M25 junction 28 improvement scheme
TR010029
6.6 Flood risk assessment

APFP Regulation 5(2)(e)
Planning Act 2008
Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

Volume 6
May 2020

Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

M25 junction 28 scheme
Development Consent Order 202[x]

6.6 FLOOD RISK ASSESSMENT

Regulation Number:	Regulation 5(2)(e)
Planning Inspectorate Scheme Reference:	TR010029
Application Document Reference:	TR010029/APP/6.6
Author:	M25 junction 28 improvement scheme project team, Highways England

Version	**Date**	**Status of Version**
1	May 2020	Application issue

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Executive summary

This Flood Risk Assessment (FRA) forms part of the Development Consent Order (DCO) application for improvements to M25 junction 28 (the “Scheme”) and has been prepared in accordance with the requirements of Regulation 5(2)(e) of The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009 (APFP).

The Scheme comprises a series of road improvements proposed by Highways England (the “Applicant”) to address congestion and journey reliability issues at junction 28/A12 of the M25 motorway.

This FRA has been completed to provide a quantitative assessment of flood risk and demonstrate that the proposed mitigation (where necessary) would achieve an acceptable level of flood risk and would not increase flood risk elsewhere. This FRA has also been completed in line with the National Policy Statement for National Networks (NPS NN) and follows the current national planning policy in relation to development and flood risk, namely the National Planning Policy Framework (NPPF) (Ministry of Housing, Communities & Local Government , 2019). The FRA addresses all sources of flood risk both under current conditions and taking climate change into account.

Environment Agency flood risk mapping and the London Borough of Havering Strategic Flood Risk Assessments (SFRA) were used as the main sources of flood risk information to inform the understanding of flood risk within the study area. This information has been supplemented with detailed hydraulic modelling undertaken specifically for the DCO application both to provide a more robust understanding of flood risk and inform the scheme design.

The primary source of flooding at the location of the Scheme is fluvial. Fluvial flood risk arises when watercourses exceed capacity and areas at risk are shown by the Environment Agency Flood Zone mapping. This Flood Zone mapping identifies that several areas of the Scheme are at high risk of fluvial flooding within Flood Zones 2 and 3. There are three geographical areas at risk from fluvial flooding where the proposed works would impact on flood risk, either through the displacement of flood water or as a result of a constriction of flow conveyance. The works in these areas have been subject to extensive hydraulic modelling to inform suitable mitigation measures ensuring negligible overall increase in flood risk due to the Scheme.

The other key source of flood risk requiring consideration is surface water runoff. The existing drainage system manages the current surface water flood risk to the road network and this will be upgraded and supplemented with additional drainage systems (where necessary) to accommodate the Scheme. The drainage system has been developed in line with the current planning policy requirements and it is described in detail within the Drainage strategy report (application document TR010029/APP/6.8). It will attenuate storm water onsite up to 1 in 100 (1%) annual probability rainfall event including an allowance for climate change.

Flood risk from all other sources is considered low, although requirements will be included within the Construction Environmental Management Plan (CEMP) (based on the Outline CEMP, application document TR010029/APP/7.2) to be produced by the Principal Contractor to minimise the impacts on flood risk through appropriate mitigation measures.

These mitigation measures include consideration of groundwater ingress into excavations and understanding the water transmission infrastructure network in the area.

This FRA demonstrates that the Scheme would be at an acceptable level of flood risk and would not increase flood risk elsewhere. This conclusion remains true over the lifetime of the Scheme taking climate change into consideration.

1. Introduction

1.1 Background

1.1.1 In December 2014, the Department for Transport (DfT) published its Road Investment Strategy (RIS) for the investment period 2015 and 2020, announcing £15 billion to invest in England's strategic road network. The RIS sets out a list of schemes that are to be delivered by Highways England over this investment period, and identified M25 junction 28 as a key junction requiring improvement to address congestion and safety issues. In their second RIS (RIS2) for 2020 to 2025, published in March 2020, the DfT reiterate their support for improvements to M25 junction 28. The Scheme is described in RIS2 as an "*upgrade of the junction between the M25 and A12 in Essex, providing a free-flowing link from the northbound M25 to the eastbound A12"*.

1.1.2 This FRA forms a quantitative appraisal of all sources of flood risk to the proposed site and any potential increases in flood risk as a result of the Scheme. It also outlines possible mitigation measures that could be proposed during construction and operation to both reduce the risk to the site and to prevent an increase in flood risk elsewhere as a result of the development.

1.2 Scope

1.2.1 This FRA has been completed in line with the NPS NN and follows the current planning policy in relation to development and flood risk, namely the NPPF and associated Planning Practice Guidance. This FRA has also been completed in line with the Highways England's Design Manual for Roads and Bridges (DMRB) Volume 11, Section 3 Part 10 Road Drainage and the Water Environment (Highways England et al 2009).

1.2.2 The assessment is required to confirm the Scheme would give rise to an appropriate level of flood risk, and to confirm that the Scheme is not increasing flood risk both on site and elsewhere, and where possible reducing flood risk overall. This is required for all sources of flood risk and over the lifetime of the development (i.e. taking into account climate change).

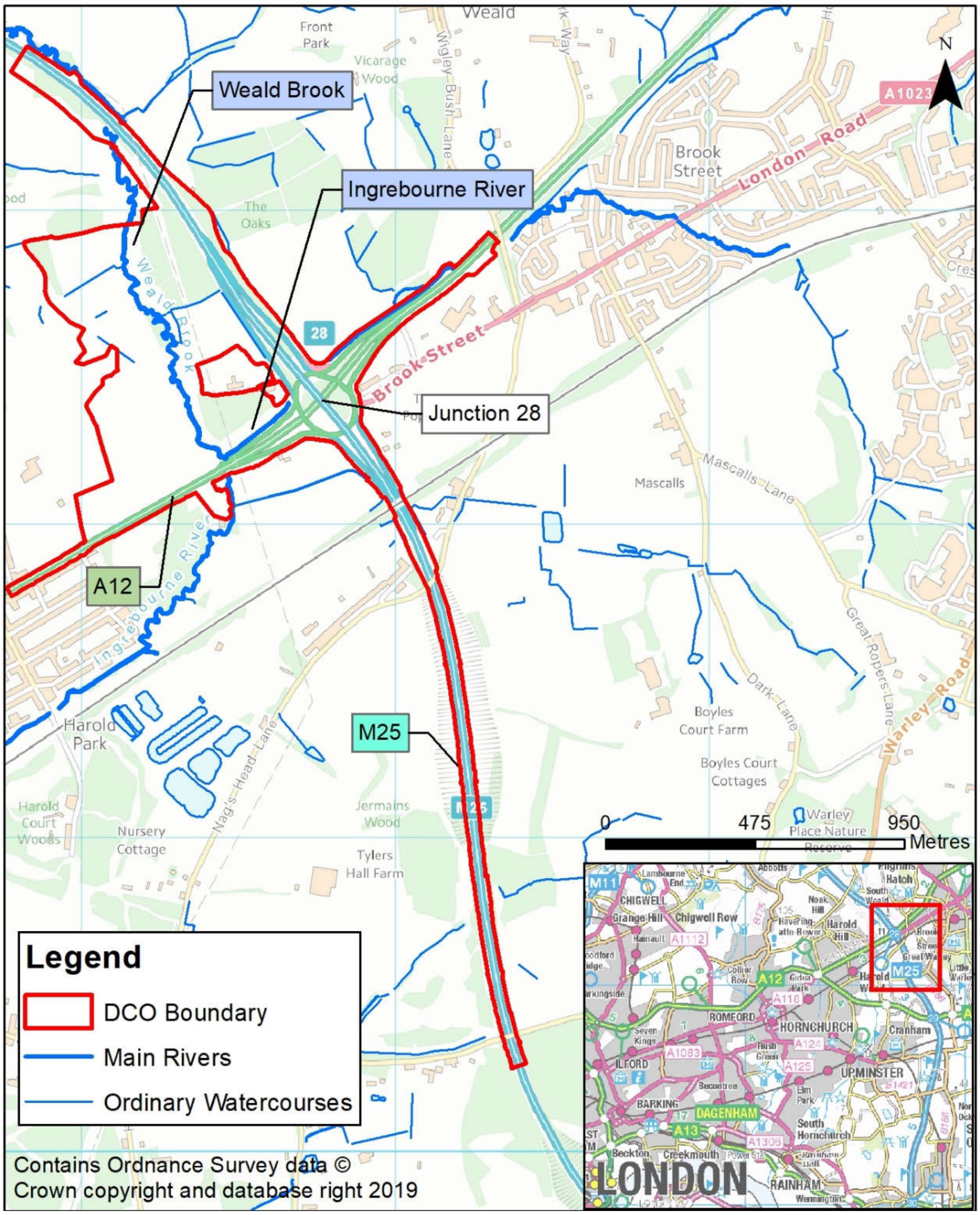
1.2.3 This FRA is a quantitative appraisal to demonstrate that the development complies with the above requirements. Therefore, this FRA:

- Defines flood risk to the site
- Determines the impact of the development on flood risk
- Outlines the proposed mitigation measures
- Provides evidence demonstrating that for the lifetime of the development, the development is at an acceptable risk of flooding, whilst ensuring the development will not increase flood risk elsewhere

1.2.4 The Scheme is located to the east of London where the A12 road crosses the M25. The location and DCO boundary of the Scheme is shown below in Figure 1.1 along with main river and ordinary watercourses for which the Environment Agency and Lead Local Flood Authorities (LLFAs) are the regulators respectively. The LLFAs responsible for watercourses within the study area are

Essex County Council and Havering Borough Council. Detailed drawings of the Scheme are shown in the Scheme layout plans (application document TR010029/APP/2.7).

Figure 1.1: Scheme location plan



1.3 Flood risk policy

1.3.1 The NPS NN, the NPPF and associated guidance are the key planning policy guidance in relation to flood risk and development to ensure that flood risk is adequately considered as part of development design. The NPS NN is the policy specific for Nationally Significant Infrastructure Projects (NSIPs) and it references much of the policy and guidance from the NPPF.

1.3.2 The NPS NN requires a Sequential Test when determining the location of the new development to promote the development away from areas at risk of flooding. The Highways England RIS for 2015-2020and RIS2 for 2020-2025 identify the significant need for capacity improvements at this junction and therefore works are required at this location. However, where possible, a sequential approach has been taken within the study area for the road improvements, such as when locating balancing ponds and site compounds.

1.3.3 The NPPF categorises development type based on vulnerability to flooding. The Scheme falls under these classifications as 'Essential Infrastructure'. This means that the proposed development would be considered acceptable for construction in Flood Zones 1 and 2, hence areas at risk from fluvial (river) flooding during the 1 in 1000 (0.1%) annual probability event and rarer. This type of development could be proposed within higher risk areas, i.e. Flood Zone 3 (both 3a and 3b) if a passed Exception Test is demonstrated.

1.3.4 A passed Exception Test demonstrates that both of the following conditions are met:

1. The development is required for wider sustainability benefits to the community that outweigh flood risk.
2. That the development is safe from flooding for its lifetime without increasing flood risk elsewhere and, where possible, will reduce flood risk overall.

1.3.5 In addition, any project that is classified as 'Essential Infrastructure' and proposed to be located in Flood Zone 3a or 3b should be designed and constructed to remain operational and safe for users in times of flood; and any project in Zone 3b should result in no net loss of floodplain storage and not impede water flows.

1.3.6 This FRA demonstrates this and test 2 above. Test 1 is also considered to be met. The benefits that the Scheme will give rise to are set out within the Case for the Scheme (application document TR010029/APP/7.1) and supported by the Environmental Statement (application document TR010029/APP/6.1).

2. Assessment of flood risk

2.1 Overview

2.1.1 As outlined in the NPS NN and the NPPF, flood risk from all sources must be addressed within an FRA to ensure that potential flood risk has been considered during the design of the Scheme. This section provides a list of the data sources used for this assessment followed by the types of flood risk impacting the study area, potential methods to mitigate against flooding and finally the impacts of climate change.

2.2 Data sources

2.2.1 The assessment makes use of readily available information as follows:

- The Environment Agency Flood Zones, surface water mapping and historical flood extents, taken from the open data available on the Data.gov.uk website[1]
- The Havering Strategic Flood Risk Assessment (SFRA) (Jacobs, 2016)
- The Havering Preliminary Flood Risk Assessment (JBA & Jacobs, 2011)
- Thames River Basin District - Flood Risk Management Plan (Environment Agency, 2016)
- Havering Local Flood Risk Management Strategy (London Borough of Havering, 2015)
- The Multi-Agency Flood Plan (London borough of Havering, 2017)
- Drainage strategy report (application document TR010029/APP/6.8)
- Highways Agency Drainage Data Management System (HADDMS)

2.2.2 This FRA has also been informed by detailed hydraulic modelling as discussed within the Hydraulic Modelling Report (Appendix A) prepared to inform the Scheme design (Atkins, 2019b).

2.2.3 A Surface Water Management Plan (SWMP) was undertaken in 2011 by the London Borough of Havering as part of the Drain London project; while the results of this study are discussed in the reports referenced above they do not indicate any relevance to our study area. Given flood risk at the site is predominantly fluvial driven in a rural location, the SWMP (surface water in normally urban areas) is unlikely to provide further information relevant to the site.

2.3 Historic flooding

2.3.1 Areas that have flooded in the past often indicate areas that are vulnerable to flooding in the future. The Environment Agency publish mapping that indicates areas which have been inundated by water in the past. In relation to the Scheme, this mapping is shown below in Figure 2.1 and shows recorded flooding downstream of the A12 culvert on the Ingrebourne River with only a small area

[1] https://data.gov.uk/

within the DCO boundary. The absence of historical data does not indicate there has been no past flooding; the study area is predominately rural and in the upper catchment reaches therefore it is unlikely data was captured at this location.

2.3.2 The SFRA (Jacobs, 2016) also indicated that this area has historically flooded with recorded floods downstream of A12 culvert in 1968 and no records further upstream of this location.

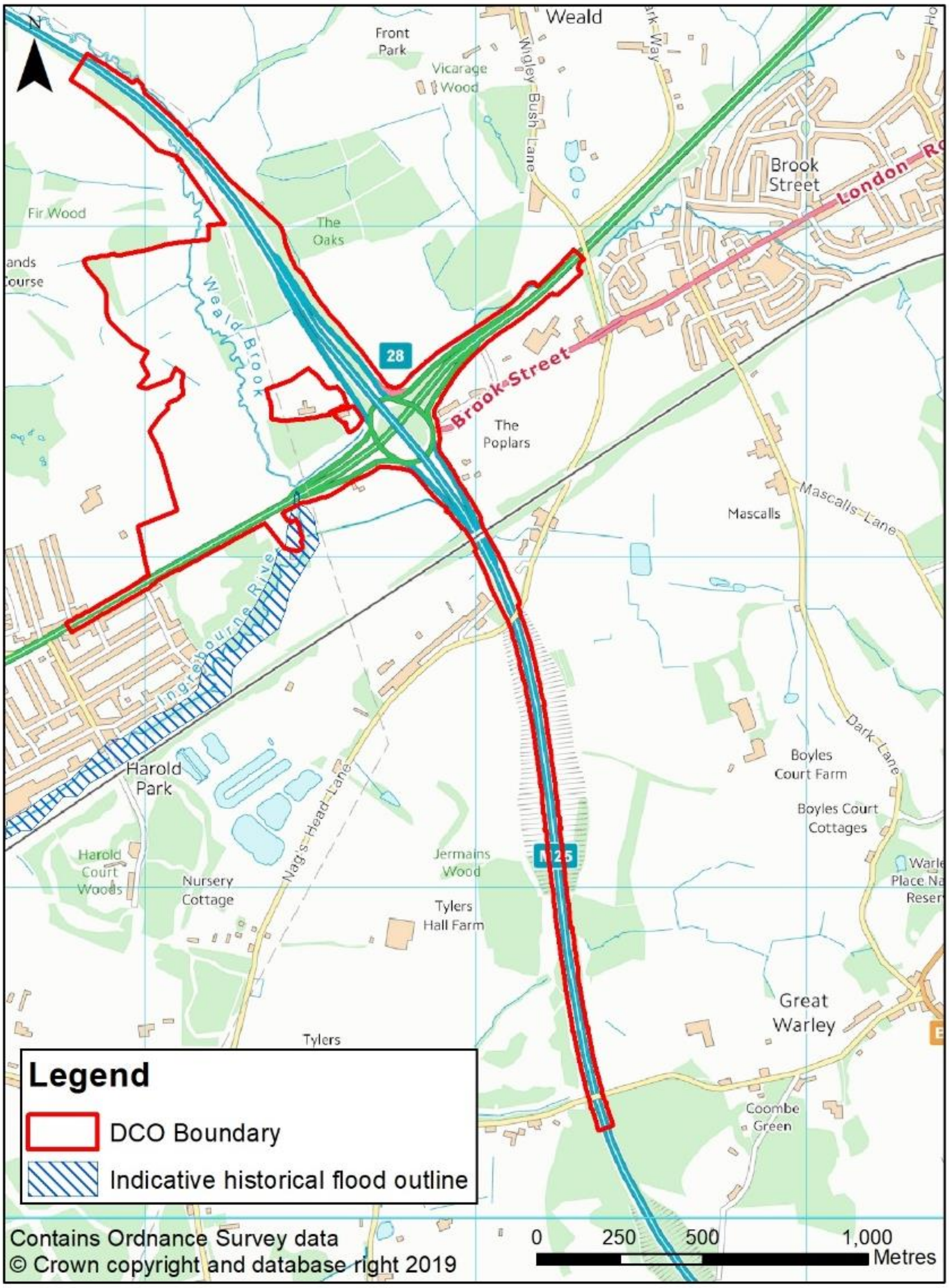
2.3.3 Flooded properties (vulnerable receptors[2]) have been recorded in the wider Ingrebourne catchment area, including sewer flooding (Jacobs, 2016). There are no vulnerable receptors at risk within the scheme boundary therefore flooding from any source is unlikely to be widely reported.

2.3.4 There are no Section 19[3] Flood Investigation reports within the scheme DCO boundary. However, there is a Section 19 report covering the urban areas surrounding the Ingrebourne River downstream of the Scheme undertaken following widespread flooding in June 2016 (Jacobs, 2017). The report concluded the flooding was a result of higher than average rainfall and adverse antecedent soil conditions across the wider region and not localised to the London Borough of Havering. While this area is not directly within the study boundary it highlights the importance that flows downstream should not be increased as a result of the Scheme.

[2] Vulnerability is a measure of the potential of people or things to be harmed. A vulnerable receptor is one where it is likely to impact people or infrastructure that is critical to essential services/emergency response.

[3] Formal investigation into the causes of locally significant flooding incidents, required under the Flood and Water Management Act (FWMA) 2010.

Figure 2.1: Environment Agency historical flooding



2.4 Fluvial flood risk

2.4.1 Fluvial flood risk occurs when the capacity of a watercourse is exceeded such that water overspills the watercourse channel.

Baseline flood risk

2.4.2 Three watercourses that pass through the study area, Weald Brook, Ingrebourne River and Paine's Brook, are classified as main rivers as shown in Figure 1.1 and therefore fall under the regulation of the Environment Agency.

2.4.3 The Weald Brook flows north to south through the study area discharging into the Ingrebourne River upstream of the A12 culvert. It has an entirely rural upstream catchment where it is culverted under the existing M25 over 1 km upstream of the A12. The watercourse has high sinuosity and a natural floodplain approximately 100 m wide throughout the study area.

2.4.4 The Ingrebourne River flows east to west entering the study area through an existing 160 m long dual bore box culvert. Its upper catchment is largely urbanised with a heavily modified straight channel running through the study area adjacent to the existing A12 road. There are three further significant culverts upstream of the study area (Jacobs, 2016). The Weald Brook joins the Ingrebourne River directly upstream of the A12, from here on it is known only as the Ingrebourne River as it leaves the study area through the existing single bore 8m wide A12 culvert.

2.4.5 Fluvial flood risk on the Paine's Brook will not be affected as there are no physical works on this watercourse.

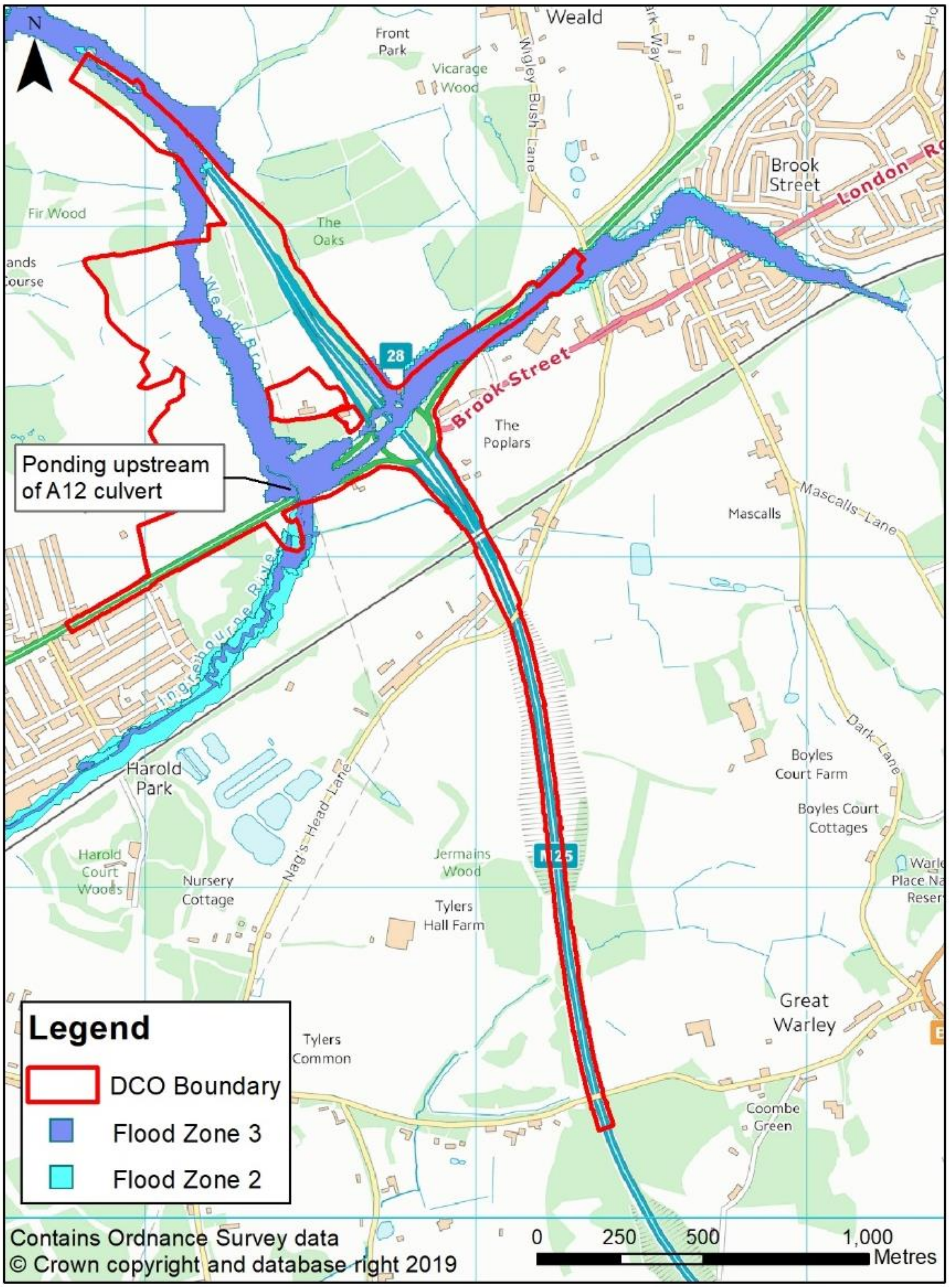
2.4.6 The initial source of information used to determine fluvial flood risk to a proposed development is the Environment Agency Flood Zone mapping. The Flood Zones are defined as:

- *Flood Zone 1* – Areas with a 'Low Probability' of flooding and where the annual probability of flooding is lower than 1 in 1000 (0.1%) for either fluvial or tidal flooding. The NPPF imposes no constraints upon the type of development within Flood Zone 1.
- *Flood Zone 2* – Areas with a 'Medium Probability' of flooding and where the annual probability of flooding is between 1 in 1000 (0.1%) and 1 in 100 (1%) for fluvial flooding or between 1 in 1000 (0.1%) and 1 in 200 (0.5%) for tidal flooding. The NPPF recommends that Flood Zone 2 is suitable for most types of development with the exception of 'Highly Vulnerable' land uses.
- *Flood Zone 3* – Areas with a 'High Probability' of flooding and where the annual probability of flooding is 1 in 100 (1%) or greater for fluvial flooding or 1 in 200 (0.5%) or greater for tidal flooding. The NPPF recommends that appropriate development is based upon a further classification of Flood Zone 3 into 3a 'High Probability' and 3b 'Functional Floodplain' (where water has to flow or be stored in times of flood during the 1 in 20, 5%, event).

2.4.7 The Environment Agency mapping also indicates areas that benefit from flood defences and areas of floodplain storage, however neither are located within or adjacent to the Scheme.

2.4.8 Figure 2.2 shows that the scheme DCO boundary encroaches into Flood Zone 2 and 3 along the alignment of both watercourses. Both Flood Zones encroach onto the A12 road and small parts of the M25. The Flood Zones show ponding upstream of the A12 culvert indicating a significant flow constriction during high flow events, this area is shown in Figure 2.2.

Figure 2.2: Environment Agency Flood Zone mapping and watercourse location plan

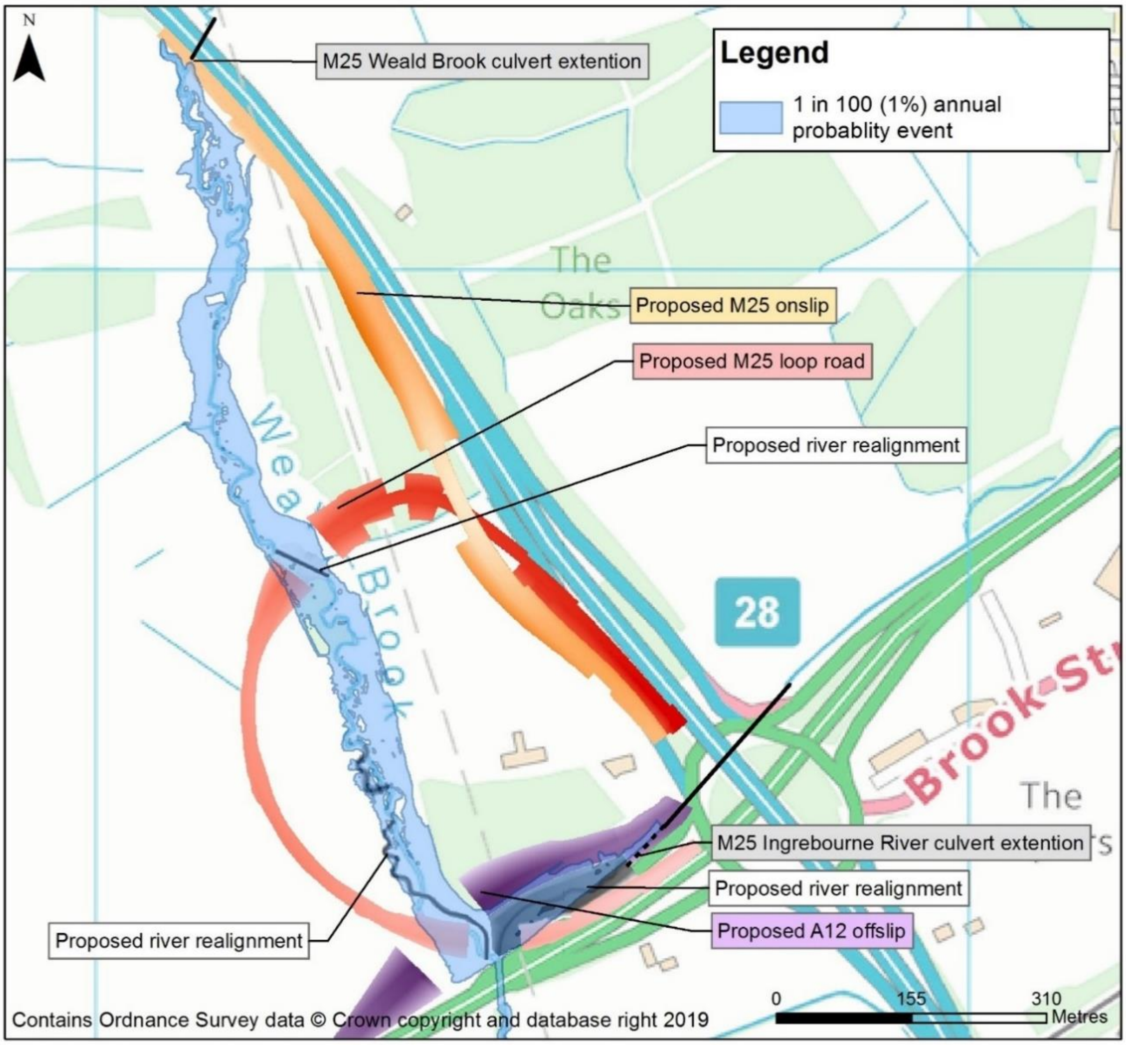


Post Scheme impacts

2.4.9 Any development that encroaches into Flood Zones 2 or 3 or works to watercourse crossings has the potential to increase fluvial flood risk. This can occur as a result of displacement of flood water when development is located in floodplain or owing to constriction of flood flows at the location of watercourse crossings. Where there is an impact on flood risk, flood compensation is required.

2.4.10 The proposed works that may impact on flood risk associated with main rivers are shown in Figure 2.3. The works have been overlaid with the modelled 1 in 100 (1%) annual probability event as below and discussed in the following paragraphs.

Figure 2.3: Elements of the Scheme



2.4.11 The Scheme will encroach into the floodplain at three locations:

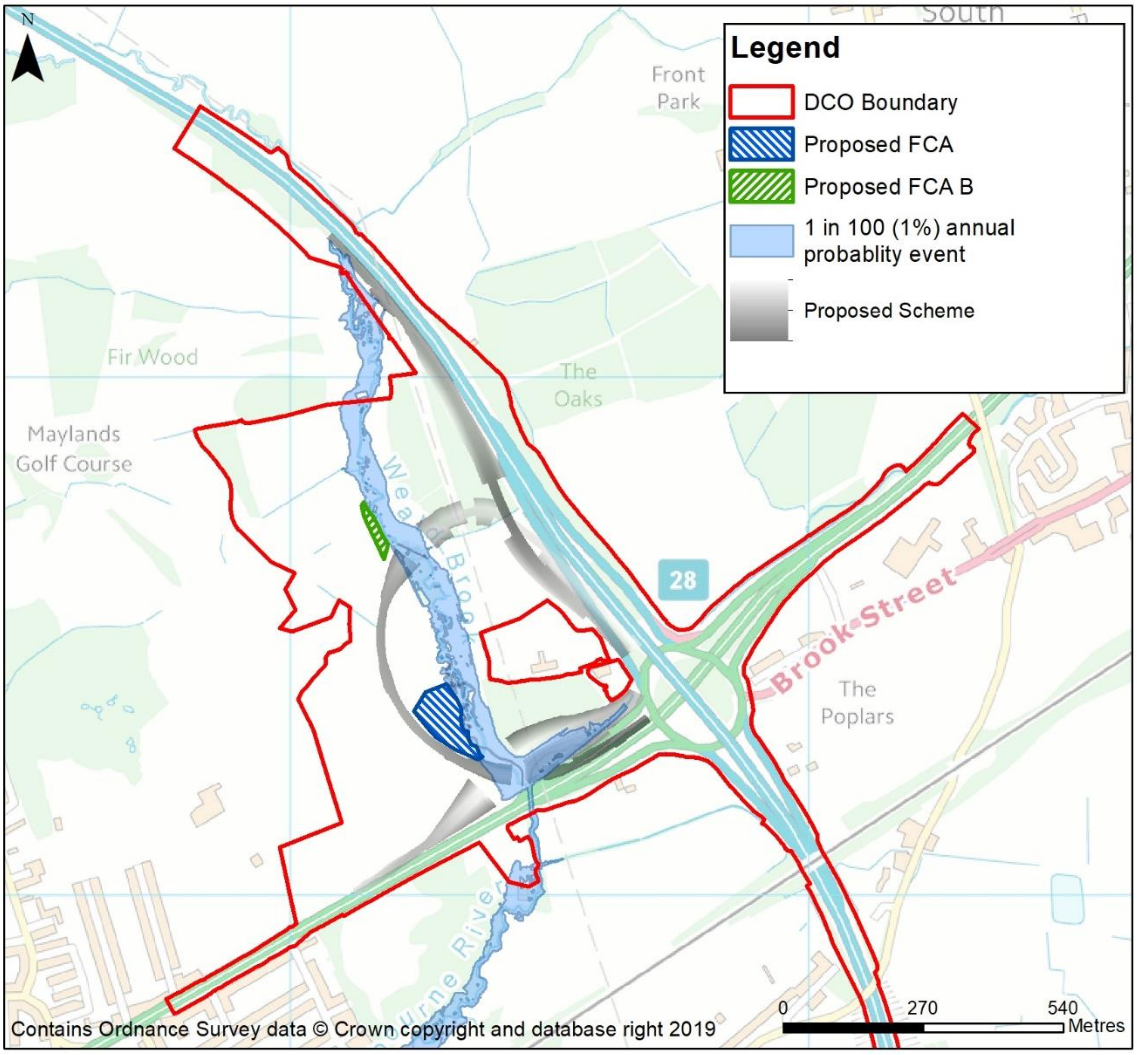
- Upstream of the A12 culvert it is proposed to construct the A12 off-slip. The off-slip will be north of the existing A12 alignment crossing the Weald Brook directly upstream of the confluence. The bridge abutments and embankments for the proposed slip road will overlap and therefore infill the existing Weald Brook channel on the right bank. On the left bank the embankments will be minimised through use of a retaining wall to minimise floodplain losses.

- The proposed loop road exits from the M25 and loops around from north of the junction to join the A12 eastbound. In doing so it will cross the Weald Brook in two locations:
  - Firstly, at the same location at the on-slip, crossing above both the watercourse and on-slip road.
  - Secondly, approximately 500 m further upstream where bridge abutment on the right bank will slightly encroach into the floodplain.
- At the northern point of the Scheme where widening of the M25 will encroach on a small amount of floodplain as a result of extending the Weald Brook M25 culvert.

2.4.12 Floodplain compensation areas (FCAs) will be provided as mitigation for the removal of floodplain on a level-for-level and volume-for-volume basis to ensure there is no overall loss of functioning floodplain during any given design flood event, including allowances for climate change. In accordance with the guidance at the time the preliminary design was being developed and in agreement with the Environment Agency, the climate change allowance used for the design of the FCAs is the higher central allowance of +35%. The Flood Risk Assessment: Climate change allowances guidance has since been updated (Dec 2019), and further updates are expected in 2020, however the Environment Agency have confirmed that the earlier agreement to use the higher central allowance remains valid.

2.4.13 The FCAs have been designed in conjunction with the Water Framework Directive (WFD) mitigation works (outlined in application document TR010029/APP/6.7) to ensure they maximise ecological benefit alongside flood risk. Full details can be found in the hydraulic modelling report (Appendix A) where extensive flood modelling has been undertaken to ensure negligible impact due to the Scheme and suitable locations for floodplain compensation have been found. The proposed FCAs are shown below in Figure 2.4.

Figure 2.4: Proposed floodplain compensation areas



2.4.14 The existing Ingrebourne River M25 culvert will be extended from 160 m to 240 m in order to accommodate the new road layout. The new culvert will be a single bore box culvert extending the existing dual bore 2.4 m x 2.1 m culverts. The culvert will be sized to ensure no constriction in flow width from the dual bore arrangement to the single bore. The impact of the culvert extension has been assessed with the flood model. The modelling results show a negligible impact to flood risk as a result of the extension. The full details can be found in the hydraulic modelling report in Appendix A.

2.4.15 Hydraulic modelling has been undertaken to demonstrate the impact of the Scheme on fluvial flood risk on a range of flood events including climate change scenarios. Both baseline and with-scheme scenarios have been modelled and compared to ensure there is no increased risk to vulnerable receptors.

2.4.16 The hydraulic modelling shows the proposed new roads will not flood during the 1 in 100 (1%) annual probability flood event with a 35% allowance for climate change (the fluvial flooding design standard for the Scheme). The higher climate change factor (70%) will cause flooding of the existing A12 carriageway to the same extent as in the existing baseline scenario.

2.4.17 The hydraulic modelling shows with suitable mitigation the flood levels during a 1 in 100 (1%) annual probability flood event with a 35% allowance for climate change will be reduced by 19 mm upstream of the culvert and 3 mm at the northern portion of the loop road creating a minor overall betterment in flood risk. Full details can be found in the hydraulic modelling report.

Construction impacts

2.4.18 To ensure that both the Scheme and construction staff are at an acceptable level of flood risk, and to ensure the construction activities do not impact on fluvial flood risk a CEMP will be prepared to detail the environmental risk and suitable mitigation.

2.4.19 The CEMP will be prepared by the Principal Contractor and its implementation is secured by requirement 4 of the DCO (application document TR010029/APP/3.1). The Register of Environmental Actions and Commitments (REAC) (application document TR010029/APP/7.3) outlines the following actions:

- The Environment Agency flood warning system will be adopted. A suitable plan should be put in place to ensure effective and safe evacuation of personnel (and plant if safe to do so) from the areas at risk on receipt of a flood warning.
- The two site compounds will be located outside the 1 in 100 (1%) annual probability modelled flood extents based on the existing constructability report (GRAHAM, 2019).
- No plant or materials will be stored within the 1 in 100 (1%) annual probability modelled flood extents based on the existing constructability report (GRAHAM, 2019).
- Floodplain compensation will be required prior to construction of the Scheme elements that would affect floodplain storage. A suitable phasing plan prior to construction commencing is discussed in the hydraulic modelling report (Appendix A) where only limited parts of the Scheme can be constructed until both compensation areas have been excavated and are providing sufficient mitigation.

2.5 Tidal flood risk

The Ingrebourne River drains into the tidal River Thames, however the study area is upstream of the tidal limit and therefore is not at risk of tidal flooding.

2.6 Surface water flood risk

2.6.1 Surface water flooding occurs when rainfall intensities exceed the infiltration capacity such that water collects on the ground surface. Therefore, there is a greater risk of flooding from this source within urbanised areas where there is a higher proportion of impermeable surfacing.

Baseline flood risk

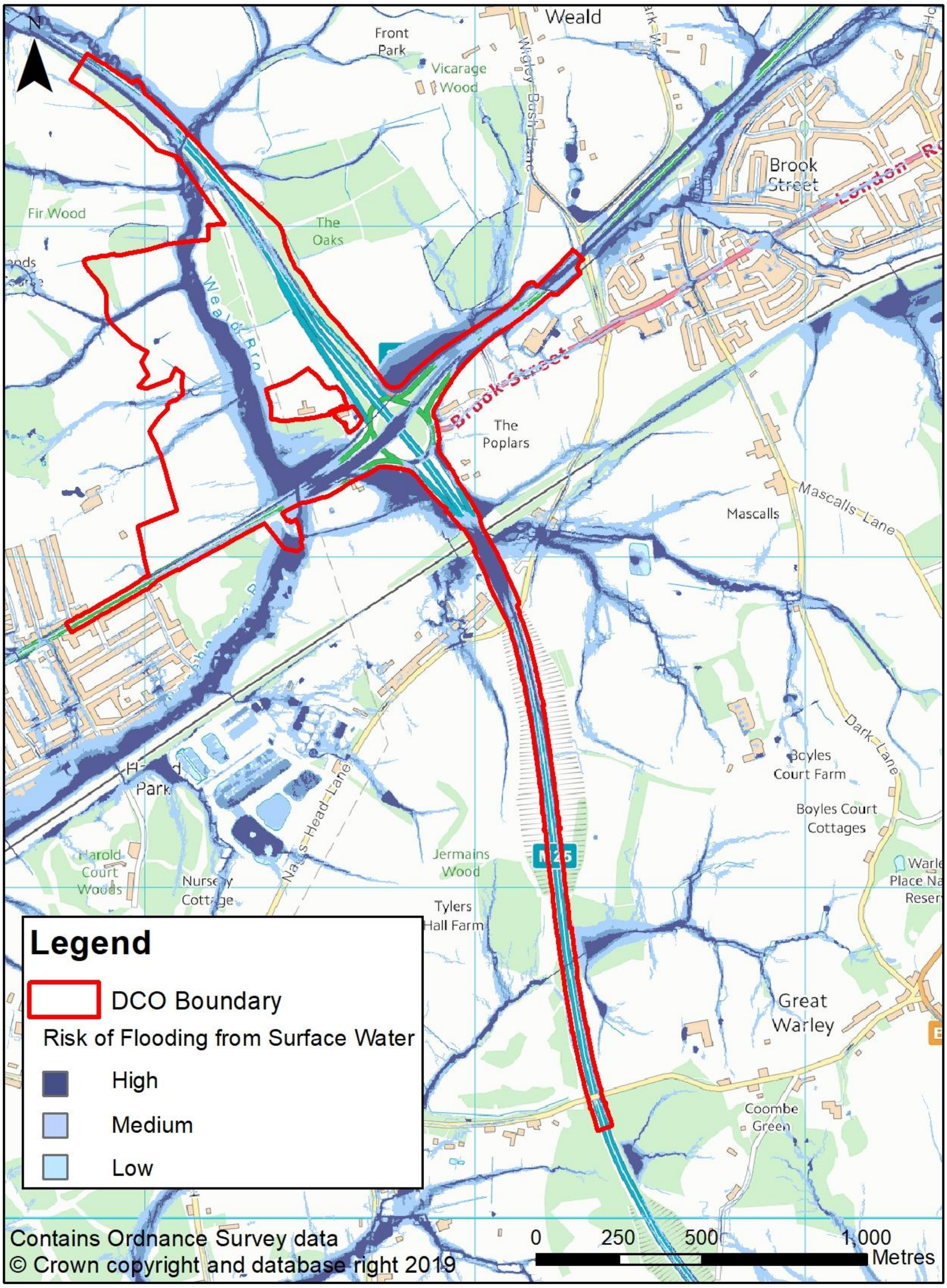
2.6.2 The Environment Agency published mapping shows areas at risk from surface water flooding. This data set is based on broad scale mapping, often identifying areas of low lying land which would be vulnerable to surface water accumulation. Figure 2.5 shows the predicted extents of surface water flooding during three event categories:

- High risk – At risk during the 1 in 30 (3.3%) annual probability event and more frequent.
- Medium risk – At risk during events between the 1 in 30 (3.3%) and 1 in 100 (1%) annual probability events.
- Low risk – At risk during events between the 1 in 100 (1%) and 1 in 1000 (0.1%) annual probability events.

2.6.3 Figure 2.5 identifies areas at risk of surface water flooding throughout the Scheme area as noted below. However, the majority of these high-risk areas are associated with watercourses and are considered as fluvial flood risk, as described in the sub section above. The other areas shown to be at risk are either likely to be associated with isolated depressions in topography and areas along the A12 and M25 which are at a slightly lower elevation than other sections of the road. The notable areas at risk from surface water flooding that are not associated with the main rivers are the drainage channels flowing west to east into Weald Brook on the western side of the scheme boundary.

2.6.4 Although the surface water flood risk within the DCO boundary is considered high, the existing drainage system reduces this risk to an acceptable level along the road network and there are no vulnerable receptors (residential, commercial or industrial properties) identified to be at risk.

Figure 2.5: Environment Agency surface water mapping



Post Scheme impacts

2.6.5 Any new development has the potential to impact on ground permeability and therefore surface water flood risk. This is of primary importance where development would increase the impermeable ground coverage within a site, and therefore would require mitigation.

2.6.6 The Scheme involves additional roads, access tracks and road widening which would involve an increase in impermeable surfacing.

2.6.7 To ensure that the proposed works would not cause an increase in surface water flooding, the surface water drainage system would be upgraded where appropriate and a new system installed for areas of new road/access. The drainage system would be designed in line with current Highways England standards (DMRB) to ensure that runoff from the site does not exceed the greenfield rate up to the 1 in 100 (1%) annual probability event taking into account a climate change allowance of 20% as discussed in the Drainage strategy (application document TR010029/APP/6.8). The proposed drainage system involves a variety of drainage ditches and attenuation basins to receive water from the new road catchments and return it at greenfield rates. Further details associated with the drainage design are included within the Drainage Strategy Report.

2.6.8 The proposed new loop road would cut off some of the existing drainage pathways flowing from the west of the Scheme. These would be captured by the proposed new drainage channels at the toe of the new loop road embankments (Atkins, 2019a).

2.6.9 Therefore, the proposed drainage design would ensure that the Scheme is at an acceptable risk from surface water flooding and would not increase flood risk elsewhere. This will be true for present day scenarios and over the lifetime of the development taking climate change into account.

Construction impacts

2.6.10 Based on the risk identified above, it is considered that the risk during the construction phase is low. However, as plant moves around within the DCO boundary, in areas that are currently permeable, there is a risk that the ground would be compacted and the infiltration potential temporarily reduced. Similarly, site compounds have the potential to temporarily increase surface water runoff.

2.6.11 Given the nature of the works, these risks are likely to be short term and not extensive. Nevertheless, the CEMP will identify this risk and put in place necessary mitigation to prevent a temporary increase in surface water flood risk through the use of formal site drainage within the construction compounds and storage areas.

2.7 Groundwater flood risk

2.7.1 Groundwater flooding normally occurs where the water table meets the ground surface in low lying areas which are underlain by permeable rock known as aquifers. Groundwater flooding tends to follow long periods of sustained rainfall but can also be caused by local obstructions to groundwater flow (e.g. following the placement of engineering structures or buildings with foundations) or by the rebound of groundwater levels after a decrease in abstraction or dewatering.

Baseline flood risk

2.7.2 Based on the groundwater flood risk mapping provided within the SFRA (Jacobs, 2016), the study area is predominantly low to moderate risk with 25-50% at risk of groundwater flooding from water within the limited superficial geology deposits. These are primarily Alluvium and Head deposits within 100 m of the watercourses, further away the London Clay is not overlain, outcropping at the surface throughout the scheme area. The high-pressure gas pipeline intersecting the site is also identified as infrastructure at risk of flooding from groundwater (Jacobs, 2016).

2.7.3 Borehole logs within the study area suggest low groundwater levels over 3 m below the existing ground levels (TQ59SE138) adjacent to Weald Brook. However, these should be viewed with caution as they only provide a snapshot of groundwater at the time of borehole excavation.

Post Scheme impacts

2.7.4 The baseline assessment of groundwater flooding indicates a low risk within the wider study area with smaller areas of moderate risk where superficial geology deposits are present. The road itself and the upgrade works are all above ground level and therefore would be at low risk.

2.7.5 The new drainage network and attenuation features are below ground level. The proposed drainage ditches will be to an approximate depth of 1 m below existing ground levels. Similarly, the attenuation features are unlikely to be at significant depths (details provided in the Drainage Strategy Report). Although the potential for water ingress into these features will need consideration as part of the design, the overall impact/risk of groundwater flooding to the Scheme is considered low.

2.7.6 Construction below ground level, such as foundations and sheet piling, has the potential to interrupt groundwater movements that can cause an increased flood risk.

Construction impact

2.7.7 As outlined above, development below existing ground levels would be at a slightly higher risk from flooding where it intersects the superficial geology. Therefore, there is potential that any excavations required for enabling works would be at risk of groundwater ingress. The greater the depth of excavation the more likely for water ingress. The associated water mitigation measures proposed for the enabling works[4] activities would be outlined in the CEMP.

[4] Enabling works are preparations to make a building site ready for construction. It covers activities from site preparation, creation of access routes, and the installation of facilities like security fencing, ramps, and placing of signs.

2.8 Other sources of flooding

Reservoir flooding

2.8.1 The Environment Agency produces flood risk mapping indicating areas at risk of inundation should a designated reservoir fail. This mapping shows that there are no areas at risk from inundation due to reservoir failure within the study area.

Canal flooding

2.8.2 There are no canals located either within the study area that could be affected by the proposed works. Therefore, it is considered that there is no risk from this source of flooding within the DCO boundary.

Water transmission infrastructure

2.8.3 There is an inherent risk of flooding from water transmission infrastructure, both potable and sewerage, owing to burst or leaking pipes. The risk will be dependent on the location and age of the network in this area. Thames Water infrastructure is present within the study area based on the services search undertaken at the time of writing, however it does not appear to intersect the proposed ground works. The exact location of sub surface infrastructure is often unknown therefore care should be taken to locate nearby pipelines prior to construction.

Other sources of flood risk summary

2.8.4 The flood risk from reservoirs, canals and water transmission infrastructure is low. By following standard construction principles and best practice these risks will remain low during the construction and operational phases of the Scheme. Furthermore, this risk is anticipated to remain low over the lifetime of the development, taking climate change into account.

2.8.5 There are no other known sources of flooding that would pose a risk to the Scheme or would be impacted as a result of the works. This remains true for the current situation and over the lifetime of the development taking climate change into account.

2.9 Temporary works

2.9.1 Temporary works would be required during the construction phase of the Scheme. This would primarily include:

- Two temporary bridges over the Weald Brook
- A main site compound and a smaller satellite compound
- Construction of haul roads
- Material storage and treatment area

2.9.2 The temporary bridges would cross the Weald Brook within the proposed loop road location. The bridges would be open span structures that would need to be designed to weir over during high flow events and ensure that there is no unacceptable effect on flood levels to vulnerable receptors.

2.9.3 Both of the proposed site compounds are planned to be situated outside the floodplain and therefore would have no impact on fluvial flooding. They would however need suitable drainage installed to manage surface water runoff as described in the Drainage strategy report (application document TR010029/APP/6.8).

2.9.4 Construction of haul roads will occur at existing ground level and therefore not obstruct floodplain flows or divert flow paths. Drainage and surface water runoff from the haul roads would need to be managed appropriately depending on the form of construction.

2.9.5 The material storage and treatment area is located outside the floodplain, suitable site drainage will be required to mitigate surface water flood risk. Further details are provided in the Drainage strategy report (application document TR010029/APP/6.8).

2.10 Climate change

2.10.1 The Scheme is located within the Thames Basin. The estimated increases in peak river flows as a result of climate change for this area are taken from the Environment Agency Guidance[5] and shown in Table 2.1 below. As the purpose of the Scheme is a major junction upgrade for a key motorway of strategic importance it is considered essential infrastructure and therefore the upper end allowance of +70% to peak river flows should be used when investigating the design's resilience to climate change and the higher central allowance used to determine design levels as agreed with the Environment Agency (Atkins, 2019a). Due to the expected long lifetime of the Scheme the 2080s epoch is considered the most suitable for design purposes.

Table 2.1: Peak river flow allowances for Thames Basin

Allowance category	Change anticipated for the '2020s'	Change anticipated for the '2050s'	Change anticipated for the '2080s'
Upper end	25%	35%	70%
Higher central	15%	25%	35%
Central	10%	15%	25%

2.10.2 Peak rainfall intensities will increase as a result of climate change. It is important to design drainage systems to cope with these changes throughout the lifetime of the Scheme in order to avoid increases to flood risk both on the road and the surrounding land. Table 2.2 shows the predicted increases in peak rainfall intensities. Due to the nature of the Scheme, with an expected lifespan into the 2080's, drainage designs should be undertaken using a 20% climate change allowance as discussed in the Drainage strategy report (application document TR010029/APP/6.8) and in agreement with Highways England.

[5] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances This guidance was updated in December 2019, however the factors for fluvial climate change allowances remain the same.

Table 2.2: Peak rainfall intensity allowance in small and urban catchments

Allowance category	Change anticipated for the '2020s'	Change anticipated for the '2050s'	Change anticipated for the '2080s'
Upper end	10%	20%	40%
Central	5%	10%	20%

2.11 Flood risk summary

2.11.1 A summary of all known sources of flood risk to the Scheme is provided in Table 2.3.

2.11.2 The effects which could arise from the works is provided in Table 2.4. This table is based on the DMRB volume 11 section 3 part 10 - HD 45/09 (DMRB, 2009) categorisations of importance, impact magnitude and significance, which are defined in the Environmental Statement.

Table 2.3: Flood risk summary

Source of flood risk	Flood risk	Comments
Fluvial	High	Floodplain compensation areas designed for level-for-level and volume-for-volume replacement replaces floodplain lost to the Scheme
Tidal	None	No tidal flood risk
Surface water	High	Drainage strategy in place to manage surface water and attenuate run off to greenfield rates including climate change allowances
Groundwater	Low	Underlying impermeable geology
Reservoir	None	No risk from reservoir inundation
Canal	None	No risk from canal infrastructure
Water transmission infrastructure	Low	Low risk from water transmission infrastructure

Table 2.4: Flood risk summary based on DMRB categorisation

Source of flood risk	Importance	Impact magnitude taking into account mitigation	Significance of effect
Fluvial	Low	Negligible	Neutral
Surface water	Low	Negligible	Neutral
Groundwater	Low	Negligible	Neutral
Reservoir	Low (None)	Negligible	Neutral
Canal	Low (None)	Negligible	Neutral
Water transmission infrastructure	Low	Negligible	Neutral

3. Conclusions and recommendations

3.1 Conclusions

3.1.1 The conclusions that have been reached from this FRA are:

- The Scheme is an NSIP and based on the principles of current relevant national planning policy (NPS NN and NPPF) would be acceptable for flood risk if a passed Exception Test can be demonstrated.
- This FRA provides evidence for the second part of the Exception Test, whereby the development would remain safe and not increase flood risk elsewhere, over the lifetime of the development taking into account climate change.
- Fluvial flood risk mapping indicates that there are large portions of the Scheme intersecting Flood Zone 3 where it will have an adverse impact on flood risk. This impact can be successfully mitigated through use of floodplain compensation areas to replace lost floodplain and prevent increases to fluvial flood levels.
- Floodplain compensation will be required prior to construction of the Scheme elements that would affect floodplain storage. A suitable phasing plan will be required before commencement of works.
- The Scheme will remain safe and operational in times of flood up to the design requirement of the 1 in 100 (1%) annual probability flood event with a 35% allowance for climate change.
- A model representing the 1 in 100 (1%) annual probability flood event with a 70% allowance for climate change has been undertaken as a sensitivity check. Flooding of the A12 occurs in both baseline and with scheme scenarios for this event, therefore potential for increased resilience may be required in the future.
- The modelling undertaken confirms there would be no detriment in terms of flood risk above the existing situation.
- Suitable blockage mitigation may be required upstream of the Ingrebourne M25 culvert.
- The hydraulic modelling shows there would be a minor reduction in fluvial flood levels across the area as a result of the Scheme.
- Current surface water flood risk mapping shows a high proportion of the area within the red line boundary as being at risk from surface water flooding. However, the vast majority of this risk is due to watercourses (which is assessed as fluvial flood risk). There are several drainage paths that would be intersected by the Scheme, these would be captured and diverted as part of the Drainage strategy report (TR010029/APP/6.8).
- The detailed drainage design would be completed in line with current planning policy requirements and will ensure that the new and upgraded drainage systems will serve to prevent unacceptable surface water flood risk to the Scheme. The drainage design will also present a system that would prevent an unacceptable increase in runoff from the site.

- There are no other sources of significant flood risk to the Scheme, however consideration of construction impacts would be considered in the CEMP.
- Temporary works are proposed during construction of the Scheme, these will have negligible overall impact on flood risk in the areas. This conclusion is only valid if the temporary works are constructed in accordance with the assumptions made in this report (section 2.9).

3.2 Recommendations

3.2.1 It is recommended that the Scheme, with the incorporation of flood risk mitigation/considerations (as above) is considered acceptable from a flood risk perspective.

4. References

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Appendices

Appendix A. Flood modelling report

Technical Note

Project:	M25 junction 28 improvement scheme		
Subject:	Flood modelling		
Author:	Atkins		
Date:	28/07/2019	Project No.:	551519

1. Introduction

The Scheme aims to upgrade the road infrastructure at junction 28 of the M25 where it connects to the A12 as shown on Figure 1-1. The junction is located at the far eastern boundary of Havering London Borough.

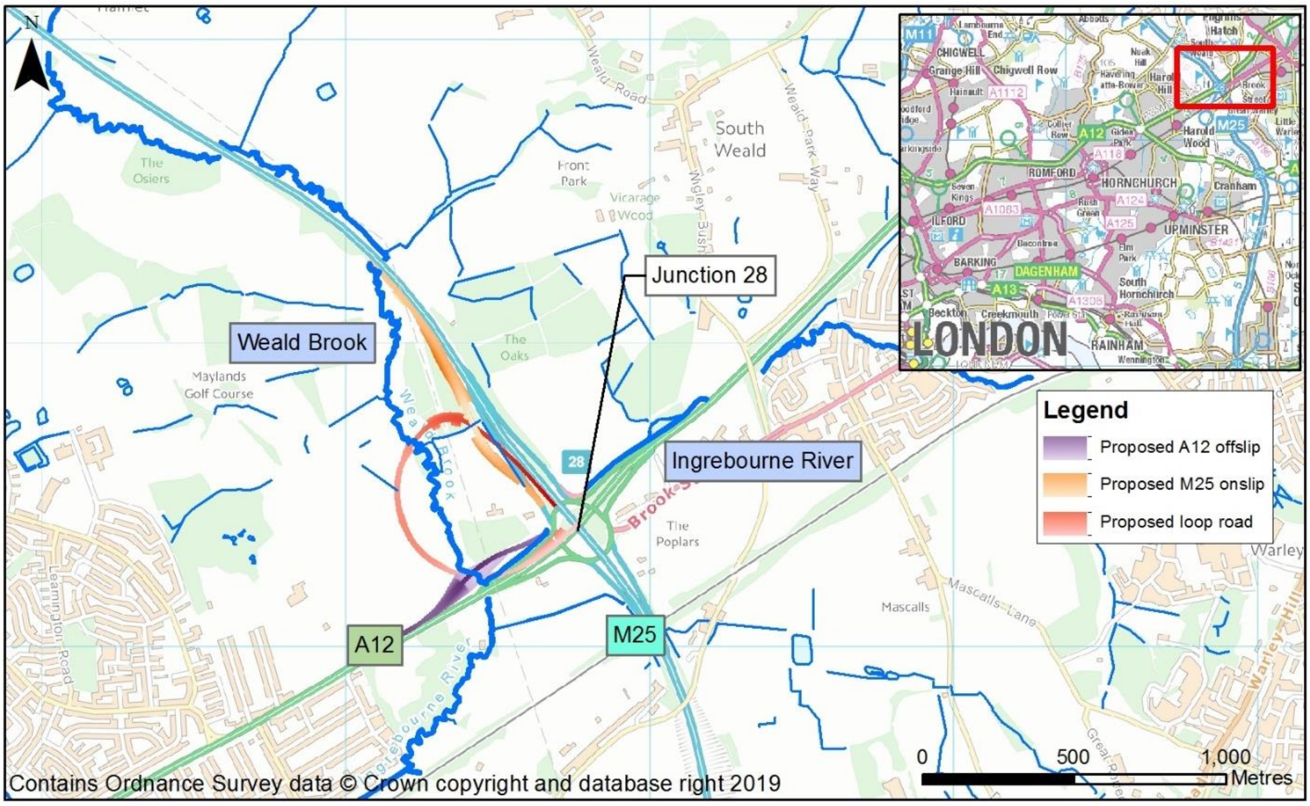

Figure 1-1 - Location Plan

The Scheme involves three major design features that could potentially impact flood risk across the site. Detailed assessment of these features is required to understand the potential locations and magnitudes of impacts and investigate potential mitigation options where it is unfeasible to alter the Scheme design. The key areas for assessment include:

- M25 widening crossing Weald Brook approximately 1 km north of junction 28 on the M25.
- New slip road from the A12 eastbound to the M25 westbound.

- New loop from the M25 to the A12 eastbound.

The new infrastructure will impact two key watercourses in the area as well as impacting surface water drainage and overland flow paths. The two key watercourses are:

- The Weald Brook; the watercourse is main river for approximately 4.5 km upstream of the study area and crosses the M25 three times before passing under the A12.
- The Ingrebourne River; the watercourse is main river for approximately 17 km upstream of the study area and drains a highly urbanised catchment including large portions of the town of Brentwood in Essex.

The confluence of the Weald Brook and Ingrebourne River occurs immediately upstream of the existing A12 culvert with a large area of shared floodplain between both watercourses. The significant re-working of the junction will introduce new groundwork within this floodplain and has the potential to increase flood risk in the area as a result.

In line with the National Policy Statement for National Networks (NPS NN), the National Planning Policy Framework (NPPF) and relevant CIRIA guidance, the loss of floodplain will need to be replaced on a like-for-like basis to mitigate the adverse impacts introduce by the scheme. This Technical Note outlines the hydraulic modelling undertaken to firstly understand the baseline flood risk at the site and then propose and assess suitable mitigation.

2. Data

In order to construct a hydraulic model suitable for assessment of the Scheme, various datasets are required to describe the topographic and physical characteristics of the site. Table 2-1 below lists the datasets used for both the baseline and with-scheme modelling work.

Table 2-1 - Data used in the study

Type	Data
Elevation data	1m LiDAR data from the Environment Agency (downloaded 02/19) general vertical accuracy ±0.15 m Site topographic survey data (HE551519-ATK-VTO-XX-M3-CH-000001) River survey; bed and bank levels and alignment (HE551519-ATK-VTO-XX-M3-VT-000001)
Scheme design data	Design drawing of the Scheme proposals: HE551519-ATK-HML-XX-M3-CH-000002 HE551519-ATK-HAW-XX-M3-CH-000001 HE551519-ATK-HAW-XX-M3-CH-000002
Hydrology	For inflows to the model, taken from the Beam, Ingrebourne & Mayes Brook FRM Study, October 2013.
River realignment data	For proposed channel realignment of the Weald Brook and Ingrebourne River; 3D elevation model from the design drawings
Site photographs	For manning's roughness and culvert entrance schematisation

Environment Agency LiDAR data at 0.5 m resolution covers the study area. Topographic survey data has also been undertaken for the majority of the area. Comparisons between the topographic survey data and the LiDAR data shows a good overall match in levels. Therefore, there is a high confidence in the data for areas where the topographic survey does not cover.

The Environment Agency Beam, Ingrebourne & Mayes Brook FRM Study (Halcrow, 2013) model covers the Ingrebourne River downstream of the existing A12 culvert. The model provides two inflows, one for the Weald Brook and one for the Ingrebourne River but does not explicitly model the upstream watercourses.

3. Model build and schematisation

To assess the changes to flood risk at the site it is necessary to construct hydraulic models representing both the existing site layout and that of the scheme. This section outlines the key decisions made during the model build process with an overview of the key model features shown in Figure 3-1.

3.1. Model type

Due to the complex flow paths upstream of the A12 culvert a 2D model approach has been adopted. 2D models utilise a grid of fixed sized cells which spatially cover the study area. Water levels are calculated for each timestep of the model at each cell location based on the cells' elevation and the application of the shallow water equations.

A 2D model is more appropriate in this area due to complex flow paths involving the lateral movement of water perpendicular to the watercourse, high channel sinuosity on Weald Brook and the ability to better represent the physical features of the scheme. Overall this approach provides higher confidence as it is a better representation of real-world processes across the site.

The model has been constructed using the TUFLOW software version 2018-AA using the HPC solver with GPU to achieve run times of approximately 1.5 hours.

3.2. Cell size and topography

The model cell size has been selected as 1 m. This allows suitable representation of both the Weald Brook, Ingrebourne River and the minor drainage channels within the area. Both the main rivers have channel widths exceeding 4 m throughout the study area, therefore a 1 m cell size provides a good resolution of the channels. The fine scale also provides a suitable resolution to model the high sinuosity of the Weald Brook upstream of the A12 and represent the correct dimensions of the A12 culvert natively within the cell size.

The LiDAR data has been used in preference to the topographic survey data due to better consistency of levels throughout the floodplain. While topographic levels are likely to be more accurate, they have only been surveyed in discrete locations. Use of these with LiDAR data elsewhere would produce erroneous changes in elevations, gradients and flow paths.

The channel bed and bank levels are superimposed onto the model grid to ensure the correct channel capacity is represented and out of bank flooding does not occur at lower flows. The A12 culvert has been modelled as an 8 m wide gap in the A12 road embankment. Bed elevations from the survey data were used to represent the non-uniform channel throughout its length and a layered flow constriction used to represent the soffit. As the culvert does not have a bespoke structure, nor do flood levels reach the soffit level of the culvert during all but the most extreme climate scenario (+70%), this is considered a suitable representation.

3.3. Boundaries

The model inflow boundaries provide the flows for the Weald Brook and Ingrebourne River, approximately 200 m and 250 m upstream of the M25 respectively. The boundaries of both watercourses are positioned upstream of their respective culverts under the M25. The culverts have been explicitly modelled to ensure changes to them as a result of the scheme are fully captured.

The model extent covers the Ingrebourne River 700 m downstream to ensure no backwater effects impact the model results.

3.4. Structures

The culvert under the existing A12 is represented in the model by enforcing an 8 m wide channel through the existing road embankment. This simplified representation is considered suitable as water levels do not reach the culvert's soffit level during the design 1 in 100 with 35% climate change design scenario.

The entrance to the culvert is partially blocked by sedimentation and vegetation; this has been represented within the model DTM.

3.5. Roughness

A materials file has been developed to spatially define the roughness values throughout the model. A Manning's' roughness of 0.05 has been adopted as the general out of bank roughness for the model based on the floodplain roughness in the original Environment Agency model verified against recent site photographs showing grassland and light scrub. The channel also has the same 0.05 roughness value to account for the fine scale changes to the roughness from the vegetated banks that is at too finer scale to represent within the model.

The roughness through the A12 culvert was set at 0.035 to represent the unvegetated channel within the culvert and the smoother concrete side walls of the culvert.

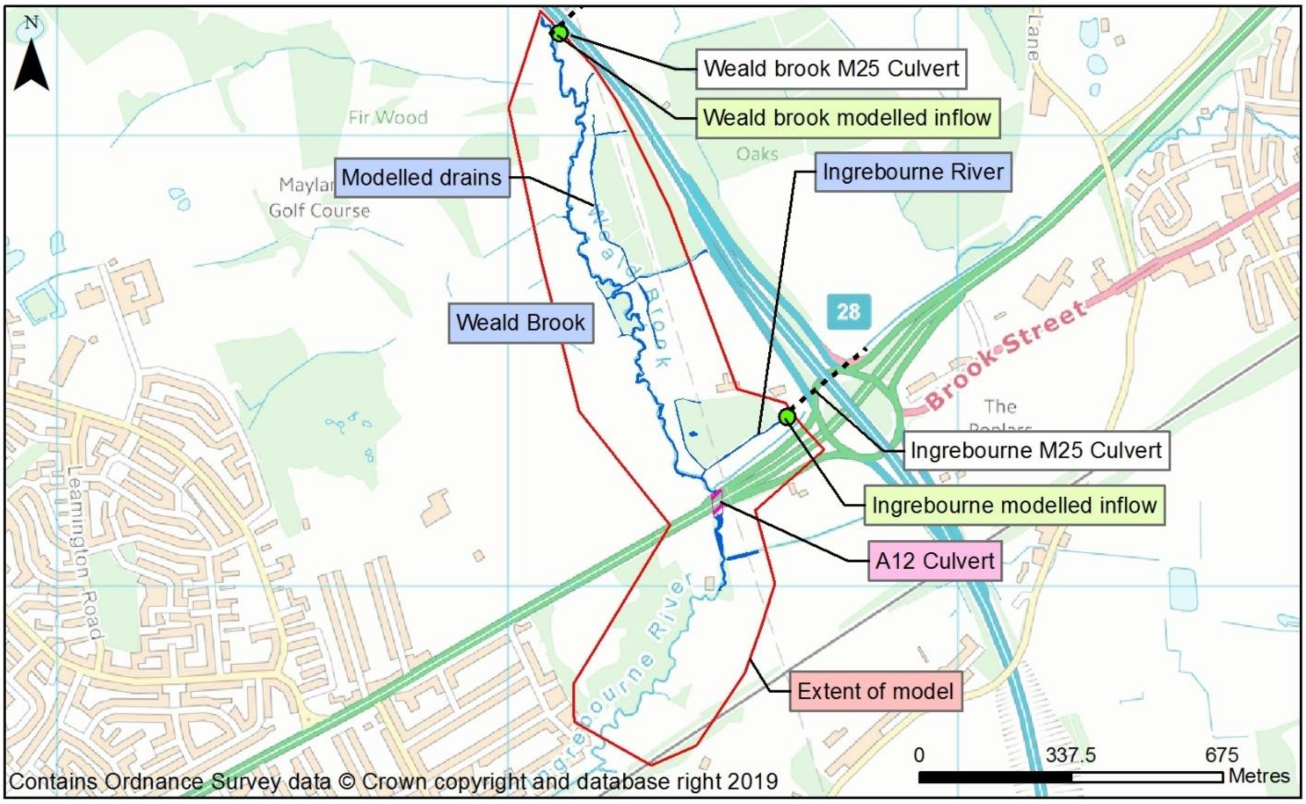

Figure 3-1 - Base model schematisation

3.6. Hydrology

The inflows for both the Weald Brook and Ingrebourne River originate from the Environment Agency's Beam, Ingrebourne & Mayes Brook FRM Study model (Halcrow, 2013).

The upstream Ingrebourne River is a highly urbanised catchment draining the western parts of the town of Brentwood. The watercourse is heavily modified with many structures upstream of the Scheme and hence there is uncertainty associated with the catchment response. As the watercourse has not been explicitly modelled the impact of the numerous culverts and bridges and urbanised drainage systems are not accounted for in the Scheme modelling. As a result the current inflows used for the Ingrebourne River possibly overestimate flows in the river.

The Weald Brook has headwaters to the north of the scheme. Whilst it crosses under the M25 in three places it is mostly a naturalised catchment with little other urban influences.

Both watercourses will accept drainage flows from the roads which cross them. The drainage outfalls can be seen in the walls of the A12 culvert in the site visit photographs. The exact amount and timing of these flows is unknown however it is assumed that road drainage will peak long before the main watercourse, conveying flows downstream prior to the main flood event, therefore additional drainage inflows have been excluded from the modelling.

3.6.1. Climate change

The Scheme is located within the Thames basin and the fluvial climate change allowances for this area are shown in Table 3-1 below. As the purpose of the Scheme is a major junction upgrade for a key motorway of strategic importance, it is considered as essential infrastructure. Therefore the "upper end" allowance of +70% to peak flows should be used when investigating the design's resilience to climate change and the "higher central” allowance used to determine design levels as agreed with the Environment Agency (Atkins, 2019). Due to the expected long lifetime of the Scheme the “2080s” epoch is considered the most suitable.

Table 3-1 - Climate change allowances for peak river flows in the Thames region

Allowance category	change anticipated for the ‘2020s’	Change anticipated for the ‘2050s’	Change anticipated for the ‘2080s’
Upper end	25%	35%	70%
Higher central	15%	25%	35%
Central	10%	15%	25%

4. Baseline modelling

4.1. Flood extents

The baseline model constructed as described in Section 0, has been run for a suite of design flood events. The results of the key flood events are shown in Figure 4-1 below.

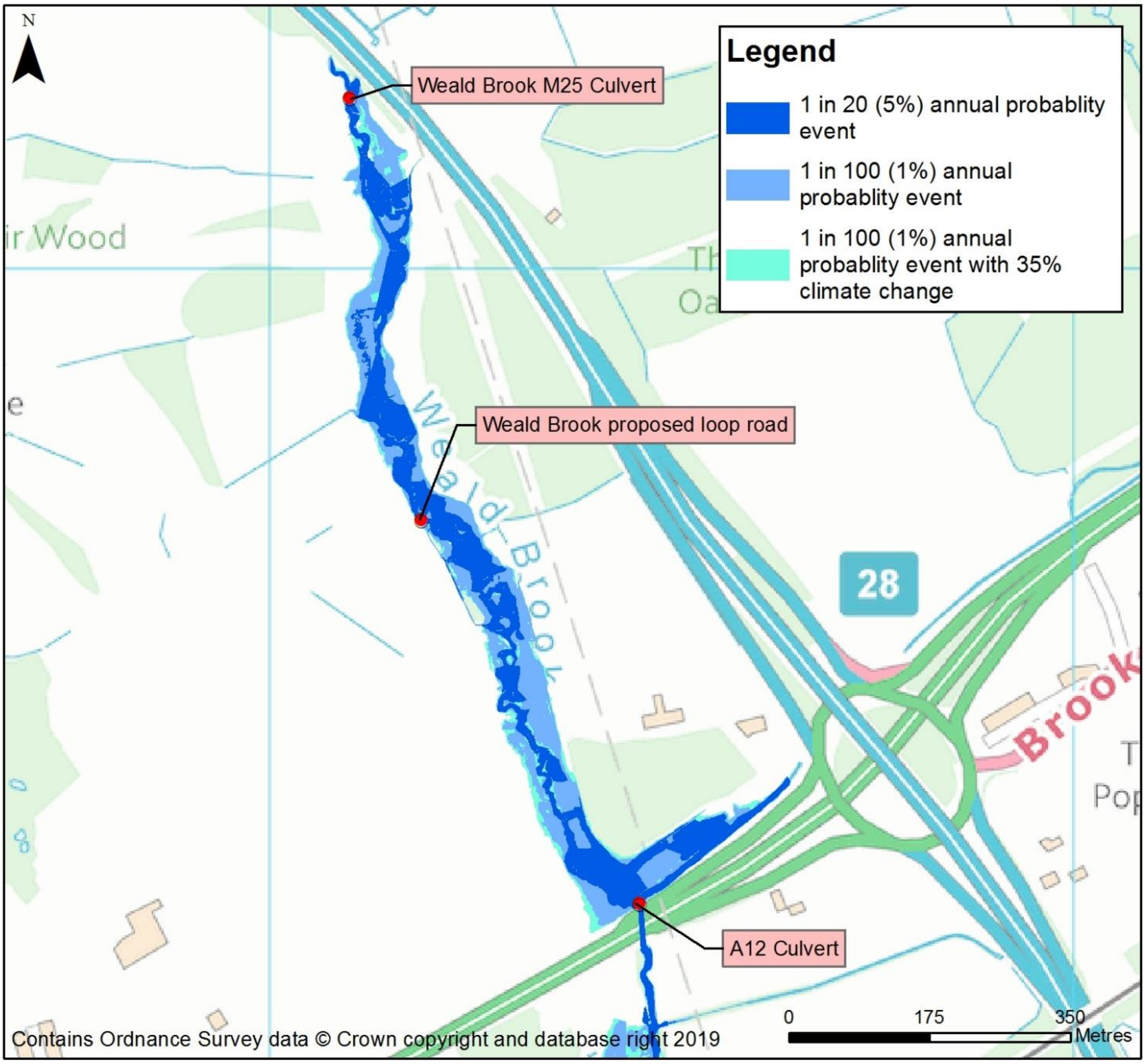

Figure 4-1 - Baseline flood extents

Table 4-1 – Baseline flood levels (mAOD)

Flood event	Upstream A12 culvert	Weald Brook proposed loop road	Weald Brook M25 culvert
1 in 20	31.186	33.411	35.655
1 in 100	31.706	33.589	35.990
1 in 100 with 35% climate change	32.012	33.672	36.125

4.2. Calibration

There is no available data from which to calibrate the model. The model itself is an upstream extension of the Beam, Ingrebourne & Mayes Brook model (Halcrow, 2013) which has been calibrated; it is therefore assumed that the flows used are a suitable representation of flows within the study area.

Anecdotal information on past flooding can be useful and help assess the ability of the model to predict known flooding patterns. No anecdotal information has been provided to aid verification, however, the new modelled 1 in 100 (1%) annual probability event is very similar to the existing Environment Agency Flood Zone 3 providing some confidence the model is performing as expected.

4.3. Flood mechanisms

The two rivers peak at very different times due to different catchment responses, the Ingrebourne first, then Weald Brook. Peak levels downstream at the A12 culvert are dominated by the Ingrebourne's early peak, this is also evident in the lower reaches of Weald Brook where backing up of water occurs due to the high flows in the Ingrebourne. Further upstream on the Weald Brook the influence of the Ingrebourne is not visible, with peak levels driven by the much longer hydrograph of the Weald Brook.

Flooding starts on the Ingebourne river immediately upstream of the confluence with Weald Brook.

Water ponds upstream of the A12 culvert during the peak event from the Ingrebourne River. Later, peak flows from the Weald Brook back up at the same location exacerbating flooding. Out of bank ponding at this location is the primary flood mechanism. Whilst overland flows do occur upstream on the Weald Brook, due to high sinuosity these are not in full effect until the 1 in 20 event whereas ponding at the culvert begins during events greater than a 1 in 5.

Flooding in the area is characterised by open floodplain over predominantly grassland. There are no vulnerable receptors at risk during any of the flood events modelled within the study area.

5. Scheme modelling

5.1. Proposed Scheme

The Scheme impacts fluvial flood risk in three key locations:

- Increases to the width of the M25 carriageway to accommodate the new on-slip road as it passes over Weald Brook north of junction 28. This will increase the length of the culvert running under it and potentially remove small amounts of floodplain from active use.
- The construction of a new A12 off-slip road. This will be constructed over the floodplain of the Ingrebourne River and will encroach on the floodplain of the Ingrebourne Brook and Weald Brook.
- The construction of a new loop road to access the A12 from the M25 northbound, this will encroach on the floodplain of both the Ingrebourne River and Weald Brook.

The Scheme elements shown in Figure 5-1 have been added to the model by modifying the topographic dataset used to determine flow paths. Detailed drawings of the Scheme elements are shown in the Scheme Layout Plans (application reference TR010029/APP2.6). The Scheme, river realignments and floodplain compensation areas have been represented in the model using this method. This changes the routing of water in the model and provides an estimation of the scheme's impact on flood flows when compared to the baseline model.

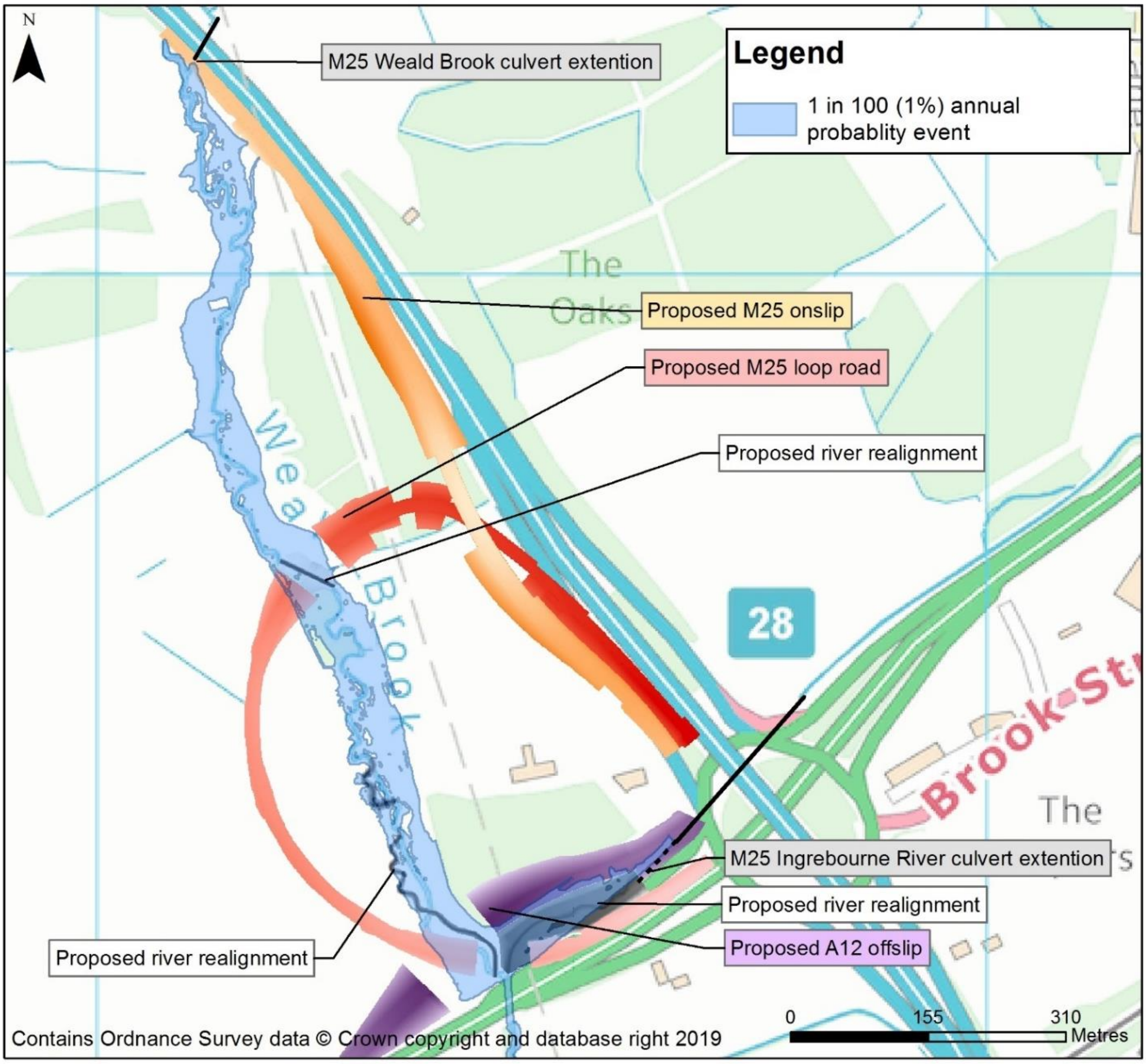

Figure 5-1 - Scheme elements

5.1.1. A12 off-slip

The proposed slip road will be constructed using a 10 m high retaining wall structure on the south side. It has been designed in this fashion purely to reduce its footprint in the floodplain and minimise loss of floodplain as a result. A new bridge carries the road over the Weald Brook, avoiding floodplain losses in the area by doing so, and therefore is not represented in the model. Flood mechanisms in the area are entirely driven by ponding upstream of the existing A12 Culvert, therefore the bridge piers have not been represented in the model as their impact on conveyance would be negligible.

5.1.2. River re-alignments

The construction of the new slip road will require realignment of the Ingrebourne River upstream of its confluence with the Weald Brook. Part of the realignment will involve increasing the sinuosity of the river as part of the water framework directive (WFD) mitigation.

The gradient of the new, realigned watercourse was maintained with the same invert levels upstream and downstream as existing. These were used to interpolate the gradient of the new river bed.

Additional re-alignments were undertaken at the downstream of Weald Brook where the proposed loop road would cross the watercourse adjacent to the confluence with the Ingrebourne River. The embankments of the proposed bridge would encroach on the channel requiring it to be moved slightly north of its existing alignment. As with the Ingrebourne, the channel sinuosity was increased as part of the WFD mitigation.

A final realignment was undertaken where the proposed loop road crosses the Weald Brook to the north. This realignment straightened the river to allow passage under the proposed bridge and avoid conflict of the river with the bridge pier. The full details behind the designs of the realignments can be found in the WFD report (application reference TR010029/APP/6.7).

5.1.3. M25 loop road

The proposed new loop road crosses the Weald Brook in two locations; a new bridge spanning the floodplain is proposed in both cases with embankments encroaching slightly into the floodplain. At these locations the Weald Brook will require realignment where the embankment footprint restricts the existing watercourse.

The embankment to the south near the confluence with the Ingrebourne River takes up a larger amount of floodplain than other elements of the scheme. This is due to the complicated interaction with the A12 off-slip which is bridged over both the watercourse and the loop road. The off slip is also vertically constrained due to the high voltage cables above the existing A12.

5.1.4. M25 Weald Brook culvert extension

At the north of the scheme, the widening of the M25 as part of the on-slip construction will require a small extension to the Weald Brook culvert as it conveys the watercourse under the existing road. This will encroach a small amount into existing floodplain.

It is proposed to extend the Weald Brook culvert by approximately 10m in order to accommodate the widening of the M25. The 10m increase in length will be undertaken using prefabricated concrete box culvert sections 5.5m wide and 2.2m internal height (after embedment). This extension will be 0.5m wider than the existing box culvert at 5.0m wide and 2.2m high.

5.1.5. M25 Ingrebourne River culvert extension

The existing River Ingrebourne culvert conveys flows under the M25 at the eastern side of the scheme. The existing culvert is approximately 160 m long in a twin bore configuration of 2.4 m wide x 2.1 m high box culverts.

In order to provide sufficient space for the loop road to be constructed, the culvert must be extended 80 m further downstream creating a total culvert length of 240 m. The existing 160m dual bore arrangement (No.2 x 2.4m x 2.1m) will be extended by a single bore prefabricated box culvert 4.8m x 2.1m. While the proposed extension does maintain the total width, it will be subject to lower friction throughout the extension due to the single bore arrangement.

There is limited data regarding the Ingrebourne River upstream of the culvert therefore this part of the model is based solely on LiDAR data. The culvert is assumed to be double bore throughout its length due to limitations of the modelling software this provides the most conservative estimate of conveyance. The actual culvert design will have a transition length to join the extension to the existing structure. The model has a number of further assumptions listed briefly below:

- No trash screen upstream or downstream due to limited information
- No blockage
- Typical roughness of bed (0.04) to represent culvert several months after construction based on existing site photographs

5.1.6. Model sensitivity

To increase confidence in the model results, sensitivity tests have been carried out to determine the impact to model results should key parameters require changing. Two key sensitivity tests were carried out:

1. Increase the channel Manning's coefficient to 0.07 to represent a lower channel conveyance. This was undertaken to test the limitations of the channel definition by understanding the impact conveyance has should channel cross sections change significantly.
2. Increase to flows to understand uncertainties associated with the hydrology for the Weald Brook and Ingrebourne River. This sensitivity was undertaken as part of the climate change assessment where flows were increased by 70%.

During a 1 in 100 event with 35% climate change allowance the increase in channel Manning's causes a +100 mm impact over the ponding area reaching 250 m upstream of the A12 culvert and around the outfall of the Ingrebourne River culvert. Further upstream of this there is a 10-20 mm increase in levels and a reduction of 5 mm downstream of the A12 culvert. The spatial extents of the impacts are shown in Figure 5-2 below.

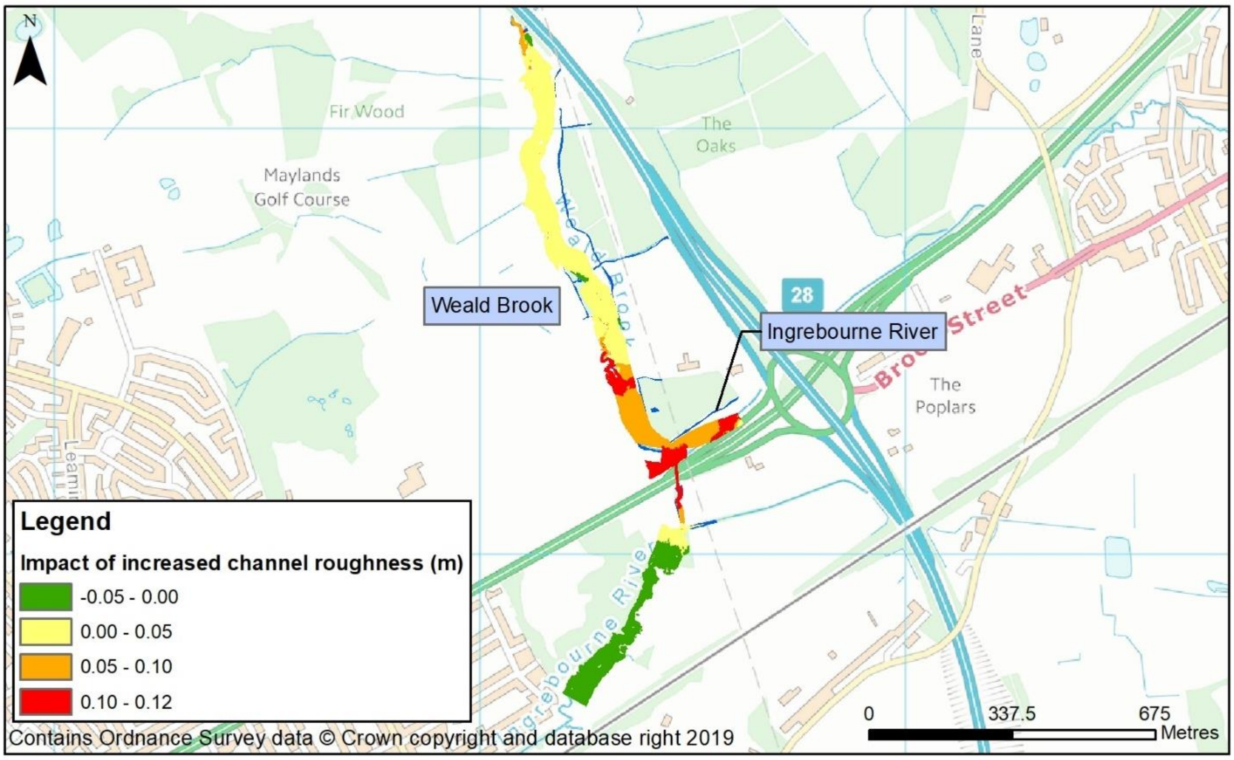

Figure 5-2 – Results of roughness sensitivity test

5.2. Floodplain compensation

The Scheme will remove floodplain from active use by both watercourses and therefore additional new floodplain will need to be provided to compensate for the loss.

In line with CIRIA guidance (CIRIA, 2004), the loss of floodplain must be compensated on a like-for-like basis, replacing an equivalent area of floodplain at the correct levels and volumes with enough connectivity to the watercourse. For example floodplain lost at 30.5 mAOD must be replaced at 30.5 mAOD.

There are three broad locations where flood storage will be removed from the Scheme as shown below in Figure 5-3:

- The confluence of the Weald Brook and Ingrebourne River (5, 6 and 7 in Figure 5-3).
- The proposed loop bridge embankments over the Weald Brook (4 in Figure 5-3).

- The widening of the M25 at the northern limit of the Scheme (0 to 3 in Figure 5-3).

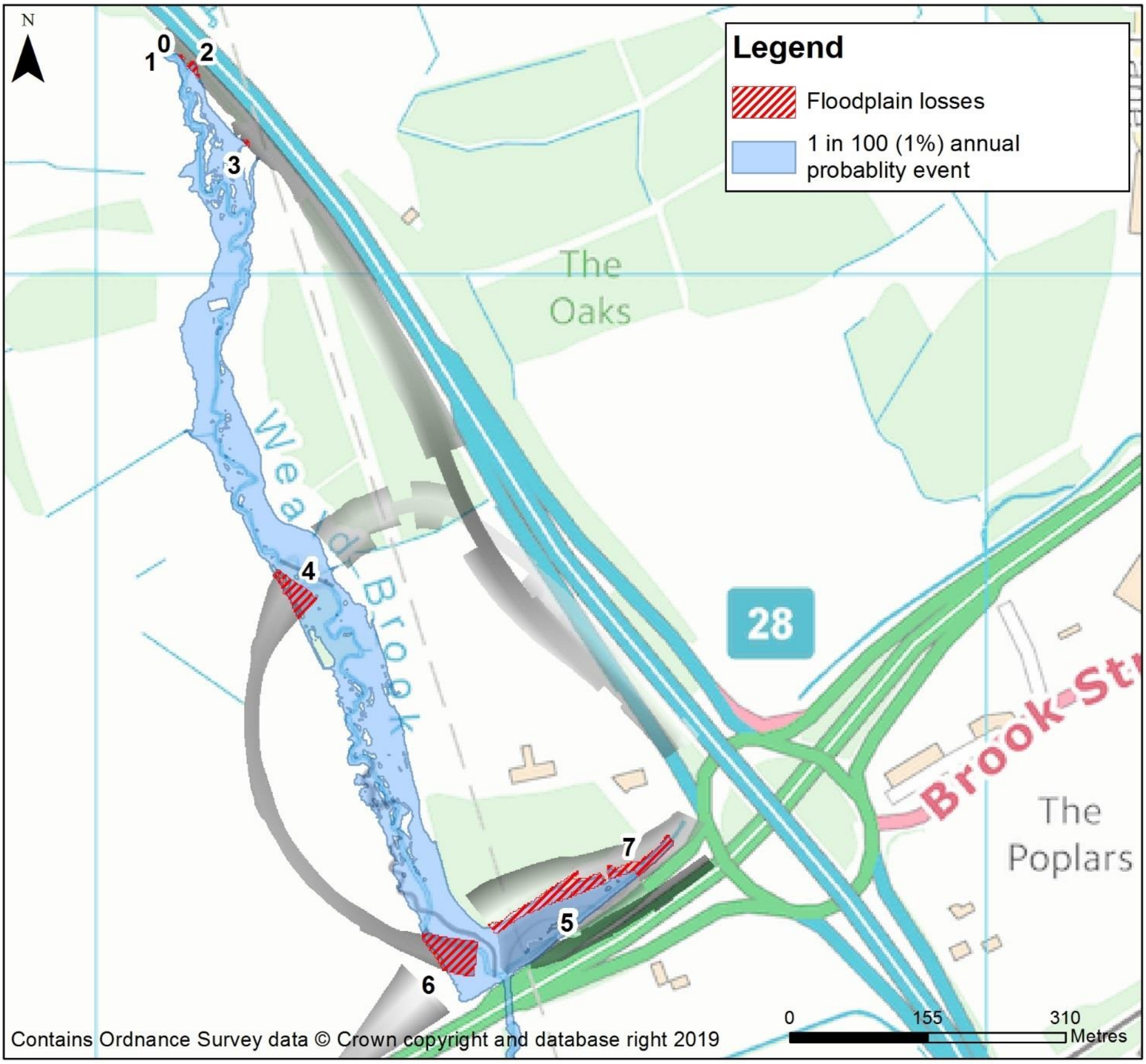

Figure 5-3 - Floodplain losses

Each area has been assessed separately in order to allow compensation to be provided at locations as close to the original loss as possible. Losses associated with the infilling of a watercourse to be realigned have been removed from the process as these will be replaced on a like for like basis in the new channels. For each area the volumes lost at each 0.2 m increment has been assessed using a bespoke tool in ArcGIS 10.3 to produce the tabulated losses shown below in Table 5-1. The tool compares the volumes of an existing and proposed DTM to determine the changes in volume within the modelled flood extents.

Table 5-1 - Floodplain loss volumes

Level (mAOD)	Confluence of the Weald Brook and Ingrebourne (5-7) m^3	Proposed loop bridge embankments (4) m^3	Widening of the M25 at the northern limit (0-3) m^3
31.2	149		
31.4	295		
31.6	506		
31.8	617		
32	687		
32.2	755		
32.4	147		
32.6	172		
32.8	180		
33	185	20	
33.2		42	
33.4		107	
33.6		160	
33.8		180	
34.0		178	
…	…	…	…
35.8			21
36			17
36.2			24
36.4			20

5.2.1. Proposed floodplain compensation

Floodplain compensation needs to be provided as close to the original loss as possible, preferably in an upstream location to ensure impacts are mitigated prior to the hydraulic effects of any new earthworks.

There are several physical constraints restricting the areas which can be used for floodplain compensation. The existing river corridor of the Weald Brook is used for numerous underground services on both the left and right bank. The gas main present on the right bank will be diverted around the boundary of the proposed loop road as part of the Scheme freeing up potential areas for compensation. Services on the left bank prevent ground lowering in this location, with overhead electrical structures also present and constraining designs. The locations of the existing services are shown below in Figure 5-4.

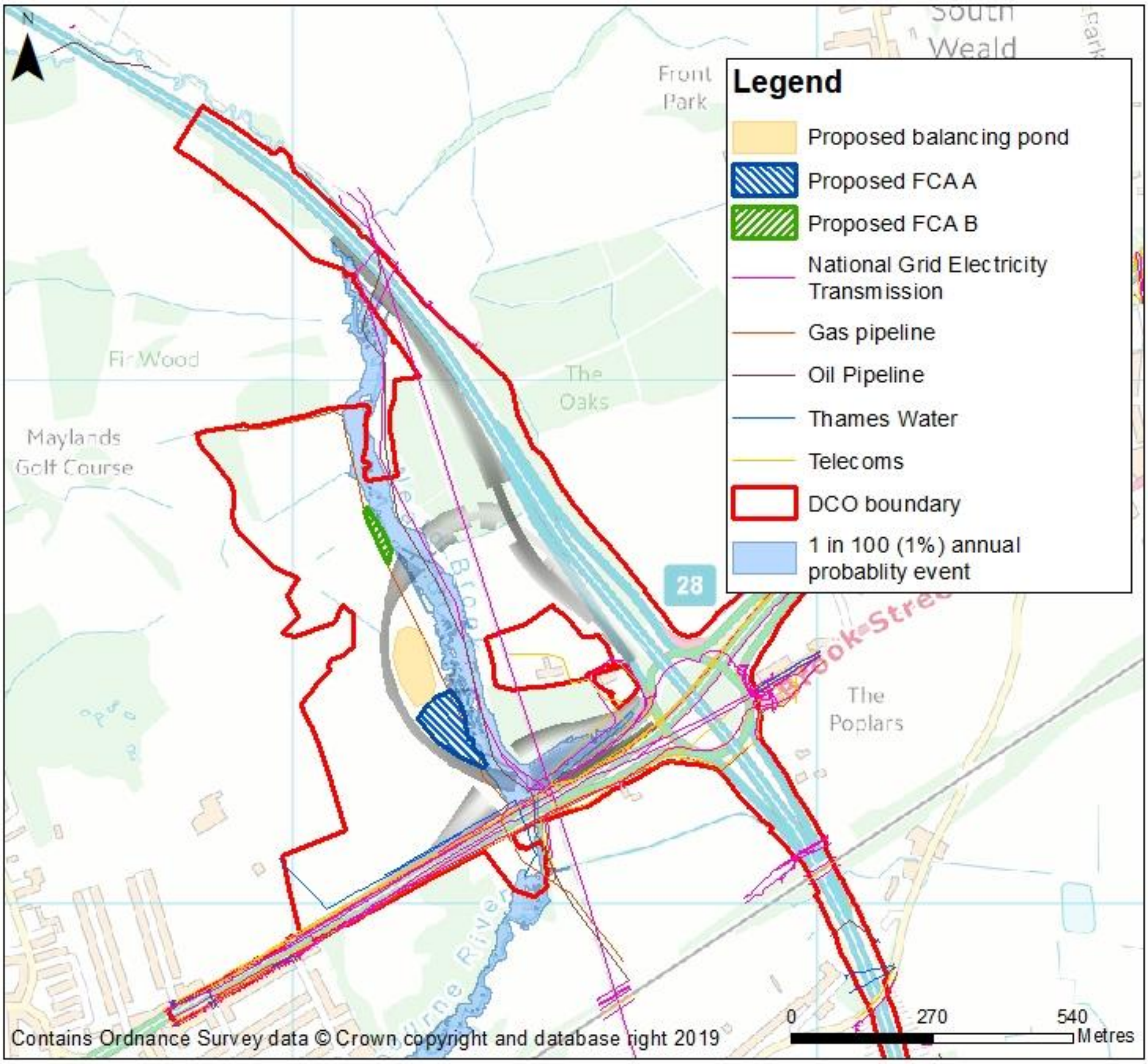

Figure 5-4 - Proposed compensation areas and constraints

The floodplain compensation volumes provided by the proposed Compensation Areas A and B are shown below in Table 5-2 and Table 5-3 where they are compared to the losses discussed above.

The losses from widening the M25 at the northern extent of the Scheme are difficult to compensate for directly adjacent to the losses due to constraining underground utilities on the left bank and the existing golf course on the right bank. Levels elsewhere in the vicinity are not suitable to provide compensation on a level for level basis. Therefore, Compensation Area B compensates for both the loss of floodplain adjacent to it from the proposed loop road bridge abutments and the small losses from widening at the M25 at the northern extent of the scheme.

As the compensation is approximately 400 m downstream of the losses a relative level approach has been adopted. Peak flood levels at Compensation Area B are approximately 2.4 m lower than peak flood levels at the northern extent of the Scheme (

Table 4-1). Therefore, in order to provide floodplain volume at the same point during a flood event the required volumes have been shifted and provided 2.4 m lower at Compensation Area B.

Table 5-2 shows the reductions in floodplain near Compensation Area A can be suitably compensated on a level for level basis. Table 5-3 shows that the compensation requirements can almost be made at Compensation Area B with deficiencies of 2 m^3 and 28 m^3 at 33.6 mAOD and 33.8 mAOD respectively. The modelling results discussed in Section 5.3 show negligible impact from this minor deficiency and considerable excess compensation at other levels.

Table 5-2 - Floodplain Compensation Area A

Level (mAOD)	Losses, Confluence of the Weald Brook and Ingrebourne, m^3	Compensation area A, m^3	Balance +/- (m^3)
31.2	149	269	+120
31.4	295	514	+219
31.6	506	656	+150
31.8	617	774	+157
32	687	891	+204
32.2	755	863	+108
32.4	147	841	+694
32.6	172	833	+661
32.8	180	819	+639
33	185	803	+618

Table 5-3 - Floodplain Compensation Area B

Level (mAOD)	Losses, Proposed loop bridge embankments, m^3	Losses, Widening of the M25 at the northern limit, m^3 (Shifted 2.4m lower, due to relative level approach)	Compensation Area B, m^3	Balance +/- (m^3)
33	20	-	60	+40
33.2	42	-	121	+79
33.4	107	21	160	+32
33.6	160	17	175	-2
33.8	180	24	176	-28
34.0	0	20	178	+158

5.2.2. Additional floodplain volume gains

The area between the existing A12 and the proposed A12 off-slip will be landscaped with a new realigned channel for the Ingrebourne river through this area. The surrounding floodplain will be lowered to provide additional floodplain storage with good connectivity to the realigned channel. By landscaping the area an additional 1000 m^3 of floodplain storage will be created immediately upstream of the A12 culvert between 31.2-33.0 mAOD. This additional storage is within the existing flood extents and therefore cannot be formally considered floodplain compensation. However, additional floodplain volume will lower flood levels and create flood risk betterment throughout the local area.

5.2.3. Climate change sensitivity

A sensitivity of the floodplain compensation assessment has been undertaken against the 1 in 100 event with 70% allowance for climate change. This shows that Compensation Area A is still able to fully meet the increased compensation requirements while retaining 70% overprovision across the combined bands.

Compensation Area B is not able to fully meet requirements in the 70% climate change scenario with only 82% of the total compensation requirements being met.

5.3. Scheme modelling results

5.3.1. New roads and river realignments

The with scheme model has been created with the above inclusions discussed throughout Section 0. “With-Scheme” flood extents have been created for the 1 in 20 (5%) and 1 in 100 (1%) with 35% allowance for climate change design flood events and are shown below in Figure 5-5 and Figure 5-6 with levels at key locations reported in Table 5-4.

The with scheme modelling shows that the Scheme with mitigation in place has an overall beneficial impact on flood risk by reducing flood levels throughout the modelled area.

The mapping shows a negligible difference in flood extents for the 1 in 20 (5%) and 1 in 100 (1%) annual probability flood events with only the floodplain compensation areas and realignment locations showing an increase in flooding. Elsewhere, the extents do not differ within the 1m resolution of the model.

Table 5-4 – Change in flood levels with Scheme

Flood event	Upstream A12 Culvert (mm)	Weald Brook proposed loop road (mm)	Weald Brook M25 culvert (mm)
1 in 20	-22	-184	-2
1 in 100	-19	-145	-9
1 in 100 with 35% climate change	-19	-122	-3

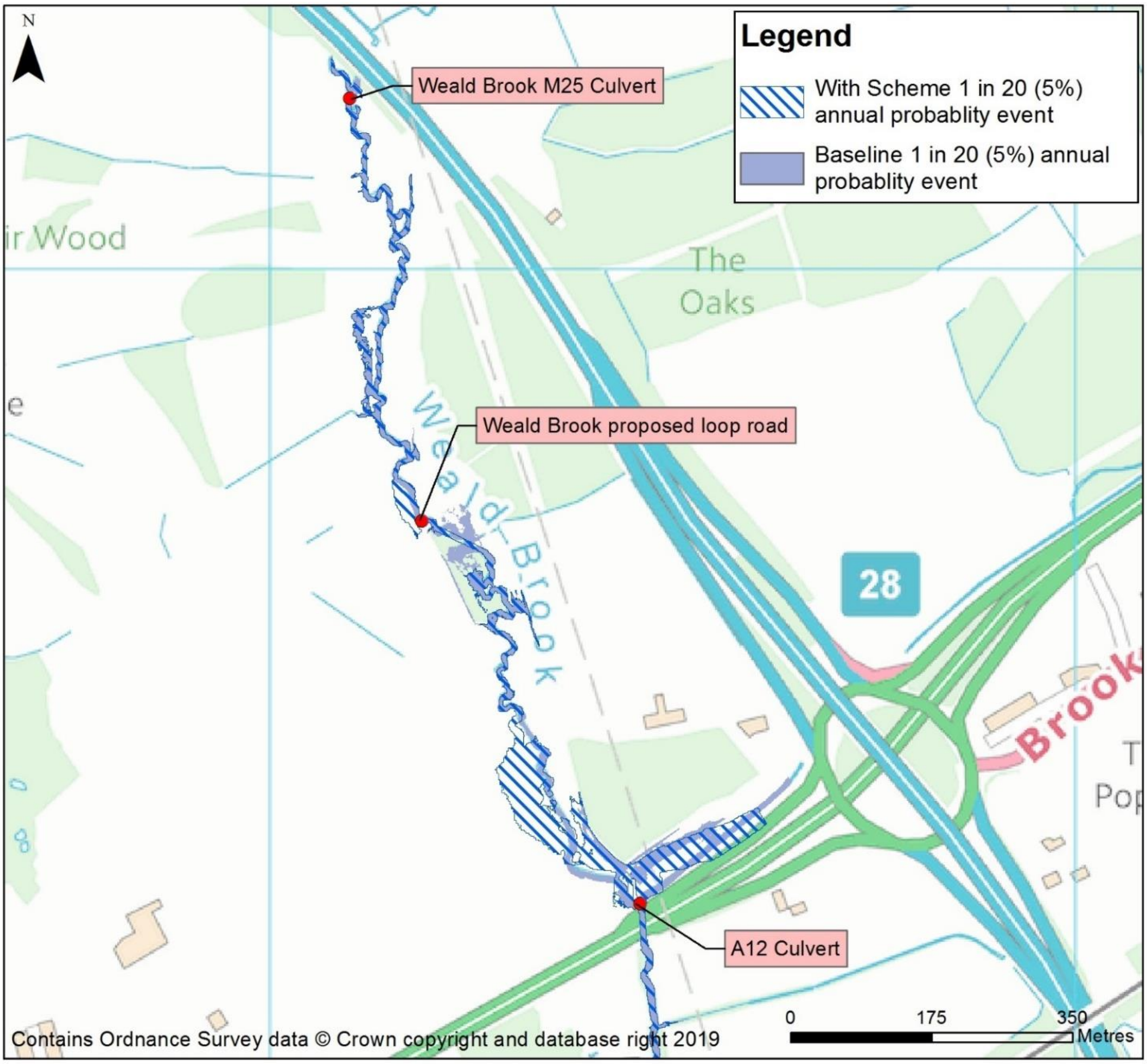

Figure 5-5 - Existing and proposed 1 in 20 (5%) annual probability flood extents

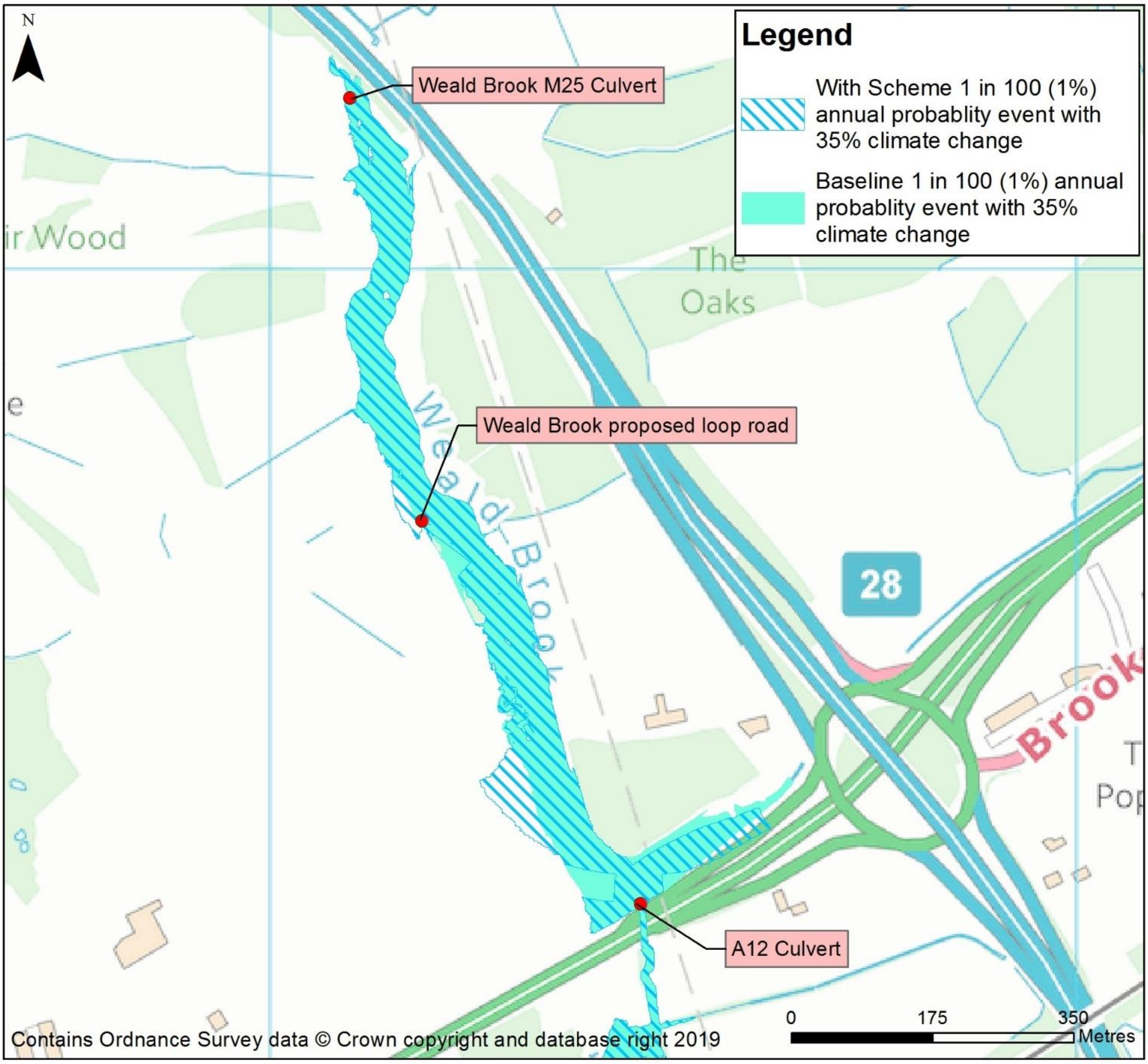

Figure 5-6 - Existing and proposed 1 in 100 (1%) with 35% climate change annual probability flood extents

5.3.2. Weald Brook culvert

The tables below shows the modelled existing and proposed peak water levels upstream of the Weald Brook M25 Culvert and peak flows passed downstream.

Table 5-5 - Weald Brook change in culvert peak water level upstream

	1 in 100 with 70% Climate change (mm)	1 in 100 with 35% Climate change (mm)	1 in 20 event (mm)
Change in level (mm)	-5	-12	0

Table 5-6 - Weald Brook change in culvert peak flows downstream

	1 in 100 with 70% Climate change (m^3/s)	1 in 100 with 35% Climate change (m^3/s)	1 in 20 event (m^3/s)
Change in flow (m^3)	+0.083	-0.177	-0.062

The results show a decrease of 12 mm immediately upstream of the culvert during the 1 in 100 event with 35% climate change allowance, this changes to a 5 mm reduction during the 1 in 100 event with 70% climate change allowance and no difference during a the 1 in 20 event. Given the overall accuracy of the models these changes are considered negligible.

5.3.3. Ingrebourne River culvert

The tables below shows the modelled existing and proposed peak water levels upstream of the Ingrebourne M25 Culvert and peak flows passed downstream.

Table 5-7 - Ingrebourne culvert change in peak water level upstream

	1 in 100 with 70% Climate change (m)	1 in 100 with 35% Climate change (m)	1 in 20 event (m)
Change in level (mm)	0	0	-1

Table 5-8 - Ingrebourne Brook change in culvert peak flows downstream

	1 in 100 with 70% Climate change (m^3/s)	1 in 100 with 35% Climate change (m^3/s)	1 in 20 event (m^3/s)
Change in flow (m^3)	-0.002	-0.007	-0.012

The results show negligible differences of up to 1 mm between existing and proposed scenarios, this is well within the models ability to predict accurate levels between subtly different scenarios. The modelling shows that the changes to the culvert setup does not fundamentally alter the ability of the lengthened culvert to convey flows during the highest analysed flood events.

5.4. Culvert freeboards

The new bridges that are to be constructed as part of the Scheme are designed to include 600 mm freeboard. The culvert extensions do not increase flood levels within or upstream of the culverts, therefore the existing freeboard is not affected.

5.5. Construction phasing

During construction, sufficient floodplain compensation will need to be provided prior to construction of elements within the floodplain. The construction of the floodplain compensation is constrained by the timing of the diversion of the pipeline on the right bank (looking downstream) of the Weald Brook. The pipeline diversion will be complete mid-programme and is required before construction can begin on the loop road and Floodplain Compensation Area A.

Floodplain Compensation Area B can be constructed straight away – this compensates for the northern elements of the Scheme.

To allow construction to begin on the southern elements of the Scheme additional floodplain compensation volume will be required. These floodplain volume gains can be found where groundworks in the area between the A12 and the new A12 off-slip will lower the floodplain upstream of the A12 culvert. This provides additional floodplain storage volumes listed below in Table 5-9, along with the losses for the two main work areas in the floodplain near the A12. Two conclusions can be made from the table:

- The floodplain in the area between the A12 and the new A12 off-slip cannot provide level-for-level compensation for both elements of the southern works.
- The floodplain in the area between the A12 and the new A12 off-slip can provide total volume compensation for one element of the southern works.

Total compensation in this case should be suitable as the primary flood mechanism is water ponding upstream of the A12 culvert at this location (i.e. culvert forms the flood control mechanism) and the compensation is provided at a lower level than required.

The hydraulic model has been used in order to provide evidence that the additional volume provided between the A12 and proposed A12 off-slip will be sufficient during construction of the A12 off-slip but before construction of the loop road. The model shows only a 6 mm increase in flood levels upstream of the A12 culvert when the A12 off-slip is present, but the loop road and Compensation Area A is not. Given the temporary nature of the works and absence of vulnerable receptors, this is considered a negligible level of risk during the construction period and therefore the proposed construction phasing is as follows:

1. Construction of Compensation Area B to allow northern elements to be constructed.
2. Construction of the Area between the A12 and the new A12 off-slip, this will provide sufficient volume for the A12 off-slip; while not formal compensation, it does provide replacement storage during construction,
3. Pipeline will be moved mid programme.
4. Construction of Compensation Area A.
5. Construction of elements of the loop road that are within the floodplain.

Table 5-9 – Change in floodplain volume between the A12 and proposed A12 off-slip

Level	Volume gains between the A12 and the new A12 off-slip (m^3)	A12 off-slip volume losses (m^3)	Southern loop road volume losses (m^3)
31.2	718	-124	-86
31.4	504	-181	-168
31.6	263	-274	-297
31.8	89	-354	-335
32.0	36	-420	-338
32.2	9	-124	-337
Total	**1619**	**-1477**	**-1561**

6. Climate change

It is important to understand how the proposed scheme will impact the climate change outlines and flood levels to ensure there will not be significant detriment due to the proposed changes to the river systems in the area. Table 6-1 shows the changes in flood levels upstream of the A12 culvert; the flood levels and extents do not change significantly during the design 1 in 100 with 35% climate change flood event beyond the floodplain compensation and earthworks areas.

The 1 in 100 with 70% climate change has been run as a sensitivity and shows a minimal 135mm increase directly upstream of the culvert. During this event flood water gets close to spilling onto the A12, to prevent occurring ground levels between the re-aligned Ingrebourne and the existing A12 should be retained to a height of at least 33m.

Table 6-1 - Climate change levels upstream of the A12 Culvert

Scenario	Peak flood level upstream of A12 Culvert (mAOD)
Baseline 1 in 100 with 35% climate change allowance	32.012
Baseline 1 in 100 with 70% climate change allowance	32.441
With Scheme 1 in 100 with 35% climate change allowance	31.993
With Scheme 1 in 100 with 70% climate change allowance	32.410

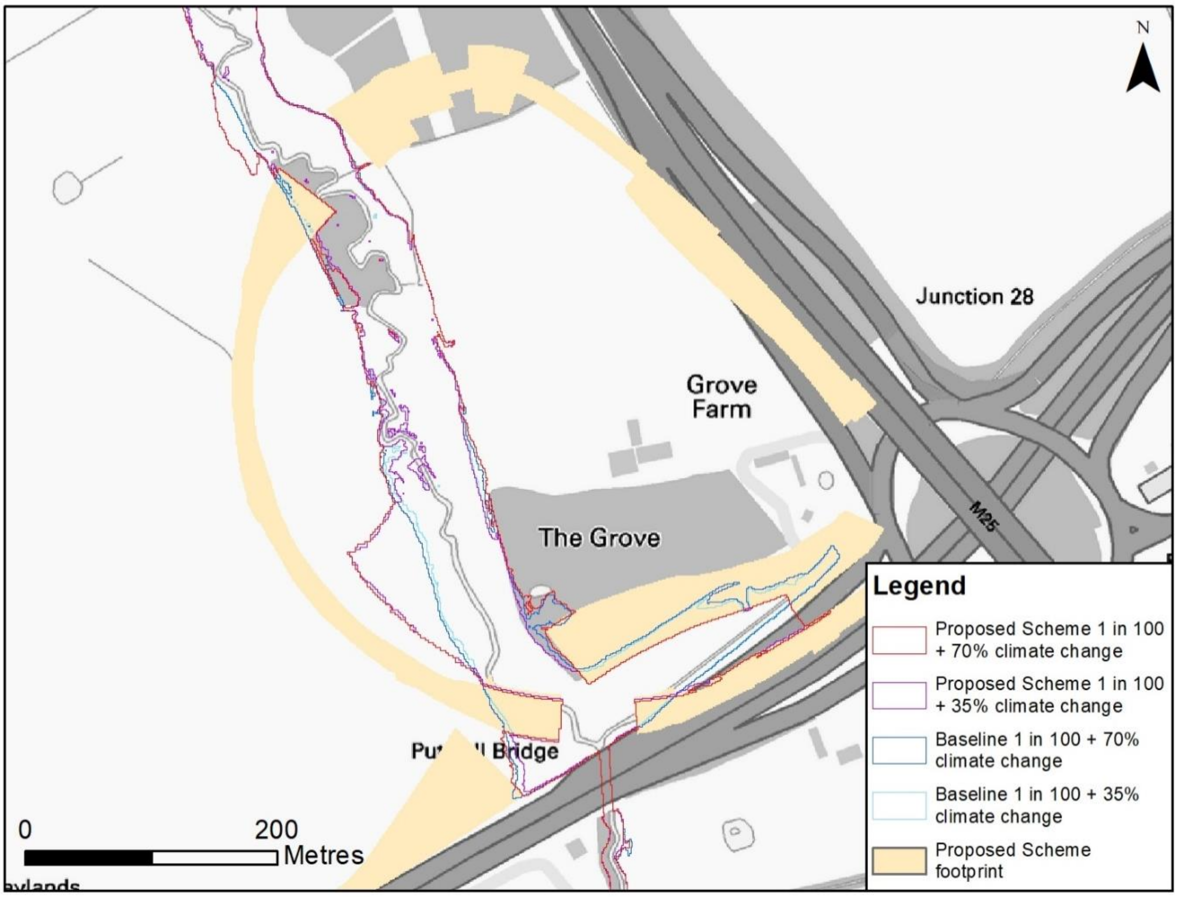

Figure 6-1 – Changes to climate change flood outlines as a result of the proposed scheme

7. Conclusions and recommendations

7.1. Conclusions

This modelling report details the work undertaken to ensure sufficient flood risk mitigation is provided to allow construction of the M25 junction 28 upgrade scheme. The following conclusions can be made:

- There will be a reduction in floodplain volumes caused by construction of the Scheme.
- Two suitable floodplain compensation areas have been found and demonstrated to mitigate the impact of the Scheme.
- The proposed culvert extension on the Ingrebourne River shows negligible impact on upstream flood levels.
- Construction of Floodplain Compensation Area B and the lowered area between the A12 and proposed A12 off-slip will provide temporary mitigation during construction of the Scheme elements prior to construction of the loop road.
- Through construction of the floodplain compensation areas there is a wider flood risk benefit to the area and over 1000 m^3 of informal additional floodplain storage as a result of the Scheme.
- The Scheme provides overall betterment to fluvial flood risk.

7.2. Recommendations

The following items are recommended for further investigation during the detailed design stage, prior to construction:

- The need for a trash screen on Ingrebourne River M25 culvert should be investigated.
- The size of Compensation Area B should be maximised during detailed design to reduce the minor deficiencies in volume identified in Table 5-3.
- Ground levels between the re-aligned Ingrebourne River and the existing A12 should be retained to a height of at least 33 m to prevent spills from the river during the most extreme events.

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