A12 Chelmsford to A120 widening scheme

TR010060

DEVELOPMENT CONSENT ORDER CHANGE APPLICATION CONSULTATION

FLOOD RISK ASSESSMENT ADDENDUM

Advice Note 16 (Version 3) 2023

May 2023

Infrastructure Planning

Planning Act 2008

Advice Note 16 (Version 3) 2023

A12 Chelmsford to A120 widening scheme

Development Consent Order 202[ ]

Development Consent Order Change Application: Flood Risk Assessment Addendum

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Regulation Reference	Advice Note 16 (Version 3) 2023
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Author	A12 Project Team & National Highways

Version	**Date**	**Status of Version**
Rev1	May 2023	DCO Change Application

CONTENTS

LIST OF PLATES

LIST OF TABLES

1 Introduction

1.1 Background

1.1.1 This Change Application relates to an application submitted by National Highways (the Applicant) to the Secretary of State for Transport (through the Planning Inspectorate) for a development consent order (DCO) under the Planning Act 2008. The A12 Chelmsford to A120 Widening Scheme (the proposed scheme) involves widening the A12 to three lanes throughout (where it is not already three lanes) with a bypass between junctions 22 and 23 and a second bypass between junctions 24 and 25. It also includes safety improvements, including closing off existing private and local direct accesses onto the main carriageway, and providing alternative provision for walkers, cyclists and horse riders to existing routes along the A12, which would be removed.

1.1.2 A DCO application for the proposed scheme was accepted for examination by the Planning Inspectorate on the 12th of September 2022 (DCO Application). The proposed scheme is currently in examination which started on 12th January 2023 and is due to close on 12th July 2023.

1.1.3 Since the DCO application was made, the Applicant has continued to engage and refine designs to identify opportunities to further improve the proposals. As a result of this, the Applicant is proposing six changes to the proposed scheme during the Examination stage to address suggestions by interested parties and to implement improvements to the proposed scheme.

1.1.4 This Change Application comprises the Applicant's request to the Examining Authority (appointed by the Planning Inspectorate) to accept into the Examination of the DCO Application six changes to the proposed scheme for which development consent is sought.

1.1.5 On 30 March 2023, in accordance with paragraph 3.2 of Advice Note 16: Requests to change applications after they have been submitted for examination (AN16), the Applicant submitted its Change Notification to the Examining Authority (ExA) [REP2-031] (Change Notification). The Change Notification set out the Applicant's intention to make a change request, detailed its consultation proposals and confirmed the likely date for the Change Application to be submitted as 30 May 2023. The Change Notification also provided the details and background to the Applicant's request for the proposed changes as required by Figure 2a of AN16.

1.1.6 The proposed six changes to the proposed scheme in summary are:

- Junction 19 – redesign of north bound on slip road
- Exclusion of Anglian Water pumping station from land proposed for compulsory acquisition at Hatfield Peverel
- Changes to the provision of replacement land at Whetmead and additional consequential changes reflecting change of ownership for open space in the Witham area
- Drainage works associated with B1023 Kelvedon Road at Inworth

- Junction 24/Inworth Road B1023 - Removal of the segregated left turn lane
- Junction 25 - Removal of the signalised crossroads and partial signalisation of the existing roundabout at A120/junction 25

1.1.7 The ExA responded to the Applicant's Change Notification on 6 April 2023 [PD-011] confirming that the Applicant had satisfied the requirements of Figure 2a of AN16 and acknowledged the Applicant’s intent to submit a Change Application (Rule 9 Letter). In the Rule 9 Letter the ExA also confirmed the information required by Step 2 of AN16. Purpose of this document.

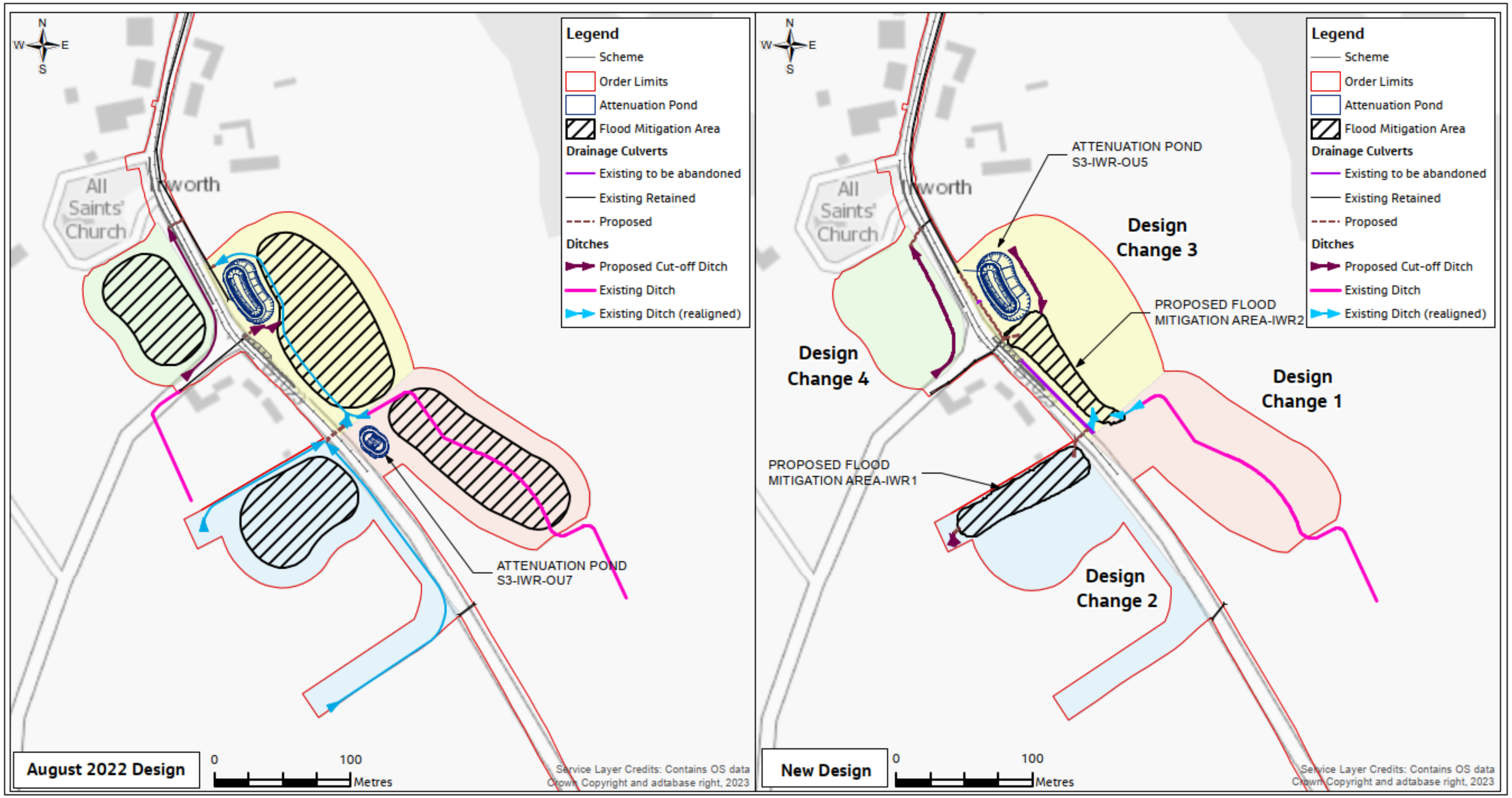
1.2 Purpose of Flood Risk Assessment (FRA) Addendum

1.2.1 This Flood Risk Assessment (FRA) Addendum provides an updated assessment of the flood risk to the B1023, Inworth Road, and an assessment of the impact of the proposed changes to the A12 Chelmsford to A120 widening scheme development consent order (DCO) application (the ‘DCO change application’). This FRA addendum is intended to supersede the information provided in Section 3.3 of the Flood Risk Assessment submitted with the DCO application [APP-162] relating to the flood risk to the B1023 due to Ordinary Watercourses.

1.2.2 The changes to the proposed scheme are illustrated on Plate 1.1 and Plate 1.2 (numbered design changes labelled on the plates are described in Tables 1.1 and 1.2). In relation to flood risk and drainage, the proposed changes primarily consist of changes to drainage ponds and flood mitigation areas, along with associated watercourse and culvert works. The proposed changes result in a reduced number of flood storage areas and drainage ponds from those presented in the original FRA [APP-162], while still achieving the design standards for the proposed scheme.

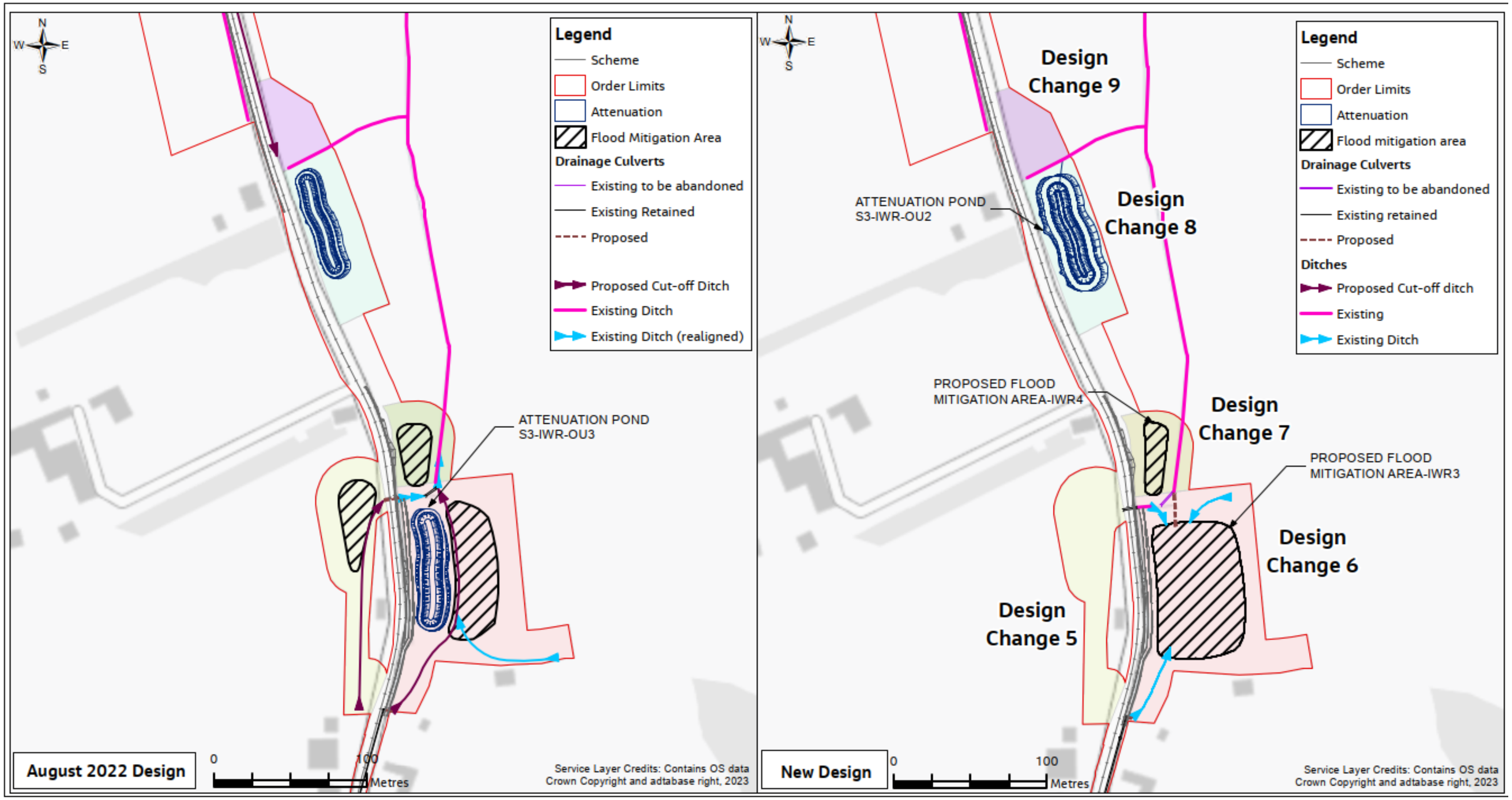
1.2.3 Further information on the proposed drainage changes can be found in the Surface Water Drainage Strategy Addendum that has been submitted with the DCO change application [TR010060/EXAM/10.17].

Plate 1.1 New design proposals as part of the DCO change application in comparison with DCO design submitted in August 2022 (cluster area 1)*



*Although the New Design flood mitigation areas shown above have been based on the results of the hydraulic modelling undertaken, the design of these areas has since been further developed (to allow consideration for grading of earthworks etc) and as a result the outlines of the flood mitigation areas shown in this figure do not exactly match modelling outputs shown elsewhere in this report.

Plate 1.2 New design proposals as part of the DCO change application in comparison with DCO design submitted in August 2022 (cluster area 2)*



*Although the New Design flood mitigation areas shown above have been based on the results of the hydraulic modelling undertaken, the design of these areas has since been further developed (to allow consideration for grading of earthworks etc) and as a result the outlines of the flood mitigation areas shown in this figure do not exactly match modelling outputs shown elsewhere in this report.

Table 1.1 Summary of design changes - drainage and flood mitigation measures in the vicinity of the B1023 near Inworth (cluster area 1)

Land take area reference from Plate 1.1	New design solution
Design Change 1	**Attenuation pond S3-IWR-OU7 has been removed.** There are no highway widening works within the catchment S3-IWR-OU7 boundary. Hydraulic checks indicate minor increase in flows due to an increase in rainfall values for climate change allowance which will be manageable through localised upgrades to drainage collection features. The DCO design submitted in August 2022 included a flood mitigation storage area that would have required excavation over a gas main, the location of which was unknown at DCO stage design. The new design has taken this constraint into account and developed the solution through hydraulic modelling that confirmed **removal of the flood mitigation measures in this area**.
Design Change 2	**New drainage ditches adjacent to the B1023 near Inworth** that were considered previously as part of flood risk mitigation **are not required**. New design proposal has considered the constraint imposed by an existing gas main and has been informed by hydraulic modelling. The **new design (proposed flood mitigation - IWR1) provides a reduction in the flood mitigation storage area requirements**.
Design Change 3	**Attenuation pond S3-IWR-OU5 has been retained**. The **new design proposal (proposed flood mitigation – IWR2)** has been informed through hydraulic modelling and provides a **reduction in the flood mitigation storage area requirements**.
Design Change 4	The new design has been developed through hydraulic modelling which has confirmed the **removal of flood mitigation measures in this area**. The **proposed drainage ditch is retained**, although it is required to move further away from the road and is enlarged to capture the overland runoff from the catchment upstream which forms part of the overall solution for flood mitigation measures in this area.

Table 1.2 Summary of design changes - drainage and flood mitigation measures in the vicinity of the B1023 near Inworth (cluster area 2)

Land take area reference from Plate 1.2	New design solution
Design Change 5	**New drainage ditch and flood mitigation storage area** adjacent to the B1023, near Inworth, that were considered for the design submitted at DCO **are not required**. Existing field drains/ditches found in the location of the new drainage ditch will be retained.
Design Change 6	A new design solution has been developed to optimise the combined design solutions that would work for the mitigation required for the highway drainage (attenuation storage) and for the flood risk mitigation storage. **Attenuation pond S3-IWR-OU3 has been removed** and the highway drainage catchment is now diverted to attenuation pond S3-IWR-OU2. **Flood mitigation storage area (proposed flood mitigation area – IWR3)** has been informed through hydraulic modelling and has **increased in area** (i.e. in comparison to the DCO design submitted in August 2022 but is still within the Order Limits).
Design Change 7	**Flood mitigation storage area (proposed flood mitigation area – IWR4)** is proposed to be retained. Minor adjustments will be required to minimise the impact to the existing foul sewer in the area.
Design Change 8	**Attenuation Pond S3-IWR-OU2 is retained**. Note there has been an **increase in the attenuation storage volume for attenuation pond S3-IWR-OU2** (i.e. in comparison to the DCO design submitted in August 2022 but is still within Order Limits) as a result of the additional highway drainage catchment draining to this attenuation storage pond which was previously associated to attenuation pond S3-IWR-OU3 (i.e. Design Change 6). Attenuation pond S3-IWR-OU2 has been adjusted locally to minimise the impact on the existing foul sewer located in this area.
Design Change 9	This area is considered as potential attenuation for the highway drainage for catchment S3-IWR-OU1 that will be **reduced in size** as this catchment now drains through proposed catchment S3-OU8B+OU8D. Refer to consultation Sheet 20 of the updated Surface Water Drainage plan in Map Book 4 [TR010060/EXAM/10.8] submitted with the DCO change application for the revised catchments for the proposed S3-OU8B + OU8D catchments that includes the diverted existing S3-IWR-OU1 catchment.

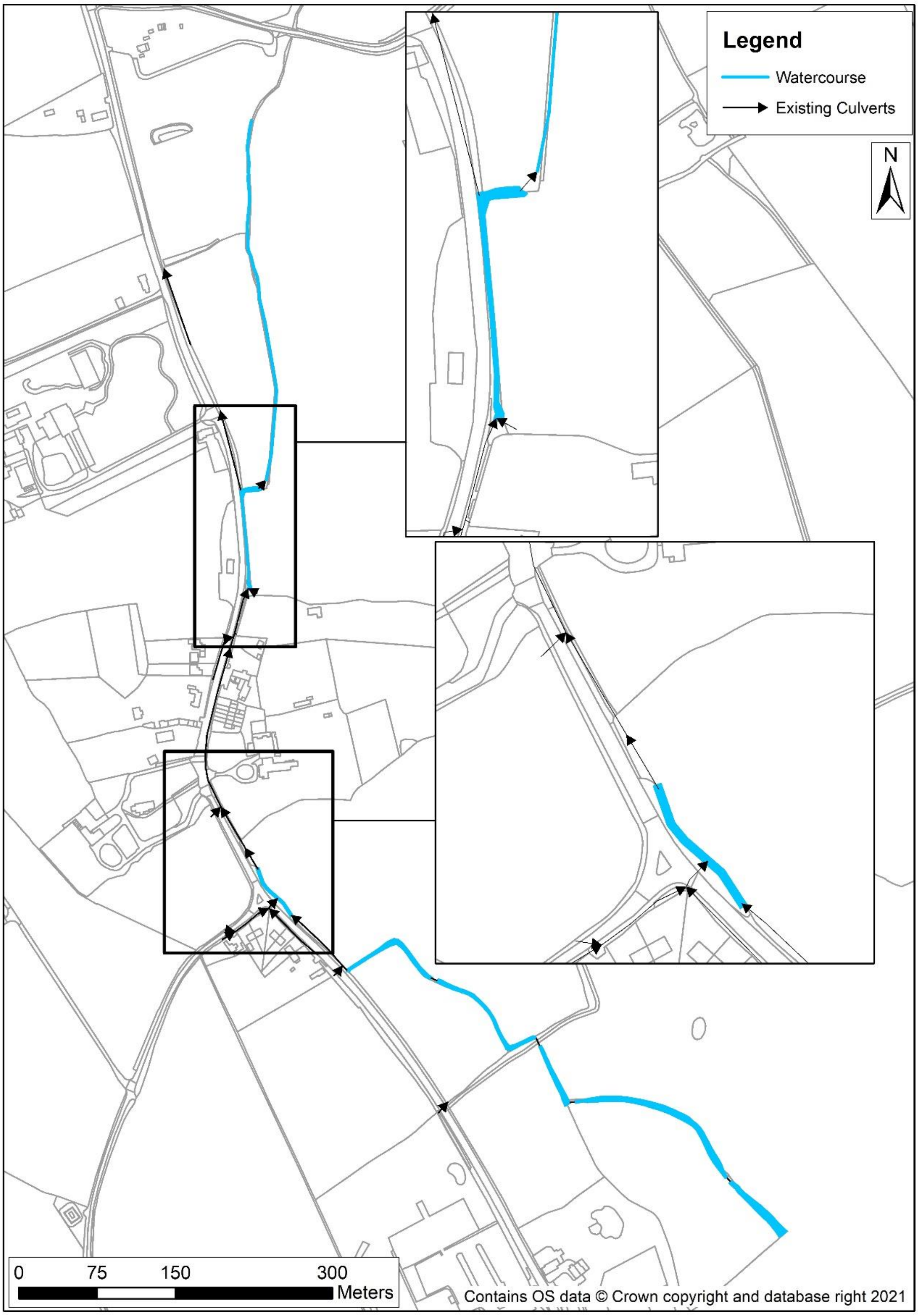
2 Baseline scenario

2.1 Baseline flood risk

2.1.1 Ordinary Watercourse 34 and its tributaries are closely aligned with, or crossed by, the B1023 (shown on Plate 2.1).

2.1.2 Ordinary Watercourse 34 originates east of the B1023, north-west of Tiptree, and flows north-west along a ditch before reaching the B1023. Ordinary Watercourse 34 flows are then conveyed approximately 75m northwards through a pipe (850mm diameter) before outfalling into an open ditch aligned alongside the B1023. Flows continue northwards approximately 60m through the open ditch before entering a pipe system (pipes with diameters of 900mm, 1000mm and 650mm consecutively) and continuing north approximately 290m. Flows then outfall into an open channel which conveys flows northwards alongside the B1023 for approximately 100m before the channel veers north-east (diverging away from the B1023), conveying flows a further 1.1km north-east (including flowing underneath Kelvedon Road) before the Ordinary Watercourse's confluence with the Domsey Brook Main River (approximately 210m upstream (east) of the existing western A12 crossing of the Domsey Brook).

Plate 2.1 B1023 baseline watercourse layout



2.2 Hydraulic modelling of Ordinary Watercourses associated with the B1023

2.2.1 Hydraulic modelling has been undertaken to determine existing flood risk, to assess the impact of the operational phase of the proposed scheme, and to design appropriate mitigation as required.

2.2.2 There are uncertainties, limitations, and assumptions associated with the modelling. Refer to the hydraulic modelling report (Annex A of this FRA addendum) for full details. Notably, modelling does not include representation of the road drainage system, however, surface water runoff from the road is included in the input hydrology of the model. This is considered to be a conservative representation as flood risk in reality would be anticipated to be reduced from that modelled as the road drainage network (not represented in the model) would receive a portion of the surface water runoff.

2.2.3 It should also be noted that CCTV survey of the existing water conveyance structures identified that an existing drainage chamber has collapsed. Modelling undertaken assumes that this would be repaired/replaced and would therefore be functioning as intended in both the baseline and with scheme scenarios.

2.3 Baseline modelled flooding

2.3.1 Modelled baseline flood extents (5% (1 in 20) Annual Exceedance Probability (AEP) event, 1% (1 in 100) AEP event, and 1% (1 in 100) AEP event plus 45% allowance for climate change) are included in Plate 2.2. Modelled baseline flood depths for the 1% (1 in 100) AEP event plus 45% allowance for climate change are included in Plate 2.3.

2.3.2 The existing B1023 is at risk of fluvial flooding during all modelled baseline flood events. During the 5% (1 in 20) AEP event, the majority of flooding predicted on the B1023 has depths of <100mm. The maximum depth of flooding predicted to be experienced by the road (approximately 140mm) occurs where Inworth Hall Farm access road (north) joins the B1023. During the 1% (1 in 100) AEP plus 45% climate change event, the predicted flooding is deeper in many areas, with a maximum depth of flooding on the road of 175mm.

Plate 2.2 B1023 modelled baseline fluvial flood extents

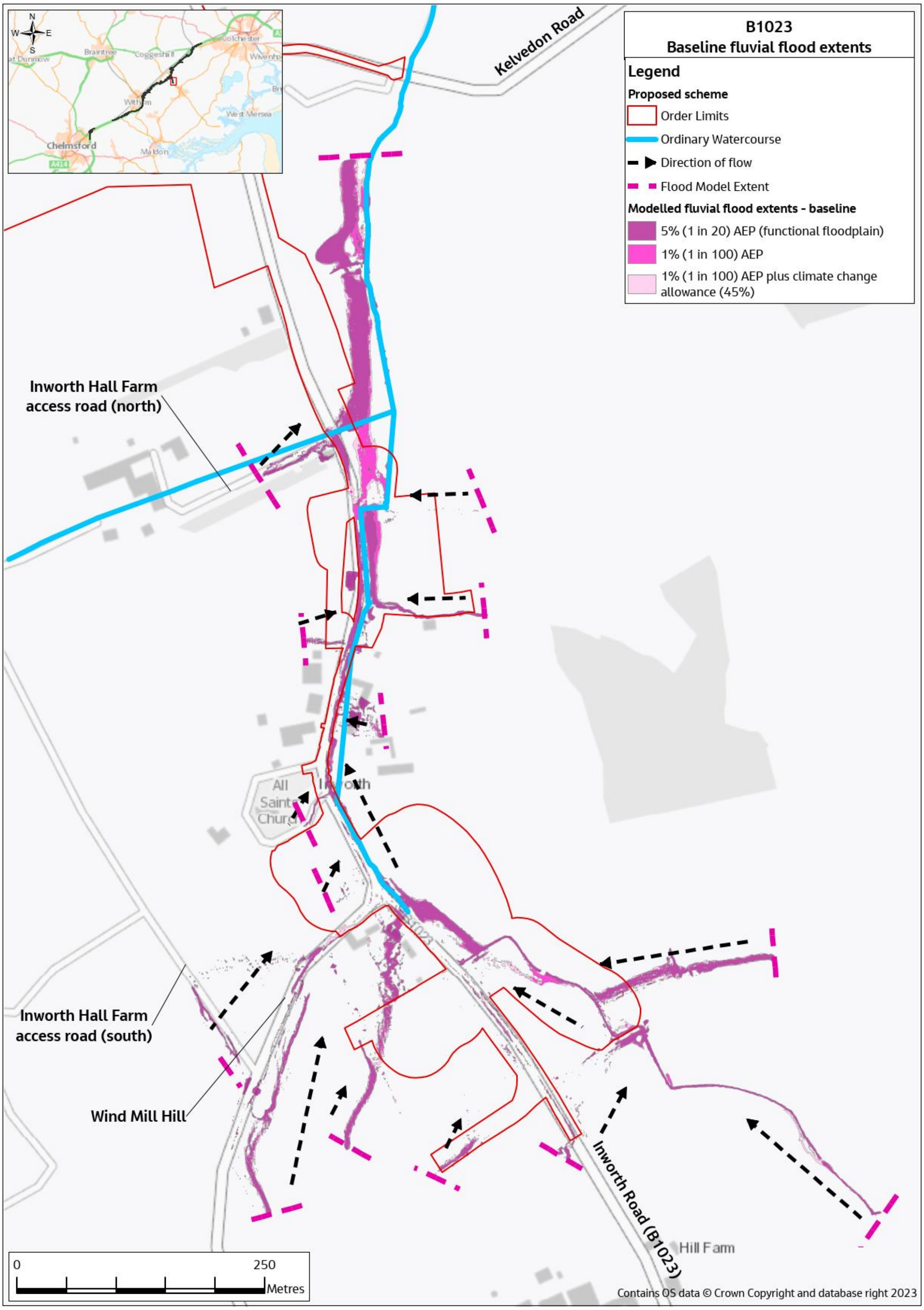
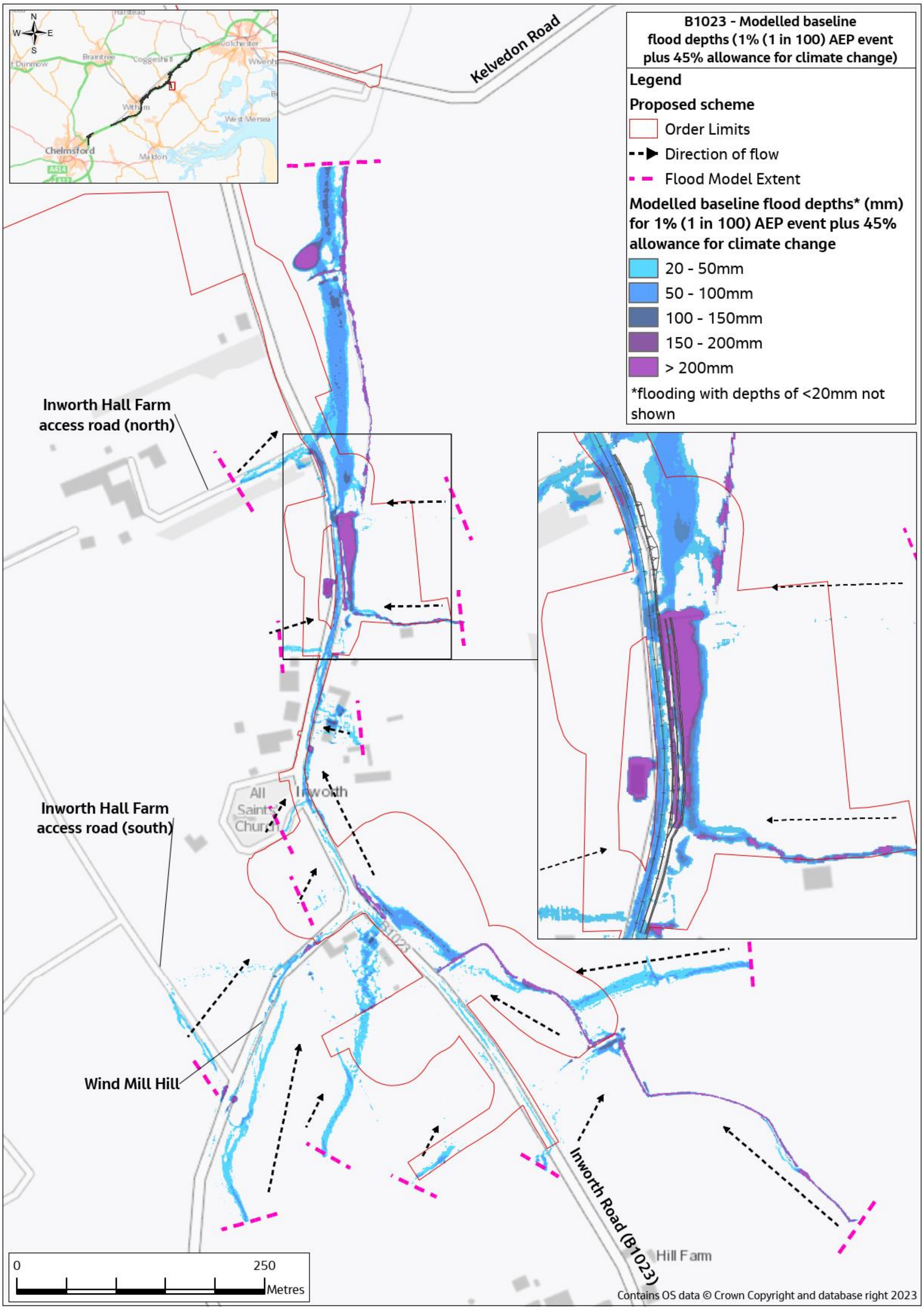


Plate 2.3 Modelled flood depths experienced by B1023 during 1% (1 in 100) AEP plus 45% allowance for climate change event



3 With-scheme scenario

3.1 Proposed scheme design

3.1.1 The proposed scheme works to the B1023 are illustrated on Sheets 14 and 20 of the DCO General Arrangement Plans [AS-012 and AS-013].

3.1.2 To accommodate the predicted traffic flow and improve the safety of road users along the B1023, carriageway widening between the proposed junction 24 roundabout and the Perrywood Garden Centre has been proposed. The proposed carriageway widening ranges from 0.25m to approximately 1.5m. The main purpose of the widening is to improve the substandard width of the existing carriageway and also to remove the pinch-points along the curvatures of the road to facilitate the smooth flow of traffic and reduce the risk of collisions between heavy goods vehicles.

3.2 Flood risk to the proposed scheme (pre-mitigation)

3.2.1 The risk of flooding predicted for the B1023 following the proposed online widening is unlikely to differ materially from that of the baseline situation (Section 2.3 of this FRA addendum). It is predicted that the finished proposed scheme would experience maximum flood depths of up to 175mm during the 1% (1 in 100) AEP plus 45% allowance for climate change event. Therefore, flood mitigation is required at this location to reduce the existing level of flood risk.

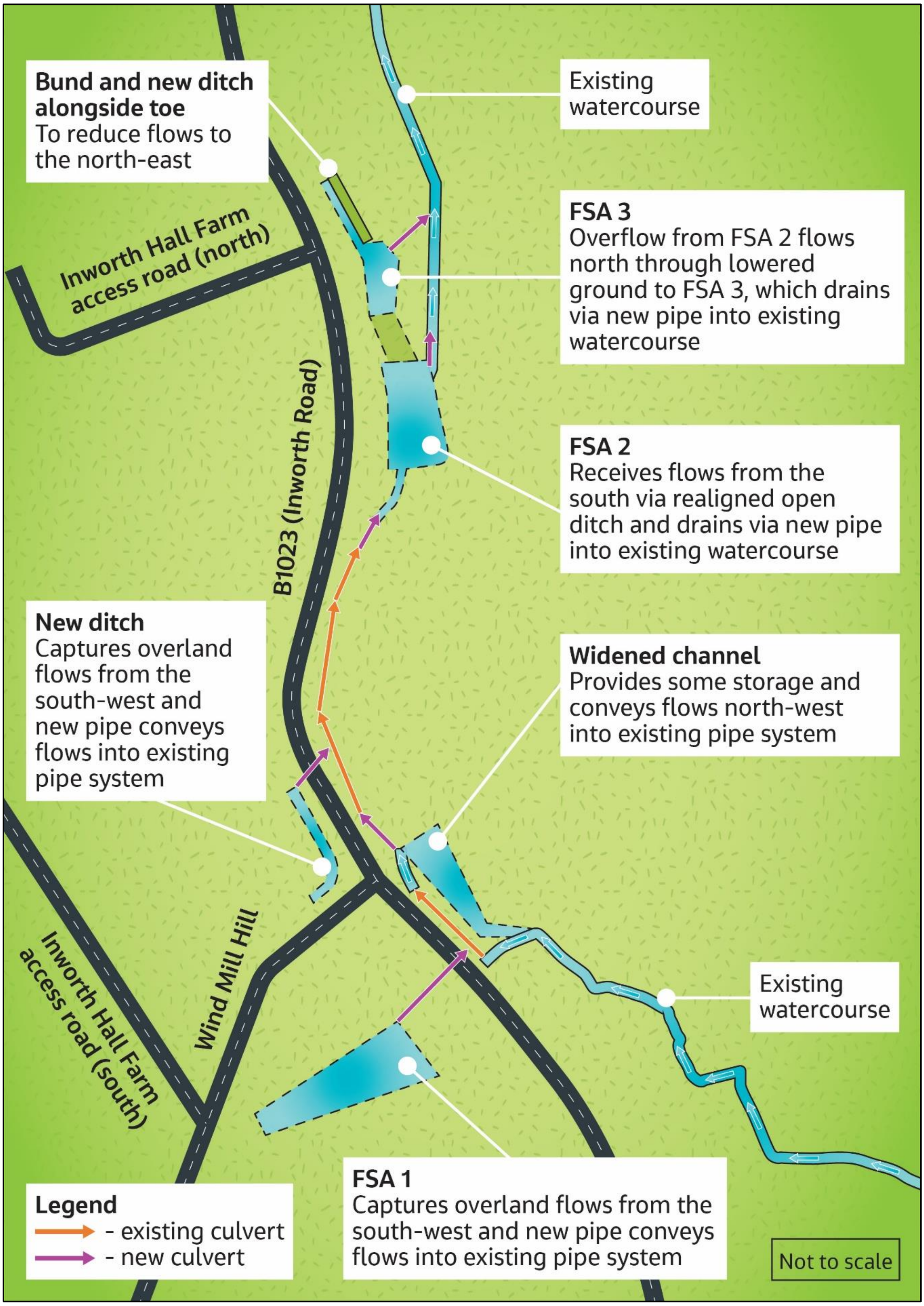
3.3 Proposed mitigation

3.3.1 The following mitigation measures have been included in the proposed scheme to reduce the risk of flooding (see Plate 3.1 for indicative illustration of proposed mitigation works, and Annex A of this FRA addendum for more detailed description of proposed mitigation works):

- Three excavated flood storage areas (FSA); south to north, FSA 1, FSA 2 and FSA 3
- Lowering of ground between FSA 2 and FSA 3 to facilitate FSA 2 overflow conveyance into FSA 3 during extreme rainfall events
- Widening of an existing channel
- Various new and realigned ditches to capture flows and convey them to the proposed flood storage areas
- A bund (with drain along the toe)
- Summary of culverted watercourses associated with the proposed flood mitigation measures as provided in Annex B of this FRA Addendum

3.3.2 These changes reduce the number of FSAs from five to three as well as reducing the size of those provided, compared to the mitigation in the original FRA [APP-162]. The changes result in reduced land requirements, lower environmental impact and lower costs, while still providing sufficient mitigation of the existing flood risk to meet design requirements.

Plate 3.1 Proposed B1023 flood mitigation works (indicative)



3.3.3 Table 3.1 details the maximum volume of water the proposed flood storage areas are predicted to contain, and the total length of time the flood storage areas would contain water during each of the events modelled.

Table 3.1 Modelled maximum water volume and total length of time water stored in proposed flood storage areas

Flood event	Maximum volume of water stored in flood storage area	Total length of time water stored in flood storage area
Flood storage area 1		
5% (1 in 20) AEP	139 m^3	18 hrs*
1% (1 in 100) AEP	182 m^3	19 hrs*
1% (1 in 100) AEP plus 45% allowance for climate change	261 m^3	19 hrs*
Flood storage area 2		
5% (1 in 20) AEP	1651 m^3	18 hrs*
1% (1 in 100) AEP	2183 m^3	18 hrs*
1% (1 in 100) AEP plus 45% allowance for climate change	2323 m^3	18 hrs*
Flood storage area 3		
5% (1 in 20) AEP	<1 m^3	<1 hr
1% (1 in 100) AEP	181 m^3	10 hrs
1% (1 in 100) AEP plus 45% allowance for climate change	1194 m^3	15 hrs

*Approximation extrapolated from longest model run completed (15hrs)

3.4 With-scheme modelling (including mitigation)

3.4.1 The proposed mitigation has been included in the with-scheme modelling. The modelled change in flood extent predicted for the proposed scheme (including mitigation) for the 1% (1 in 100) AEP event plus 45% allowance for climate change is shown on Plate 3.2. Modelled changes in flood depth predicted for the proposed scheme (including mitigation) are shown on Plate 3.3 (5% (1 in 20) AEP event) and Plate 3.4 (1% (1 in 100) AEP event plus 45% allowance for climate change).

Plate 3.2 B1023 - modelled change in flood extent predicted for the proposed scheme (including mitigation works) (1% (1 in 100) AEP event plus 45% allowance for climate change)

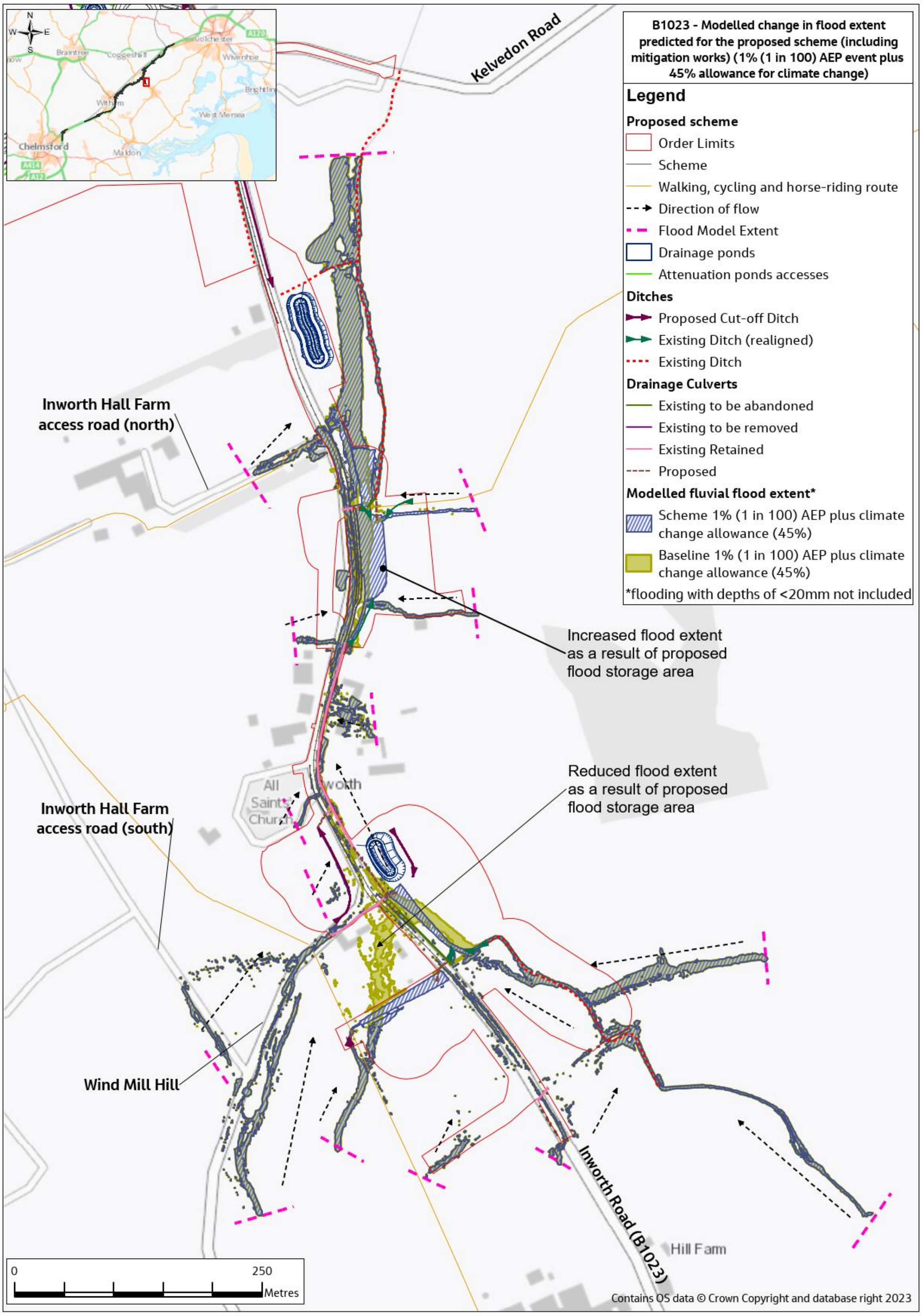


Plate 3.3 B1023 - modelled change in flood depths predicted for the proposed scheme (including mitigation works) (5% (1 in 20) AEP event)

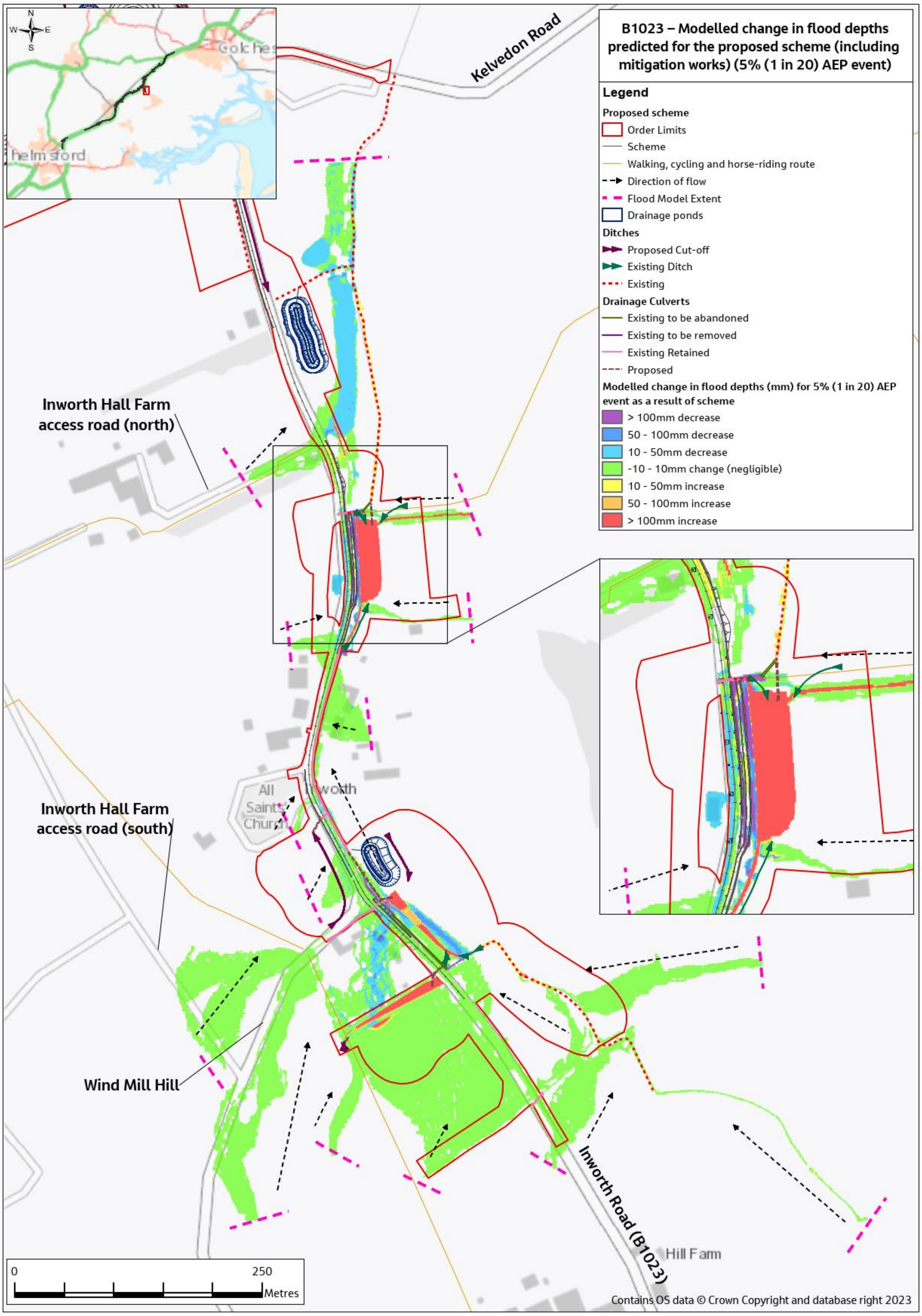
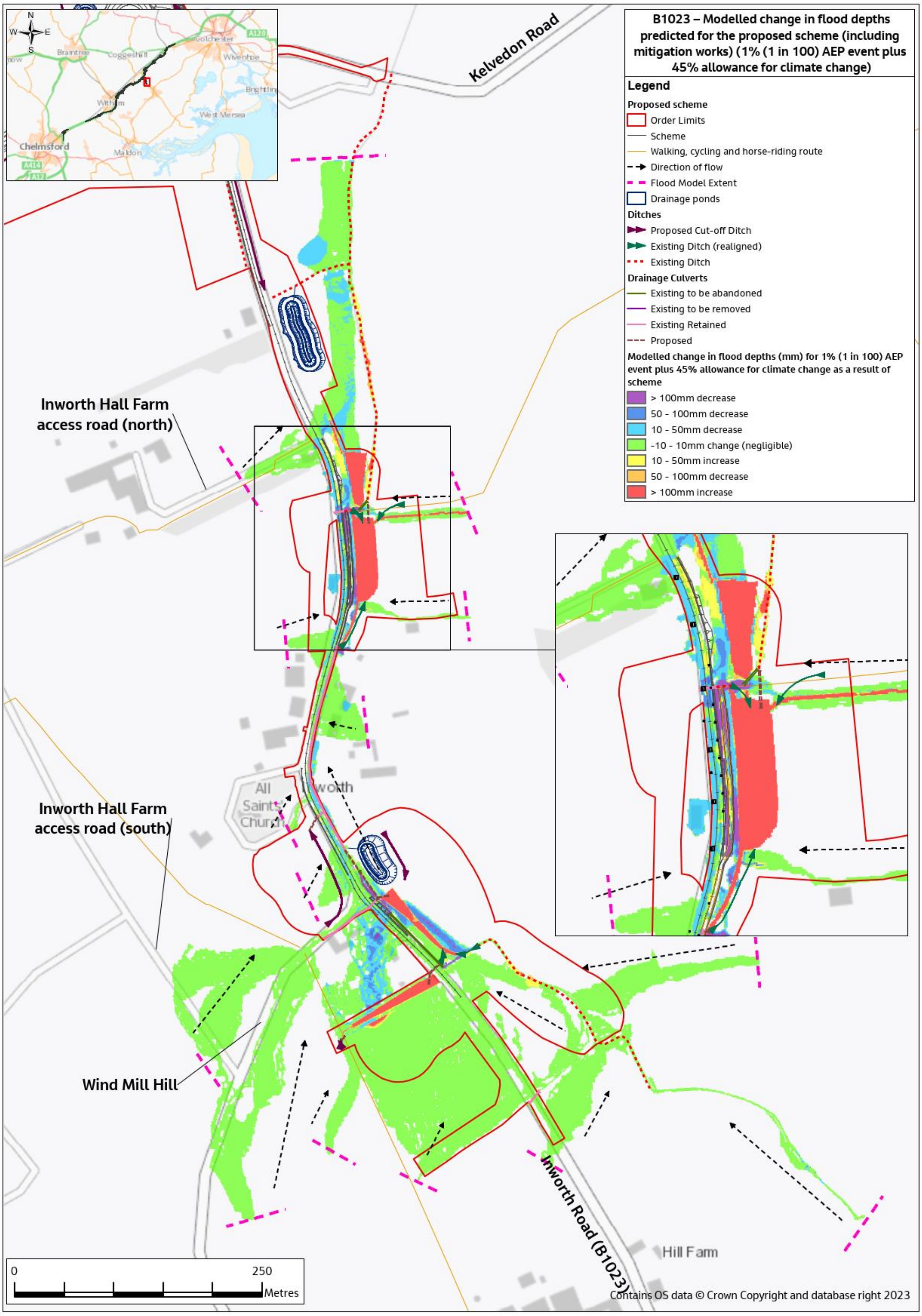


Plate 3.4 B1023 - modelled change in flood depths predicted for the proposed scheme (including mitigation works) (1% (1 in 100) AEP plus 45% allowance for climate change event)



3.5 Flood risk to the proposed scheme (post-mitigation)

3.5.1 The inclusion of the proposed mitigation measures generally results in decreased flood risk to the B1023 in comparison to the baseline situation (see Plate 3.3 and Plate 3.4). However, with-scheme (including mitigation) modelling does show that the road experiences some residual flood risk. Modelled with-scheme (including mitigation) flood depths are shown on Plate 3.5 (1% (1 in 100) AEP event plus 45% allowance for climate change).

3.5.2 With the inclusion of the proposed mitigation measures, flood levels on the B1023 would generally not exceed 100mm in up to a 1% (1 in 100) AEP event plus 45% allowance for climate change. There are three locations where peak flood depth on the road would exceed 100mm. These are all low velocity flow paths along the side of the road (as opposed to directly across the road as in the baseline scenario), and therefore the road would remain passable under such flood conditions.

3.5.3 With the inclusion of the proposed mitigation measures, the total duration of flooding (>0mm depth) occurring on the road would not exceed 15hrs in up to a 1% (1 in 100) AEP event plus 45% allowance for climate change. The duration for which flood depths on the road would exceed 100mm would be considerably shorter than 15hrs.

3.5.4 It has not proved practicable to completely remove this residual flooding due to the local topography and constraints on the size and location of flood storage areas due to local services, public rights of way and the invert level of downstream watercourses.

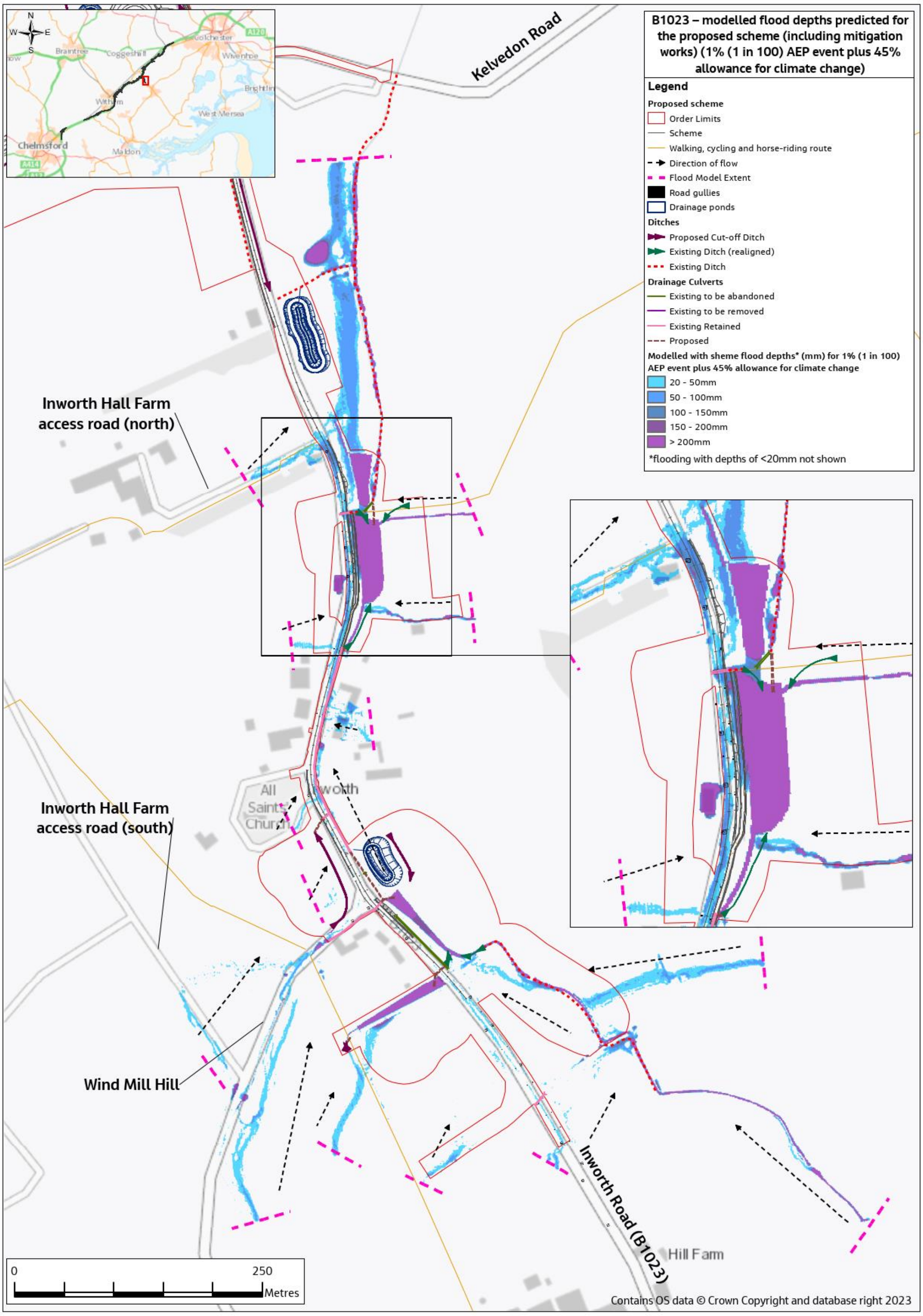
3.6 Flood risk from the proposed scheme

3.6.1 The proposed scheme results in an increase in flood depths immediately upstream of FSA 1 for all modelled rainfall events. The proposed scheme also results in an increase in flood depths to the area in between FSA 2 / FSA 3 and the B1023 for all modelled flood events. These areas for which the proposed scheme causes increased flood risk would be acquired by National Highways for the purpose of the proposed scheme and would remain as unused land (i.e. this land does not and would not contain any receptors which could be harmed by the increase in peak flood depth). Therefore, it is not anticipated that any further flood mitigation would be required to mitigate these areas of increased flood risk.

3.6.2 The proposed scheme results in an increase in water depths within the existing watercourse channel downstream of FSA 2 and FSA 3 for all modelled flood events (maximum increase of approximately 240mm during the 1% (1 in 100) AEP event plus 45% allowance for climate change). This effect of increased water level within the channel is not sustained for the length of the downstream reach of model extent as reduced flows from the west result in water levels with negligible change from existing by approximately 250m downstream of the mitigation areas. There would be negligible change in the total volume of flows from this watercourse entering the Domsey Brook as a result of the proposed mitigation. The areas of increased water level within the watercourse do not result in any out of bank flooding.

3.6.3 The proposed scheme causes negligible (<10mm change in depth) or beneficial change to flood risk elsewhere for all modelled flood events. The proposed scheme would result in major beneficial effects to flood risk on the B1023.

Plate 3.5 B1023 - modelled with scheme (including mitigation works) flood depths (1% (1 in 100) AEP plus 45% allowance for climate change)



4 Conclusion

4.1.1 The updated flood risk assessment of the impact of the DCO change application on the B1023 concludes that with proposed mitigation measures in place, the proposed scheme would result in a reduction in flood risk to the B1023, such that the road would remain operational in a 1% (1 in 100) event plus 45% climate change.

4.1.2 There is residual risk to the road in a 1% (1 in 100) event plus 45% climate change, however it is not considered practicable to resolve this flooding given the constraints.

4.1.3 The mitigation measures are predicted to cause areas of increased flood risk in discrete areas of unused land that does not and would not contain any receptors that could be harmed by an increase in peak flood depth.

Annex A B1023 hydraulic modelling report

A12 Chelmsford to A120 widening scheme

TR010060

DEVELOPMENT CONSENT ORDER CHANGE APPLICATION CONSULTATION

FLOOD RISK ASSESSMENT – MODELLING ANNEX

Advice Note 16 (Version 3) 2023

May 2023

Infrastructure Planning

Planning Act 2008

A12 Chelmsford to A120 widening scheme

Development Consent Order 202[ ]

DEVELOPMENT CONSENT ORDER

CHANGE APPLICATION CONSULTATION: FLOOD RISK ASSESSMENT – MODELLING ANNEX

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CONTENTS

APPENDICES

LIST OF PLATES

LIST OF TABLES

0 Executive Summary

0.1.1 This report describes the hydraulic modelling and the results obtained, for the existing and proposed-scheme of Inworth Road running alongside Minor Watercourse 34 (MWC34), at NGR grid reference TL88010. The modelling and hydrological analyses have been undertaken in line with the latest relevant industry standards, using the most up to date available data, including detailed topographic survey. The model is a 2-dimensional (2D) type using TUFLOW software (BMT, 2022) and was built from scratch.

0.1.2 Three design events were simulated; these are the 5% (1 in 20), 1% (1 in 100) and 1% (1 in 100) Annual Exceedance Probability (AEP) plus 45% climate change (CC). No flow reconciliation was required to be carried out for the design hydrology. No data was available for calibration, but the model was verified using the Environment Agency (EA) surface water flood maps. Sensitivity analysis of roughness and inflows was carried out to further validate the results.

0.1.3 The proposed-scheme works to Inworth Road were directly implemented in the mitigation scenario. To accommodate the predicted traffic flow and to improve the safety of the road users along Inworth Road, the widening of the carriageway between the proposed junction 24 roundabout and the Perrywood Garden Centre has been proposed. The proposed carriageway widening ranges from 0.25m to approximately 1.5m.

0.1.4 The baseline (existing) modelling scenario showed that Inworth Road is flooded for all simulated events. Therefore, some mitigation works were required. The main mitigation measures comprised of three ponds located along Inworth Road. These mitigation works were effective in preventing flooding of the proposed-scheme. The mitigation design was also demonstrated to produce negligible flood risk impact on the watercourse downstream from the scheme.

1 Introduction

1.1 Purpose of the report

1.1.1 The A12 Chelmsford to A120 Widening Scheme would improve the A12 between Junction 19 (Boreham) and Junction 25 (Marks Tey). The proposed-scheme includes widening of the A12 to three lanes throughout the length of the scheme plus associated works to junctions and side roads.

1.1.2 A Flood Risk Assessment (FRA) (National Highways, 2022) has been prepared as Appendix 14.5 to the Environmental Statement for the proposed scheme to inform design development and support a Development Consent Order (DCO) application. Hydraulic modelling was required to support the FRA, which took the form of computational hydraulic modelling, including catchment hydrology. Modelled water levels for the baseline scenario, alongside Inworth Road, and the associated flood extents were determined for a range of storm flood events.

1.1.3 The main river crossings for which hydraulic modelling was carried out to support the FRA (listed south to north) are:

- Boreham Brook
- River Ter
- River Brain and Lower Blackwater
- Rivenhall Brook
- Middle Blackwater
- Domsey Brook
- Roman River
- Minor Watercourses 7, 21, 21A, 23, 26, 34 (this report)

1.1.4 This report details the methodology and the results of the hydraulic modelling carried out to assess the baseline scenario for an unnamed tributary of the Domsey Brook. The watercourse is designated as Minor Watercourse 34 based on the A12 drainage design numbering system. This is a technical report, focused on the hydraulic modelling, and therefore the intended audience is those with a reasonable understanding and knowledge of hydraulic modelling principles, although no specific knowledge of particular software is needed.

1.1.5 The Inworth Road will be widened and the drainage system covering Watercourse 34 will also be improved. Additionally, three mitigation ponds and one new ditch will be necessary to shift and reduce floodwater. Full details of the mitigation arrangements are given in Section 7.

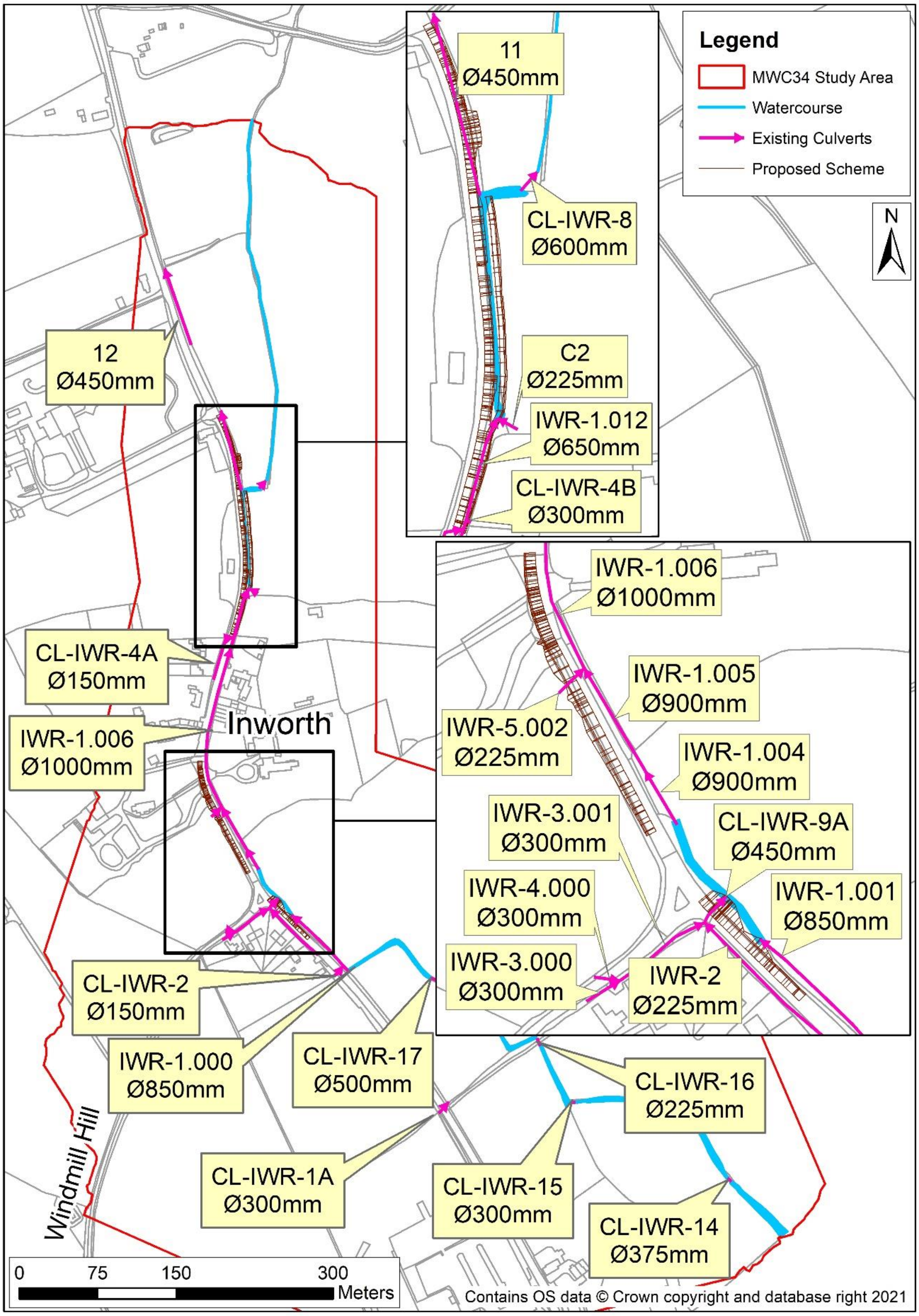
1.1.6 This report should be read in conjunction with the FRA [R10060\APP\6.6] (National Highways, 2022).

1.2 Study area

1.2.1 The study area is detailed below in Plate 1.1. MWC34 is situated between Tiptree and Kelvedon. The modelled area is located to the south-east of the A12 – Kelvedon Bypass. The watercourse originates in the south-east part of the model area and runs north-west to reach Inworth Road (B1023). From here, MWC34 is intercepted by an 850 mm diameter pipe that runs along the road on its eastern side for 75m, then discharges into a 60m long open ditch, before the watercourse enters another 290m long pipe of varying diameter, ranging from 650 to 1000 mm, that also runs along the road. Downstream of this pipe, MWC34 goes parallel to Inworth Road as a man-made open channel for another 100m to the point where it leaves the road and bends to the north-east and becomes a natural watercourse until its confluence with Domsey Brook.

1.2.2 The model extent covers an area of 0.46km^2 and includes a total reach length of approximately 1450m.

Plate 1.1 MWC34 study area



2 Input data

2.1.1 The data used to construct the hydraulic model for MWC34 is summarised in Table 2.1.

Table 2.1 MWC34 hydraulic model inputs

Data	Description	Source
LiDAR	1m resolution composite Digital Terrain Model (DTM) from LiDAR (Light Detection And Ranging) 2020 data. Used to inform the hydraulic model with ground level information.	Department for Environment, Food & Rural Affairs (DEFRA), 2021
Ordnance Survey (OS) Mastermap	Land use data used to specify roughness values across the 2D floodplain.	National Highways, 2022
Outline Design Drawings	Drawings of the proposed-scheme design.	National Highways, 2021
Flood Zone Mapping	EA Risk of Flooding from Surface Water (RoFSW) flood maps. Used for model verification.	Environment Agency
Topographic Survey	Survey data of channel bed levels. Used to represent the bed topography of MWC34.	Costain, 2017-2021
Site Visit Photographs	Photographs of existing culverts taken during a site visit. Used to represent the MWC34 culverts.	MKSurveys & Flowline, 2021

3 Hydrology

3.1 Introduction

3.1.1 Design peak flows and hydrographs were required for input into the numerical hydraulic model of MWC34 at Inworth for the 5% (1 in 20) and 1% (1 in 100) AEP events. The 1% (1 in 100) AEP event is also required including an allowance for climate change (plus CC). For full details of the flow derivation methods and background hydrology, refer to Appendix A– Minor Watercourse 34 Hydrology Annex (HE551497-JAC-EWE-5_SCHME-RP-LE-0013).

3.2 Hydrological considerations

3.2.1 The main road through the village, the B1023, is at risk of flooding and analysis was required to ensure that the risk of potential flooding is not increased by the A12 widening scheme. The Environment Agency's Surface Water Flood Maps (https://flood-warning-information.service.gov.uk/long-term-flood-risk) show flow paths running northwards from Tiptree which then flow in a ditch along the B1023 before continuing as a watercourse north from Inworth, joining the Domsey Brook to the east of Kelvedon.

3.2.2 Catchment descriptors were taken from the FEH webservice [redacted] for the watercourse to the downstream location of flooding on the B1023. The catchment area was checked for accuracy using online OS maps and the FEH website. The catchment was shown not to include a drainage ditch through Perry's Wood. The catchment area was adjusted to include this ditch which increased the size of the catchment from 0.68 to 0.73km^2, or 7%. The DPLBAR was adjusted following guidelines in the Flood Estimation Handbook[1] (FEH) volume 5 from 0.81 to 0.84. All other catchment descriptors remained the same.

3.3 Peak flow derivation

3.3.1 The unnamed watercourse is a small ungauged catchment and therefore flow estimation is likely to be open to great degree of uncertainty. Both ReFH2.3 and FEH Statistical methods were therefore applied to estimate design peak flows for this watercourse. The statistical method included a data transfer from the River Ter at Crabbs Bridge to improve reliability of the QMED estimate.

3.3.2 The pooling group constructed for the Domsey Brook analysis was deemed suitable for estimating the flood growth for the watercourse at Inworth. Details of the construction of the pooling group and calculation of

[1] Institute of Hydrology. (1999). Flood Estimation Handbook Volume 5, Catchment Descriptors. Wallingford

the flood growth factors is documented in document referenced HE551497-JAC-EWE-SCHW-RP-LE-0080.

3.3.3 The ReFH2.3 resulted in higher design peak flow estimates for the unnamed watercourse at Inworth than the FEH Statistical method.

3.3.4 Application of ReFH2.3 on the donor catchment, the River Ter @ Crabbs Bridge gauge suggests that the ReFH2.3 method overestimated the commoner return period flows. However, the ratio of ReFH2.3 to statistical is greater than the equivalent for the River Ter. It was therefore considered prudent to give some weight to the ReFH2.3 estimates and the average of the FEH Statistical and ReFH2.3 flows was used to provide the final peak flows. Hydrograph shapes were derived from the application of ReFH2.3.

3.4 Hydraulic model inflows

3.4.1 A single flow estimate location was required for the hydraulic model at NGR TL 8805 1815. The design inflows are quoted in Table 3.1

Table 3.1 Design peak flows for the unnamed watercourse at Inworth.

Site code	Peak Flow (m^3/s)		
	AEP 20% (1 in 5)	AEP 1% (1 in 100	AEP 1% +CC 45% uplift (1 in 100)
INW	0.62	0.86	1.28

3.4.2 During modelling work it was found that downstream boundary of the model needs to be moved further downstream. Original area of the catchment was revised based on the detail LiDAR and existing drainage network information. The detailed catchment division is represented in the Plate 3.1. The design peak flows for all modelled inflows are quoted in Table 3.2.

Plate 3.1 Sub-catchment schematisation

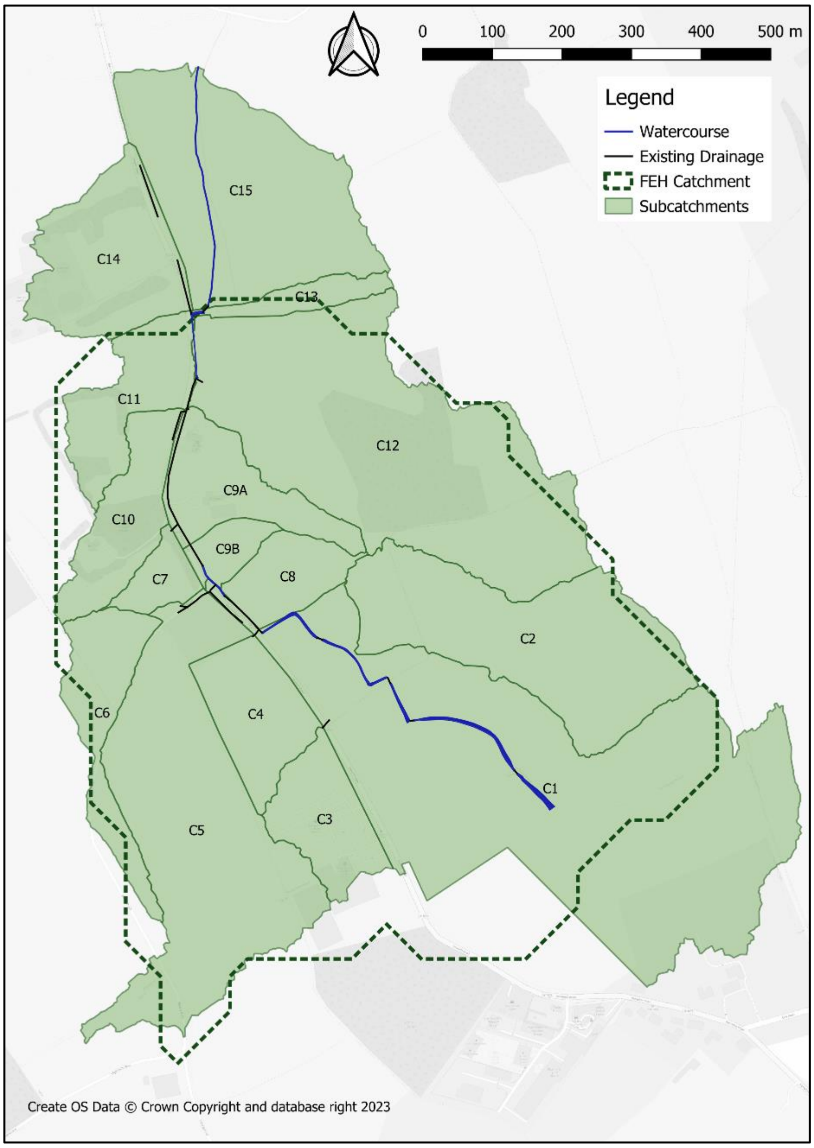


Table 3.2 Final peak flows for the unnamed watercourse at Inworth

Inflow	Percentage of total flow (%)	Peak Flow (m^3/s)		
		AEP 20% (1 in 5)	AEP 1% (1 in 100)	AEP 1% +CC 45% uplift (1 in 100)
C1	25.1	0.19	0.27	0.39
C2	9.1	0.07	0.10	0.14
C3	2.7	0.02	0.03	0.04
C4	3.0	0.02	0.03	0.05
C5_a	6.2	0.05	0.07	0.10
C5_b	6.2	0.05	0.07	0.10
C6	3.0	0.02	0.03	0.05
C7	1.0	0.01	0.01	0.02
C8	1.9	0.01	0.02	0.03

Inflow	Percentage of total flow (%)	Peak Flow (m^3/s)		
		AEP 20% (1 in 5)	AEP 1% (1 in 100)	AEP 1% +CC 45% uplift (1 in 100)
C8A (C8+C9B)	2.8	0.02	0.03	0.04
C9	4.0	0.03	0.04	0.06
C9A	3.1	0.02	0.03	0.05
C9B	0.9	0.01	0.01	0.01
C10	3.0	0.02	0.03	0.05
C11	3.1	0.02	0.03	0.05
C12	16.1	0.12	0.17	0.25
C13	1.0	0.01	0.17	0.25
C14	5.0	0.04	0.01	0.02
C15	9.6	0.07	0.05	0.08

3.4.3 Catchment C5 was divided into two equal point inflows. Location of the inflows is shown on Plate 4.1.

3.4.4 Catchment C9 was divided into two parts to represent portion of flow which will be captured by designed ditch in that catchment. Ditch will be redirecting water into the open channel in the catchment C8. Therefore, inflow C8A is sum of the flow from catchment C8 and C9B applied at the same location as inflow C8.

3.4.5 The rest of the flow from catchment C9 – C9A is applied at the same location as C9 – see Plate 4.1.

3.5 Model runs and critical storm duration

3.5.1 The ReFH model to Inworth was amended to test for the critical storm duration, that is the storm duration that resulted in the maximum peak flow. Runs of the model were tested at 1 hour intervals. The peak flows (1% AEP events) are detailed in Table 3.3 with the maximum peak occurring at 6.5 hours.

Table 3.3 Peak flows produced during assessment of the critical storm duration

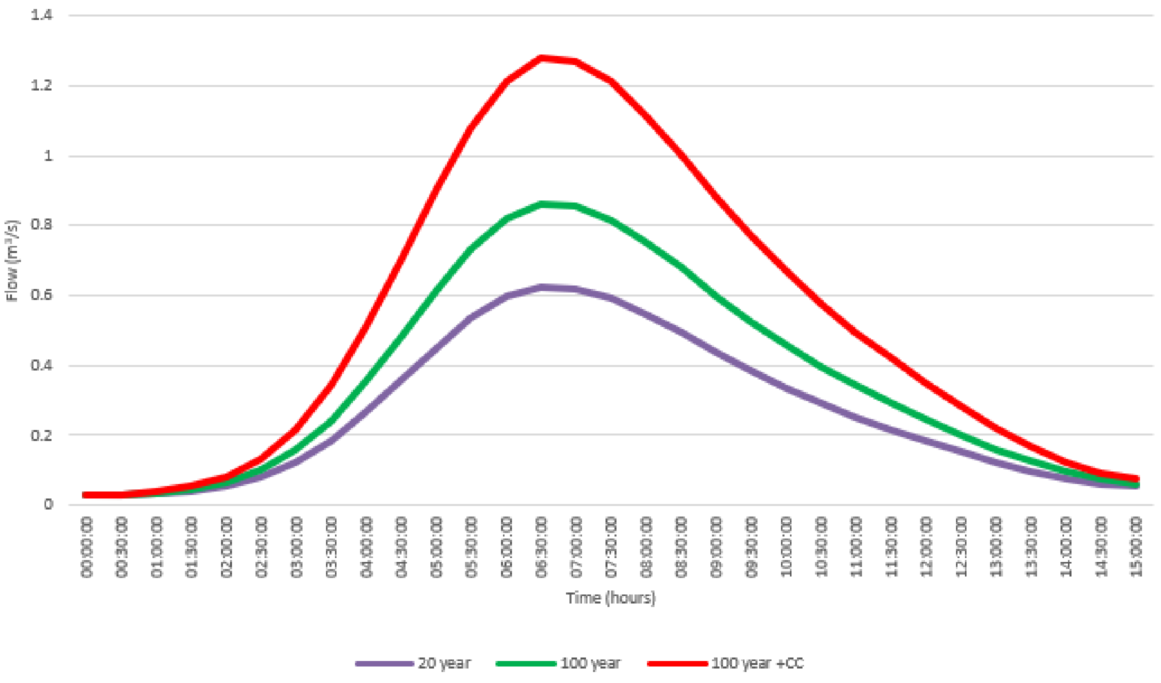
Duration (hours)	Peak flow 1% AEP event (m^3/s)
2.5	0.98
3.5	1.08
4.5	1.14
5.5	1.18
6.5	**1.18**
7.5	1.16

Duration (hours)	Peak flow 1% AEP event (m^3/s)
8.5	1.13
Note – the adoption of a 6.5 hour critical duration was based on the largest peak flow achieved for other AEP events in addition to the 1% event	

3.6 Inflow hydrograph shape

3.6.1 As the unnamed watercourse catchment is ungauged it was assessed as appropriate to derive hydrograph shapes for input into the hydraulic model using ReFH2.3. The inflow hydrographs are displayed in Plate 3-2.

Plate 3-2 Design hydrographs for the unnamed watercourse at Inworth



3.7 Climate change

3.7.1 A climate change uplift factor of plus 45% was applied for the 1% AEP (100-year return period) event as per the latest government guidance at the time of assessment (Environment Agency 2021).

3.8 Summary

3.8.1 Design peak flows and hydrographs for the unnamed watercourse at Inworth were derived using the average of the peak flow estimates using ReFH2.3 and FEH statistical methods. Both methods used the FEH catchment descriptors available from the FEH Web Service with the statistical analysis incorporating a data transfer using the River Ter at Crabbs Bridge gauging station. Appropriate climate change allowance was applied as per the latest Environment Agency guidance. The design inflow hydrographs to be used in the numerical hydraulic model were derived for MWC34 using the critical storm duration of 6.5 hours.

4 Baseline modelling

4.1 Methodology

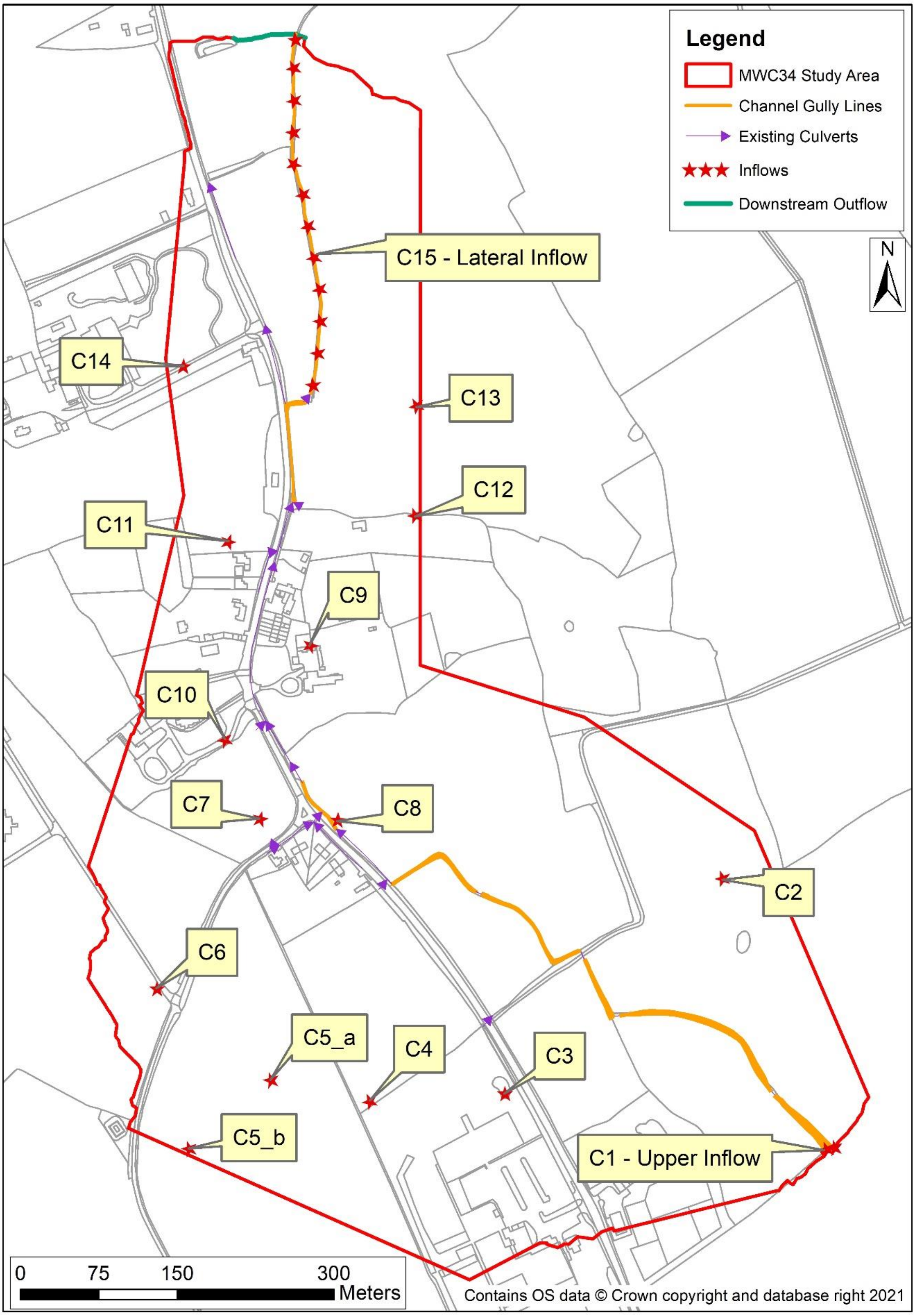
4.1.1 The MWC34 hydraulic model uses a two-dimensional (2D) schematisation, built in TUFLOW version 2020-10-AB (BMT, 2020). 1D 'ESTRY' elements were used to represent the culverts within the TUFLOW model and linked to the 2D domain via SX links. The 2D representation of the channel was considered appropriate as the culverts that conveys MWC34 flows alongside the road control pass-forward flows and upstream water levels. Therefore, detailed representation of the channel capacity is not required.

4.1.2 The model was built from scratch and used to simulate the baseline and mitigation scenarios. Three design events were simulated for each scenario: the 5% (1 in 20), 1% (1 in 100) and 1% (1 in 100) AEP +45%CC events

4.2 Model extent

4.2.1 The 2D model domain covers an area of 0.46km^2. The model extent has been drawn in a way to capture the floodplains and the downstream watercourse. Representation of the model extent is shown in Plate 4.1 and model configuration is explained in detail in Section 4.3. It should be noted that inflows have been placed at the location of the natural flow path of the terrain.

Plate 4.1 MWC34 TUFLOW model setup



4.3 Model resolution and topography

4.3.1 1m horizontal resolution LiDAR DTM data from 2020 was available for the model extent and was downloaded from the DEFRA website to inform the hydraulic model with ground level information.

4.3.2 A 1m grid cell resolution was deemed appropriate for the model as this is sufficient to represent the open channel, the floodplain topography and the active floodplain details whilst avoiding a long simulation run time. The model grid was oriented to be aligned with key flow paths.

4.3.3 The open channel sections were represented in the model using 1.5m wide gully lines to define channel width. Also, to reduce instabilities at the upstream part of model, the watercourse was represented with z-shape polygons. The riverbed and bank levels were reinforced using nominal point data taken from the channel survey (see Section 2). Four culverts were implemented in the southern open channel section.

4.3.4 The watercourse flows from south to north. It starts as a 575m long open channel, before entering an 850mm pipe (IWR-1.000) on the eastern side of the Inworth Road. From that place, the watercourse flows along the road in a series of different size pipes and open channels as follows:

- Culvert (IWR-1.001) with diameter 850mm and 70m length.
- An open channel with a length of 75m.
- Two 900mm consecutive culverts (IWR-1.004 and IWR-1.005).
- A 1000mm culvert (IWR-1.006) with a length of 159m – pipe location is assumed based on the site visit. This is a part of underground system with limited access.
- A 650mm culvert (IWR-1.012).
- An open channel which diverges from the road at its northern end and allows water to flow through a 600mm culvert (CL-IWR-8) to the downstream end of the modelled watercourse.

The west drains cross Inworth Road at three places and enter the main pipe/open channel system which discharges at the north to regular watercourse.

4.3.5 MWC34 runs north-east for approximately 0.7km before finally discharging into the Domsey Brook. It was not considered necessary to model the watercourse to the Domsey Brook and an appropriate downstream boundary was chosen at the location shown in Plate 4.1 (Downstream Outflow). Culverts were schematised in the model using embedded 1D ‘ESTRY’ elements with a Manning’s ‘n’ roughness value of:

- 0.011 for PVC which are a high value for that culvert types (ODOT, 2014)

- 0.015 for concrete pipes, which are a high value for that culvert types (Chow, 1959).

High values were chosen intentionally because system is old and partially collapsed or filled with debris. Culvert losses are applied based on standard recommended values of 0.5 and 1 for the inlet and outlet loss, respectively.

4.4 Hydraulic friction

4.4.1 OS MasterMap data was used to identify land use type and inform the TUFLOW model with different hydraulic roughness (Manning's 'n' coefficient) values. Hydraulic roughness coefficients were applied over each grid cell of the 2D domain depending on the land use taken from the MasterMap data, as shown in Table 4.1. Roughness values adopted were taken from standard guidance (Chow, 1959). Depth-varying roughness was used to stabilise the model at shallow depths. Roughness values adopted are shown in Table 4.1. For depths between 50mm and 100mm, Manning's 'n' value is interpolated between n1 and n2. Below 50mm, n1 is applied, and above 100mm, n2 is applied. The default interpolate method uses a curved fit so that the n values transition gradually.

4.4.2 As mentioned in Section 4.3.5 above, the culverts were modelled assuming a roughness values between 0.011 and 0.015, taken as a high value for either concrete or PVC culverts.

Table 4.1 MWC34 hydraulic roughness

Land Use	Depth varying Manning's 'n' roughness	
	n1	n2
Manmade Surface	0.05	0.025
General Surface (Step)	0.05	0.025
Property Gardens	0.1	0.05
Roads/Tracks/Paths	0.05	0.025
Manmade Structures	0.05	0.025
Natural Land	0.1	0.05
Slopes	0.1	0.05
Buildings	1.0	
Natural Land	0.1	
Average roughness for watercourse	0.07	
Stability patch	0.1	

4.5 Boundary conditions

4.5.1 Two types of boundary conditions were implemented in the model and can be seen in Plate 4.1.

- QT boundaries were applied to the 2D domain. These include:
  - One at the upstream end of the watercourse (upper inflow),
  - Point inflows at 13 locations representing the upstream connection of each digitised sub catchment to the watercourse
  - One distributed evenly throughout the downstream watercourse.

The sum of the above inflows corresponds to the entirety of the contributing catchment. The catchment hydrology analysis is explained in detail within Section3.

4.5.2 Water level vs flow (HQ) boundary was implemented to the north of the model extent to allow channel flows out of the model and prevent ‘glass-walling’ of water. The boundary applied a normal depth assumption with slope determined by inspection of the LiDAR data.

5 Modelled events

5.1.1 Table 5.1 shows the AEP events and model scenarios that were simulated with the hydraulic model. The 45% climate change uplift event was modelled in accordance with the latest EA guidance as detailed in Section 3.

5.1.2 To test the model sensitivity to key hydraulic parameters, a series of simulations were undertaken for the baseline 1% (1 in 100) AEP event. The assessed hydraulic parameters were: Manning’s ‘n’ roughness coefficients and hydrological inflows (see Section 6.4).

Table 5.1 Modelled events for MWC34

Scenario	5% AEP (1 in 20)	1% AEP (1 in 100)	1% AEP +45%CC (1 in 100)
Baseline	✓	✓	✓
Design	✓	✓	✓
Mitigation	✓	✓	✓
Roughness Sensitivity		✓	
Hydrological Inflow Sensitivity		✓	

6 Model Proving

6.1 Introduction

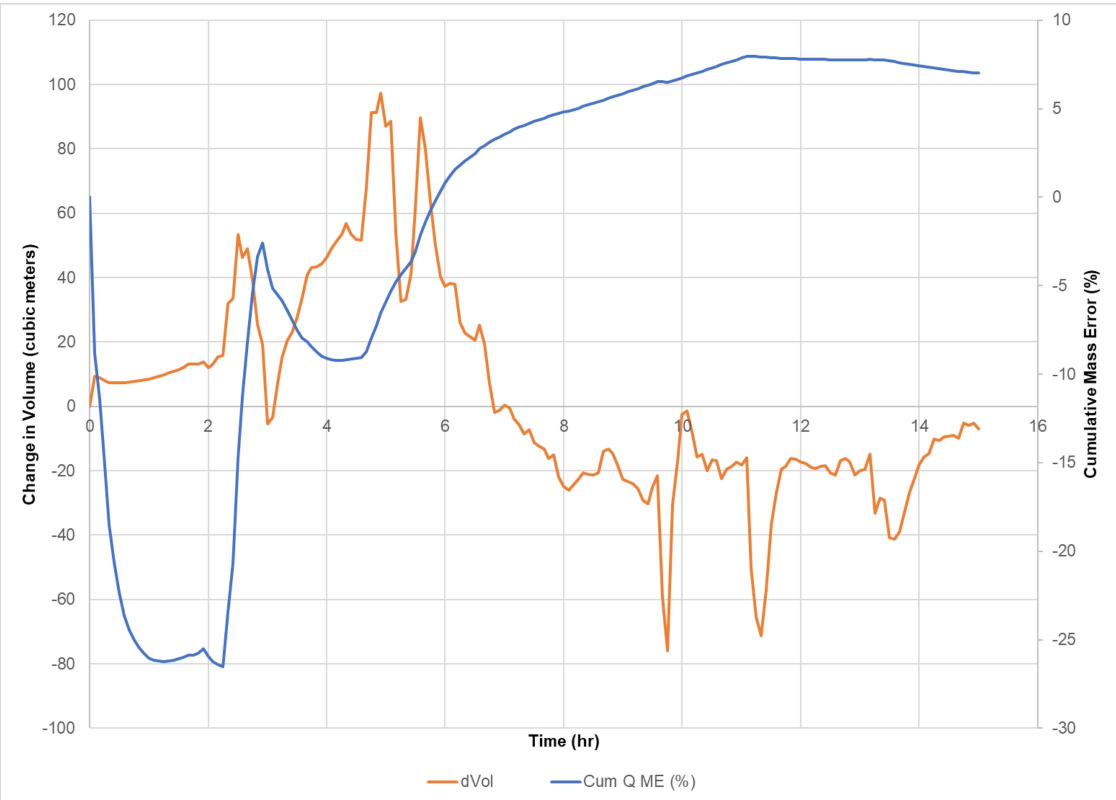
6.1.1 The following sections discuss the model performance and the verification process. In addition, details relating to the additional runs carried out to test the sensitivity of the model to key variables are also discussed.

6.2 Model Performance

6.2.1 Run performance was monitored throughout the model build process and then during each simulation carried out, to ensure a suitable model computational performance was achieved. The cumulative mass error diagnostics output from the model have been checked for each model simulation. Plate 6.1 shows the cumulative mass error (Cum ME) and the change in volume (dVol) for the baseline 1% (1 in 100) AEP event simulation. This plot is typical for all the events and scenarios simulated. The tolerance range recommended by the software manual is +/-1% mass balance error.

6.2.2 The cumulative mass error tolerance is exceeded at the onset of the floodplain wetting which is expected and then stabilises to 6-7% error before after the peak of the inflow hydrographs (Plate 6.1).

Plate 6.1 Model proving Cumulative ME and dVol plot for 1% (1 in 100) AEP event



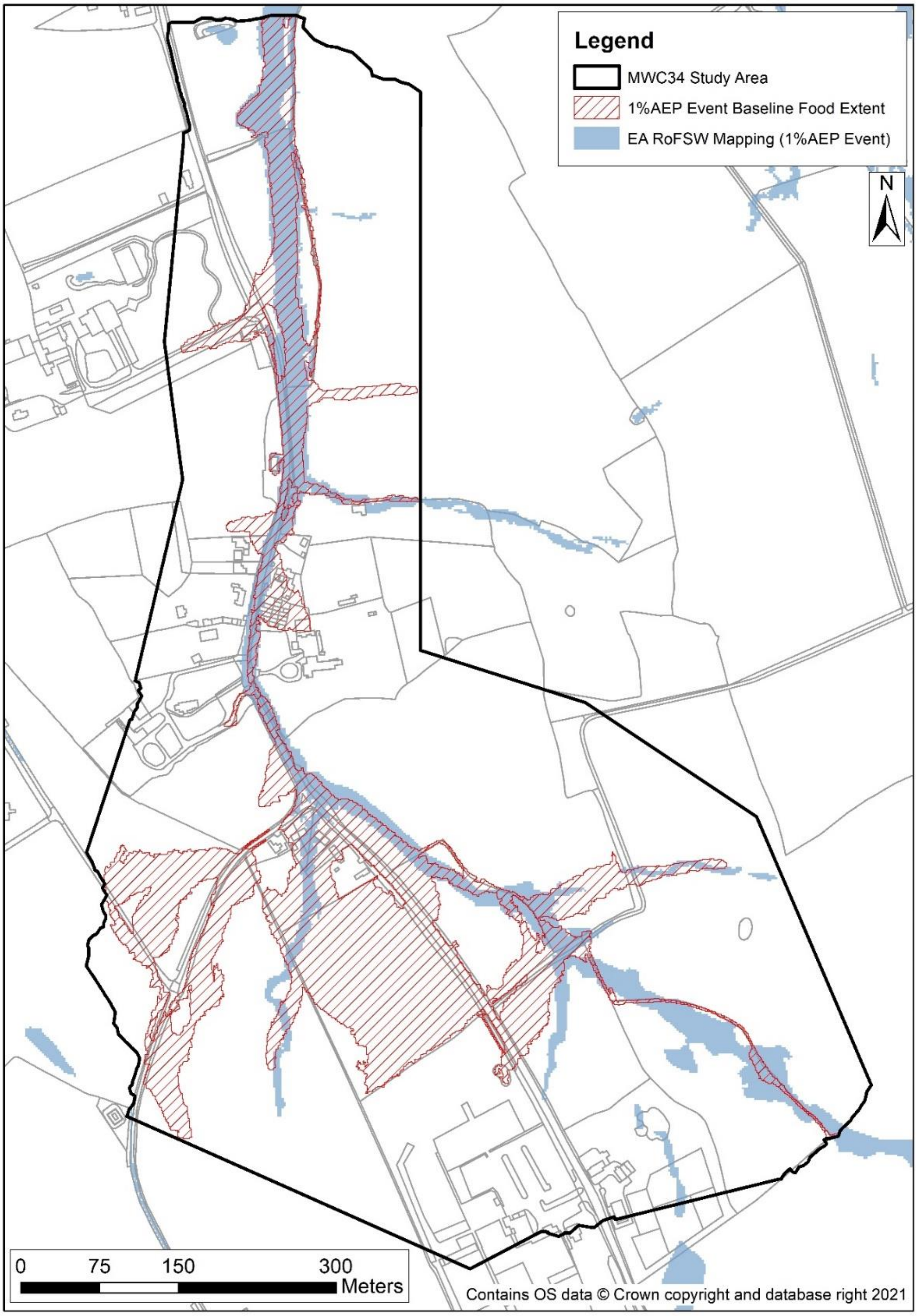
6.3 Comparison with Environment Agency flood maps

6.3.1 MWC34 has not been included in the Environment Agency (EA) published Flood Zone mapping of fluvial flood risk. Therefore, a direct comparison between model results and EA flood maps is not possible. However, the EA Risk of Flooding from Surface Water (RoFSW) mapping can be used to identify areas of pooling.

6.3.2 Plate 6.2 shows the modelled 1% (1 in 100) AEP event flood extent and the EA RoFSW mapping extents. Flood extents are very similar on and around the road from the area where Windmill Hill road crosses with Inworth Road and downstream.

6.3.3 The biggest difference in flood extends occurs upstream of the Windmill Hill. The upstream part of the catchment, where flow paths can significantly differ between the two approaches – direct rainfall for the RoFSW against rainfall-runoff. At this location the EA RoFSW flood map shows no risk of flooding, whereas the model predicts widespread flooding across the floodplain. Considering this, full verification of the model cannot be based on the comparison of results with EA RoFSW maps. The analysis is therefore reliant on the use of industry standard modelling and hydrology tools, as is common for small watercourse studies.

Plate 6.2 EA Risk of Flooding from Surface Water and 1% (1 in 100) AEP Extent



6.4 Sensitivity analysis

6.4.1 Simulations were carried out to determine the sensitivity of the model to roughness and hydrological inflows. All sensitivity tests were performed using the 1% (1 in 100) AEP event.

Roughness sensitivity

6.4.2 In-channel and floodplain roughness coefficients (Manning's 'n') were changed by +20% and -20%. Plate B.1 and Plate B.2 in Appendix B shows the impact of changing the model roughness on predicted peak water levels. The results show that areas close to the upstream (south) part of open watercourse and north ditch are moderately sensitive to change in roughness, with a water level response up to ±90mm.

6.4.3 Unexpected results such as minor adverse effect in the channel at the south part of the model and next to the road upstream of Inworth Hall for the decreased roughness test occurred. This is due to instabilities of the flow in the model. To reduce the instabilities depth-varying roughness was used. The final mitigation option was tested against results obtained from the sensitivity runs and it showed no impact on the final design performance.

Hydrological Inflow Sensitivity

6.4.4 The flows into the model were adjusted by +20% and -20%. Plate B.3 and Plate B.4 provided in Appendix B shows the impact of changing the model inflows on predicted peak water levels. The results show that adjusting inflows by +/-20% has no effect outside of the main flow path. Only reduced flow scenario caused changes which can be seen in the southern model domain beyond the watercourse. A -20% adjustment, however, decreases in-channel water levels by -160mm. At the downstream end of the model extent, adjustments to inflows result in a +380mm and -325mm change to in-channel water levels, when inflows are increased and decreased, respectively.

7 Mitigation modelling

7.1.1 For this task a scheme and mitigation scenario were run as a single coupled scenario. The full list of changes made to the baseline model to build the mitigation model is described below.

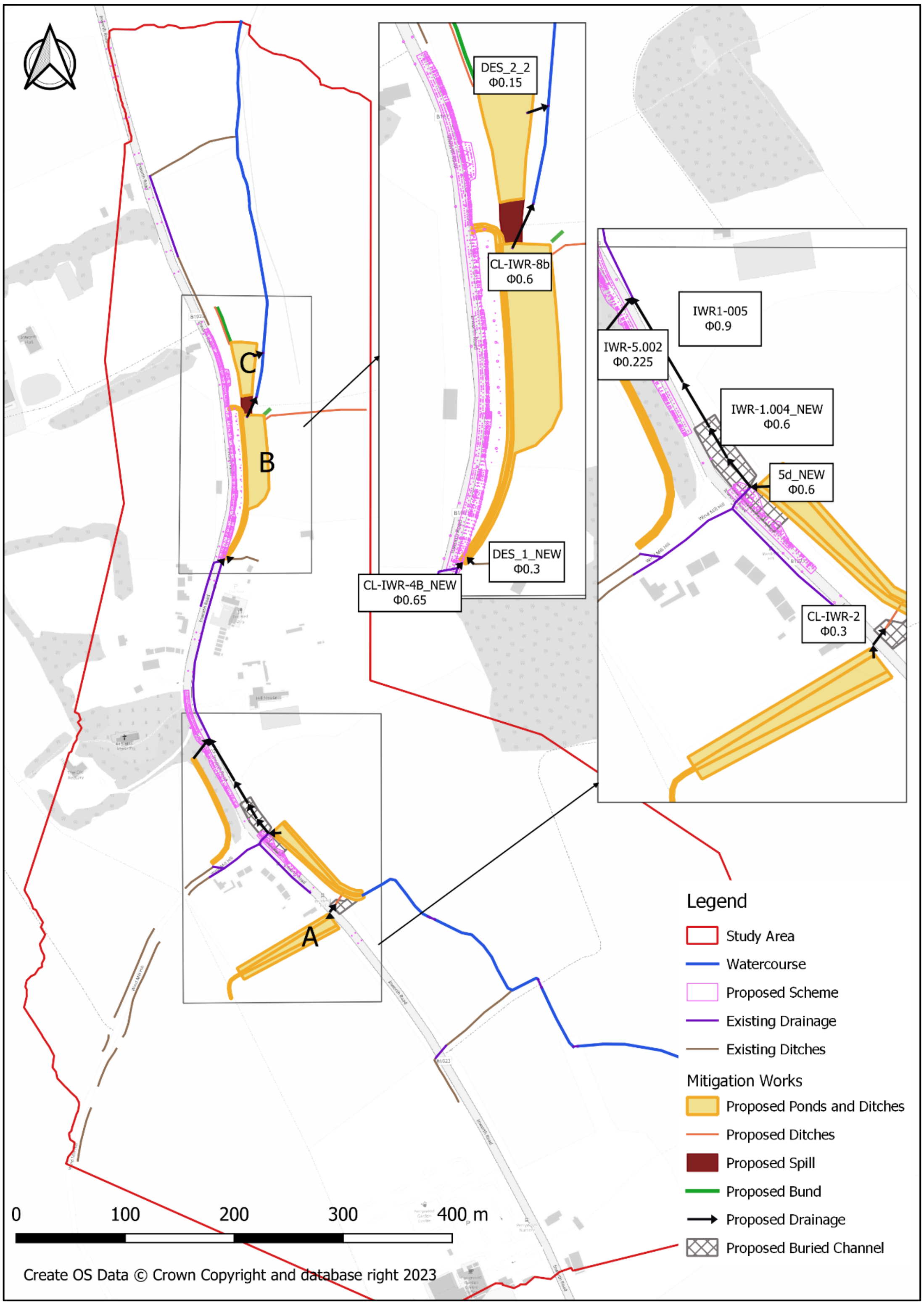
7.2 Mitigation model build

7.2.1 The baseline model was updated to include the proposed Inworth Road scheme and mitigation. Changes to the model were as follows and as illustrated in Plate 7.1.

- The proposed Inworth Road design was included in the model as a modification to the baseline model topography using an ascii DTM surface overlain.
- For the proposed-scheme, the pipes IWR-1.000/1001 of 850mm were decommissioned. The open channel between 1.001 and 1.004 was filled in. The pipe 1.004 was replaced with the pipe 600mm IWR-1.004_NEW which was connected to unchanged IWR1-005 with the diameter 900mm. IWR-1.004_NEW and IWR1-005 form a continuous pipe system.
- An alleviation pond – A was proposed - shown in Plate 7.1, which was connected to a ditch. A wall was constructed for the pond on its eastern side. The existing 150mm diameter pipe (CL-IWR-2) crossing Inworth road was replaced with a 300mm diameter pipe that will control flows from the pond and was partially realigned to discharge into the realigned watercourse mentioned above.
- A new ditch (west of an Inworth Road) was implemented alongside the proposed-scheme to capture water from the C7 sub-catchment before discharging into the existing 225mm diameter culvert IWR-5.002 which was realigned.
- Two north mitigation ponds were also proposed just east of Inworth Road. A relief channel was implemented into the model between two ponds. The first pond –B was drained with 600mm pipe (CL-IWR-8b) and the second pond with 150mm pipe (DES_2_2) to the watercourse. The existing ditch at the area of design footpath (alongside Inworth Road) was partly buried and realigned to the first pond.
- North from the second pond – C, an approximately 35m long and 80-100mm high bund was implemented to reduce the flow on the field. At the toe of the bund a 200mm deep ditch was placed.
- Gradient was provided to all storages to allow emptying of those under low flow conditions.
- In the baseline, flow from catchment C13 was represented as overland flow. That flow in the mitigation scenario was redirected to the first

storage area via culvert. For the purpose of this study, it was not necessary to model this in detail. Therefore, the ditch was represented in the mitigation model using a thick line, and flow was directed into the pond by a small bund

Plate 7.1 MWC34 mitigation setup



8 Model results

8.1 Baseline results

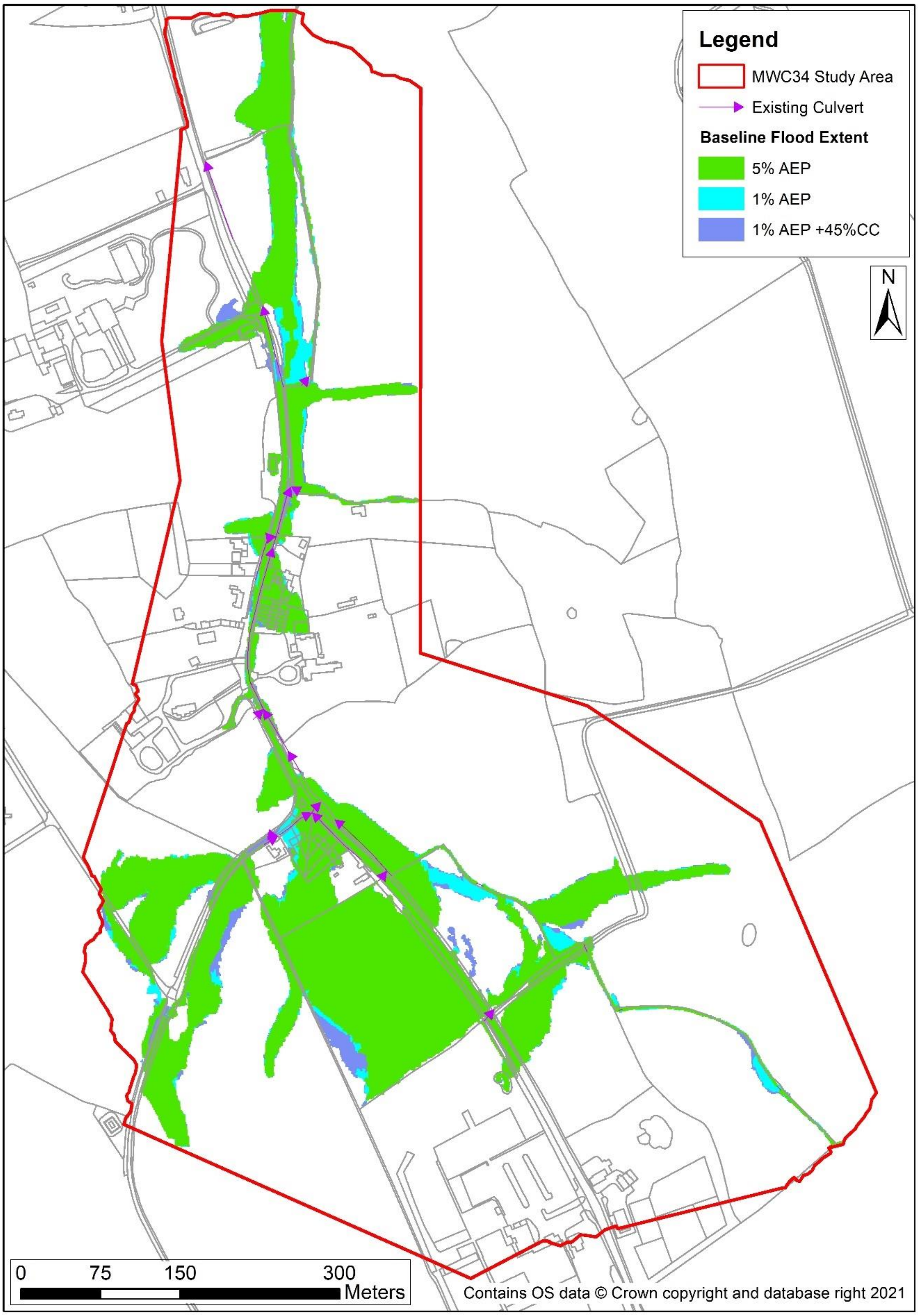
8.1.1 Plate 8.1 shows the maximum flood extent for all modelled events in the baseline scenario. The flood extents for each of the modelled events can be found in Appendix C.

8.1.2 The area upstream of crossing with Windmill Hill is flooded for all events simulated, with almost identical flood extents between the 5% (1 in 20) and 1% (1 in 100) AEPs. The Inworth Road is locally in cut in relation to its left and right side so due to that terrain topography all water from inflow points flows onto the Inworth Road. Surface water conveyed by the road is partly captured by the drainage system and partly runs off the road. From the crossing with Windmill Hill to almost Inworth Hall the road is flooded.

8.1.3 Just upstream from Inworth Hall water is flowing on the fields in a south-east direction.

8.1.4 The combined flow, from both drainage and surface runoff, along Inworth Road is causing flooding to 16 properties for 5% (1 in 20) AEP event. During a 1% (1 in 100) AEP +45%CC event, these properties flood to depths of over 350mm.

Plate 8.1 Baseline Flood Extents



8.2 Mitigation Model Results

8.2.1 Plate 8.3 shows the changes to the water level due to the proposed scheme and mitigation works for the 1% (1 in 100) AEP +45%CC event. The maximum flood level differences between baseline and mitigation scenarios are categorised into levels of impacts due to the proposed design and mitigation measures. The impact of the proposed design and mitigation measures for all other flood events can be found in Appendix C.

8.2.2 The proposed-scheme, because of topographic conditions, is under the water for all AEP events as demonstrated by Plate 8.2.

8.2.3 The realigned channel, mitigation pond A and new west ditch improves the condition on the road from Windmill Hill until the north mitigation ponds B and C. This solution also reduces risk of flooding at the properties within Inworth.

8.2.4 Flows pond against the southern edge of the mitigation pond A causing adverse effect. In reality the storage area will tie into existing ground to allow the surrounding surface runoff to be captured by the pond.

8.2.5 Small adverse effects can be seen in the channel at the southern extent of the model due to local instabilities in this steep part of the reach. Sensitivity tests were carried out demonstrating that these instabilities do not impact on the model results at the location of the proposed works.

8.2.6 The north mitigation pond B – draws the water levels of the road down at its west bank. Water flowing from upstream part of the model flows mainly into the pond, not down the road as it was in the baseline scenario

8.2.7 The second north pond is capturing excess water from the first pond when the water level exceeds the relief channel elevation – 39.87m AOD. The relief channel operates from 1% (1 in 100) AEP event.

8.2.8 The flow response through the north part of watercourse is attenuated and delayed. This is because water is being held in the storage area upstream.

8.2.9 The depth difference map (Plate 8.3) shows that the only detrimental effect outside the red line boundary occurs immediately downstream of the northern ponds and remains in-bank. Also, at the downstream end, the impact is beneficial (as response attenuated by the mitigation).

Plate 8.2 Mitigation Flood Extents

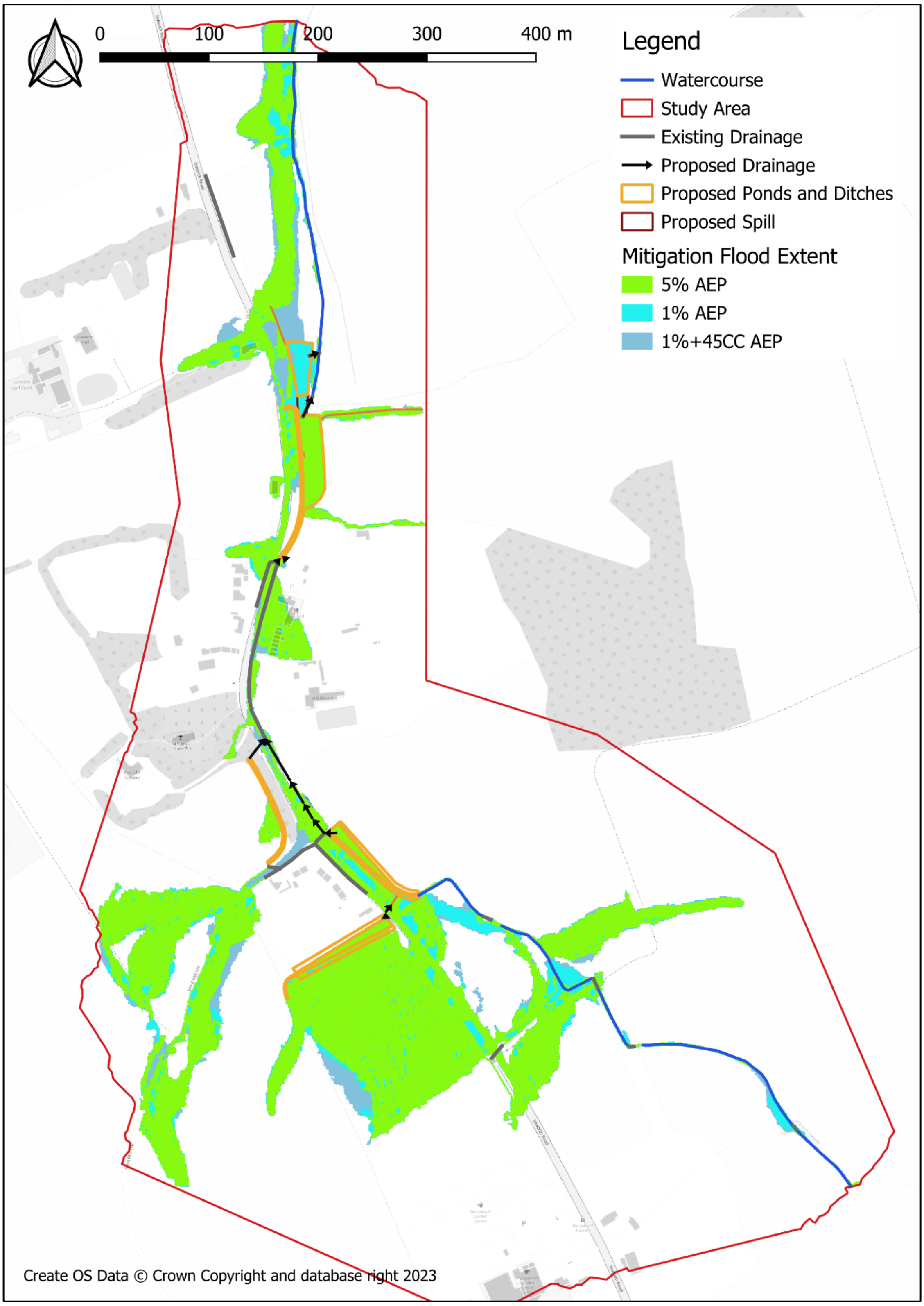
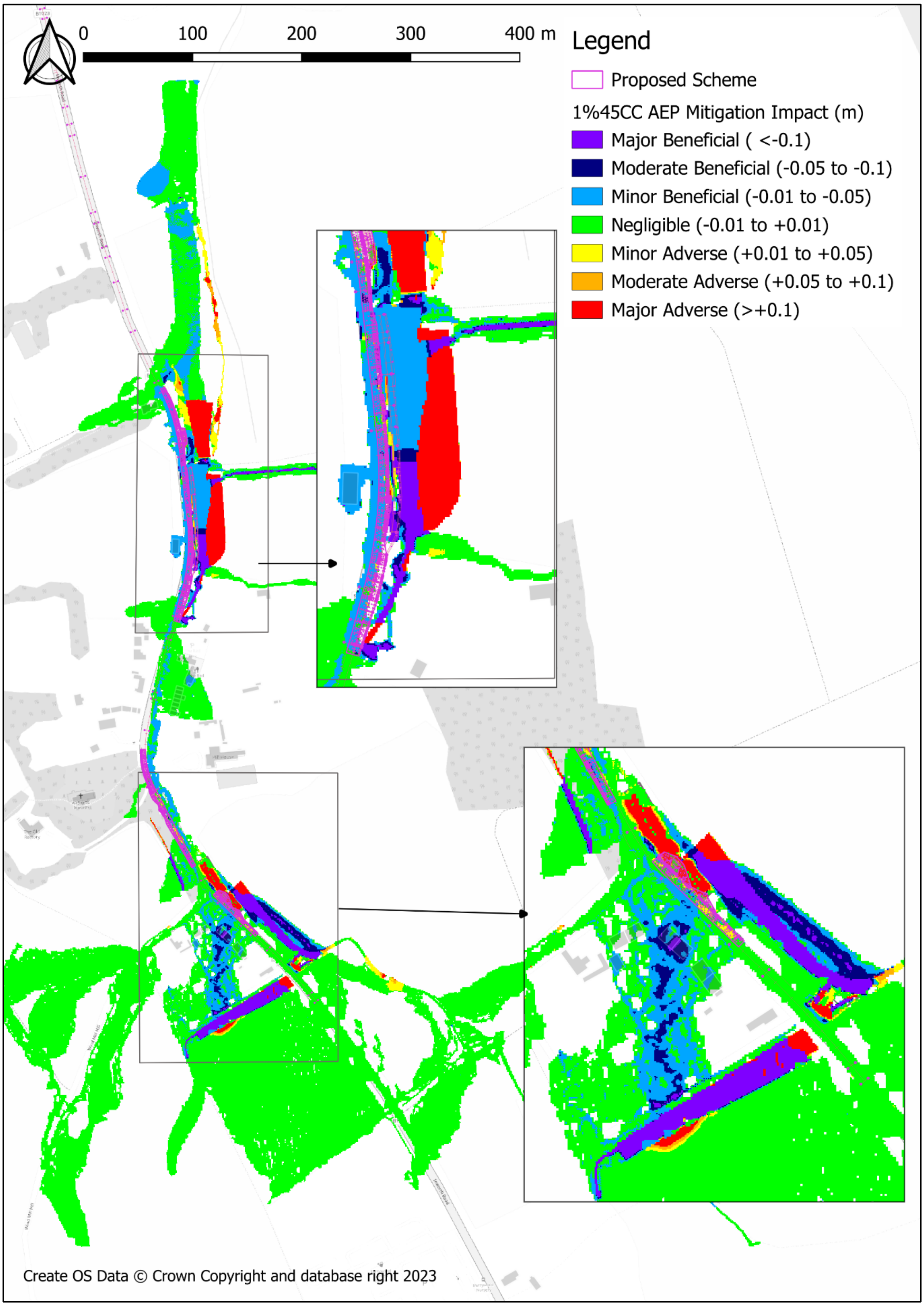


Plate 8.3 Water Level Difference (Mitigation – Baseline) for 1% (1 in 100) AEP +45%CC



9 Model Assumptions and Limitations

9.1 Introduction

9.1.1 The accuracy and validity of the hydraulic model results is dependent on the accuracy of the hydrological, surveyed, and topographic data included in the model. While the most appropriate available information has been used to construct the model to represent fluvial flooding mechanisms, there are uncertainties and limitations associated with the model. These include assumptions made as part of the model build process.

9.1.2 Efforts have been made to assess and reduce levels of uncertainty in each aspect of the modelling process. The assumptions made are generally conservative for modelled water levels at the proposed-scheme and are therefore, appropriate for the flood risk assessment.

9.2 Hydrology

9.2.1 The main hydrological assumptions and limitations used in this investigation are as follows:

- As the unnamed watercourse is a small ungauged catchment there is inevitable uncertainty associated with flow estimation for small, ungauged catchments.
- Both FEH statistical method and ReFH2.3 are appropriate for the target catchment as they use BFIHOST19 and in the case of ReFH2.3, the most recent (FEH13) rainfall data.

9.3 Hydraulic Modelling

9.3.1 The key sources of uncertainty and the limitations associated with the modelling undertaken for MWC34 are as follows:

- Culvert and model roughness values was assigned across the model using the best available information (survey data and aerial photographs). The used roughness values based on available guidance (Chow 1959 and ODOT 2014).
- Hydraulic coefficients for structures was applied using available guidance within the TUFLOW Manual. The dimensions for structures based on detailed survey measurements.
- The LiDAR data is assumed to appropriately represent the floodplain.
- A 1m grid was used. This is deemed a sufficient level of detail to represent floodplain topography and flooding mechanisms predicted by the model in the vicinity of the proposed scheme.
- No survey of the full length of 1000mm pipe were received, and arrangement is based on the provided site visit photos. It is a part of

underground system with limited access. Manholes suggests that 1000mm pipe is connected to 650mm pipe.

- No calibration was carried out as the catchment is ungauged.
- The mitigation solution was designed using TUFLOW-ESTRY software, and it provides some partial flood protection to the Inworth Road up to a 1% (1 in 100) AEP +45%CC standard of protection, and it also ensures that there are no adverse impacts downstream of the scheme. Detailed design may need to consider more in-depth hydraulic analysis.

10 Conclusion

10.1.1 This report has detailed the modelling carried out to assess the baseline, and with-mitigation flood risk for Minor Watercourse 34 with respect to the proposed Inworth Road scheme.

10.1.2 The results of the baseline modelling have shown that the existing Inworth road drainage system is not efficient and flooding on the road occurs.

10.1.3 The proposed scheme was based on Inworth Road extension in few places. Because of topographic reasons - Inworth Road is in cut – proposed scheme would not change flood situation so mitigation works were proposed. Both activities scheme and mitigation were modelled in one model. To reduce flood risk, a storage ponds, channel realignment and new ditches/pipes were represented in the model. These mitigation measures are effective in preventing flooding of the proposed-scheme above depth of 100mm and produce no negative impacts downstream.

Acronyms

Abbreviation	Term
AEP	Annual exceedance probability
BFIHOST	Base Flow Index derived using the HOST soil classification
CC	Climate change
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FRA	Flood Risk Assessment
MWC34	Minor Watercourse 34
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SPRHOST	Standard percentage runoff derived using the HOST soil classification

References

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Appendix A – Minor Watercourse 34 Hydrology

A12 Chelmsford to A120 widening scheme

TR010060

DEVELOPMENT CONSENT ORDER CHANGE APPLICATION CONSULTATION

MODELLING REPORT – HYDROLOGY APPENDIX

Advice Note 16 (Version 3) 2023

May 2023

Infrastructure Planning

Planning Act 2008

A12 Chelmsford to A120 widening scheme

Development Consent Order 202[ ]

Development Consent Order Change Application: Modelling Report – Hydrology Appendix

Regulation Reference	Advice Note 16 (Version 3) 2023
Planning Inspectorate Scheme Reference	TR010060
Application Document Reference	TR010060/EXAM/10.16
Author	A12 Project Team & National Highways

Version	**Date**	**Status of Version**
Rev1	May 2023	DCO Change ApplicationS3 - SUITABLE FOR REVIEW AND COMMENT

CONTENTS

0 Executive Summary

0.1.1 This document has been prepared to support the scheme modelling of an unnamed watercourse at Inworth.

1 Introduction

1.1.1 This document is to provide a record of the calculations and decisions made during flood estimation for an unnamed watercourse at Inworth which crosses the A12. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future.

2 Summary of assessment

2.1 Summary

2.1.1 A summary of the key information contained within the detailed hydrological assessment of the unnamed watercourse at Inworth is provided in the table below.

Catchment location	The unnamed watercourse at Inworth is located in Southeast England. This minor watercourse discharges to the Domsey Brook.
Purpose of study and scope	The main road through Inworth is subject to flooding. Analysis was required to ensure that the A12 upgrades do not increase the flood risk. Flows have been derived for the following Annual Exceedance Probability (AEP) events: 5%, 1% and 1% plus climate change (plus cc), equivalent to the 20-year, 100-year and 100-year plus cc return period events respectively.
Key catchment features	The minor watercourse has a rural catchment.
Flooding mechanisms	Peak flows / volumes.
Gauged / ungauged	Ungauged.
Final choice of method	FEH statistical / ReFH2.3
Key limitations / uncertainties in results	Small ungauged watercourse.

2.2 Note on flood frequencies

2.2.1 The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.

2.2.2 Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval.

2.2.3 The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

Table 2.1 Annual exceedance probability (AEP) and related return period reference table

AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

3 Method Statement

3.1 Requirements for flood estimates

Overview	A hydrological assessment was required to assess flood risk in Inworth. The main road through the village, the B1023, is at risk of flooding and analysis was required to ensure that the risk of potential flooding is not increased by the A12 widening scheme. The Environment Agency's Surface Water Flood Maps (https://flood-warning-information.service.gov.uk/long-term-flood-risk) show flow paths running northwards from Tiptree which then flow in a ditch along the B1023 before continuing as a watercourse north from Inworth, joining the Domsey Brook to the east of Kelverdon. Previous analysis on the Domsey Brook has been used to inform this assessment (HE551497-JAC-EWE-SCHW-RP-LE-0080). Design peak flows and hydrographs were required for the following AEP events: 5%, 1% and 1% plus climate change (plus cc). This is equivalent to the 20-year, 100-year and 100-year plus cc return periods). A climate change uplift factor of plus 45% was be applied for the 1% AEP (100-year return period) event. The unnamed watercourse is small and ungauged.
Project scope	This is a simple hydrological study for one minor watercourse with a catchment area of 0.73km^2.

3.2 The catchment

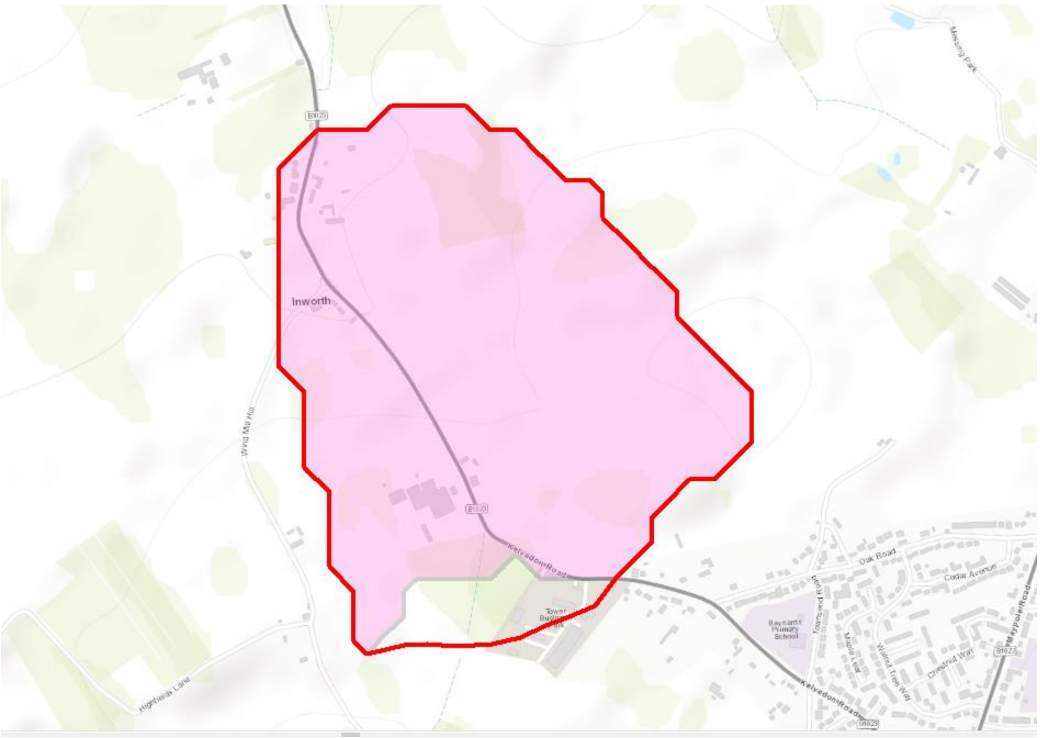


Figure 1 Amended catchment for the unnamed watercourse at Inworth

Description	Catchment descriptors were taken from the FEH webservice [redacted] for the watercourse to the downstream location of flooding on the B1023. The catchment area was checked for accuracy using online OS maps and the FEH website. The catchment was shown not to include a drainage ditch through Perry's Wood. The catchment area was adjusted to include this ditch which increased the size of the catchment from 0.68 to 0.73km^2, or 7% (Figure 1). The DPLBAR was adjusted following guidelines in the Flood Estimation Handbook[1] (FEH) volume 5 from 0.81 to 0.84. All other catchment descriptors remained the same.

3.3 Source of flood peak data

Source	NRFA peak flows dataset, Version 8, released September 2019, which was the latest version during the time this assessment. Contains data updated to 30th September 2018.

[1] Institute of Hydrology. (1999). Flood Estimation Handbook Volume 5, Catchment Descriptors. Wallingford

3.4 Gauging stations (flow or level)

Watercourse	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of record and end if station closed
River Ter	Ter @ Crabbs Bridge		37003	77.8	Theoretically rated	1932 to present

3.5 Data available at each flow gauging station

Station name	Start and end of NRFA flood peak record	Update for this study?	OK for QMED?	OK for pooling ?	Data quality check needed?	Other comments on station and flow data quality
Ter @ Crabbs Bridge	1963 to present	N	Yes	No	N	Recently removed from suitable for pooling category. This was noted as due to many AMAX events being out of bank and this is not accounted for in rating.

3.6 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data	Details
Check flow gaugings	N/A			Not required for this assessment.
Historical flood data	N/A			Not Available
Flow or river level data for events	N/A			Not available for this assessment.
Rainfall data for events	N/A			Not required for this assessment.
Potential evaporation data	N/A			Not required for this assessment.
Results from previous studies	N/A			Not available for this assessment.
Other data or information	N/A			Not available for this assessment.

3.7 Hydrological understanding of catchment

Conceptual model	Hydraulic modelling of the watercourse is required to assess potential impacts of upgrading the A12 and to ensure that the existing flood risk is not increased.
Unusual catchment features	The catchment is a small rural catchment located in Southeast England.

3.8 Initial choice of approach

Is FEH appropriate?	Yes, FEH methods are appropriate.
Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	ReFH2.3 and FEH Statistical methods have been applied to derive the peak flow estimates and hydrographs for this catchment. The hydrographs have been derived using ReFH2.3 method.
Software to be used (with version numbers)	FEH Web Service[2] / WINFAP 5[3] / ReFH2.3

3.9 Locations where flood estimates required

3.9.1 The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

3.10 Subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEHweb service (km^2)	Revised AREA if altered
INW	L	Unnamed	B1023	588050	218150	0.68	0.73

[2] CEH 2015. The Flood Estimation Handbook (FEH) Online Service, Centre for Ecology & Hydrology, Wallingford, UK.

[3] WINFAP 5 © Wallingford HydroSolutions Limited 2016.

3.11 Important catchment descriptors at each subject site (incorporating any changes made)

3.11.1 Catchment descriptors were taken from the FEH webservice [redacted] for the watercourse to the downstream location of flooding on the B1023. The catchment area was checked for accuracy using online OS maps and the FEH website. The catchment was shown not to include a drainage ditch through Perry's Wood. The catchment area was adjusted to include this ditch which increased the size of the catchment from 0.68 to 0.73km^2, or 7% (Figure 1). The DPLBAR was adjusted following guidelines in the Flood Estimation Handbook[4] (FEH) volume 5 from 0.81 to 0.84. All other catchment descriptors remained the same.

Site code	FARL	PROPWET	BFIHOST	BFIHOST 19	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 2000	FPEXT
INW	1	0.23	0.197	0.225	0.84	35.6	566	0.011	0.0476

4 Statistical method

4.1 Application of Statistical method

What is the purpose of applying this method?	The FEH Statistical method was used as a comparison against ReFH2.3 peak flow estimates.

[4] Institute of Hydrology. (1999). Flood Estimation Handbook Volume 5, Catchment Descriptors. Wallingford

4.2 Overview of estimation of QMED at each subject site

Site code	QMED (rural) from CDs (m^3/s)	Final method	Data transfer					Urban adjustment factor UAF	Final QMED value (m^3/s)
			NRFA numbers for donor sites used (see 4.3)	Distance between centroids d_{ij} (km)	Moderated QMED adjustment factor, (A/B)[a]	If more than one donor			
						Weight	Weighted ave. adjustment		
INW	0.21	DT	37003	14.8	0.94	N/A	N/A	1.008	0.195
Are the values of QMED spatially consistent?						N/A			

4.3 Search for donor sites for QMED (if applicable)

Comment on potential donor sites	The River Ter @ Crabbs Bridge (37003) was selected as a donor for QMED adjustment.

4.4 Flood estimates from the statistical method

4.4.1 The pooling group constructed for the Domsey Brook analysis was deemed suitable for estimating the flood growth for the watercourse at Inworth. Details of the construction of the pooling group and calculation of the flood growth factors is documented in document referenced HE551497-JAC-EWE-SCHW-RP-LE-0080.

INW	Flood peak (m^3/s) for the following return periods (in years)									
	2	5	10	20	30	50	75	100	100+CC	1000
	Flood peak (m^3/s) for the following AEP (%) events									
	50	20	10	5	3.33	2	1.33	1	1+CC	0.1
Growth	1.00	1.443	1.737	2.032	2.211	2.446	2.64	2.783	N/A	N/A
Flow	0.195	0.282	0.339	0.397	0.432	0.478	0.515	0.543	0.787	1.07

5 Revitalised flood hydrograph 2 (ReFH2) method

5.1 Application of ReFH2 method

What is the purpose of applying this method?	ReFH2.3 has been applied to derive both peak flow estimates and hydrographs for the target watercourse at key locations for input into a hydraulic model.

5.2 Parameters for ReFH2 model

Site code	Method	Tp_{rural} (hours)	C_{max} (mm)	PR_{imp}	BL (hours)	BR
INV	CD	3.0	217.1	0.7	23.6	0.293

5.3 Design events for ReFH2 method: Lumped catchments

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
INV	Rural	Winter	4.5

5.4 Flood estimates from the ReFH2 method

Site code	Flood peak (m^3/s) for the following return periods (in years)										
	2	5	10	20	30	50	75	100	100 + CC 45% Uplift	200	1000
	Flood peak (m^3/s) for the following AEP (%) events										
	50	20	10	5	3.33	2	1.33	1	1 + CC 45% Uplift	0.5	0.1
INV	0.430	0.600	0.712	0.826	0.895	0.990	1.07	1.14	1.71	1.36	2.24

5.5 Critical storm duration

5.5.1 The ReFH model to Inworth was amended to test for the critical storm duration, that is the storm duration that resulted in the maximum peak flow. Runs of the model were tested at 1hour intervals. The peak flows (50% AEP and 1% AEP events) are detailed in Table 7 with the maximum peak occurring at 6.5 hours

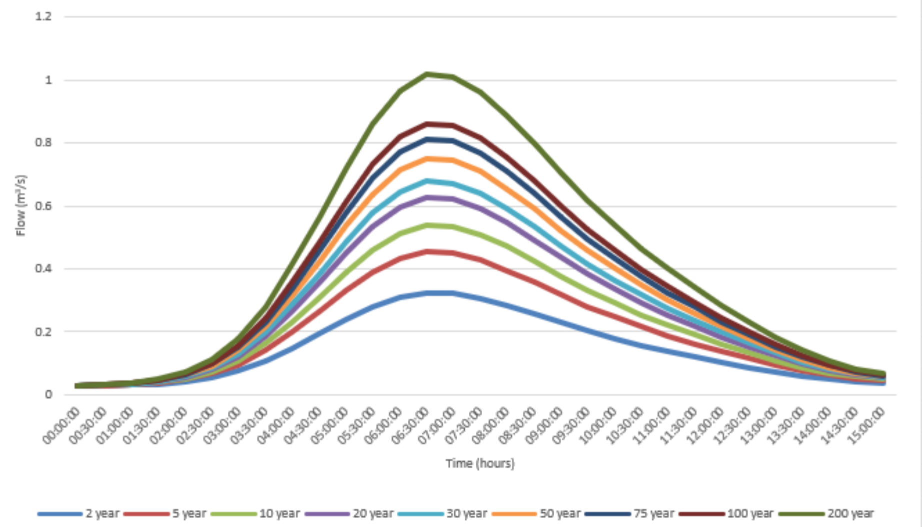
Duration (hours)	**Peak flow 50%AEP event (m^3/s)**	**Peak flow 1% AEP event (m^3/s)**	**Peak flow 0.1% AEP event (m^3/s)**
2.5	0.35	0.98	1.85
3.5	0.40	1.08	2.09
4.5	0.43	1.14	2.24
5.5	0.45	1.18	2.33
6.5	**0.45**	**1.18**	**2.35**
7.5	0.45	1.16	2.31
8.5	0.44	1.13	2.27

6 Discussion and summary of results

6.1 Comparison of results from different methods

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2-years / 50% AEP			Return period 100-years / 1% AEP		
	FEH Statistical	ReFH2.3	Ratio	FEH Statistical	ReFH2.3	Ratio
INV	0.195	0.450	2.31	0.543	1.18	2.17

6.2 Final choice of method

Choice of method and reasons	ReFH2.3 produces much higher peak flows than the FEH Statistical method for the watercourse at Inworth. Application of ReFH2.2 on the donor River Ter @ Crabbs Bridge gauge suggests that the ReFH2.2 method overestimated the commoner return period flows. However, the ratio of ReFH2.2 to statistical shown above is greater than the equivalent for the River Ter. It was therefore considered prudent to give some weight to the ReFH2.3 estimates and the average of the FEH Statistical and ReFH2.3 flows was used to provide the final flows. Hydrograph shapes are derived from the application of ReFH2.3 with a duration of 6.5 hours (Figure 2).  Figure 2 – Design Hydrographs for the unnamed watercourse at Inworth

6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The FEH statistical and ReFH2.3 method of flow estimation are appropriate for the small catchment size at Inworth. The flood growth for the Domsey Brook is representative for the growth for the unnamed

	watercourse at Inworth. There is a large difference between flow estimates from the 2 different methods of flow estimation. An assumption has been made that the average of the 2 methods is an appropriate estimate of the flows at the study site.
Discuss any particular limitations	Apart from the incorporation of a donor site in the statistical method QMED calculation no further recorded data was available to improve or check the flow values calculated.
Provide information on the uncertainty in the design peak flow estimates and the methodology used	The 95% confidence intervals for QMED are 0.1 – 0.42
Comment on the suitability of the results for future studies	The design peak flows have been estimated for the purposes of the A12 road improvements project only. Future studies should assess the appropriateness of these peak flow estimates / hydrographs for the purposes of their investigation.
Give any other comments on the study	N/A

6.4 Checks

Are the results consistent, for example at confluences?	N/A
What do the results imply regarding the return periods / frequency of floods during the period of record?	N/A
What is the range of 100-year / 1% AEP growth factors? Is this realistic?	1% AEP (100 year) growth factor for statistical method = 2.783 1% AEP (100 year) growth factor for ReFH2.3 method = 2.622 These are within the recommended guidance
If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?	ReFH2.3 ratio between 0.1% (1,000 year) and 1% (100 year) = 1.96
How do the results compare with those of other studies? Explain any differences and	N/A

conclude which results should be preferred.	
Are the results compatible with the longer-term flood history?	N/A
Describe any other checks on the results	N/A

6.5 Final results

Site code	Flood peak (m^3/s) for the following return periods (in years)										
	2	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**100 + CC 45% Uplift**	**200**	**1000**
	Flood peak (m^3/s) for the following AEP (%) events										
	50	**20**	**10**	**5**	**3.33**	**2**	**1.33**	**1**	**1 + CC 45% Uplift**	**0.5**	**0.1**
INW	0.32	0.45	0.54	0.62	0.68	0.75	0.81	0.86	1.28	1.02	1.71

6.6 Uncertainty bounds

6.6.1 The Flood Estimation Guidelines 197_08 (2020) notes that it is more difficult to quantify uncertainty in design flows estimated from the ReFH rainfall-runoff model than for the FEH Statistical method which it reports approximate uncertainty bounds for. It is therefore highlighted that the final flow estimates are open to uncertainty, but uncertainty bounds have not been provided for this assessment.

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g., give filename of spreadsheet, hydraulic model, or reference to table below)	

Acronyms

Abbreviation	Term
AEP	annual exceedance probability
AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
OS	Ordnance Survey
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
ReFH2	Revitalised Flood Hydrograph 2 method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

References

British Geological Survey. The Geology of Britain Viewer accessed 2021 at: [redacted]

Centre for Ecology and Hydrology. Flood Estimation Handbook Web Service accessed 2021 at: [redacted]

Environment Agency (2021). Flood risk assessments: climate change allowances guidance.

Environment Agency (June 2020). Flood Estimation Guidelines, Technical guidance 197_08

Soil Survey of England and Wales (1983). Soil Maps of England and Wales Scale 1:250,000

Appendix B – Sensitivity Testing

Plate B.1 Water level difference (Manning's 'n' Roughness changed by -20%) for the 1% AEP event

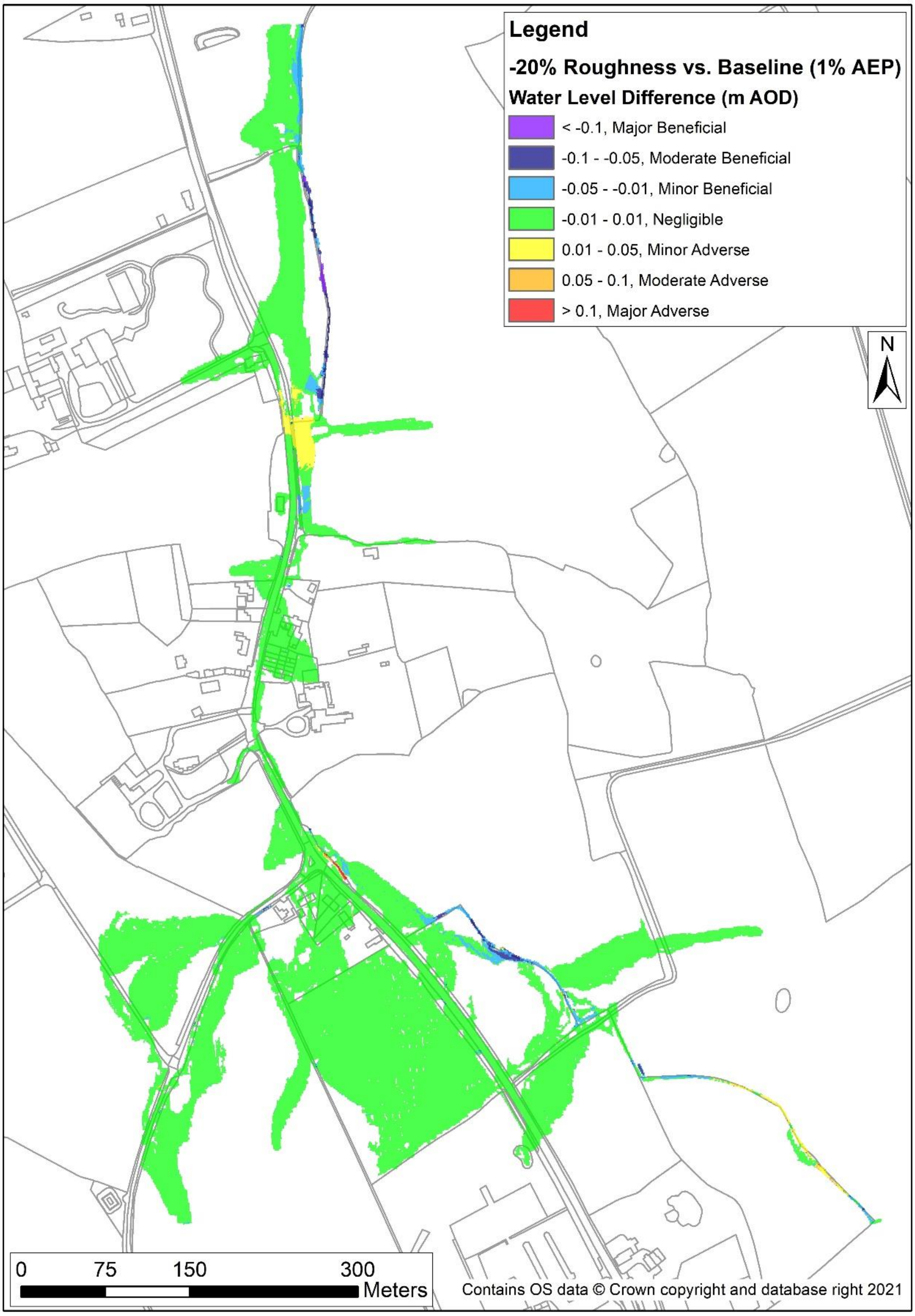


Plate B.2 Water level difference (Manning's 'n' Roughness changed by +20%) for the 1% AEP event

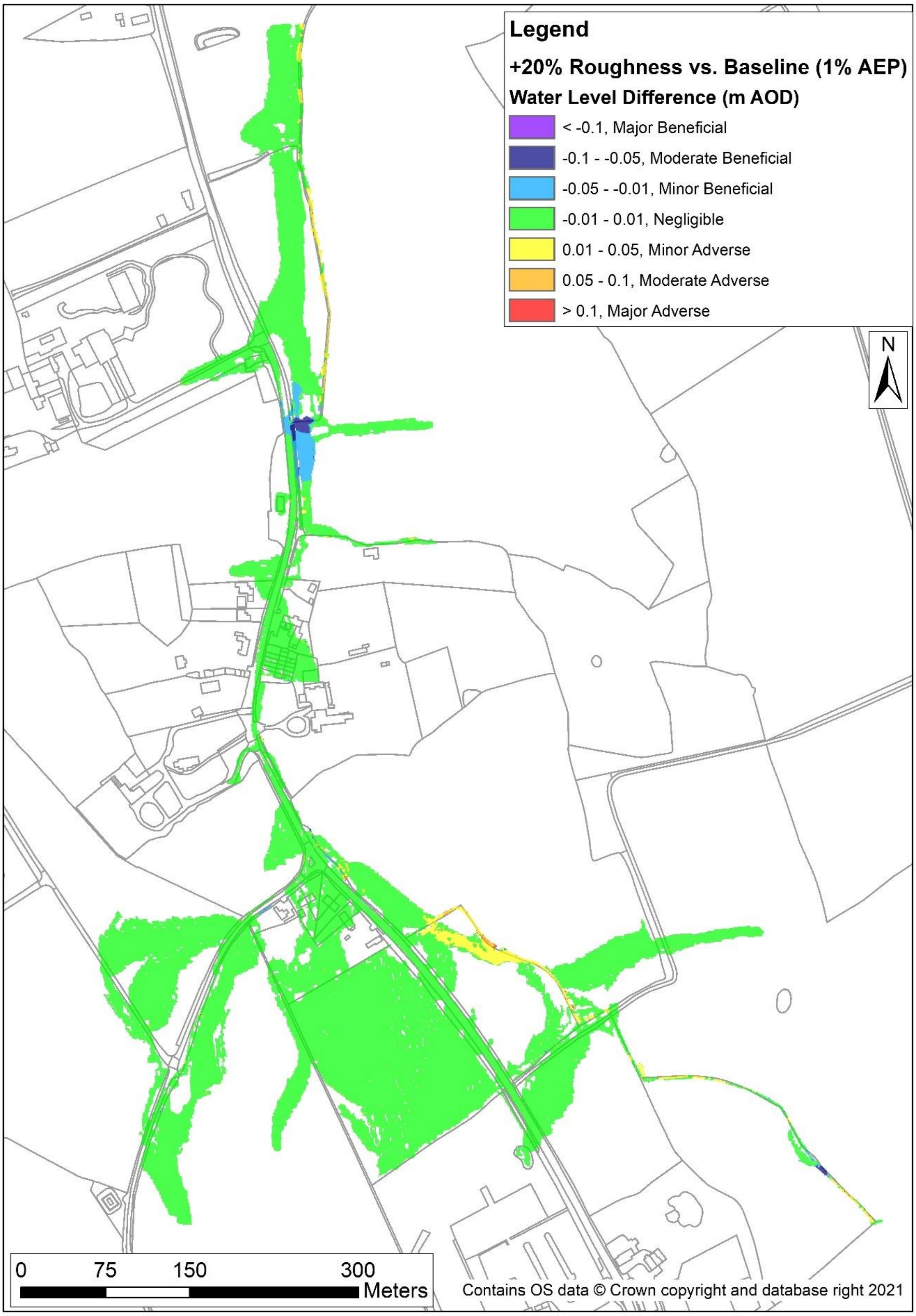


Plate B.3 Water level difference (Hydrological inflows into model changed by -20%) for the 1% AEP event

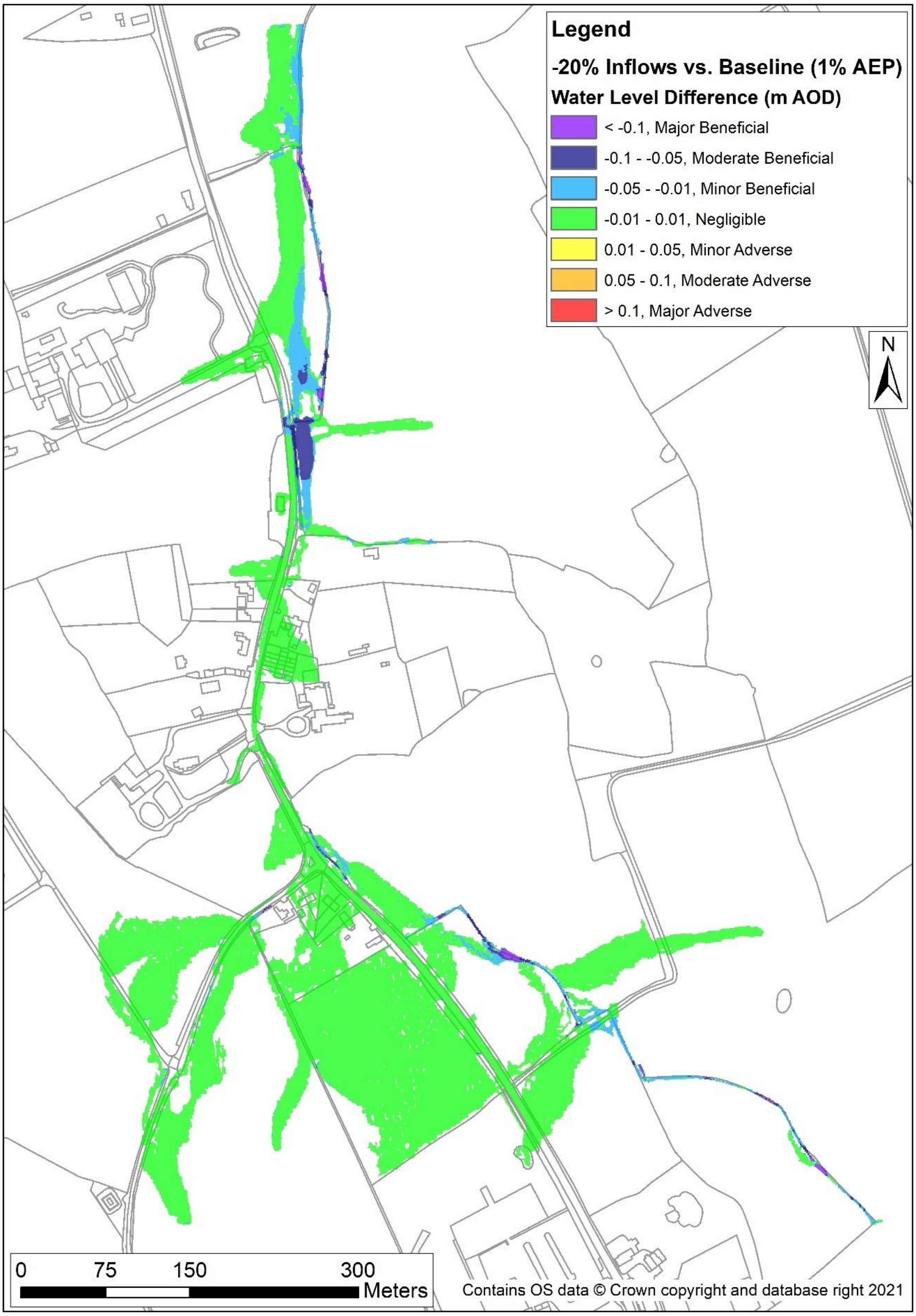
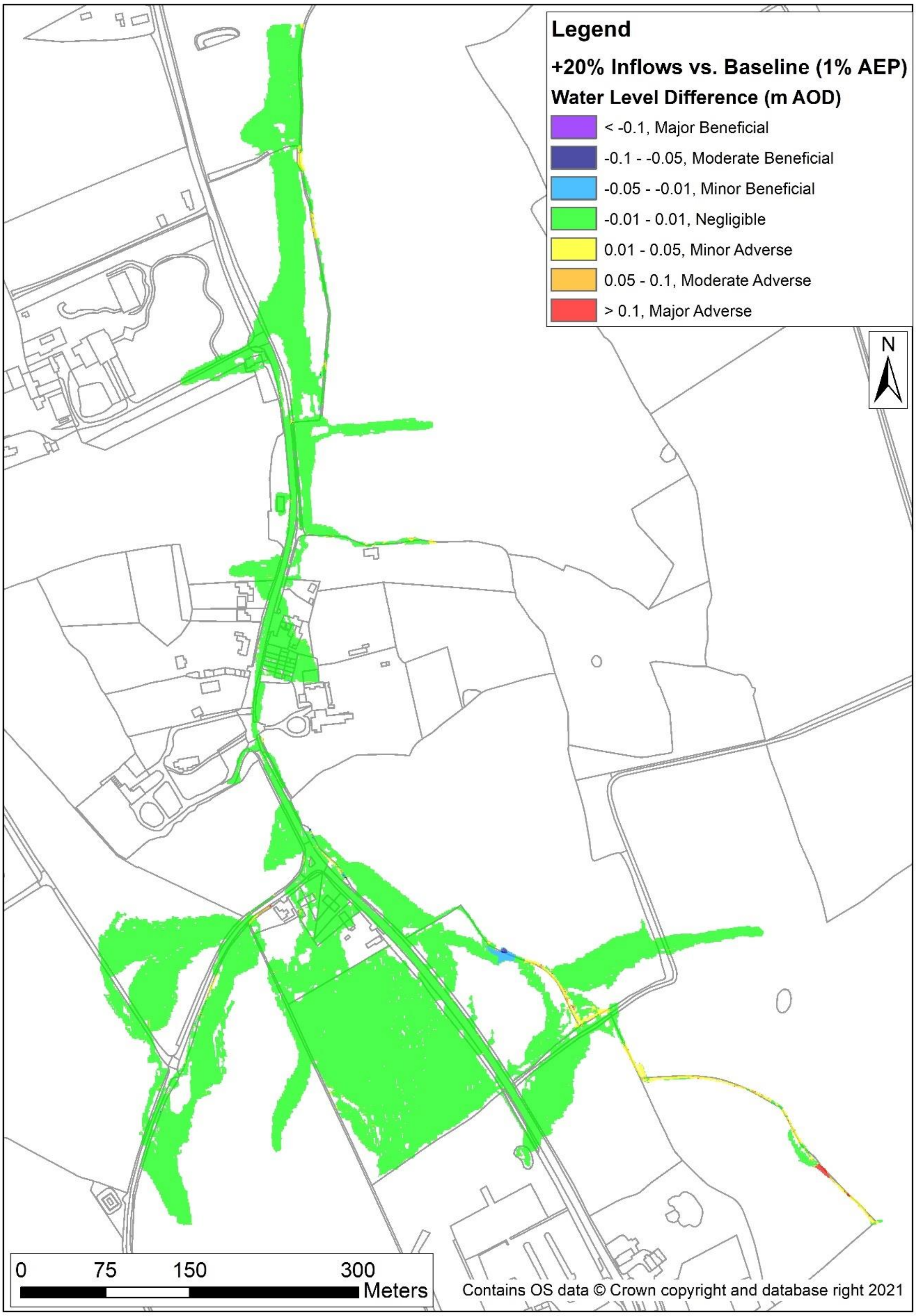


Plate B.4 Water level difference (Hydrological inflows into model changed by +20%) for the 1% AEP event



Appendix C – Mitigation Flood Mapping

Plate C.1 5% AEP maximum flood extent for baseline and mitigation scenarios

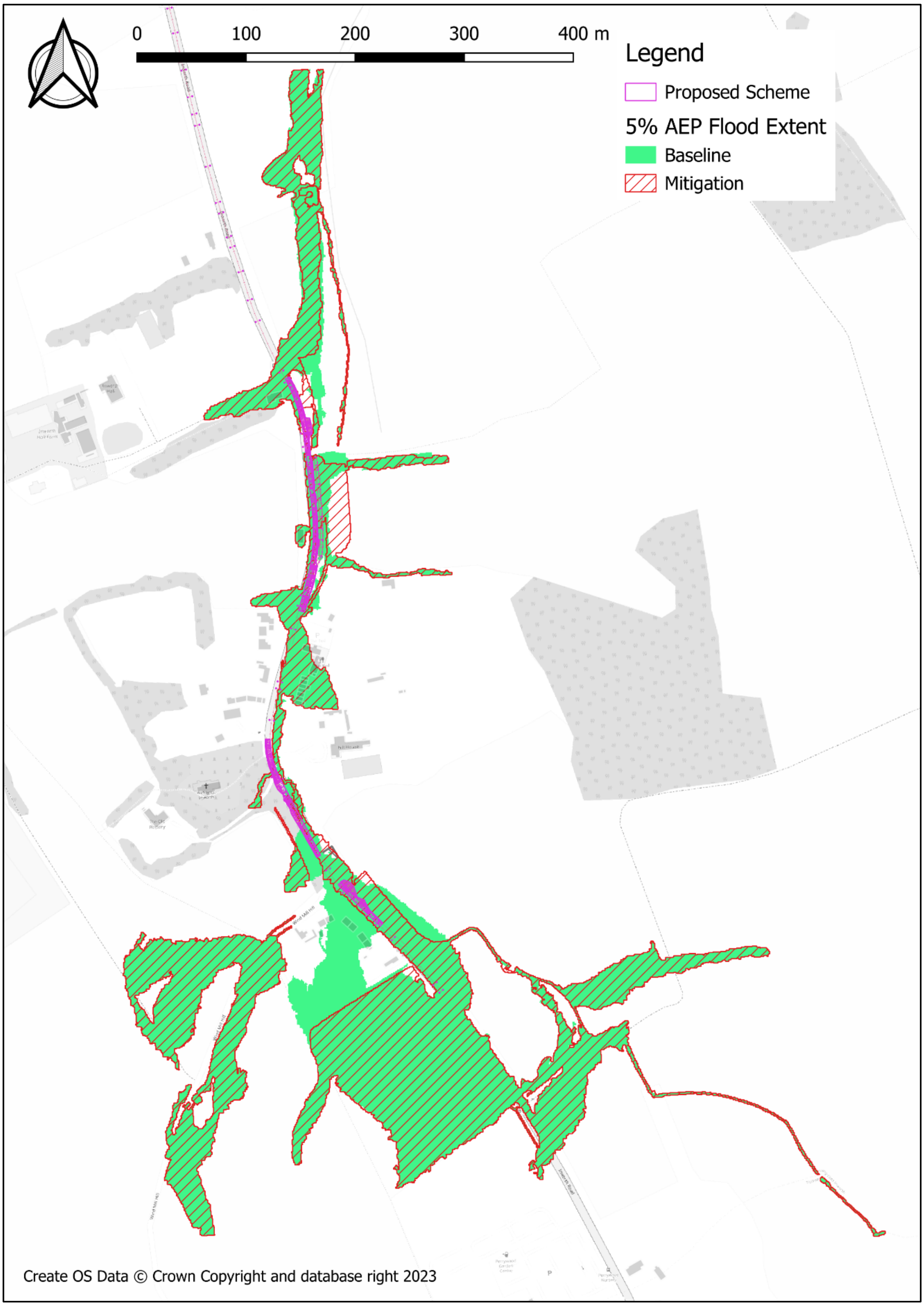


Plate C.2 1% AEP maximum flood extent for baseline and mitigation scenarios

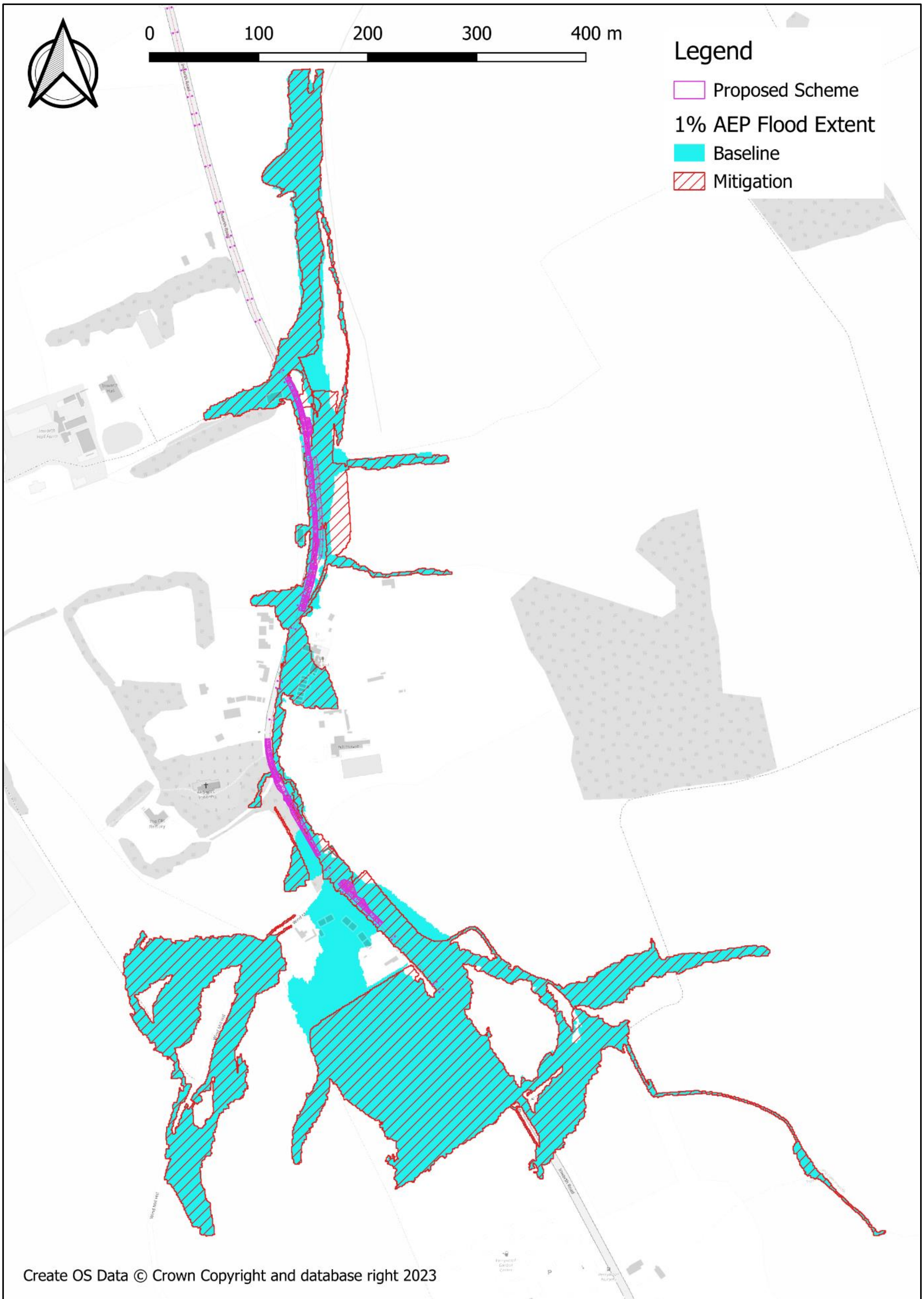


Plate C.3 1% AEP +45%CC maximum flood extent for baseline and mitigation scenarios

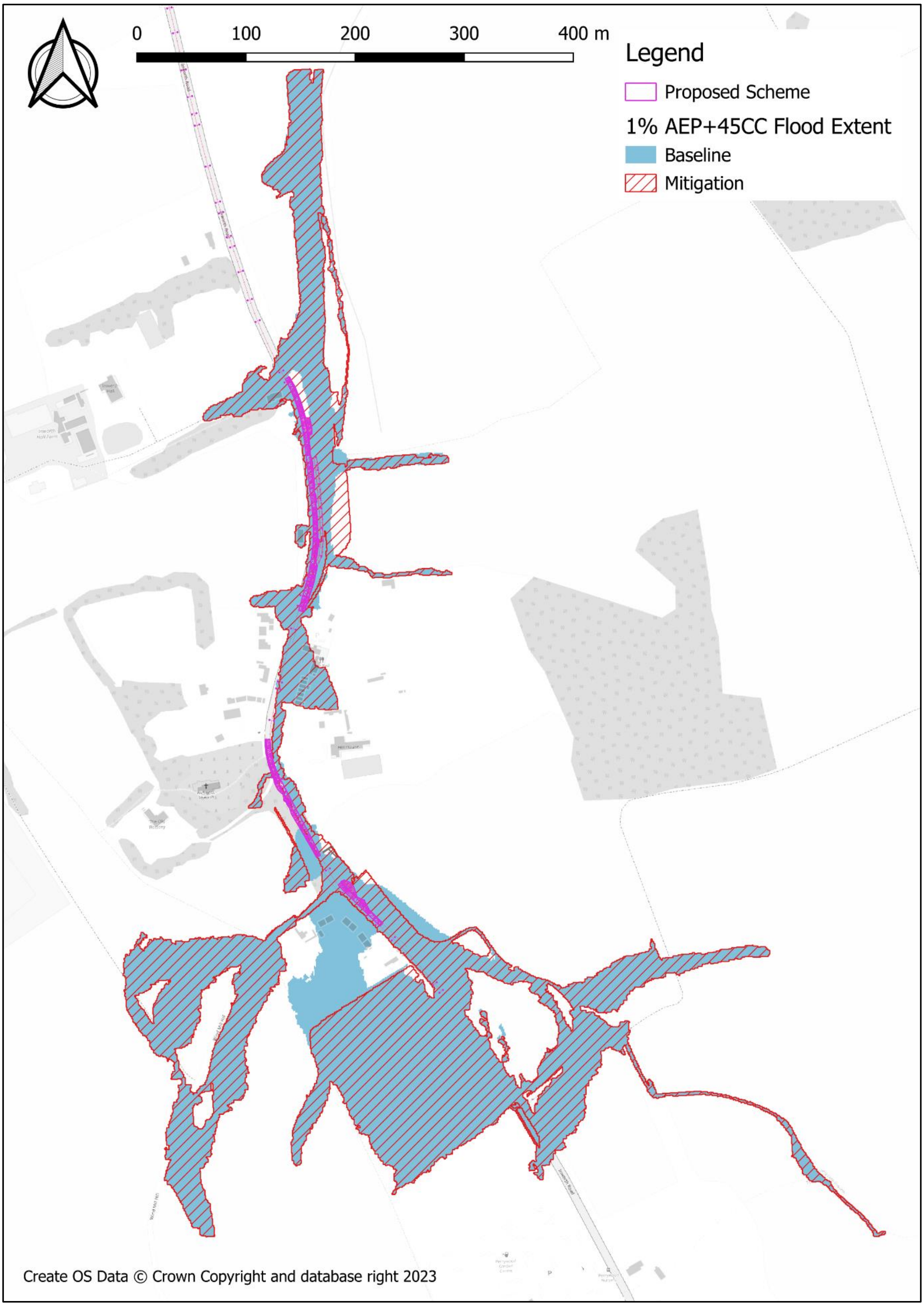


Plate C.4 Water level difference (mitigation - baseline) for the 5% AEP event

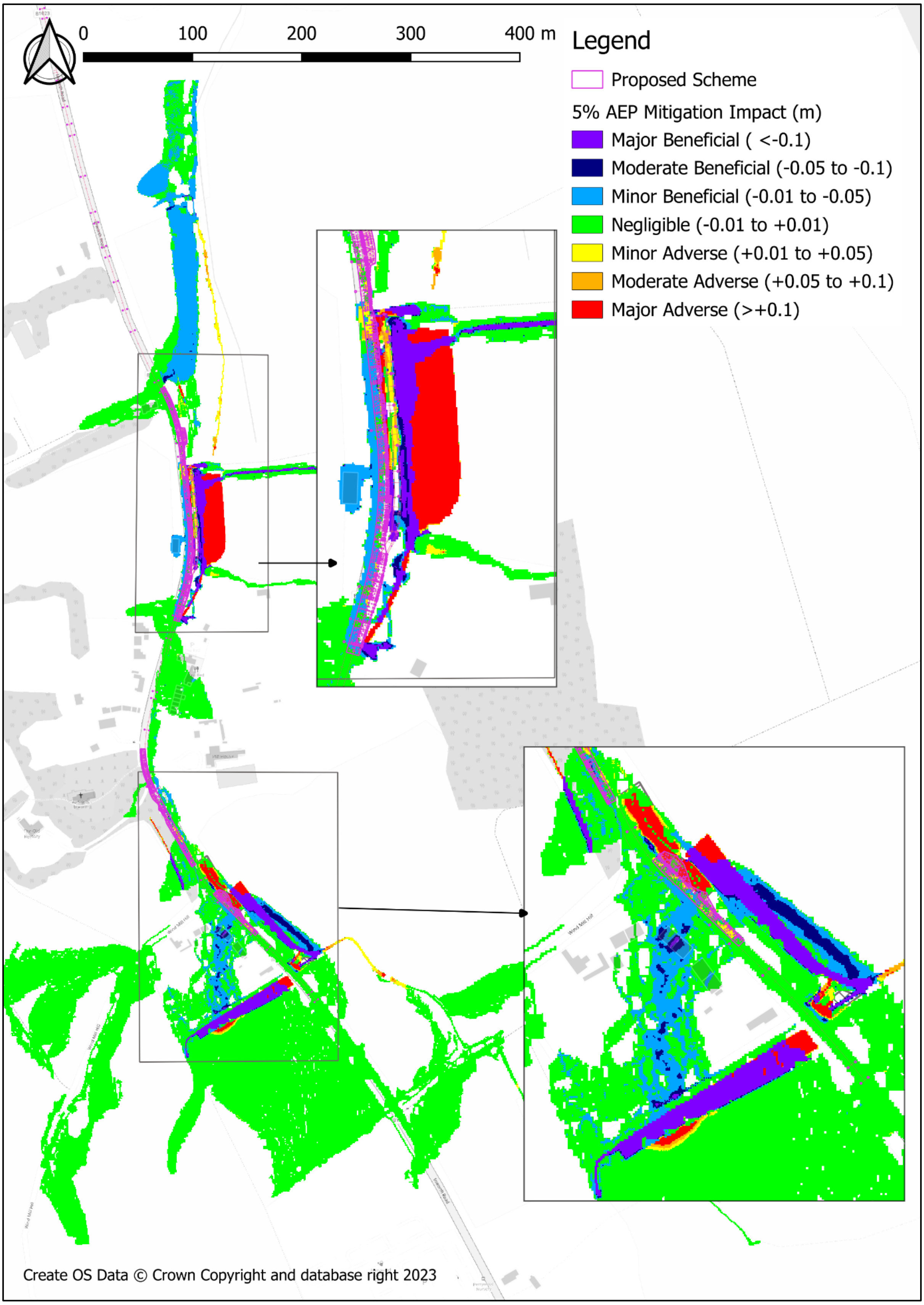


Plate C.5 Water level difference (mitigation - baseline) for the 1% AEP event

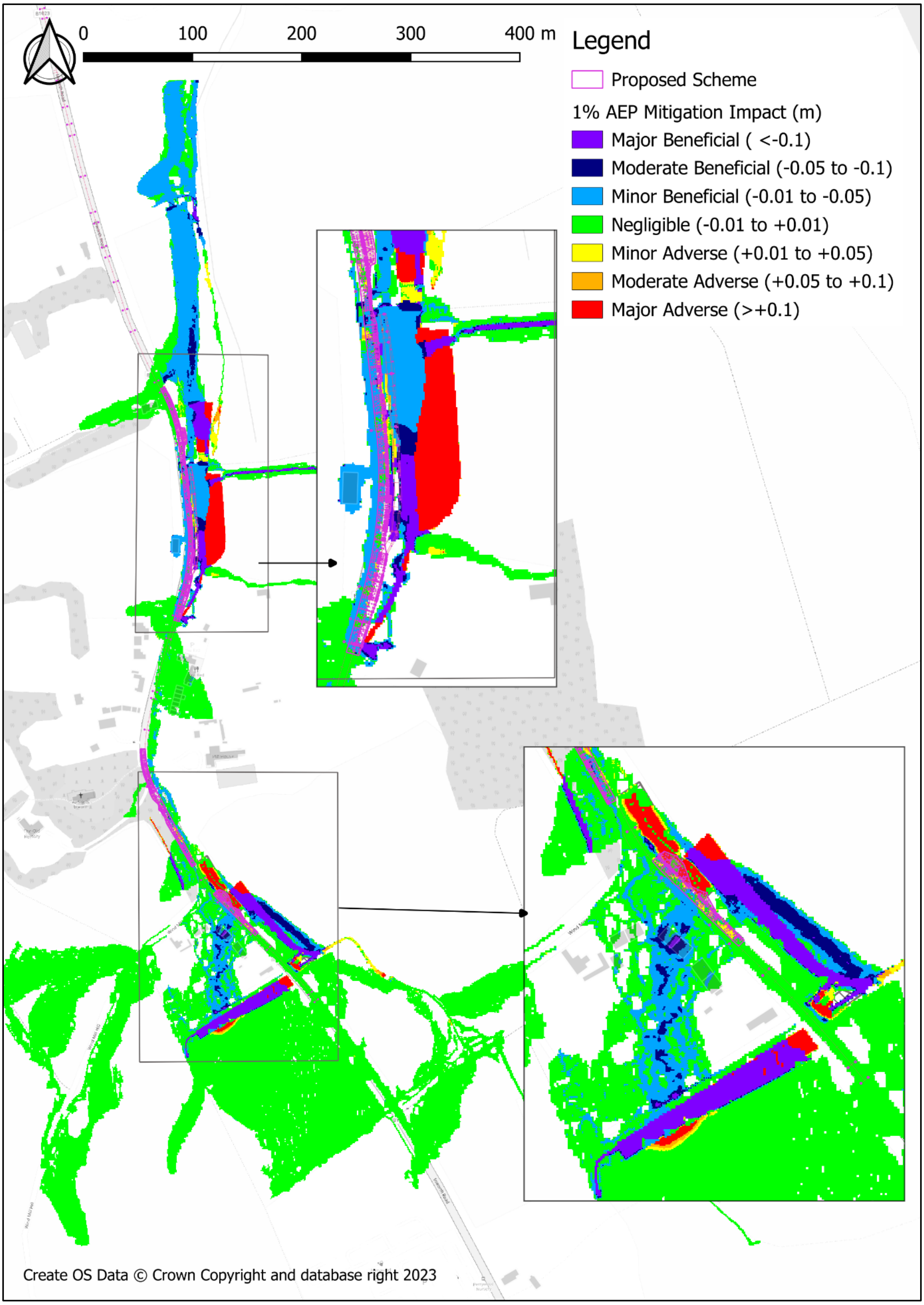
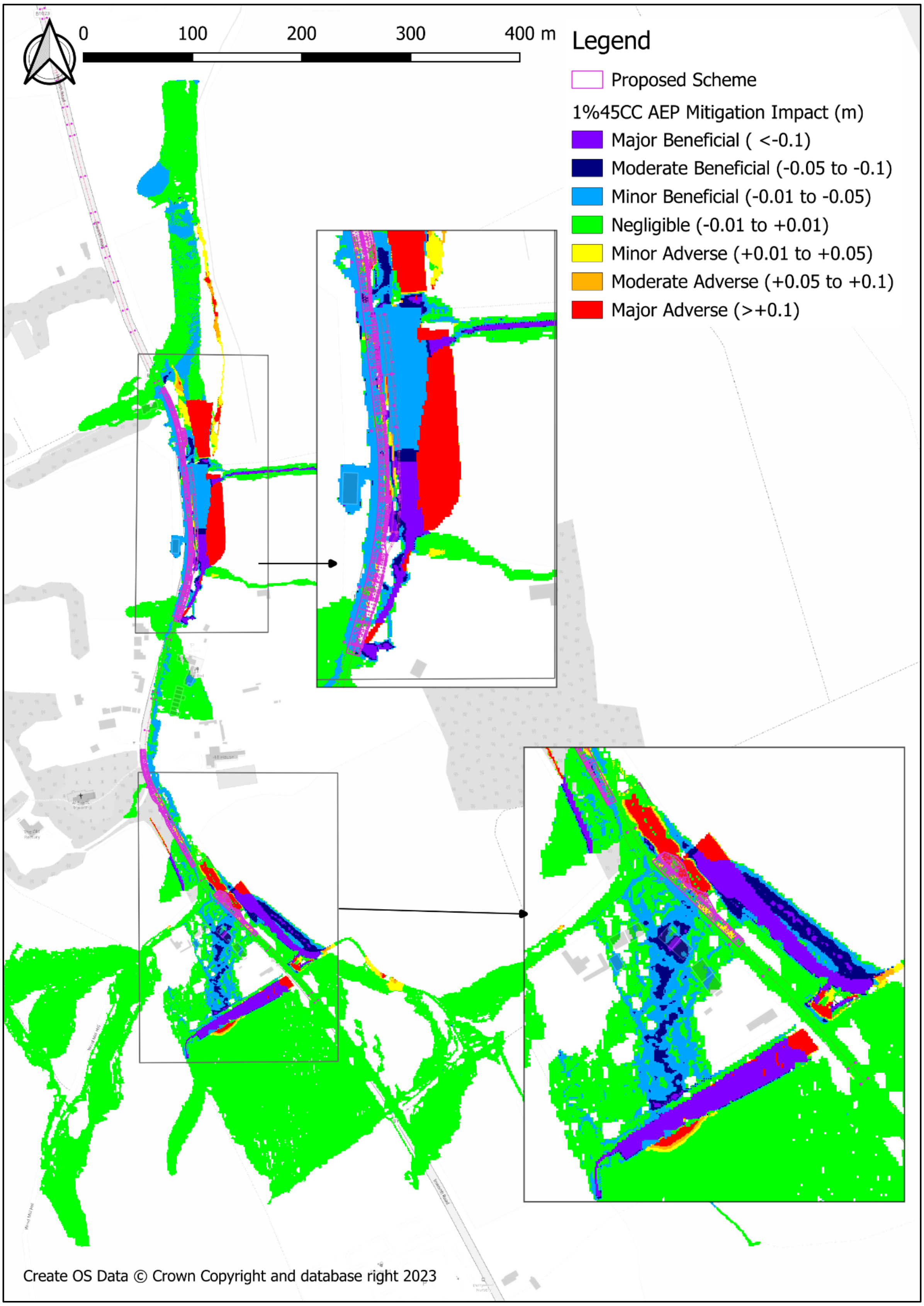


Plate C.6 Water level difference (mitigation - baseline) for the 1% AEP +40%CC event



Annex B Existing and Proposed Culvert Schedule for the B1023 Kelvedon Road

Culvert name[1]	National Grid Reference (NGR)	Existing culvert (retained/ extension/ abandoned) or Proposed Culvert	Culvert type	Culvert dimensions[3] (m)	Total culvert length (m)	Approx. length of proposed culvert extension (m)	Culvert crossing (watercourse / ditch)	Comments
CL-IWR-1A	TL88362 17267	Existing to be retained	Pipe	0.3	15	N/A	Ordinary Watercourse 34C	Existing culvert is not affected by the proposed highway improvement works
CL-IWR-2	TL88114 17692	Proposed	Pipe	0.3	25	N/A	Ordinary Watercourse 34C	New culvert located downstream of proposed flood mitigation storage area IWR1. The culvert size is determined through hydraulic modelling to restrict the flows from the upstream catchment as part of the flood mitigation proposals
CL-IWR-2A	TL88022 17625	Proposed	Pipe	1.2	5	N/A	Ordinary Watercourse 34C	New culvert required for draining the diverted ditch at an existing footpath
CL-IWR-4.1	TL88114 17692	Existing to be abandoned	Pipe	0.85	74	N/A	Ordinary Watercourse 34C	The existing culvert will be abandoned The existing watercourse upstream of this culvert will be diverted to the proposed flood mitigation storage area IWR2. The attenuated flows from the proposed mitigation storage

Culvert name[1]	National Grid Reference (NGR)	Existing culvert (retained/ extension/ abandoned) or Proposed Culvert	Culvert type	Culvert dimensions[3] (m)	Total culvert length (m)	Approx. length of proposed culvert extension (m)	Culvert crossing (watercourse / ditch)	Comments
								area IWR2 will be drained through proposed culvert CL-IWR-4B
CL-IWR-9	TL88031 17749	Existing to be extended	Pipe	0.45	68	2.7	Ordinary Watercourse 34C	The existing culvert hydraulic capacity was found to be adequate. Proposed culvert length includes approximately 2.7m of culvert extension to account for the highway widening works. The culvert extension will retain the existing pipe culvert geometry and gradient
CL-IWR-4B	TL88052 17760	Proposed	Pipe	0.6	69	N/A	Ordinary Watercourse 34C	New culvert located downstream of proposed flood mitigation storage area IWR2. The culvert size is determined through hydraulic modelling to restrict the flows from the upstream catchment as part of the flood mitigation proposal. This culvert partially replaces about 25m of an existing 900mm diameter pipe culvert
CL-IWR-4	TL87982 17901	Existing to be retained	Pipe	0.9 1.0 0.65	25 (0.9m dia pipe) 158 (1.0m dia pipe)	N/A	Ordinary Watercourse 34C	A chamber exists along the existing culvert alignment where the pipe diameter changes from 900mm (upstream) to 1000mm and then to 650mm diameter (downstream). Hydraulic modelling undertaken has taken into account the existing culvert to be retained. The flood

Culvert name[1]	National Grid Reference (NGR)	Existing culvert (retained/ extension/ abandoned) or Proposed Culvert	Culvert type	Culvert dimensions[3] (m)	Total culvert length (m)	Approx. length of proposed culvert extension (m)	Culvert crossing (watercourse / ditch)	Comments
					14 (0.65m dia pipe)			mitigation measures proposed upstream of Culvert CL-IWR-4B and downstream of CL-IWR-4A are also applicable to this culvert location
CL-IWR-4A	TL88012 18015	Proposed	Pipe	0.65	5	N/A	Ordinary Watercourse 34C	For sizing this new culvert, flow is taken from existing retained culvert CL-IWR4 as this culvert is located downstream of Culvert CL-IWR4. Mitigation measures proposed upstream of Culvert CL-IWR4 and Culvert CL-IWR-4B are also applicable to this culvert
CL-IWR-5	TL87996 17846	Existing to be extended	Pipe	0.6	23	12	Drainage culvert	The existing culvert hydraulic capacity was found to be adequate. The proposed culvert length includes approximately 12m of culvert extension to account for the highway widening works. The culvert extension will retain the existing pipe culvert geometry and gradient
CL-IWR-8	TL88046 18162	Existing to be abandoned	Pipe	0.5	9	N/A	Ordinary Watercourse 34	The existing culvert will be abandoned

Culvert name[1]	National Grid Reference (NGR)	Existing culvert (retained/ extension/ abandoned) or Proposed Culvert	Culvert type	Culvert dimensions[3] (m)	Total culvert length (m)	Approx. length of proposed culvert extension (m)	Culvert crossing (watercourse / ditch)	Comments
								The existing watercourse upstream of this culvert will be diverted to proposed flood mitigation storage area IWR3. The attenuated flows from the proposed mitigation storage area IWR3 will be drained through proposed culvert CL-IWR-8A
CL-IWR-8A	TL88044 18160	Proposed	Pipe	0.6	21	N/A	Ordinary Watercourse 34	New culvert located downstream of proposed flood mitigation storage area IWR3. The culvert size is determined through hydraulic modelling to restrict the flows as part of the flood mitigation proposals
CL-IWR-7	TL87894 18524	Existing to be retained	Pipe	0.45	56	N/A	Drainage culvert	Existing culvert hydraulic capacity assumed to be adequate (See note 2)

Notes:

1. The culvert schedule should be read in conjunction with Sheet 14 of 21 and Sheet 20 of 21 of the Drainage and Surface Water Plan, included within consultation Map Book 4.
2. Appropriate assumptions have been made where the existing drainage surveys have been found to be incomplete.
3. The new culverts sizes are based on hydraulic modelling undertaken for the Ordinary Watercourses and are to restrict the flows as necessary as part of proposed flood mitigation works.

Culvert name[1]	National Grid Reference (NGR)	Existing culvert (retained/ extension/ abandoned) or Proposed Culvert	Culvert type	Culvert dimensions[3] (m)	Total culvert length (m)	Approx. length of proposed culvert extension (m)	Culvert crossing (watercourse / ditch)	Comments
4. Where existing culverts are proposed to be retained, their condition assessment (including defects identification and remediation work requirements) will be undertaken at the detailed design stage.								