E99

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

Background Information and Data

CA1: Fradley to Colton

Hydraulic modelling report - Moreton Brook (BID-WR-004-003)

July 2017

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Department for Transport

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Introduction

1.1 Background

1.1.1 This document presents the results of the hydraulic modelling carried out in the Fradley to Colton area (CA1) relevant to High Speed Rail (West Midlands - Crewe). The following hydraulic modelling reports are also relevant to the Fradley to Colton area:

- Hydraulic modelling report - Pyford Brook (Background Information and Data 004: BID-WR-004-001);
- Hydraulic modelling report - River Trent and Bourne Brook (Background Information and Data 004: BID-WR-004-002); and
- Hydraulic modelling report - Stockwell Heath (Background Information and Data 004: BID-WR-004-004).

1.1.2 The water resources and flood risk assessment is detailed in the High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)[1]. Volumes 2, 3 and 4 discuss water resource and flood risk effects and Volume 5, Appendices sets out the following relevant to the Fradley to Colton area:

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

1.2 Aims

1.2.1 The Proposed Scheme includes a number of locations where the route will cross watercourses and their floodplains. The Proposed Scheme crossing locations have the 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 Moreton Brook on the proposed Moreton Brook viaduct.

1.2.3 A hydraulic model of Moreton Brook was created to simulate the risk of flooding in this location for an approximate 1.5km stretch of the brook, also incorporating an unnamed drain downstream. This report documents the methods used and discusses the results, assumptions and limitations imposed by them.

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[1] HS2 Ltd (2017), *High Speed Rail (West Midlands - Crewe) Environmental Statement (ES)*, www.gov.uk/hs2

1.2.4 Hydraulic models of the existing conditions and with the Proposed Scheme included have been evaluated to assess the impact of the Proposed 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 Proposed 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 Proposed 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 Proposed Scheme, based on the most suitable data available and flow hydrographs developed; and
- analyse the impact of the Proposed 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 provide an awareness of existing flood risk to inform the Proposed Scheme design. The detail included identifies potential impacts of the Proposed Scheme on surrounding land, and to ensure that 0.6m freeboard to soffit is provided in a 1.0% + CC AEP event and 1.0m freeboard to track level is provided in a 0.1%AEP event.

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 solver within Two-dimensional Unsteady FLOW (TUFLOW).

1.4.3 Due to the Proposed Scheme crossing the floodplain on a viaduct, and thus causing a high level of risk for the design of the project and its impact on the environment, it was proposed that hydrological calculations be undertaken to a full level of detail. This considered Flood Estimation Handbook (FEH) Statistical, Revitalised Flood Hydrograph 2 (ReFH2) and the hybrid methods. This is particularly relevant in this location where both abutments are driven by flood risk.

1.5 Scope

1.5.1 The scope of the study is to undertake hydraulic modelling to enable an assessment to be made of the impact of the Proposed Scheme on the local environment. 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 Moreton Brook being modelled is located at Hamley Heath. Figure 1 shows the modelled extent, with the model upstream boundary situated approximately 580m east of Moreton Farm and the downstream boundary located approximately 330m upstream of Moreton Lane. Approximately 1.5km of Moreton Brook watercourse and the unnamed drain has been modelled.

2.1.2 Within the study area, there are very few flood risk receptors. Jongham's Cottage is located approximately 90m south-east of the upstream extent of the unnamed drain towards the downstream extent of the model. A boating lake is located next to the cottage. There are no significant water bodies in the area and no structures cross Moreton Brook within this extent. A small lane crosses the unnamed drain.

2.1.3 The catchment size at the downstream model extent is 12.6km² and ungauged. The proposed Moreton Brook viaduct is located approximately 4.3km upstream of the confluence with the River Trent and it is, therefore, assumed that the Trent will have no impact on peak flood level at Moreton Brook in this location.

Hydrological description

2.1.4 Moreton Brook originates north-east of the small village of Drointon, approximately 2.5km north-west of Blithfield Reservoir.

2.1.5 The catchment area contributing to the downstream boundary of the proposed hydraulic model is 13.3km^2 and is predominantly rural.

2.1.6 There are no gauging stations present within the Moreton Brook catchment.

2.1.7 Standard annual average rainfall for the catchment at the model downstream boundary is 721mm.

Railway alignment

2.1.8 The route of the Proposed Scheme crosses the study area from the south-east before crossing over Moreton Brook, at Hamley Heath, heading north-west towards Great Haywood. Further detail on the Proposed Scheme can be found in Map CT-06-209 in the Volume 2 Map Book.

Flood mechanisms

2.1.9 There is a narrow flow path under the proposed Moreton Brook viaduct situated towards Moreton North embankment.

2.1.10 At the model inflow location, the left bank is slightly perched.

2.2 Existing understanding of flood risk

Sources of information

2.2.1 Sources of Environment Agency data were assessed as below:

- Flood Map for Planning (Rivers and Sea)[2]; and
- updated Flood Map for Surface Water (uFMfSW)[3].

2.2.2 The proposed Moreton Brook viaduct spans Flood Zones 2 (0.1%AEP) and 3 (1.0%AEP) of the Environment Agency Flood Map for Planning and uFMfSW (0.1%AEP) as shown in Figure 1.

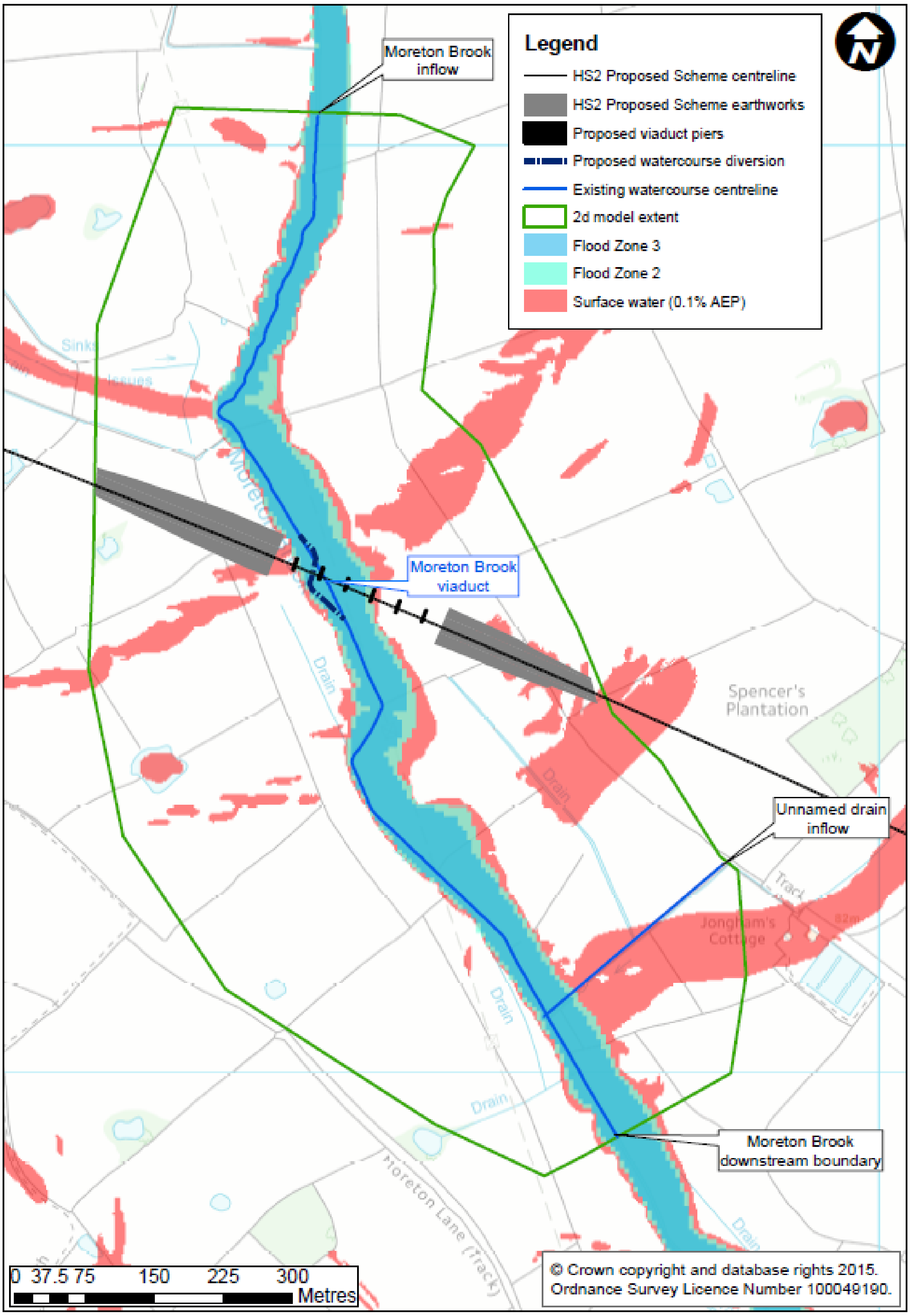
2.2.3 The uFMfSW shows that the main flow paths are confined largely to the channel with an overland flow path joining Moreton Brook at the downstream extent.

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 believed to be derived by National Generalised Modelling.

[2] Gov.uk, *Flood map for planning*, https://flood-map-for-planning.service.gov.uk
[3] 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 Moreton Brook



2.3 Availability of existing hydraulic models

2.3.1 There were no existing models for Moreton Brook identified for this study.

2.4 Site visit

2.4.1 A site visit was undertaken in October 2016 to determine the dimensions of the channel and any existing infrastructure.

2.4.2 There are no structures present within the modelled extent and small drains joined the main channel along the extent. The only structure identified on the site visit was a wide deck bridge located downstream of the model extent. No images were taken of the channel around the proposed viaduct location.

2.4.3 A section of Moreton Brook was visited at the downstream extent of the modelled area along a reach of approximately 150m; approximately 1.06km downstream of the Proposed Scheme. Photographs were taken along this stretch. The remaining channel was inaccessible during the site visit. Photographs can be seen in Figure 2.

2.4.4 The images taken were used for identifying the channel width and vegetation density. The channel roughness was verified within the model according to the photos provided.

2.4.5 Moreton Brook channel appeared to be approximately 1.5m wide throughout, with a depth of approximately 0.4m throughout the modelled extent. There are also debris dams along the channel extent.

Figure 2: Images of Moreton Brook taken approximately 200m, approximately 1.05km and approximately 1.2km upstream of the downstream model boundary

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 as there was no survey data available for the watercourse extent. Additionally, as there were no structures present, a 1D approach was deemed inappropriate. Using 2D allows more confidence in the flood extent under the proposed Moreton Brook viaduct which is important in this area as it defines the abutment positions and viaduct width.

3.1.3 The upstream extent of the model was limited due to LiDAR availability.

3.2 Software

3.2.1 TUFLOW (2016-AA) has been used. This methodology is in line with standard practice to use the latest available build at the time modelling commenced, while TUFLOW is industry standard software.

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 study area was produced using 200mm LiDAR flown specifically for HS2 Ltd and covers 500m either side of the route centreline.

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 FEH methodologies were followed, in particular the Statistical Method. No gauged flows were available in the catchment, 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 the 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 this instance, the ReFH2 method was adopted.

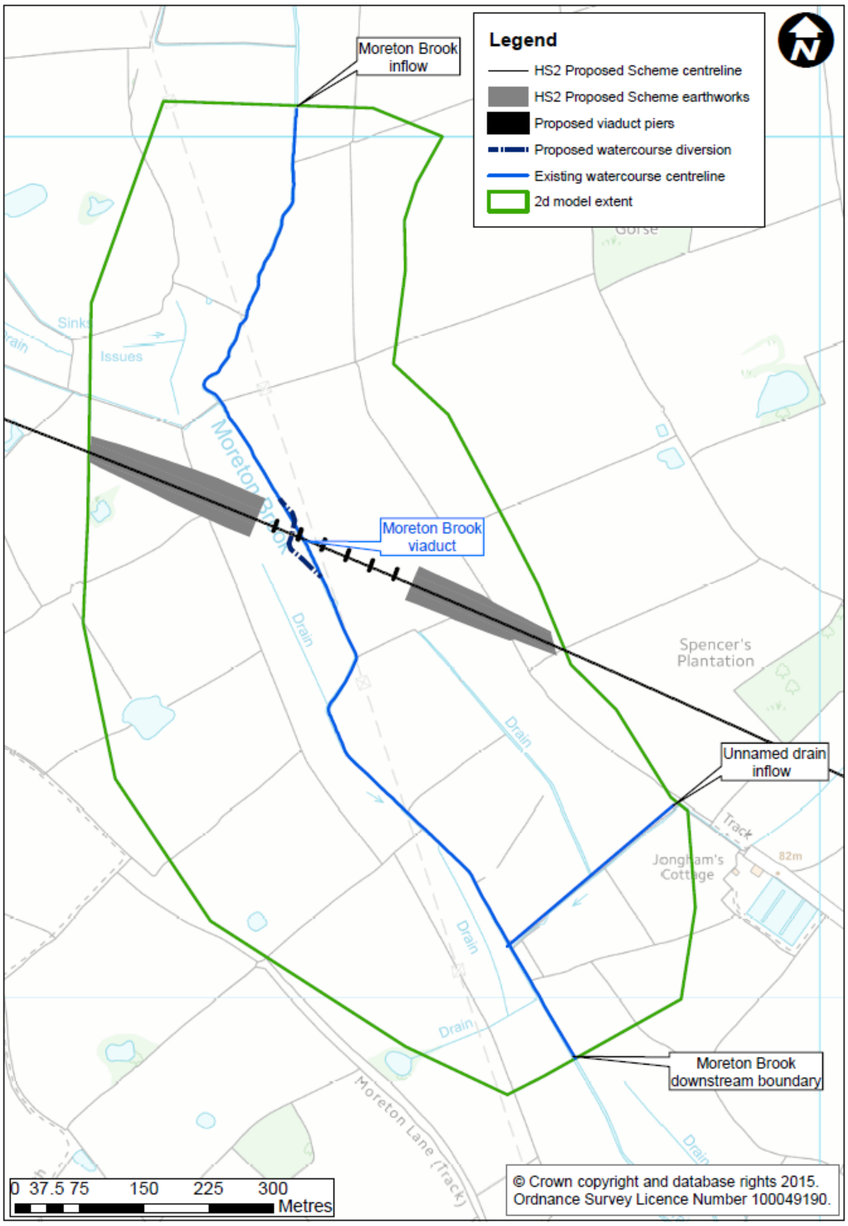
4.1.5 The design hydrographs used for the hydraulic modelling stage were generated using ReFH2 as the FEH Statistical Method does not produce time series, just peak flows. The values were scaled so the peak flow for each return period matched that selected as the design value.

4.1.6 Table 1 shows the peak flows used for the computational hydraulic modelling work. Figure 3 highlights the inflow locations and the associated river networks assessed as part of this study.

Table 1: Peak flows used for hydraulic analysis

	AEP	Return period	Site code	
			Moreton Brook inflow	**Unnamed drain inflow**
Flood peak (m^3/s)	50%	2yr	4.66	0.41
	20%	5yr	6.42	0.58
	5.0%	20yr	9.48	0.87
	1.33%	75yr	13.6	1.26
	1.0%	100yr	14.67	1.36
	1.0% + CC	100yr + CC	19.07	1.77
	0.5%	200yr	17.51	1.63
	0.1%	1000yr	24.99	2.34

Figure 3: Schematic of inflows and modelled river network



4.2 Hydraulic model build - baseline model

1D representation

4.2.1 As there are no structures within this model there are no 1D model elements.

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 Proposed Scheme piers.

4.2.3 Channel sections have been modified in the 2D as the LiDAR used did not adequately pick up the features of the existing channel. The observations from the site visit were used to provide a more accurate representation of the channel as the LiDAR represents a channel width of approximately 4m throughout.

Inflow boundaries

4.2.4 The study area has two inflows. The main inflow, Moreton Brook, is located at the upstream extent of the model area and the second inflow meets the main channel approximately 145m upstream of the downstream extent. The second inflow is an unnamed drain. There is a small drain just south of the Proposed Scheme that has not been included in the model. These are shown in Figure 3.

Downstream boundary

4.2.5 A normal depth boundary was used at the downstream cross-section of Moreton Brook, 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 0.0026 m/m (1 in 385) is used within the channel and slopes of 0.0037 m/m (1 in 270) and 0.0043 m/m (1 in 233) for the floodplain. These were derived from LiDAR.

Key structures

4.2.7 No structures are present within the modelled baseline extents.

Roughness

4.2.8 Roughness values utilised are in line with the recommended values stated within Chow, 1959[4].

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 – Proposed Scheme

4.3.1 The Proposed Scheme model has been edited from the baseline to include the following:

Viaduct piers

4.3.2 The proposed Moreton Brook viaduct spans approximately 195m and will be supported by six piers, spaced approximately 22.5-30m apart.

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

4.3.3 A deactivated code layer was used to represent the piers. The modelled dimensions of each pier constitute a deactivated area of the model of $28m^2$ per pier, for a pier size of 14.5m x 2m ($29m^2$).

Topographic changes

4.3.4 The Proposed Scheme embankments (Moreton South embankment and Moreton North embankment) have been included using the relevant heights for embankment crest. The footprints of these embankments are based on design as shown in Map CT-06-209 in the Volume 2 Map Book.

4.3.5 The Moreton North embankment is located in the modelled flood zones for baseline conditions at its southern extent.

4.3.6 The OS Mastermap layer was modified to correctly represent any changes to the roughness and planting associated with the Proposed Scheme.

Replacement floodplain storage areas

4.3.7 Although there are only localised changes between baseline and post-development, provision for replacement floodplain storage has been made based on the 1.0% + CC AEP levels, on a level for level, volume for volume basis. This has not been included within the hydraulic modelling.

Channel realignments and diversions

4.3.8 A channel realignment is required directly underneath the proposed Moreton Brook viaduct as a viaduct pier is proposed within the existing channel. The existing channel was filled in to top of bank level and the OS Mastermap updated to reflect the surrounding land use. No diversions of the river channel have been proposed. The realignment of Moreton Brook was included in the hydraulic model.

Production of flood extents

4.3.9 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 – and any dry islands less than $48m^2$.

Modelling assumptions made

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

4.3.11 The upstream boundary location is located close to the Proposed Scheme due to limited LiDAR. Consequently, no attenuation has been accounted for in the catchment upstream.

4.4 Climate Change

4.4.1 The climate change allowance for Moreton Brook is 30% which is not in line with the new climate change approach developed by the Environment Agency and published in February 2016[5].

4.4.2 The new climate change approach considers the design life of the Proposed Scheme (120 years), the River Basin District (Humber) and the receptors within the existing Flood Map for Planning. Due to the presence of more vulnerable receptors (National Planning Policy Framework (National Planning Policy Framework Table 2[6]), the upper end value for the longest duration would result in 20% increase for climate change.

4.4.3 As the new climate change percentage (20%) is lower than previously advised HS2 guidance (30%) for this scenario, the most conservative percentage has been utilised.

4.4.4 The new climate change guidance recommends consideration of the H++ scenario[7]. While these percentages have not been explicitly assessed, the sensitivity for the 20% increase in flow on the 1.0% + CC AEP event is assumed to be representative of an event greater than the H++ scenario.

[5] Environment Agency, *Flood risk assessments: climate change allowances*, https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances
[6] Gov.uk, *Flood Zone and flood risk tables*, https://www.gov.uk/guidance/flood-risk-and-coastal-change#flood-zone-and-flood-risk-tables
[7] 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 30% increase in flows.

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

5.1.3 In all return periods modelled, impacts are observed around the proposed Moreton Brook viaduct with average changes in flood level of between 10-50mm and very localised impacts of 50-100mm. The localised change is associated with the realigned channel. There is a minor change to the flood extent as Moreton North embankment cuts off a flow path.

5.1.4 Model results conclude that the current proposed design ensures a freeboard of a minimum of 1m to the rail track in a 0.1%AEP event and a minimum of 0.6m to the viaduct soffit in a 1.0%AEP + CC (30%) event for all scenarios.

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.

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.

6.4.2 Flood extents generated for this study follow the Environment Agency Flood Maps for Planning but the extents modelled herein span a wider area of the floodplain.

6.5 Sensitivity analysis

6.5.1 Sensitivity scenarios were undertaken as below:

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

Roughness

6.5.2 The model is sensitive to increases in roughness with a 20% increaseresulting in increases in water level between 10-50mm throughout the modelled extent with a small area of 50-100mm near the downstream boundary at the confluence of the unnamed drain with Moreton Brook. A negligible change to flood extent is observed.

6.5.3 Decreasing the roughness by 20% results in a general decrease in peak water level throughout the model with a maximum, very localised, increase of 10mm at the unnamed drain. A negligible decrease in the flood extent is observed.

Inflows

6.5.4 An increase in inflow of 20% results in a general impact of between 10-50mm throughout the modelled extent and at the viaduct, with patches of water in the flood plain increasing up to 100mm. A negligible change to flood extent is visible.

Downstream boundary

6.5.5 There was no impact at the Proposed Scheme crossing when the downstream boundary was reduced and increased by 20%, with negligible impact of below 50mm observed at the downstream boundary. No impact is seen greater than 40m from the Moreton Brook downstream extent.

Summary

6.5.6 The sensitivity analysis shows the model is moderately sensitive to changes in flows and roughness values at the proposed Moreton Brook viaduct. The changes in the downstream boundary gradient had no impact at the proposed Moreton Brook viaduct with negligible impact 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 (30%) event for all scenarios.

6.6 Blockage analysis

6.6.1 One blockage scenario was assessed which modelled a 2% blockage at the proposed Moreton Brook viaduct.

6.6.2 This blockage scenario result was compared to the 0.1% AEP results for the Proposed Scheme model.

6.6.3 The viaduct blockage of 2% was represented for the proposed Moreton Brook viaduct by expanding the size of the pier standing nearest to the main channel by 2% of the length of the viaduct.

6.6.4 The results of the blockage scenario show impacts of between 0-10mm in the vicinity of the viaduct and a small area behind the blocked pier with an impact between 10-50mm.

6.6.5 Blockage tests conclude that the current proposed design ensures a freeboard of a minimum of 1m to the rail track in a 0.1%AEP event for all scenarios.

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 was 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. Therefore all channels have been represented in 2D, meaning channel conveyance will not be fully represented in the model; however, this will lead to a conservative estimation of flood risk for the purposes of the Environmental Impact Assessment. Onsite observations have been used to reduce the number of assumptions.

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

7.1.3 The extent of the model is slightly limited upstream due to LiDAR availability. LiDAR was unavailable at the upstream extent of Moreton Brook. Only 5m LiDAR was available in this area but it was unsuitable due to its poor accuracy.

7.1.4 Due to lack of topographic survey, LiDAR has been utilised to inform the size of the existing channel and consequently the size of the proposed channel realignment.

7.1.5 Calibration has not been able to be carried out due to a lack of available data.

8 Conclusions and recommendations

8.1.1 The aim of developing a hydraulic model of Moreton Brook to simulate the baseline and Proposed Scheme scenarios and to determine the peak water levels and flows throughout the catchment has been met.

8.1.2 Increases in water level caused by the Proposed Scheme are around 10-80mm over a localised area close to the viaduct.

8.1.3 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 the critical freeboard requirements.

8.1.4 At detailed design stage, the hydraulic modelling of the watercourse should be revisited. Topographic survey data of the channel 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, allowing the model to be used to confirm flood risk from the Phase 2a scheme and test any necessary flood risk mitigation measures within the model following the channel realignment.

9 References

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

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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 Figures A-1 and A-2.

Figure A-1: Moreton Brook at Hamley Heath Impact Map for 5%AEP (1 in 20 year)

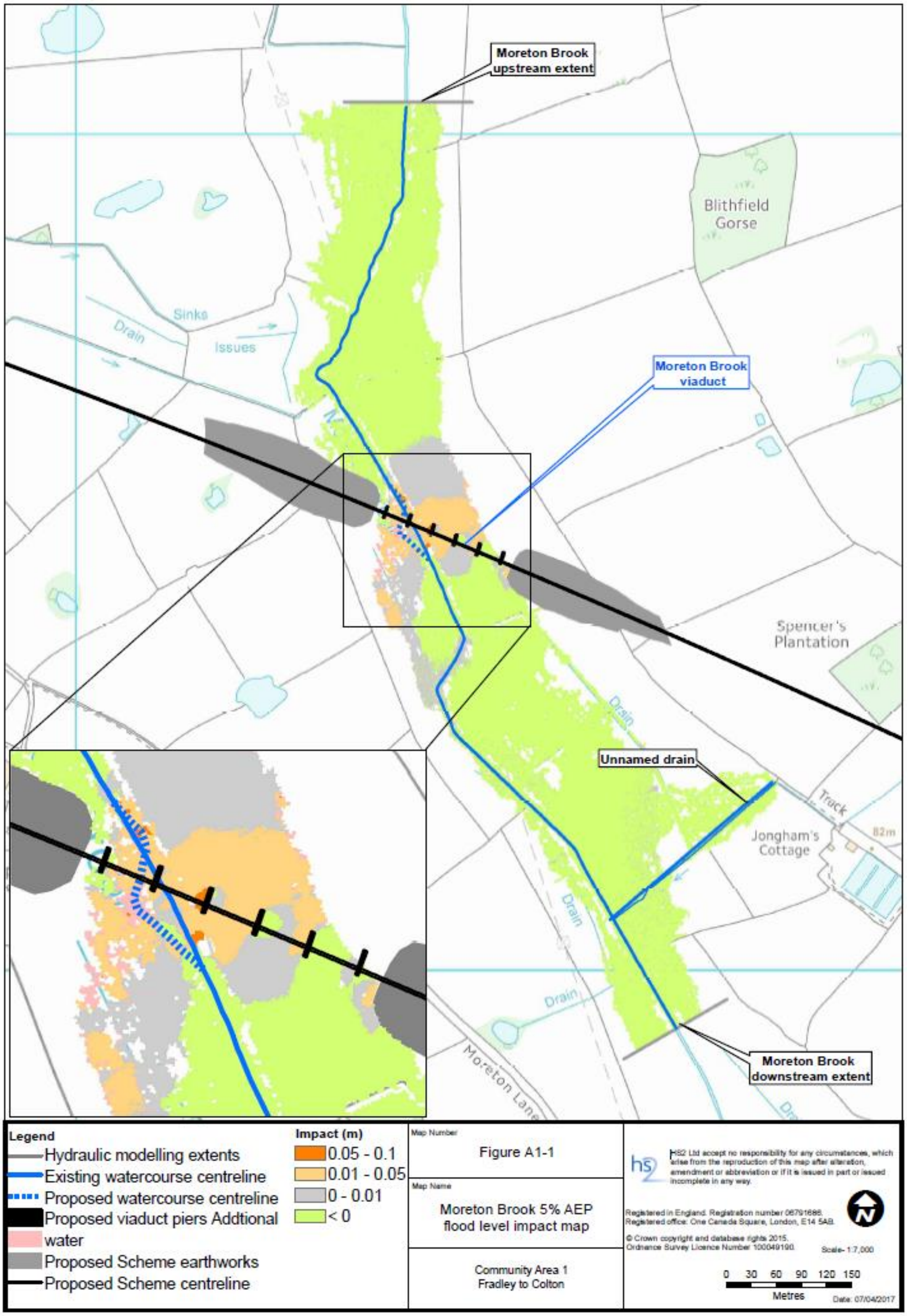
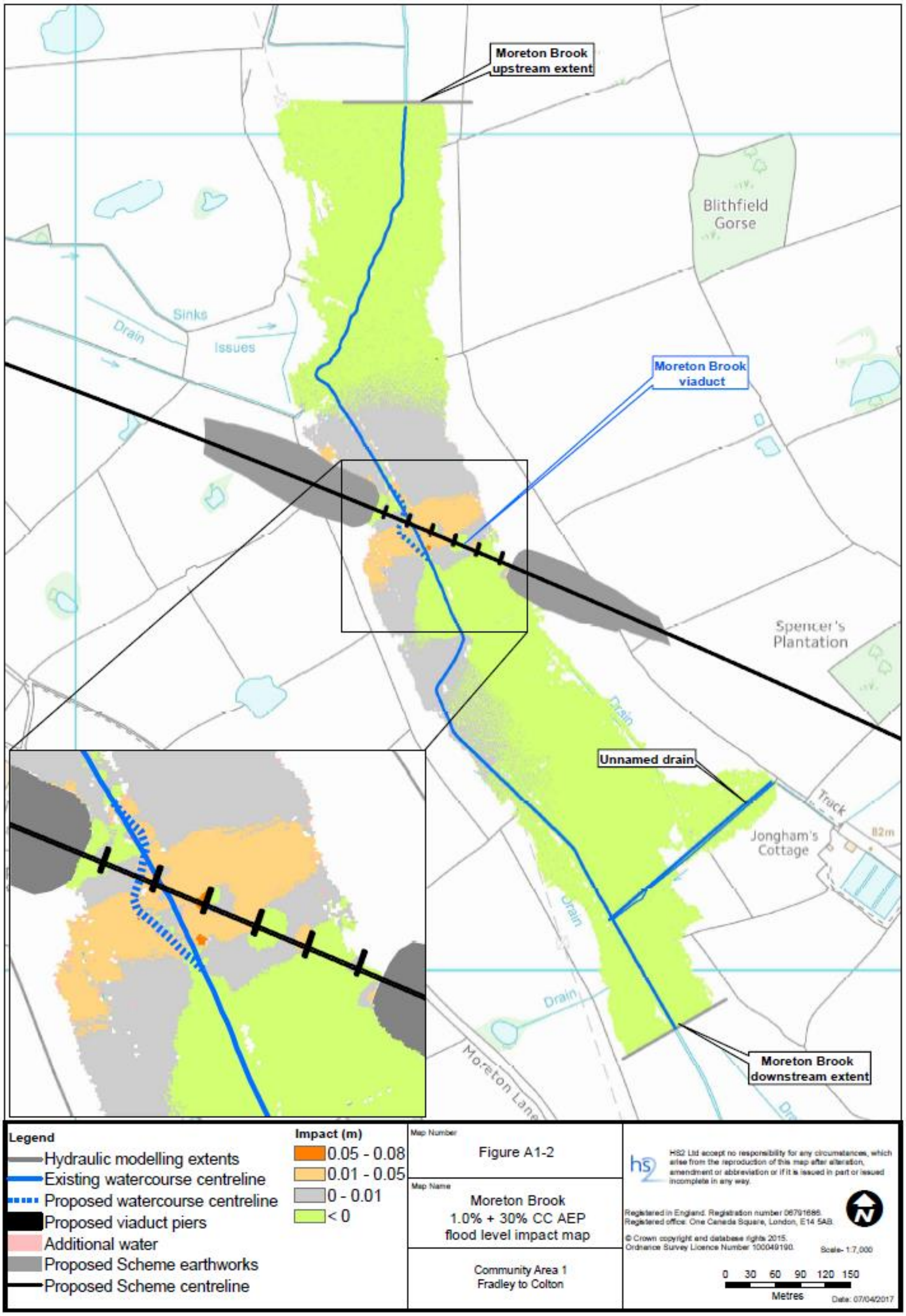


Figure A-2: Moreton Brook at Hamley Heath Impact Map for 1%AEP + CC (1 in 100 year) plus 30% climate change allowance



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