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

Background Information and Data

CA4: Whitmore Heath to Madeley

Hydraulic modelling report - River Lea (BID-WR-004-009)

July 2017

BID

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1 Introduction

1.1 Background

1.1.1 This document presents the results of the hydraulic modelling carried out in the Whitmore Heath to Madeley area (CA4) relevant to High Speed Rail (West Midlands - Crewe). The following hydraulic modelling reports are also relevant to the Whitmore Heath and Madeley area:

- Hydraulic modelling report – Meece Brook (Background Information and Data 004: BID-WR-004-008); and
- Hydraulic modelling report - Checkley Brook (Background Information and Data 004: BID-WR-004-010).

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 Whitmore Heath to Madeley area:

- a route-wide Water Framework Directive compliance assessment (Volume 5: Appendix WR-001-000);
- a water resources assessment (Volume 5: WR-002-004);
- a flood risk assessment (Volume 5: WR-003-004); 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 the River Lea on the proposed River Lea viaduct.

1.2.3 A hydraulic model of the River Lea was created to simulate the risk of flooding in this location for an approximate 2.4km stretch of the river. 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 Proposed Scheme included have been evaluated to assess the impact of the Proposed Scheme on

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

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 should 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 as both abutments are located within the modelled floodplain.

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 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 the River Lea being modelled is located near Madeley. Figure 1 shows the modelled extent, with the model upstream boundary situated approximately 80m east of Manor Road and the downstream boundary located approximately 170m south of Vicarage Lane. Approximately 2.4km of the River Lea has been modelled.

2.1.2 Within the study area, there are several major receptors. The River Lea passes underneath the West Coast Main Line (WCML) and Madeley Chord. One of the drains to the south-east also passes under the WCML and also flows under the out-of-use Stoke to Market Drayton Railway (also known as the Silverdale Line of the Stoke to Market Drayton Railway). Hey House is a listed building that is located approximately 750m to the north-west from the further upstream culvert on the River Lea. There are no significant water bodies identified in the area.

Hydrological description

2.1.3 The River Lea originates in the hills to the south-east of Onneley, Staffordshire and flows east towards the Proposed Scheme. The Proposed Scheme also crosses the River Lea beneath the Checkley Brook viaduct further downstream.

2.1.4 The catchment area contributing to the downstream boundary of proposed hydraulic model is 14.4km^2 and is predominantly rural.

2.1.5 There are no gauging stations present at the locations for which flow estimates are required. No local gauging stations are therefore available for use as potential donor sites.

2.1.6 Standard Annual Average Rainfall for the catchment at the proposed River Lea viaduct is 771mm.

Railway alignment

2.1.7 The route of the Proposed Scheme crosses the study area from south-east to north-west. The route will be in a north-west direction passing Whitmore Wood on the Lea South embankment before crossing over the WCML. The alignment then passes over the out-of-use Stoke to Market Drayton Railway, the watercourse and then Madeley Chord on the proposed River Lea viaduct heading north-west. After the viaduct, the route descends along the Lea North embankment before crossing underneath Manor Road overbridge to the north-west. Further detail on the Proposed Scheme can be found in the design as shown in Maps CT-06-231 and CT-06-232 in the Volume 2 Map Book.

Flood mechanisms

2.1.8 The River Lea is crossed by two railways in the immediate vicinity of the Proposed Scheme, the Madeley Chord and the WCML. The Madeley Chord in particular causes a constriction and a barrier to peak flood flows. These peak flood flows are diverted along the embankment toe, passing a hill adjacent to Hey House and discharging across the WCML into the River Lea to the north of Hey House.

2.1.9 The River Lea additionally flows through the culvert under Madeley Chord, and causes backflow up a culvert under the out-of-use Stoke to Market Drayton Railway, causing flooding of two low lying fields with networks of drainage channels.

2.2 Existing understanding of flood risk

Sources of information

2.2.1 Sources of Environment Agency data were utilised as below:

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

2.2.2 The proposed River Lea viaduct spans 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.

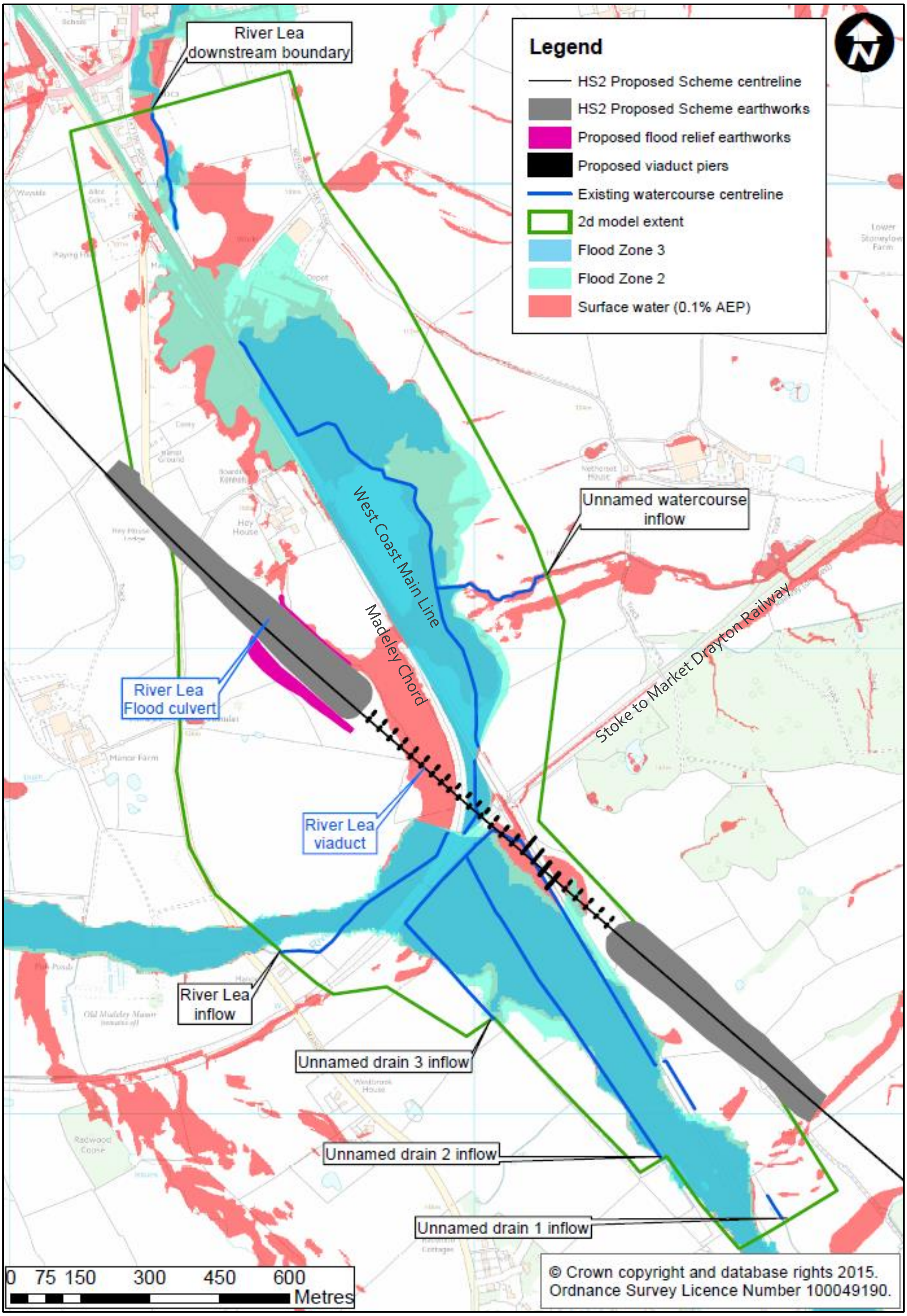
2.2.3 The proposed River Lea viaduct spans the majority of a flow path that is shown to exist on the uFMfSW between the downstream model extent and the WCML. However, a small section of the Lea North embankment lies within this flow path.

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 the River Lea at Madeley



2.3 Availability of existing hydraulic models

2.3.1 An existing hydraulic model was supplied by the Environment Agency which was used to inform this study.

2.3.2 The model provided was a 1D (ISIS) only model received in 2016. The model was developed in 2007.

2.3.3 The model was developed on behalf of the Environment Agency and started downstream of Madeley Chord but upstream of the WCML. The model was developed using topographic survey for the cross-section data. However, this raw survey data was not provided. This model does not form the basis of the assessment as the extent is not appropriate for the purpose of this study. However, data has been used from this model to define structures and channel bed levels.

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 Several structures were visited however, not all could be visited due to site access restrictions and general accessibility issues. For the structures that were visited, images were taken to ascertain dimensions and roughness.

2.4.3 The River Lea appeared to be approximately 4m wide with a depth of approximately 0.7m throughout the surveyed extent.

2.4.4 There is an existing structure on the River Lea that passes underneath the Madeley Chord section of the railway. This structure (LeaCul01), shown in Figure 2 is approximately 1.5m high and 0.95m wide.

Figure 2: Inlet of LeaCul01

2.4.5 One significant structure, as seen in Figure 3, runs underneath the out-of-use Stoke to Market Drayton Railway in a northerly direction. The outlet of the structure is approximately 4m from the outlet of LeaCul01. This structure (Culv06) is an egg-shaped brick culvert with the height of its central portion at 0.7m with its width at 1.5m. An arch was located at the top and bottom of the structure at a height of 0.5m.

Figure 3: LeaCul01 outlet and Culv06 inlet

2.4.6 Figure 4 and Figure 5 below show the inlet and outlet of a United Utilities pipe which runs alongside the WCML and underneath the out-of-use Stoke to Market Drayton Railway. Figure 4 shows the inlet that is connected to unnamed drain 1 whereas Figure 5 shows the outlet that comes out of a wingwall into the River Lea. The inlet is a circular culvert with a diameter of 0.45m whereas the outlet is a circular culvert with a diameter of 0.9m.

Figure 4: Outlet of United Utilities Pipe (Culv18)

Figure 5: Inlet of United Utilities Pipe (Culv18)

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 because there was no survey data available for the watercourse extent. Using 2D allows more confidence in the flood extent under the proposed River Lea 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.

3.1.4 Channel bed levels were utilised from the existing 1D only hydraulic model supplied by the Environment Agency to inform channel depth throughout the extent of the existing model.

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 was produced using 200mm LiDAR flown specifically for HS2 Ltd and covers 500m either side of the route centreline. In addition 2m 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 FEH methodologies were followed, in particular the Statistical Method. No suitable gauging stations were in the 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 Lea catchment at Madeley, ReFH2 provided the largest flows and thus it was the method adopted.

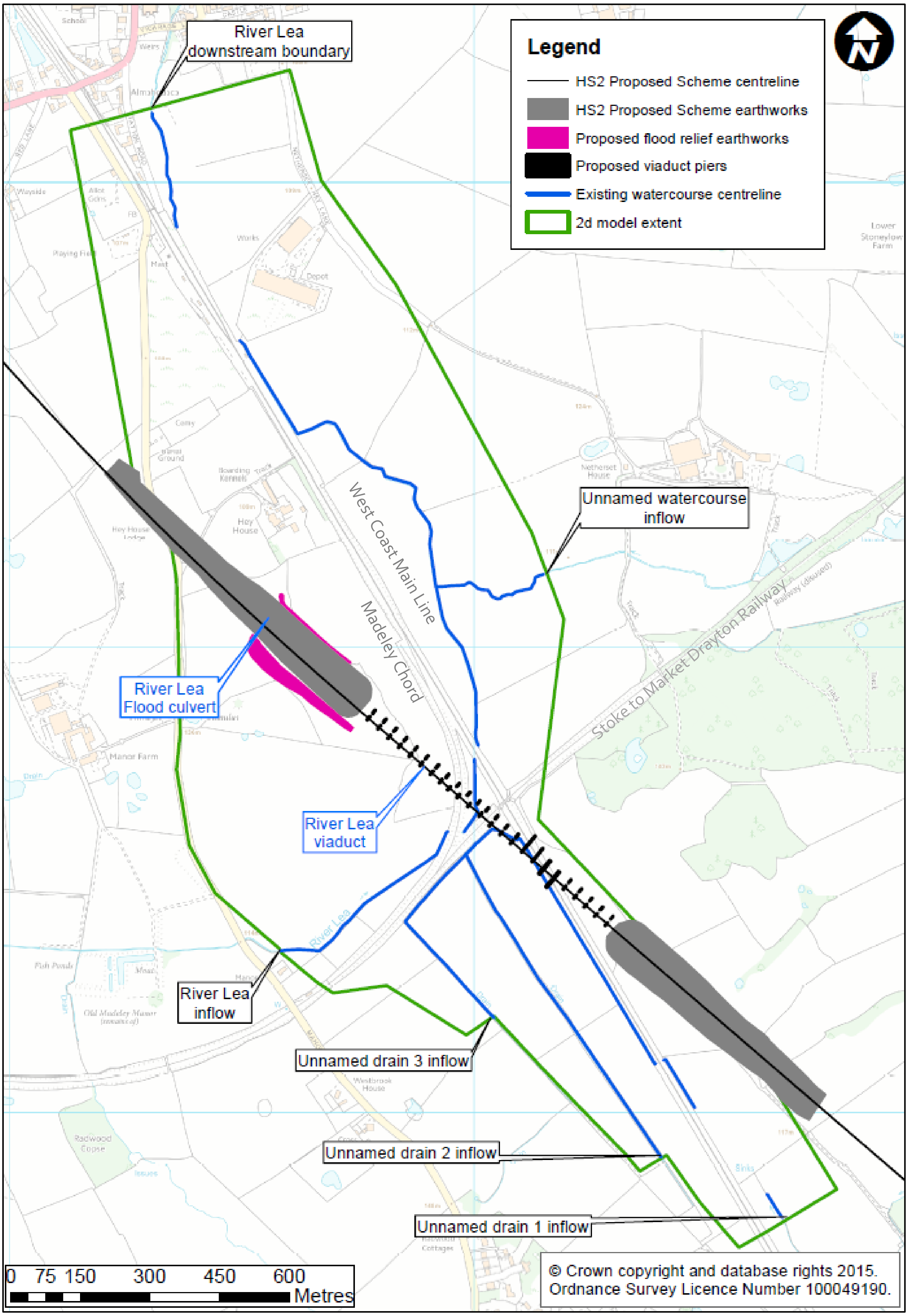
4.1.5 The design hydrographs used for the hydraulic modelling stage were generated using ReFH2 as the FEH Statistical method does not produce time series, just peak flows. The values were scaled so the peak flow for each return period matched that selected as the design value.

4.1.6 Table 1 shows the peak flows used for the computational hydraulic modelling work. Figure 6 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				
			River Lea inflow	**Unnamed drain 3**	**Unnamed drain 2**	**Unnamed drain 1**	**Unnamed watercourse inflow**
Flood peak (m^3/s)	50%	2yr	1.05	0.03	0.03	0.39	1.16
	20%	5yr	1.41	0.05	0.05	0.53	1.55
	5.0%	20yr	2.01	0.07	0.07	0.77	2.18
	1.33%	75yr	2.79	0.10	0.10	1.08	3.01
	1.0%	100yr	3.01	0.10	0.10	1.17	3.24
	1.0% + CC	100yr + CC	5.12	0.17	0.17	1.99	5.51
	0.5%	200yr	3.63	0.13	0.13	1.43	3.89
	0.1%	1000yr	5.47	0.20	0.20	2.24	5.79

Figure 6: Schematic of inflows and modelled river network



4.2 Hydraulic model build – baseline model

1D representation

4.2.1 Culverts were included in the ESTRY component of TUFLOW. The dimension of the culvert under the WCML on the River Lea and the long culvert that runs parallel to the WCML was taken from the model provided by the Environment Agency. Similar culverts were assumed to have the same dimensions. All other culvert dimensions were estimated.

4.2.2 There was a previous 1D model that was produced with its upstream extent beginning by the previously mentioned outlet of LeaCul01 and Culv06 (see Figure 7). The bed levels that were used for this model were deemed more accurate than those presented by the LiDAR as they were collected from cross-sections. Consequently, these bed levels were utilised within the nodes in the 2D model.

2D representation

4.2.3 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.

4.2.4 Channel sections have been modified in the 2D as the Environment Agency LiDAR used did not adequately pick up the features of the existing channel.

Inflow boundaries

4.2.5 The study area has five inflows. The main inflow, the River Lea, is located at the upstream extent of the model area. The second inflow, unnamed drain 1, starts at the point furthest east on the model and it meets the main channel after exiting the culvert under the out-of-use Stoke to Market Drayton Railway. The third inflow, unnamed drain 2, is located to the east of the out-of-use Stoke to Market Drayton Railway and meets the River Lea when passing through the culvert to the west of the field. The fourth inflow, unnamed drain 3, starts to the north of unnamed drain 2 and connects with the main channel at the same point. The fifth inflow, unnamed watercourse, begins towards the north of the model and flows in a westerly direction until it meets the River Lea. These are shown in Figure 6.

Downstream boundary

4.2.6 A normal depth boundary was used at the downstream extent of the River Lea, and also in the floodplain at the downstream extent. Another normal depth boundary was used at the downstream boundary on the WCML. This generates a stage-discharge curve based on the bed slope which varies across the floodplain.

4.2.7 A normal depth slope of 0.0051m/m (1 in 196) was used for the slope of the River Lea boundary and 0.0054m/m (1 in 185) was used for the slope of the WCML boundary. These were derived from LiDAR.

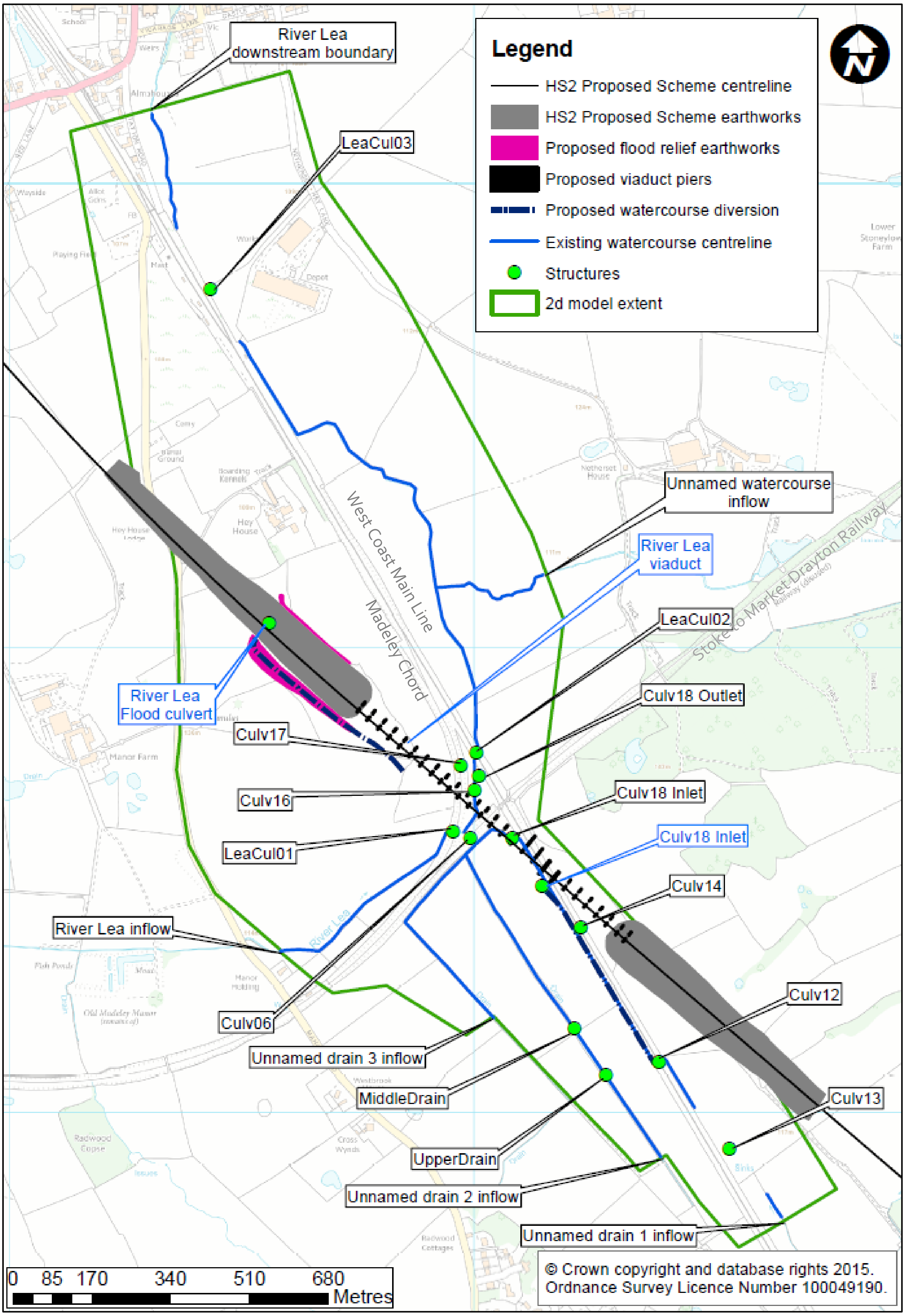
Key structures

4.2.8 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 7.

Table 2: Key structures present within the modelled extent of the River Lea at Madeley

Structure reference	Structure description	Modelling representation and justification
LeaCul03	Large culvert alongside the WCML 280.0m (L) x 2.0m (W) x 1.85m (H)	This culvert is a large box culvert. Dimensions from model obtained from the Environment Agency.
LeaCul02	Large culvert under the WCML 27.0m (L) x 2.5m (W) x 1.2m (H)	This culvert is a large box culvert. Dimensions from model obtained from the Environment Agency.
Culv06	Large arched brick culvert under the out-of-use Stoke to Market Drayton Railway 33.0m (L) x 1.5m (W) x 1.7m (H)	This culvert is an egg-shaped brick culvert. Dimensions obtained from a site visit.
LeaCul01	Small culvert under Madeley Chord 36.0m (L) x 1.2m (W) x 1.2m (H)	This culvert is a box culvert. Dimensions obtained from a site visit.
Culv16	Bridge over the River Lea 9m (L) x 2m (W) x 1.5m (H)	This bridge is a 2m x 2m arch bridge over the River Lea. Dimensions obtained from a site visit.
Culv12	Small circular culvert under the WCML 23.0m (L) x 1.2m (D)	This culvert is a small circular culvert. Dimensions obtained from a site visit.
Culv18 b/c	Small circular culvert under the out-of-use Stoke to Market Drayton Railway 200.0m (L), 0.45m (D) at inlet and 0.9m (D) at outlet	This culvert is a small circular culvert. Dimensions obtained from a site visit.

Figure 7: Existing and proposed structures within the model extent



Roughness

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

4.2.10 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.

4.2.11 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 River Lea viaduct will be separated into two parallel viaducts that span approximately 785m and will be supported by 27 piers on each side, spaced approximately 30m apart.

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 $16m^2$ per pier, for a pier size of 8m x 2m ($16m^2$).

Topographic changes

4.3.4 The Proposed Scheme embankments (Lea North and Lea South embankments) have been included using the relevant heights for the embankment crest. The footprints of the embankments for the scheme are based on the design as shown in Maps CT-06-231 and CT-06-232 in the Volume 2 Map Book.

4.3.5 The Lea North embankment is located in the modelled flood zones for baseline conditions for the majority of its length.

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 Replacement floodplain storage has been derived on a level for level volume for volume basis. It has also been modelled, however the modelling has indicated that despite a large area of land being allocated as replacement floodplain storage, the impacts cannot be fully mitigated. This is due to the local topography and presence of rail embankments. Provision of replacement

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

storage would cause the River Lea to be perched on its left bank between Manor Road and Madeley Chord, therefore the flood water that enters this area will never be able to return naturally to the River Lea as the Madeley Chord forms a barrier across the floodplain. Therefore, while land take has been allowed for this solution, further work is required if the resulting impacts at this stage are not sufficient.

Channel realignments and diversions

4.3.8 A channel diversion will be required underneath the viaduct and along both sides of the Lea North embankment as the surface water flooding had to be diverted into a channel and through the proposed River Lea Flood culvert. The culvert has been sized to retain flows. The channel along the northern side is provided to reduce impact on farmland while balancing impact on more sensitive receptors downstream. Both channels were given a width of 8m in order to mitigate the flooding effects during the higher return periods as these act as a form of storage.

4.3.9 A channel realignment will be required on unnamed drain 1 where the culvert inlet was moved further upstream as the viaduct piers blocked the existing channel.

Production of flood extents

4.3.10 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 made

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

4.3.12 Culvert sizes have been assumed in a number of locations within the model. 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.

4.3.13 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 for the River Lea is 70% based on the new climate change approach developed by the Environment Agency and published in February 2016[5].

4.4.2 This climate change percentage considers the design life of the Proposed Scheme (120 years), the River Basin District (North West) and the receptors within the existing Flood Map for Planning. Due to the presence of more vulnerable receptors (National Planning Policy Framework Table 2[6]), the upper end value for the longest duration was chosen.

4.4.3 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% AEP + CC 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 70% 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 reported in Appendix A.

5.1.3 These results are based on the model excluding replacement floodplain storage as this is worst case regarding the impacts. Inclusion of replacement floodplain storage has been shown to insufficiently mitigate these impacts. Including replacement floodplain storage results in a 6mm reduction in peak water level in a 1.0% + CC AEP scenario.

5.1.4 In return periods greater than 20% AEP, the largest impacts are observed underneath the viaduct and in the area between the Lea North embankment and the WCML. The flood depths in this region increase by up to approximately 750mm in the higher return periods. The increase in flood depths is due to the proposed Lea North viaduct blocking the flow path running parallel to the west of the WCML. The flood extents have minimal change between the existing and Proposed Scheme

5.1.5 In all return periods, an impact is observed in the region alongside the Lea South embankment and the WCML. The change in flood depth in this area does not exceed 70mm and the flood extents show minimal change.

5.1.6 In all return periods modelled, an increase in peak water level is observed in excess of 100mm within the drainage network in the field to the south-west of the Proposed Scheme. There is a large increase in flood extent within this field in the higher return periods.

5.1.7 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 (50%) event.

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 and uFMfSW.

6.4.2 Flood extents generated for this study differ to the Environment Agency Flood Maps for Planning as their maps were produced through the combination of two separate models which showed differing extents. However, the modelled extent closely correlates to the uFMfSW which demonstrates the same flow paths to the west of the WCML.

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% increase resulting in increases in peak water level of up to 100mm in some locations, with a general impact of 50-100mm. The effect of the increase has greater impact towards the downstream end of the model. The changes in roughness show extremely minimal changes to the flood extents.

6.5.3 Decreasing the roughness by 20% results in a small increase in peak water levels in some areas by up to 30mm whereas it mostly decreases peak water levels by up to 120mm. The effect of decrease in roughness has greater impact towards the downstream end of the model and alongside the Lea South Embankment. The changes in roughness show minimal changes to the flood extents.

Inflows

6.5.4 An increase in inflow of 20% results in an increase of up to 80mm at the proposed River Lea viaduct. The largest impacts from this increase in flow are seen upstream of the WCML and alongside the Lea South embankment where peak water levels rise by greater than 200mm.

Downstream boundary

6.5.5 There was no impact at the proposed River Lea viaduct when the downstream boundary was reduced and increased by 20%, with minimal impact of a maximum of 20mm at the downstream boundary. No impact is seen greater than 150m from the 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 River Lea viaduct with an increase in flooding depth in localised areas. The changes in the downstream boundary gradient had a small impact at the proposed River Lea viaduct with minimal 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 (70%) event for all scenarios.

6.6 Blockage analysis

6.6.1 One blockage scenario was assessed which modelled both a 2% blockage at the proposed River Lea viaduct and a 50% blockage of the culvert under the Madeley Chord (LeaCul01), the proposed River Lea Flood culvert and the WCML culverts (Culv12 and Culv14) on the northern tributary.

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 River Lea viaduct by expanding the size of the pier standing nearest to the main channel by 2% of the length of the viaduct. The blockage of the culverts under the WCML, Madeley Chord and the proposed River Lea Flood culvert were represented by reducing the width of the structure by 50%

6.6.4 The results of the blockage scenario show an increase in peak water level of up to 100mm adjacent to the Lea North embankment with some ingress onto the WCML. Adjacent to the Lea South embankment, increases in peak water level of greater than 100mm are observed.

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 the majority of model runs.

6.7.2 The time step parameters used were 0.2s for ESTRY and 0.5s for the 2D model. These time steps deviate from the suggested approach for a grid size of 2m however they were selected to improve stability within the culverts.

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; 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. Culvert dimensions have been estimated based upon ground levels and watercourse size, which may impact flood extent and level predictions if these were to change.

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 upstream model extent was restricted due to the extent of LiDAR available. It is not known if inclusion of this area, and greater model extent, would change the dynamics of the flow passing towards the Proposed Scheme. A number of structures and embankments are located upstream which have the potential to hold back water however the impact of these at this stage is unknown. The area was covered by a 5m OS topographical layer however this was not considered accurate enough to inform this assessment.

7.1.4 Replacement floodplain storage has been designed on a level for level and volume for volume basis and has been included within the design, with land take provisions made for the areas shown. However, following inclusion of replacement floodplain storage in the hydraulic model and extensive work to design a storage area, it has not been possible to mitigate the full impacts of the Proposed Scheme entirely without extensive additional land take.

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 the River Lea to simulate the baseline and Proposed Scheme and to determine the peak water levels and flows throughout the catchment has been met.

8.1.2 In all return periods modelled, the largest impacts are observed underneath the viaduct and in the area between the Lea North embankment and the WCML. The flood depths in this region increase by up to approximately 750mm in the higher return periods. The flood extents have minimal change between the existing and Proposed Scheme.

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 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, allowing the model to be used to confirm flood risk from the Phase 2a scheme.

9 References

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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: River Lea at Madeley Impact Map for 5% AEP (1 in 20 year)

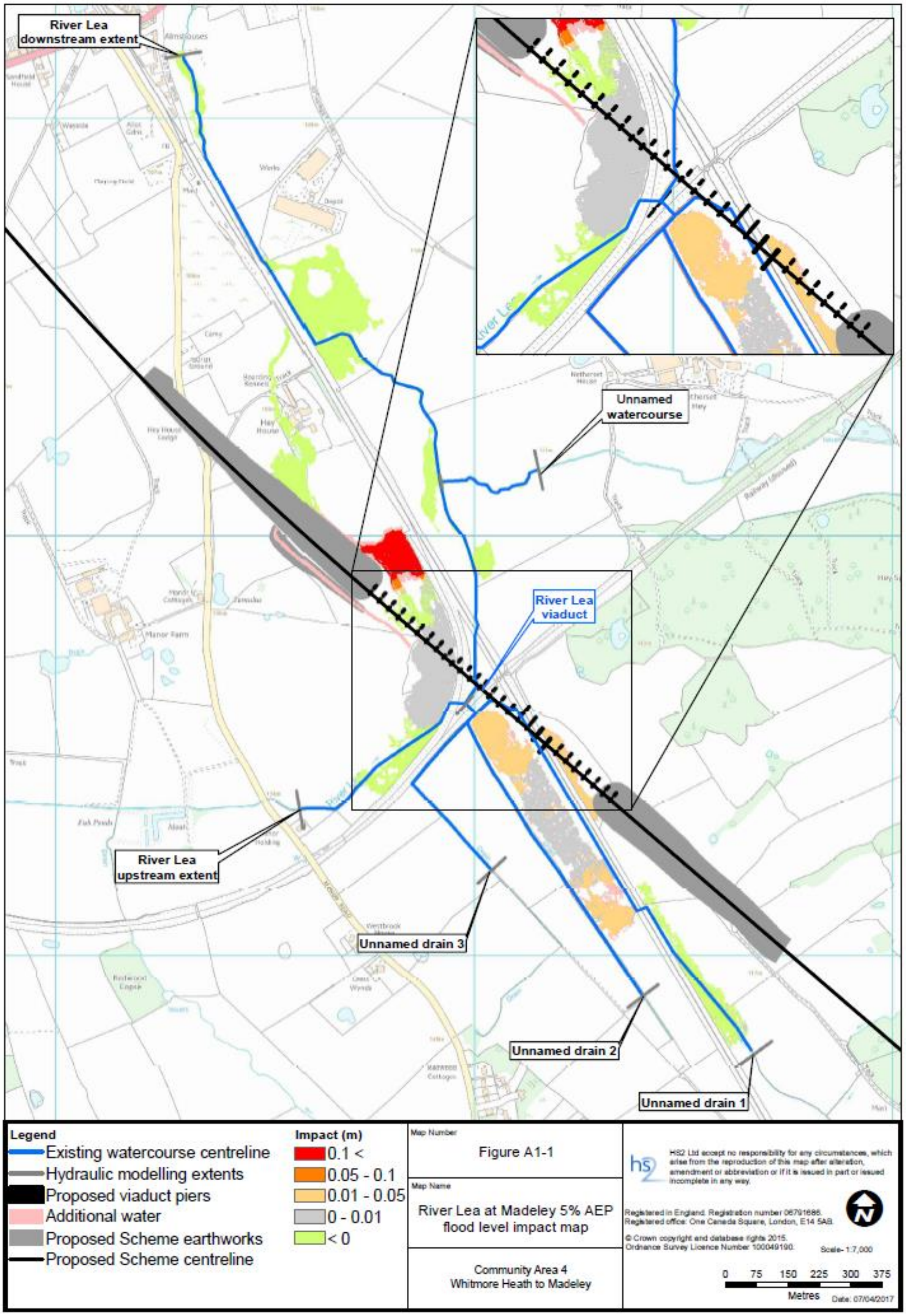
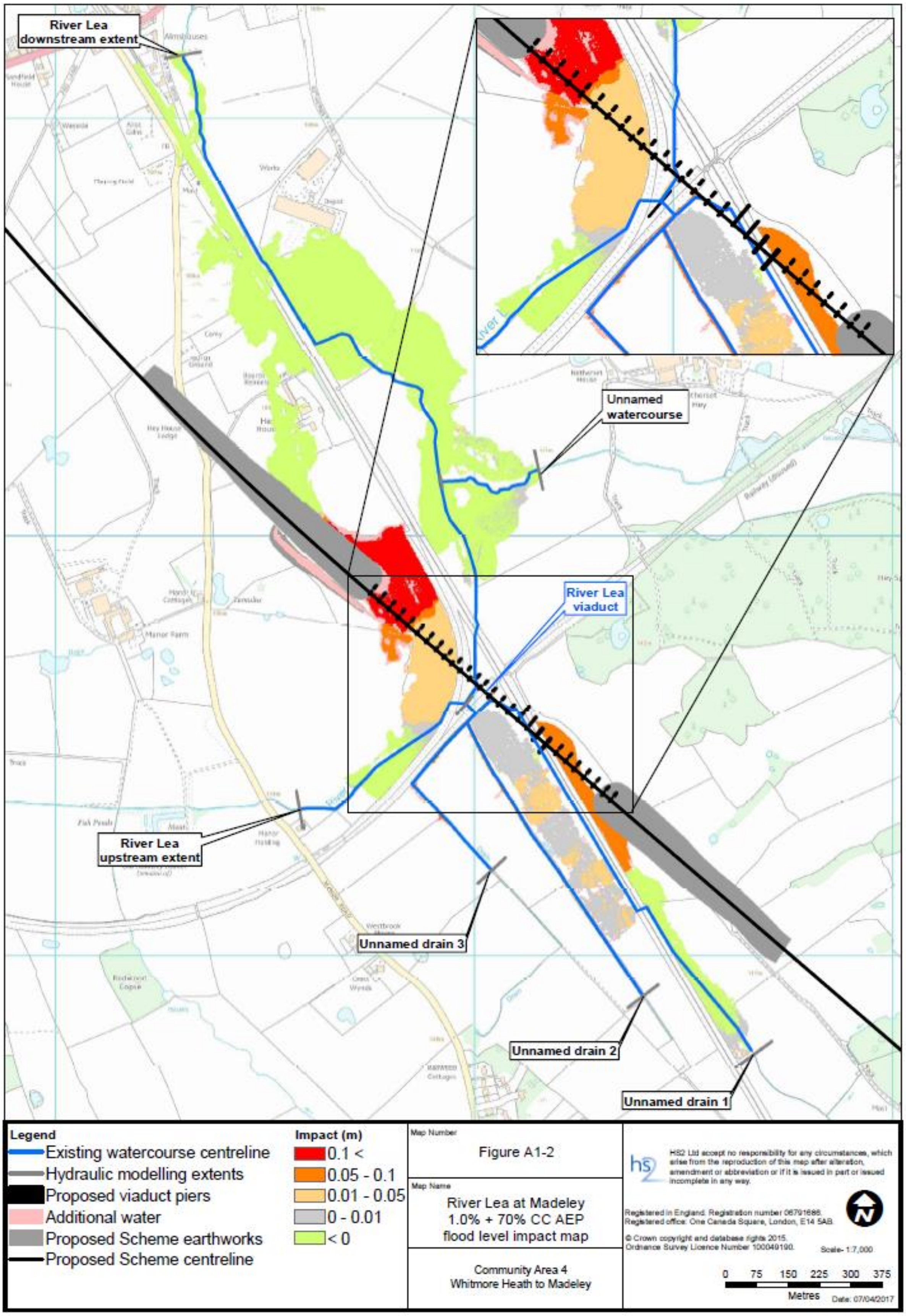


Figure A-2: River Lea at Madeley Impact Map for 1% AEP (1 in 100 year) plus 70% climate change allowance



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