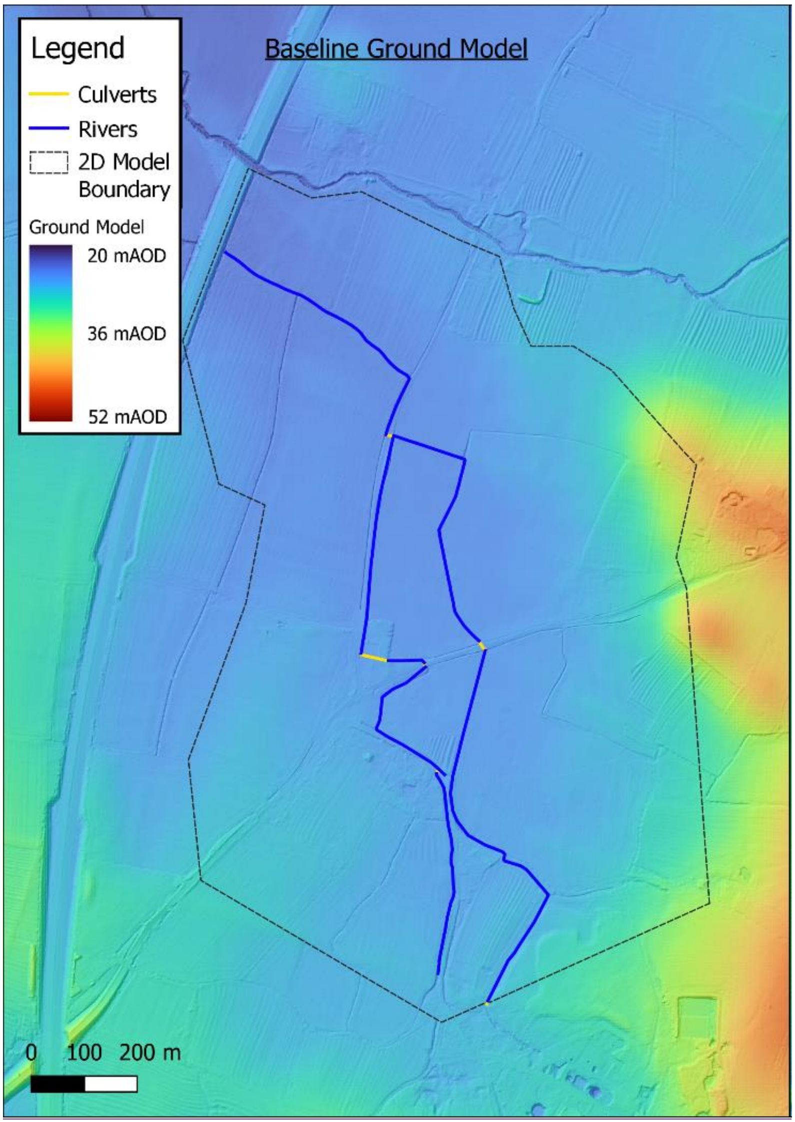
Location	Flow m^3/s								
	2yr	5yr	10yr	20yr	25yr	50yr	100yr	100yr CC	1000yr
Upstream of Old Gloucester Road	0.9	1.2	1.5	1.8	1.9	2.2	2.6	4.0	4.0
Downstream of Old Gloucester RoadWithybridge Lane	0.5	0.7	0.9	1.1	1.1	1.3	1.6	2.4	2.4
Staverton stream at M5 motorway	1.4	2.0	2.4	2.8	3.0	3.5	4.2	6.4	6.4

[1] Flood risk assessments: climate change allowances - GOV.UK (www.gov.uk).

3.3. Hydraulic model

3.3.1. The Baseline ICM model build comprises a 2D computational mesh with open water courses represented in 1D. The 2D triangular mesh is constructed with maximum triangle area of 25m^2 and a minimum of 5m^2. The roughness of the 2D zone has been modelled with a Manning's n roughness of 0.0500. A reduced roughness would increase conveyance and reduce flood levels. The boundary conditions of the 2D zone are set to normal flow condition. Ground elevations for the 2D model were taken from a 1m Digital Terrain Model (DTM), provided by the Environment Agency. This DTM is displayed in Figure 3-1.

Figure 3-1 – Topographical ground model used in the hydraulic model



3.3.2. Cross sections for the 1D channels are taken from survey information with roughness represented as manning n in the range of~~n's between~~ 0.040 to~~and~~ 0.060 to represent natural bed and overgrown banks respectively.

3.3.3. Spills from the 1D channels are controlled by banklines that act as irregular weirs with the discharge coefficient set to between 0.7 and 1.0. Lower discharge coefficients are used on the banks north of Old Gloucester Road, given the low-lying land, to improve model stability.

3.3.4. ReFH2 hydrograph boundaries feed two unnamed watercourses upstream of Old Gloucester Road: a western and an eastern channel. The upstream extent of these 1D catchments (and the location of these boundary inflows) is approximately 600 m south of Old Gloucester Road, close to The Firs Hotel on Hayden Lane.

3.3.5. The East channel flows approximately 780 m to a culvert under Old Gloucester Road. The eastern culvert under Old Gloucester Road is modelled as a 850 mm × 400 mm box culvert with a Colebrook White roughness of 1.5 mm, and a length of 17.1 m. The upstream invert of the culvert is modelled at 25.290 mAOD with the downstream being 25.433 mAOD, and as such has a negative gradient.

3.3.6. From the eastern culvert under the Old Gloucester Road, the channel flows 510 m downstream before joining the western channel at a storage node confluence.

3.3.7. The West channel flows from its upstream extent for approximately 400 m to a culvert under Hayden Lane (220 mm circular culvert), before flowing approximately 310 m to the Old Gloucester Road culvert.

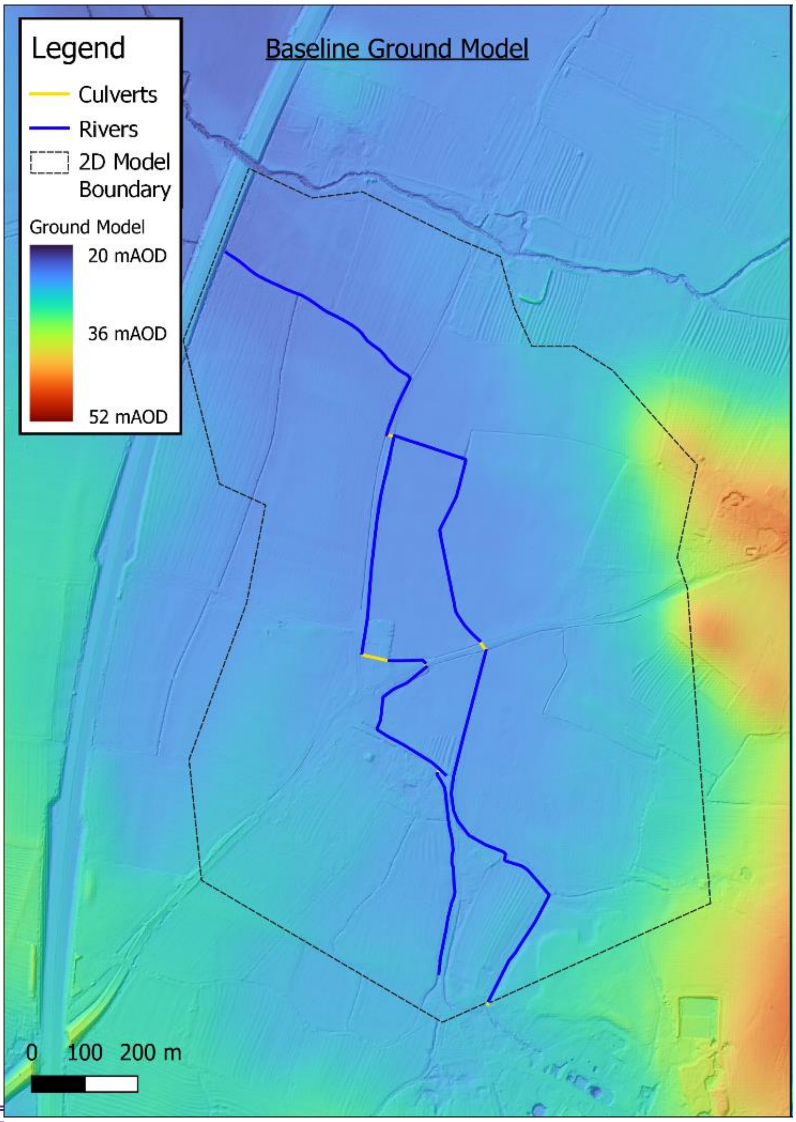
3.3.8. The western Old Gloucester Road culvert is modelled as a 400 mm diameter culvert with a Colebrook White roughness of 1.5 mm, length 7.7 m. The upstream invert of the culvert is modelled at 25.34 mAOD, with the downstream being 25.40 mAOD, and as such has a negative gradient.

3.3.9. From the western culvert, the west stream flows 70 m downstream to a culverted section beneath a small car park. This culvert is modelled as a 55.2 m long, 400 mm circular culvert with a Colebrook White roughness of 1.5 mm. The upstream invert of the culvert is modelled at 25.23 mAOD with the downstream being 25.28 mAOD and as such has a negative gradient. From here, the western channel flows 415 m downstream before joining the eastern channel at a storage node confluence.

3.3.10. From this storage node confluence, a 14.2 m long 1D culvert is modelled beneath Withybridge Lane with a 450 mm diameter circular opening and 14.2 m length. The roughness of the culvert is modelled as a Colebrook White 1.5 mm value. The upstream and downstream invert of the culvert are modelled at 24.41 mAOD ,and as such the culvert is flat.

3.3.11. From~~r~~ this culvert, the open watercourse flows approximately 400m downstream, as a 1D channel, to the culvert under the M5 motorway. At this point, the boundary condition is given by a QH relationship taken from the M5 Junction 10 River Chelt flood model (a ESTRY~~Flood Modeller~~ – TUFLOW model), which covers the northern extent of the West Cheltenham Link Road and the Junction 10 improvements.

3.4.1.1. Figure 3-1 – Topographical ground model used in the hydraulic model



3.5.1.1.

3.6.3.4. Modelled Baseline Flood Risk description

3.6.1.3.4.1. The modelled baseline flood extents for the 1% annual exceedance probability event (1 in 100-year return period) are presented in Figure 3-2. The modelled point flood depths for Network Results Points (NRPs) are shown in Table 3-2. NRPs are labelled 1 to 13 moving from upstream to downstream.

3.6.2.3.4.2. The results indicate a pattern of wide but shallow flooding, with a slow-moving overland flow.

3.6.3.3.4.3. Water is impounded behind the Old Gloucester Road until the 20% annual exceedance probability event (1 in 5-year return period) at which point floodwater begins to spill ontponto the road. At the 10% annual exceedance probability event (1 in 10-year return period) the water flowsover the road surface and flow over the road and into the fields to the north. In the 1% annual exceedance probability event (1 in 100-year return period) the peak flow and velocity over the road is 2.3 m^3/s and 0.3 m/s.

Table 3-2 – Modelled Baseline flood depths for NRPs.

Cells are coloured white to red between the min and max Baseline depths for clarity.

Results Point	Depth (m)							
	2yr	5yr	10yr	20yr	25yr	50yr	100yr	100yr CC
NRP 1	0.00	0.00	0.02	0.06	0.07	0.08	0.10	0.14
NRP 2	0.00	0.07	0.13	0.15	0.16	0.17	0.18	0.21
NRP 3	0.00	0.04	0.10	0.13	0.13	0.15	0.16	0.19
NRP 4	0.00	0.01	0.07	0.09	0.10	0.11	0.12	0.15
NRP 5	0.13	0.25	0.31	0.33	0.34	0.35	0.36	0.40
NRP 6	0.07	0.19	0.25	0.27	0.28	0.29	0.30	0.33
NRP 7	0.01	0.12	0.18	0.21	0.21	0.23	0.24	0.27
NRP 8	0.00	0.13	0.19	0.21	0.22	0.23	0.24	0.27
NRP 9	0.00	0.00	0.01	0.02	0.02	0.03	0.04	0.05
NRP 10	0.00	0.00	0.00	0.00	0.02	0.04	0.05	0.10
NRP 11	0.16	0.17	0.19	0.21	0.22	0.24	0.25	0.30
NRP 12	0.17	0.18	0.19	0.21	0.21	0.22	0.23	0.27
NRP 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06

3.6.4.3.4.4. The majority of flooding is immediately upstream of (south), and behind, the Old Gloucester Road, with the greatest depths (up to 400 mm) found at NRPs 5 to 8. The area with the second greatest depths is found downstream of the confluence between the East and West streams (and near the Withybridge Lane culvert), at NRPs 11 to 1312, with depths up to 300 mm. The shallowest depths are found across a range of return periods for NRP 9 (immediately downstream of the eastern Old Gloucester Road culvert), and NRP 10 (field to the east of the eastern stream) and NRP 13 (immediately downstream of Withybridge Lane).

3.6.5.3.4.5. Once water spills over the Old Gloucester Road, it routes downstream in the fields between the eastern and western streams and accumulates in the low-lying area between NRP 10 and 11.

3.5. Model proving

3.5.1. This section discusses run performance, sensitivity analysis and the implications of this in the context of this project. With no calibrationhistorical flood data, (observed flows or stage) no calibration has been undertaken on the Scheme model.

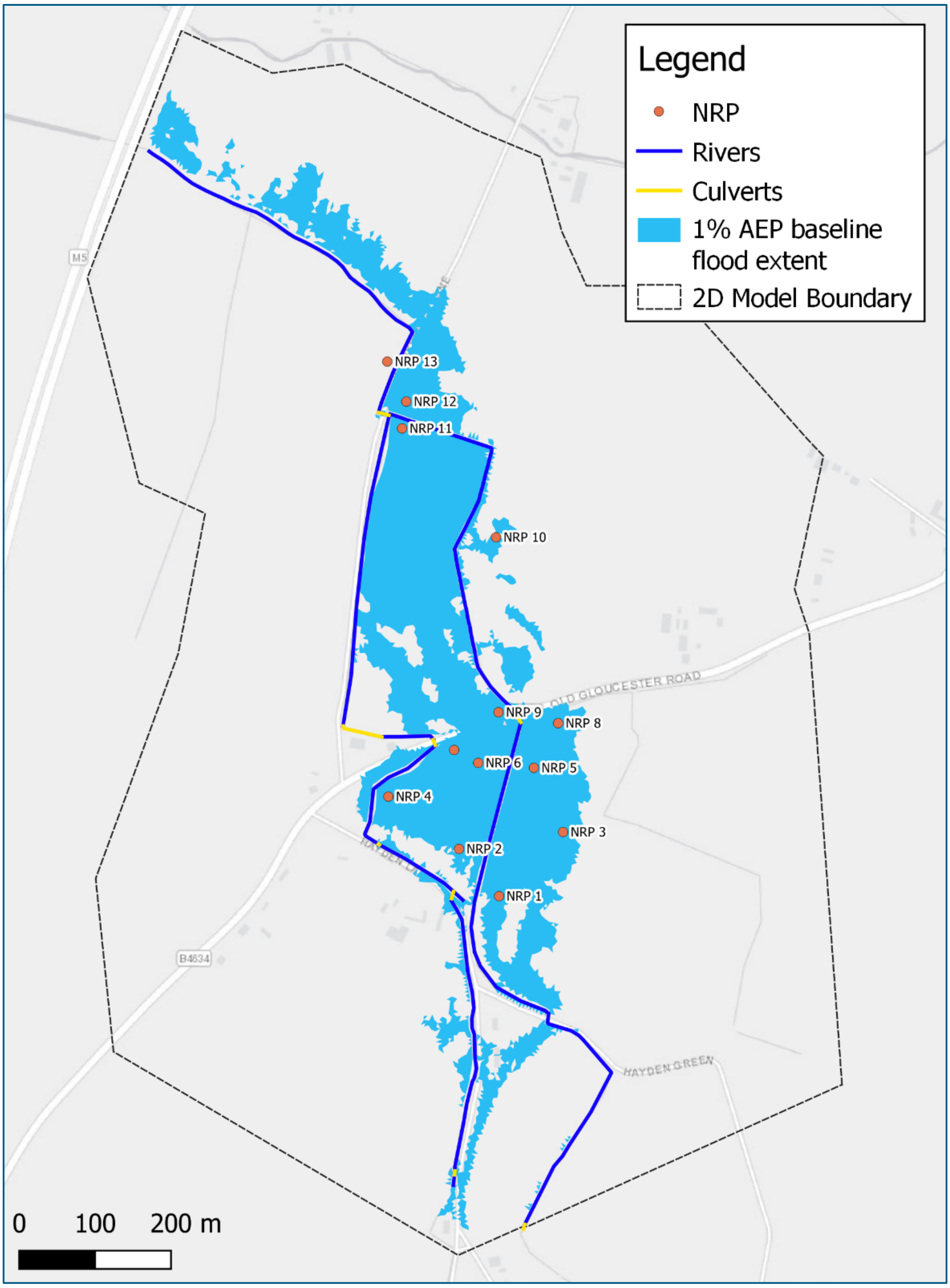
3.5.2. Sensitivity testing was undertaken to support confidence in the Baseline model. Tests with the Baseline model included:

- Sensitivity to channel and floodplain roughness;
- Sensitivity to downstream boundary;

3.5.3. Sensitivity testing has also been undertaken on the Scheme model to help understand the possible changes to the predicted impact of the Scheme caused by uncertainty in other model parameters (blockage and credible maxima climate change).

Figure 3-2: – Modelled Baseline flood extents for the 1 in 100 year return period event.

Flood depths greater than 0.02m are shown.



3.6. Sensitivity to channel and floodplain roughness

3.6.1. A sensitivity test was undertaken on the channel and floodplain roughness. Tests were made by applying a model wide modification to reflect the maximum envisaged seasonal variation from what was considered to be a reasonable spring/autumn Baseline. These are tabulated below.

Table 3-3 – Variation in Manning's roughness

	Summer	**Baseline**	**Winter**
Staverton stream (1D)	0.070	0.040	0.035
Other watercourse (2D)	0.080	0.060	0.055
Open land/agricultural land (2D)	0.070	0.050	0.020

3.6.2. The model was tested with a 5% annual exceedance probability event (1 in 20-year return period) to indicate the effect of the assumptions made on the roughness values in a flood of medium magnitude. This event was selected as the model results, described later, indicate that the impact of the scheme has less of an impact at the design event than the more frequent events.

3.6.3. The point results are tabulated below to give an indication of the scale of change, comparing with the present day 5% annual exceedance probability event (1 in 20-year return period). The location of these points are shown in Figure 3-2.

Table 3-4 – Sensitivity of flood depth to Manning's roughness

5% annual exceedance probability event (1 in 20-year return period)

Results Point	**Summer**	**Baseline**	**Winter**
NRP 1	0.09	0.06	0.04
NRP 2	0.16	0.15	0.14
NRP 3	0.14	0.13	0.12
NRP 4	0.10	0.09	0.08
NRP 5	0.34	0.33	0.33
NRP 6	0.28	0.27	0.27
NRP 7	0.22	0.21	0.20
NRP 8	0.22	0.21	0.20
NRP 9	0.02	0.02	0.02
NRP 10	0.03	0.00	0.00
NRP 11	0.23	0.21	0.20
NRP 12	0.22	0.21	0.19
NRP 13	0.00	0.00	0.00

3.6.4. The results indicate that the model is almost insensitive to changes in roughness values with a maximum variation in predicted peak flood level of only 30 mm during the 5% annual exceedance probability event (1 in 20-year return period) at NRP 1 and 10. More widely the impact was 10mm. Higher roughness values associated with the Summer simulation results in nominally more water exiting channels onto the floodplain compared to applying Baseline roughness values. However, reducing roughness values for the Winter simulation generally causes less of a difference to the Baseline.

3.7. Sensitivity to the downstream boundary

3.7.1. A sensitivity test was undertaken on the downstream 1D boundary. Tests were made by applying a modification to evaluate the impact of change in the stage-discharge relationship used. The data for the default boundary was extracted for the ~~large~~ ESTRY – TUFLOW model of the River Chelt at the point where the Staverton Stream crosses beneath the M5 motorway.

3.7.2. Changes were made to reflect extreme boundary conditions from what was considered to be a reasonable Baseline. The variations applied are tabulated below.

Table 3-5 – Variation in downstream boundary

	Reduced level	**Baseline**	**Increased level**
Staverton stream (1D)	All depths reduced by 10% for a given flow	QH from River Chelt model	All depths increased by 10% for a given flow

3.7.3. The model was tested with a 5% annual exceedance probability event (1 in 20-year return period) to indicate the effect of the assumptions made on the downstream boundary in a flood of medium magnitude. This event was selected as the model results, described later, indicate that the impact of the scheme has less of an impact at the design event than the more frequent events .

3.7.4. The point results are tabulated below to give an indication of the scale of change in the study area, comparing with the present day 5% annual exceedance probability event (1 in 20-year return period). The location of these points are shown in Figure 3-2 above.

Table 3-6 – Sensitivity of flood depth to downstream boundary

5% annual exceedance probability event (1 in 20-year return period)

Results Point	**Reduced boundary depth (m)**	**Baseline**	**Raised boundary depth (m)**
NRP 1	0.06	0.06	0.06
NRP 2	0.15	0.15	0.15
NRP 3	0.13	0.13	0.13
NRP 4	0.09	0.09	0.09
NRP 5	0.33	0.33	0.33
NRP 6	0.27	0.27	0.27
NRP 7	0.21	0.21	0.21
NRP 8	0.21	0.21	0.21
NRP 9	0.02	0.02	0.02
NRP 10	0.00	0.00	0.00
NRP 11	0.21	0.21	0.21
NRP 12	0.21	0.21	0.21
NRP 13	0.00	0.00	0.00

3.7.5. The results indicate that the area of interest within the model is insensitive to variations in the downstream boundary. Flood extents, depth and flow results are identical whether the downstream boundary levels are reduced or increased by 10%. The flood levels on the Staverton Stream at the B4634 are unaffected by flooding at the M5 motorway.

4. With-Scheme flood risk

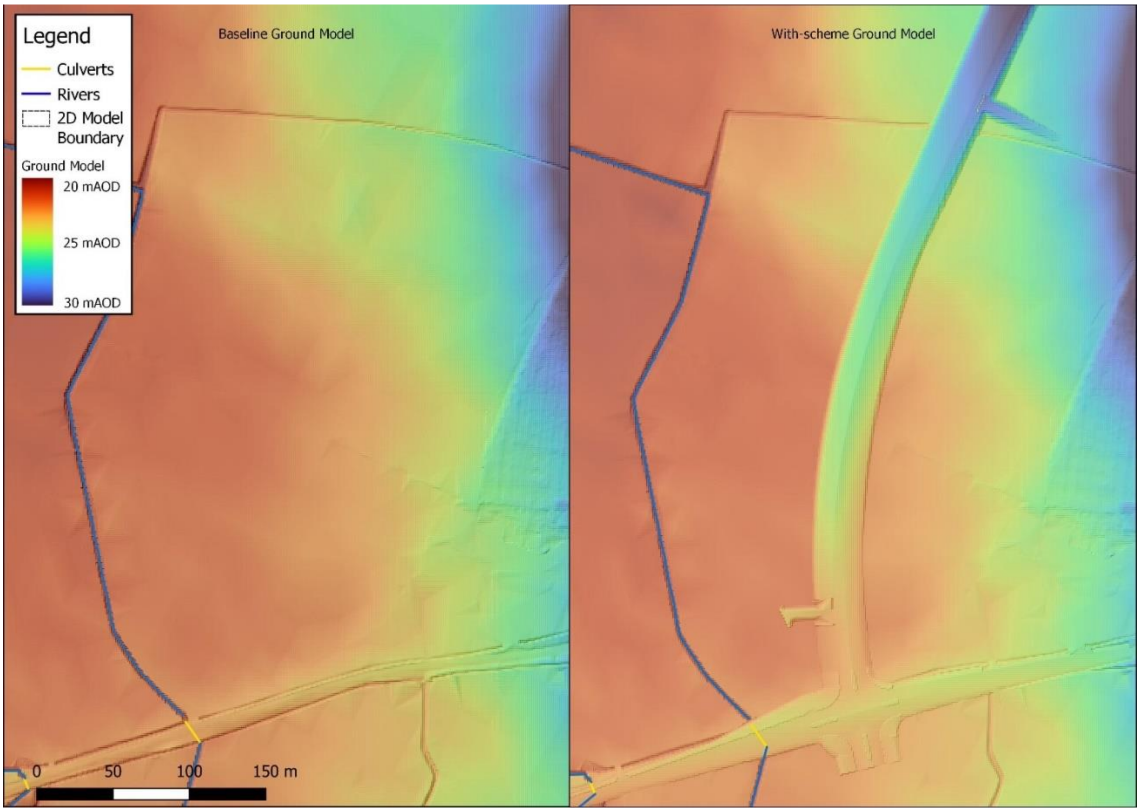
4.1. Pre-mitigation ~~Initial~~ Scheme model

4.1.1. The ~~Initial~~ pre-mitigation Scheme model contains an updated 2D triangular grid mesh to represent the new earthworks of the West Cheltenham Link Road and junction with the B4634 Old Gloucester Road.

4.1.2. For the ~~Initial~~ pre-mitigation Scheme model, it was initially assumed that the culverts under Old Gloucester Road would be replaced like-for-like, and simply extended to suit the new earthworks. This testing indicated the need for additional mitigation, which is described in the subsequent Section 4.2.

4.1.3. Figure 4-1 shows a comparison between the Baseline topography and the initial with-Scheme topography used in this model. The drainage pond was included as a ICM model object rather than raised terrain – hence not reflected below.

Figure 4-1 – C~~c~~omparison between Baseline and with-Scheme topographical model



4.1.4. The Initial-Scheme model also contains a ~~topographical~~ representation of the highway drainage attenuation pond, proposed to the north of the new junction. It is apparent from the Baseline that this pond occupies some of the existing floodplain. This pond has been modelled as a 0.62 ha mesh zone, raised to height of 10 m, to represent the complete loss of floodplain due to the perimeter bund/track and water storage in the pond. The design of this drainage pond will need to ensure that is does not fill with floodwater from the natural catchment.

4.1.5. The flood dynamics without additional mitigation are similar for those in the Baseline, with most of the changes resulting from the increased level of the proposed highway. The maximum flood depths in the ~~Initial-~~pre-mitigation Scheme model were again greater south of the proposed junction (upstream) but with deeper flooding than the Baseline. The predicted depths were marginally ~~smaller~~ shallower north (downstream) of the highway when compared to the Baseline, with more water being impounded behind the raised highway level in the ~~Initial-~~pre-mitigation Scheme model.

4.1.6. The modelled Baseline ~~Initial Scheme~~ depths for each NRP are presented in Table 3-2. The~~Figure 3-2 and~~ depth differences of the ~~initial-~~pre-mitigation Scheme compared to~~with~~ the Baseline are presented in Table 4-1.

4.1.7. ~~Overtopping of the proposed road occurs in the 10% annual exceedance probability event (1 in 10-year return period) in the with-Scheme model (no additional mitigation). This was previously in the 20% annual exceedance probability event (1 in 5-year return period) in the Baseline model.~~ The water ~~traveling~~ passing over the proposed highway in the ~~Initial-~~pre-mitigation Scheme model, in the 1% annual exceedance probability event (1 in 100-year return period), amounts to a flow of 3.5 m^3/s with a velocity of 0.5 m/s. This is an increase in flow and velocity compared to the baseline condition.

Table 4-1 – Flood depth differences (~~Initial~~ pre-mitigation Scheme – Baseline)

Positive numbers are coloured red to indicate an increase in depth in the Initial-Scheme model. Negative numbers are coloured green to indicate a decrease in depth in the Initial-Scheme model (no mitigation).

Results Point	Depth Difference (with-Scheme minus Baseline) (m)							
	2yr	5yr	10yr	20yr	25yr	50yr	100yr	100yr CC
NRP 1	0	0	0.03	0.07	0.08	0.11	0.13	0.15
NRP 2	0	0.01	0.03	0.09	0.1	0.13	0.16	0.18
NRP 3	0	0.01	0.03	0.08	0.09	0.13	0.15	0.18
NRP 4	0	0.01	0.03	0.09	0.1	0.13	0.16	0.18
NRP 5	0	0.01	0.03	0.09	0.1	0.13	0.16	0.18
NRP 6	0	0.01	0.03	0.09	0.1	0.13	0.16	0.18
NRP 7	0	0.01	0.03	0.09	0.1	0.13	0.16	0.18
NRP 8	0	-0.13	-0.19	-0.21	-0.22	-0.23	-0.21	-0.19
NRP 9	0	0	-0.01	-0.02	-0.02	-0.03	-0.04	-0.05
NRP 10	0	0	0	0	-0.02	-0.04	-0.03	-0.02
NRP 11	0	0	-0.01	-0.02	-0.03	-0.03	-0.01	-0.01
NRP 12	0	0	-0.01	-0.02	-0.02	-0.02	-0.01	-0.01
NRP 13	0	0	0	0	0	0	0	-0.02

4.1.8. All of the increases in flood depth in the ~~Initial-~~pre-mitigation Scheme model were predicted in the areas upstream of the proposed highway works (NRPs 1 -7) for all return periods, except for the 50% annual exceedance probability event (1 in 2-year return period) which showed minimal differences.

~~Minimal reductions in depth were also predicted in the areas downstream of the proposed highway junction (NRP 9 – 13). This is due to the flat topography and the unchanged conveyance through the two Old Gloucester Road culverts (or over the road) in the Initial-Scheme model. As such this gives confidence that this Initial Scheme, with no mitigation, would have minimal impacts on flood depths further downstream, beyond the downstream boundary of this model.~~

~~4.1.10.~~4.1.9. NRP 8 shows the greatest reduction in flood depths from the Baseline model due to the increase ground level at this point from to the proposed embankment footprint, meaning flood extents do not reach NRP8 in the ~~Initial-~~pre-mitigation Scheme model.

4.1.10. Minimal reductions in depth were predicted in the areas downstream of the proposed highway junction (NRP 9 – 13). This is due to -flood levels increasing upstream as a result of the Old Gloucester Road being raised resulting in more water being held upstream.

4.1.11. Due to the increases in flood depths predicted in the areas around and including Orchard House and Haydens Farm (up to 180 mm), a mitigation option needed to be~~has been~~ developed to minimise increases in flood risk and seek a balance with the predicted betterments downstream. This has been proven using the hydraulic model and referred to as the With--Mitigation model.

4.2. With-Mitigation model

4.2.1. A mitigation option was developed in the hydraulic model to replace the eastern (850 mm × 400 mm box) culvert under the proposed highway to 3nr 2100 mm × 800 mm box culverts, each embedded by a depth of 300mm. This produces a total conveyance of 3nr 2100mm × 500 mm, or 3.15 m^2. This is much larger than the existing Baseline culvert, which at 850 mm × 400 mm has a total conveyance area of~~is~~ 0.34 m^2.

4.2.2. The surveyed bed of the upstream watercourse discharging to the western culvert is 25.29 mAOD. The surveyed bed of the receiving watercourse is 25.31 mAOD. As part of the mitigation Scheme, it is proposed to level the bed of watercourse to 25.29 mAOD for a length of approximately 10 m downstream of the culvert outlet, to allow a more suitable grade for the new culvert.

4.2.3. Table 4-2 presents the predicted peak flood depths in the with-Mitigation scenario.

4.2.4. Table 4-3~~Table 3-5~~ indicates the impact on peak flood depths for the with-Mitigation condition, compared to the Baseline.

~~4.2.3.~~4.2.5. Figure 4-9 Shows~~Figure 3-10 shows~~ the 1% AEP flood extent for the with-~~Scheme~~ mitigation Scheme compared with the Baseline extent.

Table 4-2 – With-mitigation ~~Modelled~~ Scheme~~Baseline~~ flood depths for NRPs.

Results Point	Flood depth (m)							
	2yr	5yr	10yr	20yr	25yr	50yr	100yr	100yr CC
NRP 1	0.00	0.00	0.01	0.04	0.05	0.06	0.07	0.13
NRP 2	0.00	0.00	0.00	0.03	0.04	0.06	0.09	0.21
NRP 3	0.00	0.00	0.00	0.01	0.01	0.03	0.05	0.16
NRP 4	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.15
NRP 5	0.00	0.05	0.10	0.14	0.15	0.18	0.24	0.38
NRP 6	0.03	0.05	0.07	0.10	0.11	0.13	0.19	0.33
NRP 7	0.00	0.01	0.02	0.04	0.05	0.07	0.13	0.26
NRP 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRP 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NRP 10	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.08
NRP 11	0.16	0.19	0.21	0.22	0.23	0.24	0.26	0.29
NRP 12	0.17	0.19	0.20	0.21	0.22	0.22	0.24	0.26
NRP 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04

4.2.6. The 20% annual exceedance probability event (1 in 5-year return period) causes the first spill of water onto the Old Gloucester Road in the Baseline, which by a 10% annual exceedance probability event (1 in 10-year return period) floods over the road into the fields to the north. In the Mitigation option, water does not spill onto the road until the 1% annual exceedance probability event (1 in 100-year return period) with future climate change, ~~the road~~ due to the elevated highway levels and the increased culvert conveyance: runoff is instead carried through the downstream channel, towards the confluence with the western tributary, upstream of Withybridge Lane. Table 3-5An increase in pass-forward flow is predicted at the Old Gloucester Road (0.64 m^3/s increases to 0.98 m^3/s in the 20% annual exceedance probability event, and from 0.7567 m^3/s to 1.21 m^3/s in the 10% annual exceedance probability event) which spills out of the watercourse at Withybridge Lane and increases flood depths by up to 40 mm immediately adjacent to the bank, and up to 20mm across the fields in this area.

Table 4-3 – Change in flood depths for NRPs: with mitigation.

Cells are coloured green to red at the same scale as the with-scheme difference, for comparison.

Results Point	Depth Difference (with mitigation minus Baseline) (m)							
	2yr	5yr	10yr	20yr	25yr	50yr	100yr	100yr CC
NRP 1	0.00	0.00	-0.01	-0.02	-0.02	-0.02	-0.02	-0.01
NRP 2	0.00	-0.07	-0.13	-0.12	-0.12	-0.11	-0.09	-0.01
NRP 3	0.00	-0.04	-0.10	-0.12	-0.12	-0.12	-0.10	-0.03
NRP 4	0.00	-0.01	-0.07	-0.09	-0.10	-0.11	-0.10	-0.01
NRP 5	-0.13	-0.20	-0.21	-0.19	-0.19	-0.17	-0.12	-0.01
NRP 6	-0.04	-0.14	-0.18	-0.18	-0.17	-0.16	-0.11	-0.01
NRP 7	-0.01	-0.11	-0.16	-0.16	-0.16	-0.15	-0.11	-0.01
NRP 8	0.00	-0.13	-0.19	-0.21	-0.22	-0.23	-0.24	-0.27
NRP 9	0.00	0.00	-0.01	-0.02	-0.02	-0.03	-0.04	-0.05
NRP 10	0.00	0.00	0.00	0.00	-0.02	-0.02	-0.01	-0.02
NRP 11	0.00	0.02	0.02	0.01	0.01	0.00	0.01	-0.01
NRP 12	0.00	0.01	0.01	0.01	0.01	0.00	0.00	-0.01
NRP 13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.02

4.2.4.1.1.1. The 20% annual exceedance probability event (1 in 5-year return period) and 10% annual exceedance probability event (1 in 10-year return period) cause the first spill of water over the Old Gloucester Road in the Baseline, which floods the fields to the north of the road. In the Mitigation option, this water does not spill over the road due to the elevated highway levels and the increased culvert conveyance, and runoff is instead carried through the downstream channel, towards the confluence with the western tributary, upstream of Withybridge Lane. An increase in pass-forward flow is predicted at the Old Gloucester Road (0.64 m^3/s increases to 0.98 m^3/s in the 20% annual exceedance probability event, and from 0.67 m^3/s to 1.21 m^3/s in the 10% annual exceedance probability event) which spills out of the watercourse at Withybridge Lane and increases flood depths by up to 40 mm immediately adjacent to the bank, and up to 20mm across the fields in this area.

4.2.5.4.2.7. In higher return periods, this difference reduces to less than 10 mm, water is more likely to be retained behind the new road embankment due to its higher crest. This impact is considered to be beyond the numerical tolerance of the software.

4.2.6.4.2.8. The impact on flooding upstream and downstream is sensitive to the conveyance of the culverts under the B4634 Old Gloucester Road, and the magnitude of the event being considered. A range of options were tested in the hydraulic model to try to balance the betterment created upstream with the minor detriment predicted downstream. However, tThe Mitigation Scheme with 3nr 2100 mm × 800 mm box culverts provided the best balance between the upstream and downstream areas.

4.2.9. To present the full impacts of the Mitigation Scheme, full depth-difference grids have been developed for the 20% annual exceedance probability (1 in 5-year return period) event, and the

1% annual exceedance probability (1 in 100 year return period) plus climate change event. These are included asas Figure 4-3Figure 3-5 and Figure 4-4.

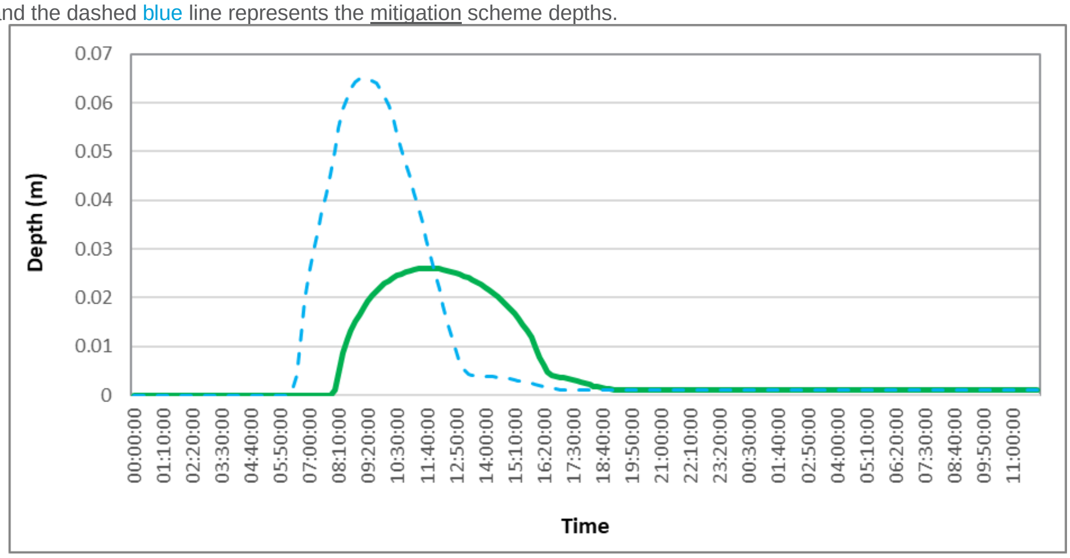
20% annual exceedance probability event (1 in 5-year return period)

4.2.7.4.2.10. The difference grid for the 20% annual exceedance probability event (1 in 5-year return period) indicates a maximum but localised 40 mm detriment in a small area of flooding adjacent to the eastern stream, approximately 140 m downstream of the Old Gloucester Road culvert, where the increased pass-forward flow spills out of bank. This can be seen labelled in Figure 4-3Figure 3-5 overleaf. More widely, the peak flood level is predicted to rise in this area upstream of Withybridge Lane by just over 20 mm.

4.2.11. Figure 4-2Figure 3-4 shows that the duration of this flooding is shortened by approximately 1½ hour when compared to the Baseline. As such this location is predicted to be flooded for shorter periods, albeit nominally deeper, as a result of the Mitigation option.

Figure 4-2 – 20% AEP depth hydrograph for the Mitigation and Baseline scenarios

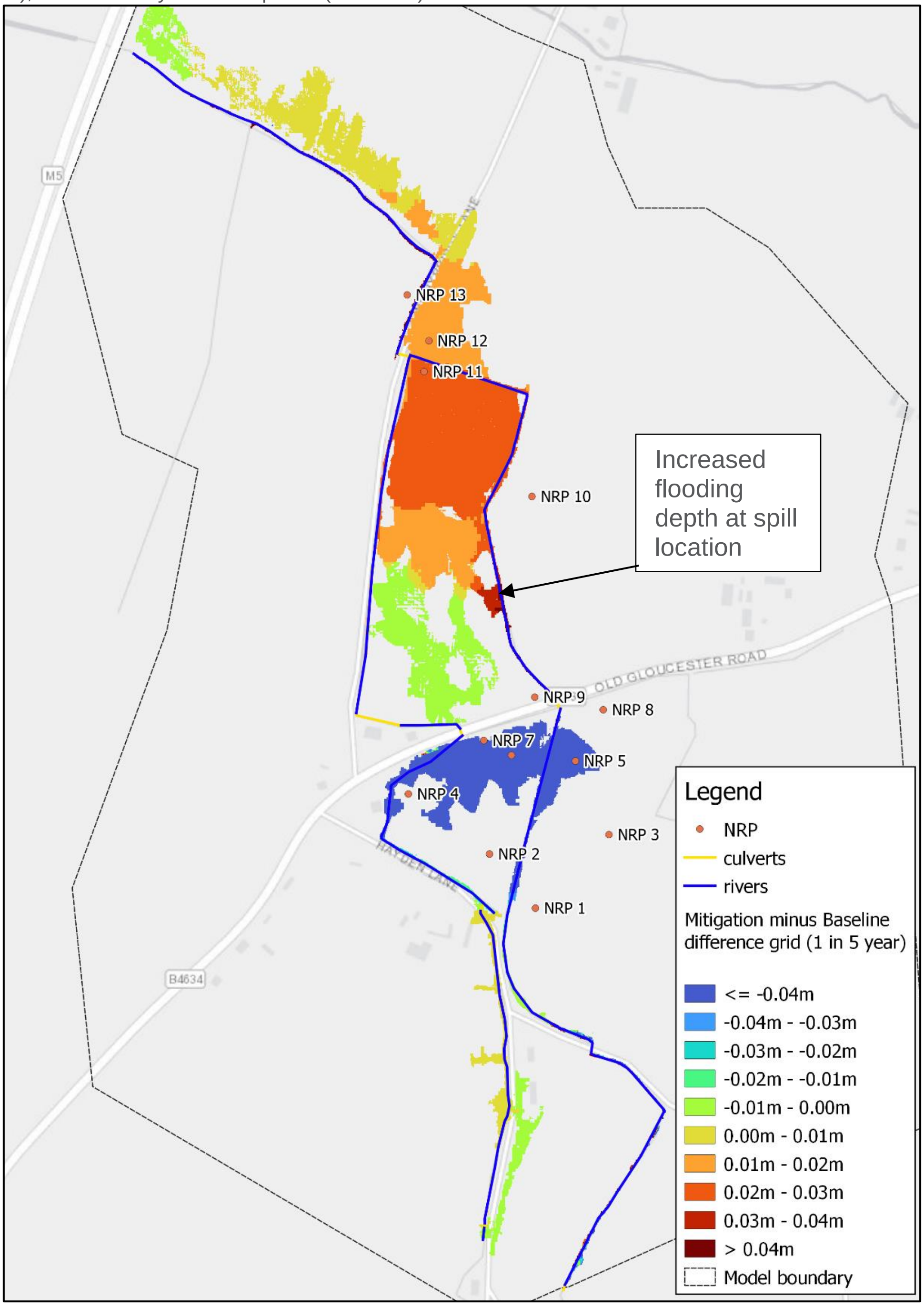
140 m downstream of the proposed Old Gloucester Road culvert, where 40mm of detriment is estimated. The green line represents baseline depths, and the dashed blue line represents the mitigation scheme depths.



4.2.12. The greatest impact was predicted for more frequent events, nothing at 50% annual exceedance probability event (1 in 2-year return period), but a widespread 20-30 mm, from 100 mm to 130 mm, in 3 fields, at the 20% annual exceedance probability event (1 in 5-year return period). Negligible impacts were predicted for the 5% annual exceedance probability event (1 in 20-year return period) and above.

Figure 4-3 – 20% AEP depth difference between the Mitigation scenario and the Baseline

(Mitigation minus baseline), for the 1 in 5-year return period (20% AEP) event.



1% annual exceedance probability event (1 in 100-year return period) including climate change

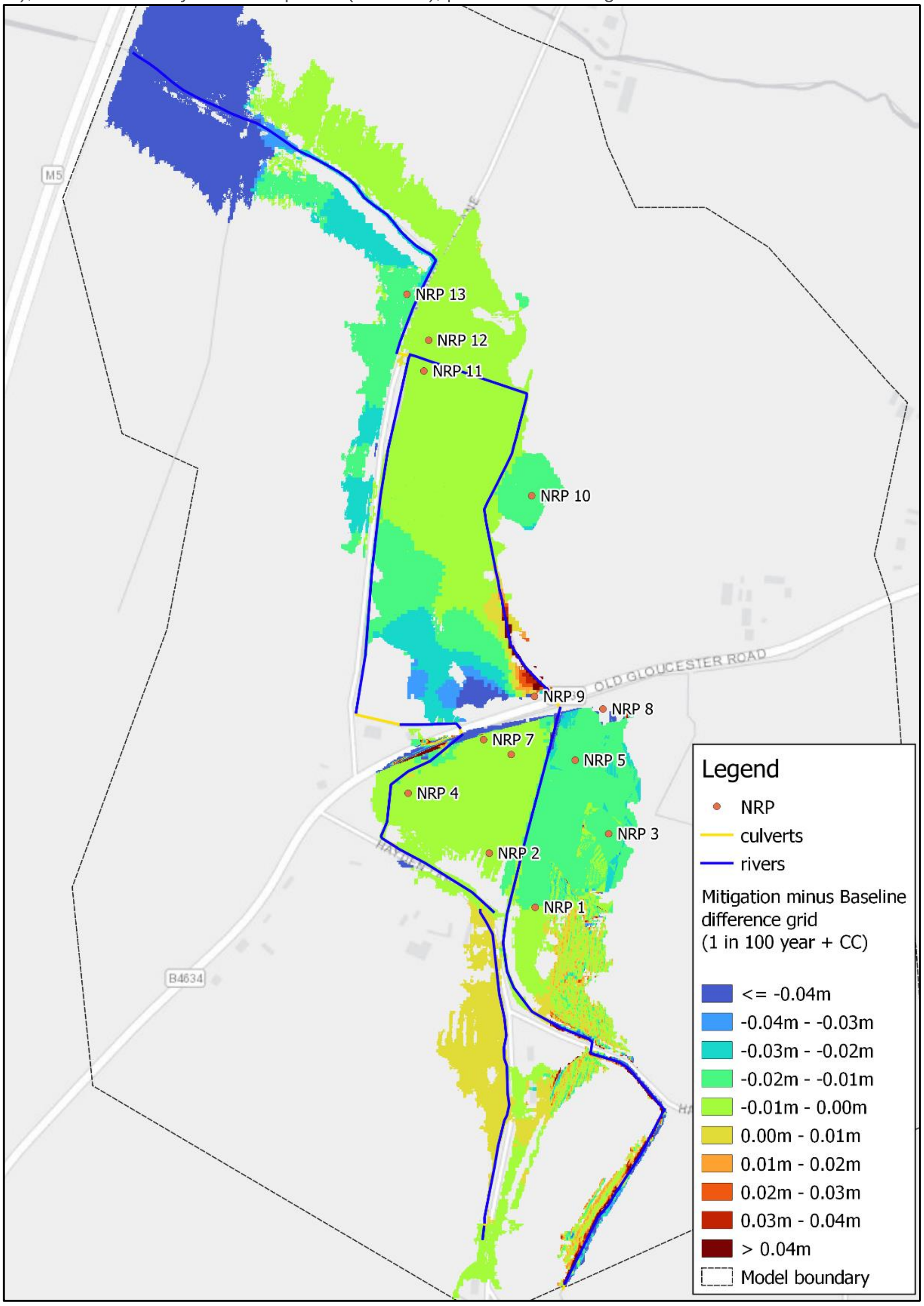
4.2.8. 4.2.13. Figure 4-4 show the depth difference grids for the 1% annual exceedance probability event (1 in 100-year return period) with allowance for future climate change. This shows a small area of increased flood depth (approximately 40mm) immediately downstream of the Old Gloucester Road culvert, on the eastern channel. However, Figure 4-5 shows that this spill duration is also shortened, meaning the mitigation option could reduce the length of time that this area is flooded, by just over ¼ hour.

4.2.14. In this event, flood depths locally increase in the watercourse and farmland between the B4634 and Withybridge Lane by a maximum of 30-40 mm, from 140 mm to 180 mm, in the design event, with a more widespread reduction in flood depth across the fields.

During this event the B4634 Old Gloucester Road is predicted to flood with an average depth of 200mm predicted.

4.2.15.

Figure 4-4 – Depth~~1% AEP depth~~ difference between the Mitigation scenario and the Baseline (Mitigation minus baseline), for the 1 in 100-year return period (1% AEP), plus climate change event.

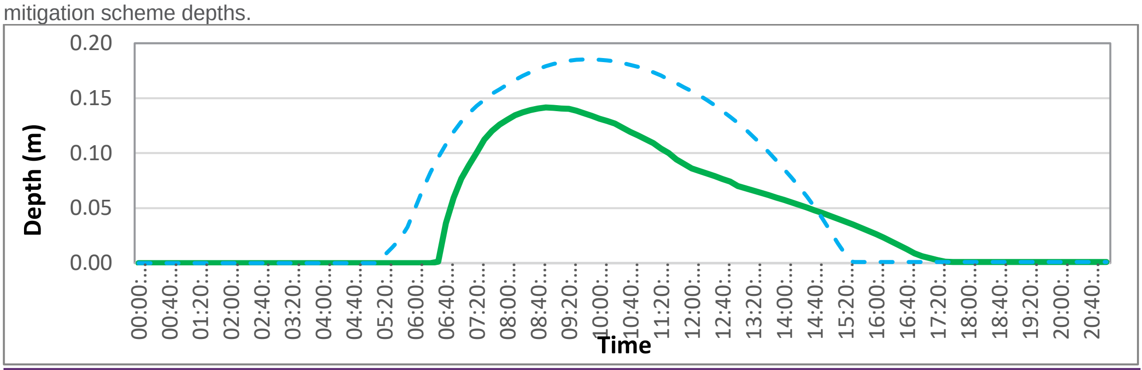


~~4.2.9.~~

~~4.2.10.~~4.2.16. The area of increased flood levels predicted at the upstream boundary of the model are a reflection of the numerical solution tolerance at this location: the impacts at Old Gloucester Road do not influence water levels this far upstream.

Figure 4-5 – 1% AEP depth hydrograph for the Mitigation and Baseline scenarios

20m downstream of the proposed Old Gloucester Road culvert. The green line represents baseline depths, and the dashed blue line represents the mitigation scheme depths.



4.3. Scheme model proving

4.3.1. Sensitivity testing has also been undertaken on the Scheme model to help understand the possible changes to the predicted impact of the Scheme caused by uncertainty in various model parameters.

4.3.2. No sensitivity testing was undertaken on the Scheme model for the channel and floodplain roughness or downstream boundaries, as it was proven that the results of the Baseline were insensitive to those parameters and hence would be similar for the Scheme model.

4.3.3. Consideration was thus made for structure blockage, and climate change.

Sensitivity to structure blockage

4.3.4. Blockage of the new B4634 culverts was considered although not tested in the hydraulic model.

4.3.5. Blockage of the culvert/s under the B4634 will raise flood levels in the land upstream more rapidly than with no blockage. The baseline system has a relief mechanism whereby floodwater eventually flows over the B4634 highway. This starts to occur in the current conditions at a 20% annual exceedance probability event (1 in 5-year return period) event, with full overtopping of the road at the 10% annual exceedance probability event (1 in 10-year return period). Blockage of the existing culvert would lead to increased flooding upstream.

4.3.6. The Scheme provides 3nr new box culverts, each 2100 mm wide and providing an open height of 500 mm. to replace the existing 850 mm × 400 mm opening under the highway. Hence the Scheme provides a much larger conveyance area of 3.15 m^2, in comparison to the existing 0.34 m^2. Hence, the Scheme will reduce the risk of blockage compared to the Baseline, by providing a greater area of flow.

4.3.7. The Scheme also raises the B4634 carriageway over the culverts and so should all 3 new culverts block, then floodwater would need to rise higher, than at present, before it could flow over the road.

4.3.8. In both Baseline and Scheme, more frequent flooding of the land upstream would occur should the capacity of the culverts reduce. However, the risk of all 3 new, and larger culverts blocking together is far less than the current Baseline risk: even if one culvert were fully obstructed then a conveyance area of 6× that in the Baseline would remain.

4.3.9. The debris catchment remains unchanged by the Scheme and so the same debris load is expected. It is also relevant that the 3-culvert Scheme over-provides flow capacity at the smaller flood events, which, as described above, leads to a small increase in flooding downstream, with a subsequent reduction in flood risk upstream. Hence the design includes a margin of safety in the smaller events and some degree of blockage is acceptable by the design.

4.3.10. Nonetheless, the new culverts will require routine maintenance (clearance) to ensure their capacity and that no detriment is caused in the land immediately upstream of the B4634

Sensitivity to flow using the Credible Maximum climate change allowance

4.3.11. The December 2014 National Policy Statement for National Networks (NPS-NN) requires taking into account the potential impacts of climate change using the latest UK Climate Projections over the estimated lifetime of the new infrastructure. Similar to the Environment Agency guidance, the policy requires demonstration that there are no critical features of the design of the Scheme which may be seriously affected by more radical changes to the climate beyond that projected in the latest set of UK climate projections. Any potential critical features should be assessed taking account of the latest credible scientific evidence (e.g. by referring to additional credible maximum scenarios such as from the Intergovernmental Panel on Climate Change or Environment Agency). Hence, the National Policy Statement for National Networks refers back to the Environment Agency guidance for definition of the Upper End climate change allowance.

4.3.12. Thus, as a NSIP, there is a need to assess the flood risk from a credible maximum climate change scenario. As such, a sensitivity test to flow using the Upper End climate change allowance was undertaken; this being a +94% increase in peak flow. It should be noted that this test was to assess how sensitive the Scheme might be to large-scale changes in the climate and help design in future adaptation measures as may be required over its lifetime. This was not a test to evaluate the impact of the Scheme on 3rd party receptors at the Upper End scenario (change from the baseline with the same climate scenario), but only to evaluate the risk of flooding to the Scheme at the Upper End scenario.

4.3.13. Whilst there is some debate on whether the Link Road is classified as Essential Infrastructure by the National Planning Policy Framework, the NSIP test has been applied for information. Hence, a sensitivity test was undertaken on the climate change allowance by applying the Upper End allowance on the 1% annual exceedance probability event (1 in 100-year return period). For the Staverton Stream, the Upper End scenario requires a +94% increase in peak flow. Changes were made to reflect this Upper End scenario by scaling the peak flows as described in Table 4-4Table 4-4Table 4-444.

Table 4-4 – Peak flows with different climate change allowances

	Peak 100yr flow m³/s		
	Present day (+0%)	Higher Central (+53%)	**Upper End (+94%)**
Upstream of Old Gloucester Road	2.6	4.0	**5.0**
Downstream of Old Gloucester Road	1.6	2.4	**3.1**
Staverton stream at M5 motorway	4.2	6.4	**8.1**

4.3.14. The flood model was then simulated to evaluate the impact of extreme climate change on the Scheme, using the +94%, or Upper End, climate change scenario.

4.3.15. The results are tabulated below in Table 4-5.

4.3.16. The modelling identified that during the credible maximum scenario flood levels would typically rise by a further 110 mm upstream of the B4634, and typically 20 mm downstream, when compared to the design flood. This is typically 140 mm higher than the present day. The Scheme would suffer some additional flood depths as a result of the credible maxima event compared to the design event, and the modelling indicates that the B4634 would be fully overtopped during this larger event.

4.3.17. In summary, the modelling demonstrates a 'cliff-edge' effect from the higher flows and measures to adapt the Scheme should a worse case future climate arise will be required: to either keep the B4634 flood free or ensure operational safety of the highway.

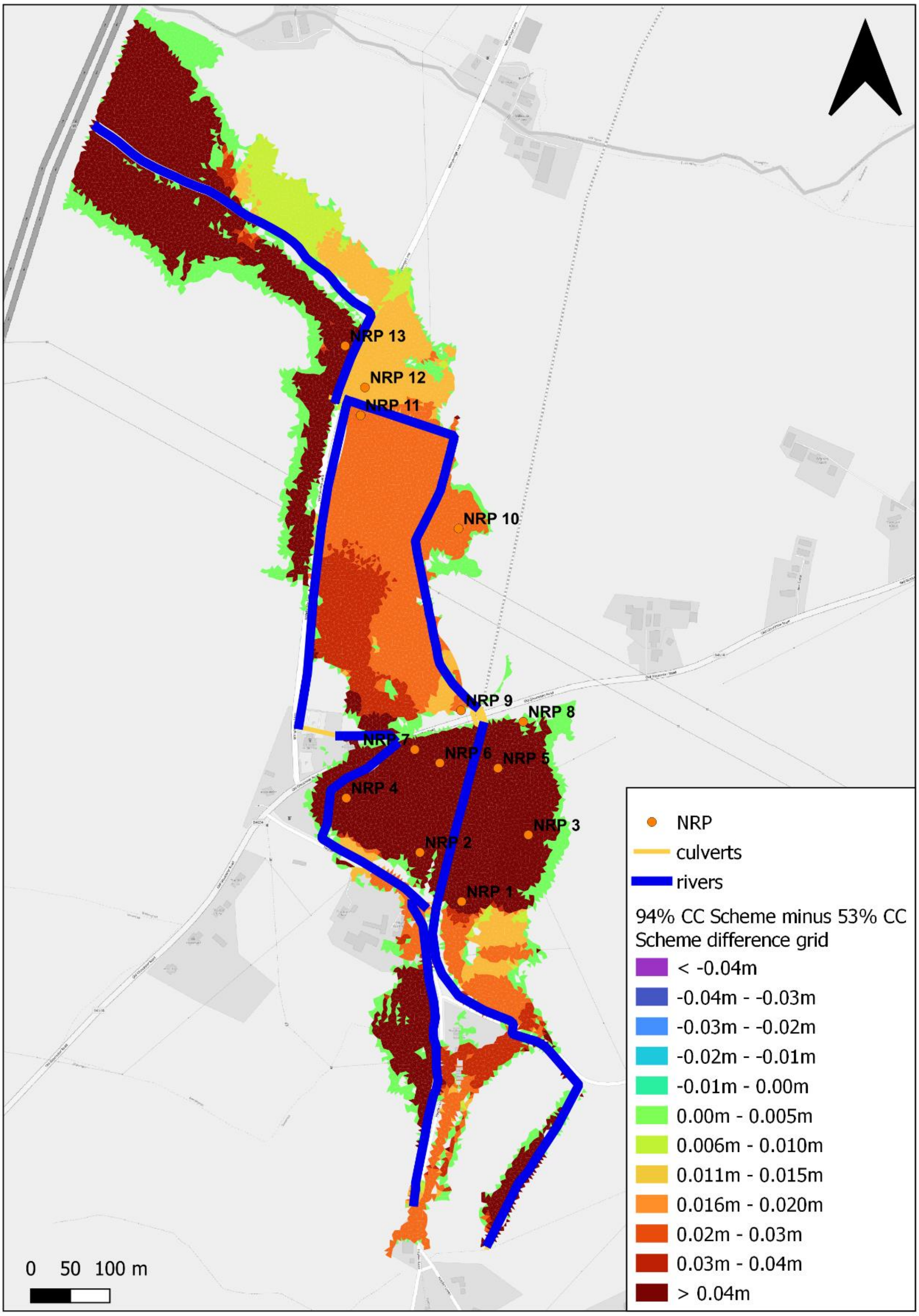
Table 4-5 – Impact of extreme climate change on Scheme

Peak flood depths (m)

Results Point	Present day	+53% climate change	+94% climate change Credible maxima
NRP 1	0.07	0.13	0.22
NRP 2	0.09	0.21	0.31
NRP 3	0.05	0.16	0.27
NRP 4	0.02	0.15	0.25
NRP 5	0.24	0.38	0.50
NRP 6	0.19	0.33	0.44
NRP 7	0.13	0.26	0.37
NRP 8	0.00	0.00	0.00
NRP 9	0.00	0.00	0.00
NRP 10	0.04	0.08	0.11
NRP 11	0.26	0.29	0.32
NRP 12	0.24	0.26	0.28
NRP 13	0.00	0.04	0.09

4.3.18. The difference grid, showing the incremental effect of moving from a design event with +53% climate change to +94% as a credible maxima is shown overleaf in Figure 4-6~~Figure 4-6Figure 4-6~~4~~6~~.

Figure 4-6 – With-Scheme depth difference between the Credible Maxima event and Design event (+94% minus +53%), for the 1 in 100-year return period (1% AEP)
Areas of reds, oranges, yellows show where the credible maxima would increase flood depths beyond the design flood.



4.4. Drainage impacts

4.4.1. A detailed drainage design has been prepared in accordance with the DMRB design standards and local planning documents to manage the risk of flooding of the road itself (i.e. from the Scheme's surface, drainage etc.). This is described in the Scheme's drainage strategy[2]. The strategy limits discharges from the new highways such that they do not exceed the present day runoff rates or volumes and climate change allowances considered. The Scheme design includes drainage attention ponds, fitted with flow controls. Peak runoff from the new paved surfaces will be restricted to the current greenfield runoff: peak outflows will be limited to greenfield runoff rate (QBAR) for events up to the 1% annual exceedance probability event (1 in 100-year return period) with an allowance of 40% applied for climate change (40% being the Environment Agency guidance for climate change impacts on rainfall as used in drainage design). A volumetric restriction will be applied to control the additional volume of runoff generated – see Section 5 below~~5~~ on loss of floodplain.

4.4.2. Under these design rules, the road drainage will reduce the rate and volume of runoff being discharged into the existing watercourses compared to the current situation. Both the 20% annual exceedance probability event (1 in 5-year return period) and 10% annual exceedance probability event (1 in 10-year return period) will be attenuated to the QBAR flow (marginally higher than the 50% annual exceedance probability event (1 in 2-year return period). However, the drainage modelling only suggests a nominal reduction in peak runoff, via the pond, of 2.4l/s. Despite this small change, the flows into the watercourse will be slightly reduced and hence the 20 mm to 40 mm predicted detriment, described above, will be marginally lower. The impact of these small changes in flows was not tested in the model as they were deemed~~, being~~ too small for the resolution of the model.

4.4.3. Further reductions in flows entering the watercourse are expected as a result of changes in the timings of the discharge hydrographs. Whilst the natural catchment was found to have a critical storm duration of 7½ hours, the new link road itself will respond much quicker. Inclusion of the drainage attenuation pond will slow this response down and limit the discharge: in fact, the critical storm for the drainage system is predicted to be a much longer at 72-hours. Hence the inclusion of the drainage features will see water released into the catchment both earlier than the natural response and yet over a much longer period, reducing the eventual peak of any flood.

[2] Atkins (2021) M5 J10 Improvements Scheme – Drainage strategy report, ref GCCM5J10-ATK-HDG-ZZ-RP-CD-000001

4.5. Scheme summary

4.5.1. TheIt is summarised that the mitigation option performs well for all return periods and for all locations with the exception of the NRP 11 – 123, and the farmland immediately south of NRP11, for the 20% annual exceedance probability event (1 in 5-year return period) and 10% annual exceedance probability event (1 in 10-year return period), with an increase in flood level of 10 mm to 30 mm predicted. The change in flood extents arising from these difference are shown in Figure 4-7 to Figure 4-9Figure 3-8 to Figure 3-10, for the 20% annual exceedance probability event (1 in 5-year return period), 10% annual exceedance probability event (1 in 10-year return period) and 1% annual exceedance probability event (1 in 100-year return period).

4.5.2. Whilst the modelling demonstrates a minor increase in peak flood level [minor as defined by LA113[3]], the impact is balanced by a reduction in flooded duration, reducing from 8 hours to 6½ hours in the 20% annual exceedance probability event (1 in 5-year return period) and 10% annual exceedance probability event (1 in 10-year return period).

4.5.3. During the 1% annual exceedance probability event (1 in 100-year return period) with climate change, the capacity of the additional mitigation (3nr box culverts) will be exceeded such that the flood levels rise similarly on the upstream side of the new highway, as they do in the Baseline. However, due to the increased culvert capacity in the proposed Scheme, a marginally shallower flood depth is predicted upstream in the mitigation option when compared to the Baseline.

4.5.4. Model testing was undertaken to find a balance although no optimum solution could be found to reduce the minor downstream impact by reducing the betterment secured upstream. This is a function of the change in hydraulics between the Baseline and Scheme model. Whilst the Scheme appears to impact 3rd party land, the impacts are minor (as defined by LA113) and not a significant effect. ConsultationIt is suggested that consultation with the land owners is beingbe undertakenheld to consider the change in flood risk (increased depth vs reduced flood duration). At the same time the DCO includes the area as flood compensation with) and agree a permanent rightRight to hold the additional waterFlood.

4.5.5. It should be noted that the climate change results relate to a 53% increase in peak flow. This allowance is based on the vulnerability classification of essential infrastructure, which was applied to the main M5 Junction improvements, and hence application of the higher central allowance. Use of the central allowance would only require a 37% uplift in flow for the 1% annual exceedance probability event (1 in 100-year return period) in 100 years' time. In such a condition, the peak catchment flow at Old Gloucester Road would reduce from 4.0 m^3/s to 3.5 m^3/s. It is inferred from the results that such a change in allowance would increase the reported benefit to the land upstream of the highway in the climate change event.

[3] Highways England et al, 2019. Design Manual for Roads and Bridges - LA113 Road drainage and the water environment, s.l.: s.n.

Figure 4-7 – Comparison of flood extents for the 1 in 5-year return period (20% AEP) event.

Baseline and Mitigation model. Flood depths greater than 0.02m are shown.

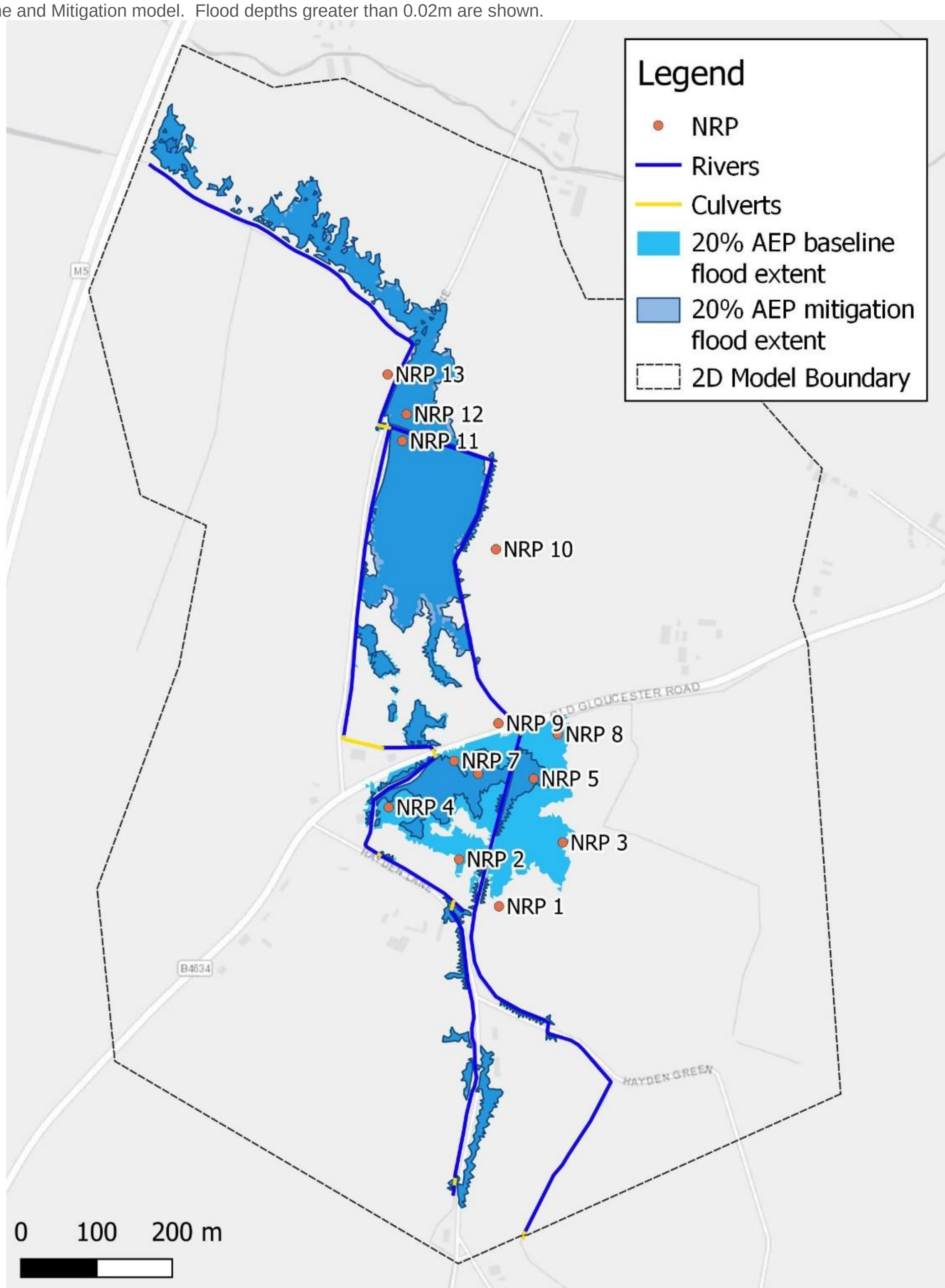


Figure 4-8 – Comparison of flood extents for the 1 in 10-year return period (10% AEP) event.

Baseline and Mitigation model. Flood depths greater than 0.02m are shown.

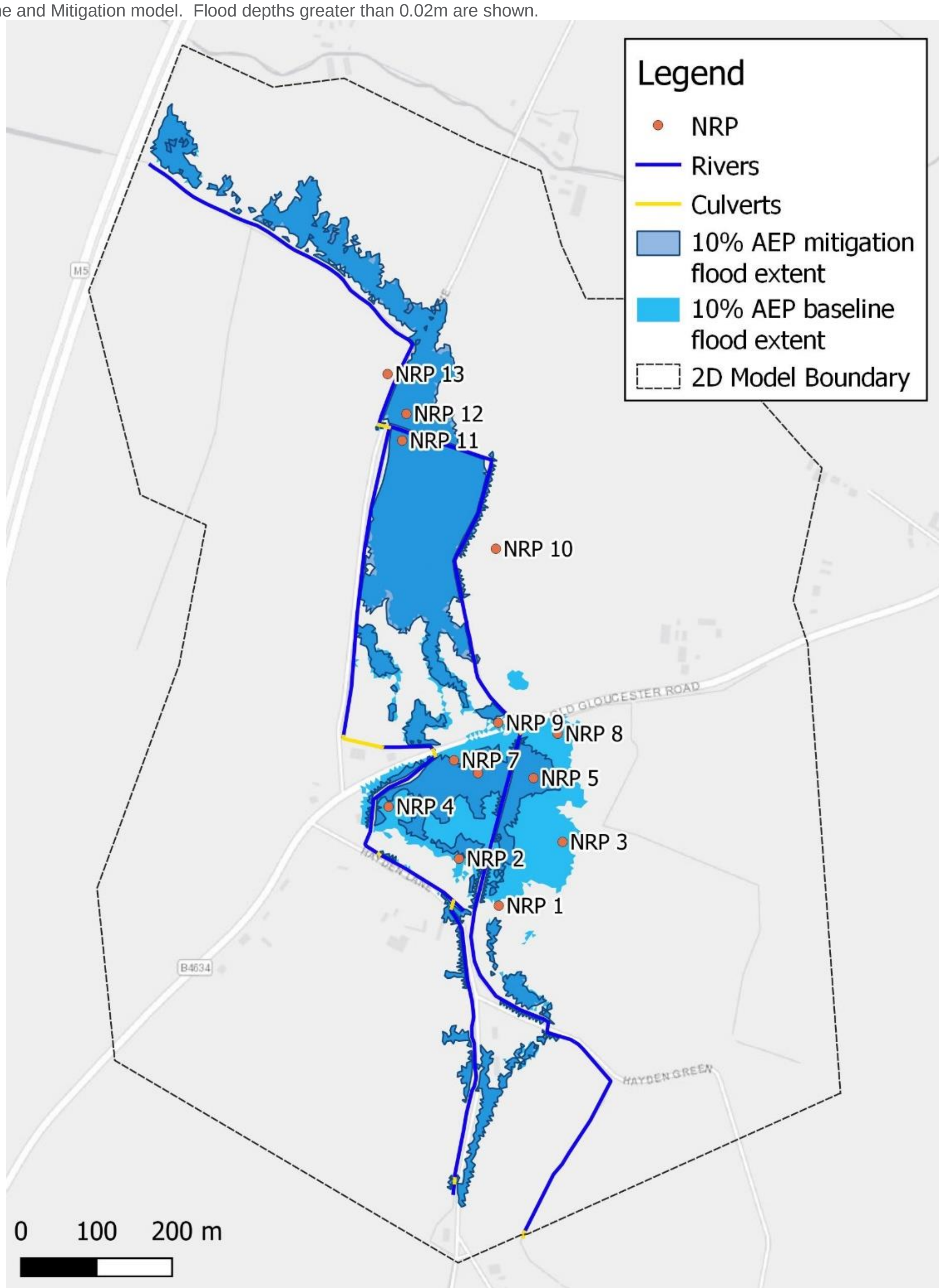


Figure 4-9 – Comparison of flood extents for the 1 in 100-year return period (1% AEP) event.

Baseline and Mitigation model. Flood depths greater than 0.02m are shown.

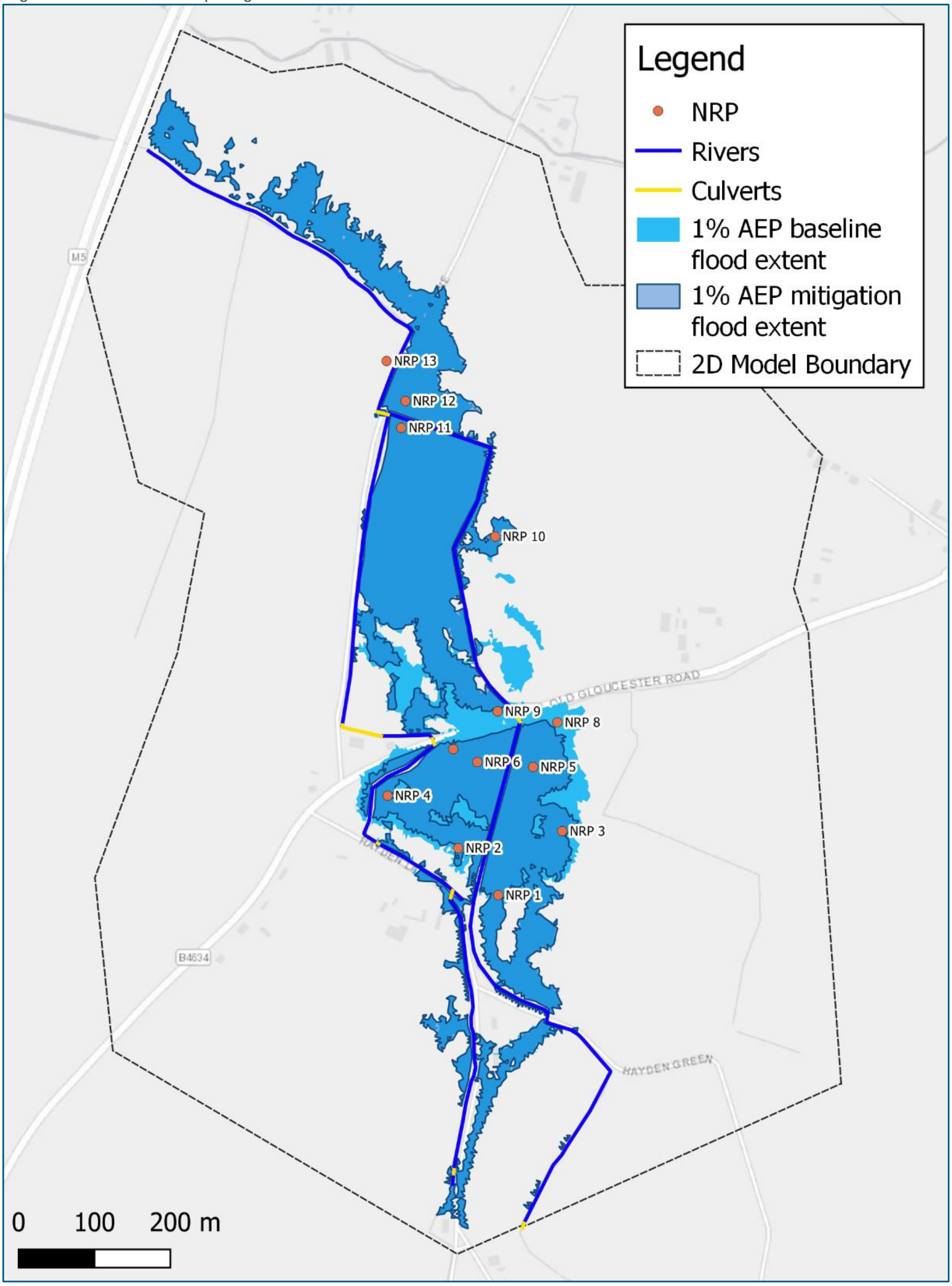
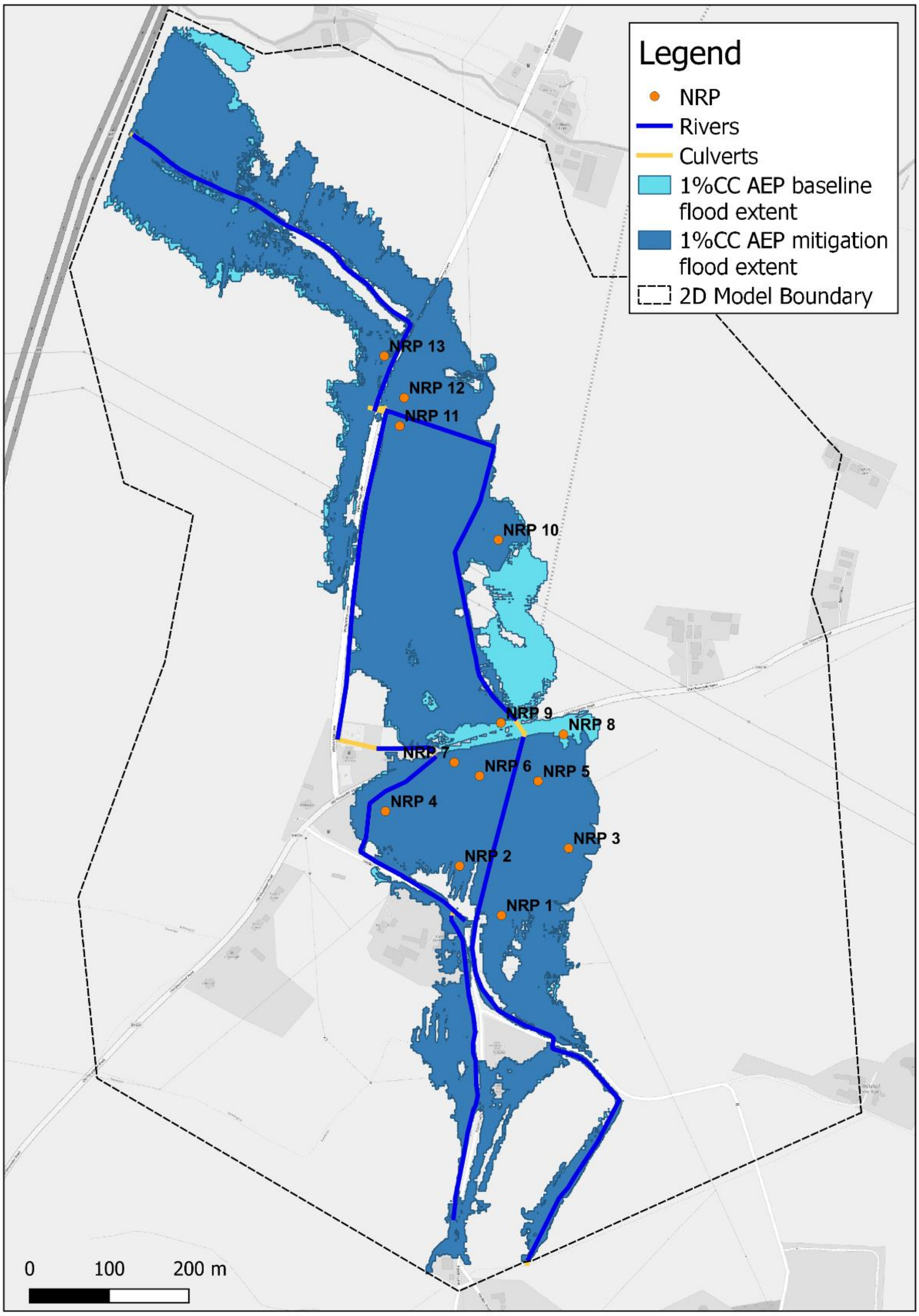


Figure 4-10 – Comparison of flood extents for the 1 in 100-year return period (1% AEP) event with 53% climate change.

Baseline and Mitigation model. Flood depths greater than 0.02m are shown.

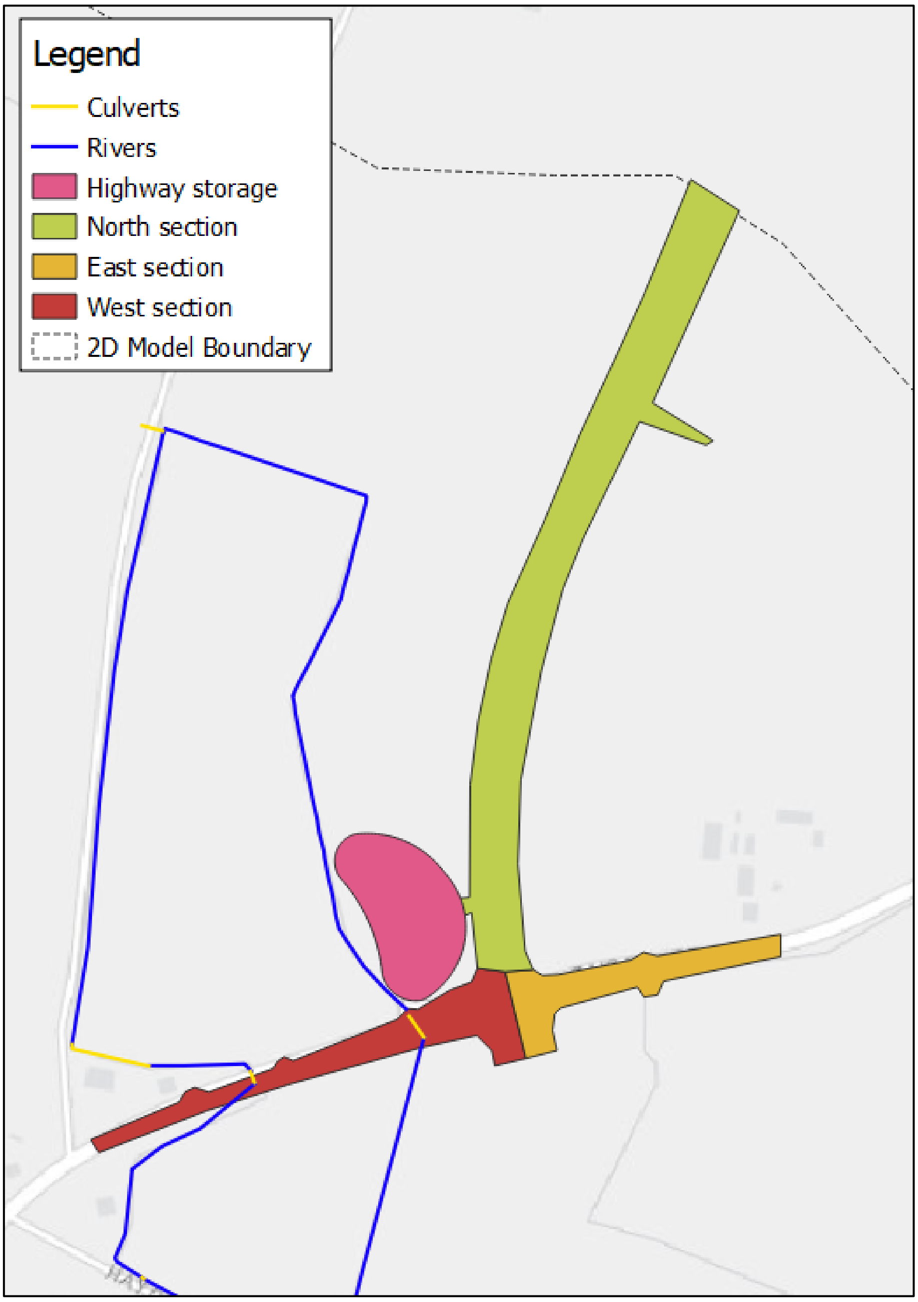


5. Floodplain loss assessment

The Mitigation model shows that flood depths downstream are relatively insensitive to the proposed changes at the Old Gloucester Road, with~~and that~~ a small increase in~~increased~~ pass-forward flood flow, as a result of the Mitigation Scheme that will be conveyed downstream towards the River Chelt by the existing watercourses, increasing~~. It is therefore proposed that any loss of floodplain as a result of the proposed work at the Old Gloucester Road (link road junction and drainage attenuation pond) be compensated for through over-compensation at the large wetland flood storage proposed as part of the main M5 Junction 10 improvement works, in the floodplain of the River Chelt between Withybridge Gardens and Butlers Court. The hydraulic modelling demonstrates that this is possible with only a minor or negligible detriment in downstream~~ flood levels on the farmland~~. Further details in the displacement of floodplain is given below~~.

For the purpose of reporting floodplain loss (where flood levels differ spatially), the proposed Scheme at the Old Gloucester Road has been divided into four sections as per Figure 5-1.

Figure 5-1 – Sections of highway Scheme as reported for floodplain loss



5.1.1. The Scheme footprint intersects with a range of flood levels for each AEP as the water surface varies across the~~, meaning a single flood level cannot equate to a single measure of~~ floodplain ~~loss~~. The volumes displaced by the Scheme were determined within the ICM software and are reported in Table 5-1.

Table 5-1 – Floodplain loss for each Scheme section for each modelled return period.

Annual Exceedance Probability	**Floodplain Loss (m^3)**				
	All Scheme	**West Section**	**East Section**	**North Section**	**Highway storage pond**
50%	140	140	0	0	0
20%	402	396	6	0	0
10%	613	566	26	0	21
5%	~~757~~756	643	35	0	78
4%	~~783~~784	659	39	0	86
2%	~~851~~852	692	48	0	112
1%	905	720	54	1	130
1% + CC	1,143	805	84	13	241

5.1.2. The total volume of floodwater displaced by the ~~with-~~Scheme~~ option~~ is 1,143 m^3 in the 1% annual exceedance probability event (1 in 100-year return period) plus climate change. ~~, having a median flood level in this area of (26.43 mAOD).~~

5.1.3. It is proposed that the loss of floodplain volume from the B4634 junction with the West Cheltenham Link Road, and drainage attenuation pond, be compensated for by:

- having a permanent right to store additional water in the farmland alongside the watercourse, this being described as flood compensation land; and
- increasing the volume contained within the large flood storage area at Junction 10 will have wider benefits within the downstream reaches of the Chelt catchment.

5.1.4. Consultation with the affected landowners alongside the Staverton Stream is being undertaken to ensure that they are fully aware of the small increases in peak flood level and find them acceptable. At the same time, a right is also being sought through the DCO process to permit some increased depth of flood on farmland between the B4634 and Withybridge Lane.

5.1.5. The River Chelt flood storage area is proposed to accommodate approximately 190,298 m^3 of floodwater. The volume of River Chelt floodwater displaced by the Scheme is 31,512 m^3 in the 1% annual exceedance probability event (1 in 100-year return period) with allowance for future climate change. The storage sizing also provides volume for the additional floodwater prevented from accessing the Leigh Brook floodplain, being approximately 153,573 m^3, and thus, simplistically, a total requirement of 185,085 m^3. Hence the flood storage area accommodates over 5,213 m^3 more floodwater than it needs to for the River Chelt alone. The beneficial impact of the oversized flood storage area will certainly be realised downstream of Boddington where the Staverton Stream joins the River Chelt, although the River Chelt floodplain merges with the Staverton Stream floodplain at the M5 motorway.

~~5.1.3.~~5.1.6. It should be noted that the drainage attenuation pond itself reduces the volume of rainfall entering the catchment which goes someway to offsetting the displacement, as well as lowering the peak runoff. In the 20% annual exceedance probability event (1 in 5-year return period) the volume of water retained by the pond in the 8-hour storm (similar to the natural catchment's critical storm of 7½-hours) is 928 m^3, rising to 1,082 m^3 in the 10% annual exceedance probability event (1 in 10-year return period). Despite the pond receiving some runoff from outside the Staverton catchment, this~~This~~ more than offsets the floodplain displacement in tho~~e~~se events.

~~5.1.4.~~ In summary, it ~~It~~ is proposed that any~~the~~ loss of floodplain as a result of the proposed work at the ~~from the~~ Old Gloucester Road (link road junction ~~with the proposed West Cheltenham Link Road,~~ and drainage attenuation pond)~~,~~ be compensated for ~~at the proposed wetland flood storage as~~

part of the M5 J10 improvement works, by having a permanent rightincreasing the volume contained within the wetland flood storage area by the losses reported here.

5.1.5.5.1.7. That River Chelt flood storage area is proposed to storeaccommodate approximately 190,300 m^3 of floodwater. The volume of River Chelt floodwater displaced by the Scheme is approximately 32,350 m^3 in the 1% annual exceedance probability event (1 in 100-year return period) with allowance for future climate change. The storage sizing also provides volume for the additional water alongside the ordinaryfloodwater prevented from accessing the Leigh Brook floodplain, being approximately 123,600 m^3, and thus, simplistically, a total requirement of 155,950 m^3. Hence the flood storage area accommodates over 34,350 m^3 more floodwater than it needs to for the River Chelt alone. This over-provision can amply compensate for the 1,143 m^3 loss in the Staverton Stream watercourse itself. Additional benefitand thus ensure no increase in volume being passed downstream of the M5 motorway will be provided by over-sizing the basin at the large wetland flood storage in the floodplain of the River Chelt between Withybridge Gardens and Butlers Court. .

6. Residual risks

6.1. Extreme event

6.1.1. The residual risks of the extreme event (0.1% annual exceedance probability event (1 in 1,000-year return period) as defined in the NPPF) are similar to the 1% annual exceedance probability event (1 in 100-year return period) with climate change: the inflows are almost identical.

6.1.2. It is recognised that the site drainage system will not cope with such intense rainfall and that water will be spilling off the roads onto the surrounding land. This water will be unattenuated. In such an extreme event, the paved areas are likely to respond in a similar way to the surrounding farmland, with no infiltration and all rainfall being held on the ground surface. In such a situation, there would be no change from the Baseline condition.

6.1.3. The Scheme and other surrounding areas will remain at flood risk in the extreme event. Surrounding areas are predicted to flood in the current situation. This frequency will increase with the impacts of climate change – although it is not currently UK best practice to apply climate change allowances on the 0.1% annual exceedance probability event (1 in 1,000-year return period).

6.1.4. The sensitivity of the predicted flooding to the impact of more extreme climate change are described in the above sections. This applies a 94% increase in flow, which is in line with the Upper End climate change scenario as required in guidance for an NSIP, and referred to in the NN NPS as the credible maxima. That testing indicates no significant increase in flood risk to the Scheme should a worst case climate impact occur.

6.2. Access and egress conditions

6.2.1. The junction design is intended to afford safe access and egress from the Old Gloucester Road from/onto the proposed West Cheltenham Link Road, and eventually serve the large development site to the south.

6.2.2. The B4634 Old Gloucester Road is likely to be flooded during an extreme event. The NPPF Planning Practice Guidance acknowledges this and states that "…where this [dry access] is not possible, limited depths of flooding may be acceptable…".

6.2.3. In the 1% annual exceedance probability event (1 in 100-year return period) plus climate change, the depth of floodwater spilt ontodepths over the highway decreases from 560 mm in the Baseline to 334 mm with the mitigation Scheme in place, and the velocity of flow reduced from 0.36 m/s to 0.06 m/s. The maximum hazard index on the highway decreases from 1.23 to 0.54. As such the Scheme will be safer than the existing arrangements.

6.3. Management over development lifetime

6.3.1. There are no significant lifetime management issues for the proposed Scheme related to the management and maintenance of the watercourses and its related infrastructure other than routine channel and culvert maintenance. Any trash/debris deposited at or in the channel will need to be removed from the site to maintain the hydraulic and storage capacity.

6.3.2. Flood levels will increase with time in line with climate change. This will increase the frequency for channel and structure maintenance.

7. Summary and conclusions

7.1.1. This technical note presents a hydraulic modelling assessment of flood risk to the proposed new highway junction of the new West Cheltenham Link Road and the existing B4634 Old Gloucester Road and the flood effects to 3rd party receptors arising from it. The junction sits partly in Environment Agency Flood Zone 1, it being an Ordinary Watercourse. It intersects the Environment Agency's High, Medium and Low risk areas for Surface water flooding.

7.1.2. Sensitivity testing has been undertaken on channel and floodplain roughnesses and the downstream boundary. The model is relatively insensitive to these parameters.

7.1.3. In the baseline case, the existing B4634 Old Gloucester Road is predicted to flood in the 20% annual exceedance probability event (1 in 5-year return period) and fully overtop during a 10% annual exceedance probability event (1 in 10-year return period).

7.1.4. Without mitigation, the proposed highway works could increase the risk of flooding to the south of the works (upstream) from a 20% annual exceedance probability event (1 in 5-year return period) and upwards.

~~7.1.2.~~7.1.5. With the mitigated Scheme in place the B4634 Old Gloucester Road will remain flood free during a 1% annual exceedance probability event (1 in 100-year return period) and will only flood as a result of the impacts of climate change (1% annual exceedance probability event (1 in 100-year return period) with climate change).

~~7.1.3.~~7.1.6. The additional mitigation avoids the increase in flood depths upstream of the road junction and in fact reduces flood levels by up to 200 mm. Some minor detriments (~20 mm) are predicted by the model downstream, around Withybridge Lane, for the 20% annual exceedance probability event (1 in 5-year return period) and 10% annual exceedance probability event (1 in 10-year return period). However, the drainage attenuation features will be performing well in such events and will slightly reduce the overall flow into the watercourse – having a beneficial effect. The greatest impact appears to be a localised detriment of 40 mm where the eastern watercourse is already overtopping its western bank: this impact is offset by a 1½ hour reduction in the overall flooded duration at this location. At the 1% annual exceedance probability event (1 in 100-year return period) the impacts are almost entirely beneficial except for a small area of land immediately downstream of the proposed culverts where the peak flood level is predicted to rise by up to 40 mm. As with the smaller event, this comes with a minor reduction in the duration of flooding, although only by just over ¼ hour ~~20 minutes~~ at this location in this event.

~~7.1.4.~~7.1.7. Whilst the Scheme will displace floodwater under its footprint, the impact of conveying this additional volume on the farmland downstream of the works is nominal, and in fact beneficial in most flood conditions: the volume of floodwater collected upstream of the Old Gloucester Road in the baseline is conveyed earlier in the event with the Scheme in place, as a result of the extra culverts. This resulted in a nonmaterial increase in flood risk to three fields, based on an associated indiscernible increase in flood frequency (which already flood at the 20% annual exceedance probability event (1 in 5-year return period)) and no change in the consequence of flooding. Negligible impact on flood depths were predicted for larger events, and the hydraulic modelling predicted no adverse impact at the design flood~~With the Staverton Stream discharging into the River Chelt near Boddington, the over-compensation of River Chelt flows by the large 190,300m³ wetland storage near the M5 Junction 10 more than offsets the additional volume passed into it by the works at the southern end of the West Cheltenham Link Road~~.

~~7.1.5.~~7.1.8. Whilst this assessment has demonstrated an~~not be able to demonstrate no~~ adverse effect of the proposed Scheme at the B4634 Old Gloucester Road on flood risk, it has proven that the impacts are at worst minor, and for the larger floods will lead to a reduction in flood risk~~be beneficial~~, especially south of the road in the upstream catchment. Consultation~~It~~ is being ~~recommended that consultation be~~ undertaken with the landowners along the Staverton Stream where an increase in flood depth is predicted, noting a negligible~~limited~~ or no increase in flood extent, and a reduction in flood duration, with a view to landowner acceptance. At the same time, a right is also being sought through the DCO process~~a Right to Flood agreement being made~~ to permit an increased depth of flooding on the farmland between the B4634 and Withybridge Lane, which is described on the Scheme plans as flood compensation~~accept the impact~~.

~~7.1.6.~~7.1.9. It is concluded that the Scheme with proposed mitigation will be appropriate in terms of all applicable surface water flood risks and effects being acceptable. This is on the basis that:

- the hydraulic modelling indicates only minor, or no, adverse, impact on peak flood levels downstream of the B4634 Old Gloucester Road in conveying any displaced water, and such will not cause any significant disbenefit (~~,~~ and in fact reduces the duration of flooding);~~;~~ and
- the wider M5 J10 Improvement Works includes additional volume within its compensatory storage ~~wetland~~ near the motorway junction to provide an overall increase in flood storage in the catchment – the catchment which merges with the Staverton Stream in the 10% annual exceedance probability event (1 in 10-year return period).~~.~~

AtkinsRéalis

5th Floor, Block 5
Shire Hall
Bearland
Gloucester
GL1 2TH