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HS2

# High Speed Rail (Crewe – Manchester) Environmental Statement

## Volume 5: Appendix WR-006-00004

### Water resources and flood risk

MA05: Risley to Bamfurlong

Hydraulic modelling report - Small Brook

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Department for Transport

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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.hs2.org.uk

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

ARUP+ ERM | FOSTER + PARTNERS | JACOBS
RAMBOLL | TYPSA | COSTAIN

MWJV
Mott MacDonald | WSP

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# 1 Introduction

## 1.1 Background

1.1.1 This appendix presents the results of the hydraulic modelling carried out for Small Brook, a headwater tributary of the Glazebrook. Small Brook runs through the Risley to Bamfurlong community area (MA05).

1.1.2 The hydraulic modelling has been used to inform the Flood risk assessment (Volume 5: Appendix WR-005-0MA05) for the Risley to Bamfurlong area.

1.1.3 The following hydraulic modelling reports are also relevant to this area:

- Hydraulic modelling report – Tributaries of Holcroft Lane Brook 2 to 4 (Volume 5: Appendix WR-006-00003);
- Hydraulic modelling report – Carr Brook (Volume 5: Appendix WR-006-00005); and
- Hydraulic modelling report – Hey Brook (Volume 5: Appendix WR-006-00006).

1.1.4 The water resources and flood risk assessments include both route-wide and community area specific appendices. The route-wide appendices comprise:

- a Water Framework Directive (WFD) compliance assessment (Volume 5: Appendix WR-001-00000); and
- a Draft water resources and flood risk operation and maintenance plan (Volume 5: Appendix WR-007-00000).

1.1.5 For the Risley to Bamfurlong community area the Water resources assessment Volume 5: Appendix WR-003-0MA05 should also be referred to.

1.1.6 Additional information is included in Background Information and Data (BID):

- Water resources assessment baseline data that are reported per community area, (BID, WR-004-0MA05)[1]; and
- Water Framework Directive compliance assessment baseline data for the Proposed Scheme (BID, WR-002-00001)[2].

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[1] High Speed Two Ltd (2022), High Speed Rail (Crewe – Manchester), *Background Information and Data, Water resources assessment baseline data,* BID WR-004-0MA05. Available online at: http://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-environmental-statement.

[2] High Speed Two Ltd (2022), High Speed Rail (Crewe – Manchester), *Background Information and Data, Water Framework Directive compliance assessment baseline data,* BID WR-002-00001. Available online at: http://www.gov.uk/government/collections/hs2-phase-2b-crewe-manchester-environmental-statement.

## 1.2 Aims

1.2.1 The aim of this study was to develop a hydraulic model for Small Brook in the vicinity of the Proposed Scheme crossing to simulate peak flood levels, with and without the Proposed Scheme. This report also aims to document the methods used, the results, assumptions and limitations.

1.2.2 The outputs from the study have been used to inform the flood risk assessment for the Risley to Bamfurlong area, that is reported in Volume 5 of the Environmental Statement. The hydraulic model has also informed the preliminary design of the Proposed Scheme, with the specific objectives of ensuring that the design of hydraulic structures – viaducts, bridges, culverts etc – takes account of flood risk issues, as detailed in the Environmental Impact Assessment Scope and Methodology Report (SMR)Technical Note: Flood risk (see Volume 5: Appendix CT-001-00001).

## 1.3 Objectives

1.3.1 The objectives of this study were to:

- develop an understanding of existing hydraulic conditions at the proposed watercourse crossing, including channel and floodplain characteristics, hydraulic structures and flow paths, through desk study and, where possible, by conducting a site visit;
- estimate peak flows, and hydrographs, at the Proposed Scheme crossing locations, associated with the following Annual Exceedance Probabilities (AEP): 5.0%, 1.0%, 1.0% + climate change (CC), and 0.1%; and
- develop a hydraulic model, using the information available at this stage, to estimate the flood levels associated with these peak flows along the study reach, both before and after construction of the Proposed Scheme.

## 1.4 Justification of approach

1.4.1 A risk-based approach has been adopted, whereby the level of modelling detail supporting the flood risk assessment at a specific site reflects the magnitude of the likely impacts of the Proposed Scheme on peak flood levels and the sensitivity of nearby receptors to flooding.

1.4.2 Small Brook is a main river and the Proposed Scheme embankment encroaches upon the Environment Agency flood zones (see Figure 1). There are a number of vulnerable receptors at risk of flooding upstream and downstream of the Proposed Scheme crossing. Due to the small size of the catchment, a direct rainfall 2D hydraulic modelling approach was adopted. Input hyetographs were derived using Revitalised Flood Hydrograph 2 (ReFH2) software[3].

[3] WHS (2016), *Revitalised Flood Hydrograph Model ReFH2: Technical Guidance.*

Upstream of the 2D direct rainfall domain, an inflow boundary has been included to allow for the flows from the upstream urban catchment (see Figure 2).

## 1.5 Scope

1.5.1 The scope of the study was to undertake hydraulic modelling to enable assessment of the impact of the Proposed Scheme on the local environment. The model aimed to be detailed enough to allow assessment of different options for the crossing locations, to allow the management of flood risk and correct sizing of crossing structures.

1.5.2 This report focuses on a 1.3km reach of Small Brook extending upstream and downstream of the Proposed Scheme crossing. The Proposed Scheme crossing consists of a composite structure that provides space for both the watercourse and vehicular/foot access. A description of the location and type of scheme is provided in Section 2.

1.5.3 The scope of the report includes:

- discussion of all relevant datasets, in terms of their quality and gaps;
- details of the hydrological analysis undertaken, the approach used and the calculation steps;
- details of how the hydrological analysis has been integrated with the hydraulic modelling;
- identification and justification of the hydraulic modelling methodology selected; and
- a description of the hydraulic modelling parameters, assumptions, limitations and uncertainty.

# 2 Qualitative description of flood response

## 2.1 Sources of information

2.1.1 The following sources of information were obtained from the Environment Agency:

- flood map for planning (rivers and sea)[4];
- risk of flooding from surface water (RoFSW)[5] map; and
- flood defence asset information.

2.1.2 Additional information from the Lead Local Flood Authority (LLFA) and publicly available sources included:

- Wigan Preliminary Flood Risk Assessment (PFRA) (2011)[6];
- Wigan Strategic Flood Risk Assessment (SFRA) (2010)[7]; and
- Wigan Local Flood Risk Management Strategy (LFRMS) (2014)[8].

## 2.2 Description of the study area

### Study area

2.2.1 Small Brook discharges into Pennington Flash WFD lake water body approximately 1km downstream of the Proposed Scheme crossing.

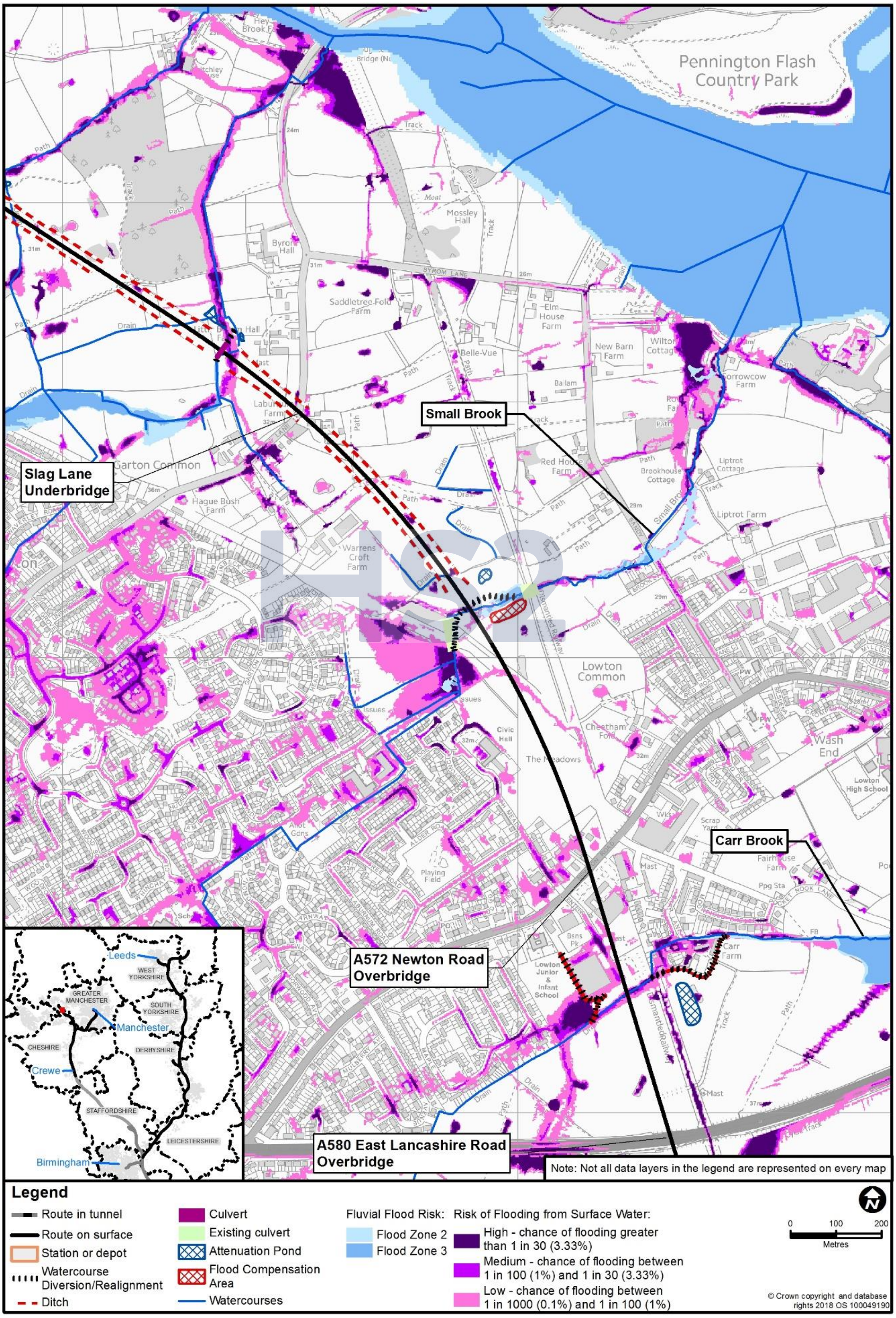
2.2.2 Figure 1 shows the 1.3km long reach of Small Brook in the study area. The upstream boundary is located near Green Meadow Independent Primary School and the downstream boundary is located near Sandy Lane. The upstream and downstream boundaries are sufficiently far upstream and downstream in order not to impact peak water levels at the location of the Proposed Scheme crossing.

2.2.3 The primary hydraulic controls of Small Brook comprise a 70m culvert upstream of the Proposed Scheme crossing and a 13m culvert downstream, at the dismantled railway line.

[4] Environment Agency (2021), *Flood map for planning*. Available online at: https://flood-map-for-planning.service.gov.uk.
[5] Environment Agency (2021), *Long-term flood risk information.* Available online at: https://flood-warning-information.service.gov.uk/long-term-flood-risk/map.
[6] JBA Consulting (2011), *Wigan Preliminary Flood Risk Assessment.* Available online at: https://www.wigan.gov.uk/Resident/Crime-Emergencies/Flooding/Flood-investigations.aspx.
[7] JBA Consulting (2010), *Wigan Strategic Flood Risk.* Available online at: https://www.wigan.gov.uk/Council/Strategies-Plans-and-Policies/Planning/Local-plan/Background/Key-Local-Studies/StrategicFloodRiskAssessment.aspx.
[8] Wigan Council (2014), *Wigan Local Flood Risk Management Strategy.* Available online at: https://www.wigan.gov.uk/Resident/Crime-Emergencies/Flooding/Local-Flood-Risk-Management-Strategy.aspx.

Flood levels at the Proposed Scheme crossing are not influenced by backwater effects from the Pennington Flash Reservoir.

### Figure 1: Study area and Environment Agency flood zones and RoFSW (0.1%AEP) at Small Brook



## Hydrological description

2.2.4 Small Brook originates to the north of the A580 East Lancashire Road, south of Lowton. The catchment area contributing to the downstream boundary of the proposed hydraulic model is 1.26$km^2$, comprising of an upstream 0.76$km^2$ urban catchment and a 0.5$km^2$ rural catchment, as shown in Figure 2.

2.2.5 There are no gauging stations present within the Small Brook catchment[9].

2.2.6 Standard annual average rainfall for the catchment at the model downstream boundary is 912mm[9].

## Proposed Scheme

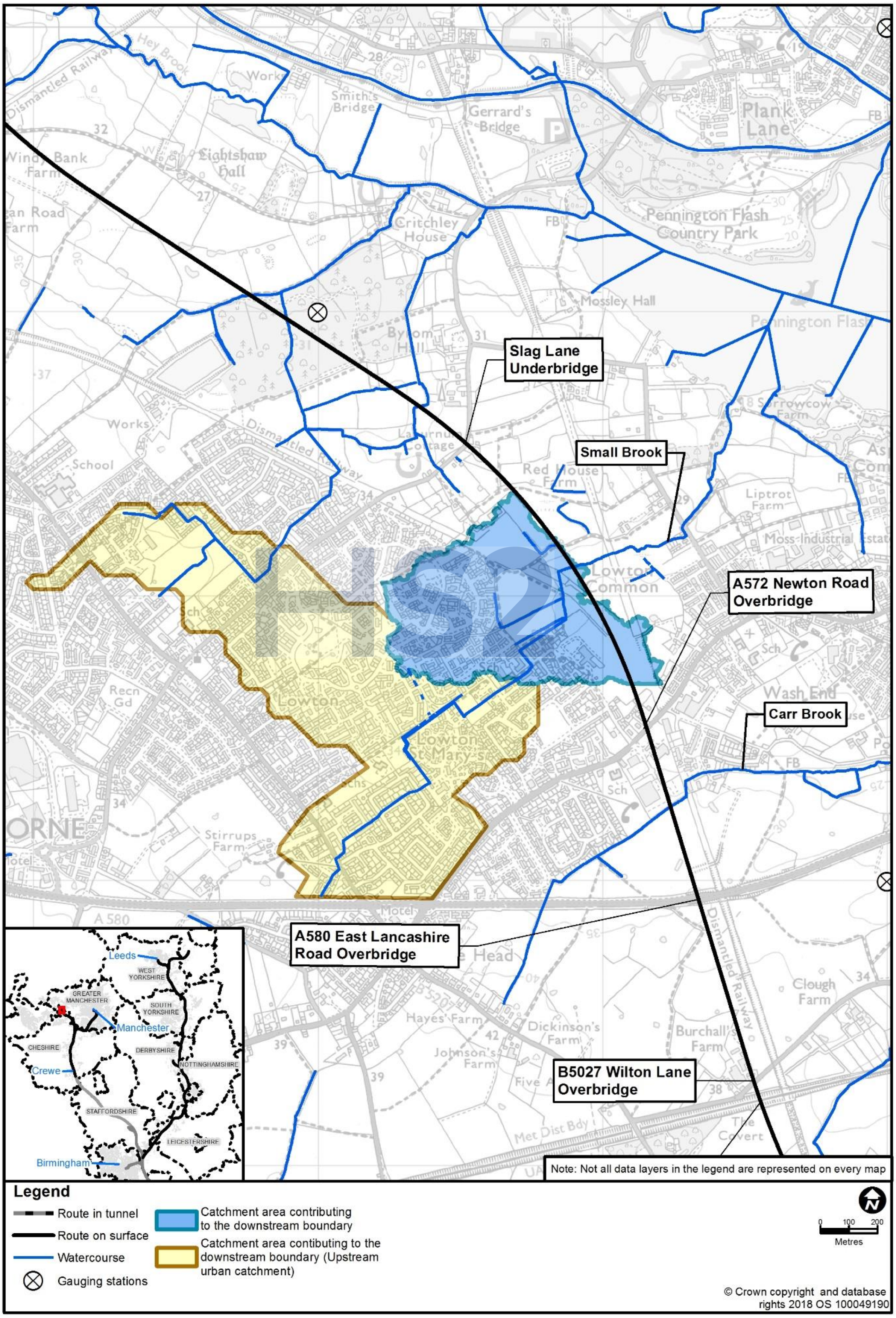
2.2.7 The route of the Proposed Scheme crosses Small Brook with an underbridge for vehicle/foot access and a new culvert beneath the Lowton St Mary south embankment 400m to the west of Sandy Lane. Further detail on the Proposed Scheme can be found in Volume 2, MA05, Map Books: map CT-06-331.

## Features of note

2.2.8 Upstream of the Proposed Scheme crossing, Small Brook has already been heavily modified as it runs in straight lines and is culverted in many locations in Lowton St Mary. From inspection of the LiDAR (Light Detection And Ranging) data, the watercourse has raised banks in the vicinity of the Proposed Scheme crossing.

[9] Centre for Ecology and Hydrology (2021), *Flood estimation handbook web service.* Available online at: http://fehweb.ceh.ac.uk.

**Figure 2: Small Brook modelled catchment area**



## 2.3 Existing understanding of flood risk

### Flood mechanisms

2.3.1 Figure 1 shows a limited presence of Environment Agency Flood Zones 2 (0.1%AEP) and 3 (1.0%AEP) in the modelled reach. The flood zones indicate that Small Brook runs mostly in-bank in the vicinity of the Proposed Scheme crossing apart from a depression located just downstream of the crossing.

2.3.2 Downstream of the Proposed Scheme crossing, the RoFSW follows a similar pattern to the flood zones. There is widespread surface water flooding approximately 100m upstream of the Proposed Scheme crossing.

2.3.3 Available information does not indicate the presence of any flood defence assets within the model extent.

### Analysis of historical flooding

2.3.4 No information on historical flood incidents has been identified from the SFRA[7], PFRA[6], or Section 19 flood investigation reports[10].

### Availability of existing hydraulic models

2.3.5 Available information, that includes information from the Environment Agency, does not indicate the existence of a hydraulic model for Small Brook.

## 2.4 Site visit

2.4.1 At this stage no site survey or site visit was undertaken to inform the proposed hydraulic analysis. When the hydraulic model is updated at the detailed design stage, in accordance with HS2 Ltd requirements, a site visit will be undertaken by a hydraulic modeller to ensure a site-specific topographic survey specification can be developed.

[10] Section 19 of the Flood and Water Management Act 2010 sets out the requirement for that on becoming aware of a flood in its area, a LLFA must investigate and report on which risk management authorities have relevant flood risk management functions and whether each authority has exercised those functions in response to the flood.

# 3 Model approach and justification

## 3.1 Model conceptualisation

3.1.1 A 2D hydraulic modelling approach was chosen for the Small Brook study area as no 1D survey data were available. The existing and Proposed Scheme culverts have been modelled as 1D elements within the 2D model.

3.1.2 Existing culverts were modelled with estimated dimensions at locations where there was a possibility that a culvert would have an effect on the size of the Proposed Scheme crossing or if the impact from the Proposed Scheme would be affected by the presence of the culvert. Culvert dimensions have been estimated based on engineering judgment from the Digital Terrain Model (DTM) and aerial photography. Sensitivity tests were undertaken for the assumed culvert dimensions at those locations where the size of the Proposed Scheme crossing could be affected or if the outcome of the impact assessment could be affected.

3.1.3 The 2D model domain has been extended sufficiently upstream and downstream to ensure the catchment in the vicinity of the Small Brook is captured, and to ensure that any effects caused by the model boundaries do not affect water levels in the area of the Proposed Scheme. A point inflow boundary has been included at the upstream extent of the 2D model to account for the upper urban catchment area of $0.76km^2$.

3.1.4 High resolution 0.2m to 1m LiDAR data have been used to define the channel and to take account of the watercourse capacity and conveyance in the 2D model domain. This potentially results in reduced modelled channel capacity, underestimated peak flows at the crossing but higher modelled peak water levels, as well as an overestimation of out-of-bank flooding. The latter leading to a more conservative assessment of replacement flood storage requirements.

## 3.2 Software

3.2.1 Infoworks Integrated Catchment Model (ICM) (version 4.03.8010) has been used to apply the 2D modelling methodology. This software is in line with standard practice to use the latest available build at the time modelling commenced, while Infoworks ICM is industry standard software.

## 3.3 Topographic survey

3.3.1 No additional topographic survey was commissioned for this study but will be collected to inform hydraulic modelling in support of detailed design.

## 3.4 Input data

3.4.1 The elevation data for the study area were derived from the 0.2m LiDAR DTM flown specifically for HS2 Ltd and covers 500m either side of the route centre line. Where required, additional 1m grid LiDAR data provided by the Environment Agency were used in areas further away from the proposed crossings, to provide full coverage of the 2D model domain.

# 4 Technical method and implementation

## 4.1 Hydrological assessment

4.1.1 No flow records are available for Small Brook. Given the size of the downstream 0.5km$^2$ rural catchment, a surface water modelling approach has been adopted in the vicinity of the crossing. Direct net rainfall is applied to the rural 2D domain and surface runoff is routed towards the downstream model boundary. A fixed runoff-coefficient of 0.4 (40% on applied rainfall) has been applied to consider infiltration losses as a reasonable estimate given the nature of the soils in the catchment.

4.1.2 To account for the contribution of the upstream 0.76km$^2$ urban area of the catchment that is not covered by direct rainfall, a point inflow boundary has been included in the model. The flow hydrograph is based on the ReFH2 hydrograph and is applied as a point inflow during the model simulation.

4.1.3 The critical ReFH2 summer storm duration for the catchment upstream of the Proposed Scheme crossing has been used for estimating the rainfall hyetographs. A summer profile has been adopted throughout the Proposed Scheme at this stage as it results in conservative estimates, in urbanised areas.

4.1.4 A hydrological verification has been undertaken by estimating catchment hydrology ReFH2 peak flow estimates[11] at the Proposed Scheme crossing, to check that the surface water modelled peak flows are similar or greater, than the ReFH2 flow estimates. ReFH2 flow calculations are based on relevant catchment descriptors, that were obtained from the FEH Web Service database[12].

4.1.5 Table 1 shows the peak flows derived from the surface water modelling with Infoworks ICM at the proposed crossing and their comparison with the ReFH2 flow estimates.

**Table 1: Peak flows at the Small Brook crossing**

| AEP | Return period | Peak flow ($m^3/s$) | Peak flow ($m^3/s$) |
|---|---|---|---|
| | | Modelled | ReFH2 |
| 5.0% | 20 year | 1.04 | 0.10 |
| 1.0% | 100 year | 1.06 | 0.15 |
| 1.0% + CC (40% rainfall, 40% flow) | 100 year + CC (40% rainfall, 40% inflow) | 1.89 | 0.21 |
| 0.1% | 1000 year | 2.62 | 0.28 |

[11] Kjeldsen.T.R, (2007), *Flood Estimation Handbook (FEH) Supplementary Report No. 1. The revitalised FSR/FEH rainfall-runoff method*. Centre for Ecology and Hydrology, Wallingford.

[12] Centre for Ecology and Hydrology (2021), *Flood estimation handbook web service.* Available online at: http://fehweb.ceh.ac.uk.

4.1.6 It is concluded therefore that the adopted modelling approach is more conservative than the estimates from the ReFH2 flows. As this assessment is precautionary, further assessment during design development to refine the understanding of the flood risks and impacts and reducing the conservatism within the precautionary approach.

# 4.2 Hydraulic model build - baseline model

4.2.1 Figure 3 shows the existing and proposed model schematic.

## 1D representation

4.2.2 1D elements were modelled at two locations:

- the 13m long culvert crossing of the dismantled railway downstream of the Proposed Scheme crossing; and
- an approximately 70m long culvert located just upstream of the Proposed Scheme crossing.

4.2.3 These sizes have been assumed based on LiDAR and aerial imagery and will need to be confirmed at the detailed design stage.

## 2D representation

4.2.4 The element size of the model was varying where maximum triangle area was set to $20m^2$ and minimum element area was set to $15m^2$. Element size and alignment for the 2D model mesh were optimised to ensure appropriate representation of the flow pathways whilst maintaining reasonable run times.

## Inflow boundaries

4.2.5 A point inflow boundary has been included in the model to account for the flow contribution of the upstream urban area of the catchment. This inflow has been placed on the alignment of Small Brook and at the boundary with the 2D domain. It represents the flow contribution from the upper catchment.

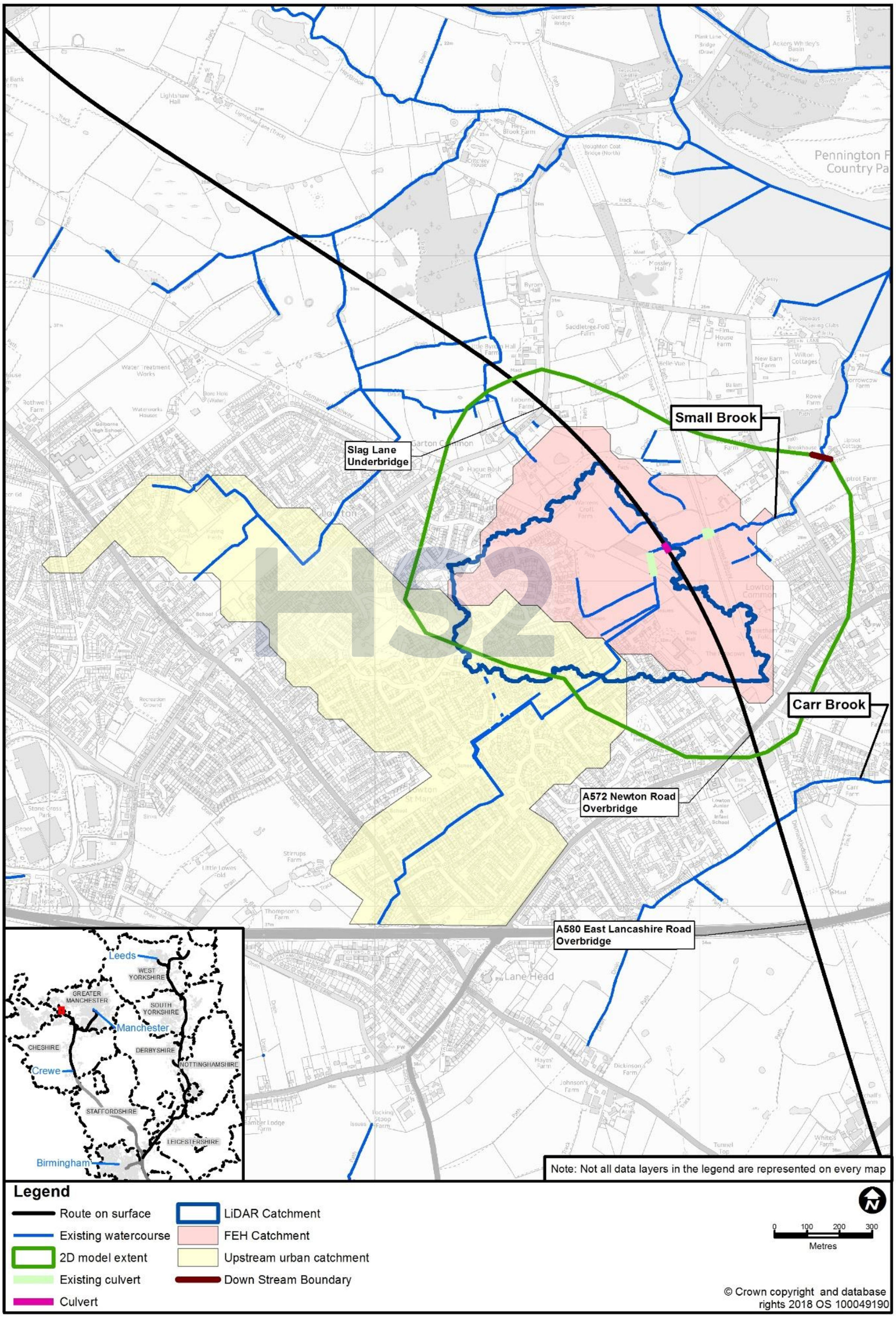
## Downstream boundary

4.2.6 Unrestricted flow out of the 2D domain has been set based on inspection of the LiDAR and mapping along the 2D domain boundary, that indicate that flood waters cannot backup and impact on the zone of influence.

## Key structures

4.2.7 The review of the model impact in peak flood depths in Annex A, Figures A 1 and A 2 indicates that there are no key structures where the size of the Proposed Scheme Crossing could be affected, or the outcome of the impact assessment could be affected. This is the case because the Proposed Scheme crossings have not been sized for capacity but are much larger, to allow for vehicular access.

## Figure 3: Model schematic



4.2.8 Modelled structures and their dimensions that have been included in the hydraulic model are shown in Table 2. The culvert sizes are not based on visual inspections or survey. However, they are considered reasonable when compared to the size of the channel cross sections (assumed from LiDAR and aerial photography) and accurate enough to characterise the potential impact of the Proposed Scheme. The sizes will need to be confirmed at the detailed design stage.

**Table 2: Modelled structures within the modelled extent**

| Structure reference | Structure description | Modelling representation and justification |
|---|---|---|
| 13m long culvert beneath the existing dismantled railway | 1.2m diameter | Culvert modelled as a circular pipe<br>Dimensions assumed from LiDAR and aerial photography |
| 70m long culvert upstream of the Proposed Scheme crossing | 0.35m diameter | Culvert modelled as a circular pipe<br>Dimensions assumed from LiDAR and aerial photography |

### Roughness

4.2.9 Roughness is represented by Manning's n, selected based on Ordnance Survey (OS) Mastermap data and aerial photography in line with the recommended values stated within Chow, 1959[13].

## 4.3 Hydraulic model build – Proposed Scheme

4.3.1 The Proposed Scheme model has been edited from the baseline to include the following design elements.

### Culverts

4.3.2 Culverts in the baseline model have been kept in the Proposed Scheme model.

### Underbridge

4.3.3 The Proposed Scheme embankment has been modelled as a raised 2D impermeable wall along the Proposed Scheme footprint to ensure any potential it has for impeding overland flows are understood. At the crossing location, an opening in the Proposed Scheme embankment wall was made. The modelling of the crossing as open area, instead of as culvert, is considered acceptable as the crossing is a 7m wide and 4m high composite structure (no surcharge conditions). This large structure allows footway and vehicular access.

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

### Topographic changes

4.3.4 The Proposed Scheme embankment has been modelled as a high impermeable wall that approximately follows the Proposed Scheme toe of embankment based on the details shown in Volume 2, MA05, Map Book: maps CT-06-331.

### Channel realignments and diversions

4.3.5 Only localised realignments are proposed at the inlet and outlet of the Proposed Scheme crossing to ensure the channel crosses at a ninety-degree angle to the route of the Proposed Scheme. This realignment has not been modelled as flow conveyance is maintained by modelling the large underbridge, as described in Section 4.3.3.

### Production of flood extents

4.3.6 Flood extents have been derived using the direct output option available in Infoworks ICM, producing maximum flood depth and peak water level. The outputs have undergone a Proposed Scheme minus baseline calculation. The resulting layer was converted to polygons and cleaned to remove all bow ties (where two polygons overlap) and any dry islands that are less than $50m^2$. The differences were mapped to indicate the potential impacts of the Proposed Scheme.

### Modelling assumptions made

4.3.7 Existing LiDAR described in Section 3.1 is assumed to be correct.

4.3.8 A 2D modelling approach is assumed to be sufficient for estimating the 5.0%, 1.0% and 0.1% AEP events.

4.3.9 Existing hydraulic structures are assumed to be drowned out in large flood events (5.0%, 1.0% and 0.1% AEP events) and therefore will not impact on the hydraulics of the return periods assessed.

4.3.10 The dimensions of key structures are not based on visual inspection or survey, however, they are considered reasonable when compared to the channel cross section assumed from LiDAR and aerial photography.

## 4.4 Climate change

4.4.1 The climate change allowance for the direct rainfall and peak inflow components of the hydrology for Small Brook is a 40% increase in peak rainfall intensity and peak river flow as the catchment is less than $5km^2$ in size.

4.4.2 The H++ allowance for Small Brook is a 60% increase in peak rainfall intensity and peak river flow, and this has been used for the purpose of sensitivity analysis.

# 5 Model results

5.1.1 The model has been run for the 5.0%, 1.0%, 1.0%+CC, and 0.1% AEPs. The 1.0% AEP + CC simulation is based on a 40% increase in peak rainfall and peak flow.

5.1.2 The water level difference has been mapped for 5.0% AEP and 1.0% AEP + CC. These flood maps are included in Annex A, Figures A 1 and A 2.

5.1.3 The modelled flood extents with and without the Proposed Scheme for the 5.0% AEP and the 1.0% AEP events are presented in the Volume 5, MA05 Map Book, Map Series WR-05-317 and WR-06-317 respectively.

5.1.4 The modelled impact of the Proposed Scheme on peak flood levels, without mitigation, indicates the potential for:

- an increase in peak flood level of up to 90mm upstream of the Proposed Scheme underbridge; and
- a decrease in peak flood level of approximately 20mm downstream of the Proposed Scheme crossing.

5.1.5 Model results indicate that the current proposed design achieves the freeboard requirements for both the top of rail level and Proposed Scheme watercourse crossing soffits.

# 6 Model proving

## 6.1 Run performance

6.1.1 The time step used was 30 seconds. Final cumulative mass balance error is within +/-1.0% for all model runs undertaken.

## 6.2 Calibration and verification

6.2.1 There is no river gauge situated within an appropriate distance of this location to provide calibration or verification data.

## 6.3 Validation

6.3.1 Flood extents generated for this study are similar to those shown on the Environment Agency RoFSW for the 1.0% and 0.1% AEP events.

## 6.4 Sensitivity analysis

6.4.1 Analysis was undertaken to assess the sensitivity of the 1.0% AEP + CC Proposed Scheme model outputs to the following scenarios:

- use of H++ climate change scenario of 60%;
- increase in roughness (channel, structures and floodplain) (Manning's n) by 20%; and
- decrease in roughness (channel, structures and floodplain) (Manning's n) by 20%.

6.4.2 No sensitivity tests have been undertaken on the downstream boundary normal depth slope at this stage. This is because the 2D model has been extended sufficiently downstream to ensure that there is no effect at the Proposed Scheme crossing. These tests will be undertaken once the models are fully converted to 1D-2D in a future stage.

6.4.3 Sensitivity tests indicate that the current Proposed Scheme hydraulic design is not unduly sensitive to changes in key input parameters. In all cases, changes in peak water levels are less than 100mm.

## 6.5 Blockage analysis

6.5.1 Blockage of 50% at the proposed crossing was simulated by reducing the width of the underbridge crossing by half. The blockage scenario results were compared to the 0.1% AEP results for the Proposed Scheme model. This comparison indicated that there is an increase of approximately 180mm in peak flood level at the crossing of Small Brook.

6.5.2 The blockage test confirms that the Proposed Scheme design ensures a freeboard of a minimum of 1m to the rail track in a 0.1% AEP event is still maintained.

## 6.6 Run parameters

6.6.1 There is no deviation from default run parameters recommended in Infoworks ICM for all model runs.

# 7 Limitations

7.1.1 Land access for new topographic survey was not possible and so the model was built using available LiDAR information supplemented by Mastermap and OS map data.

7.1.2 All channels have been represented in 2D as the 0.2m LiDAR data captures the channel width but not the full extent of the channel depth. Channel conveyance is therefore not fully represented in the model. This is likely to have resulted in a conservatively high estimate of peak flood levels.

7.1.3 Calibration was not possible due to a lack of available historical data.

# 8 Conclusions and recommendations

8.1.1 The model results indicate that there will be an increase in peak flood levels from construction of the Proposed Scheme, without mitigation, in the immediate vicinity of the Proposed Scheme of approximately 90mm upstream and 20mm downstream.

8.1.2 The modelling has shown moderate localised increases and minor decreases in peak flood levels at the embankment of Proposed Scheme that are not associated with the Small Brook watercourse. This is a result of the direct rainfall modelling approach, where small flow paths defined in the topography result in surface runoff that can be interrupted by the Proposed Scheme. These flow paths, that are not associated with a watercourse, will be collected by the toe drains at the foot of the Proposed Scheme embankment.

8.1.3 Blockage and sensitivity analyses indicate that the results are not unduly sensitive to changes in key input variables.

8.1.4 The model results indicate that the Proposed Scheme achieves the freeboard requirements for both the top of rail level and the Proposed Scheme watercourse crossing soffits.

8.1.5 At detailed design stage, the hydraulic modelling of the watercourse should be revisited. Topographic survey data of the channel and structures should be collected and used to extend the model to cover the full modelled extent reported in this document. The updated model should be used to develop the detailed hydraulic design of the Proposed Scheme with a view to reducing impacts in peak flood levels as far as is reasonably practicable. The model should also be used to verify the magnitude of residual impacts (if any) of the final scheme design, for consenting purposes.

# Annex A: Flood level impact maps

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

### Figure A 1: Small Brook impact map for 5.0% AEP (1 in 20 year)

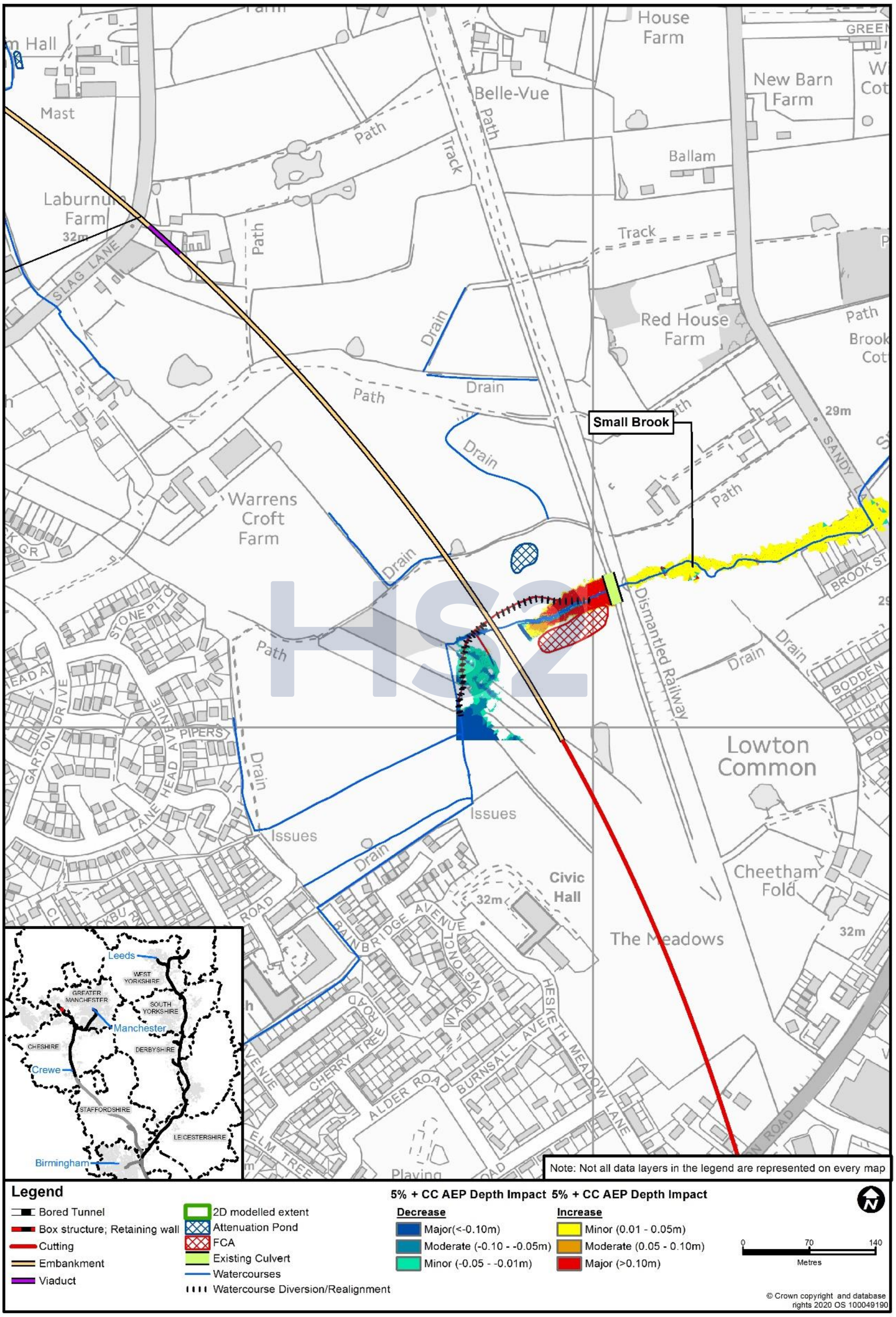
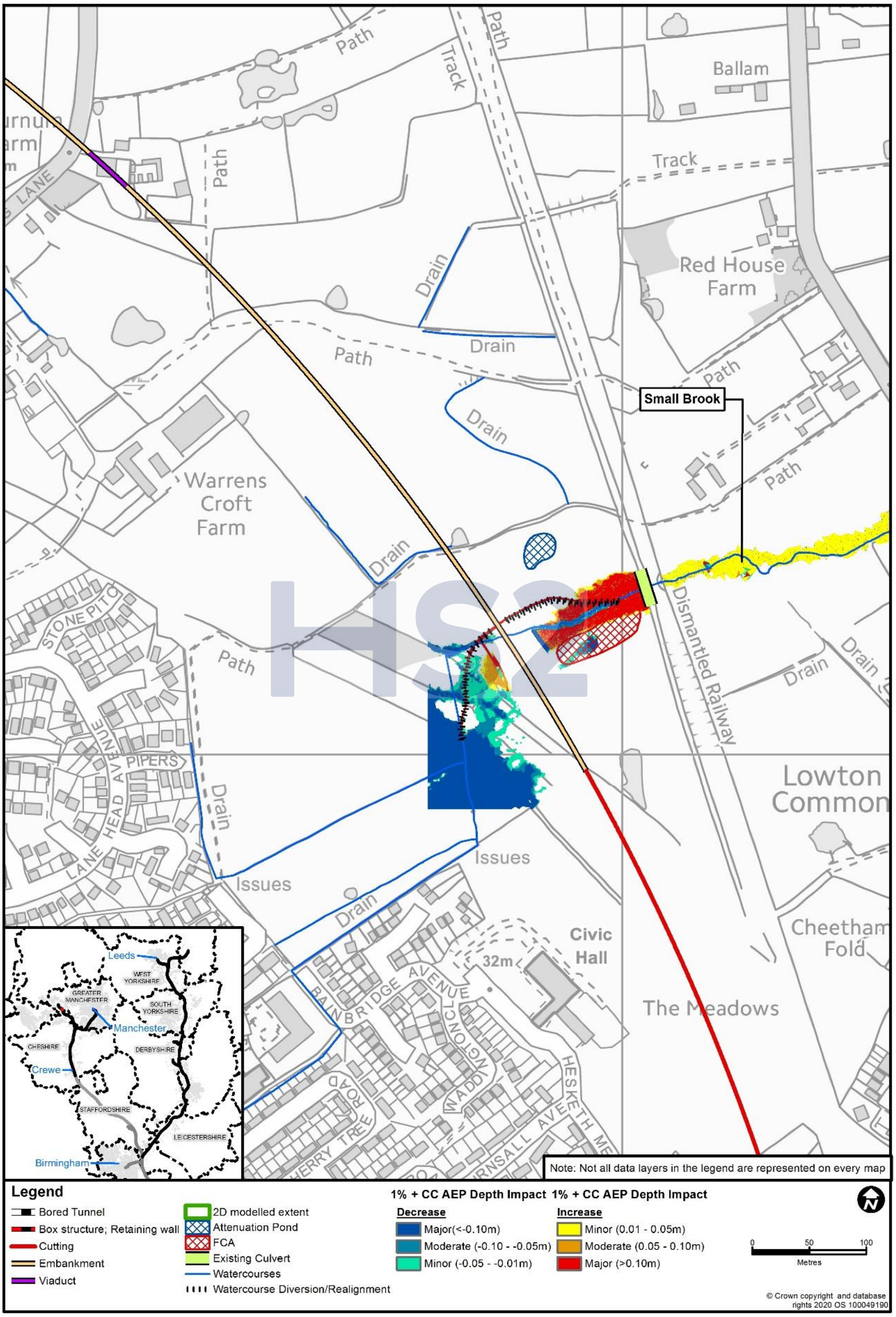


**Figure A 2: Small Brook impact map for 1.0% AEP (1 in 100 year plus climate change)**



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