High Speed Two Phase 2a (West Midlands - Crewe)

Background Information and Data

Hydraulic modelling report - Filly Brook
(BID-WR-004-000)

March 2018

G36

High Speed Two Phase 2a (West Midlands - Crewe)

Background Information and Data

Hydraulic modelling report - Filly Brook (BID-WR-004-000)

March 2018

G36

Department for Transport

High Speed Two (HS2) Limited has been tasked by the Department for Transport (DfT) with managing the delivery of a new national high speed rail network. It is a non-departmental public body wholly owned by the DfT.

High Speed Two (HS2) Limited,
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

Telephone: 08081 434 434

General email enquiries: HS2enquiries@hs2.org.uk

Website: www.gov.uk/hs2

A report prepared for High Speed Two (HS2) Limited:

ARUP

ERM

High Speed Two (HS2) Limited has actively considered the needs of blind and partially sighted people in accessing this document. The text will be made available in full on the HS2 website. The text may be freely downloaded and translated by individuals or organisations for conversion into other accessible formats. If you have other needs in this regard, please contact High Speed Two (HS2) Limited.

recycle

Printed in Great Britain on paper containing at least 75% recycled fibre.

Contents

1	**Introduction**	**1**
1.1	Background	1
1.2	Aims	1
1.3	Objectives	2
1.4	Justification of approach	2
1.5	Scope	3
2	**Site characteristics**	**4**
2.1	Description of the study area	4
2.2	Existing understanding of flood risk	5
2.3	Availability of existing hydraulic models	7
2.4	Site visit	7
3	**Model approach and justification**	**8**
3.1	Model conceptualisation	8
3.2	Software	8
3.3	Topographic survey	8
3.4	Input data	8
4	**Technical method and implementation**	**9**
4.1	Hydrological assessment	9
4.2	Hydraulic model build - baseline model	10
4.3	Hydraulic model build – AP revised scheme	13
4.4	Climate change	15
5	**Model results**	**16**
6	**Model proving**	**17**
6.1	Introduction	17
6.2	Run performance	17
6.3	Calibration and validation	17
6.4	Verification	17

6.5 Sensitivity analysis 17
6.6 Blockage analysis 18
6.7 Run parameters 19
7 Limitations 20
8 Conclusions and recommendations 21
9 References 22
Appendix A: Flood level impact maps 23

List of figures

Figure 1: Environment Agency Flood Zones 2 and 3 and uFMfSW (0.1%AEP) at Filly Brook 6
Figure 2: Existing and proposed model extents 12

List of tables

Table 1: Peak flows used for hydraulic analysis 10
Table 2: Key structures present within the modelled extent of Filly Brook 11

Appendix A

Figure A-1: Filly Brook at Yarnfield Impact Map for 5% AEP (1 in 20 year) 24
Figure A-2: Filly Brook at Yarnfield Impact Map for 1% AEP + CC (1 in 100 year) plus 50% climate change allowance 25

1 Introduction

1.1 Background

1.1.1 This document is an appendix which forms part of the Background Information and Data (BID) documents that accompany the Supplementary Environmental Statement (SES) and Additional Provision Environmental Statement (AP ES).

1.1.2 This document presents an update to the hydraulic modelling carried out in the Stone and Swynnerton area (CA3) which accompanied the High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)[1] published in July 2017 (main ES), as a result of the SES changes and amendments, assessed as part of the SES and AP ES. This update should be read in conjunction with BID document BID-WR-004-007[2] which accompanied the main ES, as well as Volume 2 (community area reports), Volume 3 (route-wide effects assessment) and Volume 5 (appendices) of the main ES, and Volume 2 (community area reports) and Volume 3 (route-wide effects assessment) of the SES and AP ES which discuss water resource and flood risk effects. The following Volume 5 Appendices in the main ES and SES and AP ES are relevant to the Stone and Swynnerton area:

- a route-wide Water Framework Directive compliance assessment (see main ES Volume 5: Appendix WR-001-000) and addendum (see SES and AP ES Volume 5: Appendix WR-001-000);
- water resources assessments (see main ES Volume 5: Appendix WR-002-003);
- a flood risk assessment (see main ES Volume 5: Appendix WR-003-003 and see SES and AP ES Volume 5: Appendix WR-003-000); and
- a route-wide draft water resources and flood risk operation and maintenance plan (see main ES Volume 5: Appendix WR-005-000).

1.1.3 In this report the scheme is referred to as the AP revised scheme, which is the original scheme (i.e. the Bill scheme submitted to Parliament in July 2017, which was assessed in the main ES) as amended by the SES changes and AP amendments.

1.2 Aims

1.2.1 The AP revised scheme includes a number of locations where the route will cross watercourses and their floodplains. The crossing locations have the

[1] HS2 Ltd (2017), *High Speed Rail (West Midlands-Crewe) Environmental Statement*, https://www.gov.uk/government/collections/hs2-phase-2a-environmental-statement.

[2] HS2 Ltd (2017), *High Speed Rail (West Midlands-Crewe) Environmental Statement, Background Information and Data, CA3: Stone and Swynnerton Hydraulic modelling report – Filly Brook, BID-WR-004-007.* www.gov.uk/hs2.

potential to increase flood risk where they restrict flood flows or change floodplain dynamics.

1.2.2 At the locations detailed in this report, the route will cross Filly Brook on two parallel embankments, the Yarnfield North Embankment and a short embankment that leads to the Infrastructure Maintenance Base – Rail (IMB-R) (IMB-R Embankment), and the M6 motorway and an unnamed watercourse on the proposed M6 Meaford viaduct.

1.2.3 A hydraulic model of Filly Brook was created to simulate the risk of flooding in this location for an approximate 3.9km stretch of the brook, also incorporating four unnamed drains and Yarnfield Brook downstream. This report documents the methods used and discusses the results, assumptions and limitations imposed by them.

1.2.4 Hydraulic models, of the existing conditions and with the AP revised scheme included, have been evaluated to assess the impact of the AP revised scheme on flood risk and to derive peak flood water levels relative to the proposed structures.

1.2.5 This report details the existing hydrological and hydraulic processes of the reaches modelled and how these will be affected by the AP revised scheme.

1.3 Objectives

1.3.1 The objectives were to:

- conduct, where feasible, a site visit to inform understanding of existing conditions, including existing channel and floodplain characteristics, hydraulic structures and flow paths;
- estimate flow hydrographs at the AP revised scheme crossing location;
- develop a hydraulic model, commensurate with the level of detail required and available at this stage, to provide peak levels at key structures for the AP revised scheme, based on the most suitable data available and flow hydrographs developed; and
- analyse the impact of the AP revised scheme on flood risk levels obtained from the results of the following Annual Exceedance Probabilities (AEP): 50%, 20%, 5.0%, 1.33%, 1.0%, 1.0%+climate change (CC), 0.5% and 0.1%.

1.4 Justification of approach

1.4.1 The hydraulic model has been constructed to allow the flood risks associated with the AP revised scheme design to be assessed.

1.4.2 A 2D hydraulic model was selected for this study as detailed 1D channel information was not available at the time of study and the Light Detection and Ranging (LiDAR) survey adequately portrayed the existing channels and features. Using a 2D approach allows for structures to be represented using the ESTRY 1D solver within Two-dimensional Unsteady FLOW (TUFLOW).

1.4.3 The AP revised scheme crosses Filly Brook in several locations, and incorporates flood defence measures to protect the Norton Bridge to Stone Railway and HS2 infrastructure. Hydrological calculations were therefore undertaken using the Flood Estimation Handbook (FEH) Statistical, Revitalised Flood Hydrograph 2 (ReFH2) and the hybrid methods.

1.5 Scope

1.5.1 The scope of the study was to undertake hydraulic modelling to enable an assessment to be made of the impact of the AP revised scheme on flood risk in the Filly Brook catchment. The models should be detailed enough to allow future assessment of different options associated with each crossing location, to allow the management of flood risk and correct sizing of crossing openings.

1.5.2 The report focuses upon:

- discussion of all relevant datasets, quality and gaps;
- hydrological analysis undertaken, approach used and calculation steps;
- integration of the hydrological analysis with the hydraulic modelling;
- hydraulic modelling methodology chosen, with clear identification of general methodologies and justification; and
- hydraulic modelling parameters, assumptions, limitations and uncertainty.

2 Site characteristics

2.1 Description of the study area

Model reach

2.1.1 The section of Filly Brook being modelled is situated between Yarnfield to the west, Stone to the east and the M6 which bisects the catchment. Figure 1 shows the modelled extent. The model upstream boundary is situated approximately 300m upstream and east of the M6 Meaford viaduct crossing and the downstream boundary is located approximately 320m downstream of the Norton Bridge to Stone Railway crossing. Approximately 3.9km of Filly Brook has been modelled.

2.1.2 Filly Brook flows south, running parallel to the east of the M6 before crossing to the west through a culvert underneath the M6 continuing in a southerly direction. The watercourse then turns east to cross the M6 again via a culvert to flow parallel to the Norton Bridge to Stone Railway, eventually passing beneath the railway and through Stone to its confluence with the River Trent.

2.1.3 There are no major tributaries of Filly Brook within the proposed model extent although there are a number of drains that converge with Filly Brook either side of the Norton Bridge to Stone Railway.

2.1.4 The area is predominantly rural with isolated properties throughout. Stone Golf Club is to the north-east of the point at which the proposed Yarnfield North Embankment crossed Filly Brook.

Hydrological description

2.1.5 Filly Brook originates to the west of Meaford. The catchment area contributing to the downstream boundary of the proposed hydraulic model is approximately 5.0km^2. There are no gauging stations present within the Filly Brook catchment and the Standard Annual Average Rainfall for the catchment at the model downstream boundary is 766mm.

Railway alignment

2.1.6 The route of the AP revised scheme crosses the study area from the south-east heading in a north-western direction, crossing the Norton Bridge to Stone Railway on viaduct and Filly Brook on the Yarnfield North Embankment. It continues heading north-west crossing the realigned Yarnfield Lane and eventually the M6 and Filly Brook for a second time on the proposed M6 Meaford viaduct. Further detail on the AP revised scheme can be found in SES and AP ES Volume 2: Maps CT-06-222, CT-06-222-R1, CT-06-223 and CT-06-223-L1.

2.1.7 Each of the two embankments on which the route crosses Filly Brook have culverts to convey flow, the Filly Brook West culvert for the IMB-R tracks and the Filly Brook culvert for the mainline.

2.1.8 Additionally, the reception sidings for the IMB-R run adjacent to the Norton Bridge to Stone Railway to the east.

Flood mechanisms

2.1.9 The updated Flood Map for Surface Water (uFMfSW) shows a connection between the Filly Brook and Yarnfield Brook catchments. The Yarnfield Brook catchment enters Meece Brook eventually reaching the River Sow therefore it does not pass beneath the AP revised scheme until it reaches the River Trent viaduct significantly downstream.

2.1.10 The uFMfSW shows a significant flow path along the existing Norton Bridge to Stone Railway, as shown in Figure 1.

2.1.11 The eastern most culvert that passes under the Norton Bridge to Stone Railway, within the modelled extent, acts as a throttle at the downstream end of the catchment.

2.2 Existing understanding of flood risk

Sources of information

2.2.1 Sources of Environment Agency data that were assessed were:

- Flood Map for Planning (Rivers and Sea)[3]; and
- uFMfSW[4].

2.2.2 The proposed embankments that cross Filly Brook are within Flood Zones 2 (0.1%AEP) and 3 (1.0%AEP) of the Environment Agency Flood Map for Planning as shown in Figure 1.

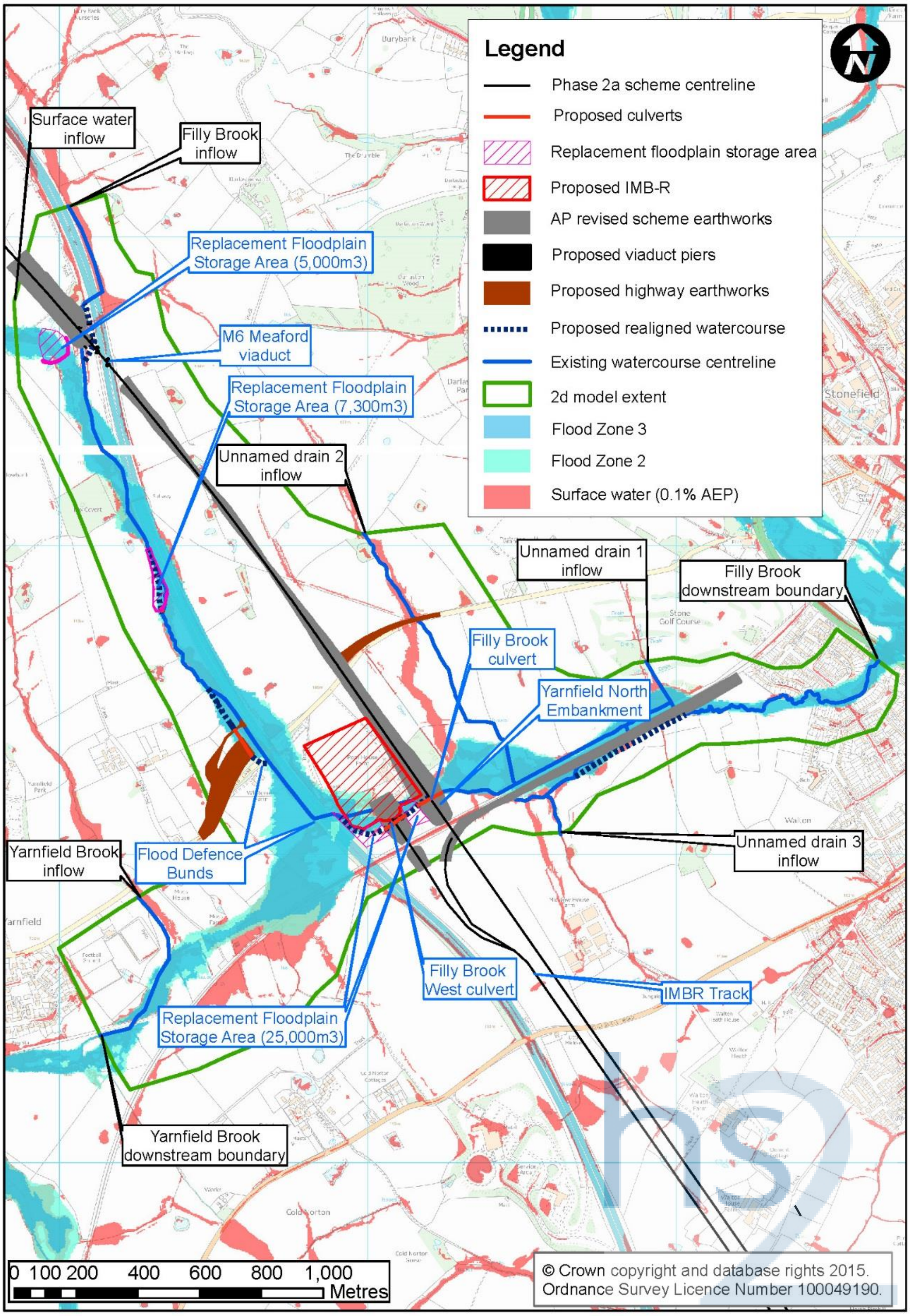
2.2.3 The uFMfSW indicates that multiple surface water flow paths exist in the area. There are four prominent flow paths east of the AP revised scheme, two either side of the Norton Bridge to Stone Railway and one west of the AP revised scheme, where Yarnfield Brook joins the flow from Filly Brook. In addition, a flow path can be seen along the centreline of the Norton Bridge to Stone Railway.

2.2.4 Available information does not indicate the presence of any flood defences within the model extent.

2.2.5 The Environment Agency flood maps are derived from National Generalised Modelling.

[3] Gov.uk, *Flood map for planning*, https://flood-map-for-planning.service.gov.uk
[4] Gov.uk, *Long term flood risk information*, https://flood-warning-information.service.gov.uk/long-term-flood-risk/map?map=SurfaceWater

Figure 1: Environment Agency Flood Zones 2 and 3 and uFMfSW (0.1%AEP) at Filly Brook



2.3 Availability of existing hydraulic models

2.3.1 There were no existing models for Filly Brook identified that could be used for the purposes of this study.

2.4 Site visit

2.4.1 A site visit was undertaken in February 2016 as part of the original scheme study to better determine the dimensions of the channel and any existing infrastructure.

2.4.2 Several structures were visited along Filly Brook. However, not all could be visited due to site access restrictions and general accessibility issues. For the structures that were visited, photographs were taken to ascertain approximate dimensions and roughness. Direct measurements were taken where possible.

2.4.3 Up to date aerial photography appeared to show a millstream parallel to the M6, immediately west of the proposed Yarnfield North Embankment. However, the site visit determined that this stream does not exist.

2.4.4 A 1.2m diameter field drainage culvert exists approximately 100m south-west of Pool House Farm.

2.4.5 A 0.3m diameter culvert crosses the Norton Bridge to Stone Railway approximately 410m east from the M6 crossing.

3 Model approach and justification

3.1 Model conceptualisation

3.1.1 Model extents were carefully selected to ensure that the model boundaries did not have any impact on the flood extent in the area of interest.

3.1.2 Utilising a 2D approach is appropriate for this area due to significant out of bank flows across the floodplain. Watercourse channels were carved out in 2D with characteristics representative of those observed on site or from other sourced information such as aerial photography. Using 2D allows more confidence in the flood extent in the vicinity of the IMB-R which is important for the design of the flood defence scheme to protect against potential surface water flows.

3.2 Software

3.2.1 TUFLOW (2016-AA) industry standard software has been used for the purposes of this analysis.

3.3 Topographic survey

3.3.1 No additional topographic survey was commissioned for this study.

3.4 Input data

3.4.1 The elevation data for the domain was produced using 200mm LiDAR flown specifically for HS2 Ltd and covers 500m either side of the route centreline. In addition, 1m LiDAR, provided by the Environment Agency, was used for the remainder of the modelled extent

4 Technical method and implementation

4.1 Hydrological assessment

4.1.1 The estimation of design peak flows and hydrographs was based on the application of the methodologies pre-approved by HS2 Ltd. These are standard in the UK Flood Risk Management Industry.

4.1.2 The Flood Estimation Handbook (FEH) methodologies were followed, in particular the Statistical Method. No gauged flows were available in the study area so the FEH Pooling Group methodology was adopted. This uses recorded river flows in hydrologically similar catchments to estimate flows at the subject location. The calculations were based on the most up to date national database available at the time of undertaking the calculations. The data was obtained from the National River Flow Archive and/or HiFlowsUK.

4.1.3 In addition, the FEH Revitalised Rainfall Runoff Method, version 2 (part of ReFH2) was used to produce an alternative set of design peak flows and event probability. ReFH2 uses the recently updated FEH13 rainfall database and parameters. The calculations are based on relevant catchment descriptors of each catchment, which were obtained from the FEH Web Service database.

4.1.4 The two sets of design peak flows (from FEH Statistical Method and ReFH2) were analysed and compared, selecting the methodology that produced the most conservative river flows, in the case of the Filly Brook catchment it was ReFH2.

4.1.5 The design hydrographs used for the hydraulic modelling stage were generated using ReFH2 as the FEH Statistical Method does not produce time series, just peak flows. The values were scaled so the peak flow for each return period matched that selected as the design value.

4.1.6 Table 1 shows the peak flows used for the computational hydraulic modelling work.

Table 1: Peak flows used for hydraulic analysis

	AEP	Return period	Site code					
			Filly Brook inflow	Surface water inflow	Unnamed drain 1	Unnamed drain 2	Unnamed drain 3	Yarnfield Brook inflow
Flood peak (m^3/s)	50%	2yr	0.32	0.65	0.12	0.30	0.39	0.86
	20%	5yr	0.44	0.88	0.17	0.40	0.53	0.92
	5.0%	20yr	0.63	1.25	0.24	0.57	0.75	1.26
	1.33%	75yr	0.90	1.75	0.34	0.80	1.05	1.60
	1.0%	100yr	0.97	1.89	0.36	0.87	1.13	1.71
	1.0% + CC	100yr +CC	1.46	2.84	0.54	1.31	1.70	2.57
	0.5%	200yr	1.19	2.30	0.44	1.05	1.38	2.02
	0.1%	1000yr	1.86	3.52	0.68	1.60	2.09	3.05

4.2 Hydraulic model build - baseline model

1D Representation

4.2.1 Culverts were included in the ESTRY component of TUFLOW. The sizes of these culverts were based on site visit observations, information from Network Rail, the Highways Agency Geotechnical Data Management System (HA GDMS)[5] and the inverts from available LiDAR information.

2D Representation

4.2.2 The cell size of the model was set as 2m. Cell size and alignment for the 2D model grid was optimised to ensure appropriate representation of the flow pathways whilst maintaining reasonable run times. The alignment for the 2D model grid follows the rotation of the AP revised scheme piers at the M6 Meaford viaduct.

4.2.3 Sections of Filly Brook downstream and east of the M6 and Yarnfield Brook west of the M6 have been modified in the 2D as the 1m Environment Agency LiDAR used did not adequately pick up the features of existing channels.

Inflow boundaries

4.2.4 The study area has six inflows. The main inflow, Filly Brook, is located at the upstream extent of the model, east of the M6. A surface water inflow is also located at the upstream extent of the model on the opposite side of the M6. Three more inflows join Filly Brook once it runs parallel with the Norton Bridge to Stone Railway, two from the north and one from the south. The Yarnfield

[5] Highways England, *Geotechnical Data Management System v5.12.0*, http://www.hagdms.com/

Brook inflow has been introduced approximately 30m downstream of where Yarnfield Lane crosses Yarnfield Brook. These are shown in Figure 2.

Downstream boundary

4.2.5 A normal depth boundary was used at the downstream extent of Filly and Yarnfield Brooks, and also in the floodplain at the downstream extent. This generates a stage-discharge curve based on the bed slope which varies across the floodplain.

4.2.6 A normal depth slope of 0.0078 m/m (1 in 128) was used within the Filly Brook channel and slopes of the floodplain. A slope of 0.0023 m/m (1 in 435) was used for the Yarnfield Brook downstream boundary. These were derived from LiDAR.

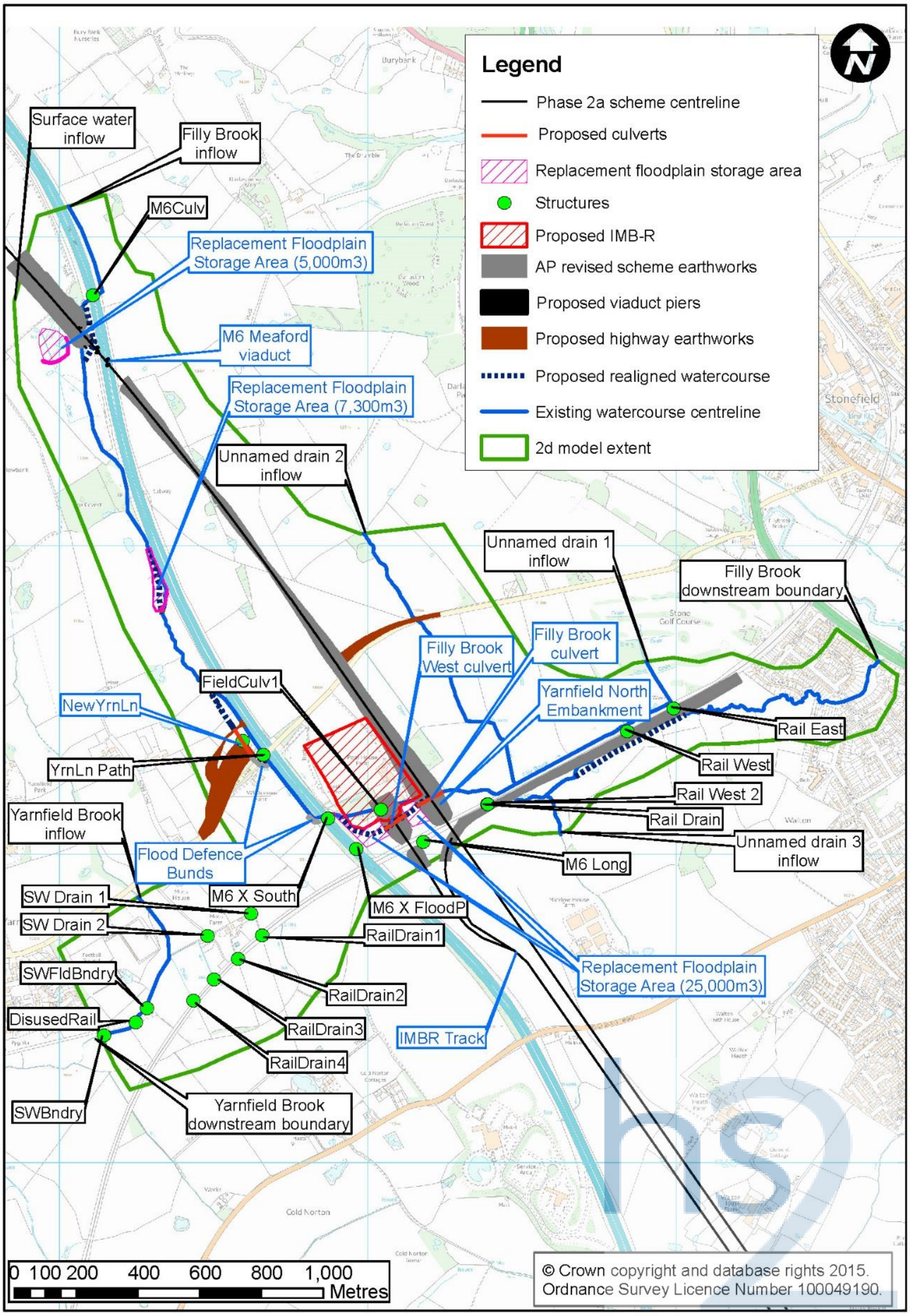
Key structures

4.2.7 There are a number of structures within the model extent that were modelled in a variety of ways. Additionally, there are a number of structures which are not modelled as no information is available. Those included in the model and deemed to be key hydraulic controls are detailed in Table 2. All structures, including key hydraulic controls, are shown in Figure 2.

Table 2: Key structures present within the modelled extent of Filly Brook

Structure reference	Structure description	Modelling representation and justification
M6 X South	M6 Crossing adjacent to Pool House Farm. 82.0m (L) x 2.2m (W) x 1.5m (H)	ESTRY rectangular culvert – dimensions taken from HA GDMS.
Rail East	Norton Bridge to Stone Railway crossing approx. 250m from the northern downstream extent. 20.0m (L) x 1.68m (W) x 1.5m (H)	ESTRY rectangular culvert – dimensions from Network Rail 5-mile diagram.
M6Culv	M6 crossing at upstream extent of model. 62.48m (L) x 0.525m (D)	ESTRY circular culvert – dimensions taken from HA GDMS.

Figure 2: Existing and proposed model extents



Roughness

4.2.8 Roughness values utilised are in line with the recommended values stated within Chow, 1959[6].

4.2.9 The 2D domain roughness values have been informed by the land use classifications within the current Ordnance Survey (OS) Mastermap data together with information derived from aerial and site visit photography for specific features.

4.2.10 In some locations the OS Mastermap data has been modified to suit the cell size of the hydraulic model, to ensure that key features such as woodland, roads and the channel itself are represented.

4.3 Hydraulic model build – AP revised scheme

4.3.1 The AP revised scheme model has been edited from the baseline to include the following:

Viaduct piers

4.3.2 The proposed M6 Meaford viaduct spans approximately 174m and would be supported by two piers west of the M6, spaced approximately 35-52m apart. Two piers will be south of the motorway however they would not be within the modelled floodplain and have not been represented. There have been no amendments to the M6 Meaford viaduct.

4.3.3 A deactivated code layer was used to represent the piers at the proposed M6 Meaford viaduct. The modelled dimensions of each pier constitute a deactivated area of the model of $12m^2$ per pier, for a pier size of 6m x 2m ($12m^2$).

Topographic changes

4.3.4 The AP revised scheme embankments (Yarnfield North and Meaford North and South), the Stone IMB-R, the realignment of Yarnfield Lane and its associated access path, as well as the flood bunds designed to alleviate flooding, in the AP revised scheme have been included using the relevant heights for embankment crest and road alignment.

4.3.5 All the topographic changes noted are based on the design as shown in SES and AP ES Volume 2 Maps: CT-06-222, CT-06-222-R1, CT-06-223 and CT-06-223-L1.

4.3.6 The OS Mastermap layer was modified to correctly represent any changes to the roughness and planting associated with the AP revised scheme.

---

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

Flood bunds

4.3.7 Two flood bunds have been introduced to alleviate the impacts of flooding on dwellings in the area caused by the Yarnfield Lane realignment and to stop the existing flow path along the Norton Bridge to Stone Railway, shown in Figure 1. This flow path would likely flood the original scheme reception tracks that are in cut to the south of the existing rail line. These comprise a small 0.3m bund at the downstream end of the proposed Yarnfield Lane culvert, to direct flow away from Whitemore Farm, with a further 1m bund added at the southern M6 crossing to direct flow through the M6 culvert. The latter will stop floodwater flowing south to join the Yarnfield Brook catchment and inundating Moss Farm and surrounding dwellings between Filly Brook and Yarnfield Brook. In addition, this will also stop flow propagating down the existing rail corridor.

Flood storage areas

4.3.8 Three new flood storage areas are proposed. These are designed to mitigate the impacts of floodplain encroachment, but also the downstream effects on Filly Brook of preventing floodwater from flowing south into the Yarnfield Brook catchment, as described above.

4.3.9 The first flood storage area is proposed upstream of the Yarnfield North Embankment, between the Stone IMB-R and the Norton Bridge to Stone Railway. The Filly Brook culvert will provide the hydraulic control. This flood storage area extends either side of the Filly Brook West Culvert on the IMB-R Embankment. Its creation results in controlled flooding of areas that are not inundated under existing conditions.

4.3.10 The second flood storage area is proposed upstream of Yarnfield Lane on the west side of the M6, where water is impounded within an excavated depression, behind a bund with a fixed culvert hydraulic control. This control comprises two 0.6m diameter pipes through the bund, one with its invert at bed level; the other at a higher level, in order to achieve an appropriate outlet hydraulic control.

4.3.11 The third storage area is on a tributary ditch adjacent to Meaford Viaduct, impounded behind a crescent shaped embankment during floods. The hydraulic control again comprises a fixed culvert. As this is already flooded during existing conditions it is not shown as replacement floodplain storage that is as a result of the AP revised scheme.

4.3.12 All storage areas will be designed with high level overflows to safely pass forward any design exceedance flows. The locations of the flood storage areas are shown on CT-06 Map Book design drawings.

Channel realignments and diversions

4.3.13 A channel realignment is required where the existing channel will be displaced by the Yarnfield Lane realignment and surrounding landscape mitigation embankments. This is also true at the proposed Meaford North embankment where the channel has been realigned to pass around the edge of the new embankment and to pass through the proposed flood storage area parallel to the M6. It is also assumed that an existing culvert approximately 90m south of Pool House Farm will be removed and replaced with an open channel. No diversions of the river channel have been proposed.

Production of flood extents

4.3.14 Flood extents have been derived using the direct output options now available in TUFLOW to produce ASCII output for the maximum depth and height. This has then been converted into a polygon, and cleaned to remove all bow ties (where two polygons overlap) as well as any dry islands less than 48m^2.

Modelling assumptions

4.3.15 Existing LiDAR is assumed to be correct as no other information is available.

4.3.16 Culvert sizes have been assumed in a number of places within the model. The exception to this is the M6 crossing where relevant information was sourced from Highways England. Where a site visit to provide photos or measurements was not possible, they have been approximated based on LiDAR information. This provided road levels and ground levels and the measured width of the top of structures from aerial photography.

4.3.17 Channel widths have been assumed based on LiDAR and site specific photos at crossing points. Channels have been defined on this basis in a number of locations.

4.4 Climate change

4.4.1 The climate change allowance used for Filly Brook is 50% based on the new climate change approach developed by the Environment Agency and published in February 2016.[7]

4.4.2 This climate change percentage considers the design life of the AP revised scheme (120 years), the River Basin District (Humber) and the receptors within the existing Flood Map for Planning (Essential Infrastructure). Due to the presence of more vulnerable receptors (National Planning Policy Framework Table 2[8]), the upper end value for the longest duration was chosen.

4.4.3 The new climate change guidance recommends consideration of the H++ scenario[9]. While these percentages have not been explicitly assessed, the sensitivity for the 20% increase in flow on the 1.0% AEP + CC event is assumed to be representative of an event greater than the H++ scenario.

[7] Environment Agency, *Flood risk assessments: climate change allowances*, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances
[8] Gov.uk, *Flood Zone and flood risk tables* https://www.gov.uk/guidance/flood-risk-and-coastal-change.
[9] Environment Agency, *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/571572/LIT_5707.pdf

5 Model results

5.1.1 The model has been run for the 50%, 20%, 5.0%, 1.33%, 1.0%, 1.0%+CC, 0.5% and 0.1% AEPs. The 1.0%+CC simulation is based on a 50% increase in flows.

5.1.2 The water level difference has been mapped for the 1.0%+CC and 5.0% AEPs. These flood maps are included in Appendix A.

5.1.3 All three flood storage areas are predicted to fill, fully inundating the areas set aside for flood storage shown on the drawings. The storage area upstream of the Yarnfield North Embankment fills to a maximum depth of 3m. The backwater effect extends upstream through Filly Brook West Culvert as far as the M6.

5.1.4 The proposals shut off the flow path southwest of Yarnfield Brook and prevent flooding of the Norton Bridge to Stone Railway southwest of the M6. HS2 infrastructure is also made safe from flooding.

5.1.5 A reduction in peak flood level of up to 270mm is predicted immediately upstream of the Filly Brook Norton Bridge to Stone Railway crossing. This beneficial impact reduces in magnitude downstream. A reduction in peak flood level of on average 30mm is predicted downstream of the Norton Bridge to Stone Railway.

5.1.6 The model predicts localised increases in peak flood level immediately downstream of the largest flood storage area, but these increases are confined to the channel.

6 Model proving

6.1 Introduction

6.1.1 This section of the report presents the analysis of the model undertaken to ensure confidence in the stability of the model build, its response to input values and consistency with previous modelling.

6.2 Run performance

6.2.1 Model output has been assessed across all open channel and model structures to assess model stability and overall model performance.

6.2.2 Final cumulative mass balance error is within +/-1.0% for all return periods and blockage and sensitivity cases simulated except for the 0.1%AEP which saw cumulative mass balance error of 3.0%. Attempts to rectify this resulted in further model instabilities. As the 0.1% AEP extent does not drive the design of the AP revised scheme, this has been deemed acceptable at this stage.

6.3 Calibration and validation

6.3.1 There is no gauge situated within an appropriate distance of this location to provide calibration or validation data.

6.3.2 There is no additional anecdotal evidence available for any effective model validation exercise.

6.4 Verification

6.4.1 Model outputs have been compared with other readily available flood risk data such as Environment Agency Flood Maps for Planning and uFMfSW.

6.4.2 Flood extents generated closely match the uFMfSW, however, they do not match the Environment Agency Flood Map for Planning as this does not take into account floodplain features such as the existing Norton Bridge to Stone Railway and the M6.

6.5 Sensitivity analysis

6.5.1 Sensitivity scenarios were undertaken as below:

- increase in flow by 20% (compared to 1.0%AEP+CC AP revised scheme);
- increase in roughness (channel, structures and floodplain) (Manning's n) by 20% (compared to 1.0%AEP+CC AP revised scheme);
- decrease in roughness (channel, structures and floodplain) (Manning's n) by 20% (compared to 1.0%AEP+CC AP revised scheme);
- increase in downstream boundary gradient by 20% (compared to 1.0%AEP+CC AP revised scheme); and

- decrease in downstream boundary gradient by 20% (compared to 1.0%AEP+CC AP revised scheme).

Roughness

6.5.2 The model is sensitive to increases in roughness, with a 20% increase resulting in increases in water level throughout the model with some locations showing levels greater than 100mm. The effect of this increase has greater impact between the M6 and the AP revised scheme and at the upstream of the proposed M6 Meaford viaduct.

6.5.3 Decreasing the roughness by 20% results in a decrease in peak water level throughout. The largest effect of the decrease in roughness is localised between the M6 and the AP revised scheme and shows a decrease in water levels up to approximately 300mm.

Inflows

6.5.4 An increase in inflow of 20% results in a maximum increase of greater than 100mm upstream of the proposed M6 Meaford viaduct and between the M6 and the AP revised scheme. Increases between 50mm and 100mm are observed at the downstream extent of the model and do not affect the AP revised scheme.

Downstream boundary

6.5.5 There was no impact in the vicinity of the AP revised scheme crossing when the downstream boundary was reduced and increased by 20%, with negligible impact of less than 40mm at the downstream boundary. No impact is seen greater than 10m from the downstream extent.

Summary

6.5.6 The sensitivity analysis shows the model is moderately sensitive to changes in flows and roughness values along the AP revised scheme. The changes in the downstream boundary gradient have no impact at the AP revised scheme with minimal impact observed at the downstream boundary of the model.

6.5.7 Sensitivity tests conclude that the current proposed design ensures a freeboard of a minimum of 0.6m to the viaduct soffit in a 1.0%AEP+CC (50%) event for all scenarios.

6.6 Blockage analysis

6.6.1 Two blockage scenarios were assessed, considering:

- blockage scenario 1 – 50% blockage of the proposed Filly Brook West culvert under the IMB-R Embankment; and
- blockage scenario 2 – 50% blockage of the proposed Filly Brook culvert under the Yarnfield North Embankment.

6.6.2 These blockage scenario results were compared to the 0.1%AEP results for the AP revised scheme model.

6.6.3 The blockage of both culverts was represented by reducing their diameters by 50%.

6.6.4 The results of blockage scenario 1 indicate that local to the blockage, between the IMB-R Embankment and the M6, increases in flood depth up to 75mm would be observed. Conversely, a decrease in flood depth of 260mm is seen in the flood compensation area between the Yarnfield North and IMB-R embankments with further decreases in depth continuing downstream. This blockage also causes flow to back up through the M6 culvert and reactivate the overland flow path to the south observed in the baseline scenario. However, unlike the baseline scenario, this didn't activate the flow path along the Norton Bridge to Stone Railway.

6.6.5 While this does increase flooding at the AP revised scheme, blockage scenario 1 concludes that this design still ensures a freeboard of a minimum of 1m to the rail track in a 0.1% AEP event.

6.6.6 The results of blockage scenario 2 indicate that increases in flood depths are observed both between the Yarnfield North and IMB-R embankments and between the IMB-R Embankment and the M6. The former sees increases of up to 240mm while in the latter, increases of up to 215mm are observed. Like blockage scenario 1, this blockage also causes flow to back up through the M6 culvert and reactivate the overland flow path to the south. However, on this occasion the Norton Bridge to Stone Railway was also flooded both from the south and now from the flood compensation area between the Yarnfield North and IMB-R embankments. This causes the proposed IMB-R reception sidings, located next to the Norton Bridge to Stone Railway and in cutting, to become inundated.

6.6.7 Blockage scenario 2 concludes that this design ensures a freeboard of a minimum of 1m to the rail track in a 0.1% AEP event. However, this highlights the need for a culvert maintenance regime and/or strengthening of the Network rail embankments to ensure the integrity of the proposed reception siding.

6.7 Run parameters

6.7.1 There is no deviation from default run parameters for all model runs.

6.7.2 The time step parameters used were 0.5 seconds for ESTRY and 1 second for the 2D model. This is the suggested approach for a grid size of 2m.

7 Limitations

7.1.1 Land access for new topographic survey was not possible and therefore all channels have been represented in 2D, meaning channel conveyance will not be fully represented in the model. This reduced level of detail surrounding channel conveyance capacity could potentially result in an over-prediction of the level of flood risk.

7.1.2 No channel survey data was available for the watercourse and the model has been developed based on the LiDAR provided.

7.1.3 Onsite observations have been used to reduce the number of assumptions. Culvert dimensions have been estimated based upon ground levels (and watercourse size (from LiDAR), which may impact flood extent and level predictions if these were to change.The small catchment west of the M6 and south of the Norton Bridge to Stone Railway has not been included in the hydrological analysis of this model. Due to the small size of this catchment it is not believed this will have a significant impact on the design.

7.1.4 In both baseline and proposed scenarios, channels that are not clearly defined in the LiDAR have been “carved out" using appropriate modelling methods. Due to instabilities in the model, the width of these channels had to be set to 4m.

7.1.5 Calibration has not been possible due to a lack of available data.

8 Conclusions and recommendations

8.1.1 The aim of developing a hydraulic model of Filly Brook to simulate the baseline and AP revised scheme scenarios and to determine the peak water levels and flows throughout the catchment has been met. The water level impacts are detailed for a range of AEP and flood maps provided in Appendix A.

8.1.2 The proposals shut off the flow path southwest to Yarnfield Brook and prevent flooding of an extensive area to the north and south of the Norton Bridge to Stone Railway, southwest of the M6. HS2 infrastructure is also made safe from flooding.

8.1.3 The flood maps indicate a localised increased in peak flood level immediately downstream of the largest flood storage area, but these increases are largely confined to the channel. The flows and levels at this location are a direct reflection of the configuration of the hydraulic control (Filly Brook Culvert) and the prescribed pass forward flow, which will be refined at the detailed design stage.

8.1.4 The modelling outputs identify a reduction in peak flood level of up to 270mm immediately upstream of the Filly Brook Norton Bridge to Stone Railway crossing at Stone. This beneficial impact reduces in magnitude downstream. A reduction in peak flood level of on average 30mm is predicted through Stone.

8.1.5 Blockage and sensitivity analyses have demonstrated that changes in key variables such as roughness, model inflows and downstream boundary location and gradient result in modelled water levels that remain below freeboard requirements.

8.1.6 At detailed design stage, the hydraulic modelling of the watercourse should be revisited. Topographic survey data of the channel and associated structures should be collected and if preliminary results deem it necessary, this model should then be converted into a linked 1D-2D model. This will provide better representation of the channel conveyance processes and refine the model outputs.

8.1.7 Detailed design of this facility should also consider how use of the available storage can be optimised, which will include refining the design of the hydraulic control and pass forward flow, in consultation with the Environment Agency and those updating the Water Framework Directive compliance assessment.

9 References

Chow, V.T (1959), *Open-channel hydraulics*, McGraw-Hill, New York.

Environment Agency, *Flood risk assessments: climate change allowances*. Available online at: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances.

Environment Agency, *Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities*. Available online at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/571572/LIT_5707.pdf.

Gov.uk, *Flood map for planning*. Available online at: https://flood-map-for-planning.service.gov.uk.

Gov.uk, *Flood Zone and flood risk tables*. Available online at https://www.gov.uk/guidance/flood-risk-and-coastal-change.

Gov.uk, *Long term flood risk information*. Available online at: https://flood-warning-information.service.gov.uk/long-term-flood-risk/map?map=SurfaceWater.

Highways England, *Geotechnical Data Management System v5.12.0*. Available online at: http://www.hagdms.com/.

HS2 Ltd (2017), *High Speed Rail (West Midlands-Crewe) Environmental Statement, Background Information and Data, CA3: Stone and Swynnerton Hydraulic modelling report – Filly Brook (BID-WR-004-007)*. Available online at: www.gov.uk/hs2.

HS2 Ltd (2017), *High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)*. Available online at: https://www.gov.uk/government/collections/hs2-phase-2a-environmental-statement.

Appendix A: Flood level impact maps

1.1.1 The water level difference has been mapped for 5.0%AEP and 1.0%+CC AEP as described in Section 5, see Figure A-1 and Figure A-2.

Figure A-1: Filly Brook at Yarnfield Impact Map for 5% AEP (1 in 20 year)

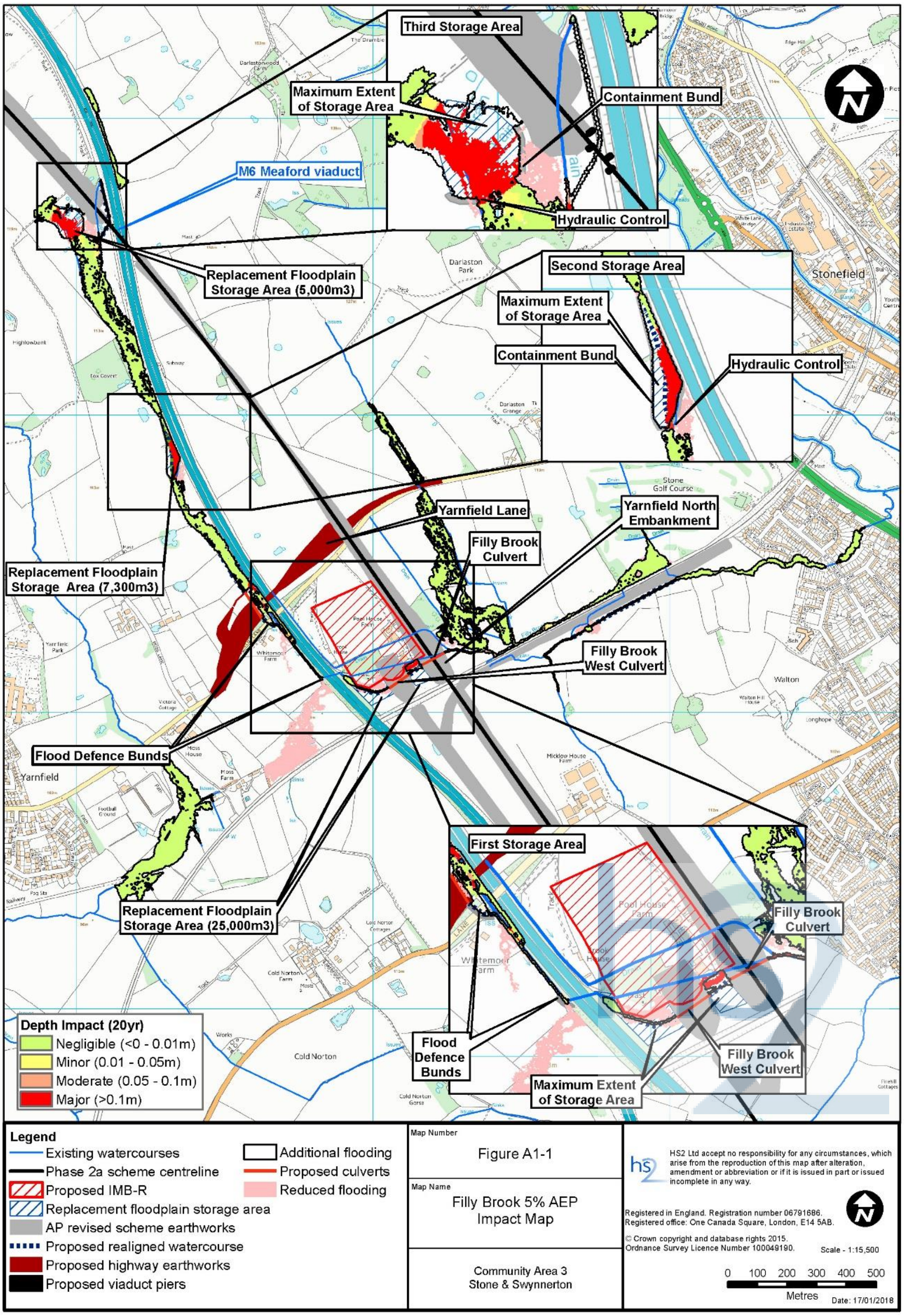
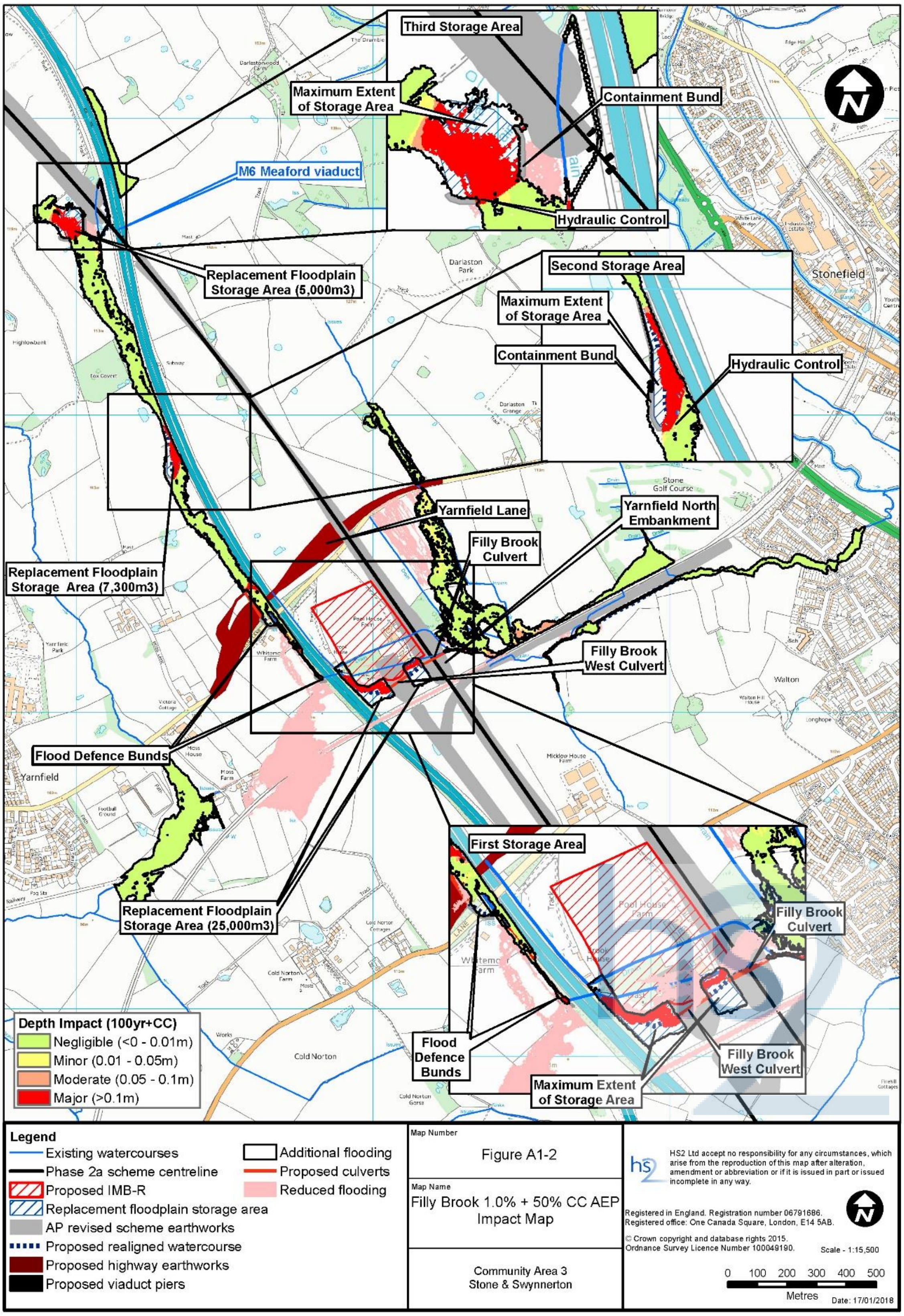


Figure A-2: Filly Brook at Yarnfield Impact Map for 1% AEP + CC (1 in 100 year) plus 50% climate change allowance



High Speed Two (HS2) Limited
Two Snowhill
Snow Hill Queensway
Birmingham B4 6GA

08081 434 434
HS2Enquiries@hs2.org.uk