A47 North Tuddenham to Easton Dualling

Scheme Number: TR010038

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6.3 Environmental Statement Appendices
Appendix 13.1 - Flood Risk Assessment, Part 1 of 2

APFP Regulation 5(2)(a)

Planning Act 2008

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

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ENVIRONMENTAL STATEMENT APPENDICES Appendix 13.1 - Flood Risk Assessment, Part 1 of 2

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1. Executive summary

1.1.1. Highways England (the applicant) has submitted a development consent order (DCO) application for the North Tuddenham to Easton Dualling Scheme (hereafter referred to as 'the Proposed Scheme').

1.2. Fluvial flood risk

1.2.1. The Proposed Scheme runs adjacent to the River Tud. A new bridge over the River Tud is proposed to the east of the Honingham and, where the Proposed Scheme crosses two ordinary watercourses south east of Hockering and at Oak Farm, new culverts will be required.

1.2.2. A review of available information indicates that there are no historic instances of fluvial flooding having directly affected the route of the Proposed Scheme. The Environment Agency Flood Map for Planning shows that most of the Proposed Scheme is at low fluvial flood risk, however, there are two locations where the route overlaps Flood Zone 3. These are at the bridge over the River Tud, and south east of Hockering, where the Proposed Scheme crosses an ordinary watercourse. There is, however, uncertainty regarding the flood risk from the watercourse at Hockering, as well as that at Oak Farm, which is not included in the Environment Agency mapping.

1.2.3. To assess the fluvial flood risk in more detail and determine the impact of the Proposed Scheme hydraulic modelling has been undertaken.

River Tud

1.2.4. Hydraulic modelling of the River Tud demonstrated that the abutments of the proposed bridge are the only part of the Scheme which overlap the 100-year flood extent (Flood Zone 3). The soffit of the bridge has a freeboard in excess of 600mm above the design 100-year (plus 65% climate change) water level and is therefore compliant with the National Planning Policy Framework and has been accepted by the Environment Agency.

1.2.5. The abutments intercept and funnel floodwaters back into the channel resulting in an increase in water levels along the River Tud. The increase in water levels upstream of the existing A47 was found to be negligible, hence, no sensitive receptors are predicted to be affected.

1.2.6. To offset the estimated 1277m^3 of floodwater displaced by the embankments and abutments at the 100-year (plus 35% climate change) peak flood level, compensatory storage is proposed along the western bank upstream of the

River Tud Crossing. This location has been identified due to its position away from sensitive receptors and proximity to the area impacted.

Oak Farm ordinary watercourse

1.2.7. A new local access road will cross the Oak Farm watercourse upstream of the existing A47 resulting in a section of the existing watercourse being culverted. The existing A47 culvert will also be extended and the channel upstream realigned. Baseline modelling indicates that the Proposed Scheme overlaps floodwater which accumulates upstream of the existing A47, and flooding is predicted downstream. An orifice will be added at the new culvert inlet to throttle flows and a bund constructed to retain floodwater.

1.2.8. The design increases water levels upstream of the bund as floodwater is displaced. This results in increased flood depths on arable land to the north, although no sensitive receptors are affected. The crest of the bund has a freeboard over 600mm above the 100-year (plus 65% climate change) peak water level. It is resilient to a 10% and 50% blockage applied to the orifice as well as the 100-year (plus 80% climate change) H++ peak water level.

1.2.9. The design ensures that water in the realigned channel remains within bank and results in a net betterment in terms of flood risk downstream. Given that there are no sensitive receptors impacted by the Proposed Scheme, as well as the essential need to maintain the existing throttle downstream and protect the new local access road, flood compensatory storage may not be required. This has been agreed, in principle, with Norfolk County Council. However, until this is confirmed at the detailed design stage, provision of a floodplain compensation area has been identified. The watercourse upstream of the new local access road is designated for riparian planting as well as channel restoration including re-meandering.

Hockering ordinary watercourse

1.2.10. As part of the Proposed Scheme a section of the Hockering watercourse will be culverted. Hydraulic modelling demonstrated that the new culvert will have a freeboard over 600mm above the 100-year (including 65% climate change allowance) peak water level.

1.2.11. The baseline results differ from the Environment Agency mapping in that floodwater is predicted to remain close to the channel where the Proposed Scheme crosses. The new culvert is predicted to result in drop in water levels of less than 150mm for the 100-year event) close to the crossing and a small loss in floodplain storage (27m^3). Given the impact doesn’t result in any increase in flood risk to others, compensatory flood storage is not considered necessary and this is agreed, in principle, with Norfolk County Council.

1.2.12. The design is sensitive to blockage. Applying a 10% and 50% blockage to the orifice was predicted to result in an increase in water levels of 170mm and 880mm respectively. A 50% blockage was predicted to result in flooding to an existing workshop building. Maintenance and inspection of the culvert will therefore be prioritised, and a trash screen included. Once a detailed topographic survey has been undertaken at the detailed design stage, the mitigation will be reviewed.

1.3. Other sources of flood risk

1.3.1. The Proposed Scheme is beyond the tidal limit of the River Wensum hence there is no risk of tidal flooding. A review of available information including the Breckland Strategic Flood Risk Assessment (2017) found no evidence of flooding from sewer or water main infrastructure failure having affected the proposed route, and the risk of reservoir failure is very low.

1.3.2. Most of the Proposed Scheme is at low risk of surface water flooding, however, the route overlaps several overland flow pathways. To mitigate this, earthwork drainage and interceptor drains or ‘dry culverts’ are included as part of the design. These use the existing topography to ensure that connectivity of existing surface water overland flow pathways is maintained and to prevent surface water accumulating adjacent to the Proposed Scheme. The ‘dry culvert’ cross drains have been designed to convey flows during a 100-year (plus 65% climate change) event.

1.3.3. The Proposed Scheme will increase the total area of impermeable surfaces which could, without mitigation, increase the rate and volume of runoff discharged from the Proposed Scheme to receiving land and watercourses. The Drainage strategy report (ES Appendix 13.2) (**TR010038/APP/6.3**) outlines the proposed drainage design and associated mitigation. This includes SuDS features to capture and attenuate runoff using a series of drainage basins or wetlands, as well as hydrobrakes. This will ensure that there is no detrimental impact on receptors and that runoff from the Proposed Scheme matches greenfield rates.

1.3.4. There was no specific evidence of groundwater flooding within the vicinity of the Proposed Scheme, although, the underlying chalk bedrock geology means that there may be a moderate risk, particularly where alluvium deposits are present. Should any groundwater flooding occur this would likely follow existing overland flow pathways. Since these have been maintained via ‘dry culverts’ or cross drains, which are sized to accommodate higher peak surface water flows, the risk of groundwater flooding affecting the Proposed Scheme is low. Embankments and the proposed River Tud Crossing will displace groundwater;

however, with mitigation embedded into the design this is unlikely to increase the risk of groundwater flooding.

1.3.5. The assessment includes an allowance for climate change following the most recent Environment Agency guidance. Using this guidance, the Proposed Scheme is classed as “essential infrastructure” and given it is considered that the lifetime of the development is 100 years, the Anglian region ‘upper end’ category is therefore applicable, with an assumed time horizon of 2080s (2070 to 2115). Subsequently, the additional climate change allowance for peak river flows is 65%. However, the ‘higher central’ climate change allowance of 35% was adopted to assess the compensatory flood storage requirements; this was agreed with the Environment Agency. Where it is considered there are safety critical issues, for example at Oak Farm, the impact assessment considers the extreme (H++) 80% climate change allowance. The drainage design uses the ‘upper end’ allowance of 40% to consider the impacts of climate change on peak rainfall intensity.

1.3.6. As part of the A47 dualling route option selection assessment several route options were reviewed and the route of the Proposed Scheme was considered to have the least impact on flood risk and the water environment. The preferred route announcement was made in 2017 and, as such, the Proposed Scheme meets the requirements of the Sequential Test. The development is classified as ‘essential infrastructure’ hence the Exception Test has been applied. This demonstrates that the sustainability benefits of the Scheme including reduced congestion outweigh the negligible flood risk impacts. The Proposed Scheme also includes several mitigation measures which will ensure that the design is safe for its lifetime and will not detrimentally impact flood risk to others. The proposal therefore passes the Exception Test. The Proposed Scheme is also compliant with paragraph 5.94 of the National Policy Statement for National Networks.

1.3.7. Potential impacts on flood risk during construction will be mitigated by the implementation of appropriate temporary drainage measures which will be outlined in the Environmental Management Plan (**TR010037/APP/7.4**).

2. Introduction

2.1. Scope of works

2.1.1. Highways England (the applicant) has applied for a development consent order (DCO) for the North Tuddenham to Easton Dualling Scheme (hereafter referred to as 'the Proposed Scheme'). This appendix supports the environmental assessment presented in ES Chapter 13 Road drainage and water environment (**TR010038/APP/6.1**).

2.1.2. This Flood Risk Assessment (FRA) is a requirement of the National Planning Policy Framework (NPPF) and informs the environmental assessment presented in Chapter 13 (Road Drainage and Water Environment) for the A47 Tuddenham to Easton Dualling Proposed Scheme (which is referred herein as the 'Proposed Scheme').

Aims and objectives

2.1.3. This FRA has considered the following:

- risk of flooding (of any form) posed to the Proposed Scheme;
- predicted impacts of climate change;
- risk of flooding (of any form) posed by the Proposed Scheme; and
- mitigation measures required.

Methodology

2.1.4. The FRA has been completed in accordance with the current guidance contained the National Planning Policy Framework (NPPF) (MHCLG, 2019) and the supporting online Planning Practice Guidance (PPG) for Flood Risk and Coastal Change (MHCLG, 2014). The assessment has been undertaken in accordance with Highways England's technical guidance provided in Design Manual for Roads and Bridges LA 113 Road Drainage and the Water Environment (Highways England, 2019), hereafter referred to as DMRB LA 113.

2.1.5. This FRA has been a partially desk-based assessment utilising freely available data. Information obtained during a river survey has also been used to 'ground truth' some of the asset and watercourse locations.

2.1.6. The steps for completing a site-specific FRA have also been followed using a range of data sources listed below.

Data sources

- The NPPF and supporting PPG documents for flood risk and coastal change;

- Environment Agency Flood Map for Planning (Environment Agency, 2020a Surface Water, Reservoir and River or Sea Flood Risk Maps (Environment Agency, 2020b), Historic Flood Map (Environment Agency, 2017c);
- British Geological Survey's GeoIndex (British Geological Survey, 2020);
- Magic Map (DEFRA, 2020);
- 2m resolution LiDAR (2017)
- Proposed Scheme design information;
- Previous and ongoing strategic flood studies conducted by the Environment Agency and Local Authorities including; Norfolk County Council Preliminary Flood Risk Assessment Report (PFRAR) (Norfolk County Council, 2011), Breckland District Council Level 1 Strategic Flood Risk Assessment (SFRA) (Breckland District Council, 2017), Greater Norwich Area SFRA (JBA, 2017).

3. Planning policy and legislative framework

3.1. National Policy Statement for National Networks

3.1.1. The National Policy Statement for National Networks (NPS NN) (Department for Transport, 2014), is a requirement of the 2008 Planning Act. It sets out the need for, and Government’s policies to deliver, development of nationally significant infrastructure projects on the national road and rail networks in England. It provides planning guidance for promoters of nationally significant infrastructure projects on the road and rail networks, and the basis for the examination by the Examining Authority and decisions by the Secretary of State. NPS NN is used as the primary basis for making decisions on development consent applications for national networks nationally significant infrastructure projects in England.

3.1.2. NPS NN policies relevant to flood risk are summarised below:

- Section 5.94: With regard to flood risk, if a Flood Risk Assessment (FRA) is required, the applicant should:
  - consider the risk of all forms of flooding arising from the project (including in adjacent parts of the United Kingdom), in addition to the risk of flooding to the project, and demonstrate how these risks will be managed and, where relevant, mitigated, so that the development remains safe throughout its lifetime
  - take the impacts of climate change into account, clearly stating the development lifetime over which the assessment has been made
  - consider the vulnerability of those using the infrastructure including arrangements for safe access and exit
  - include the assessment of the remaining (known as ‘residual’) risk after risk reduction measures have been considered and demonstrate that this is acceptable for the particular project
  - consider if there is a need to remain operational during a worst-case flood event over the development’s lifetime
  - provide the evidence for the Secretary of State to apply the Sequential Test and Exception Test as appropriate

3.2. National Planning Policy Framework

3.2.1. The NPPF and associated PPG are the relevant guidance documents that local authorities use in reviewing proposals for development with respect to flood risk. If a site was to be developed, the NPPF sets out policies for planning authorities to:

- Ensure flood risk is properly considered at all stages of the planning process
- Prevent inappropriate development in areas at high risk of flooding

- Direct development away from areas at highest risk
- Ensure that new developments take climate change into account and do not increase flood risk elsewhere

3.2.2. The NPPF provides guidance on the assessment of flood risk and how it may be addressed or mitigated. The guidance advises, among others, planning authorities in their planning decisions to use a risk-based approach to avoid flood risk wherever possible and manage flood risk elsewhere.

3.3. The Flood and Water Management Act

3.3.1. The Flood and Water Management Act (FWMA) 2010 provides for better and more comprehensive management of flood risk for people, homes and business estates. The Act states that the Lead Local Flood Authorities (either unitary authorities or county councils) are responsible for developing, maintaining and applying a strategy for local flood risk management in their areas and for maintaining a register of flood risk assets. They are responsible for managing the risk of flooding from surface water, groundwater and ordinary watercourses. Norfolk County Council is the Lead Local Flood Authority in the area of the Proposed Scheme.

3.3.2. In 2012, various amendments were introduced to the FWMA 2010. Amongst other changes the amendments specified some new duties and responsibilities of the Lead Local Flood Authorities, namely they must:

- Prepare and maintain a strategy for local flood risk management in their areas, coordinating views and activity with other local bodies and communities through public consultation and scrutiny, and delivery planning
- Investigate significant local flooding incidents and publish the results of such investigations
- Play a lead role in emergency planning and recovery after a flood event

3.3.3. An essential part of managing local flood risk will be taking account of new development in any plans or strategies.

3.3.4. The Act also states that if a flood happens, all local authorities are ‘category one responders' under the Civil Contingencies Act. This means they must have plans in place to respond to emergencies, and control or reduce the impact of an emergency. Lead Local Flood Authorities also have a duty to determine which risk management authorities have relevant powers to investigate flood incidents to help understand how they happened.

3.3.5. The Environment Agency is responsible for managing the risk of flooding from the sea and main rivers, and also for regulating the safety of reservoirs. The Environment Agency publishes flood maps which indicate the probability of river and coastal flooding and the predicted extents of the natural floodplain and extreme floods. The maps identify three zones, with Flood Zone 3 being split into two sections, which refer to the probability of river or sea flooding:

- **Flood Zone 1.** This zone comprises of land with less than 1 in 1000 annual probability of river or sea flooding in any one year (0.1%)
- **Flood Zone 2.** This zone comprises of land assessed as having between a 1 in 100 and 1 in 1000 annual probability of river flooding (1%-0.1%) or between 1in 200 and 1 in 1000 annual probability flooding from the sea (0.5%-0.1%) in any one year.
- **Flood Zone 3a.** This zone comprises of land assessed as having a 1 in 100 year or greater annual probability of river flooding (>1%) or a 1 in 200 or greater annual probability of flooding from the sea (>0.5%) in any year.
- **Flood Zone 3b.** The Functional Floodplain. This zone comprises land where water has to flow or be stored in times of flood.

3.3.6. Depending upon the NPPF classification and the Flood Zone in which the proposal is designated, a Sequential and/or Exception Test may be required. The Sequential Test ensures that alternative sites at lower flood risk are considered as part of the application and that new developments are steered to areas with the lowest probability of flooding. An Exception Test may be needed to demonstrate that flood risk will be managed appropriately, while allowing necessary development to go ahead where suitable sites at a lower risk of flooding are not available. The Exception Test is required to ensure that any development is safe for its lifetime and that it will not increase (and ideally will decrease) flood risk elsewhere.

3.4. Local planning policy

3.4.1. Local policies of relevance to the Proposed Scheme include:

- The Joint Core Strategy for Broadland, Norwich and South Norfolk (Greater Norwich Development Partnership, 2014), contains the following policies relevant to flood risk:
  - Policy 1: Addressing climate change and protecting environmental assets
- Breckland Local Plan, adopted on 28 November 2019 (Adoption Draft) (Breckland District Council, 2019), contains the following policies relevant to flood risk:
  - Policy ENV 09: Flood Risk & Surface Water Drainage
- Breckland Adopted Core Strategy and Development Control Policies Development Plan Document (Breckland Council, 2009), adopted in 2009. The document outlines the vision and overall objectives for development in Breckland up to 2026, sets out where new housing and other development should be focused contains the following policies relevant to flood risk:

- Policy DC 13: Flood Risk

3.4.2. The following Local Flood Risk Management Strategies (LFRMS) are pertinent to the Proposed Scheme:

- Norfolk LFRMS (Norfolk County Council, 2015)

3.4.3. Norfolk County Council also provide guidance to developers on their role as Lead Local Flood Authority (Norfolk County Council, 2019).

3.5. Climate change

3.5.1. For site specific flood risk assessments, the PPG for Achieving Sustainable Development, Section 14 (Meeting the challenge of climate change, flooding and coastal change) states:

"163. When determining any planning applications, local planning authorities should ensure that flood risk is not increased elsewhere. Where appropriate, applications should be supported by a site-specific flood-risk assessment. Development should only be allowed in areas at risk of flooding where, in the light of this assessment (and the sequential and exception tests, as applicable) it can be demonstrated that:

- *within the site, the most vulnerable development is located in areas of lowest flood risk, unless there are overriding reasons to prefer a different location;*
- *the development is appropriately flood resistant and resilient;*
- *it incorporates sustainable drainage systems, unless there is clear evidence that this would be inappropriate;*
- *any residual risk can be safely managed; and*
- *safe access and escape routes are included where appropriate, as part of an agreed emergency plan."*

3.5.2. In addition to this, it also states:

"149. Plans should take a proactive approach to mitigating and adapting to climate change, taking into account the long-term implications for flood risk, coastal change, water supply, biodiversity and landscapes, and the risk of overheating from rising temperatures. Policies should support appropriate measures to ensure the future resilience of communities and infrastructure to climate change impacts, such as providing space for physical protection measures, or making provision for the possible future relocation of vulnerable development and infrastructure."

3.5.3. The current online national planning guidance on climate change (Environment Agency, 2020d) established the climate change allowances for river rainfall and tidal sources for different catchment areas of the UK. Due to the nature of the Proposed Scheme, it is appropriate to class the development as "essential infrastructure". It is considered that the lifetime of the development for the purposes of the flood risk assessment is 100 years. Although the majority of the Proposed Scheme is located within Flood Zone 1 it does pass through Flood Zone 3, the Anglian region 'upper end' category is therefore applicable, with an assumed time horizon of 2080s (2070 to 2115). Subsequently, the PPG guidance states that peak river flow climate change allowance would be 65%.

3.5.4. During discussions with the Environment Agency and Norfolk County Council (see Section 4.4) it was stated that a 35% climate change allowance would be required to assess the need for compensatory storage. In the Scoping Opinion, the Environment Agency noted the requirement to consider the extreme (H++) climate change scenarios if the Proposed Scheme has safety critical elements. For the Anglian region this would be an uplift of 80% on peak river flows for the 2080s time horizon.

3.5.5. The PPG climate change allowance guidance also states the revised peak rainfall intensity (to assess surface water flood risk) climate change allowance is between 20% and 40%, for the central and upper end allowances, respectively.

4. Description of the Proposed Scheme

4.1. Existing site description

4.1.1. The A47 is a trunk road, part of the strategic road network (SRN) which links Peterborough with Lowestoft on the East Coast of England. The A47 from North Tuddenham to Easton is located approximately 10km to the west of Norwich and forms part of the main arterial highway route connecting Norwich and Great Yarmouth to Kings Lynn, Peterborough and the Midlands.

4.1.2. This section of the A47 is located between the villages of North Tuddenham and Easton where there is currently a section of single carriageway.

4.2. Description of the Proposed Scheme

4.2.1. The Proposed Scheme comprises the dualling of a section of the A47 between North Tuddenham and Easton, including the creation of two grade separated junctions (Wood Lane junction and Norwich Road junction), associated side road alterations and walking, cycling and horse-riding connections along the length of the Proposed Scheme.

4.2.2. The new mainline dual carriageway would be predominantly offline with exceptions at the route tie ins at Fox Lane to the west and Easton to the east.

4.2.3. The first of two proposed new grade separated junctions, Wood Lane junction, is located where the existing Wood Lane and Berrys Lane meet the A47. The second new grade separated junctions, Norwich Road junction, is located south of the existing staggered junction of Taverham Road and Blind Lane.

4.2.4. The existing Mattishall Lane would be rerouted to the west and a new underbridge would be provided taking the sideroad below the new A47 mainline. An additional walking and cycling link is being provided to connect the shared use path to the new Mattishall Lane Link Road.

4.2.5. A walking and cycling underpass (Honingham church underpass) would be provided from the existing roundabout on the A47 to the east of Honingham and the west of St Andrew’s Church to maintain connectivity.

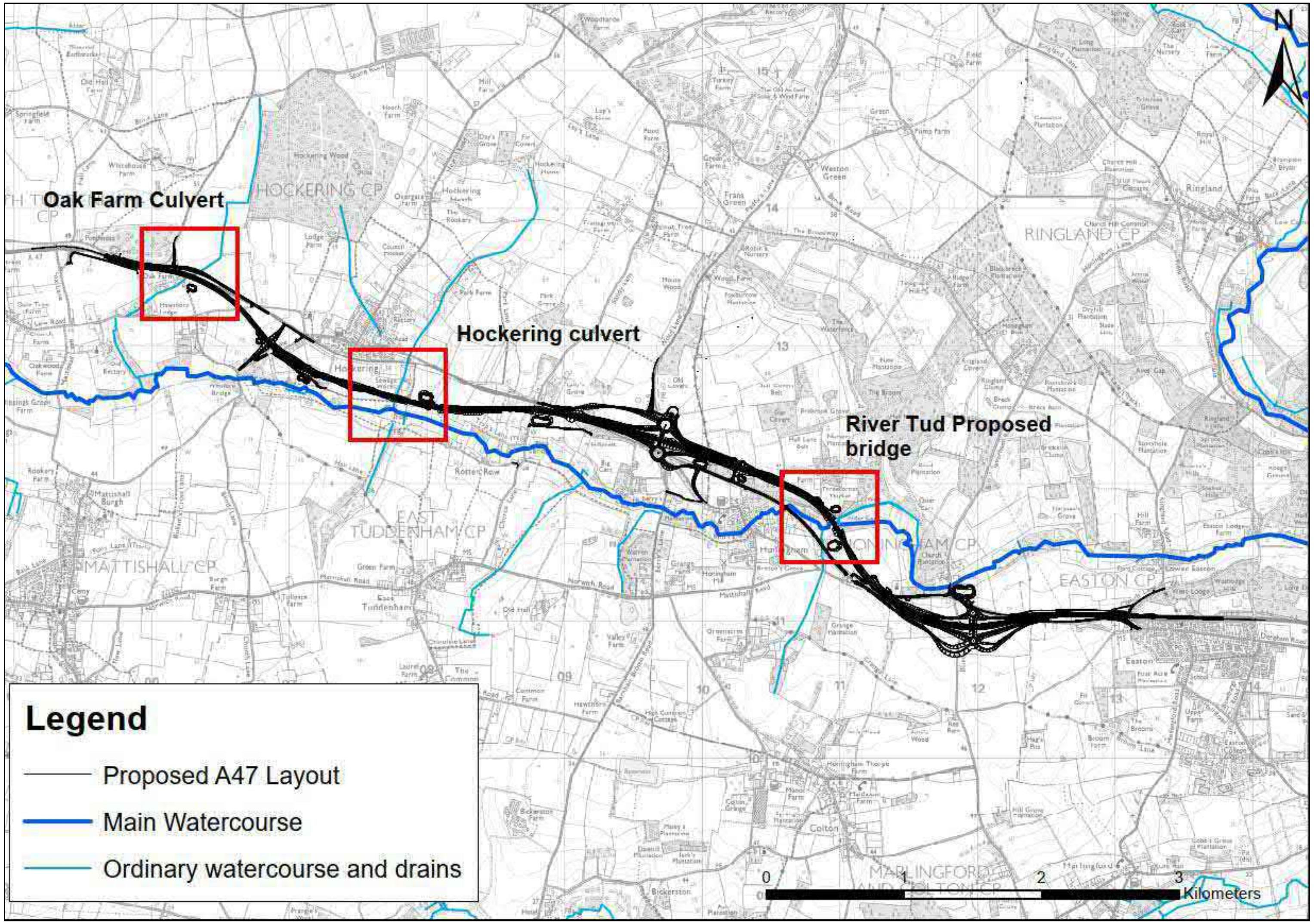
4.2.6. Sections of the existing A47 are proposed to be retained and de-trunked, becoming a local authority adopted road:

- south of Hockering, between Mattishall Lane to the west and the junction of Church Lane and Sandy Lane to the east
- north of Honingham, between Berrys Lane to the west and the existing roundabout west of St. Andrew’s Church

- immediately south of St. Andrew's Church, between the Church and Taverham Road

4.2.7. The Proposed Scheme, shown in Figure 4-1, will include a new bridge, known as the River Tud Crossing, over the River Tud approximately 300m downstream of the existing bridge east of Honingham. New culverts under the proposed road alignment will also be required to convey two ordinary watercourse tributaries to the River Tud located to the south of Hockering (known as Newgate House Culvert) and at Oak Farm (known as New West Culvert). The tributaries are unnamed but will be referred to as the Oak Farm and Hockering watercourses. An existing culvert (West Culvert Extension) at Oak Farm is also to be extended as part of the Proposed Scheme. Further details of the Proposed Scheme layout can be found in the General Arrangement Drawings (**TR010038/APP/2.2**).

Figure 4-1 Overview of Proposed Scheme layout



4.3. Existing hydrology and hydrogeology

Hydrology

4.3.1. The River Tud, is the only main river within the study area and flows for approximately 9.3km in an easterly direction south of the A47. The watercourse passes under the carriageway at Honingham and continues in an easterly direction to the north of the A47 before its confluence with the River Wensum.

4.3.2. A flow gauge is present along the River Tud at Costessey Park (34005) and a level station is also located further upstream at Stone Road Farm (ID E22008). The latter is used by the Environment Agency for flood warning purposes.

4.3.3. The River Tud has an estimated catchment area of 75km2 upstream of the confluence with the River Wensum and an average annual rainfall of 649mm. The catchment has a flat topography and is predominantly rural, with arable farming the main land use. The catchment is underlain by chalk bedrock with overlying superficial deposits including boulder clay, sands, gravels and alluvium. The permeable geology is reflected in the estimated baseflow index of 0.64 at the Costessey Park gauge, which suggests a high degree of groundwater supply to the river. According to the National River Flow Archive the groundwater catchment is smaller than the topographical catchment resulting in losses to adjacent catchments and low annual gauged runoff.

4.3.4. Numerous small ponds are present within the vicinity of the Proposed Scheme and these discharge via ordinary watercourses or land-drains towards the River Tud. These include ponds near Rookery Farm, Hall Lane, Valley Farm and Greenacre Farm which drain northwards towards the River Tud. These do not directly intercept the route of the Proposed Scheme and are therefore not judged to pose a direct flood risk. A reservoir and series of ponds are also located near Colton (south of Honingham), although the exact outfall location is unclear. The reservoir is currently used for fishing and its significant in terms of flood risk is discussed in Section 5.5.

4.3.5. A drainage pond and a cluster of drains are located to the north east of Honingham. Based on a review of OS mapping and topographic data these appear to drain southwards and discharge to a bifurcation channel of the River Tud, downstream of where the River Tud Crossing is located.

4.3.6. In relation to the Proposed Scheme two ordinary watercourses located east of Hockering (referred to as the Hockering watercourse) and close to Oak Farm (referred to as the Oak Farm Watercourse) are the most relevant. The location of these watercourses can be seen on Figure 4-2 and are discussed within the A47

Tuddenham Hydraulic Modelling report (Annex J). The following provides a brief overview:

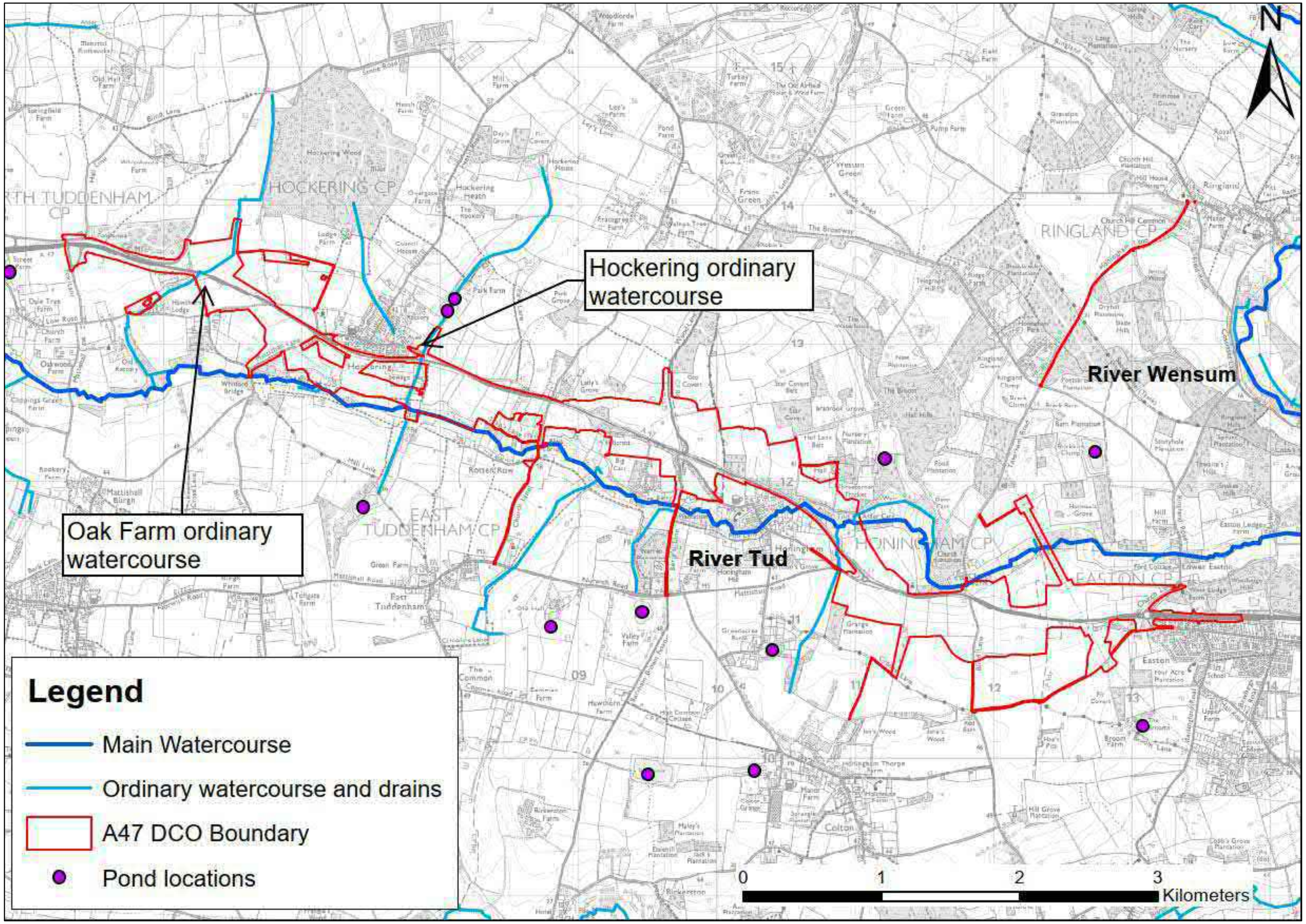
- The Hockering watercourse has a total estimated catchment area of 4.17 km^2 and covers mainly low-lying arable land to the north of the A47. The watercourse receives flows from a cluster of ponds which make up part of Park Farm Lakes, a local commercial fishery. A tributary also connects into the main watercourse close to the inlet to the A47 culvert. This drains the area to the west and covers most of the village of Hockering.
- The Oak Farm watercourse has a total catchment area of 1.5 km^2 covering mainly low-lying agricultural land to the north of the A47 and between the A47 and Low Road. The catchment also includes areas of woodland to the north east. There are several small ponds within the catchment; however, the degree of attenuation provided is considered to be negligible.

4.3.7. Both ordinary watercourses are ungauged and have relatively permeable catchments due to the underling chalk geology, hence, a more attenuated response to rainfall, and a high baseflow component, is expected. Similarly, both watercourses have multiple culverted sections, most notably at the existing A47 and Low Road, which are likely to affect flows within the channel.

4.3.8. The Proposed Scheme lies within the hydraulic catchment and boundary of the Norfolk Rivers Internal Drainage Board (IDB). Similarly, a small section of the River Tud between Church Lane and The Street at Honingham is identified as an IDB watercourse.

4.3.9. The River Yare is located to the south of the Proposed Scheme. A small section of the Yare catchment lies within the study area of the environmental assessment to the south of East Tuddenham and south of Honingham. The operational footprint of Proposed Scheme is; however, separated from the River Yare by the catchment divide between the Tud and Yare waterbodies. It is therefore assumed that there will be no interaction during operation between the Proposed Scheme and this small area of the River Yare catchment.

Figure 4-2 Overview of watercourses and ponds within the vicinity of the Proposed Scheme



Hydrogeology

4.3.10. The Proposed Scheme is underlain by chalk bedrock which varies in depth from 1.8mbgl at locations east of Hockering to 25.5mbgl at the western extent of the Scheme. The Environment Agency classifies the chalk bedrock as a Principal aquifer with high intergranular and/or fracture permeability.

4.3.11. In terms of superficial deposits, the area is predominantly underlain by glacial till of the Lowestoft Formation, with patches of glacial sands and gravels of the Sheringham Cliffs Formation that become more dominant towards the east around Easton. Within the valley of the River Tud and its tributaries river terrace deposits and alluvium are present. These are classified as Secondary A aquifers which may support water supplied at a local scale and, in some cases, form a source of baseflow to rivers. The Lowestoft Formation is described by the British Geological Survey (BGS) as undifferentiated and therefore may contain lower permeable layers and perched aquifers.

4.3.12. As part of this project, monitoring boreholes were installed along the route of the Proposed Scheme. The available groundwater monitoring data indicates that groundwater flows are predominantly directed towards the River Tud, which has a baseflow component.

4.3.13. The Chalk aquifer is thought to be largely confined by the overlying Lowestoft Formation, although permeable layers were observed in monitoring boreholes. The alluvium deposits within the floodplain of the River Tud were found to be saturated and are interpreted as being hydraulically linked to the Chalk aquifer via upward leakage. This was based on the observed artesian groundwater levels within the River Tud floodplain and hydrographs of monitoring points within the Chalk and Alluvium. This process also likely provides a source of baseflow to the River Tud. A similar close relationship was also noted at monitoring boreholes close to the Hockering watercourse, however, at Oak Farm, which is underlain by clay dominated Lowestoft Formation, a disconnect between the watercourse and groundwater levels was observed. This is supported by site observations which found levels in the watercourse to be very low, which suggests that flows are likely more seasonal. Further details on groundwater flows within the area can be found within the Groundwater assessment (ES Appendix 13.4) (**TR010038/APP/6.3**).

4.4. Summary of consultation

4.4.1. Several meetings have been held with the Environment Agency and Norfolk County Council (as Lead Local Flood Authority). The first in March 2020 was in response to concerns raised following the initial submission of the proposed modelling methodology. The key outcomes were as follows:

- The Applicant clarified that the modelling undertaken will be purely fluvial, and that drainage modelling will be carried out separately in MicroDrainage. The modelling and hydrological approach for the River Tud and ordinary watercourses were both agreed to be appropriate.
- It was confirmed that the Scheme will need to be assessed against the UKCP18 guidance. A 35% and 65% fluvial allowances will need to be tested with the model and the H++ allowances (80%) will also need to be considered, where applicable.
- The Environment Agency confirmed that net loss of floodplain storage will need to be appropriately compensated through the provision of additional storage. For this assessment a 35% climate change allowance will be applicable.

4.4.2. Three meetings were held with the Environment Agency and Norfolk County Council on the June 2020, August 2020 and November 2020. These mainly concerned design considerations relating to the River Tud crossing and during the meeting the preliminary modelling results were presented. The key outcomes included:

- The Environment Agency was concerned that any infrastructure built within 5 metres of the channel would impact riparian habitats and affect the channel's ability to migrate and required that any works be placed outside of this margin.
- Design changes to the Proposed Scheme were undertaken to ensure that any engineering works for the River Tud Crossing would satisfy the Environment Agency's requirements. A 41m span bridge design was presented and this was deemed preferable in terms of flood risk compared to previous iterations, although acceptability would depend on the review of the model outputs.
- The Environment Agency confirmed that the predicted displacement of floodwater for the two abutments will require flood compensatory storage, and that any channel realignment will not be appropriate. The impacts and any mitigation will have to be demonstrated before permits can be issued for the works.
- The Environment Agency stated that culverts should be avoided as much as possible and any required should have ecology access, soft bed \ low flow channel for fish species.
- The Applicant noted that a flood attenuation culvert is no longer proposed for the Internal Drainage Board drain close to the proposed bridge as there is no upstream catchment and the design now picks up overland flow.

4.4.3. The Environment Agency provided comments on a draft of the Drainage strategy report in December 2020.

4.4.4. The Environment Agency provided feedback on the baseline hydraulic models and associated report. The model and updated report have subsequently been reissued and include the post development results and to address comments on the baseline model. The Applicant received a response in February 2021 outlining that the Environment Agency were satisfied that all outstanding actions have been resolved and that the models are suitable for their intended use.

4.4.5. A meeting was held with Norfolk County Council in September 2020 with the focus of discussion on the proposed culverts and mitigation at Hockering and Oak Farm. A follow up email was received from Norfolk County Council clarifying several points:

- Norfolk County Council recommended that the Applicant apply for records of historic flooding held by the LLFA. This has now been received and is summarised in Section 5.
- The estimated impacts of the Proposed Scheme at Hockering and Oak Farm were discussed. No significant issues were noted with the culvert at Hockering, however, Norfolk County Council recommended that the potential of incorporating a portal rather than box culvert be explored.
- The arrangement at Oak Farm was discussed including the potential for throttling flows using an orifice. Norfolk County Council agreed in principle but stated that it must be demonstrated that reasonable consideration has been given to meeting the level for level, volume for volume requirement.
- Norfolk County Council noted a desire for further work to explore opportunities for habitat restoration upstream of the proposed new Oak Farm culvert.

4.4.6. Several aspects of the drainage design were also discussed. Norfolk County Council noted that attenuation ponds located in areas of surface of fluvial flood risk will not be deemed suitable and discharge from the Scheme will need to be attenuated to the pre-development greenfield runoff rate and volume. Existing overland flow pathways must also be maintained through dry culverts designed to convey at least the 1% AEP event with climate change.

4.4.7. Two further meetings occurred with Norfolk County Council in November 2020 to discuss alterations made to the proposed culverts south east of Hockering.

- The Applicant outlined the preference for a box culvert at the location and construction of the culvert perpendicular to the road with a minor watercourse diversion downstream due to health and safety concerns. Norfolk County Council confirmed that the realignment will be acceptable but stressed that the culvert must meet hydraulic requirements for the 100-year (65% climate change) event with a 600mm freeboard and must not prevent ecological passage.
- Maintenance of the culvert at Hockering was also discussed.

4.4.8. Correspondence were sent to the Environment Agency and Norfolk County Council on the 12 January 2021 and 19 January 2021 outlining the need for compensatory flood storage and other mitigation proposed (see Section 7). A response was received from the Environment Agency on the 29 January 2021 in which the proposed compensatory storage for the River Tud Crossing was agreed to be appropriately located to directly compensate on a volume-for-volume and level-for-level basis. An additional response from the Environment Agency was received on 9 February 2021 in which it was also agreed, in principle, that compensatory storage may not be required for both Oak Farm and Hockering. The Applicant received feedback from Norfolk County Council on 9 February 2021 requesting further clarification regarding several aspects of the design related to Oak Farm and Hockering. In subsequent discussions, Norfolk County Council has accepted, in principle, that flood compensatory storage at Oak Farm and Hockering may not required although further information was requested regarding the off-site impacts and this is provided within the flood risk assessment. The need for floodplain compensation will be confirmed at the detailed design stage, so an area has been identified in the event that floodplain compensation is later required.

4.4.9. Norfolk County Council provided comments on a draft Drainage strategy report (Volume 3, Appendix 13.2) in January 2021 including detailed comments on aspects of the drainage design.

4.4.10. Norfolk County Council and the Environment Agency has been issued the flood risk assessment in February 2021 for comment.

4.4.11. The Norfolk Rivers Internal Drainage Board was also consulted. In their response (22 January 2021) it was confirmed that a section of the River Tud between Berrys Lane and the Street is an IDB adopted watercourse and that any work within 9m will require consent to relax a relevant byelaw. Similarly, it was noted that any discharge into riparian watercourses which connect to the River Tud would require land drainage consent which will likely be conditional. Further detail was requested regarding the proposed discharge rates and method of attenuation and this has now been provided.

4.4.12. Anglian Water has been consulted with regards to water main and sewerage diversions and for the provision of historic flooding information. As the Proposed Scheme would not connect to the Anglian Water sewerage system, they have not been consulted with regards to flood risk.

5. Existing sources of flooding

5.1. Sources of potential flooding

5.1.1. Existing sources of flood risk affecting the area of the Proposed Scheme have been assessed to understand the baseline conditions upon which any impacts arising from the works can then be evaluated. This process has utilised existing flood information and informs mitigation strategies, where required. Proposed Scheme-relevant potential sources of existing flood risk include:

- Fluvial (rivers and tidal influences);
- Pluvial (surface water);
- Risk of flooding from sewer and water main infrastructure failure;
- Risk of flooding from reservoir failure, and;
- Groundwater

5.1.2. There are no canals within this area of the Proposed Scheme therefore flooding from this source has not been considered as part of this assessment.

5.2. Fluvial and tidal flood risk

5.2.1. The confluence of the River Tud is approximately 2km upstream of the tidal limit of the River Wensum at New Mills Yard. As such the River Tud, is not affected by coastal processes and the Proposed Scheme is not at risk of tidal flooding.

5.2.2. A review of the Environment Agency's Flood Map for Planning (Environment Agency, 2020a) shows that the majority of the Proposed Scheme is located within Flood Zone 1 (see Annex A). This is associated with a low risk of flooding from fluvial sources with an annual probability of less than 1 in 1,000 years.

5.2.3. At two locations the Proposed Scheme crosses areas classified as Flood Zone 3, which is associated with a high risk of flooding from fluvial sources (1 in 100 or greater annual probability of flooding). The first is located to the south east of Hockering, where the Proposed Scheme crosses an ordinary watercourse close to its confluence with the River Tud. This is identified within the Breckland SFRA (Breckland Council, 2017) as Flood Zone 3a, however, it is unclear whether the origin of this flooding is from the River Tud, the ordinary watercourse or both. If the tributary has been represented in the Environment Agency modelling it is unclear how far this extends, or if it accounts for several culverts along the watercourse.

5.2.4. The second location is where the Proposed Scheme crosses the River Tud east of Honingham and downstream of the existing A47 bridge. The Greater Norwich Area Strategic Flood Risk Assessment (JBA Consulting, 2017) identifies this as within Flood Zone 3b, which comprises land where water has to flow or be stored in times of flood and is defined using the 20-year flood extent.

5.2.5. The Proposed Scheme crosses an ordinary watercourse at Oak Farm, however, this is not represented within the Environment Agency Flood Map for Planning (Environment Agency, 2020a), hence the level of flood risk from this source is uncertain.

5.2.6. The Proposed Scheme is not within an 'Area Benefitting from Flood Defences' (Environment Agency, 2020a), however, it is within an area that benefits from both flood alerts (The Rivers Tud and Wensum from Fakenham to Costessey, including Wendling Beck) and flood warnings (The River Tud from East Dereham to New Costessey) (Environment Agency, 2020g). There are no designated Flood Storage Areas within the vicinity of the Proposed Scheme.

5.2.7. The results of the fluvial flood risk modelling, including the impacts of climate change, is presented in Section 6.

Fluvial flood history

5.2.8. There is limited information available on previous fluvial flooding within the area. The Environment Agency publish historic mapping (Environment Agency Historic Flood Map, 2020c) which indicate land previously subject to flooding from main rivers, the sea and groundwater springs. This mapping indicates that there has been no recorded flooding from these sources within the vicinity of the Proposed Scheme. There are also no noted incidences of flooding within the Chronology of British Hydrological Events (University of Dundee, 2020) or in the Breckland SFRA (2017) from the River Tud.

5.2.9. The Tud hydrology report (CH2M, 2017), developed as part of the Modelling and Forecasting Q2 Fluvial Modelling Package, notes that the largest flood event recorded at the Costessey Park Gauge was in 1993. However, no properties were reported to have been affected. The report also highlights that flooding of Taverham Road in 2014 may have been exacerbated by water levels in the River Tud impeding carriageway drainage.

5.2.10. There is also limited information regarding the two ordinary watercourses which the Proposed Scheme crosses. Within the Breckland SFRA (Breckland Council, 2017) fluvial flooding is noted to have occurred in 2002 and 2004 within Hockering. The 2004 event was described as a torrent of water across the A47 directed eastbound. The exact location of mechanism of flooding is however not outlined.

5.3. Pluvial (surface water) flood risk

5.3.1. The Environment Agency's indicative long-term flood risk map (Environment Agency, 2020b) shows that the majority of the Proposed Scheme is at very low risk of surface water flooding (see Annex B).

5.3.2. The Proposed Scheme crosses areas of low (between 1 in 1000 and 1 in 100 chance of pluvial flooding in any given year) and medium (between 1 in 100 and 1 in 30 chance of pluvial flooding in any given year) flood risk. This is associated with flood flow pathways which run in a southerly direction. There are eight locations where the Proposed Scheme crosses these pathways (see Annex B):

- east of Hockering
- east of, and at, Church Lane, East Tuddenham
- at the proposed junction at Wood Lane, high surface water flood risk ponding is also observed here
- east of the proposed junction at Wood Lane, high surface water flood risk ponding is also observed here
- west of the River Tud crossing
- west of, and at, Blind Lane
- east of Blind Lane
- west of Easton

5.3.3. The Proposed Scheme crosses four areas of high surface water flood risk (greater than 1 in 30 chance of surface water flooding in any given year);

- at the existing Oak Farm / A47 culvert, where flow appears to back up at the culvert itself, low to medium surface water flooding is associated in the adjacent and downstream areas due to this
- south-east of Hockering originating from a drain running adjacent to the River Tud
- east of Hockering (near the Sandy Lane Junction) due to a depression in the land which collects overland flow
- north and east of Honingham originating from the cluster of drains and the River Tud.

5.3.4. The Greater Norwich Area SFRA (JBA Consulting, 2017) flood risk maps show the impacts of climate change on the 1 in 100 year flood risk with a 40% allowance for climate change. The extent of the flooding shown for this scenario is similar but less than the 1 in 1000 year extent without climate change. Only the Proposed Scheme approximately east of Honingham is covered by this

SFRA. There are no corresponding surface water flood risk maps that include climate change for the Breckland Council area (Breckland Council, 2017).

5.3.5. In addition to the surface water flow pathways The Proposed Scheme crosses and intercepts a number of existing natural surface water flow catchments. These are summarised below and shown in the drainage catchment plan provided in Annex K:

- Natural catchments A, B, C, D, E and F are located towards the western end of the Proposed Scheme and flow in a generally north to south direction towards the River Tud
- Catchment G flows north to south and conveys flow from the southern edge of the Proposed Scheme towards the River Tud
- Catchments H, J and K are located in the central portion of the Proposed Scheme and flow generally north to south towards the River Tud
- Catchments L, M and N are located towards the eastern end of the Proposed Scheme and flow generally south to north towards the River Tud.

Surface water flood history

5.3.6. A pre-application surface water assessment was supplied by Norfolk County Council (15 September 2020). This gives an overview of known incidences of surface water flooding within the vicinity of three points taken at Honingham, Hockering and Oak Farm. The results indicate that all three sites are not within 0.5km of any known incident of internal surface water flooding recorded by Norfolk County Council since April 2012. The sites are however within 2.5km of a known incident of internal flooding recorded by Norfolk County Council, and the point at Honingham is within 0.5km of a property included within the Anglian Water DG5 database. No further details on the location of the property was provided.

5.3.7. HA DDMS (Highways England, 2020) identified 15 instances of historic carriageway flooding within the Proposed Scheme DCO boundary. The flooding is classified in terms of severity based on road type, extent of closure, traffic flow and duration of closure and ranges from zero to ten (Highways England, 2020). HA DDMS identified 11 of these flooding instances to be between Hockering and Honingham:

- Four low severity (0-4) flood events between 2008 and 2009 at the Sandy Lane junction causing flooding on the carriageway and at the driveway to the property
- One low severity (0-2) flood event in 2015 east of Sandy Lane junction causing localised flooding on the carriageway

- Four low severity (0-4) flood events between 2008 and 2014 at the Wood Lane junction
- One low severity (2-3) flood event in 2008 west of Hall Drive causing flooding to the carriageway
- One low severity (2-3) flood event in 2008 east of Hall Drive causing flooding on the verge and carriageway. This was reported as not being caused by rain, no further details were supplied.

5.3.8. Four instances of historical carriageway flooding were identified between Honingham and Easton:

- One low severity (0-2) flood event in 2014 near the Blind Lane junction causing flooding on the carriageway
- Two medium severity (5-6) flood events in 2016 east of Blind Lane junction causing flooding on the carriageway. This was reported as being caused by floodwater overflowing from adjacent fields and drainage ditches being filled to capacity
- One low severity (0-2) flood event in 2014 at the roundabout to the east of the Proposed Scheme DCO boundary where flooding was observed on the carriageway.

5.3.9. Unless identified above, the majority of these events were due to blocked gully pot covers, and once the gullies were cleared the water drained away.

5.3.10. There are no priority culverts within the Proposed Scheme DCO boundary.

5.4. Risk of flooding from sewer or water main infrastructure failure

5.4.1. A review of available information, including the Breckland SFRA (Breckland Council, 2017), found that there is no evidence of flooding from local sewer or water networks having occurred within the immediate area of the Proposed Scheme, thus the risk is considered low. However, it is acknowledged that data on this source of flood risk is limited.

5.4.2. The Norfolk County Council surface water assessment (see Section 5.3.6) noted that the point within Honingham is within 0.5km of a property included on the Anglian Water DG5 database. However, no further information is provided regarding the location or cause of flooding. Anglian Water has confirmed that they have no records of flooding in the vicinity of the Proposed Scheme that can be attributed to capacity limitations in the public sewerage network.

5.5. Risk of flooding from reservoir failure

5.5.1. The Environment Agency's indicative flood risk map (Environment Agency, 2020b) shows that most of the Proposed Scheme is not at risk should there be failure of a local reservoir. However, the area where the Proposed Scheme crosses the River Tud east of Honingham is predicted to be affected by floodwater in the event of a failure of a reservoir to the south west. Based on the flood depth maps it is assumed that this risk originates from the reservoir at Colton with floodwaters appearing to flow north eastwards towards the A47, before following the route of the River Tud. At the bridge crossing depths of up to 2m are predicted.

5.5.2. These maps are designed to be used for emergency planning purposes and show only the worst-case scenario. Given the inspection regimes in place for reservoirs the risk of failure is very low.

5.6. Groundwater flood risk

5.6.1. The geological review found that the Proposed Scheme is underlain by chalk bedrock classified as a Principal aquifer. The Chalk is overlain by superficial deposits defined as Secondary A or Secondary (Undifferentiated) aquifers, which vary in terms of their groundwater potential. Groundwater flooding may therefore be a risk within the area.

5.6.2. The Breckland SFRA (Breckland Council, 2017) notes that, following significant rainfall in 2012, there were instances of flooding associated with high groundwater levels. However, there is limited understanding of the risk in the district and there is no further information to identify if the route of the Proposed Scheme was affected.

5.6.3. The BGS produce detailed ‘susceptibility to groundwater flooding’ maps which were obtained for the study area (see Annex C). These indicate that the level of susceptibility to groundwater flooding is variable along the route of the Proposed Scheme. There are areas with the potential for groundwater flooding to occur at the surface during periods of extended intense rainfall south east of Hockering, at the River Tud Crossing, as well as close to Taverham Road. These areas correspond to a ground level of approximately 30m AOD along of the route of the River Tud. There are also areas at moderate risk close to the two grade separated junctions at Wood Lane and Norwich Road, where there is the potential to experience groundwater flooding for any property or asset located below ground level. These areas correspond to a ground level of approximately 40m AOD along the route of the River Tud.

5.6.4. The patterns of potential groundwater flooding are supported by borehole investigations which indicated that that high groundwater levels are likely related to alluvium deposits, which are hydraulically linked to the Chalk aquifer. In particular, shallow and artesian groundwater levels were recorded where the Proposed Scheme crosses the River Tud at Honingham and a tributary of the

River Tud southeast of Hockering. Within the wider area there may also be the potential of localised flooding relating to permeable superficial deposits.

5.6.5. The climate change projections do not affect the overall annual recharge volumes for groundwater, although the groundwater recharge season is likely to be shorter and more intense, leading to more variable groundwater levels and a greater drought vulnerability (Environment Agency, 2019).

5.7. Summary of existing flood risk to the development

A summary of the estimated level of flood risk for each source, based on a review of available information, can be found in Table 5-1 below.

Table 5-1 Summary of the estimated level of flood risk from each source

Source of flood risk	Risk Level
Fluvial	High-Medium
Surface Water (pluvial)	High-Medium
Sewer	Very Low
Groundwater	Medium-Low
Reservoir	Very Low

5.7.1. The Environment Agency maps indicate that the Proposed Scheme intercepts multiple surface water flow pathways which range in terms of risk from high to low. The risk from this source is therefore considered to be high to medium.

5.7.2. There was no historic evidence of groundwater flooding having affected the route of the Proposed Scheme, however, data is lacking. A review of available information suggests that there is a potential risk particularly where the Proposed Scheme intercepts alluvium deposits within the floodplain of the Tud and its tributaries. The risk of flooding from this source is, therefore, considered to be a medium to low.

5.7.3. There was no evidence of flooding from sewerage or water infrastructure having affected the route of the Proposed Scheme and, given the inspection regimes in place, the risk from reservoir flooding are both considered to be very low

5.7.4. There is limited historic evidence regarding past fluvial flooding within the area. The Proposed Scheme intersects Flood Zone 3 at two locations including at the River Tud Crossing. The Proposed Scheme also crosses two minor watercourses although the level of flood risk at these locations are uncertain. Detailed modelling has therefore been undertaken. The baseline results are presented in Section 6 along with a summary of the predicted impacts, including the effects of climate change, of the Proposed Scheme.

6. Flood risk from the development

6.1. Fluvial flood risk

6.1.1. To assess the impact of the Proposed Scheme on flood risk in more detail hydraulic modelling was undertaken. A comprehensive overview can be found in the Tuddenham hydraulic modelling report (Annex J).

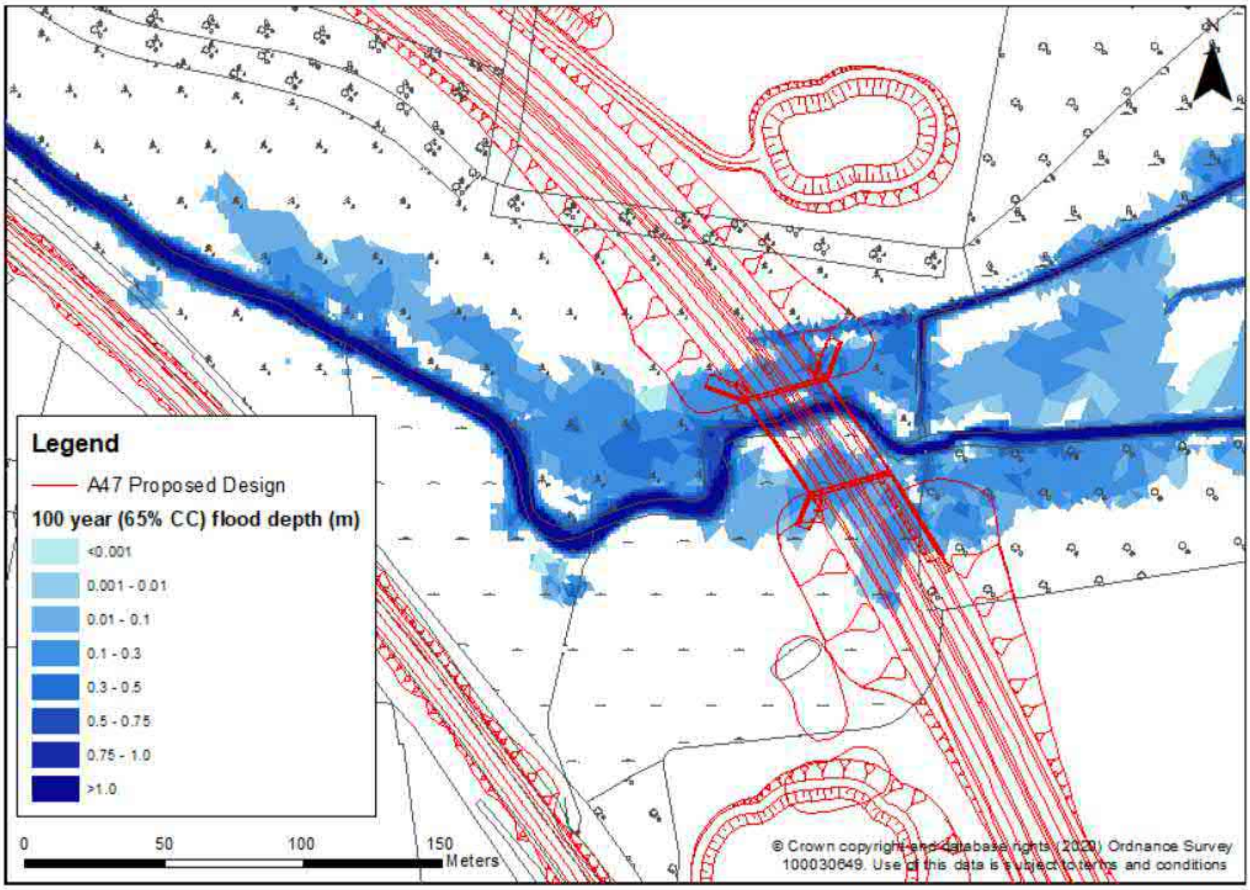
River Tud

6.1.2. A hydrodynamic model of the River Tud was constructed using Infoworks Integrated Catchment Model (Version 9). The model was based on an existing 1D Flood Modeller model of the River Tud developed by CH2M and was supplemented with additional survey undertaken in 2019 as part of this assessment.

6.1.3. The updated model predicted similar flood extents to those shown in the Environment Agency mapping, however, there are variations due to the integration of new survey and updates to the modelling approach. The flood maps provided in the hydraulic modelling report (Annex J) show that most of the Proposed Scheme is outside of the existing 100-year floodplain, both with and without a 65% climate change allowance. Note that an extremely small section of embankment close to Hockering overlaps the 100-year (65% climate change) floodplain. At detailed design stage, and following a detailed topographic survey, the footprint of the embankment will be reviewed to avoid encroaching the predicted flood extent.

6.1.4. The only element of the design within the floodplain are the abutments of the proposed River Tud Crossing, as can be seen in Figure 6-1. At this location flooding is predicted along both banks with floodwaters flowing eastwards before re-entering the main watercourse or the secondary channel downstream (east) of the new bridge.

Figure 6-1 Flood extent for the 100-year event with a 65% climate change allowance



6.1.5. The soffit of the bridge will have an elevation over 2m above the 22.563m AOD design water level predicted at the location of the bridge. As such, the amount of freeboard provided is compliant with DMRB guidance and the only element of the design that will impact flows are the two abutments. A drawing of the proposed design is shown in the DCO engineering drawings (**TR010038/APP/2.7**).

6.1.6. Post development modelling undertaken using a 2D model of the Proposed Scheme found that the bridge abutments will intercept, and funnel flows back into the main watercourse. This results in an increase in peak water levels upstream and downstream of the crossing. A maximum increase of 17mm is predicted immediately upstream of the bridge for the 100-year event and 72mm with a 65% climate change allowance respectively. The 100-year flood maps with and without a 65% climate change allowance and be found in Annex D (baseline), Annex E (post development), Annex F (depth difference) and the full model results in Annex J.

6.1.7. Figure 6-2 provides an overview of the main area impacted by the Proposed Scheme. There was predicted to be an increase in water level extending approximately 400m downstream and 700m upstream of the bridge. There are however no sensitive receptors downstream and the increase upstream of the existing A47 bridge within Honingham was below 10mm for all events. This increase is within model tolerance hence the impact in terms of flood risk is negligible and no sensitive receptors are predicted to be impacted.

Figure 6-2 Difference in depths for the 100-year event with a 65% climate change allowance

6.1.8. In summary, the hydraulic modelling of the River Tud demonstrates that the Proposed Scheme will have no significant impact on flood risk to receptors. However, as a result of the abutments of the proposed bridge causing a displacement of floodwater, compensatory flood storage will be required. This mitigation is outlined within Section 7.1.

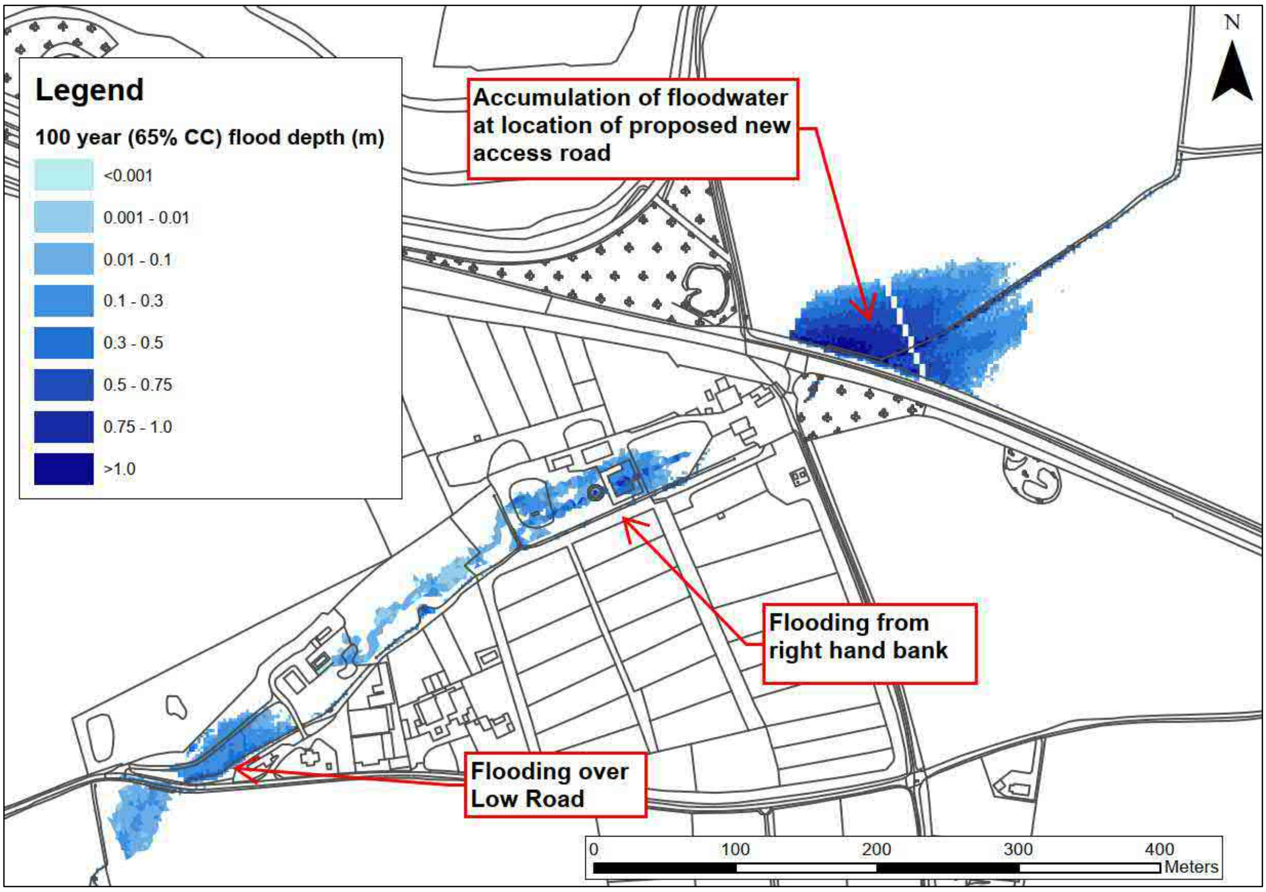
Oak Farm ordinary watercourse

6.1.9. As part of the Proposed Scheme, a new link road will cross the Oak Farm watercourse upstream of the existing A47. As such, a 43m section of the channel will be culverted. The existing A47 culvert will also be extended upstream by approximately 17m and the channel upstream realigned. The new and extended culverts will both have internal dimension of 750mm to match the existing A47 culvert. The culverts and connecting drainage are shown in the DCO drainage plans (**TR010038/APP/2.8**).

6.1.10. The Environment Agency modelling does not include the Oak Farm watercourse hence a new site-specific hydraulic model was created. Further details on the model construction and hydrological analysis can be found within the Tuddenham hydraulic modelling report (Annex J).

6.1.11. The baseline modelling identified that the existing A47 culvert and a culvert downstream provided a constraint on flows resulting in water backing up. Both the new road and the extended section of the A47 overlap this area of accumulation. In addition, flooding is predicted downstream of the existing A47 along the right-hand bank and over Low Road. Floodwaters are predicted to affect one residential property. An overview of the baseline flood patterns can be seen in Figure 6-3 and Annex G.

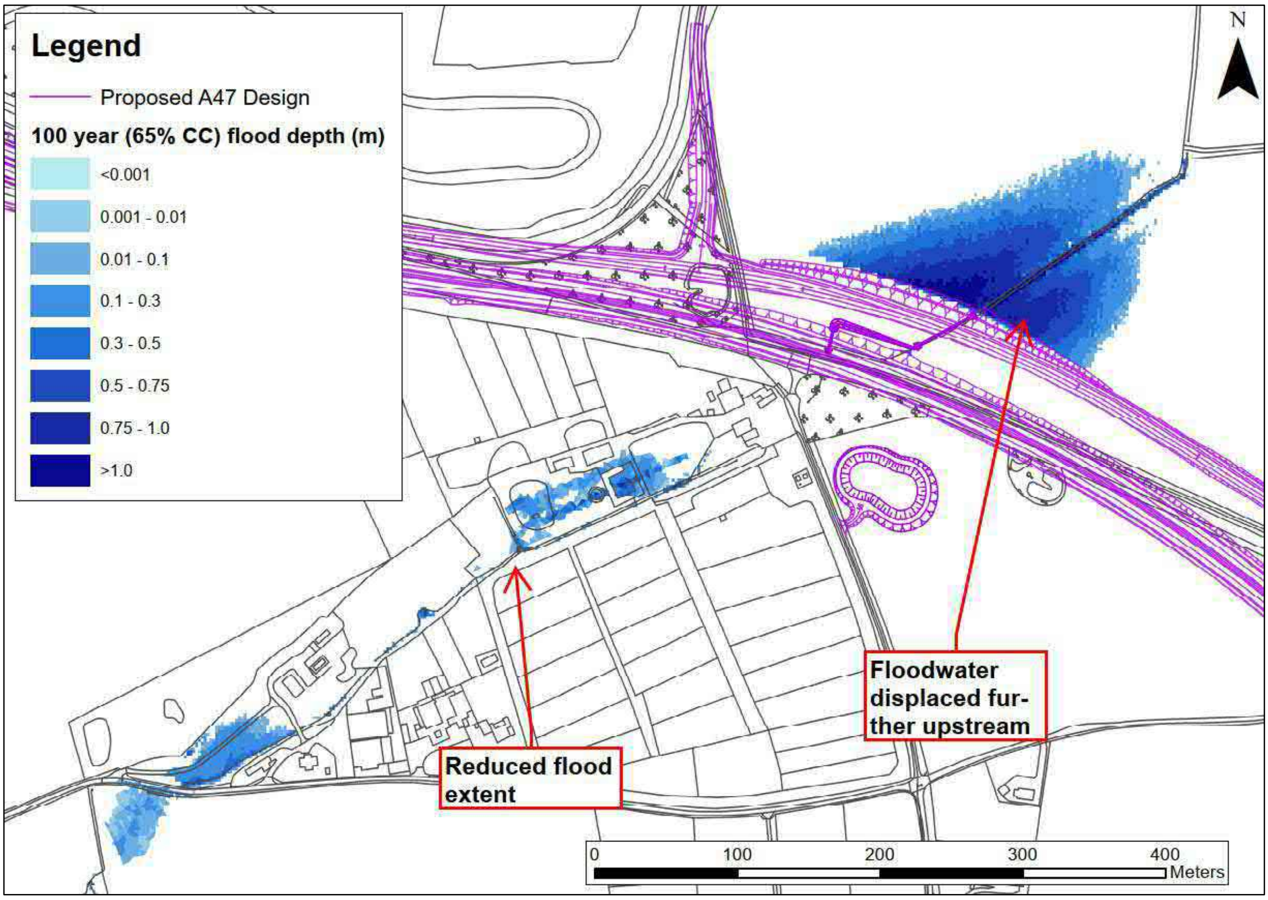
Figure 6-3 Baseline flood extent for the 100-year event with a 65% climate change allowance



6.1.12. To ensure that there is no detrimental impact on flood risk downstream, a 350mm circular orifice will be placed at the inlet to the new culvert to throttle flows. Similarly, an embankment with a crest level of 46.5m AOD will be constructed upstream to contain any floodwaters that accumulate as a result of the orifice and ensure that there is no flood risk to the road. The crest level will be tapered into the existing ground levels at the western and eastern extents.

6.1.13. Post development modelling demonstrated that the design relocates the floodwater which previously accumulated at the inlet to the existing A47 culvert further upstream to the inlet of the new culvert. This results in an increase in water levels upstream of the new road with a peak water level of 45.513m AOD predicted at the embankment for the 100-year event plus 65% climate change allowance. This also results in a greater inundation of arable land to the north. However, no sensitive receptors are predicted to be affected (see Figure 6-4).

Figure 6-4 Post development flood extent for the 100-year event with a 65% climate change allowance



6.1.14. The proposed embankment crest level of 46.5m AOD provides greater than 600mm freeboard for the 100-year event (with 65% climate change). Due to the potential impact on road users and downstream receptors, the high end (H++)

80% climate change allowance was also applied to the 1 in 100-year peak river flows. The model demonstrated that the bund would not be overtopped, the new local access road would not be flooded and no sensitive flood risk receptors will be impacted. Over 600mm freeboard would also be provided for this event for the 100-year event with 80% climate change allowance.

6.1.15. Further sensitivity testing demonstrated that the design is robust with the embankment providing over 300mm freeboard with a 10% and 50% blockage applied (see Table 6-1) to the proposed 350mm orifice. A peak volume of flood water accumulation upstream of the embankment was predicted to increase from 9388m^3 to approximately 21,800m^3 for the 50% blockage scenario and 11,300m^3 for the 10% blockage scenario.

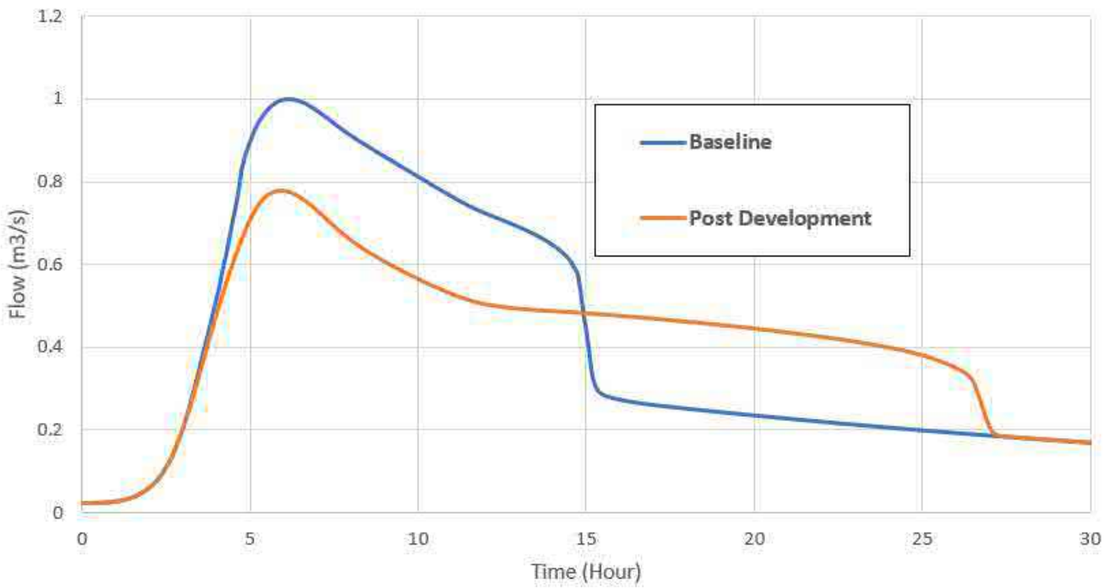
Table 6-1 Peak water levels upstream of the embankment for the 100-year (65% climate change) event

	No Blockage	10% Blockage		50% Blockage	
	level (mAOD)	level (mAOD)	Difference (mm)	Level (mAOD)	Difference (mm)
Upstream of culvert	45.513	45.613	100	46.044	531
Freeboard (m)	0.987	0.887	-	0.456	-

6.1.16. Immediately upstream of the proposed new culvert water levels are predicted to increase by a maximum of 1011mm for the 100-year event without climate change (44.078 to 45.089m AOD) and by 825mm with a 65% allowance (44.688 to 45.513m AOD). A maximum decrease in water levels of 678mm and 1047mm is predicted immediately downstream of the existing A47 culvert. Further downstream there are reduction in flood depths of between 5mm and 167mm for the 100 year event without climate change and between 1mm and 78mm with a 65% allowance for climate change.

6.1.17. The orifice ensures that water is retained within the realigned channel between the new and existing A47 culverts. This also ensures that there is no increase in flows and a net betterment in terms of flood risk downstream of the existing A47. For the 1 in 100 year This can be seen in the flow hydrographs taken downstream of the A47 (Figure 6-5) as well as the flood and hazard mapping provided in Annex G (baseline) and Annex H (post-development) which show a reduction in both flood depths and flood extents.

Figure 6-5 Hydrographs taken downstream of the A47 for the 100 year (65% climate change) event



Hockering ordinary watercourse

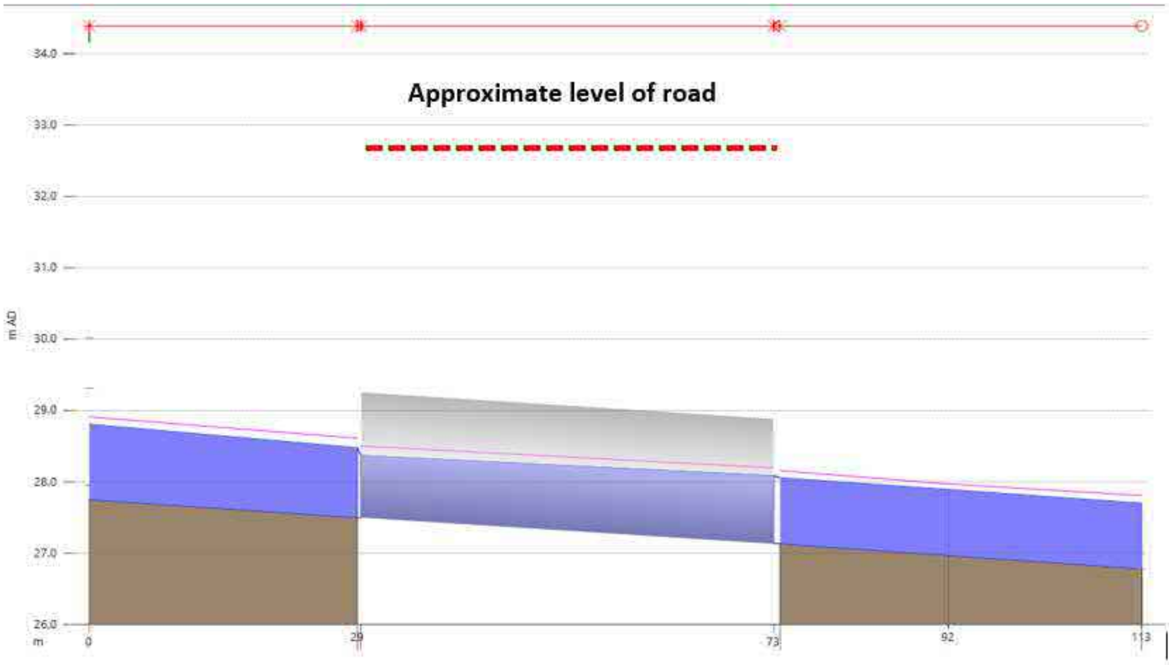
6.1.18. The new carriageway crosses an ordinary watercourse located to the east of Hockering and to facilitate this a new culvert will be required. This structure would be a 2.05m by 2.05m precast concrete box frame of approximately 44m in length. The structure includes a mammal ledge with suitable access and a 300mm bed layer at base of the culvert to tie-in with the existing bed levels upstream and downstream. A minor watercourse diversion is also proposed at the culvert outlet to tie into the existing watercourse. A drawing of the proposed drainage design is shown in the DCO drainage plans (**TR010038/APP/2.8**).

6.1.19. Detailed modelling of the watercourse was undertaken using Infoworks ICM (version 9). Further details on the model construction and hydrological analysis can be found within the Tuddenham hydraulic modelling report (Annex J).

6.1.20. The baseline modelling results differ from the Environment Agency mapping in that water is predicted to remain within or close to the channel in the vicinity of the Proposed Scheme for all modelled events. The existing A47 culvert was found to constrain flows resulting in the backing up of water upstream, although the existing A47 was not predicted to be flooded. The results were also found to be sensitive to the downstream boundary with the River Tud.

6.1.21. Post development modelling demonstrates that the proposed box culvert would be able to convey the estimated 100-year flows (including a 65% climate change allowance) with a freeboard exceeding 600mm (see Figure 6-6). A bank full water level of 27.7m AOD was applied to the downstream boundary of the model to account for the influence of the River Tud on the proposed culvert

Figure 6-6 Longitudinal profile through the culvert for the 100-year event (with 65% climate change)



6.1.22. The culvert results in a small increase in velocities and a reduction in water levels immediately upstream and downstream. A maximum drop in water levels of approximately 145mm was predicted upstream of the proposed culvert for the 100-year event without climate change and 68mm with a 65% allowance. Downstream of the proposed culvert a drop of 109mm and 105mm was predicted respectively. Note that for these results a bank full level was not applied to ensure that the results were not influence by the downstream boundary condition. A detailed overview of the predicted impact of the Proposed Scheme can be found in the Tuddenham hydraulic modelling report (Annex J).

6.1.23. Further sensitivity testing indicates that blockage of the culvert is a potential risk. Applying a 10% and 50% blockage to the structure was predicted to result in an increase in water levels of 170mm and 880mm respectively. Applying a 50% blockage resulted in flooding to the east of the watercourse which is predicted to intercept an existing workshop building. The lowest ground level within the footprint of the building is 28.95m AOD approximately 400mm below the peak water level of 29.367m AOD. Measures to mitigate this impact are outlined in Section 7.

6.2. Surface water flood risk

6.2.1. The Proposed Scheme, through the construction of new carriageway, will result in an increase in impermeable area. Without mitigation this will increase the rate of surface water runoff and could exacerbate downstream flood risk. Similarly, several sections of the Proposed Scheme will tie-into the existing drainage, which is assumed to discharge to the River Tud or its tributaries. Without mitigation, this could increase flood risk to parts of the existing drainage network. During operation, the Proposed Scheme would be hydraulically disconnected from the River Yare, and therefore it is considered that there will be no impact on this watercourse.

6.2.2. The Proposed Scheme intercepts several surface water flow pathways noted in Section 5. Without mitigation, interception of these pathways may cause localised flooding by diverting flood risk on to others or to the Proposed Scheme itself. The Proposed Scheme will intersect 13 natural catchments (Annex K) and thereby form new sub-catchments. The potential impacts are summarised as follows:

- A small proportion of the southern extents of Catchments A and B will be intercepted by the Proposed Scheme which passes through the catchments in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the northern edge of the new carriageway. Small new sub-catchments will be formed to the south of the Proposed Scheme.
- Catchments C, D and E are intercepted approximately halfway by the Proposed Scheme in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the northern edge of the new carriageway. Smaller, new sub-catchments will be formed to the south of the Proposed Scheme which flow in a generally north to south direction.
- A small proportion of the southern extent of Catchment F will be intercepted by the Proposed Scheme which passes through the catchment in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the northern edge of the new carriageway. A small, new sub-catchment will be formed to the south of the Proposed Scheme which flows in a generally north to south direction.
- A small proportion of the northern extent of Catchment G will be intercepted by the Proposed Scheme which passes through the catchment in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the northern edge of the new carriageway.
- Catchment H is intercepted approximately halfway by the new proposed junction and associated access roads. A number of smaller sub-catchments will be formed by the new junction access roads and a larger sub-catchment to the south of the Proposed Scheme. These new sub-catchments flow in a generally north to south direction.
- Catchments J and K are intercepted approximately halfway by the Proposed Scheme in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the northern edge of the new carriageway. New sub-catchments will be formed to the south of the Proposed Scheme which flow in a generally north to south direction.

- Catchments L and N are intercepted approximately halfway by the Proposed Scheme in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the southern edge of the new carriageway. New, smaller sub-catchments will be formed to the north of the Proposed Scheme which flow in a south to north direction.
- A small proportion of the southern extent of Catchment M will be intercepted by the Proposed Scheme which passes through the catchment in an east-to-west direction. Without mitigation, runoff generated from this catchment may accumulate along the southern edge of the new carriageway

6.3. Reservoir flood risk

6.3.1. The risk of flooding due to reservoir failure is very low. The Proposed Scheme would have no impact on this source of flood risk.

6.4. Groundwater flood risk

6.4.1. The assessment of groundwater flood risk (Section 5.6) indicates that, although there are no specific historic records, there is a potential risk of groundwater flooding based on an assessment of the underlying hydrogeology. Groundwater flows are interpreted to be directed towards the River Tud, where artesian groundwater conditions were encountered within the floodplain. Should any groundwater flooding occur then it is likely that water would follow existing surface water routes noted in Section 6.2 and could result in water accumulating behind embankments or other structures.

6.4.2. Structures extending below the water table, such as overbridge foundations and cuttings, could potentially impede flow and locally affect groundwater levels. Where the Proposed Scheme crosses alluvium deposits, notably at the proposed River Tud Crossing, there may be some disruption to groundwater flow.

7. Flood mitigation

7.1. River Tud compensatory flood storage

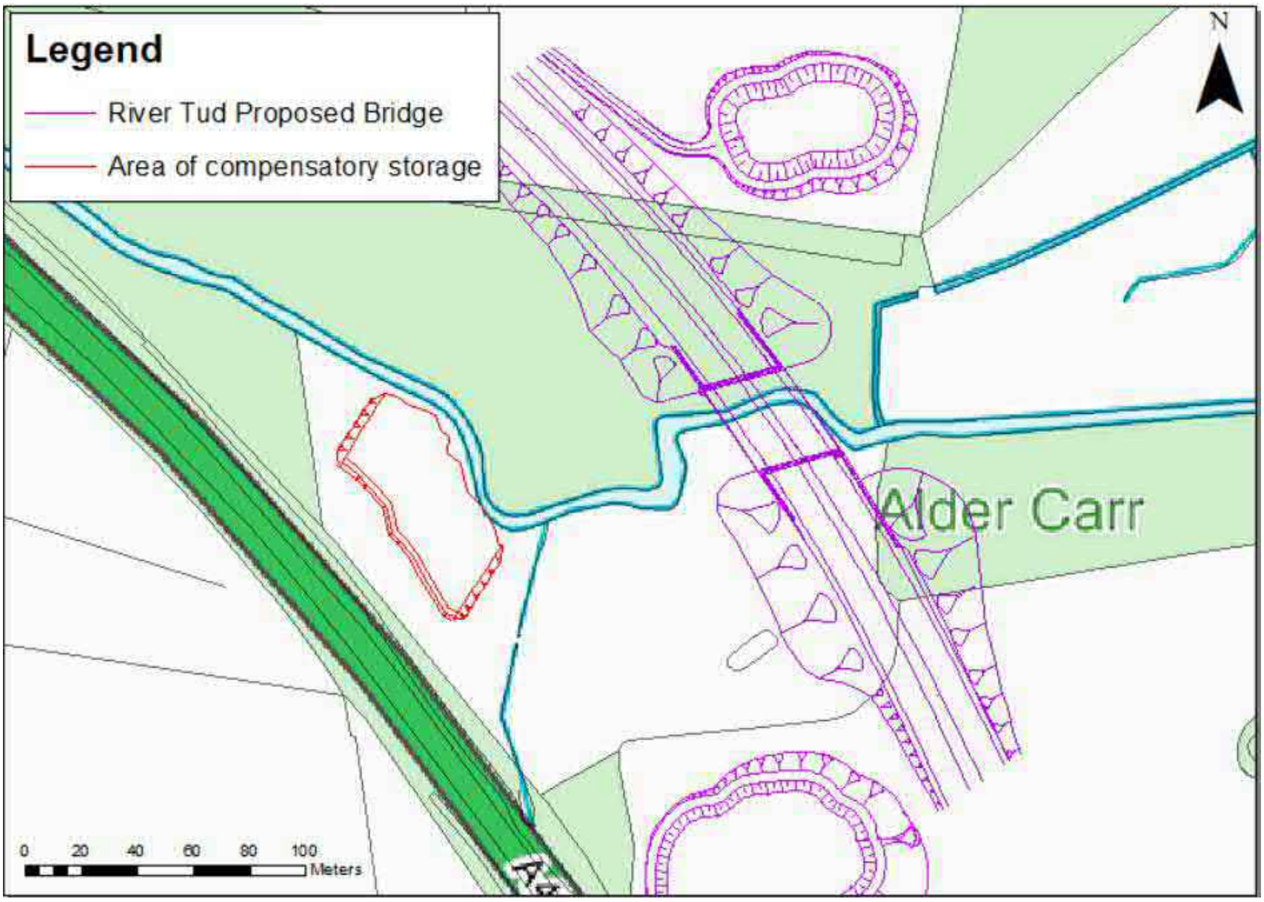
7.1.1. The abutments of the proposed River Tud Crossing overlap the floodplain of the River Tud therefore, to offset the impact, compensatory flood storage is proposed. The volume displaced has been calculated based on the peak level of 22.6m AOD found within the footprint of the abutments for the 100-year flood (with a 35% climate change allowance). This event was selected following agreement with the Environment Agency and the level was assumed to coincide with Flood Zone 3. The results shown in Table 7-1 have been divided into 20cm elevation slices. A total volume of 1277m^3 was estimated to be displaced mainly from the northern bank.

Table 7-1 Compensatory volume required per elevation contour

Elevation slice (m AOD)	Area (m^2)	Contour Interval (m)	Volume per contour (m^3)
21.8-22.0	177	0.2	35
22.0-22.2	1590	0.2	318
22.2-22.4	3295	0.2	659
22.4-22.6	1324	0.2	265
Total Volume (m^3)			**1277**

7.1.2. The area where compensatory storage is proposed can be seen in Figure 7-1 and is approximately 70m long and 28.5m wide, with the base level of 21.8m AOD and top level of 22.6mAOD. This provides a total storage volume of 1396m^3 and was identified as it was at an appropriate elevation, away from environmentally sensitive receptors and close to the area impacted. The proposal will be further reviewed at detailed design, where it will be appropriately contoured and sensitively tied into the landscape following the provision of updated topographic survey.

Figure 7-1 Location of proposed compensatory storage along the River Tud



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7.2. Oak Farm ordinary watercourse

7.2.1. The Proposed Scheme crosses the Oak Farm watercourses and overlaps an area of existing flood water accumulation upstream of the existing A47. An orifice will be placed at the inlet to the proposed culvert under the new local access road and a bund installed to retain the relocated accumulated water. This results in a net betterment in terms of flood risk (a reduction in flood depths and extents) downstream but will displace floodwater further upstream.

7.2.2. The loss of floodplain volume resulting from the widened dual carriageway and the local access road was estimated to be 2785m^3. This also includes the area between the widened dual carriageway and the new access road and was based on the 100-year (plus 35% climate change) baseline peak flood level of 44.4m AOD (as previously agreed with the Environment Agency). A summary of the estimated level for level volume lost is given in the Table 7-2 and the extent of the displaced volume is shown in Annex I.

Table 7-2 Oak Farm floodplain volume analysis

Elevation slice (m AOD)	Area (m^2)	Contour Interval (m)	Volume per contour (m^3)
43.2-43.4	82.7	0.2	16.5
43.4-43.6	233.8	0.2	46.8
43.6-43.8	902.0	0.2	180.4
43.8-44.0	2094.2	0.2	418.8
44.0-44.2	4111.5	0.2	822.3
4.2-44.4	6499.8	0.2	1300.0
Total Volume (m^3)			**2784.8**

7.2.3. The proposed bund displaces water upstream such that the provision of level for level compensatory flood storage is not feasible and would require extensive landscaping of the arable land upstream. Given that there are no sensitive receptors impacted by the Proposed Scheme, as well as the essential need to maintain the existing throttle downstream and protect the new local access road, it is proposed that no flood compensatory storage is provided. This has been agreed, in principle, with Norfolk County Council subject to the provision of more detail of the flood risk impacts within this assessment. As the need for floodplain compensation will need to be confirmed at the detailed design stage, an area of land has been identified in the DCO application in the event that floodplain compensation is later required. The landowner has been consulted with regard to the additional flood risk to their land.

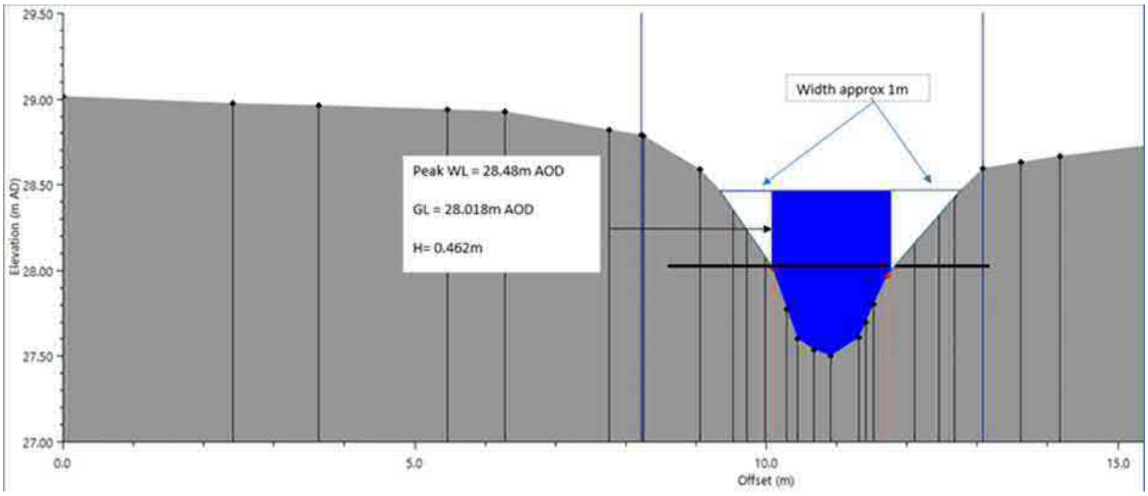
7.2.4. It should be noted that the throttling effect of the orifice ensures that there will be an increase in available floodplain volume upstream of the existing A47. For the 100-year event (without climate change) the peak volume upstream of the existing A47 was predicted to increase from 830m^3 to 3600m^3. With 35% climate change, the peak volume upstream of the existing A47 was predicted to increase from 2470m^3 to 6560m^3. The watercourse upstream of the new local access road is designated for riparian planting as well as channel restoration including re-meandering. This will provide multiple benefits including to flood risk through greater attenuation of runoff and flows upstream.

7.3. Hockering ordinary watercourse

7.3.1. The culvert south east of Hockering is not predicted to be within the floodplain of the River Tud (see Section 6). The Hockering watercourse is also not predicted to flood upstream of the new culvert. However, as the culvert is smaller in width than the extent of water within the channel for the 100-year event with a 35% climate change, there will be a small displacement of water. The amount of water displaced was calculated to be 27m^3 (see Figure 7-2). Due to the poor quality of

LiDAR within this area and the fact that cross-sections are mainly based on interpolation, an uncertainty allowance of 20% has been included in the estimate.

Figure 7-2 Baseline peak water for the 100 year event (with a 35% climate change)



7.3.2. A comparison of flows indicates that the new culvert will result in a small increase in velocities but there was not predicted to be any significant change in flows through this section of watercourse (Annex J). Given this minor impact and the small amount of volume displaced it is proposed that compensatory storage is not required. This has been agreed in principle with Norfolk County Council and the Environment Agency. A detailed topographic survey is currently being undertaken, therefore the estimated volume of floodplain storage displaced will be reviewed at detailed design.

7.3.3. Sensitivity analysis indicates that blockage is a potential risk therefore it is recommended that a trash screen be incorporated at the culvert inlet to intercept debris. The proposal will be further explored at the detailed design stage but may also include an additional horizontal overflow screen.

7.3.4. Regular maintenance and inspection of the culvert should also be prioritised. All culverts will be periodically inspected to determine their current serviceability and status in line with DMRB CS 450 (Highways England, 2020b). This will include checks on the accumulation of debris, siltation or any other factor which may restrict flows and will also include checks for water accumulation upstream of the culvert. Additional special inspections shall also be undertaken following severe rainfall events. These inspections will determine whether measures are required including the removal of debris using an appropriate method. At detailed design a debris assessment will also be undertaken.

7.4. Surface water flooding

7.4.1. The Proposed Scheme, through the construction of new carriageway, will result in an increase in impermeable area. To ensure that this does not increase peak runoff rates and detrimentally impact flood risk an appropriate drainage strategy has been proposed. Further details can be found in the Drainage Strategy (Volume 3, Appendix 13.2 of the Environment Statement).

7.4.2. All road drainage will drain to the River Tud or its tributaries at 12 locations, utilising nine new surface water outfalls. Prior to entering the watercourse, the runoff from the new outfalls will be directed through filter drains and attenuated using vegetated detention basins or wetlands. Flow control device such as hydrobrakes and orifice plates will also be used in order to reduce the peak flows to the outfall locations. The proposed drainage has been designed for the 100-year pluvial event (with a 40% climate change allowance) and outflows will be limited to the calculated greenfield runoff rate at the outfalls.

7.4.3. Several sections of the Proposed Scheme will tie-in to the existing drainage, which is assumed to discharge to the River Tud or its tributaries. Without mitigation, this could increase flood risk to these parts of the existing drainage network. The runoff from the road will be attenuated via flow controls and oversized pipes which will limit the impact on the existing drainage system.

7.4.4. The Proposed Scheme intercepts several surface water flow pathways and natural catchments noted in Sections 6.2. The proposed post development catchment plans can be found in Annex K. The existing flow pathways have been maintained via appropriately designed collection drains and cross-drains, also known as ‘dry culverts’. The contributing areas and peak flows for these surface water pathways have been estimated and dry-culverts designed to convey a 100-year flow including a 65% climate change allowance. These will ensure that surface water does not accumulate behind embankments and increase flood risk on the site or elsewhere.

7.4.5. A detailed topographic survey is scheduled which will confirm the correct location of the surface water pathway routes and inform the design of the ‘dry culverts’.

7.5. Groundwater flooding

7.5.1. The assessment of groundwater flood risk (Section 5.6) indicates that, although there are no specific historic records, there is a potential risk of groundwater flooding based on an assessment of the underlying hydrogeology. Should any groundwater flooding occur then it is likely that water would follow existing surface water routes which will be maintained using cross drains or ‘dry culverts’. These have been designed to accommodate high surface water peak flows and account for baseflow, hence it is assumed that they would be able to accommodate flows generated via groundwater flooding.

7.5.2. To reduce the impact below ground structures shall be appropriately designed to minimise the disruption of groundwater flows. This includes careful consideration of any ground improvement works, which, if required, must have appropriately selected fill material for working in saturated ground, thus allowing groundwater to dissipate in a controlled manner. The proposed bridge structure for the River Tud crossing will also be designed to minimise disruption to groundwater flows to the river. Piling and ground improvement design shall also ensure appropriate methods are selected to prevent creation of pathways for artesian groundwater to rise to surface.

7.5.3. Cuttings may require permanent slope drainage where intersecting shallow or perched groundwater. This water will be partially returned to the catchment via filter drains incorporated into the drainage design.

8. Construction related flood risk impacts and mitigation

8.1. Construction related flood risk

8.1.1. This section details the potential impacts on flood risk to the Proposed Scheme and elsewhere during the construction phase. Further information is available in the Environmental Statement, Chapter 2 (The Proposed Scheme).

8.1.2. During construction there will be an increase in new hardstanding areas, including the main site, satellite and material storage compounds, which, if not mitigated, will increase the flow rate and volume of runoff from the construction areas. This could result in the increased localised flooding to the Proposed Scheme and other flood-sensitive downstream receptors. Additionally, this could adversely impact upon surface water features such as unnamed ordinary watercourses, ditches and ponds, and tributaries of the River Tud.

8.1.3. During construction, there is an increased risk of flooding during and following extreme rainfall events, including those areas identified as at risk of surface water flooding and where surface water flow pathways may cross areas of construction activities. Works may lead to temporary changes in the surface water runoff regime by the alteration of ground elevations, diversion of drainage ditches, alteration of overland flow pathways or the construction of new structures. This could cause localised flooding to the Proposed Scheme and nearby receptors due to changes in surface water flood flow pathways. Indirectly, overloading of the temporary drainage system could adversely impact on surface water features. This could include local watercourses, ditches and ponds, due to overloading of the potential flood flow pathway connection.

8.1.4. Increased flood risk as a result of the construction activities could also result in the mobilisation of sediments and other contaminants which would adversely impact on surface water features. The River Tud is sensitive to sediment input and any temporary sediment pollution incidents are likely to have a long-term impact on the river (ES Appendix 13.5 Geomorphological assessment).

8.2. Mitigation of construction related flood risk

8.2.1. This section sets out the proposed mitigation to ensure the construction phase of the Proposed Scheme is not at significant flood risk nor does it pose additional flood risk elsewhere.

8.2.2. During construction, best practice methods for mitigation of temporary flood risk to and from the Proposed Scheme will be implemented as part of the wider Environmental Management Plan (EMP) (**TR010038/APP/7.4**).

8.2.3. There are construction activities planned immediately adjacent to a main river, the River Tud. As such, a Flood Risk Activity Permit from the Environment Agency will be required. There are also construction activities planned immediately adjacent to, and within, a number of ordinary watercourses or drainage ditches. As such, consent from Norfolk County Council (as Lead Local Flood Authority) will be required. In addition, land drainage consent from Norfolk River Internal Drainage Board will be required for any areas managed by the drainage board.

8.2.4. A temporary works drainage strategy must be specified within the EMP and this will include measures to attenuate runoff from construction sites, compounds and material lay down areas; this will be informed by the Drainage Strategy (ES Appendix 13.2) (**TR010038/APP/6.3**) and this assessment. In addition, the temporary works drainage strategy shall propose how flood risk from surface water flow pathways will be managed. Discharges to surface water or ground must only be made with the appropriate consents or permits in place and infiltration features will be suitably designed considering local ground conditions.

8.2.5. The compaction of soils, alteration of ground levels, alteration of overland flow pathways and increases in hardstanding areas during construction have the potential to impact on flood risk. This shall be managed by the implementation of a construction-phase drainage system which will include cross-drains where overland flow pathways are intercepted by construction activities. Where practicable, the Proposed Scheme drainage shall be constructed in the early phases of the project.

8.2.6. SuDS shall be implemented as part of the temporary works drainage strategy to attenuate runoff to existing rates and avoid contamination of water receptors. Sediment management measures must be implemented to ensure sediment discharges to surface water features are limited to background concentrations.

8.2.7. To avoid the mobilisation of sediments and other contaminants that may detriment downstream surface water receptors, materials including, but not limited to, exposed soil, fuels, oils, chemicals, wastewater and concrete or cement admixtures, shall not be stored in areas of medium, high or very high flood risk area as defined in this assessment.

8.2.8. A flood emergency response plan must be developed as part of the temporary works drainage strategy within the EMP to manage the flood risk impacts during construction and to ensure construction workers are not exposed to increased levels. The Site shall sign up to the Environment Agency’s flood alerts (The Rivers Tud and Wensum from Fakenham to Costessey, including Wendling Beck) and flood warnings service (The River Tud from East Dereham to New Costessey) (Environment Agency, 2020g). The flood emergency response shall specify safe access and egress routes for all construction areas in the event of anticipated flooding.

8.2.9. Given the above mitigation, it is anticipated that the Proposed Scheme will be at a low risk of flooding during construction and will not cause an increase in flood risk elsewhere.

9. Sequential and Exception Test

9.1.1. The Sequential Test aims to steer development away from areas of high flood risk to areas of lower flood risk. The Proposed Scheme is mainly located within Flood Zone 1, however, the proposed River Tud Crossing to the east of Honingham and a section of the route close to Hockering intersects Flood Zone 3.

9.1.2. The Proposed Scheme is an upgrade to the A47 and therefore needs to run close to, or be built over, the existing road. As part of the route option selection assessment several route options were reviewed and the route of the Proposed Scheme was considered to have the least impact on flood risk and the water environment. The preferred route announcement was made in 2017 and, as such, the Proposed Scheme meets the requirements of the Sequential Test.

9.1.3. In terms of flood risk vulnerability, the Proposed Scheme is classified as essential infrastructure. Section 5 indicated that part of the Proposed Scheme is within Flood Zone 3b hence, in accordance with Table 3 of the NPPF PPG on flood risk and coastal change (Table 9-1), an Exception Test has been applied.

Table 9-1 Flood Risk Vulnerability and Flood Zone Compatibility - NPPF Guidance

	Flood Risk Vulnerability Classification				
Flood Risk Zone	Essential Infrastructure	Highly Vulnerable	More Vulnerable	Less Vulnerable	Water Compatible
Zone 1	✓	✓	✓	✓	✓
Zone 2	✓	Exception Test required	✓	✓	✓
Zone 3a †	Exception Test required †	×	Exception Test required	✓	✓
Zone 3b*	Exception Test required*	×	×	×	✓ *

Key	
✓	Development is appropriate
×	Development should not be permitted
†	In Flood Zone 3a essential infrastructure should be designed and constructed to remain operational and safe in times of flood
*	In flood zone 3b (functional floodplain) essential infrastructure that must be there and has passed the Exception Test, and water-compatible uses, should be designed and constructed to: - Remain operational and safe for users in times of flood; - Result in no net loss of floodplain storage; - Not impede water flows and not increase flood risk elsewhere.

9.2. The Exception Test

9.2.1. The Exception Test is composed of two parts. Firstly, it must be demonstrated that the sustainability benefits of the development to the community outweigh the flood risk. Secondly, the Proposed Scheme will need to be safe for its lifetime, accounting for the vulnerability of its users, and should not increase flood risk elsewhere.

9.2.2. In terms of the first point, this section of A47 road is currently at capacity and unable to cope with the high traffic volume and there are limited opportunities to overtake slower vehicles on the single carriageway. The Proposed Scheme aims to reduce congestion, improve safety, improve journey times and increase the overall capacity of the A47. This will in turn provide multiple socio-economic benefits for communities and businesses within the wider area. The Proposed Scheme also provides a range of environmental benefits which are detailed within the Environmental Statement (**TR010038/APP/6.1**) and the Environmental Masterplan (**TR010038/APP/6.8**).

9.2.3. The analysis outlined in Section 6 demonstrates that most of the Proposed Scheme is outside of the 100-year flood extent (65% climate change allowance) of the River Tud. The only component within this zone is the proposed River Tud Crossing east of Honingham and, as the road deck will be over 2m above the predicted peak water level, there is negligible flood risk to users. Similarly, several measures have been incorporated into the design of the culverts at the ordinary watercourses including the use of an orifice, a flood bund and trash screens which will ensure that the Proposed Scheme is safe for its lifetime. As such the benefits of the Proposed Scheme are considered to outweigh the flood risk.

9.2.4. The flood risk assessment including the hydraulic modelling demonstrates that the Proposed Scheme will not increase flood risk elsewhere. The River Tud Crossing along the River Tud is predicted to increase water levels, however, the extent of impact is limited, and no sensitive receptors are predicted to be affected. As part of the Proposed Scheme, compensatory storage is proposed to offset the displacement of water associated with the abutments of the River Tud Crossing. At the Oak Farm watercourse, the use of an orifice and flood bund is predicted to provide a net betterment in terms of flood risk downstream.

9.2.5. An appropriate drainage strategy (ES Appendix 13.2) (**TR010038/APP/6.3**) is summarised in Section 6.2 which includes the use of SuDS and 'dry culverts' or cross drains in order to maintain continuity of surface water flow pathways where they are intercepted by the Proposed Scheme. This will minimise the risk of surface water accumulating behind the proposed road and minimise flood risk to others. All areas of proposed highway drainage will be attenuated to greenfield runoff rates and runoff rates from existing highway drainage will not increase. Thereby, avoiding any increase is surface water runoff rates and flood risk impacts, as part of the Proposed Scheme.

9.2.6. The above demonstrates that the Proposed Scheme will provide multiple sustainability benefits. The use of appropriate drainage and several mitigation measures including compensatory storage, a flood bund and an orifice and trash screens will minimise any residual flood risk to others. The design is therefore, considered to meet the requirements of the Exception Test.

9.2.7. It is considered the Proposed Scheme meets the requirements of the NPS NN section 5.94.

10. Conclusion

10.1.1. The Tuddenham to Easton Dualling Proposed Scheme runs adjacent to the River Tud. A new bridge over the River Tud is proposed to the east of the Honingham and, where the Proposed Scheme crosses two ordinary watercourses south east of Hockering and at Oak Farm, new culverts will be required.

10.1.2. To assess the existing flood risk and the impact of the Proposed Scheme hydraulic models were constructed of the River Tud and the two minor watercourses. The modelling of the River Tud demonstrated that the abutments of the bridge are the only part of the Proposed Scheme which overlap the 100-year flood extent. The abutments intercept and funnel floodwaters back into the channel resulting in an increase in water levels. This increase was negligible within Honingham and no sensitive receptors are affected.

10.1.3. The soffit of the bridge has a freeboard greater than 600mm above the 100-year (65% climate change allowance) water level. To offset the 1277m^3 of floodwater displaced by the bridge abutments, compensatory storage is proposed along the right bank (looking downstream) upstream of the River Tud Crossing.

10.1.4. The model of the Oak Farm watercourse predicts flooding upstream of the existing A47 where the proposed new access road will be located. To mitigate this, an orifice will be placed at the inlet to the access road culvert to throttle flows and a bund installed to prevent flooding of the road. Post development modelling indicated that this would provide a net betterment in terms of flood risk downstream and that the bund is sufficiently sized and resilient to blockage without overtopping. The model also demonstrated that the new local access road would not be flooded and no sensitive flood risk receptors will be impacted for the H++ scenario (100-year event with 80% climate change allowance).

10.1.5. As the Oak Farm design will not result in a reduction of the total flood volume upstream of the A47 and, given the impact of landscaping works on the arable land upstream, the need to limit forward flows and protect the road, compensatory storage is not considered suitable. This has been agreed, in principle, with Norfolk County Council. However, the need for floodplain compensation will need to be confirmed at the detailed design stage, so an area of land has been identified in the DCO application in the event that floodplain compensation is later required.

10.1.6. For the Hockering watercourse floodwaters are predicted to remain within the channel in the area of interest. The proposed culvert has over 600mm freeboard for the 100-year design event (including a 65% climate change allowance) and has a negligible impact on flows. The design is sensitive to blockage hence maintenance of the culvert must be prioritised, and a trash screen installed.

10.1.7. Other sources of flooding were also investigated. The Proposed Scheme is beyond the tidal limit of the River Wensum so there is no risk of tidal flooding. There is also no evidence of flooding from sewerage and water main infrastructure having affected the route of the Proposed Scheme and the risk of reservoir failure is very low.

10.1.8. The Proposed Scheme will increase the amount of impermeable area, and hence runoff rates. To mitigate this, SuDS features are proposed as part of the drainage strategy to treat and attenuate surface water runoff. Furthermore, interceptor drains or ‘dry culverts’ will be installed to maintain continuity of existing overland surface water flow pathways where they are intercepted by the Proposed Scheme and ensure that surface waters are not able to accumulate and are directed away from the site, thereby preventing flooding.

10.1.9. A review of the underlying geology suggests that there may be a moderate risk of groundwater flooding, particularly where alluvium deposits are present. Should any groundwater flooding occur this would likely follow existing overland flow pathways. Since these have been maintained via culverts, the risk of increased groundwater flooding affecting the road is low.

10.1.10. It is considered that the Proposed Scheme meets the requirements of the Exception Test and the flood risk requirements of the NPS NN section 5.94.

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Annex A. Environment Agency Flood Zone maps

Figure 11-1 Environment Agency Fluvial Flood Zones for western part of the Proposed Scheme

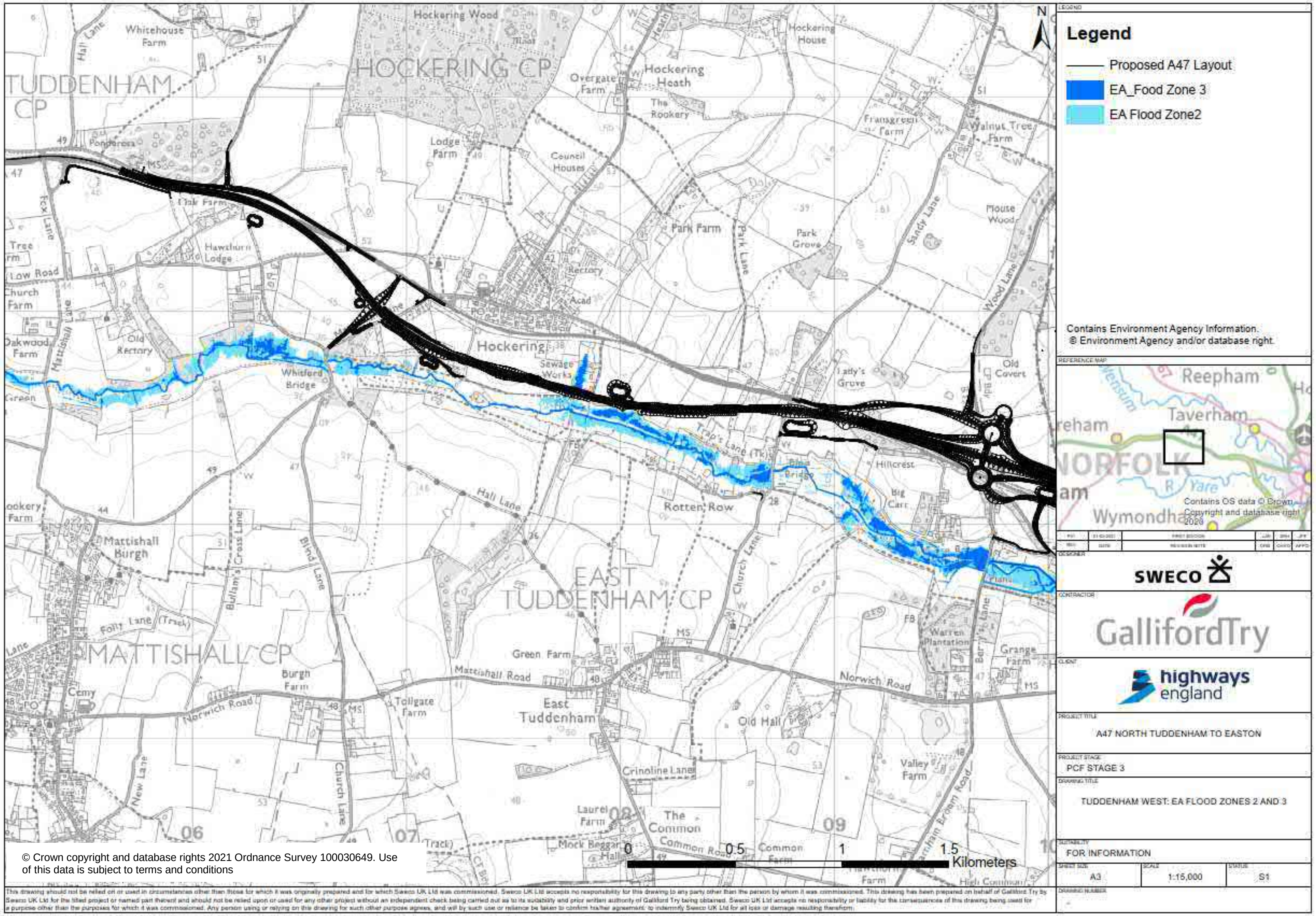
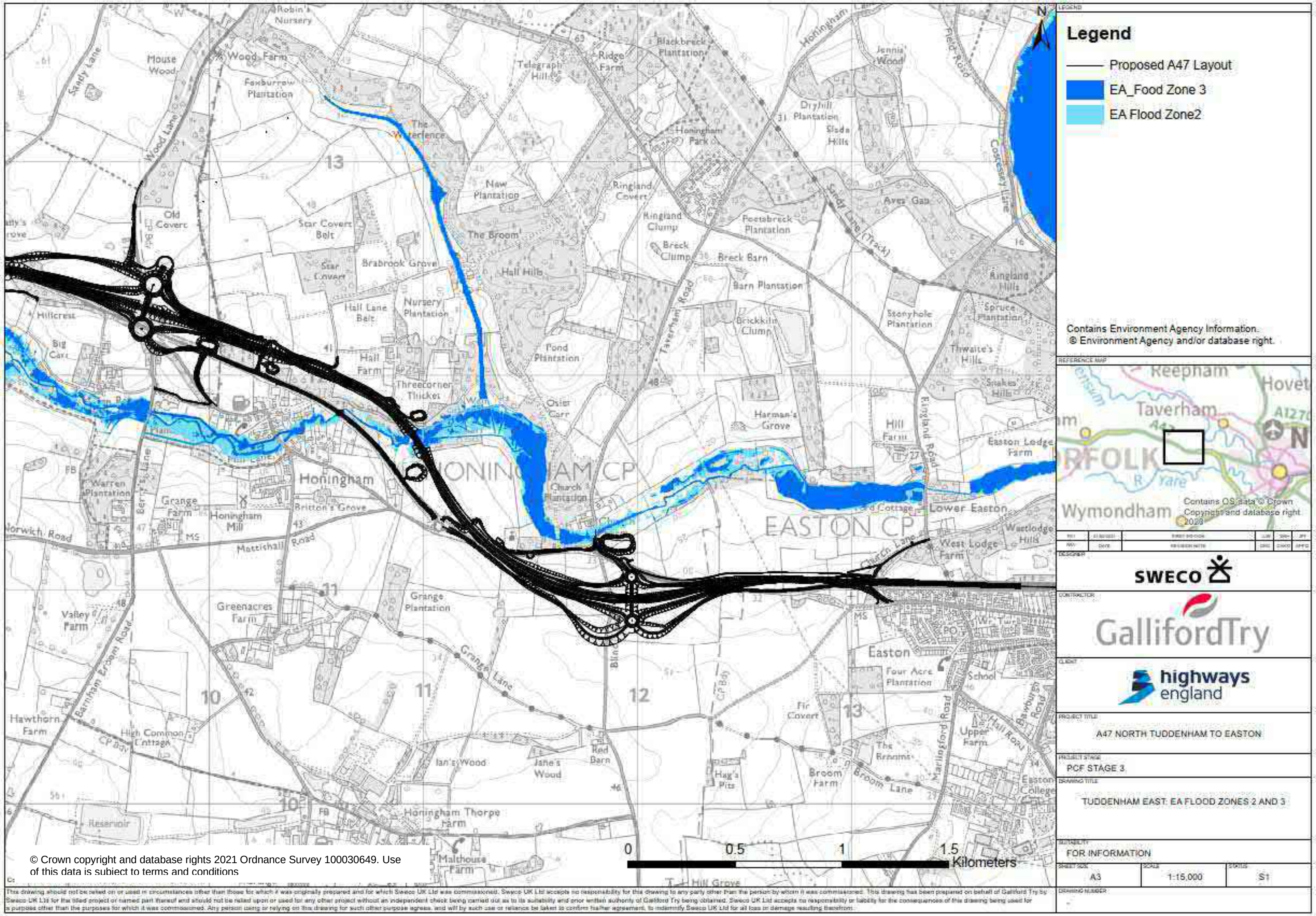


Figure 11-2 Environment Agency Fluvial Flood Zones for eastern part of the Proposed Scheme



Annex B. Surface water flood risk maps

Figure 11-3 Environment Agency Pluvial Flood extent for the western part of the Proposed Scheme

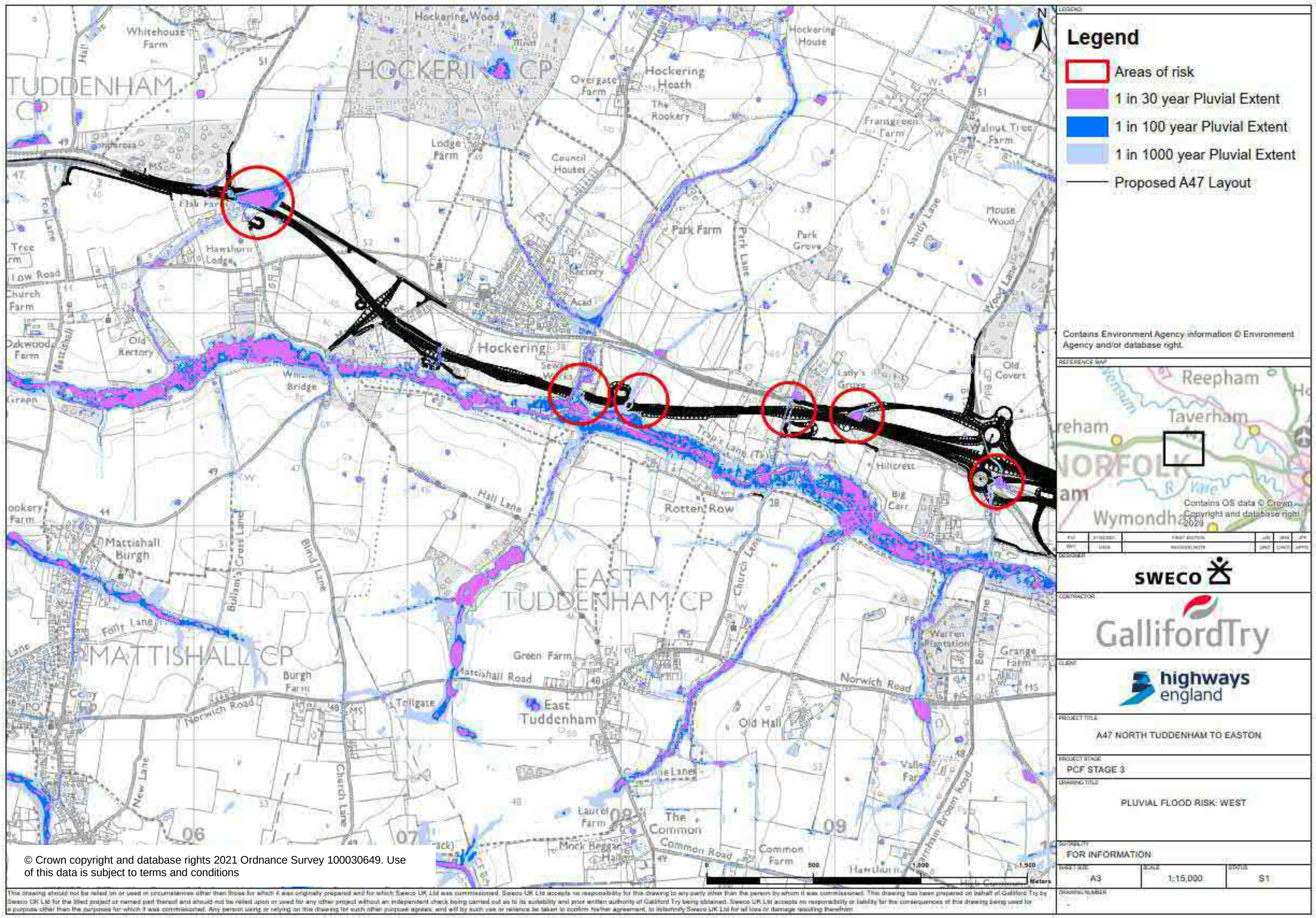
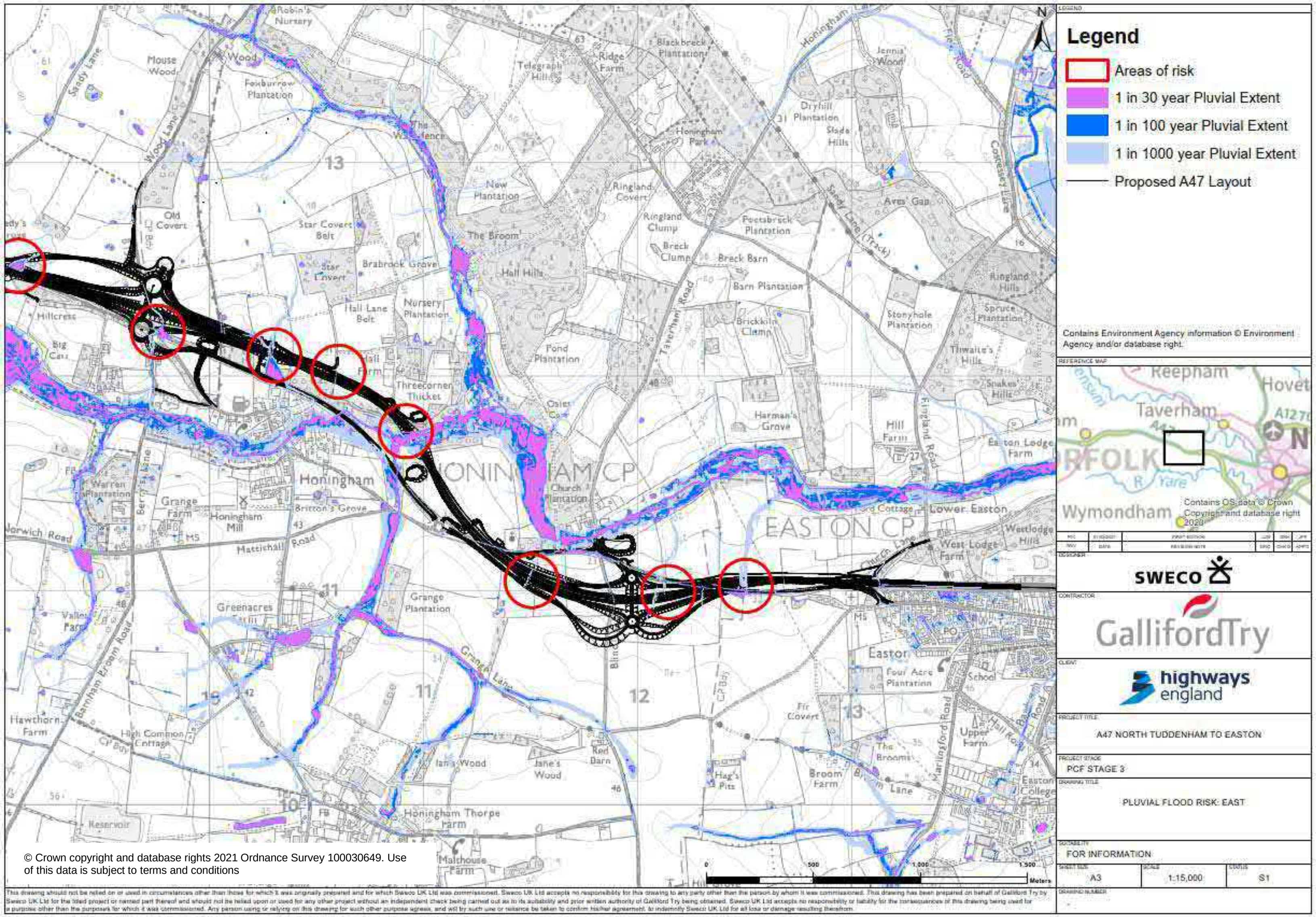


Figure 11-4 Environment Agency Pluvial Flood extent for the eastern part of the Proposed Scheme



Annex C. Groundwater flood susceptibility map

Figure 11-5 BGS groundwater susceptibility map for the western part of the Proposed Scheme

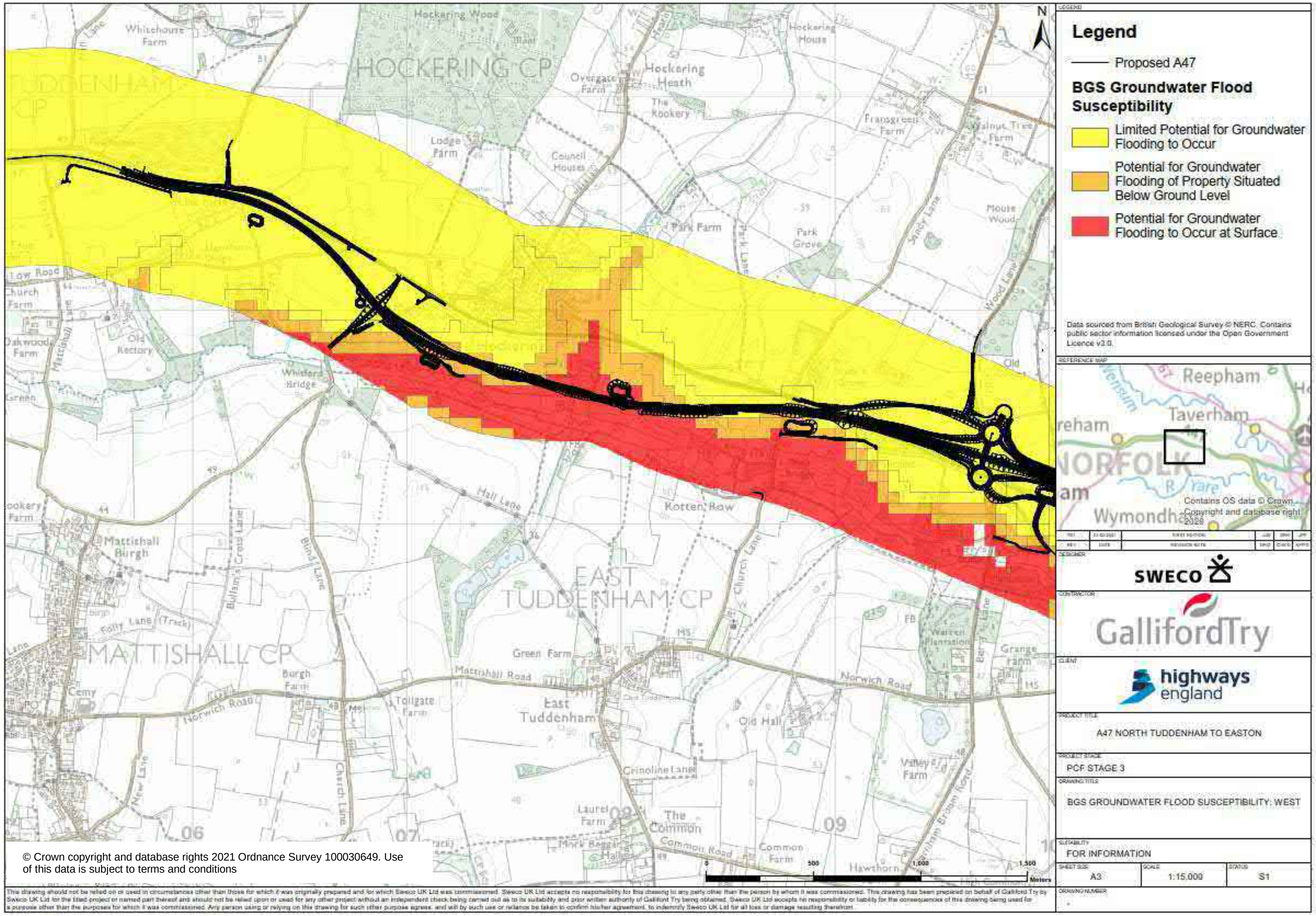
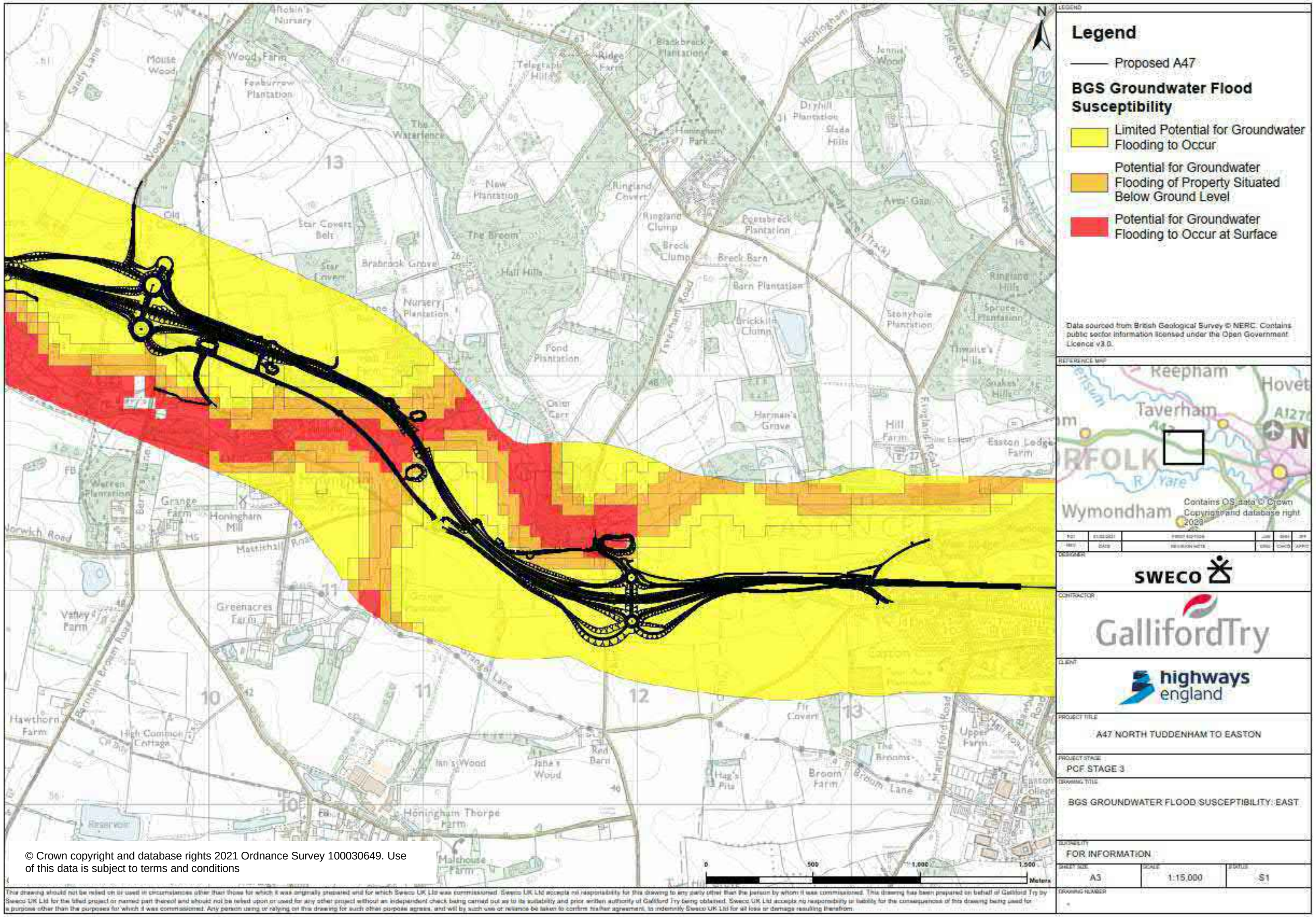


Figure 11-6 BGS groundwater susceptibility map for the eastern part of the Proposed Scheme



Annex D. River Tud baseline flood mapping

Figure 11-7 Baseline: Flood Extent (west)

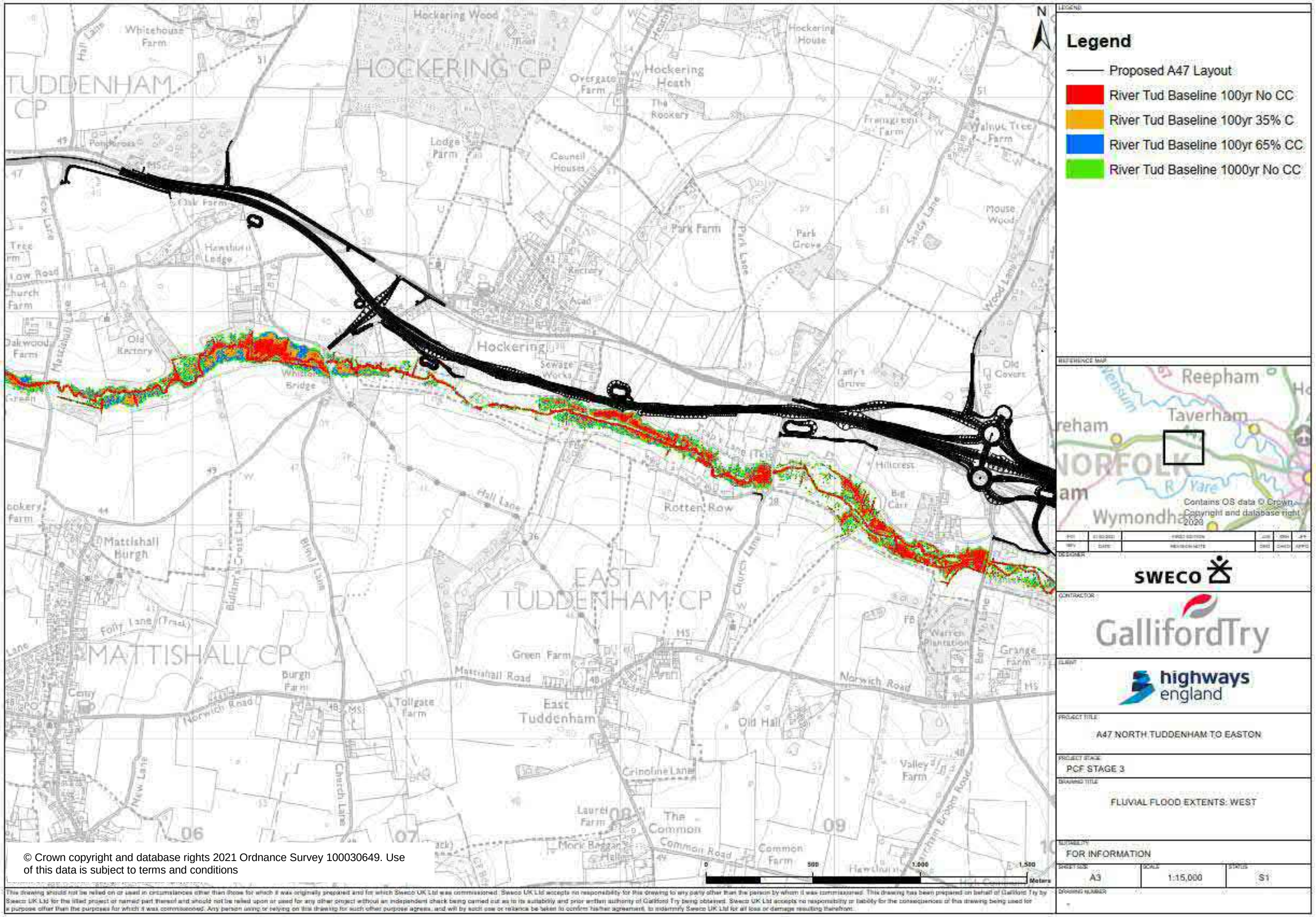


Figure 11-8 Baseline: Flood Extent (east)

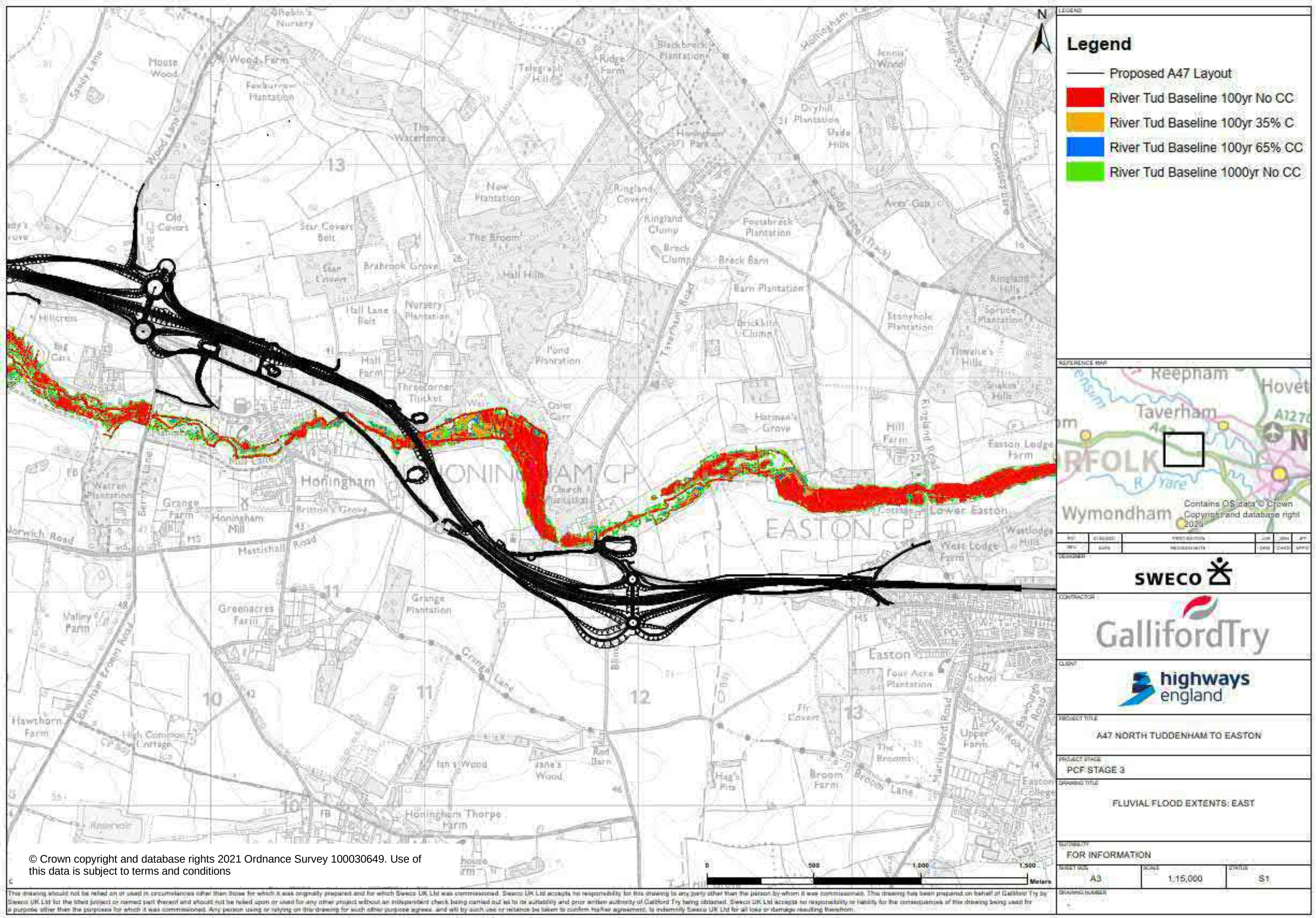


Figure 11-9 Baseline 100-year flood map (no climate change) flood map

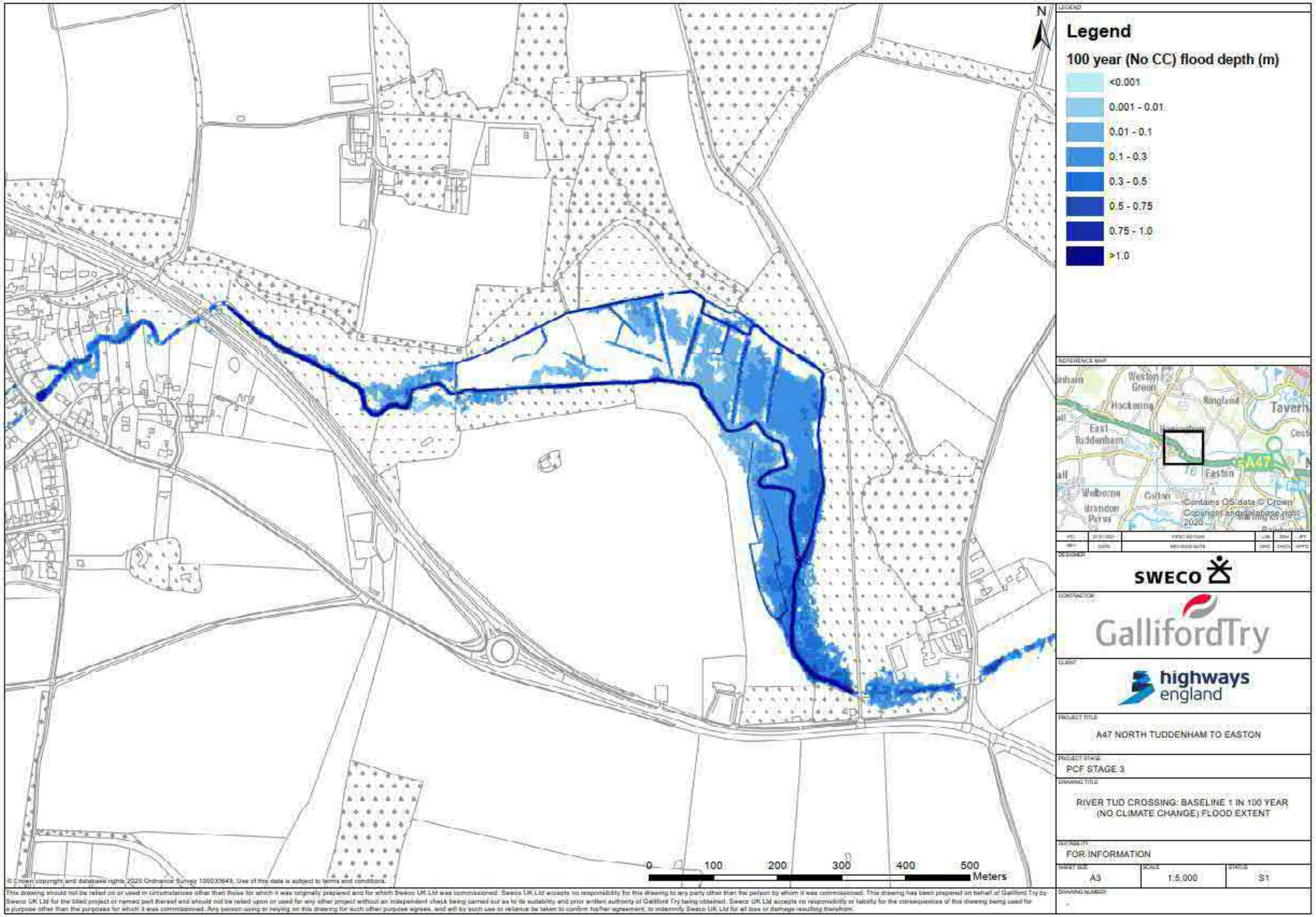


Figure 11-10 Baseline: 100-year (65% climate change) flood map

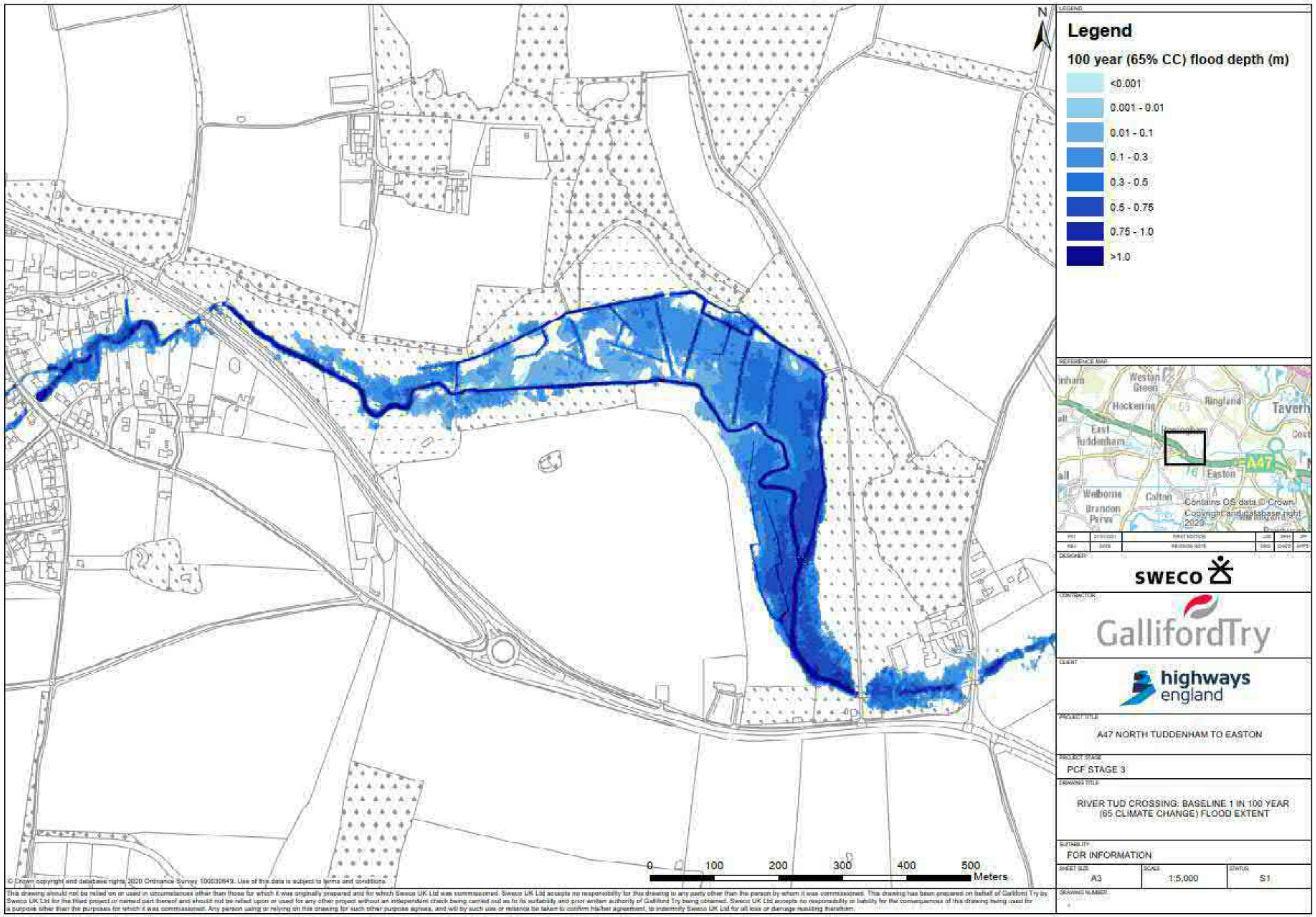
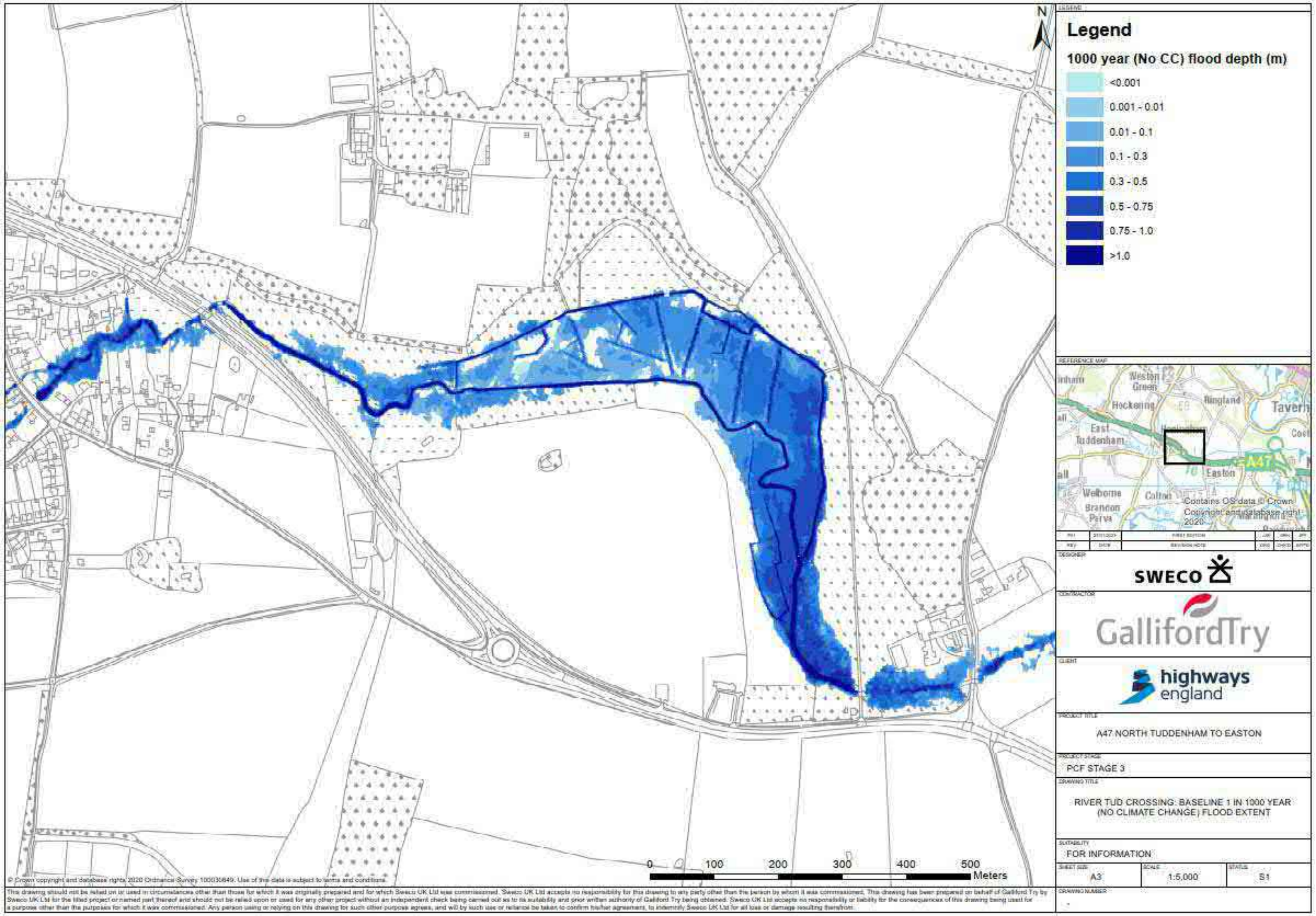


Figure 11-11 Baseline 1000-year (No climate change) flood map



Annex E. River Tud post development maps

Figure 11-12 Post Development 100-year (no climate change) flood map

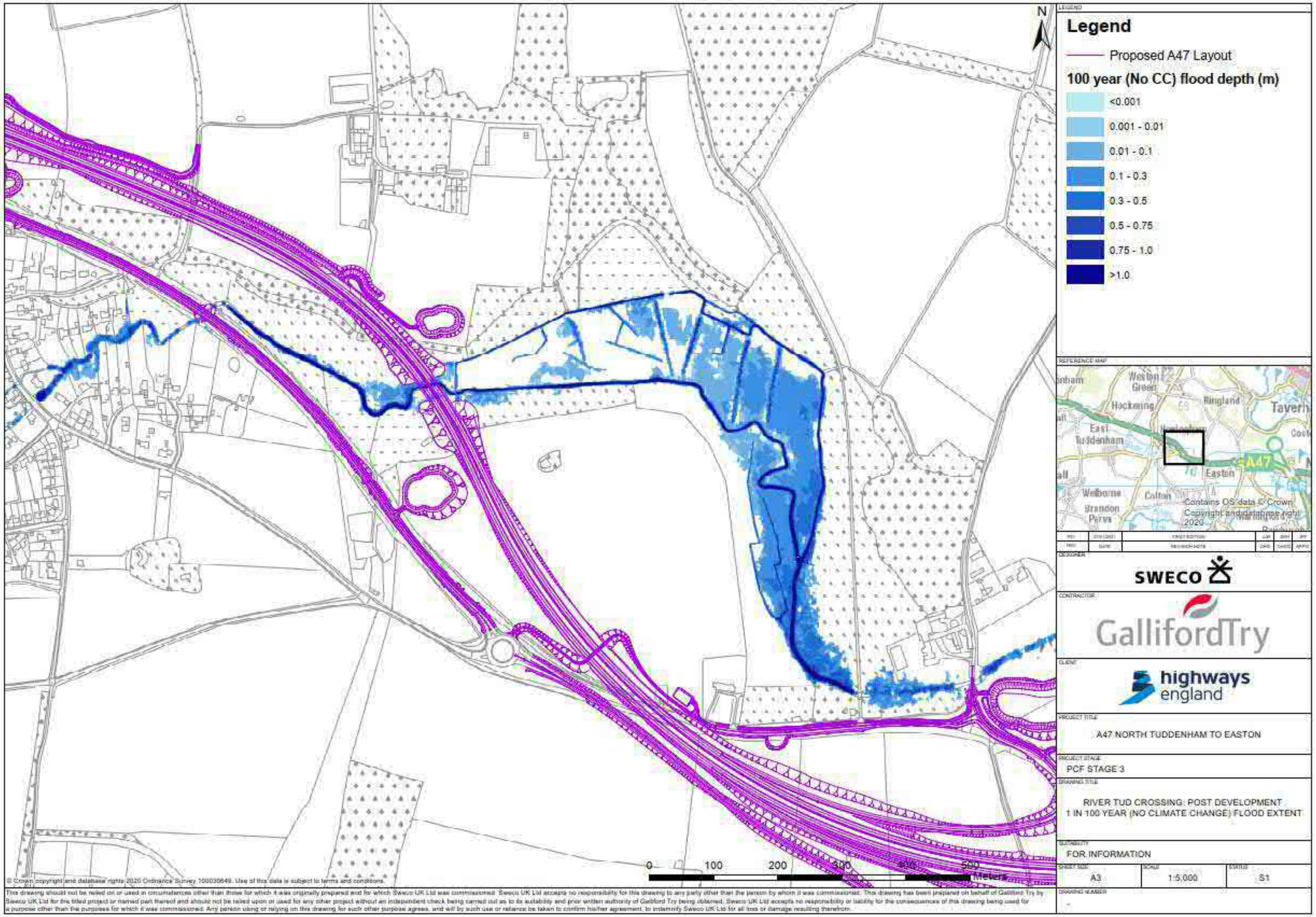


Figure 11-13 Post development 100-year (65% climate change) flood map

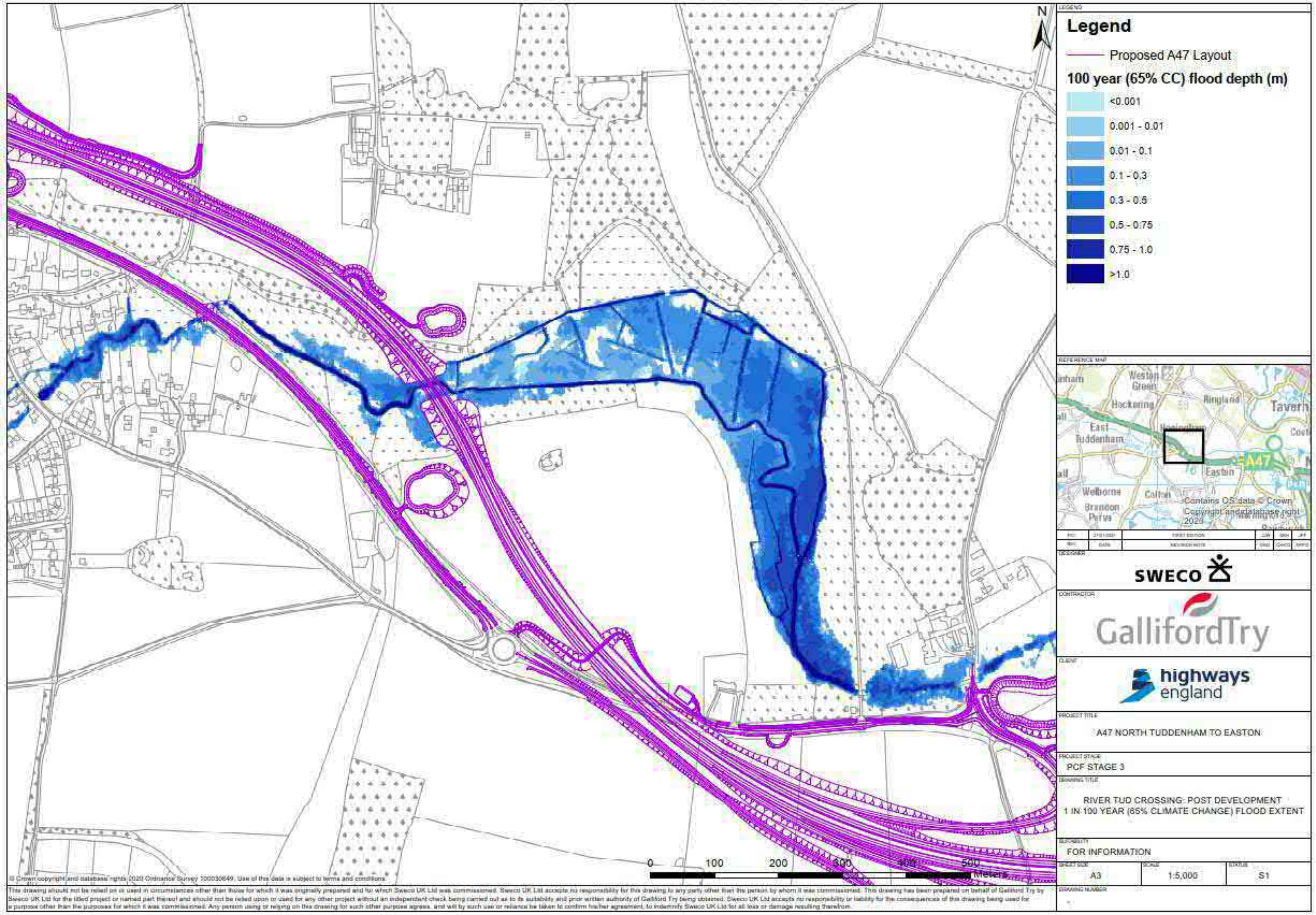
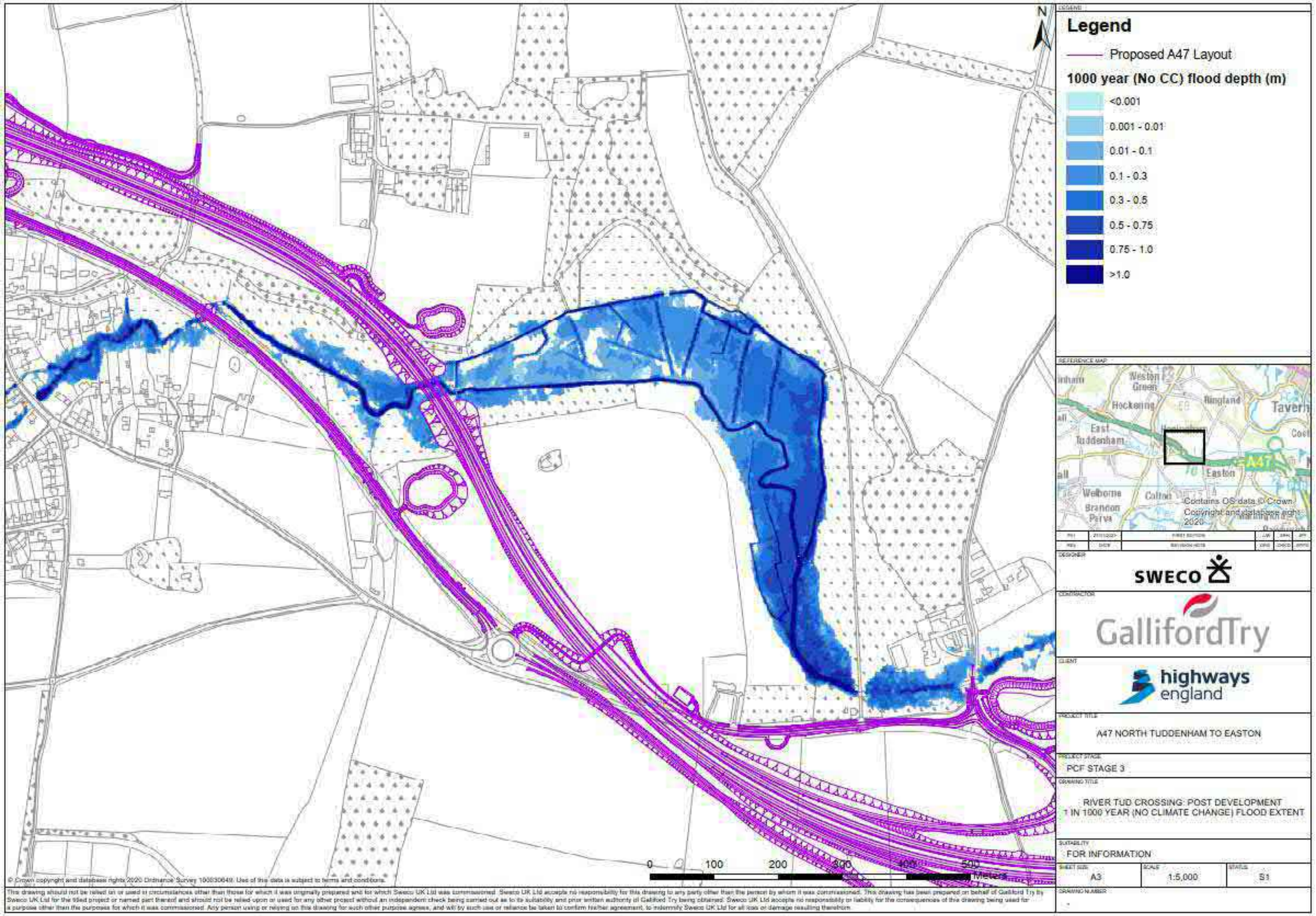


Figure 11-14 Post-development 1000-year (no climate change) flood map



Annex F. River Tud depth difference maps

Figure 11-15 100-year depth difference map

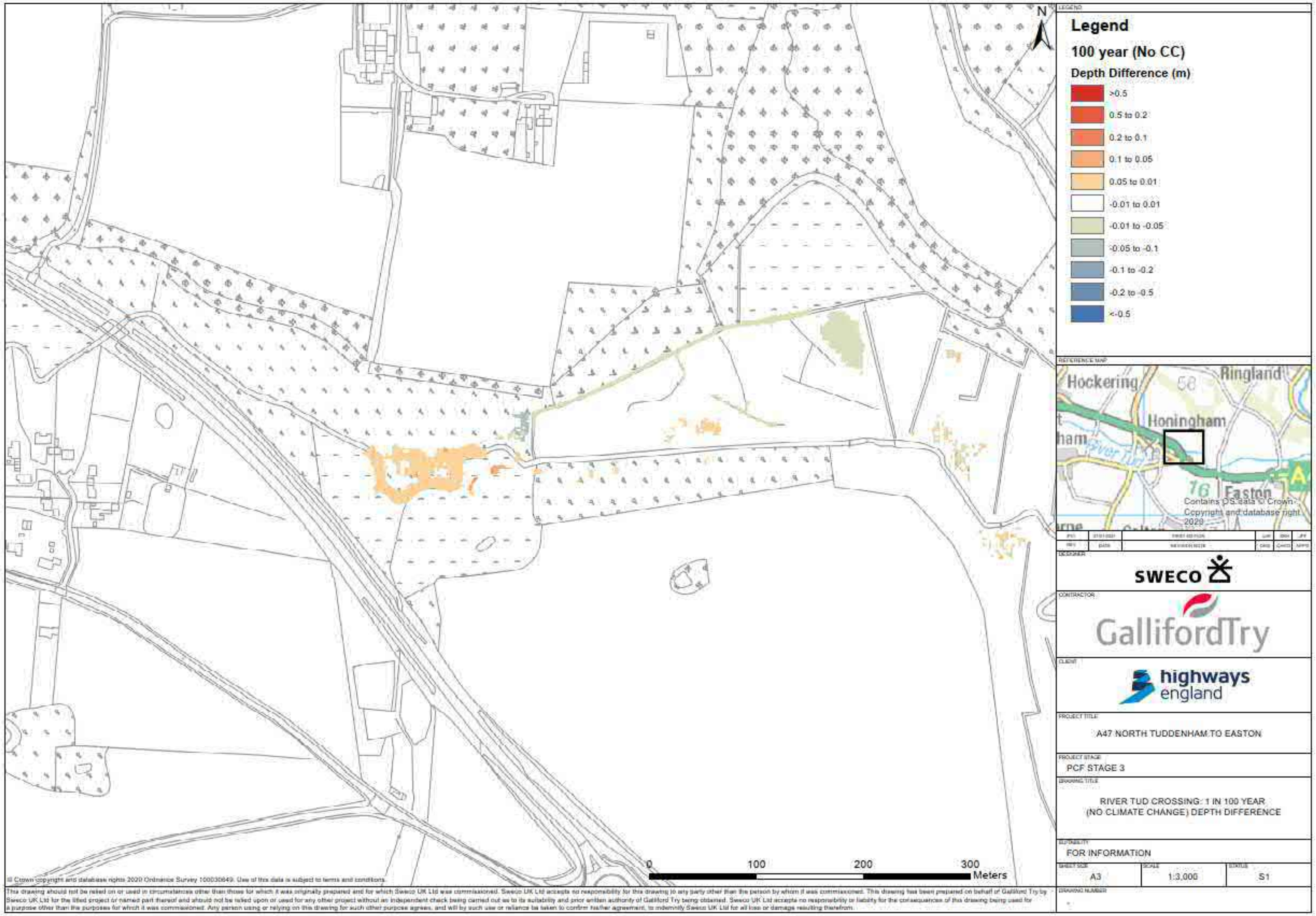
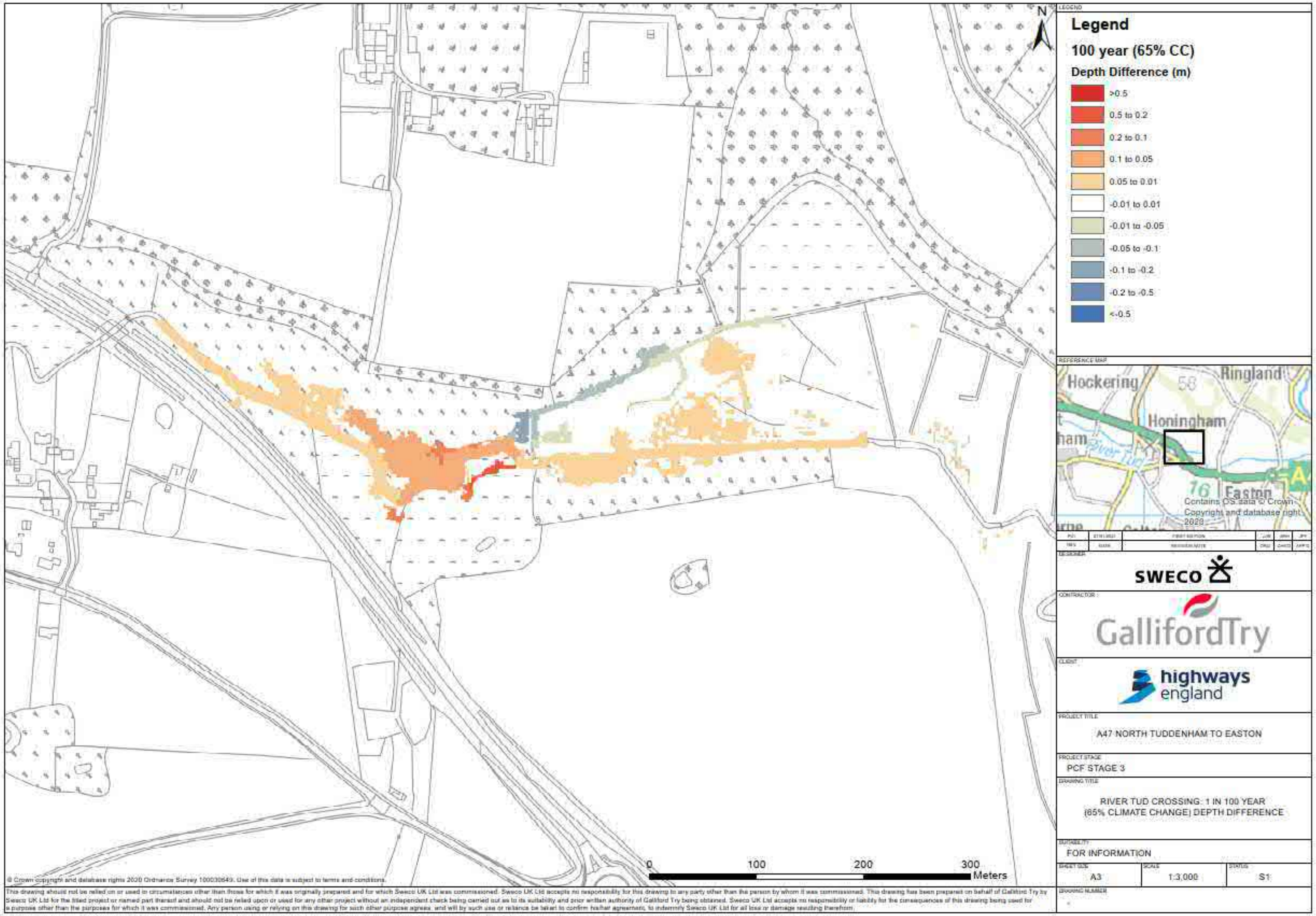


Figure 11-16 100-year (65% climate change) depth difference map



Annex G. Oak Farm baseline flood and hazard maps

Figure 11-17 Baseline: 100-year (No climate change) flood extent

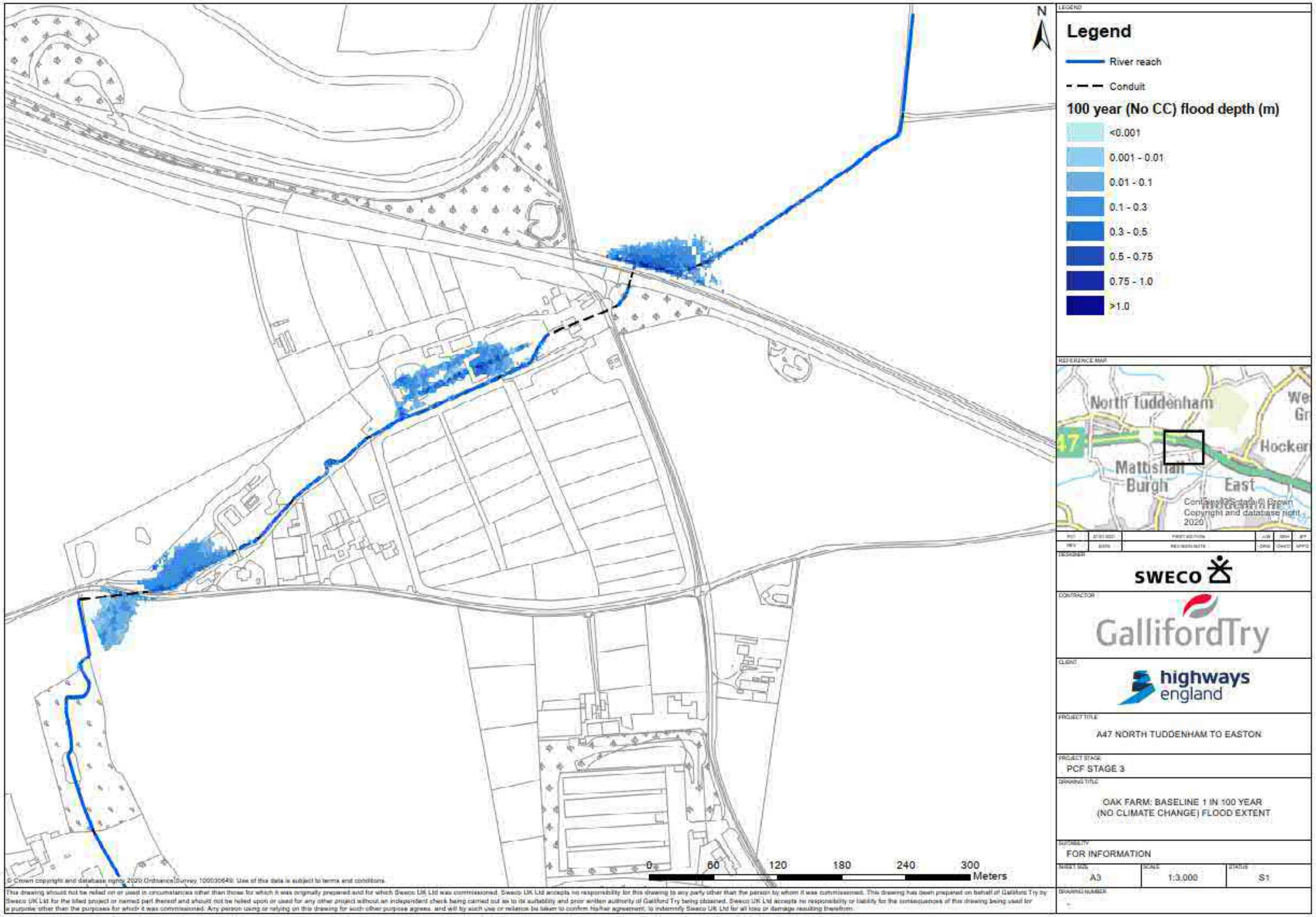


Figure 11-18 Baseline 100 year (No climate change) hazard map

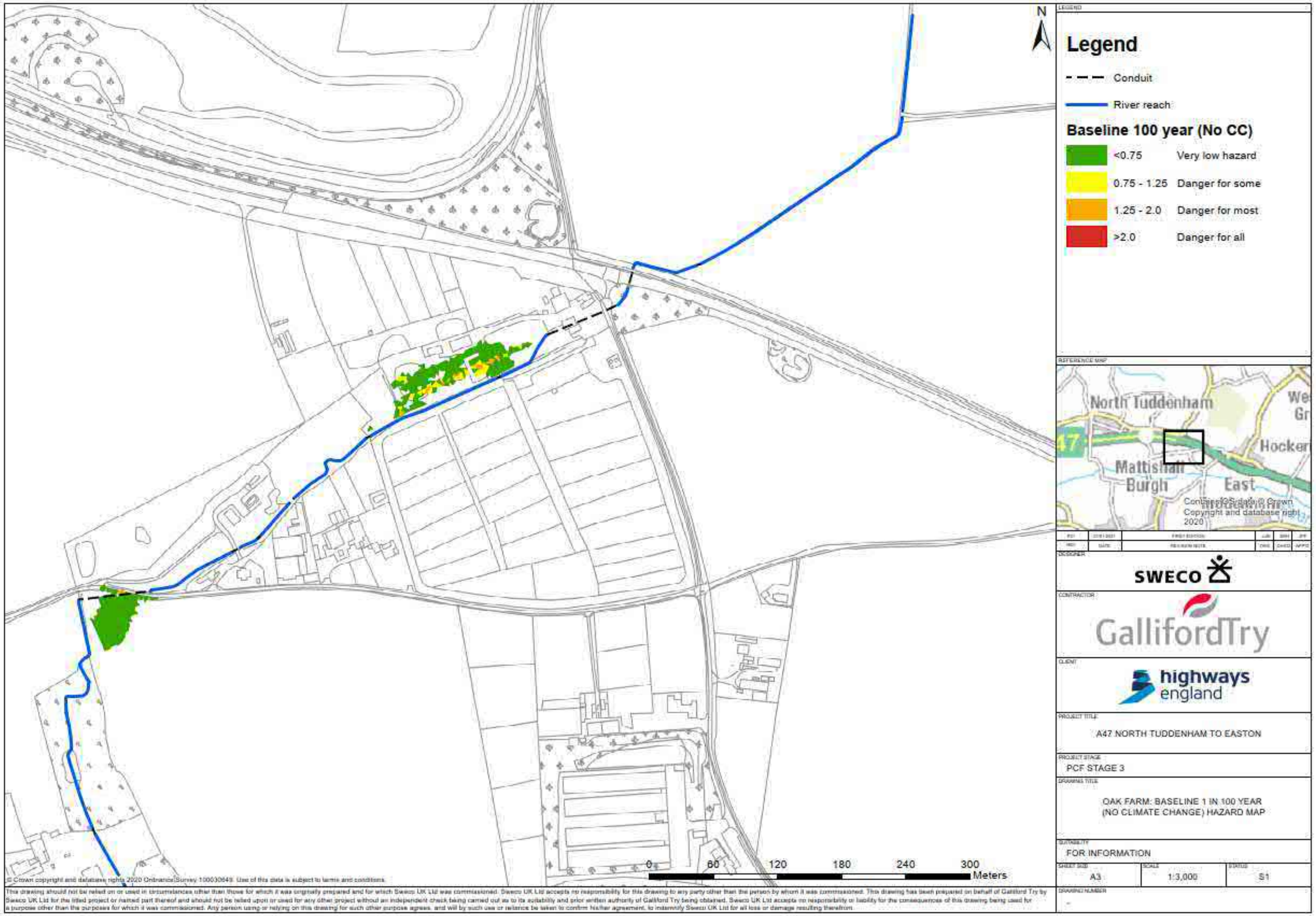


Figure 11-19 Baseline: 100-year (65 climate change) flood map

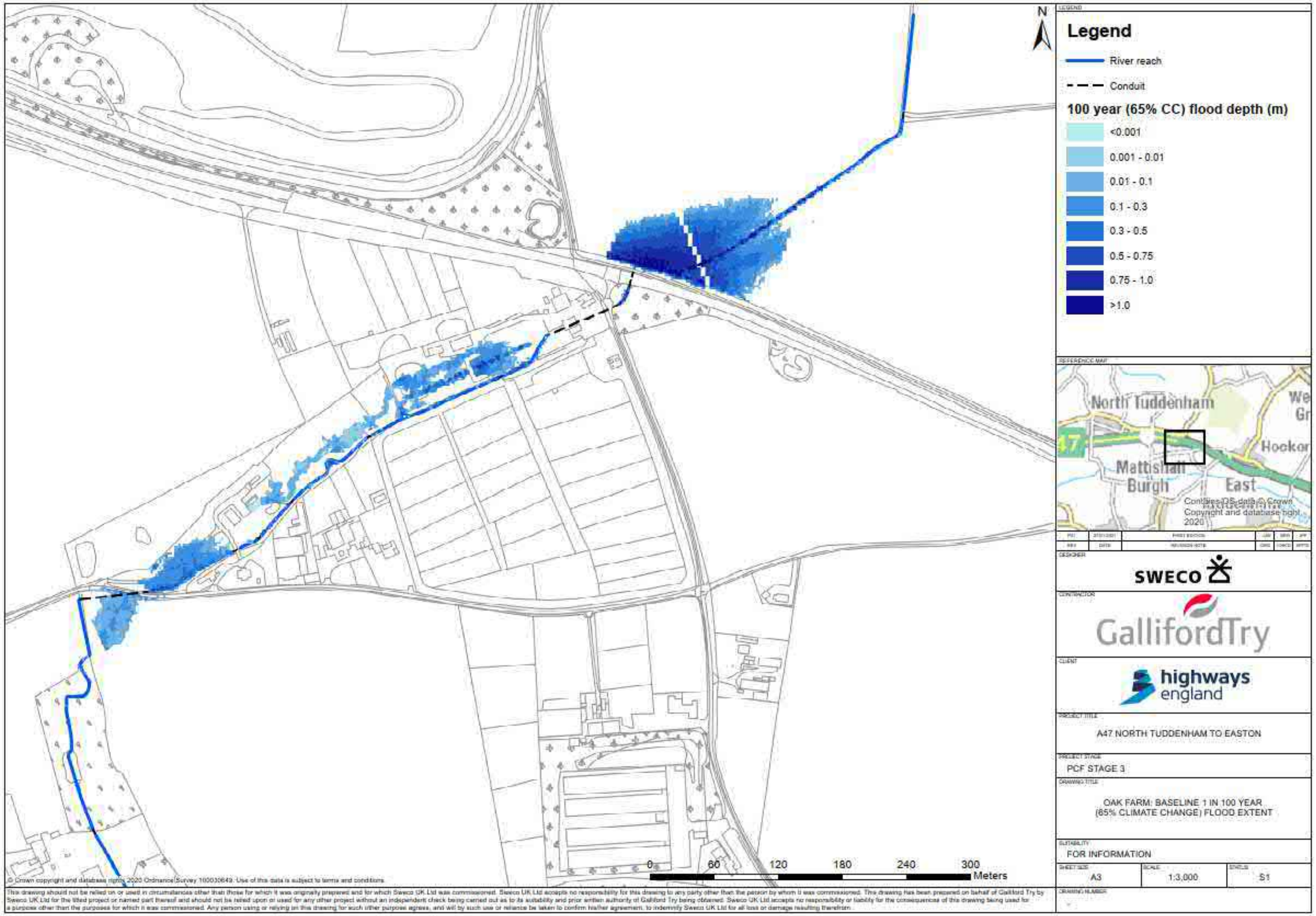


Figure 11-20 Baseline 100-year 65% climate change flood hazard map

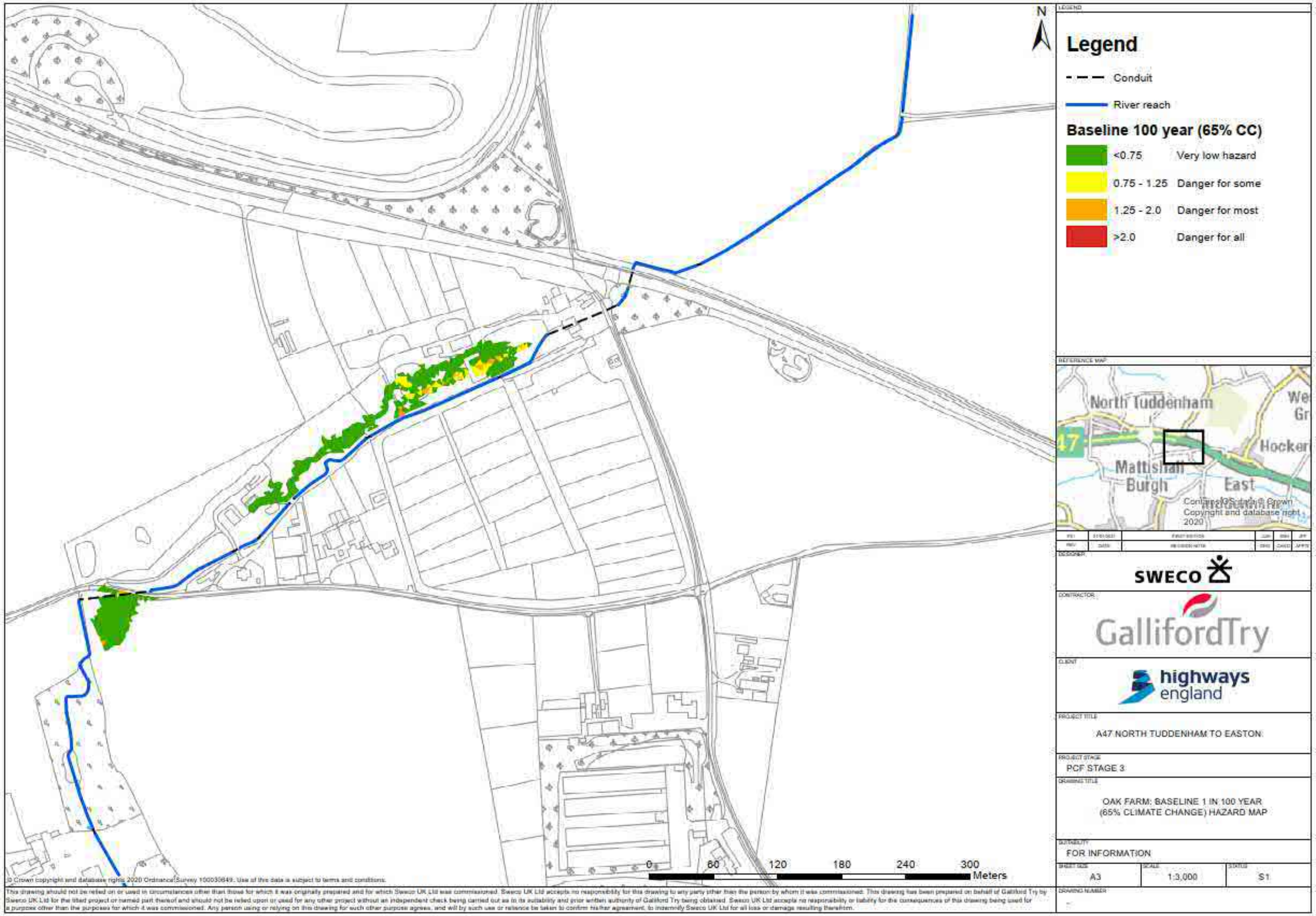
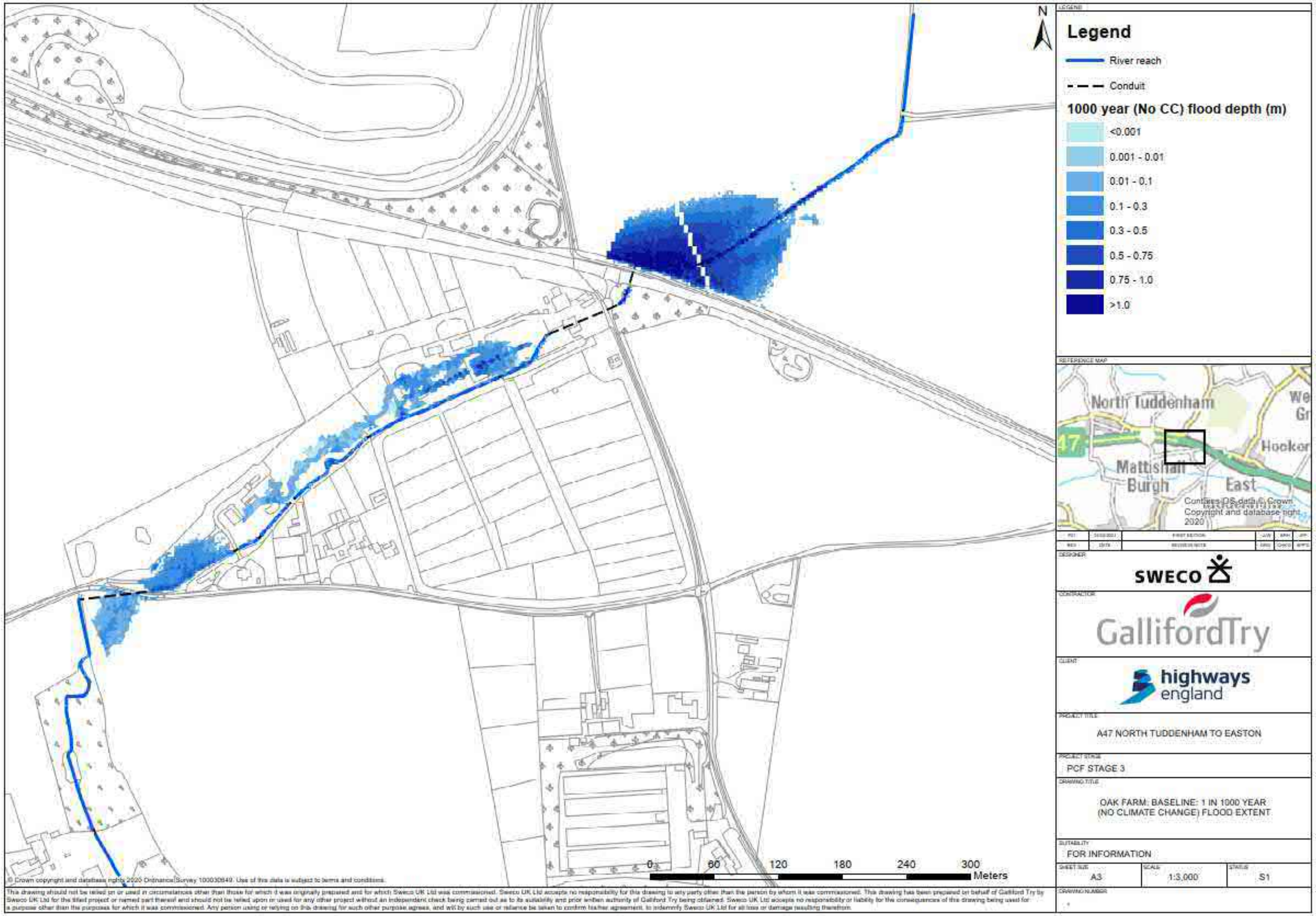


Figure 11-21 Baseline: 1000-year (no climate change) flood map



Annex H. Oak Farm post development mapping

Figure 11-22 Post development 100 year (No climate change) flood map

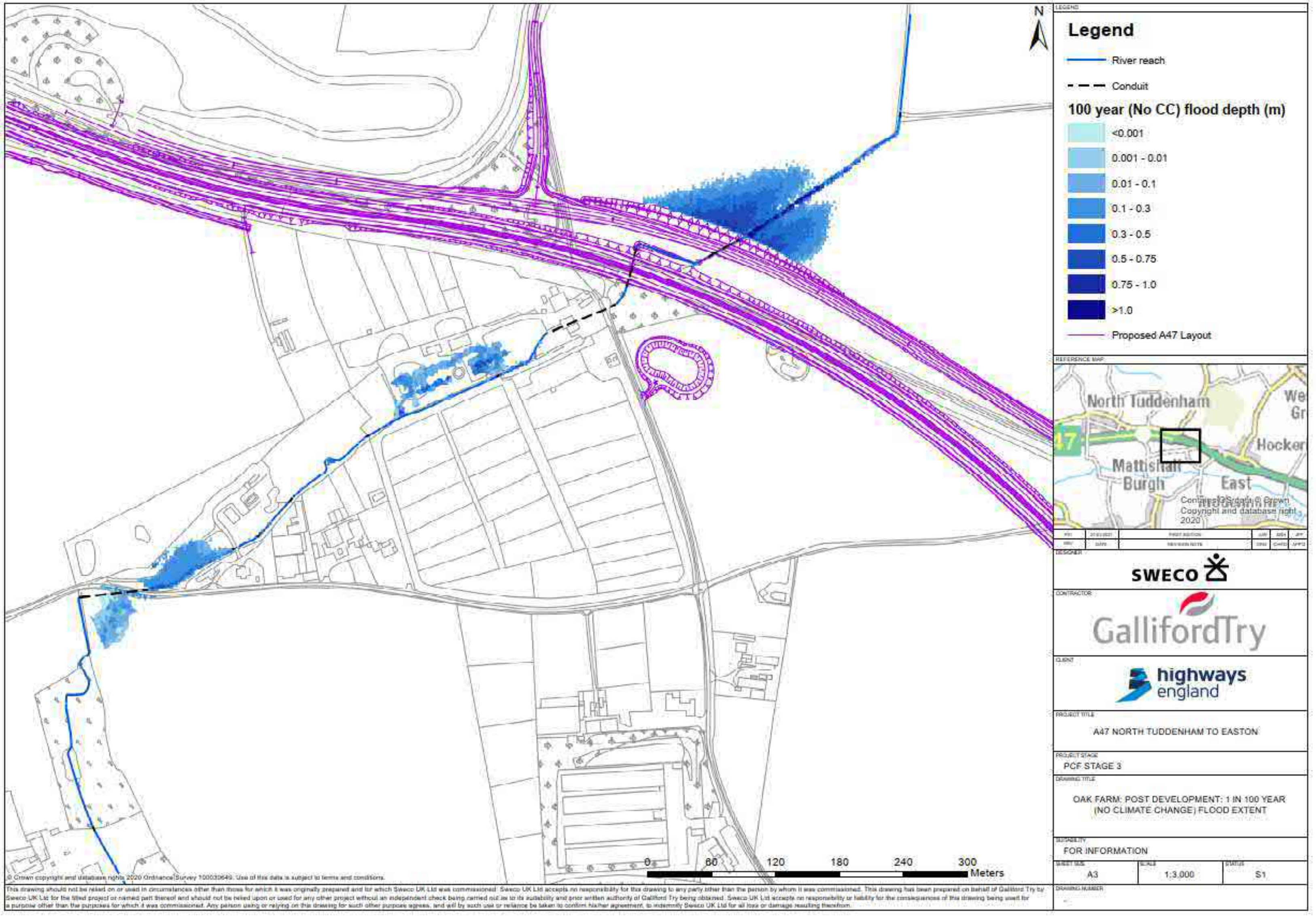


Figure 11-23 100-year (no climate change) flood hazard map

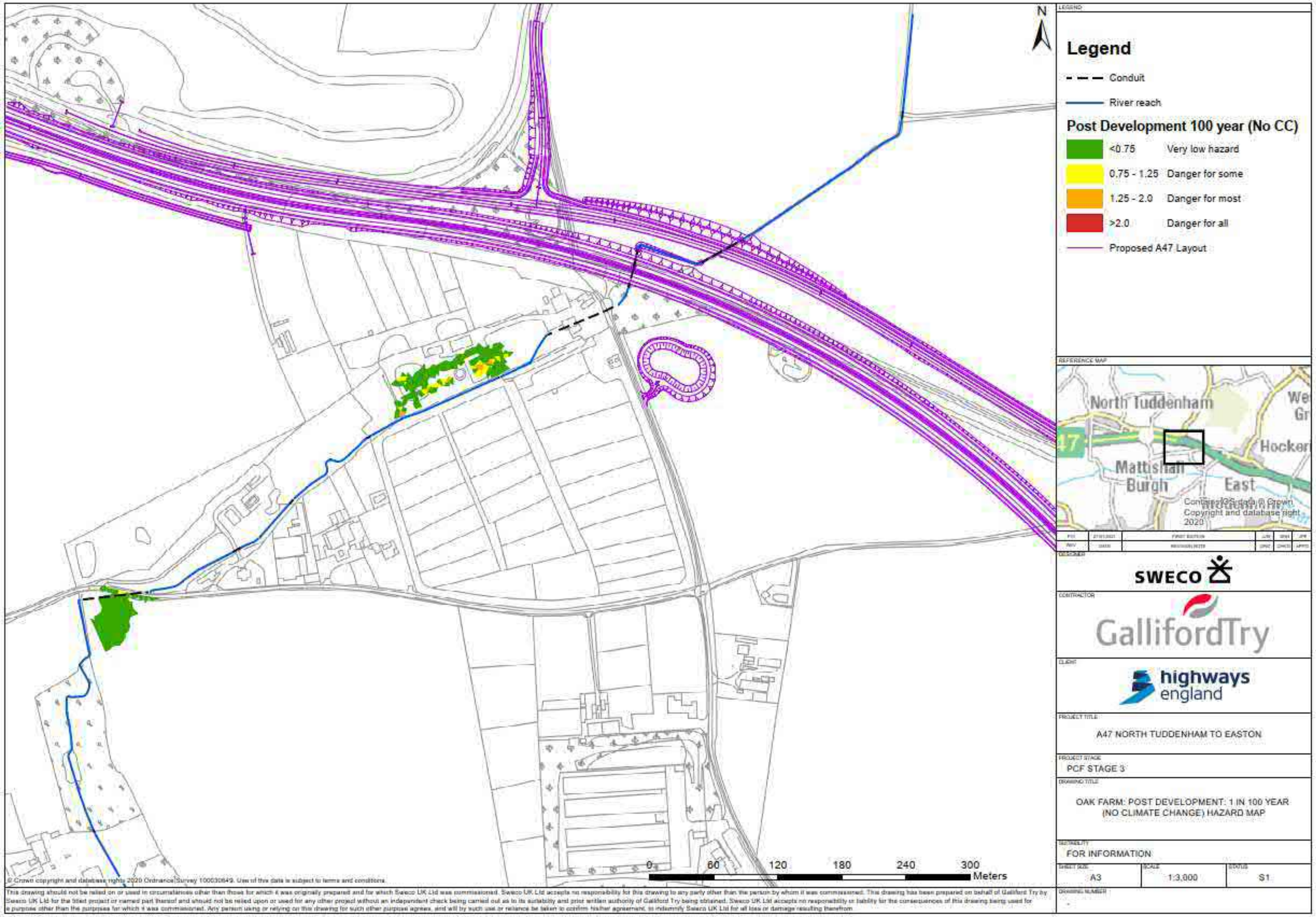


Figure 11-24 100-year (65% climate change) flood extent

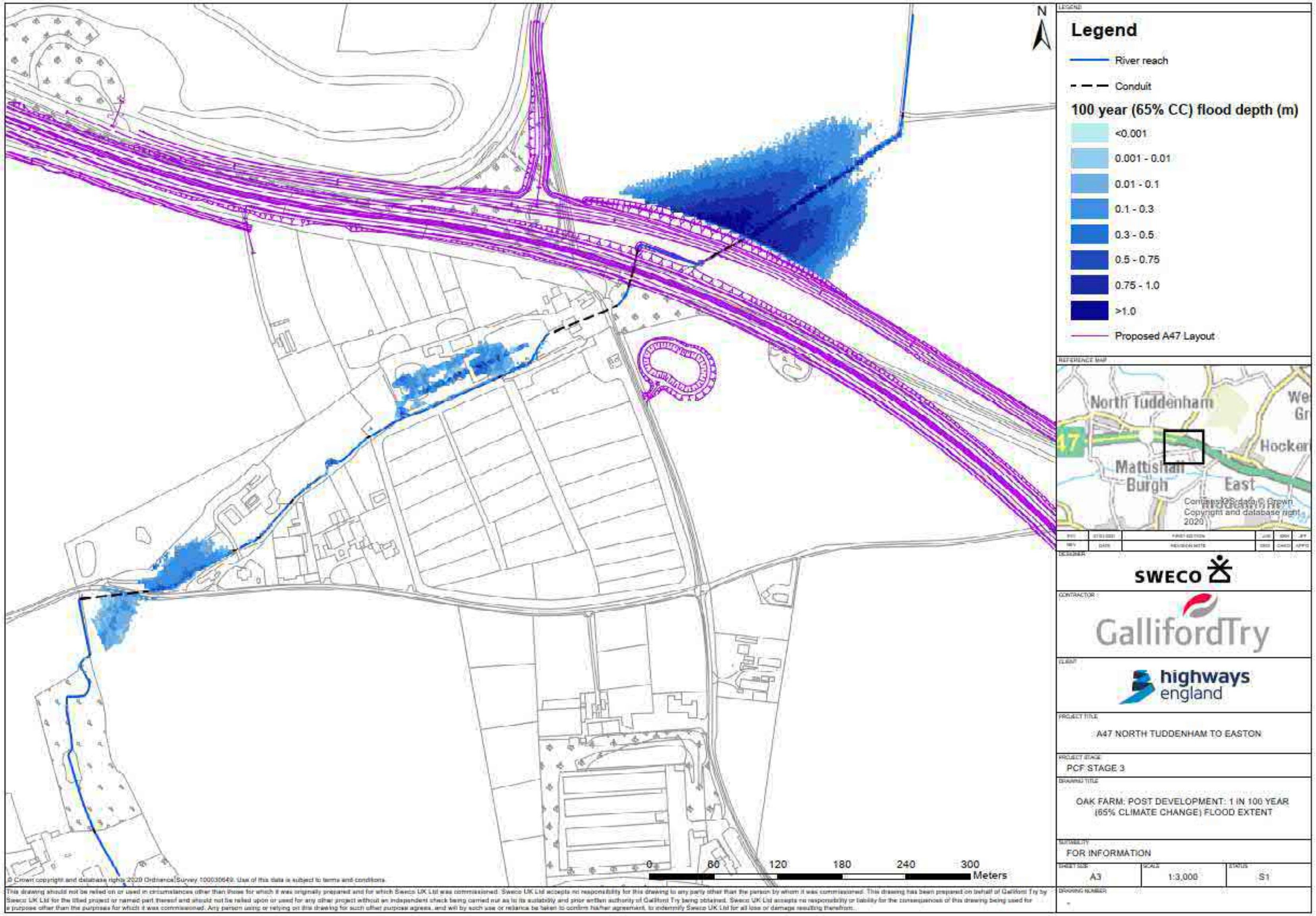


Figure 11-25 Post development 100-year 65% climate change flood hazard map

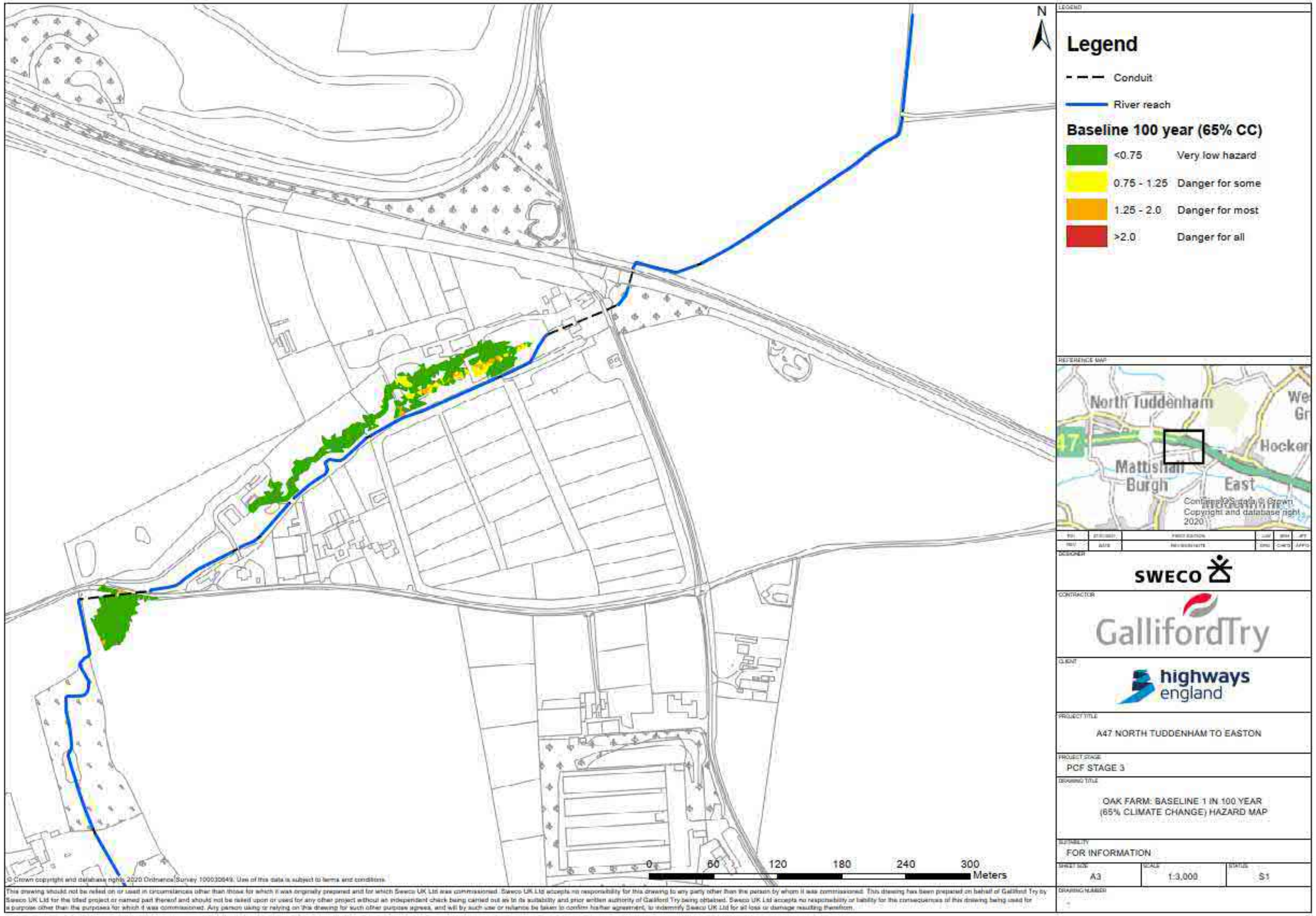
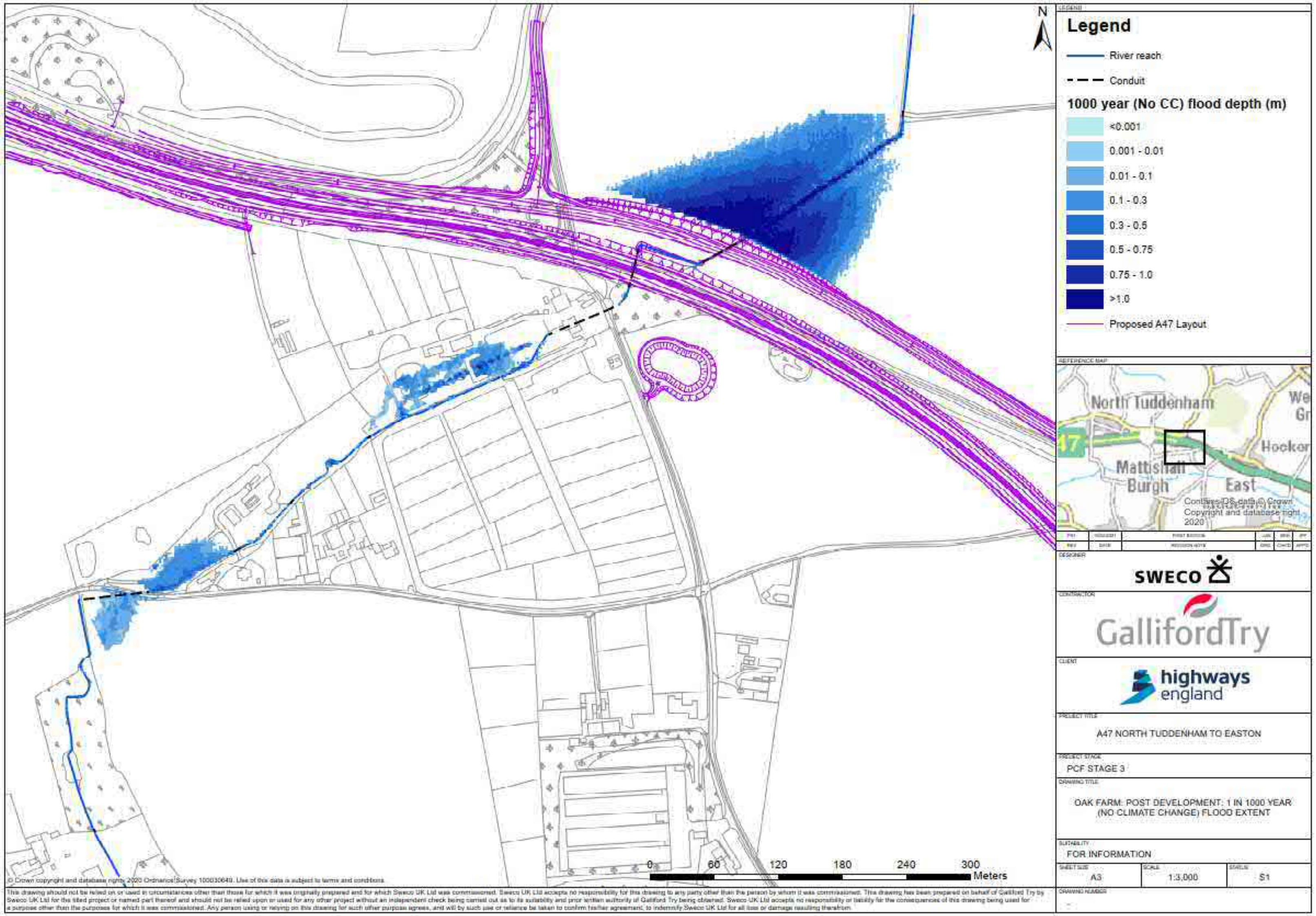
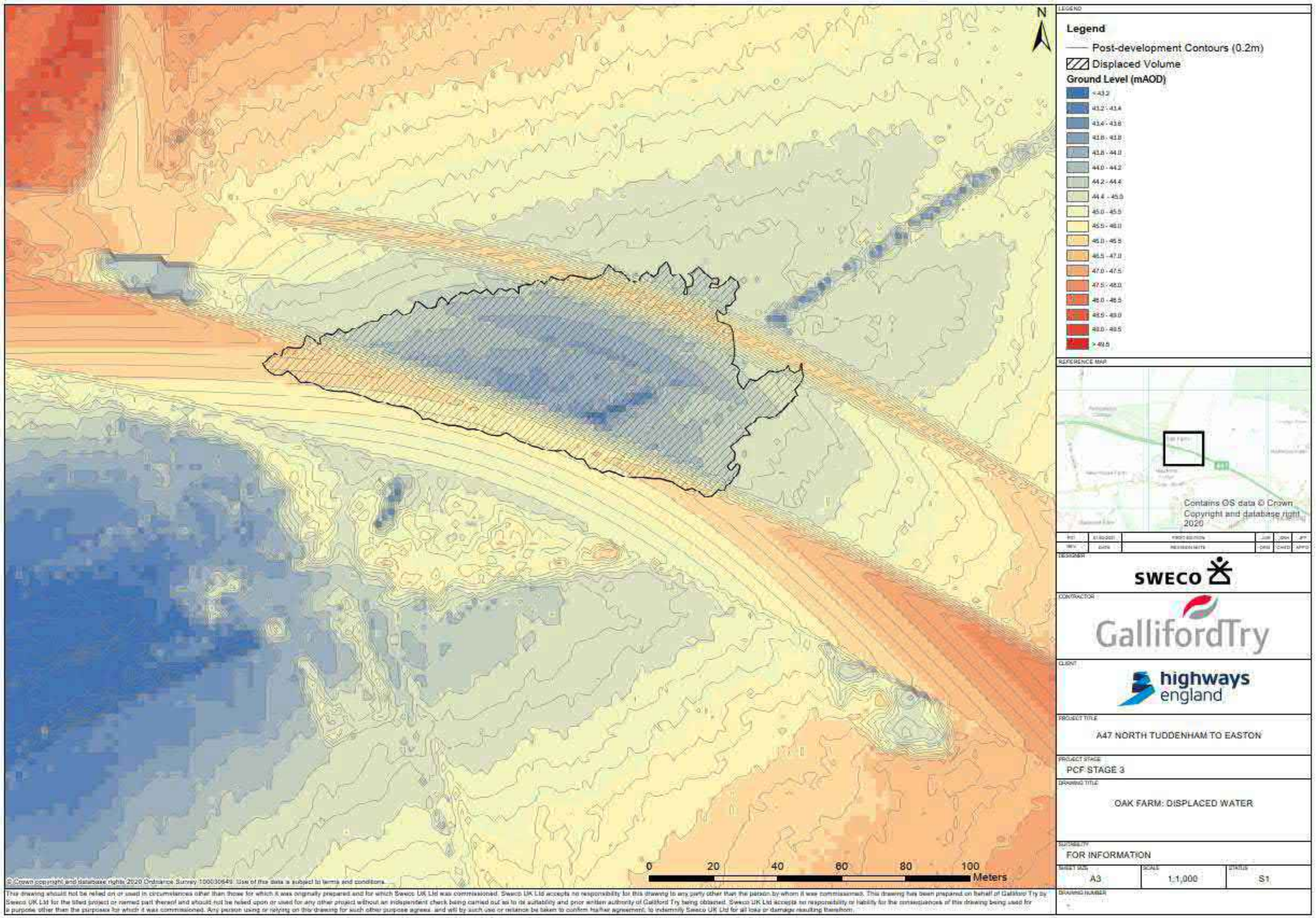


Figure 11-26 Post Development 1000-year no climate change flood map



Annex I. Oak Farm water displacement

Figure 11-27 Floodwater displaced for the 100 year event (35% climate change) at Oak Farm



Annex J. Hydraulic modelling report

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1. Introduction

1.1.1. As part of the wider A47 North Tuddenham to Easton Junction Improvement Scheme ('Proposed Scheme'), three hydraulic models have been developed to represent the River Tud and two of its minor tributaries at Oak Farm and Hockering. The models will be used to inform the Flood Risk Assessment and the design of the proposed bridge and culvert crossings. This technical note was prepared to provide a summary of the hydraulic modelling methodology, as well as an overview of the modelling results.

1.2. Guidance and data sources

1.2.1. The following guidance documents were used during the assessment:

- Estimating flood peaks and hydrographs for small catchments: Phase 1 (SC090031), Environment Agency, 2012[1].
- Flood Estimation Guidelines LIT 11832 (version 2), Environment Agency, 2020
- Flood risk assessments: climate change allowances, Environment Agency, 2020[2].
- Design Manual for Roads and Bridges (DMRB) Volume 11 Section 3 Part 19 LA 113 Road Drainage and the Water Environment (formerly HD 45/09), Highways England, 2019[3].
- National Standard Contract and Specification For Surveying Services: STANDARD TECHNICAL SPECIFICATION, Environment Agency, 2013[4]

1.2.2. The following data sources were used as part of this assessment:

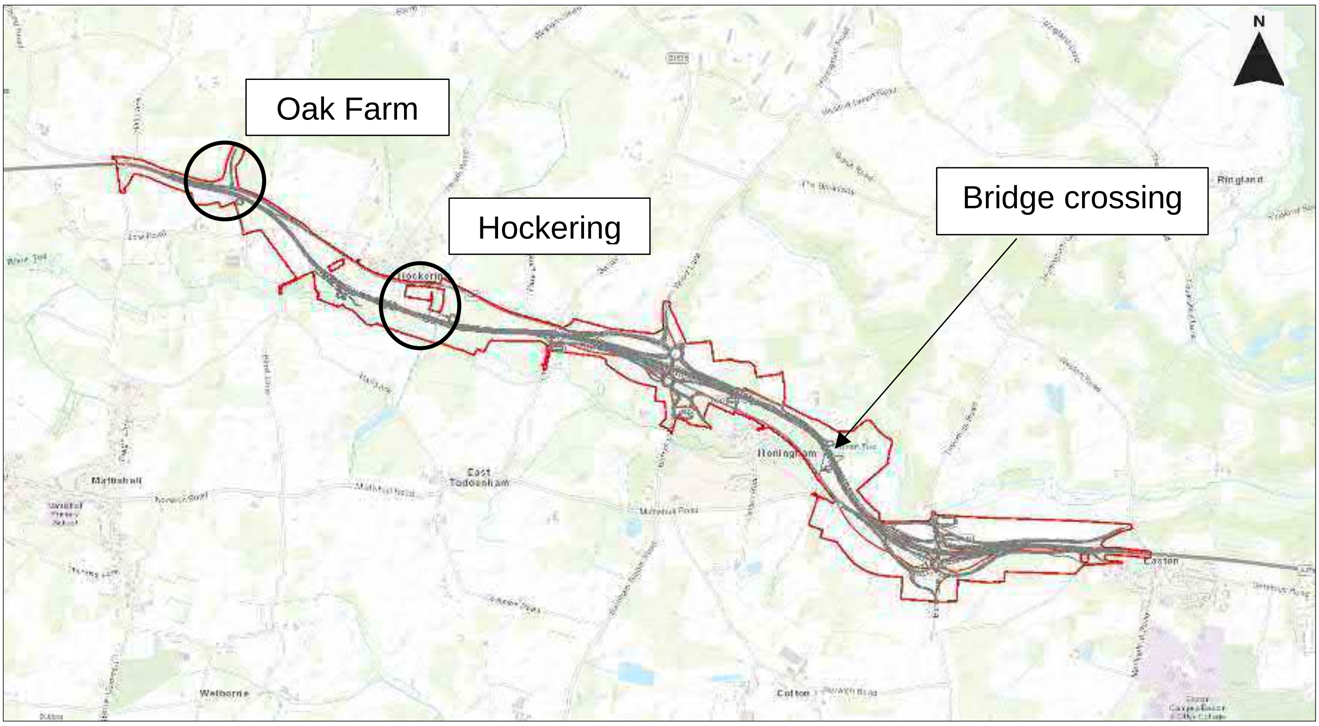
- Flood Modeller Model of the River Tud developed by CH2M in 2017 as part of the Wensum Modelling and Forecasting project on behalf of the Environment Agency;
- National River Flow Archive flow gauge information;
- FEH web service portal for catchment descriptors;
- River and hydraulic structures survey undertaken by Storm Geomatics as part of this Scheme in November 2019.
- 2m resolution LiDAR (2017 composite)[5].

[1] http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/SC090031_-_Phase_1_Technical_Report.sflb.ashx
[2] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances
[3] http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol11/section3/LA%20113%20Road%20drainage%20and%20the%20water%20environment-web.pdf
[4] https://www.channelcoast.org/national/procurement/EA_Nat_Survey_Specs_V3.2.pdf
[5] https://environment.data.gov.uk/DefraDataDownload/?Mode=survey

2. Proposed development

2.1.1. The Proposed Scheme, shown in Figure 2-1, will include a new bridge crossing over the River Tud approximately 300m downstream of the existing bridge at Honingham. New culverts will be required to convey two minor watercourses under the proposed road alignment (referred to as the Oak Farm and Hockering watercourses). Hydraulic modelling was required to inform the design and assessment of the proposed bridge crossing and culverts. Results from the hydraulic modelling will inform the Flood Risk Assessment for the Proposed Scheme.

Figure 2-1 Overview of the proposed North Tuddenham to Easton Scheme



Esri, HERE, Garmin, FAO, NOAA, USGS

2.1.2. The analysis of the Proposed Scheme on flood risk was based on the most recent design available at the time of this assessment. This may be subject to change as the project progresses through preliminary to detailed design.

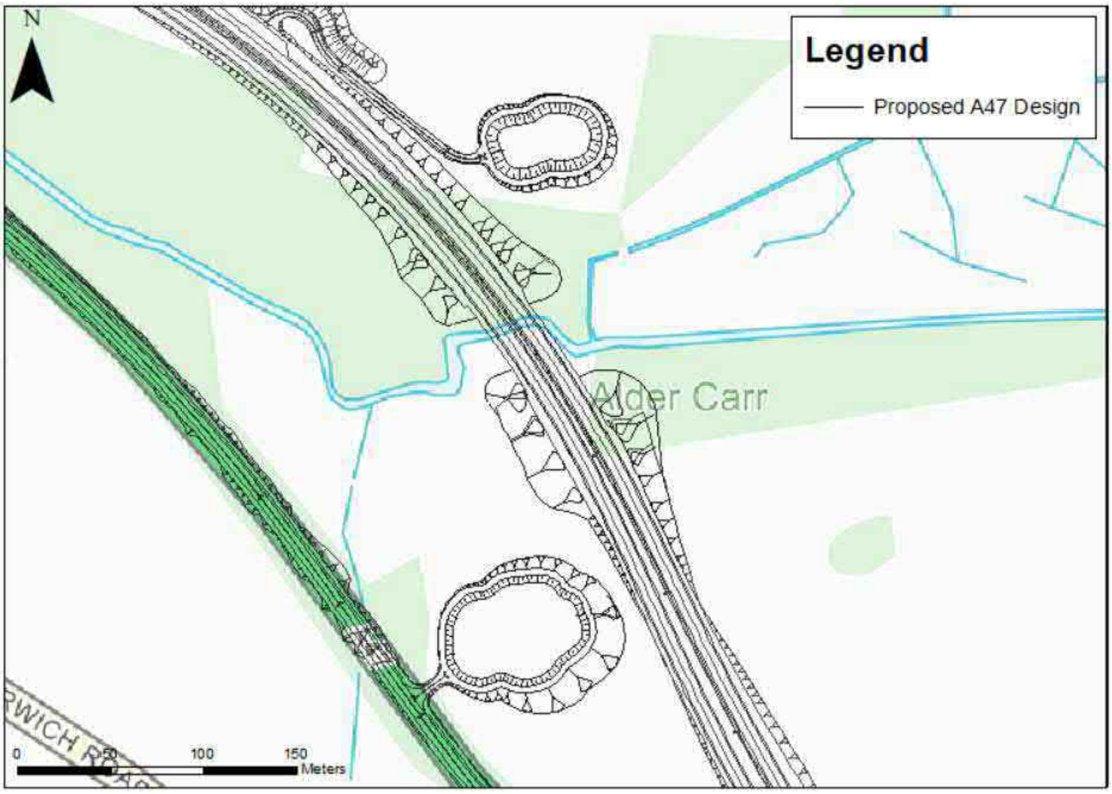
3. River Tud hydraulic modelling

3.1.1. The River Tud, is the only main river within the study area and flows in an easterly direction south of the existing A47. The watercourse crosses under the carriageway at Honingham where it continues in an easterly direction to the north of the existing A47 before its confluence with the River Wensum.

3.1.2. The River Tud has an estimated catchment area of 75km^2 upstream of the confluence with the River Wensum and an average annual rainfall of 649mm. The catchment has a flat topography and is predominantly rural, with arable farming the main land use. The catchment is underlain by chalk bedrock with overlying superficial deposits including boulder clay, sands, gravels and alluvium. According to the National River Flow Archive[6] the groundwater catchment is smaller than the topographical catchment resulting in losses to adjacent catchments and low annual gauged runoff.

3.1.3. There are notable ponds within the catchment including those near Hall Farm Cottages, Valley Farm, and Green Farm. Further details on the Tud catchment can be found within the Tud Hydrology Report (CH2M, 2017). An overview of the proposed bridge can be seen in Figure 3-1.

Figure 3-1 Overview of the proposed bridge crossing along the River Tud



[6] https://nrfa.ceh.ac.uk/data/station/info/34005

3.2. Model build

3.2.1. A 1D hydrodynamic model of the River Tud was constructed using Infoworks Integrated Catchment Model (ICM, Version 9). The model covers approximately 15km of the River Tud from a point 400m downstream of Mill Road (604524, 312886) to 100m downstream of Longwater Lane Bridge (617042, 311233.26). The model's downstream extent was taken from the previous Flood Modeller model (CH2M, 2017) and is located approximately 6.8km downstream of the proposed bridge location. The model extent incorporates the Costessey gauge, which is located between two parallel bridge crossings at Longwater Lane close to the downstream extent of the model.

3.2.2. The model was based on an existing 1D Flood Modeller (FM) model of the River Tud developed by CH2M and was supplemented with additional survey undertaken in 2019 for this Scheme. The FM model itself was updated by CH2M from a previous 2005 model as part of the Environment Agency's Modelling and Forecasting Fluvial Q2 Package. This was part of a wider review of several River Wensum catchment models which also included the Norwich and Upper Wensum. Further details on the CH2M FM Model can be viewed in the Modelling & Forecasting 2015-16 Q2 Wensum Model Report (2017). Figure 3-2 and Figure 3-3 provide an overview of the model developed of the River Tud upstream and downstream of the existing A47 bridge.

Figure 3-2 Overview of the Tud hydraulic model upstream of the existing A47 bridge

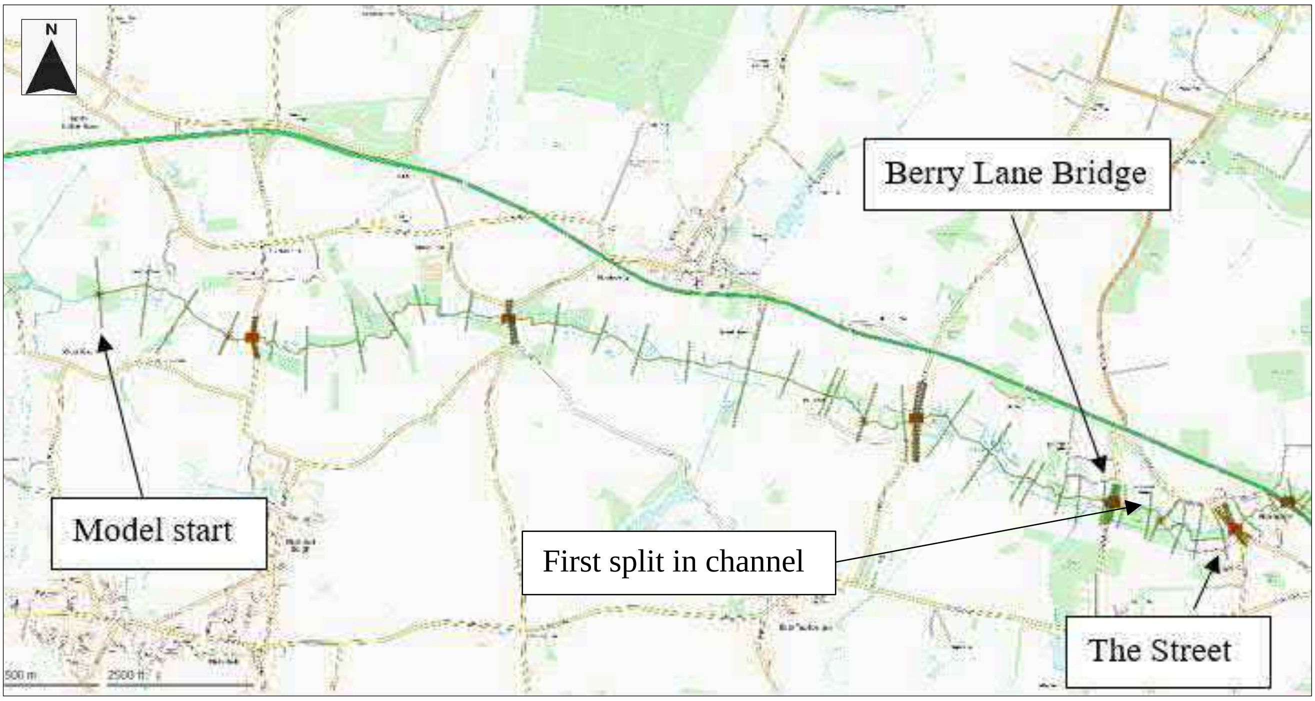
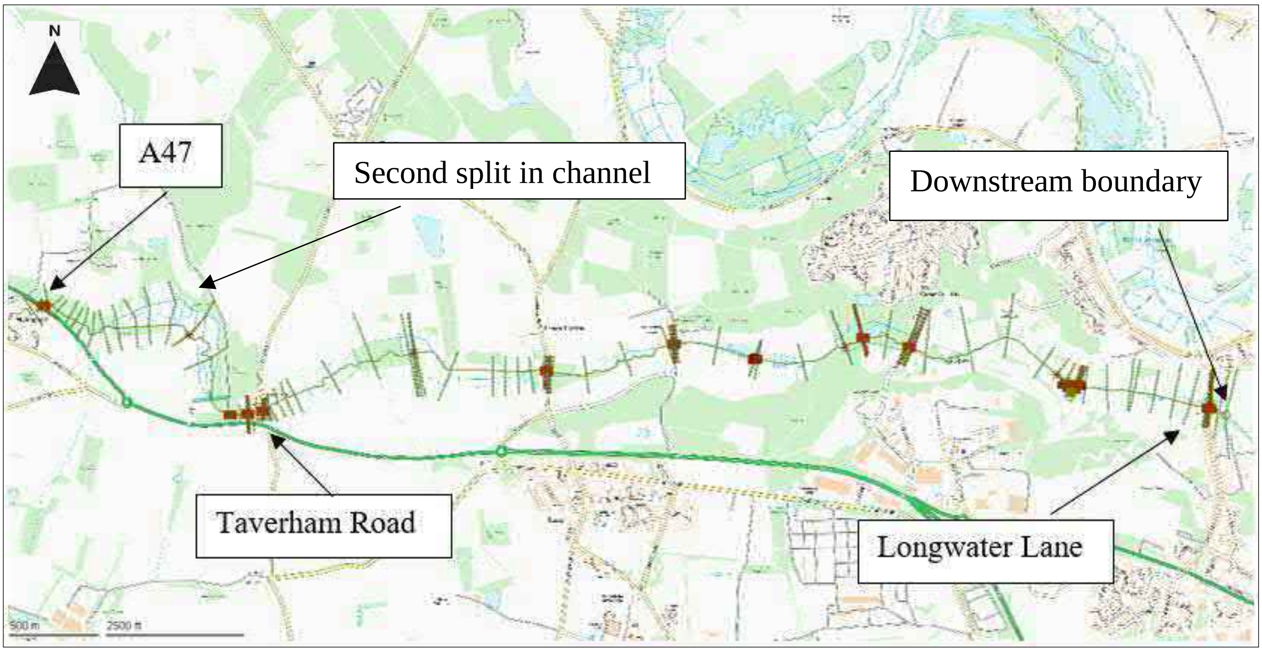
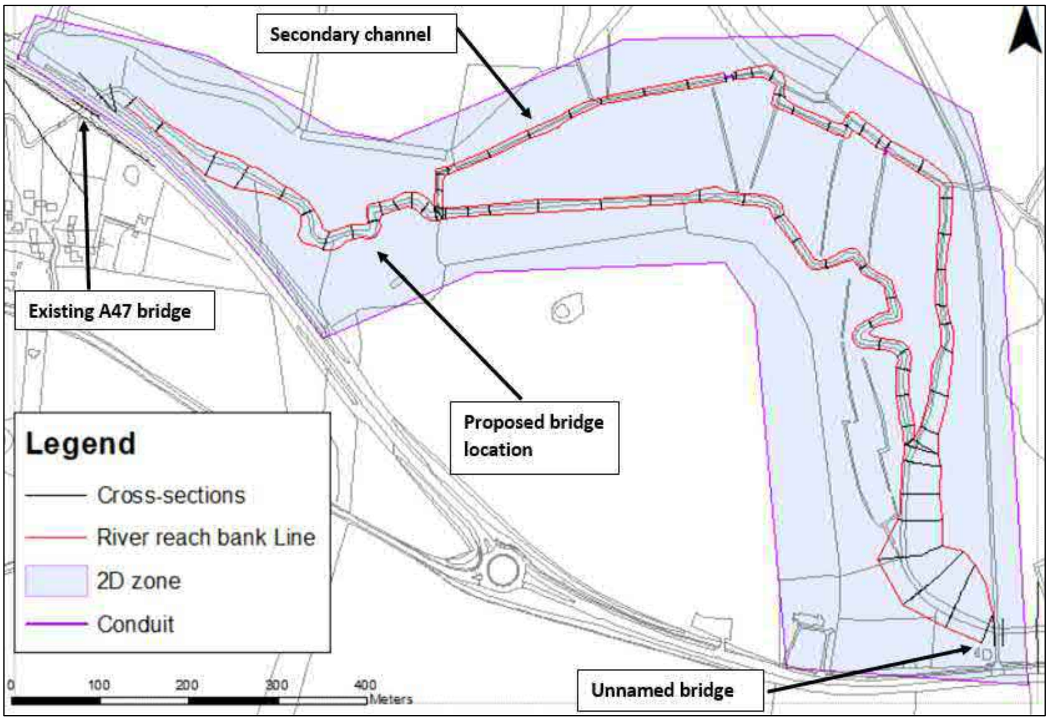


Figure 3-3 Overview of the Tud hydraulic model downstream of the existing A47 bridge



3.2.3. To improve the representation of flow pathways within the vicinity of the proposed bridge, a section of the model downstream of the existing A47 was converted to 1D-2D. The 2D extent of the model can be seen in Figure 3-4.

Figure 3-4 Overview of the 1D-2D part of the model



3.2.4. The following sections provide an overview of each component of the model.

3.3. 1D elements

3.3.1. The model includes 245 cross-sections with 27 based on survey undertaken by Storm Geomatics in November 2019 as part of this assessment. An overview of the survey cross-section locations can be seen in Appendix B. Surveyed sections were provided in EACSD format and were checked for errors before being imported into ICM. Where these overlapped with existing sections the more recent survey was prioritised as the date of survey in the FM model ranges from between 1993 and 2016.

3.3.2. There are two locations along the River Tud where the watercourse splits into two channels. These are located between Berry Lane and The Street, and between the existing A47 bridge to Taverham Road bridge. For the section between Berry Lane and The Street the two channels were incorporated within a single cross-section by merging the two surveyed sections together. The intervening floodplain area was updated and incorporated into the sections using recent LiDAR. For the section downstream of the existing A47 the two channels were modelled as separate reaches connected to a 2D mesh representing the floodplain.

3.3.3. Multiple interpolated sections were added primarily upstream and downstream of bridges and structures to allow for the contraction and expansion reaches to be included within ICM. Furthermore, several interpolates were added downstream of the A47, around Taverham Road bridge, and at lateral inflow points to improve model stability. For each of these interpolated cross-sections the banks and floodplain were updated using 2m resolution LiDAR.

3.4. Hydraulic structures

3.4.1. The model included 16 bridges. Of these, 14 were represented as 1D bridge units with bridge geometry based on the 2019 survey, or the previous FM model. Structures judged to have the potential to influence flows at the new A47 crossing, or be affected by the new A47 crossing, were updated in the model based on the 2019 survey. This included the structures found at Berry Lane, the Street, the A47 (at Honingham), and Taverham Road.

3.4.2. The upstream bridge opening head loss coefficients were increased to 1 following discussions with Innovyze. This was to account for an underprediction of levels upstream of bridges compared to the original FM model.

3.4.3. The bridges at Berry Lane (Figure 3-5) and Longwater Lane were represented using a series of conduits with inlet and outlet nodes attached. An irregular weir was used to represent the road deck and allow for any overtopping should this occur. This arrangement provided increased stability compared to the use of a bridge unit, particularly for the 100-year event (without climate change).

Figure 3-5 Three main culverts at Berry Lane Bridge

3.4.4. The culvert for the secondary channel at Berry Lane bridge (see Figure 3-5) was observed to be blocked in the survey hence a 50% sediment level and a higher roughness value were applied.

3.4.5. For the remaining FM bridges interpolated sections were added to represent the contraction and expansion sections upstream and downstream of the bridge. The banks and floodplains of these interpolates were then updated using 2m resolution LiDAR. Several FM bridge sections did not align correctly with the road profile as defined on the most recent OS MasterMap data. These sections were, therefore, reoriented and repositioned.

3.4.6. A culvert associated with a footpath crossing was also added along the secondary channel downstream of existing A47. This was represented using a conduit with inlet and outlet links added. An irregular weir was also included to allow for overtopping of the footpath deck and sediment added to the conduit. All dimensions were taken from values recorded in the 2019 survey.

3.4.7. Four weirs or sluices are also included in the model. Most of these were based on the FM model with the same properties retained. The weir upstream of Berry Lane Road was represented as an irregular weir which incorporates both the main and secondary channel. The weir crest was based on the values within the FM model. The weir upstream of The Street was represented in a river cross-section with sections upstream and downstream taken from the FM model (see Figure 3-6 and Figure 3-7). Although typically inline weirs such as this are represented explicitly as regular or irregular weir units within ICM this alternative arrangement was identified as providing the most stable model performance given its proximity to nearby bridges.

Figure 3-6 Weir upstream of The Street

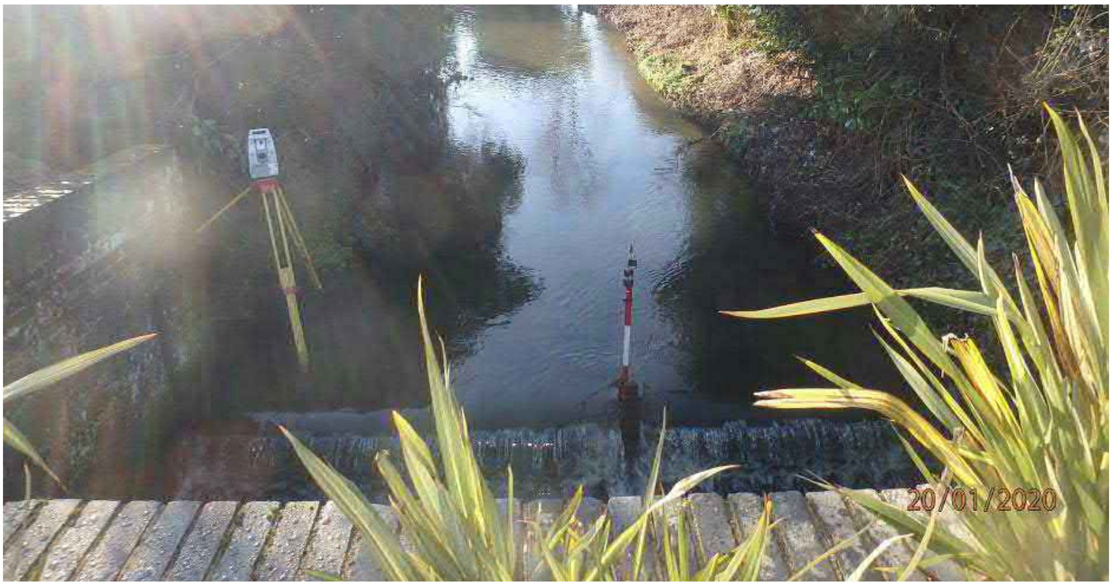
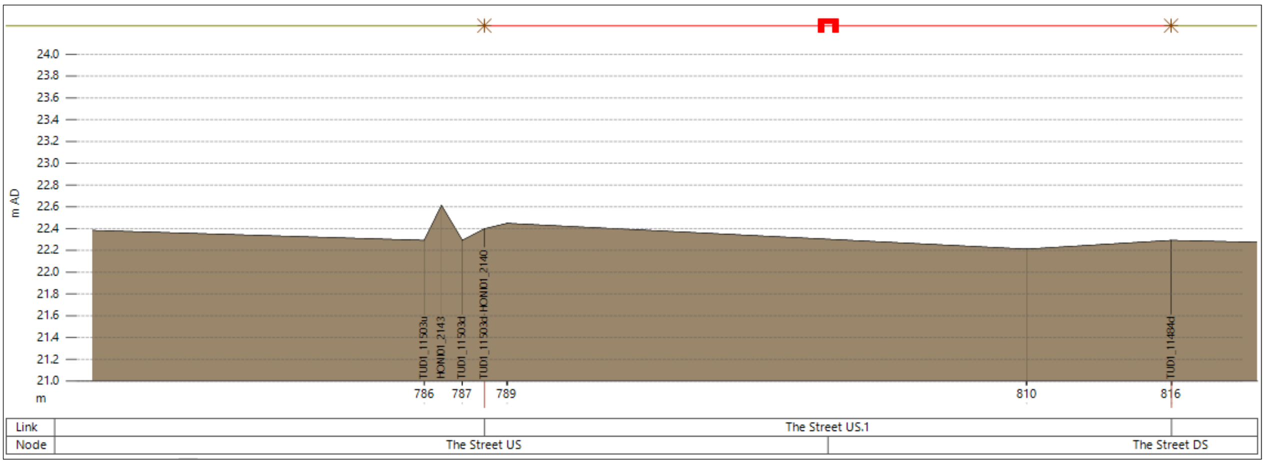


Figure 3-7 Long section showing the weir upstream of the Street



3.4.8. Several pond or floodplain storage units including those upstream of Berry Lane Road were removed and the attached cross-sections were extended. This was judged to be appropriate given that stream-wide land-drains are present and hence floodplain conveyance was assumed to dominate over storage at the design event and that flood flows pathways would be generally parallel to the direction of normal flow in the channel. The pond unit upstream of the Costessey gauge was however retained as this area was judged to be dominated by floodplain storage.

3.5. 2D elements

3.5.1. The 2D domain was defined to cover all areas where out-of-bank floodwaters were predicted to occur between the existing A47 and an unnamed bridge downstream. This was meshed using a ground model built from 2 metre resolution LIDAR (2017 composite dataset). The maximum meshing element size was 50 m^2 and the smallest element area was 2 m^2. Terrain sensitive meshing was enabled, with a maximum height variation of 0.25 specified. This ensured that enough ground detail was captured in areas that have a large variation in height and that flow pathways were well represented.

3.5.2. Several small land drains were captured within the LiDAR and the inflow points from major drains were recorded in the survey. There were represented within the 2D domain using mesh level zones with elevations specified to match recorded bed values. For drains not captured within the bank survey but visible in the LiDAR break lines were added to ensure that enough detail was provided in the mesh.

3.6. 1D-2D connections

3.6.1. The 2D area was linked to the 1D river channels through bank lines, where flow can pass between the 1D and 2D model domains. These were constructed using the end points of cross-sections and supplemented with LIDAR elevations between cross-sections. A discharge coefficient of 0.4 and modular limit of 0.3 were applied to most bank lines. These values provided the most stable arrangement and were identified as appropriate for non or slightly elevated overbank terrain. Further sensitivity testing was undertaken which identified that increasing or decreasing the coefficients by 20% had a negligible impact of peak water levels.

3.7. Roughness values

3.7.1. Roughness values applied were taken from the original FM model which were reviewed and judged to be appropriate. A Manning’s n value of 0.05 was applied for the channel banks and 0.04 for the channel bed. These roughness values were found to result in comparable water levels to the FM model with a small reduction due to the improved representation of the secondary channels.

3.7.2. The roughness values applied to bridges along the watercourse were taken from the previous FM model. A higher roughness value of 0.025 and head loss coefficient of 0.6 were applied to the bridge downstream of Longwater Lane. These values were identified as part of the validation for levels at the structure against the Flood Modeller model and were judged to be appropriate following a review of the structure.

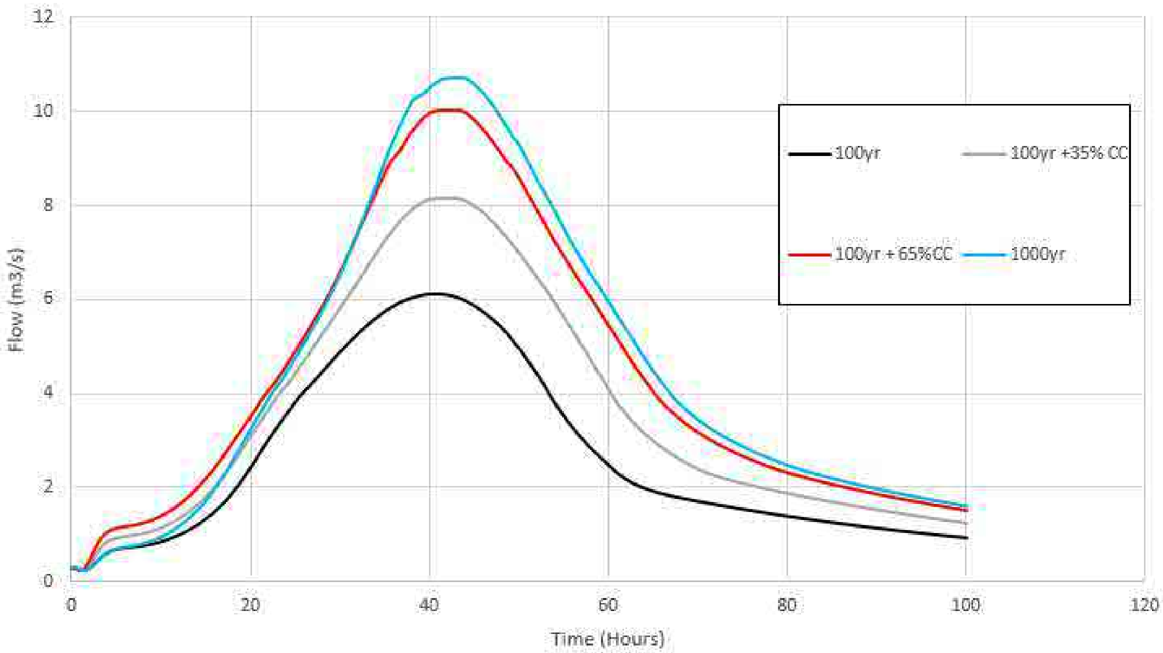
3.7.3. Within the 1D-2D section of the model the roughness for banks of river sections were increased to 0.1 where woodland was observed. A default roughness value of 0.04 was applied to the 2D zone. This was selected based on site observations and aerial imagery within the area, which showed a mixture of medium grass and scrub vegetation. Roughness zones were added in the 2D zone where areas of woodland were identified with a Manning's roughness of 0.1 applied.

3.8. Boundary conditions

3.8.1. The boundary conditions used in the previous FM model were, in agreement with the EA, retained for the updated ICM model. Details of the methodology used to derive these inflows can be found within the Wensum Model and Tud Hydrology Reports (CH2M, 2017). Hydrographs were extracted from the FM results files and applied to the upstream cross-section (TUD1_18250) of the ICM model. The following events (shown in Figure 3-8) were modelled:

- 100-year (without an allowance for climate change);
- 100-year (with a 35% climate change allowance);
- 100-year (with a 65% climate change allowance);
- 1000-year (without an allowance for climate change).

Figure 3-8 Inflow hydrographs applied at the upstream boundary of the model



3.8.2. The climate change allowances were identified and agreed with the Environment Agency based on the current national planning guidance on climate change. Due to the nature of the Proposed Scheme, it is appropriate to class the development as "essential infrastructure". It is considered that the lifetime of the development for the purposes of the flood risk assessment is 100 years. As the Proposed Scheme does pass through Flood Zone 3, the Anglian region 'upper end' category is therefore applicable, with an assumed time horizon of 2080s (2070 to 2115). Subsequently, the PPG guidance states that peak river flow climate change allowance would be 65%. During discussions with the Environment Agency and Norfolk County Council it was stated that a 35% climate change allowance would be required to assess the need for compensatory storage.

3.8.3. There were six lateral ReFH inflows along the section of the River Tud covered in the ICM model. These were included in ICM by extracting the hydrographs from the ReFH units in the FM result files and scaling these using the same factor used in the original model. The hydrographs were then directed to break nodes along the river reach at the same inflow points. An overview of the inflows used in the modelling is shown in Table 3-1.

Table 3-1 Overview of modelled upstream and lateral boundary inflows.

			Peak Flow (m^3/s)			
Node ID	**Node ID**	**Easting/northing**	**100-year**	**100-year (35% CC)**	**100-year (65% CC)**	**1000-year**
Upstream Boundary	TUD1_18250	604524.65/312886.22	6.101	8.160	10.029	10.713
Lateral 1	TUD1_17500	605183.08/312676.27	0.875	1.190	1.4524	1.5482
Lateral 2	TUD1_13750	608437.10/312233.83	0.875	1.190	1.4524	1.5482
Lateral 3	TUD1_12000	609960.25/311736.48	0.396	0.538	0.657	0.8315
Lateral 4	HONI01_0836	611402.40/311671.88	0.396	0.538	0.657	0.8315
Lateral 5	TUD1_8500	612636.71/311569.08	0.317	0.431	0.5256	0.6652
Lateral 6	TUD1_6000	614972.57/311604.71	0.475	0.646	0.7884	0.9978
Total	**-**		**9.434**	**12.693**	**15.562**	**17.135**

3.8.4. At the downstream boundary a free outfall condition was applied, and additional sensitivity tests were undertaken to test this assumption.

3.9. Run parameters

3.9.1. The model was run for a duration of 90 hours with a 1 second minimum timestep and a 5-minute output interval. No hot start files were required for any of the simulations.

3.9.2. All simulations have a mass and volume balance error below 1%. There are several amber error messages within the simulation log files, however, these mainly relate to minor differences between the culvert inverts and bed level. As all bridges were either based on the previous FM model or updated using new survey these errors are not considered relevant.

4. Tud baseline and proposed model results

4.1.1. The predicted baseline flood maps are provided in Appendix E and F. The updated model predicts similar flood extents to those produced in the previous FM model. There are areas of notable flooding around Hockering and to the east of Honingham, where the proposed bridge crossing is located.

4.1.2. An overview of the predicted peak levels close to the proposed A47 bridge can be seen in Table 4-1. Appendix C compares baseline levels to the proposed scheme with cross section locations provided in Appendix B. The predicted peak water levels at the cross-section close to the upstream face of the proposed bridge is 22.412m AOD for the 100-year event and 22.563m AOD with a 65% climate change allowance included.

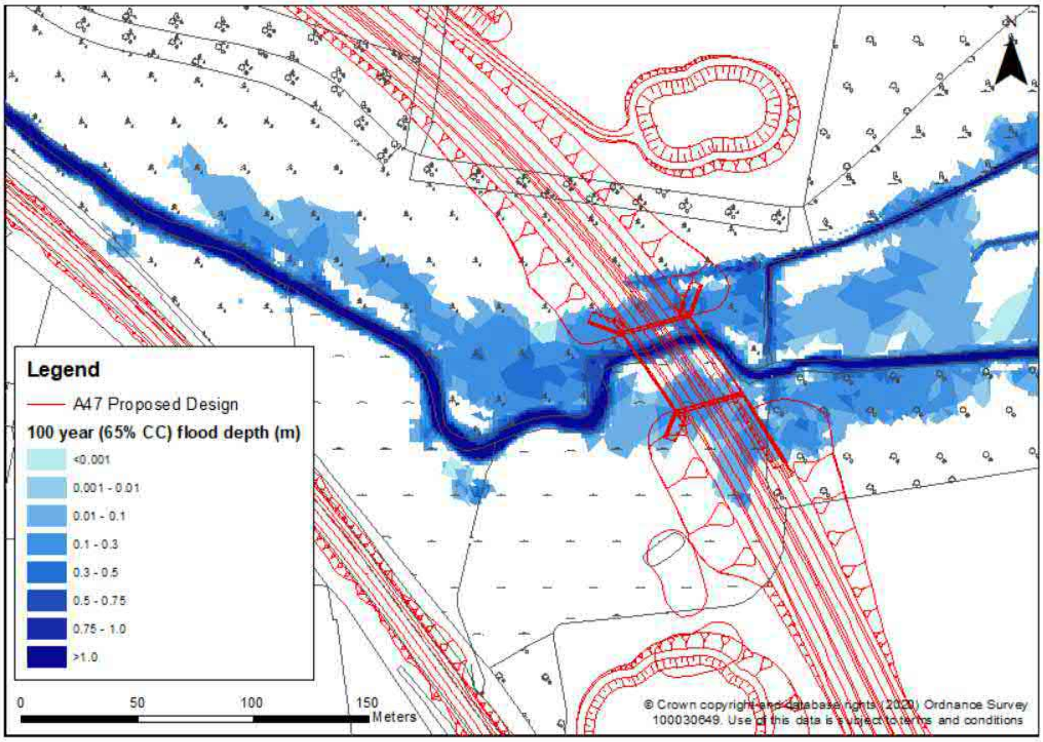
Table 4-1 Predicted baseline peak water levels in the vicinity of the proposed bridge crossing (where INT refers to an interpolated cross-section)

Section ID	100-year No CC	100-year 35%CC	100-year 65%CC	1000-year No CC
	Level (m AOD)	Level (m AOD)	Level (m AOD)	Level (m AOD)
HONI01_1427	22.591	22.685	22.751	22.775
INT	22.559	22.647	22.708	22.730
INT	22.500	22.590	22.654	22.677
TUD1_10750 (Proposed Bridge Location)	22.412	22.500	22.563	22.586
INT	22.306	22.397	22.461	22.485
INT	22.228	22.321	22.386	22.410
INT	22.125	22.211	22.271	22.293
INT	22.052	22.130	22.185	22.205
INT	22.048	22.126	22.182	22.201
INT	22.048	22.126	22.182	22.201
HONI01_1257	22.041	22.118	22.173	22.193

4.1.3. The flood maps provided in Appendix E demonstrate that most of the Proposed Scheme footprint is outside of the existing 100-year floodplain, both with and without a 65% climate change allowance. Note that an extremely small section of embankment close to Hockering (Figure 7-5) overlaps the 100 year (with 65% climate change) flood extent. A topographic survey will be undertaken at detailed design stage when the position of the embankment will be reviewed to ensure it does not overlap the 100 year (with 65% climate change) flood extent.

4.1.4. The only element of the design within the floodplain are the abutments of the proposed bridge crossing downstream of the existing A47 (see Figure 4-1). Flooding is predicted along both banks with floodwaters flowing eastwards before re-entering the main watercourse or the secondary channel. The footprint of both abutments overlaps these pathways hence compensatory storage will be required. This will be outlined in more detail within the FRA.

Figure 4-1 Cross Section Locations within the area of interest.



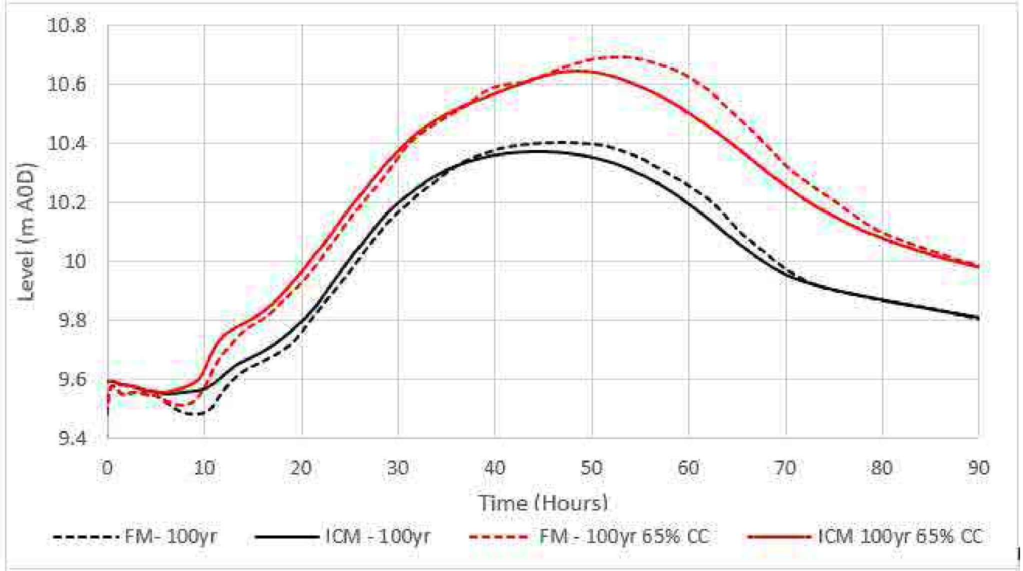
4.1.5. It should be noted that at certain sections of the 1D portion of the model areas behind embankments or raised areas adjacent to the channel are shown to be flooded. This was present in the original FM model and was judged to be reasonable model behaviour because these are not thought to be linear or formal defences hence conveyance around these features may be possible at or above the 100-year event.

4.2. Model verification

4.2.1. The model was not explicitly calibrated to the gauge at Costessey. By agreement with the EA a verification process was undertaken to provide good comparison with the existing FM model.

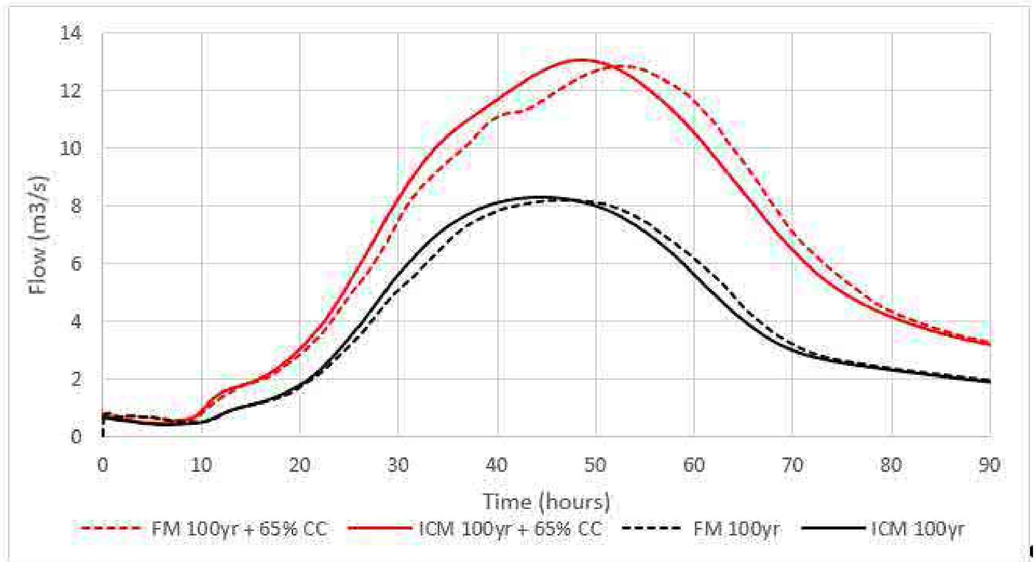
4.2.2. A comparison of the predicted peak levels at several cross-sections in the original 1D FM model and ICM is shown in Appendix G. The ICM model predicts higher peak water levels at the proposed bridge and downstream compared to the FM model, with the largest difference at HONI01_0969. This is due to the incorporation of new survey data, as well as the conversion of the model to 1D-2D within this area, resulting in a better representation of the split channels and floodplain throughout this area. There was a small reduction in peak water levels at section HON0322 and TUD9500 likely due to their location downstream of the 1D-2D section. An overview of the peak levels and flows at the Costessey gauge can be seen in Figure 4-2 and Figure 4-3. The results show a close similarity between the FM and ICM results in terms of peak levels but a greater variance in the shape of the hydrograph. This again likely relates to the integration of new survey and the improved representation of the secondary channels.

Figure 4-2 100-year water level at Costessey Park Gauge



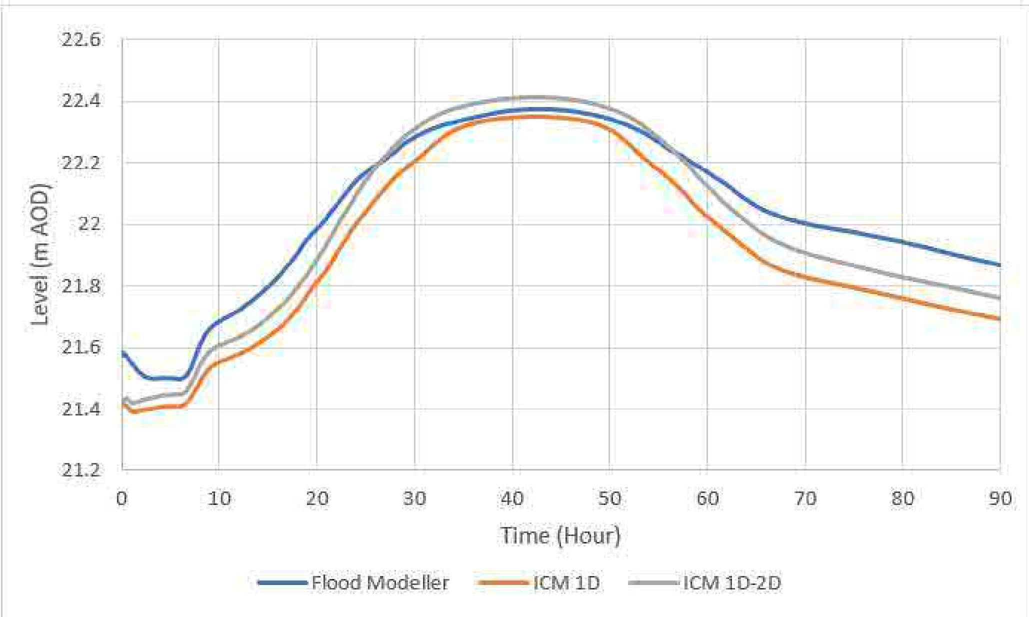
4.2.3. A peak flow of 8.235 m^3/s is predicted at the Costessey gauge for the 100-year event (without climate change, see Figure 4-3) which is slightly higher than the FM estimate of 8.203m^3/s.

Figure 4-3 100-year flow at Costessey Park Gauge



4.2.4. Figure 4-4 provides a comparison of levels at the proposed bridge location (TUD1_10750). This again shows a close comparison in terms of the peak levels however the rising and receding limb can be seen to be steeper in the ICM model. For comparative purposes the hydrograph from a purely 1D earlier iteration of the ICM model is also included in which all elements are kept the same as with the FM model except that the new survey data has been integrated. This highlights that the differences in hydrograph shape reflect the changes in channel geometry and not the estimated roughness.

Figure 4-4 level at cross-section close to proposed A47 bridge (TUD1_10750)



4.3. Sensitivity analysis

4.3.1. A series of additional model runs were undertaken to evaluate the sensitivity of the model to different factors. These included:

- altering the channel roughness by +/- 20%;
- altering the inflow hydrographs by +/-20%[7]
- lowering the weir discharge coefficients at Berry Lane weir;
- Adding a level file to the downstream boundary set to 600mm above the predicted 100-year peak water level.

4.3.2. The results at nine cross-sections close to the proposed bridge are shown in Table 4-2. This indicates that the model is moderately sensitive to variations in roughness and inflows, however, the percentage change in depth is less than

[7] The upstream boundary files were taken from the FM model.

10%. The model was insensitive to the downstream boundary condition, the weir parameters at Berry Lane and variations in bank coefficients.

4.3.3. The original Tud model was judged to be good by CH2M with peak levels within 0.1m of observed values. This model has been calibrated to the FM model and matches the peak level at the gauge well (within 36mm). Given the results of the sensitivity testing the predicted water levels should be considered accurate to approximately ± 20cm.

Table 4-2 Results from the sensitivity analysis for the 100-year event (without climate change)

Scenario	Max change in peak Level (m)	Average change in peak level (m)	Max % Change in Depth	Average % change in depth
+20% Roughness	0.058	0.052	4.2%	3.4%
-20% Roughness	-0.098	-0.084	-7.0%	-5.5%
+20% flows	0.055	0.051	3.8%	3.3%
-20% flows	-0.078	-0.070	-5.6%	-4.6%
+20% bank coefficient	0.001	0.000	0.0%	0.0%
-20% bank coefficient	0.001	0.000	0.1%	0.0%
DS Boundary + 1m	0.000	0.000	0.0%	0.0%
Weir coefficient at Berry Lane Bridge lowered to 0.5	0.000	0.000	0.0%	0.0%

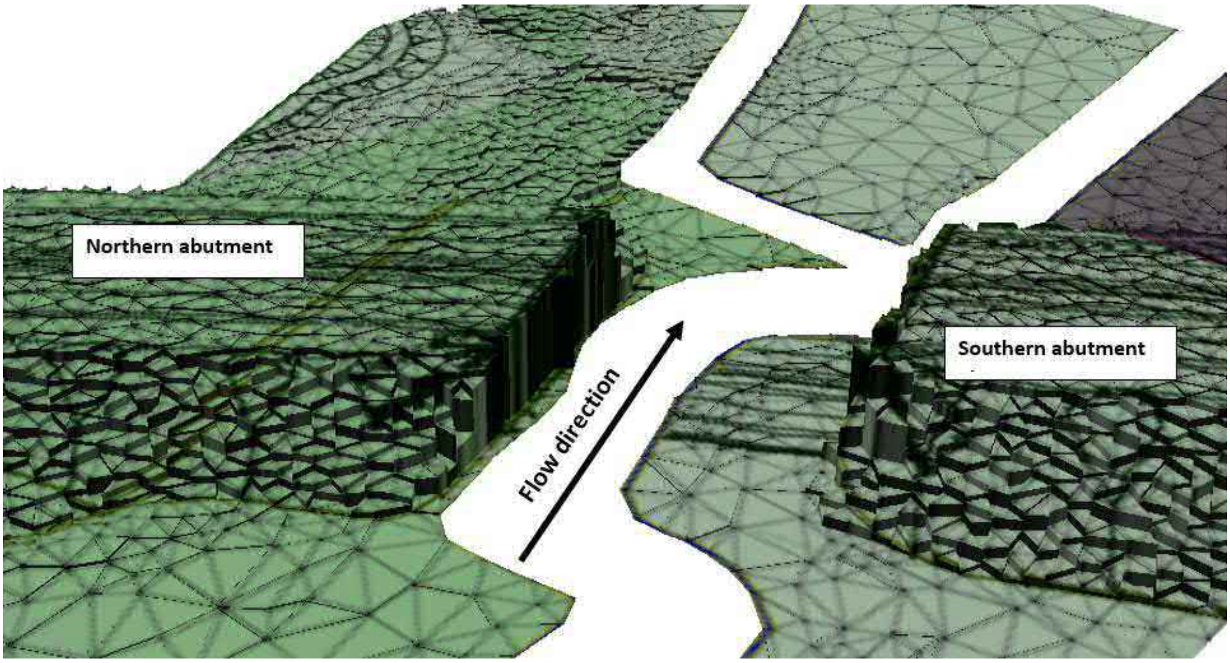
4.4. Post development modelling

4.4.1. The baseline modelling demonstrates that the proposed bridge to the east of Honingham crosses an area where flooding is predicted from both banks of the River Tud. To assess the impact of the proposal further modelling was therefore undertaken.

4.4.2. The bridge has been designed based on the water levels outlined above. The soffit will have an elevation at least 2m above the 22.563m AOD design water level. As such, adequate freeboard will be provided and the only element of the design that will impact flows are the two abutments. For the post development modelling the bridge has therefore been represented purely within the 2D domain of the model.

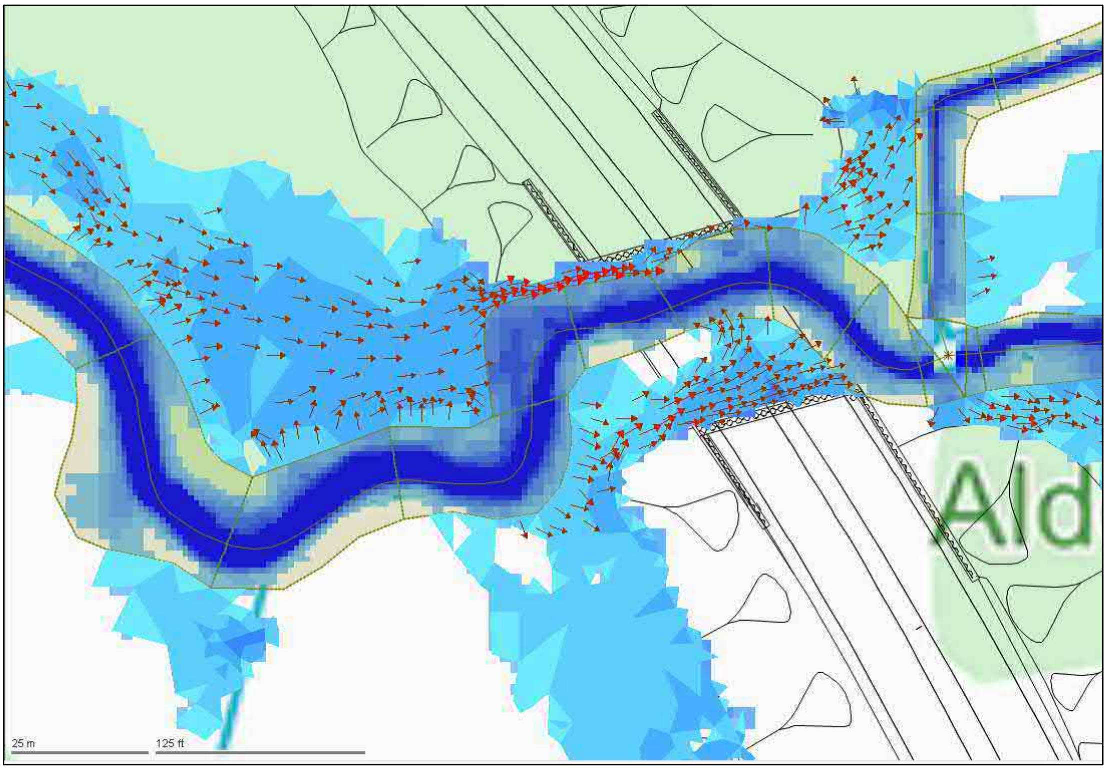
4.4.3. The post development modelling involved integrating a 3D model of the scheme into the baseline ground model (see Section 3.5). The 2D zone was then re-built using the updated ground model, and break lines added to ensure enough detail was captured. Four bank points located close to the abutments had their bank coefficients set to 0 to prevent flow oscillations and reduce instability. All other elements of the model remained unchanged from the baseline. An overview of the bridge abutments as represented in the model mesh can be seen in Figure 4-5. The new A47 bridge was only represented in the 2D mesh, no 1D bridge openings or deck geometry was included. This was deemed appropriate as the proposed bridge deck soffit will be constructed well above the design flood level with freeboard well in excess of 600mm,

Figure 4-5 Overview of the bridge abutments represented in the model mesh



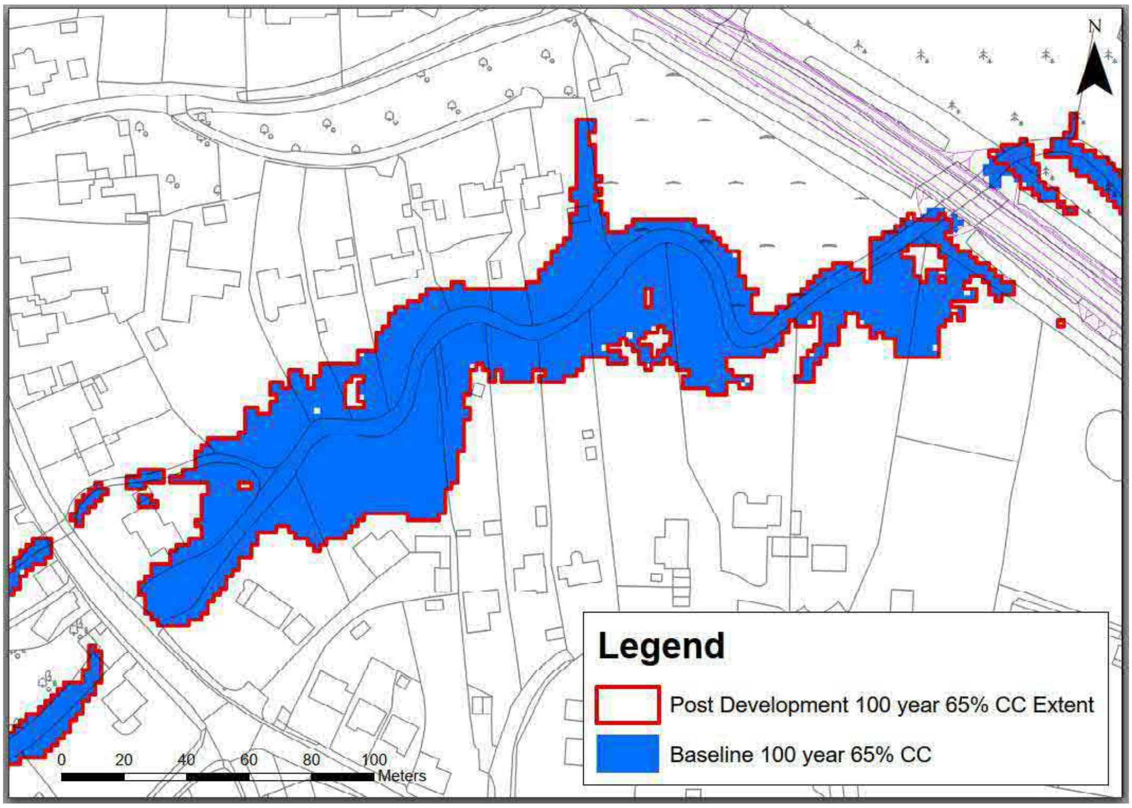
4.4.4. A comparison of peak water levels can be seen in Appendix C and indicate that the bridge will increase water levels upstream and downstream of the crossing. A maximum increase of 17mm is predicted immediately upstream of the bridge for the 100-year event and 72mm with a 65% climate change allowance respectively. This increase is due to the abutments intercepting and funnelling floodwater back into the channel, as can be seen in Figure 4-6.

Figure 4-6 Flow velocity arrows around the abutments for the 100-year event (plus 65% climate change).



4.4.5. The impacts of the bridge on peak water levels extend approximately 500m downstream and 700m upstream of the crossing, beyond the existing A47. There are, however, no receptors downstream within the area of impact and the increase in peak levels upstream of the existing A47 is below 10mm, which amount to less than 1% change in depth. A comparison of the flood extent for the 100-year event (65% climate change) is shown in Figure 4-7 and demonstrates that no new receptors will be affected by the proposal.

Figure 4-7 Comparison of the baseline and post development flood extent for the 100-year event with a 65% climate change allowance.



4.5. Summary

4.5.1. Hydraulic modelling has been undertaken to assess the impact of the proposed A47 scheme on flood risk. Baseline modelling shows flooding around Honingham, downstream of the existing A47, and at Hockering. Most of the Proposed Scheme is outside of the 100-year flood extent both with and without a climate change allowance (both 35 and 65%). The footprint of both abutments of the proposed bridge crossing (south of Honingham) are within the floodplain of the River Tud hence compensatory storage will be required.

4.5.2. The model results were found to be moderately sensitivity to variations in roughness and inflows, however, the percentage change in depth at cross-sections within the area of interest remained below 10%. The model was found to be insensitive to variations in the bank coefficients and the downstream boundary.

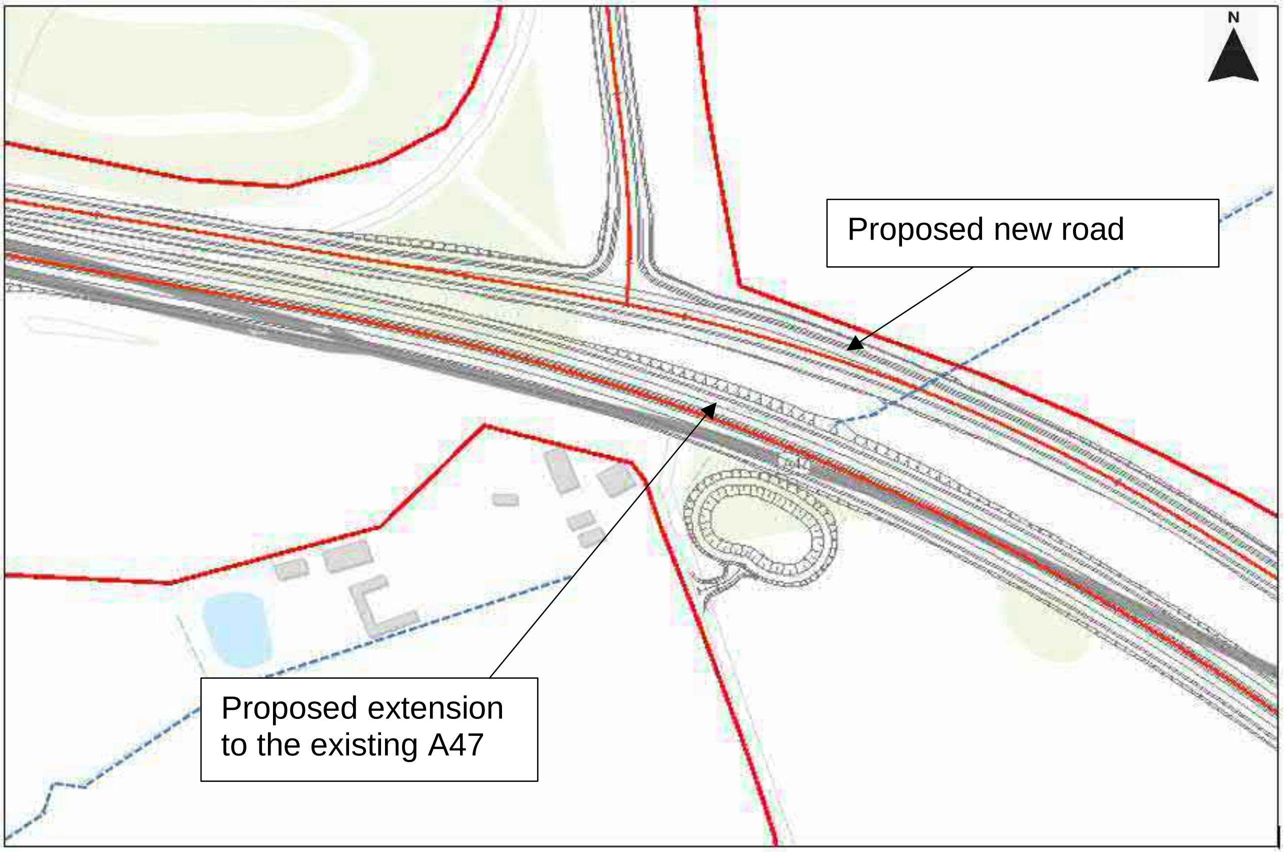
4.5.3. The post development modelling demonstrates that the abutments will intercept and funnel floodwaters back into the main River Tud channel. This is predicted to increase water levels upstream and downstream of the bridge. There are, however, no receptors downstream of the crossing within the area of impact.

Similarly, the increase in water levels upstream of the existing A47 were found to be minor (< 10mm) and within model tolerance. No new receptors are therefore predicted to be affected by the proposal.

5. Oak Farm ordinary watercourse baseline and proposed modelling

5.1.1. The Oak Farm watercourse is located approximately 3km west of Hockering. The watercourse drains agricultural land to the north of the A47 and between the A47 and Low Road. The watercourse passes south westwards under the A47 and Low Road via culverts before flowing southwards and discharging into the River Tud. An overview of the proposed new A47 crossing can be seen in Figure 5-1 with the watercourse denoted by the light blue dashed line.

Figure 5-1 Proposed crossing of the Oak Farm watercourse.



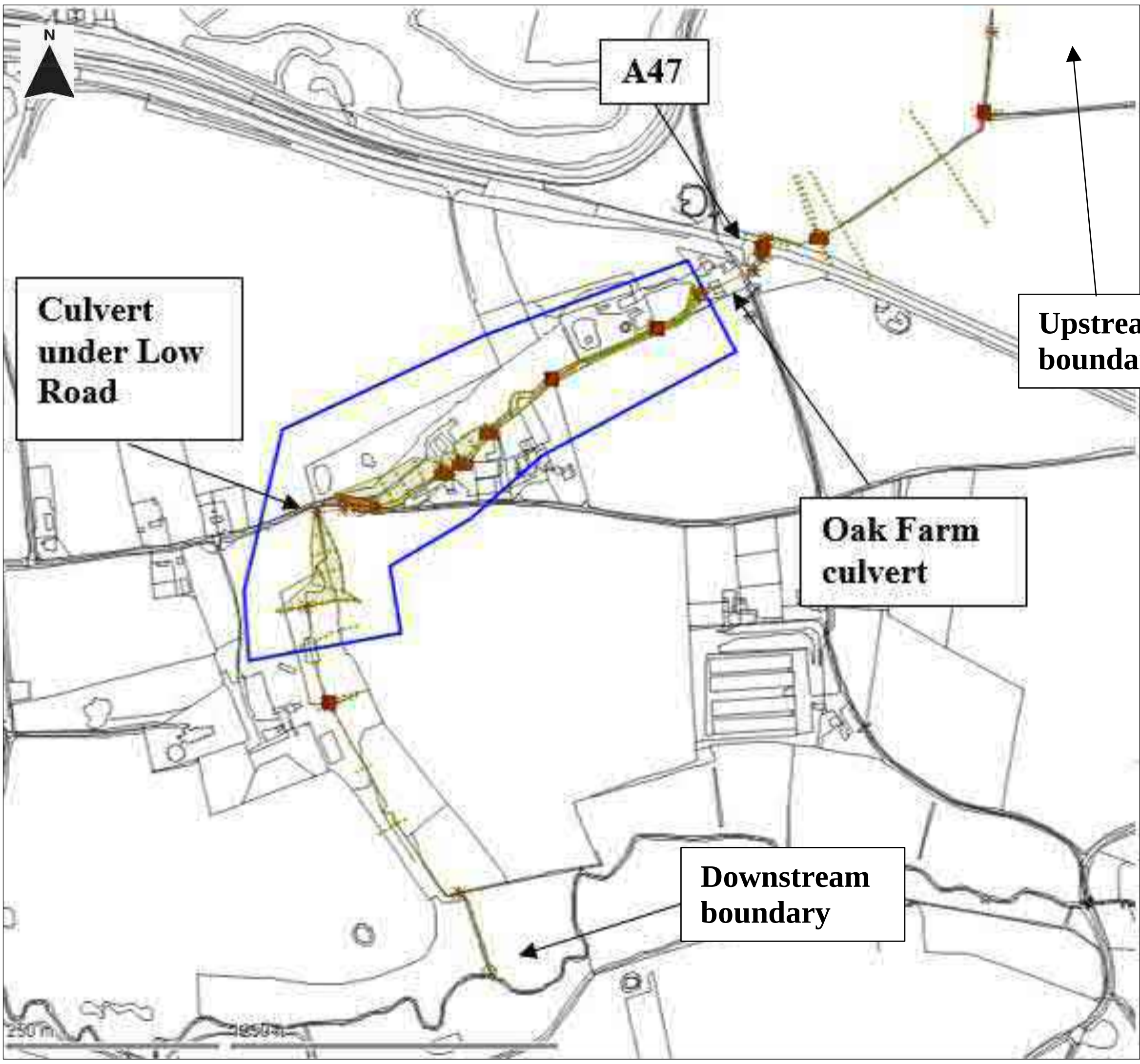
Esri, HERE, Garmin, FAO, NOAA, USGS

5.1.2. The watercourse has a total estimated catchment area of 1.5km^2 and an average annual rainfall of 660mm. The catchment has a low-lying topography, particularly north of the A47, and covers mainly rural (arable) land to the north of the A47 as well as between the A47 and Low Road. There are several small ponds within the catchment; however, the degree of attenuation provided is considered to be negligible.

5.1.3. The catchment is underlain by chalk bedrock hence flows are likely to have a significant baseflow component. The Lowestoft Formation is the main superficial deposit and this is described by the BGS as chalky till with outwash sands, gravels and till. The north-western part of the catchment is dominated by glacio-fluvial sand deposits of the Sheringham Cliffs Formation.

5.1.4. A 1D-2D model of the Oak Farm watercourse and its floodplain was created in Infoworks ICM (version 9). An overview of the model can be seen in Figure 5-2 and Appendix H. The blue area denotes the 2D zone extent, the green area represents the 1D domain. The following sections provide an overview of each component of the model.

Figure 5-2: Overview of the hydraulic model extent and 2D domain



5.2. 1D domain

5.2.1. The model covers approximately 1.7 km of the Oak Farm watercourse from a point 400 m upstream of the existing A47 culvert (606515, 313752) to the confluence with the River Tud (606514, 313752).

5.2.2. The model contains a total of 47 cross-sections, 20 of these were taken from survey undertaken by Storm Geomatics in November 2019. A further 26 interpolated cross-sections were added mainly at the downstream elevations of minor culverts and upstream of Low Road to improve the definition of the channel, as well as model stability. The banks of the interpolated sections were updated using 2m resolution LiDAR.

5.2.3. The upstream boundary was set approximately 400m upstream of the first surveyed hydraulic structure. The cross-section at the upstream boundary was created using 2m resolution LiDAR and the bed was lowered based on the average difference in level between the survey and LiDAR. This was found to provide a bed gradient consistent with the remainder of the channel downstream.

5.2.4. The downstream boundary was located at the surveyed cross-section immediately upstream of the confluence with the River Tud. Further sensitivity testing was undertaken and demonstrated that the results within the area of interest were insensitive to variations in water level along the River Tud.

5.2.5. The upper reaches of the watercourse upstream of the A47, and from a point 300m downstream of Low Road to the confluence, were retained as 1D. Cross-sections were extended using 2m LiDAR to ensure floodwaters for all events were captured within the 1D section and no glass walling occurred. This was judged to be an appropriate modelling approach given that floodwaters were predicted to be contained close to the channel in these locations. There were also unlikely to be any complex floodplain flow patterns given the rural nature of the floodplain.

5.3. 2D domain

5.3.1. The 2D domain was defined to cover all areas where out-of-bank flows are predicted within the area of interest (see Figure 5-2). The 2D domain was meshed using the same ground model (based on 2m LiDAR) used to extend the river sections. The maximum meshing element size was set to a value of 50 m^2 and the smallest element area was 5 m^2. The maximum height variation between elements was 0.125 m, with terrain sensitive meshing applied to ensure that enough ground detail was captured. The default Manning's roughness value of the 2D Zone was set to 0.04 to represent medium height grass and brush vegetation.

5.3.2. During meshing, at the 1D-2D interface, mesh elements above ground level were lowered to the surveyed 1D bank levels. This ensured that there was consistency between the two datasets and reduced any potential numerical instability.

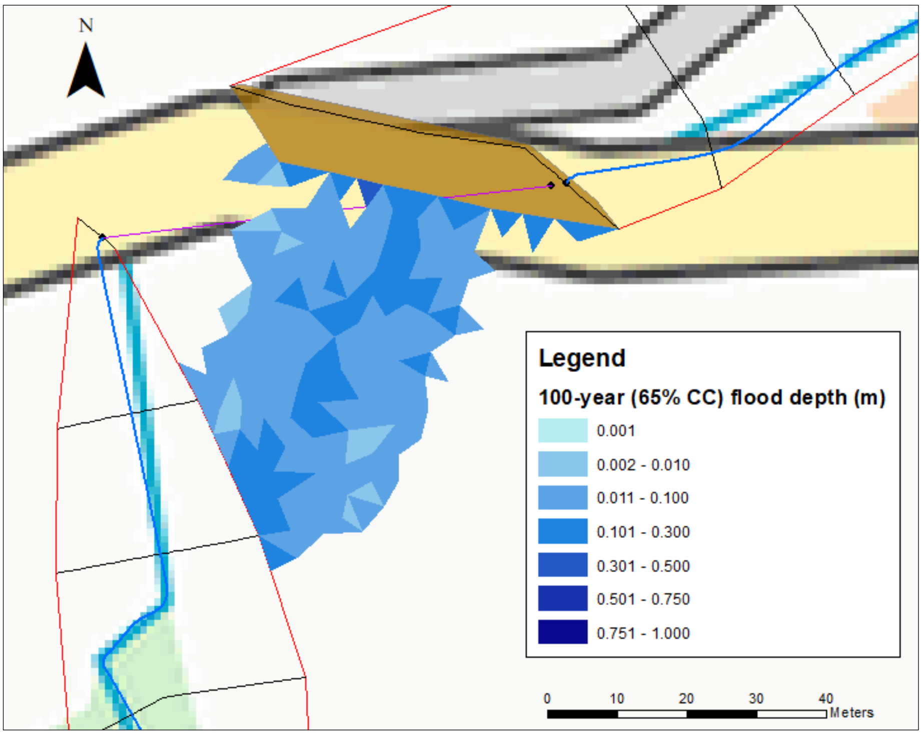
5.3.3. One building, which was predicted to be affected by flooding, was represented as both a mesh and a roughness zone within the 2D zone. The building threshold was set to a value of 300mm above the LiDAR ground level and the Manning's roughness value was set to 1.

5.4. 1D-2D connections

5.4.1. The 2D area is linked to the 1D river channel through bank lines, where flow is passed between the 1D and 2D computational model domains. All riverbanks from 50m downstream of the A47 to 200m downstream of Low Road can exchange flow between domains, with a discharge coefficient of 1 and a modular limit of 0.7 applied.

5.4.2. Low Road was predicted to overtop for the 30-year event with flows re-entering the channel further downstream. To represent this process an in-line bank was added along the road crest with elevations taken from LiDAR (see Figure 5-3). This acts as a connection between the 1D river reach and the 2D zone allowing for any water which exceeds the road height to flow south west. This had a bank coefficient of 1 and a modular limit of 0.7 applied. This approach allowed for the volume of water over the road to be quantified while also ensuring that the model was stable.

Figure 5-3 Overview of the flooding predicted through the inline bank at Low Road



5.5. Hydraulic structures

5.5.1. The model includes 11 culverts which were considered to potentially impact flows and flood risk within the area of interest. These were represented as culvert links with inlet and outlet nodes added where appropriate. Overtopping of these structures was accounted for by adding regular or irregular weirs.

5.5.2. The inverts and dimensions of all culverts were taken from the 2019 Storm Geomatics survey. Where inverts were found to be significantly below the recorded bed level, a sediment depth was added to ensure continuity in the bed profile.

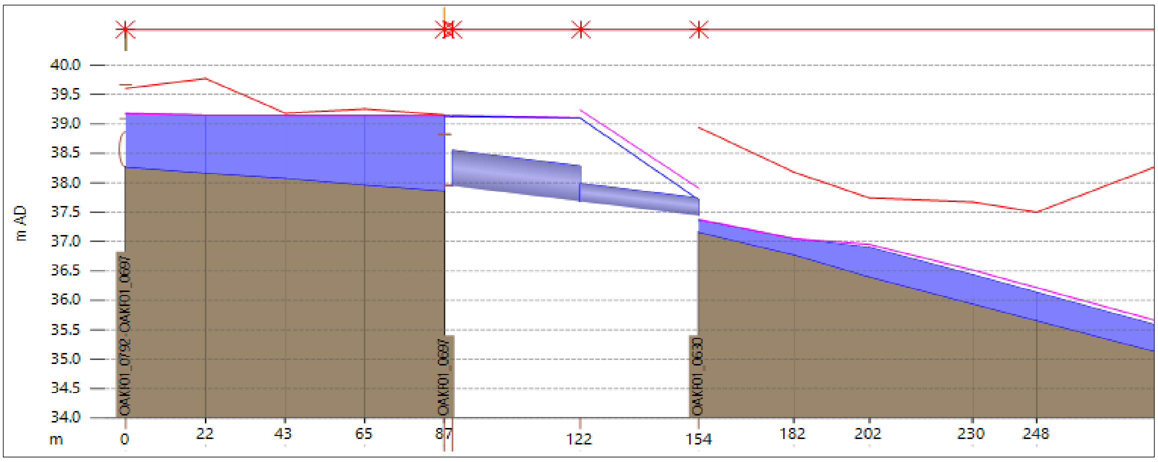
5.5.3. The survey indicated that three hydraulic structures present a potential constraint on flows. In particular, the outfall from a 72m culvert downstream of the A47 (adjacent to Oak Farm, see (Figure 5-4) was not fully captured within the survey and only the informal structure shown was identified. The change in dimensions were accounted for in the model by dividing the culvert link and setting the downstream section to a rectangular shape. The size of the culvert downstream was estimated using the survey drawing with a width of 2400mm and height of 420mm applied. A sediment depth of 50% was then added to represent the reduced area and the Colebrook White roughness for the culvert barrel increased to 15mm.

Figure 5-4 (A) Inlet and (B) outlet from the culvert downstream of the A47

The circular culvert under Low Road was also noted to change in diameter from 600mm to 300mm (see Figure 5-5). This was accounted for by splitting the culvert into two sections and applying separate dimensions as can be seen in Figure 5-6. The Colebrook White roughness value for the culvert barrel was also increased to a value of 15mm.

Figure 5-5 (A) Inlet and (B) outflow of the culvert under Low Road

Figure 5-6 Longitudinal profile along the culvert under Low Road



5.5.4. Sedimentation and overgrowth were noted at the most downstream culvert (culvert 11, see Figure 5-7) hence a 50% sediment depth was applied.

Figure 5-7 Inlet to culvert 11 showing significant blockage

5.6. Roughness values

5.6.1. The roughness values used in the model are shown in Table 5-1. Channel roughness values of 0.04 for the channel bed is consistent with site photographs which show overgrowth (weeds) and some pebbles. A value of 0.06 was considered appropriate for the bank, as site photos showed several sections with heavy brush/overgrowth.

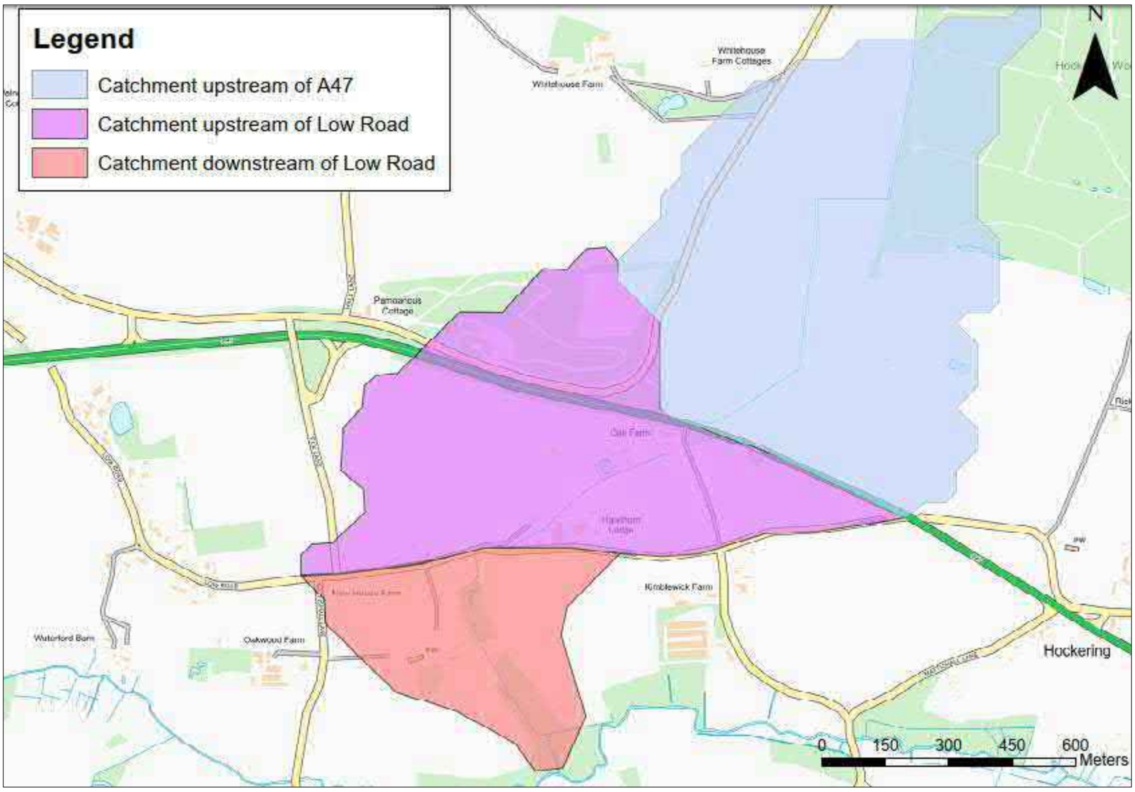
Table 5-1 :Roughness values

Domain	Feature	Roughness type	Value
1D	Channel bed	Manning	0.04
1D	Channel banks	Manning	0.06
1D	Culverts	Colebrook White (mm)	1.5
1D	Blocked culvert	Colebrook White (mm)	15
2D	2D Zone (default)	Manning	0.04
2D	Buildings	Manning	1

5.7. Hydrological analysis

5.7.1. The Oak Farm watercourse is ungauged therefore catchment descriptors were obtained from the FEH web service (see Appendix A). The catchment boundaries were then checked and refined using LiDAR. The difference in area was approximately 0.21 km^2. An overview of the refined catchment areas can be seen in Figure 5-8.

Figure 5-8 Overview of the catchment areas for the Oak Farm watercourse



Contains OS data. © Crown copyright and database rights 2020

5.7.2. The catchment is defined as rural (URBEXT <0.125) and the descriptors (provided in Appendix A) show a relatively high base flow index (>0.6), which reflects the underlying highly productive chalk aquifer.

5.7.3. For comparative purposes peak flows have been estimated using ReFH2-FEH13 (V2.3), FEH rainfall-runoff (FEH RR) and FEH statistical methods. The FEH statistical peak flows were calculated in WINFAP-FEH (V 4) and the FEH RR method was applied using the Flood Modeller software package.

5.7.4. The critical duration and all other ReFH2 model parameters were based on the default catchment-based equations[8]. For the catchment upstream of the A47 a critical duration of 5.5 hours was estimated and downstream 4.5 hours, hence the average of 5 hours was used. For FEH RR a critical duration of 10 hours produced the highest peak flow and was therefore used in the analysis. For both techniques a winter storm event was selected.

5.7.5. For the FEH statistical method QMED was calculated for both the upper and lower catchment areas using the catchment descriptor equation, and then a pooling group was identified for the total catchment. Several potential donor sites for QMED adjustment were identified in WINFAP however all had large

[8] http://files.hydrosolutions.co.uk/refh2/ReFH2_Technical_Report

size differential to the subject site. To be conservative the donor (33046 - Thet at Redbridge) was used as this resulted in a slight increase in QMED.

5.7.6. The initial default pooling group had a heterogeneity greater than 2 therefore a review of the most discordant gauges was undertaken using the National River Flow Archive website. Following this, all sites were judged to be suitable for inclusion based on a review of their catchment and gauge characteristics. A refinement to the pooling group to reduce H2 further was found to reduce peak flow estimates and hence retaining the original pooling group was considered conservative.

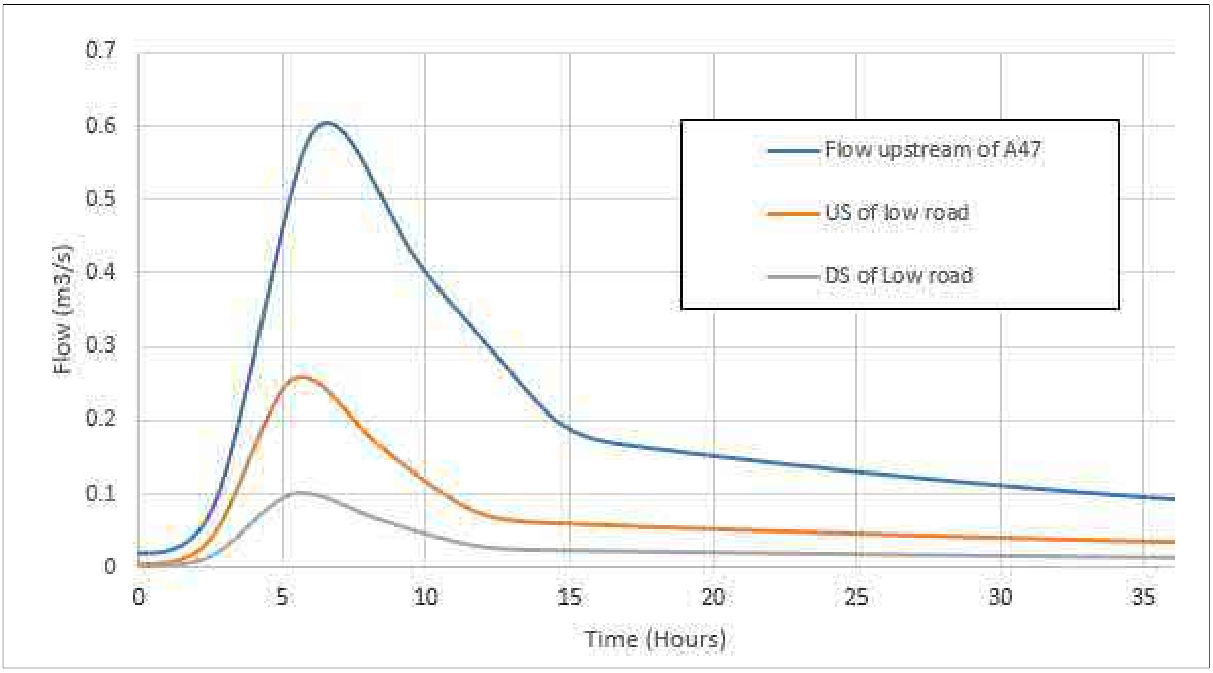
5.7.7. The results, shown in Table 5-2, indicate that the FEH rainfall-runoff method provided the most conservative estimate of peak flows; however, this has been largely superseded by ReFH2. On the other hand, FEH statistical produced the lowest estimate of flows and, given the uncertainty for small permeable catchments, was not judged to be appropriate. ReFH2 peak flows were therefore selected.

Table 5-2 Comparison of peak flow estimates calculated using three techniques

Return period (1:X)	ReFH2 urbanised peak flow (m^3/s)	FEH rainfall-runoff peak flows (m^3/s)	FEH statistical: default donor and pooling group (m^3/s)
30	0.685	1.374	0.65
100	0.965	1.950	0.864
1000	1.760	3.829	1.487

5.7.8. Hydrograph shapes were defined using the ReFH2 software for the area upstream and downstream of the A47 using their associated catchment descriptors (see Figure 5-9). The catchment downstream of the A47 was scaled based on the area upstream/downstream of Low Road and applied at two separate points within the model.

Figure 5-9: Overview of the 100-year (no climate change) ReFH2 hydrographs used in the model



5.7.9. Following the most recent guidance on climate change allowances for the Anglian region[9], the hydrograph peaks were scaled by 35% and 65%. In addition, due to the potential for flooding of the new local access road outlined in Section 5.11 the 100-year event was also run with an 80% uplift to assess the high (H ++) end climate change scenario.

5.8. Run parameters

5.8.1. The model was run for a duration of 36 hours with a 1 second timestep and a 5-minute output interval. All simulations have volume and mass balance errors below 1% and hot start files were not required for any of the simulations.

5.9. Oak Farm baseline results

5.9.1. An overview of peak water levels at cross-sections within the vicinity of the A47 is shown in Table 5-3, and the cross-section locations have been provided in Appendix H. Upstream of the existing A47 a peak water level of 44.070 AOD is predicted for the 100-year event without an allowance for climate change. This increases to 44.687 and 44.849mAOD with a 65% climate change allowance and for the 1000-year event respectively.

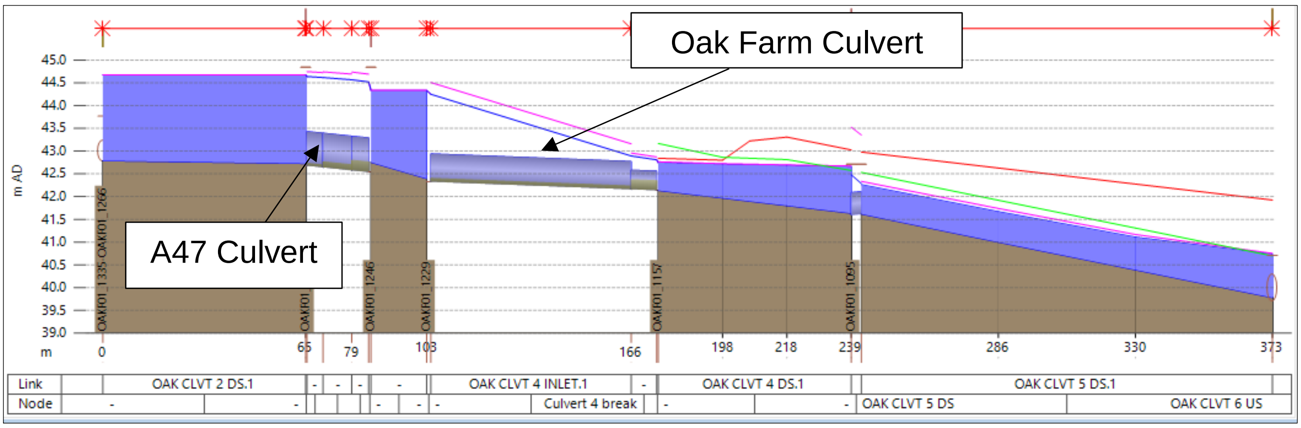
[9] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#table-1

Table 5-3 Estimated peak levels at cross-sections within the vicinity of the A47

	Peak Section Level (m AOD)			
Cross-section ID	**30-year**	**100-year**	**100-year (65% climate change)**	**1000-year**
OAKF01_1361	43.826	44.078	44.688	44.849
OAKF01_1335	43.822	44.078	44.688	44.849
OAKF01_1266	43.517	44.070	44.687	44.849
Existing A47 Culvert				
OAKF01_1246	43.377	43.838	44.360	44.566
OAKF01_1229	43.362	43.834	44.358	44.564

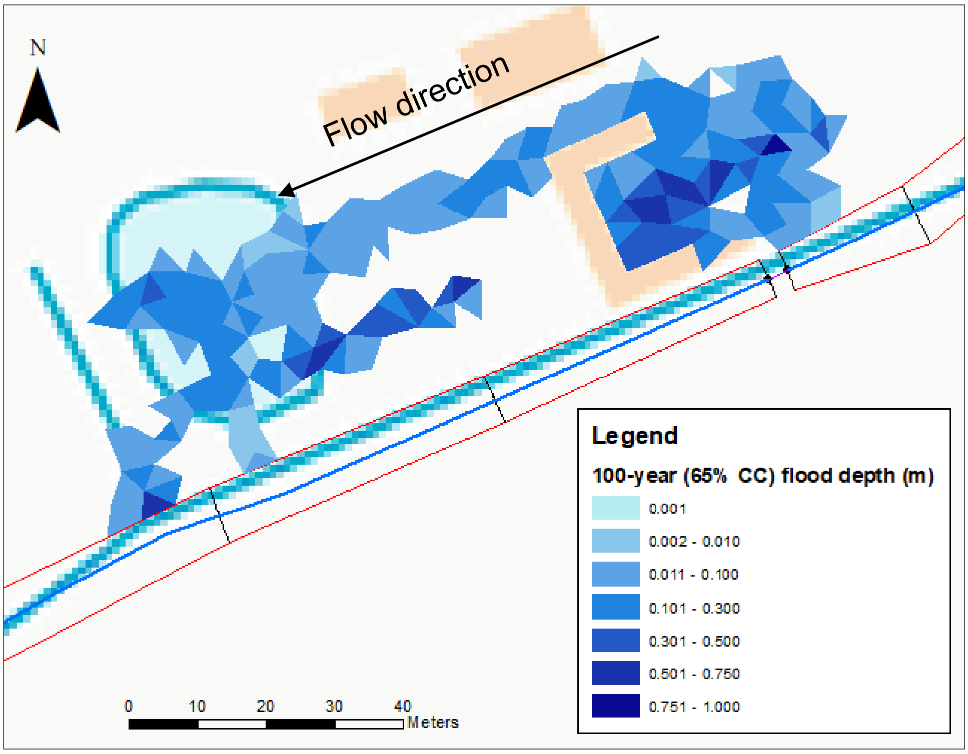
5.9.2. The culvert downstream of the A47 (close to Oak Farm) was found to provide a significant constraint on flows which results in backing up upstream where the new culvert is proposed, This can be clearly seen in Figure 5-10 where water levels exceed the soffit of the culvert for the 100-year (including a 65% climate change) scenario. The flood extent upstream of the existing A47 overlaps both the location of the new link road and the extension to the existing A47 (see Appendix J).

Figure 5-10 Longitudinal section showing backing up upstream of the A47 and the Oak Farm culvert



5.9.3. Flooding was predicted from the northern bank downstream of the A47 for all modelled events. This was thought to be caused by the undersized footpath culvert and the resulting floodwaters flow south-westwards and affect a residential property (see Figure 5-11).

Figure 5-11 Flooding downstream of the A47 for the 100-year event with a 65% climate change allowance



Contains OS data. © Crown copyright and database rights 2020

5.9.4. Similarly, flooding is predicted for all events over Low Road to the south due to the undersized culvert outfall noted in the survey. This provides a significant constraint on flows and elongates the hydrograph upstream of the culvert. Photos taken during the site survey (see Figure 5-5) show that the road is at a low elevation relative to the headwall of the culvert hence this flow pathway was considered to be realistic.

5.10. Sensitivity analysis

5.10.1. The watercourse is ungauged and, following a review of available data, no information could be found of previous flooding. The model results could therefore not be calibrated or validated.

5.10.2. A series of additional model runs were undertaken to evaluate the sensitivity of the model to different factors. For all runs the 100-year event without a climate change allowance was applied. The parameters assessed included:

- altering the channel roughness by +/- 20%;
- altering the inflow hydrographs by +/-20%
- adding a level file to the downstream boundary set to the 1 in 50-year peak water level at the confluence with the River Tud.

- adding a level file to the downstream boundary set to the 1 in 100-year peak water level at the confluence with the River Tud.

5.10.3. The sensitivity analysis (Table 5-4) indicates that the results within the vicinity of the new road are moderately sensitive to variations in roughness and, to a greater extent, inflows. Analysis of the downstream boundary indicates that modelled flood levels in the area of interest around the A47 are insensitive to water levels of the River Tud. In the absence of calibration and validation the model results should be considered accurate to approximately ± 30cm.

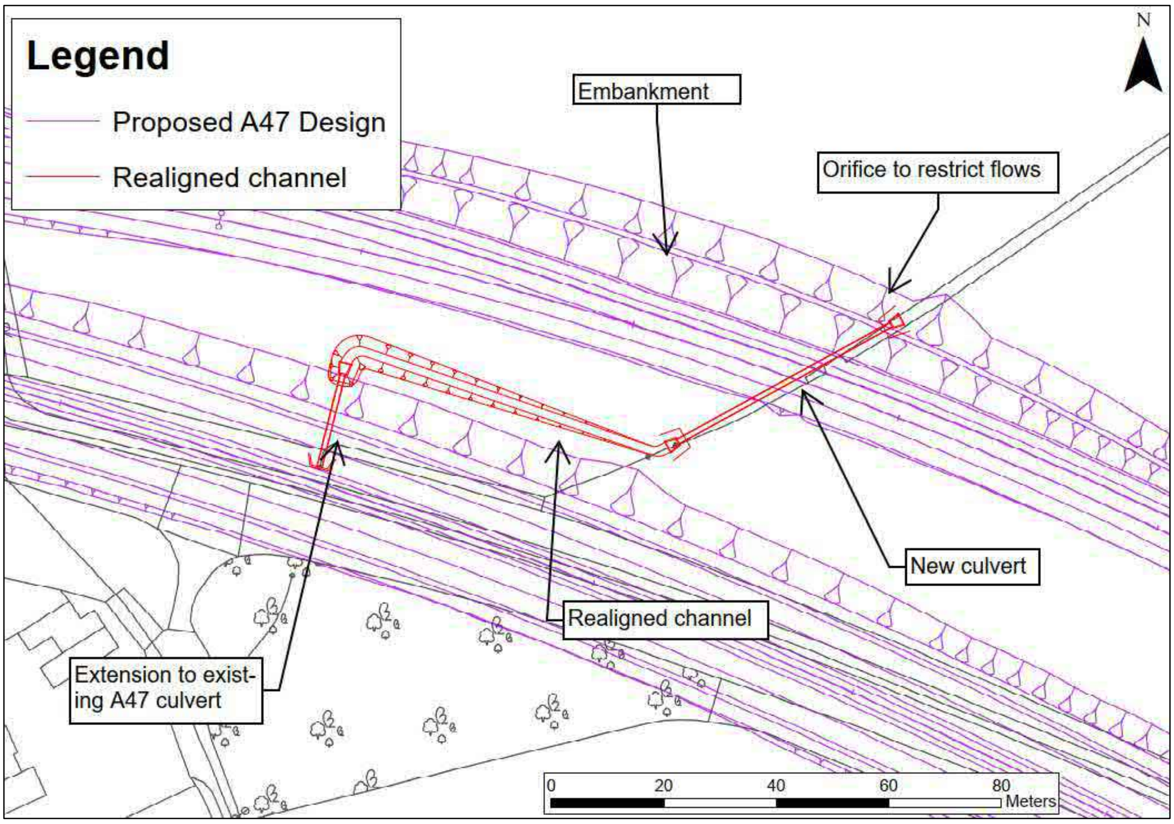
Table 5-4 Oak Farm watercourse sensitivity analysis results for nine cross-sections upstream and downstream of the existing A47 culvert

Scenario	Maximum change in peak level (m)	Average change in peak level (m)	Average % Change in Depth	Maximum % change in depth
+20% Roughness	0.048	0.019	2.8%	9.3%
-20% Roughness	-0.058	-0.020	-3.1%	-10.8%
Downstream boundary set to peak 50-year Tud Level	0.000	0.000	0.0%	0.0%
Downstream boundary set to peak 100-year Tud Level	0.000	0.000	0.0%	0.0%
+20% flows	0.241	0.186	17.1%	30.3%
-20% flows	-0.341	-0.221	-19.8%	-26.3%

5.11. Post development modelling

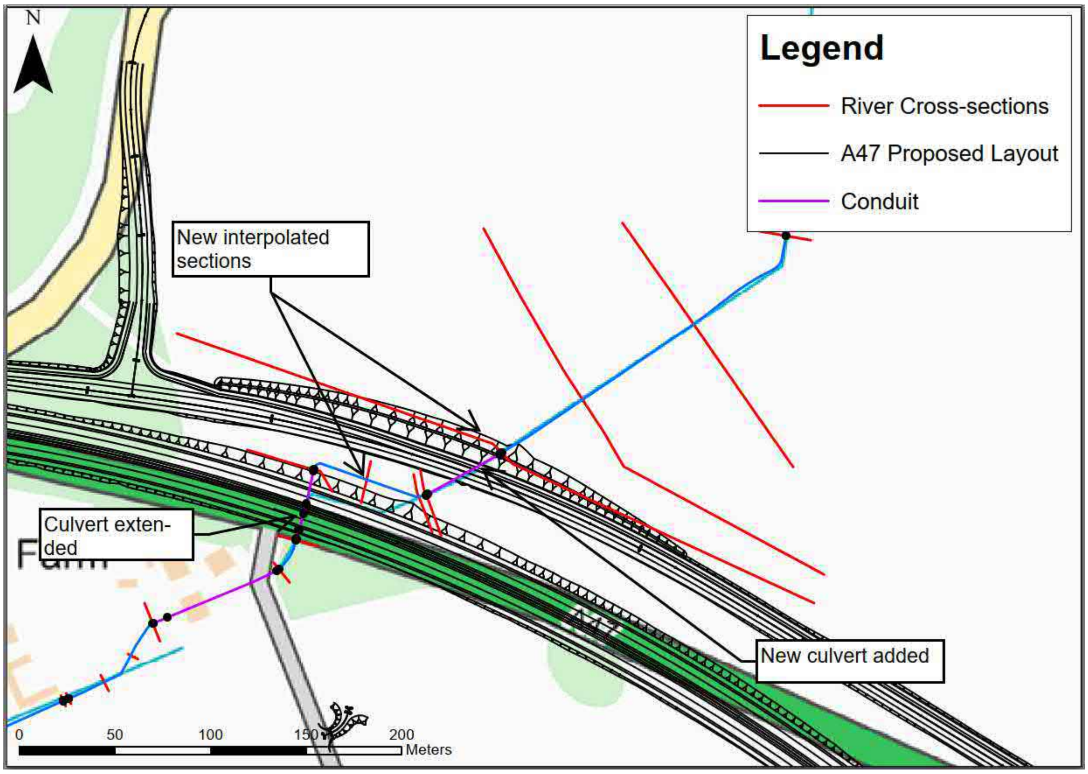
5.11.1. As part of the Proposed Scheme, a new link road will cross the Oak Farm watercourse upstream of the existing A47. A section of the channel will be therefore be culverted. In addition, the existing A47 culvert will be extended northwards and the channel upstream realigned. To ensure that there is no detrimental impact on flood risk downstream a 350mm circular orifice will be placed at the inlet to the new culvert to throttle flows. Similarly, an embankment will be constructed upstream to contain floodwater and ensure that there is no flood risk to the new local access road. An overview of the proposal can be seen in Figure 5-12.

Figure 5-12 Overview of proposed development at A47



5.11.2. For the post-development scenario, interpolated cross section were added upstream and downstream of the new road. The reach in-between was removed and replaced with a culvert link. The invert levels of the new culvert were set to the lowest ground elevation of the closest cross section to ensure that the bed gradient was maintained. The new road was not explicitly represented in the model and no overtopping can occur, instead water can build up upstream. This allowed for a peak water level to be extracted and used to inform the design of the embankment. A 350mm orifice was attached to the inlet of the new culvert. An interpolate was added at the location of the inlet to the extended A47 culvert and a new conduit link added. An overview of the post development model can be seen in Figure 5-13.

Figure 5-13 Overview of the Oak Farm Post Development Model



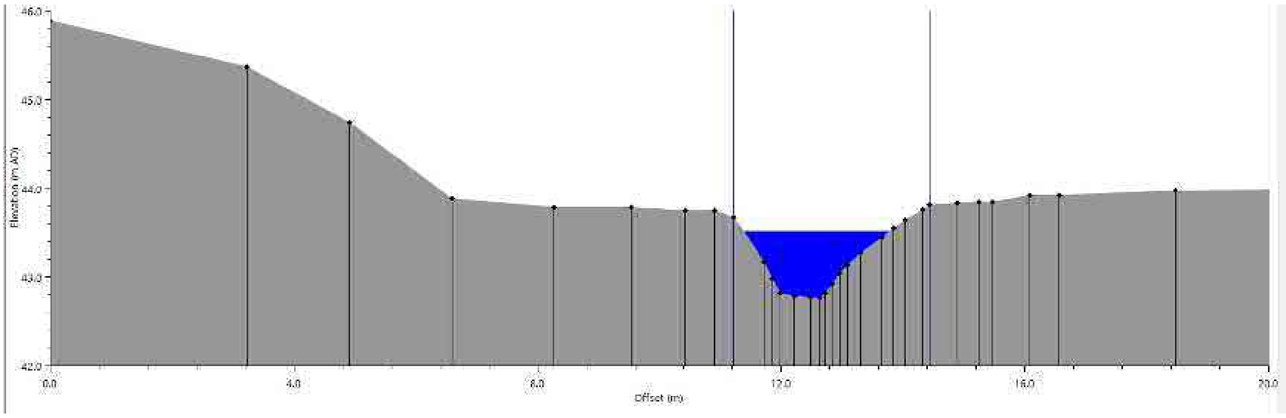
5.11.3. The analysis indicates that the 350mm orifice would ensure that water between the existing A47 and new link road remains in bank (see Figure 5-14). However, the orifice results in a build-up of water upstream of the new road with a peak water level of 45.513m AOD predicted at the embankment for the 100-year event plus 65% climate change allowance. The proposal moves the floodwater which previously accumulated at the inlet to the existing A47 in the baseline scenario further upstream thereby increasing water levels (see Appendix I).

5.11.4. The crest of the embankment has been designed to have an elevation of 46.5m AOD which provides greater than 0.6m freeboard above the modelled flood level. The new embankment would also contain the 1000-year flood event (see Table 5-5).

Table 5-5 Peak water levels upstream of the proposed culvert inlet and freeboard to the embankment crest

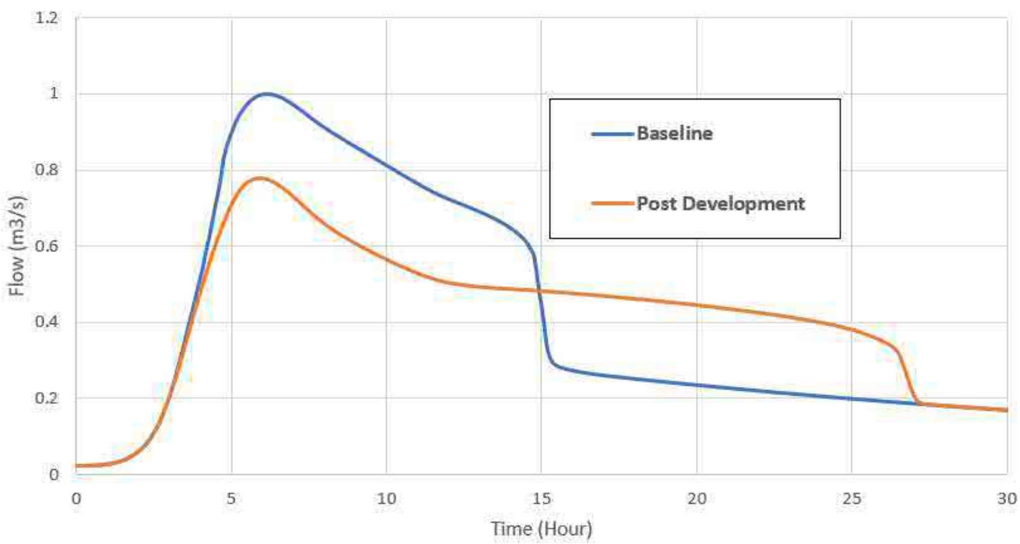
	Peak Level (m AOD)					
Object ID	30 year (No CC)	100 year (No CC)	100 year (35% CC	100 year + 65% CC	100 year + 80% CC	1000 year No CC
Upstream of new road	44.771	45.089	45.337	45.513	45.708	45.671
Freeboard (mm)	1729	1411	1163	987	792	829

Figure 5-14 Water levels at cross-section between the extended A47 and new culverts for the 100 year event with a 65% allowance for climate change.



5.11.5. A comparison of the hydrographs downstream (Figure 5-15) demonstrates that the orifice would result in a reduction in flow downstream of the existing A47 culvert. This results in a net betterment in terms of flood risk when compared with baseline conditions, as can be seen in the table of water levels and flood extent maps in Appendix I and Appendix J.

Figure 5-15 Comparison of flows downstream of the existing A47 culvert for the 100-year event with a 65% allowance for climate change



Blockage scenarios

5.11.6. Further sensitivity analysis was undertaken to assess the potential impact of blockage to the new culvert. This was modelled by reducing the diameter of the 350mm orifice by 10% and 50%. The survey photos show the watercourse to be relatively clear and the upstream culverts would likely intercept any large debris hence these values were considered appropriate. For all scenarios the design 100-year event with a 65% climate change allowance was applied.

5.11.7. The results (Table 5-6 and Table 5-7) indicate that a 10% blockage would increase water levels by 100mm and by 531mm for the 50% blockage. This equates to a percentage change in depth of 4% and 22%. The impacts are, however, relatively localised and do not result in any overtopping of the embankment.

Table 5-6 Blockage scenario impacts on water levels

	No Blockage	10% Blockage		50% Blockage	
	level (m AD)	level (m AD)	Difference (mm)	Level (m AD)	Difference (mm)
Upstream of culvert	45.513	45.613	100	46.044	531
Freeboard (m)	0.987	0.887	-	0.456	-

Table 5-7 Blockage scenario impacts on water depths

	No Blockage	10% Blockage		50% Blockage	
	Depth[m]	Depth[m]	% Difference in Depth	Depth[m]	% Difference in Depth
Upstream of culvert	2.380	2.480	4%	2.911	22%

5.11.8. A peak volume upstream of the embankment of approximately 21,800m^3 was predicted for the 50% blockage scenario and 11,300m^3 for the 10% blockage scenario.

5.12. Summary

5.12.1. Hydraulic modelling has been undertaken to assess the flood risk from the ordinary watercourse adjacent to Oak Farm. Baseline modelling indicates that the existing A47 culvert and a culvert downstream provide a constraint on flows resulting in floodwaters accumulating upstream for the 100-year event. The footprint of the proposed new road and extension to the A47 overlaps with this flood extent.

5.12.2. Flooding was also predicted along the right-hand bank downstream of the existing A47 and over Low Road. Any development will therefore need to ensure that this flood risk is not exacerbated.

5.12.3. The proposed development includes the installation of a culvert under the new link road, an extension to the existing A47 culvert and the realignment of the channel in-between. To manage flood risk, an orifice will be placed at the inlet to the new culvert an embankment installed.

5.12.4. Post development modelling indicates that the incorporation of a 350mm orifice ensures that there is no increase in flows and a net betterment in terms of flood risk downstream. The proposed embankment crest level of 46.5m AOD provides greater than 600mm freeboard for the 100-year event (with a 65% climate change). The design also provides over 300mm freeboard for the 50% blockage scenario and is therefore considered to be robust.

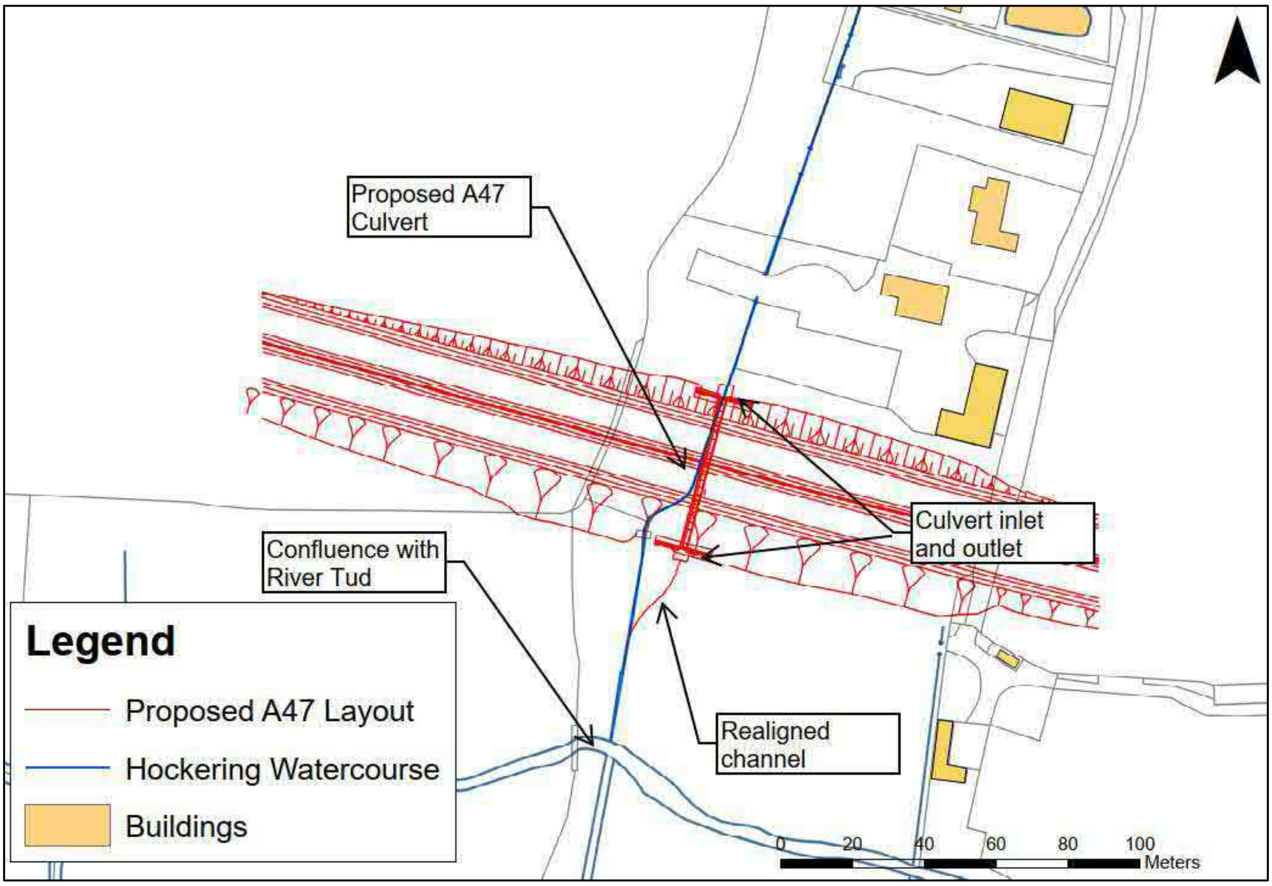
5.12.5. A peak volume upstream of the embankment of approximately 21,800m^3 was predicted for the 50% blockage scenario and 11,300m^3 for the 10% blockage scenario.

5.12.6. Inflows into the model were assessed using several methods and ReFH was selected as the most appropriate. Although this provided higher values compared to the FEH statistical method, it is significantly lower than the FEH rainfall-runoff method. If the FEH rainfall-runoff values are a better estimate of real flows, then the embankment could potentially be overtopped. The hydrology should be reviewed as the project progresses in detailed design.

6. Hockering ordinary watercourse modelling

6.1.1. A new culvert crossing is proposed beneath the new A47 carriageway along a minor watercourse located to the east of Hockering. An overview of the crossing can be seen in Figure 6-1. This includes the installation of a 2.05m by 2.05m box culvert with a 300mm bed layer at the base. In addition, the channel to the south will be realigned to facilitate better flow conditions out of the proposed culvert.

Figure 6-1 Proposed culvert crossing location at Hockering

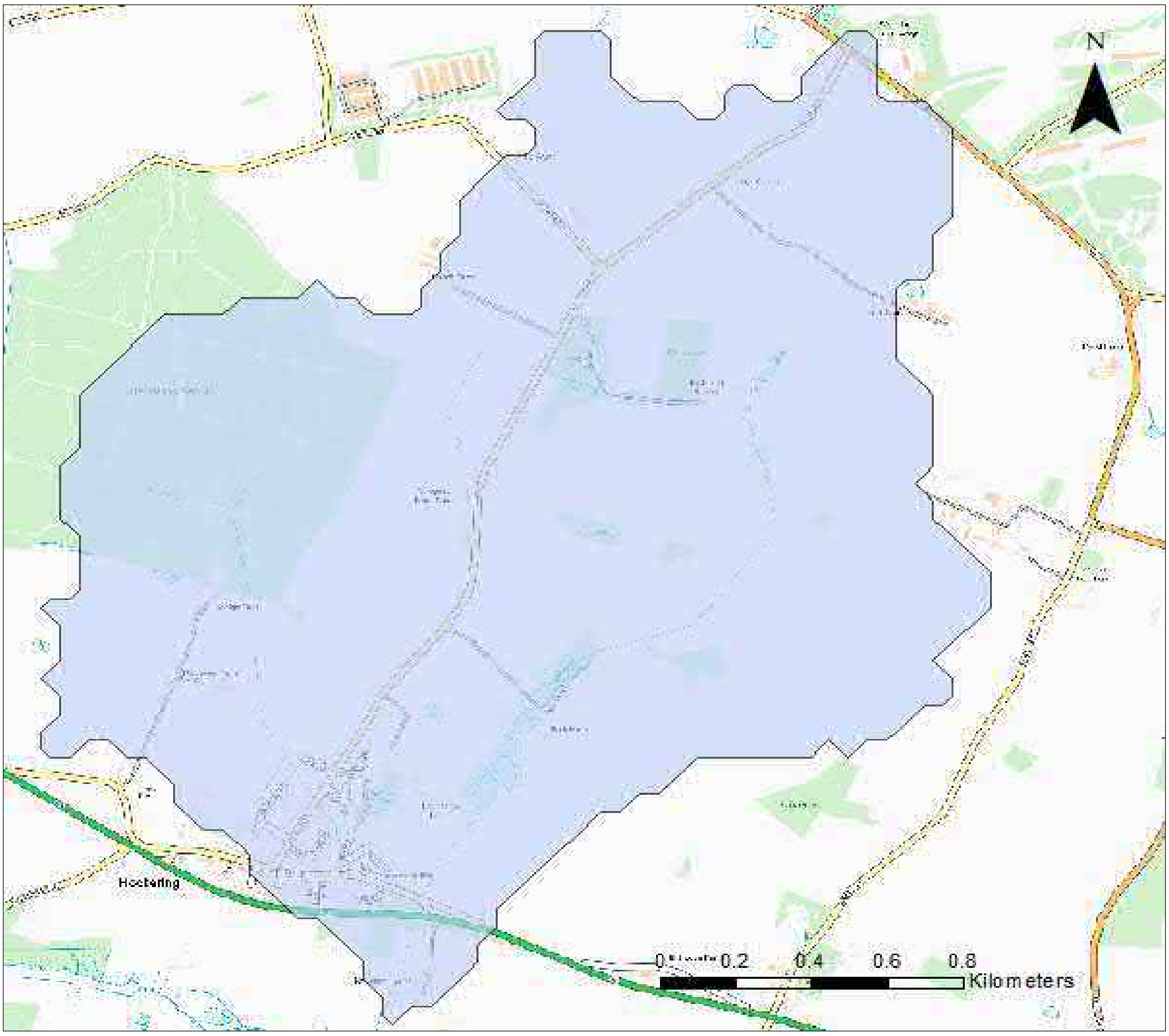


Esri, HERE, Garmin, FAO, NOAA, USGS

6.1.2. The Hockering watercourse runs to the east of Hockering. This has a total estimated catchment area of 4.17 km^2 (see Figure 6-2) and an average annual rainfall of 650mm. The FEH catchment boundary was checked against OS mapping and contour data and found to be acceptable. The catchment has a relatively flat topography and covers the mainly rural (arable) land to the north of the A47, as well as most of the village of Hockering. The watercourse receives flows from a series of ponds upstream of the A47, close to Park Farm. The catchment descriptors (see Appendix A) suggest that the catchment has only slight attenuation from reservoirs and lakes

6.1.3. The catchment is underlain by chalk bedrock categorised as a primary aquifer by the British Geological Survey hence flows are likely to have a significant baseflow component. The Lowestoft formation is the main superficial deposit and this is described by the BGS as chalky till with outwash sands, gravels and till. The upper part of the catchment is dominated by glacio-fluvial sand deposits of the Sheringham Cliff Formation.

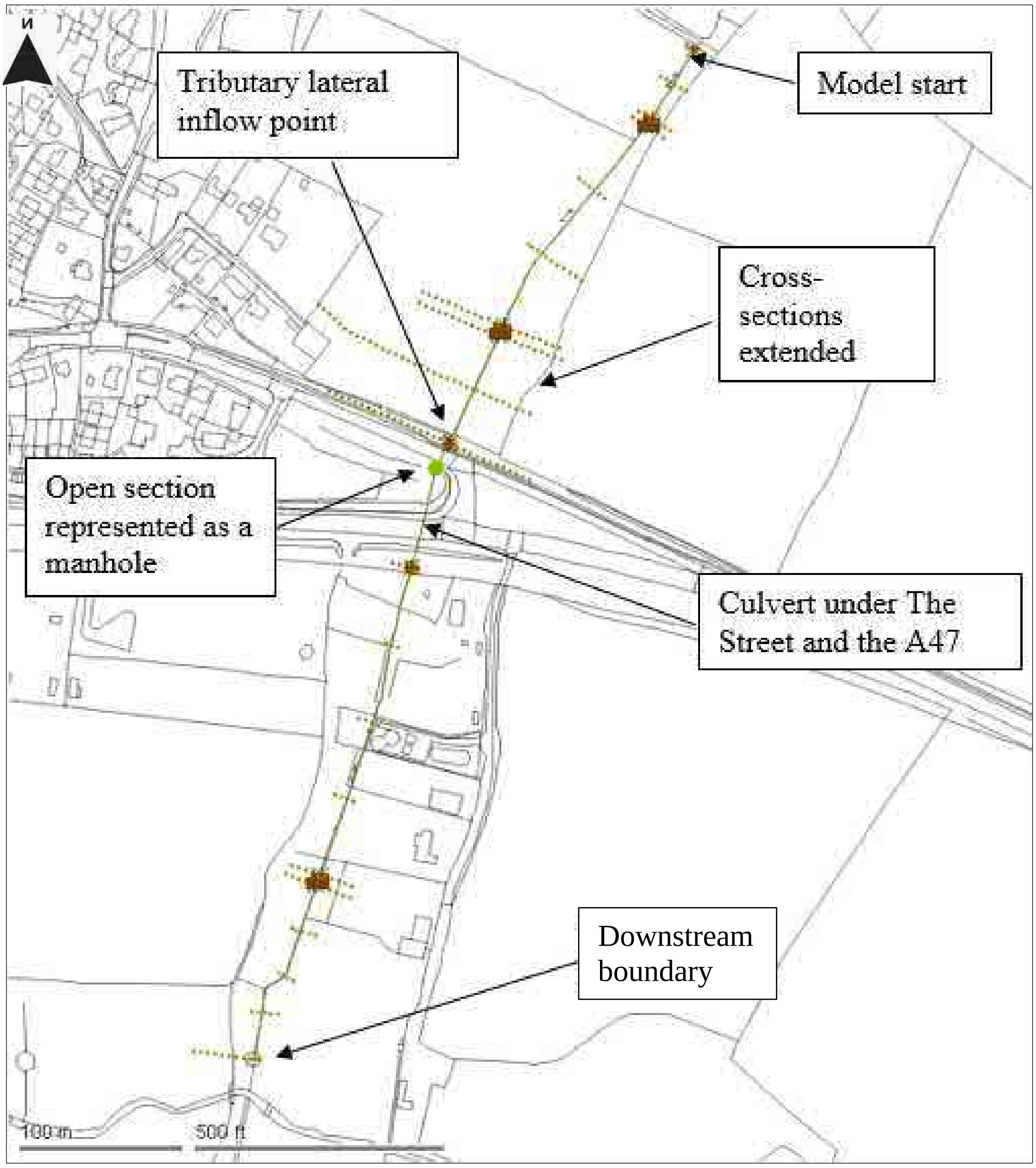
Figure 6-2 Overview of the FEH catchment for the Hockering watercourse



6.1.4. The watercourse flows in a south westward direction passing under the existing A47 and The Street via an extensive culvert. The watercourse then discharges into the River Tud, approximately 300m south of the existing A47. A tributary also connects into the watercourse immediately upstream of the inlet to the A47 culvert. This drains the area to the west and covers most of the village of Hockering.

6.1.5. A hydraulic 1D hydrodynamic model of the Hockering watercourse was created in Infoworks ICM (version 9). An overview of the model can be seen Figure 6-3 and Appendix K. The following sections provide an overview of each component of the model.

Figure 6-3 Overview of the ICM Hockering model



6.2. 1D domain

6.2.1. The model covers 676m of the Hockering watercourse from the upstream extent at an outfall from a large pond associated with Park Farm (608026, 313171) to the confluence with the River Tud (607761, 312562).

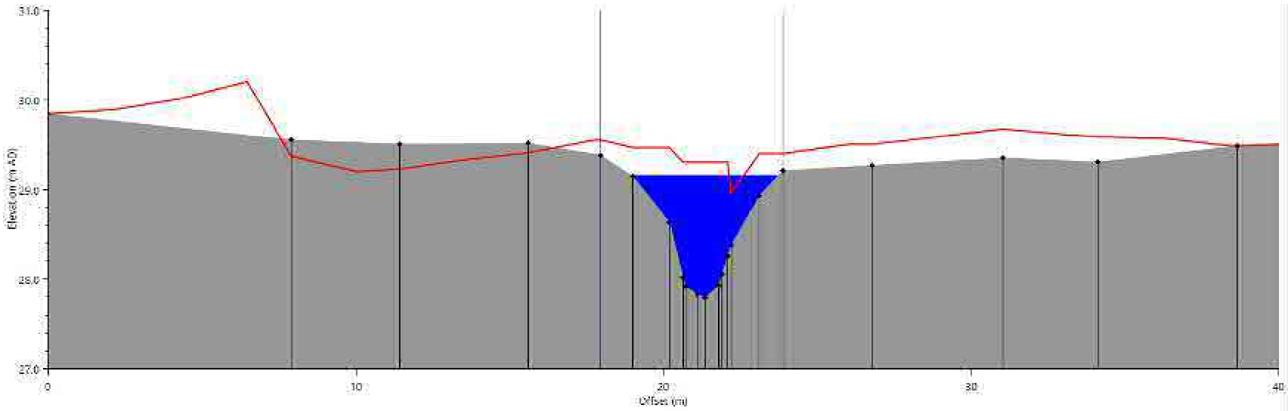
6.2.2. The model contains a total of 20 cross-sections, 7 of these were taken from survey undertaken by Storm Geomatics in November 2019. A further 13 interpolated cross-sections were added mainly at the downstream of minor culverts and downstream of the A47 culvert to improve the definition of the channel, as well as model stability. The banks of the interpolated sections were updated using 2m resolution LiDAR.

6.2.3. The downstream boundary was set at the closest surveyed cross-section to the confluence with the River Tud. Further sensitivity testing was undertaken and demonstrated that the results within the area of interest were sensitive to variations in water level along the River Tud.

6.2.4. The entire model was represented in 1D with cross-sections extended using 2m LiDAR to ensure that floodwaters were captured and that no glass-walling occurred. This approach was judged to be appropriate as floodwaters for the 1 in 1000-year event were predicted to be contained close to the channel and the A47 was not predicted to be overtopped or flooded during such an event. Furthermore, flood flow pathways in the floodplain are likely to be in the same general direction parallel to those in the channel itself. This ensured that the model was computationally efficient and stable.

6.2.5. LiDAR data may be poor over rivers as the laser is reflected on the water surface. In this instance the LiDAR data downstream of the existing A47 does not adequately capture the channel with ground levels appearing higher than the surveyed bed, as can be seen in Figure 6-4. To overcome this shortcoming cross-sectional survey was used to define the river channel within the 1D domain. The downside of this approach is that to produce flood maps for a 1D model, peak levels are projected onto a ground model to estimate water depths. As water is predicted to remain within bank (i.e. below the LiDAR) there is no flood mapping to present. Topographic survey is planned within the area to provide further confidence in the model results.

Figure 6-4 Cross-section 0814 with the 100-year water level (No climate change) and LiDAR elevations shown in red



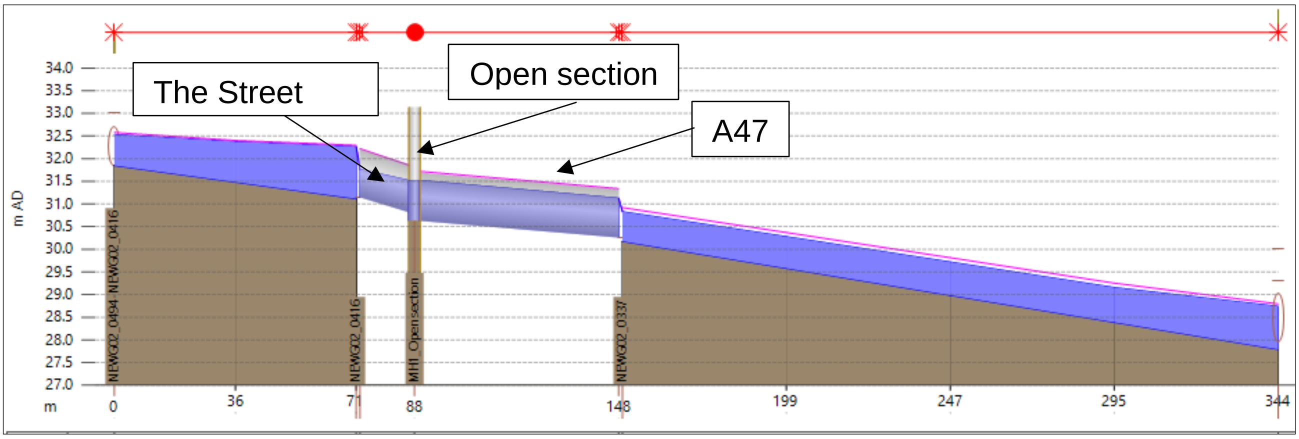
6.3. Hydraulic structures

6.3.1. Four culverts, which were thought to potentially impact flood risk within the area of interest, have been included in the model. These were represented as culvert links with inlets outlet nodes added, where appropriate. Dimensions and invert levels were all taken from the 2019 Storm Geomatics survey. Overtopping of these structures was accounted for by adding regular or irregular weirs to represent the deck or road levels.

6.3.2. The model includes an extensive 75m long 1.07m diameter culvert running under The Street and the A47 (see Figure 6-5). An open section between the A47 and The Street was also noted in the survey however, due to access and safety issues, only invert levels of the incoming and outgoing culverts and above ground levels could be captured. This section was therefore represented as a manhole with the ground level set to the lowest surveyed ground level and a base area of $10m^2$. The flood type was set to ‘stored’ as a review of the surrounding topography indicated that, should any flooding occur, that this would be contained close to the opening. Given the size and extent of this culvert a higher Colebrook White roughness of 15mm was applied. A longitudinal profile through this culvert is shown in Figure 6-6.

Figure 6-5 (A) Inlet to the culvert under the A47 and (B) open section between The Street and the A47

Figure 6-6 Long section through the A47 culvert for the 100-year (without climate change) event



Roughness values

6.3.3. The roughness values applied are the same as those outlined in Table 5-1 as per the Oak Farm watercourse model.

Boundary conditions

6.3.4. For comparative purposes peak flows have been estimated using ReFH2-FEH13 (V2.3), FEH rainfall-runoff (FEH RR) and FEH statistical methods. The FEH statistical peak flows were calculated in WINFAP-FEH (V 4) and the FEH RR method was applied using the Flood Modeller software package.

6.3.5. The critical duration of 7.5 hours and all other ReFH2 model parameters were based on the default catchment-based equations outlined in the ReFH2 Technical Report[10]. A critical duration of 9 hours was calculated for the FEH rainfall runoff method in Flood Modeller, and the winter storm event was selected.

6.3.6. All peak flows were derived from a single catchment descriptor taken at the confluence of the Oak Farm watercourse with the River Tud. For the FEH statistical method a review of suitable donor sites for QMED adjustment was undertaken however all were found to be either unsuitable due to large differences in catchment size and/or resulted in a reduction in QMED. A conservative approach was therefore adopted and the original QMED calculated using the catchment descriptor without adjustment was retained.

6.3.7. As with Oak Farm, the default pooling group identified within WINFAP had a heterogeneity greater than 2 hence a review of the most discordant gauges was undertaken. All were however considered to be suitable for inclusion and a refinement of this group resulted in a reduction in peak flows. A conservative

[10] http://files.hydrosolutions.co.uk/refh2/ReFH2_Technical_Report

approach was therefore adopted, and the original unadjusted pooling group retained.

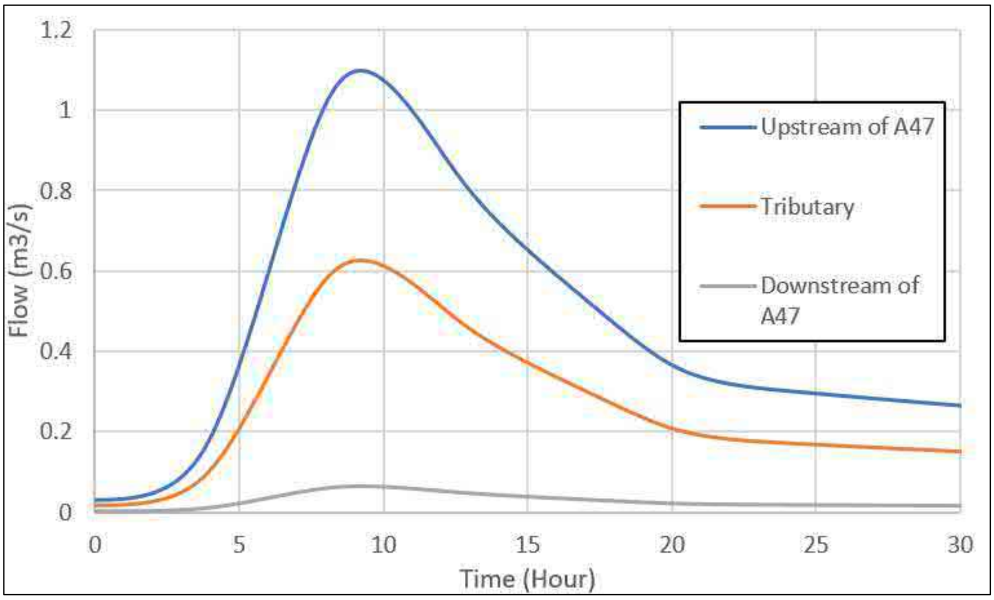
6.3.8. An overview of the results is shown in Table 6-1. As with the Oak Farm watercourse ReFH2 values were found to provide a good and moderately conservative estimate and were therefore judged to be appropriate for use in this study. The FEH RR method has largely been superseded by ReFH2 and was judged to provide unrealistically high flows for such a small, permeable chalk catchment.

Table 6-1 Comparison of peak flow estimated for the Hockering watercourse

Return period (1:X)	ReFH2 Urbanised peak flow (m3/s)	FEH Rainfall-runoff peak flows (m3/s)	FEH statistical: default donor and pooling group (m3/s)
30	1.137	2.797	1.105
100	1.661	3.896	1.520
1000	3.074	7.407	2.786

6.3.9. The ReFH2 hydrograph for the total catchment was divided into three to account for the sub-catchments draining the areas upstream and downstream of the A47, and the tributary to the west. A 35% and 65% uplift was applied to peak flows to account for climate change. In addition, the high (H++) climate change allowance of 80% was also applied to provide a further assessment of the robustness of the design. The hydrographs used for the 100-year event (without climate change) are shown in Figure 6-7. Note that following initial discussions with the EA, inflows have been increased by a further 8% to account for additional areas which likely drain to the watercourse.

Figure 6-7 ReFH2 hydrographs for the 100-year event

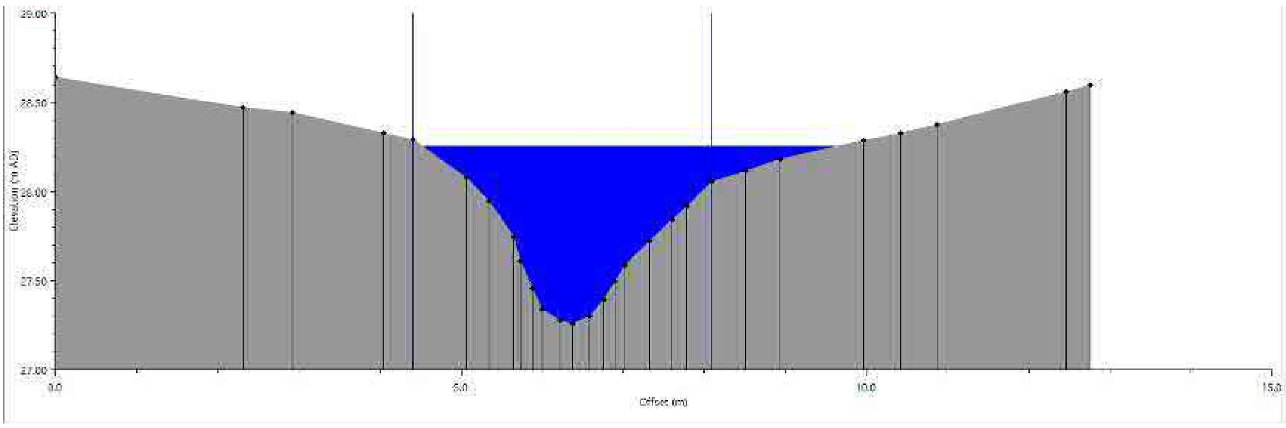


6.3.10. The hydrology does not account for the attenuative effect of the large pond upstream noting that it has been conservatively assumed that, for larger events, this would be overtopped and discharged into the watercourse. Similarly, the urban drainage system is not explicitly represented within the model although the ReFH2 inflows did use the urban runoff model included in the ReFH2 software.

6.4. Baseline model results

6.4.1. An overview of peak water levels and the cross-section locations are given in Appendix K and L. Flooding was predicted to remain in or close to the channel within the vicinity of the bridge crossing for all modelled events (Figure 6-8). Peak water levels of 28.374m AOD were predicted for the 100-year event (without an allowance for climate change) close to the location of the proposed culvert inlet. This increases to 28.545m AOD and 28.576m AOD for the 100-year (with a 65% allowance for climate change) and 1000-year events respectively.

Figure 6-8 Peak water level at cross-section overlapping the proposed scheme for the 100 year event with a 65% allowance for climate change



6.4.2. The results show that for the 100-year event with 65% climate change and the 1000-year flood that the A47 culvert provides a significant constraint to flows with backing up upstream (see Figure 6-9). The deck level of the road was however not predicted to be overtopped or flooded with water remaining within the upstream channel for all events (Figure 6-10).

Figure 6-9 Long section through the A47 culvert for the 100-year event with a 65% climate change allowance

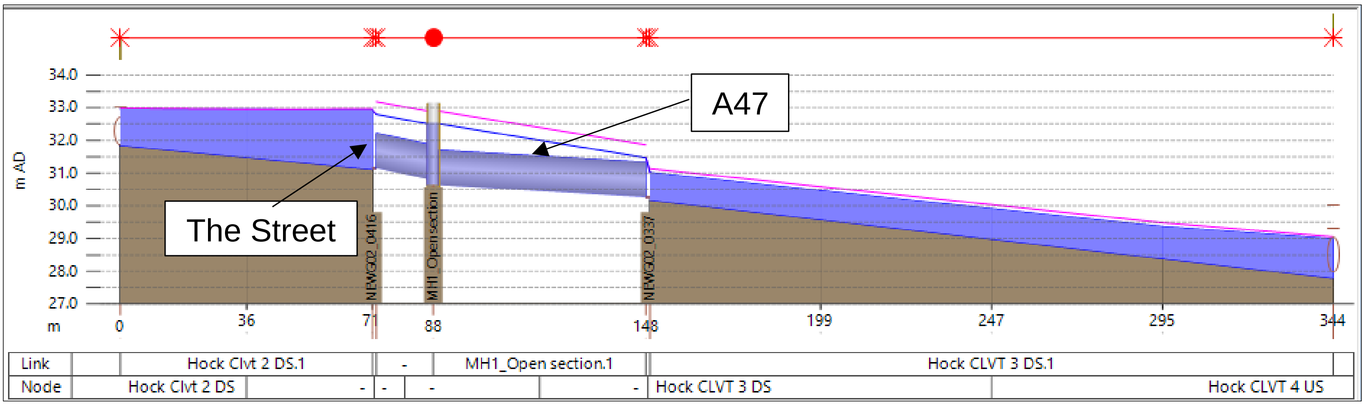
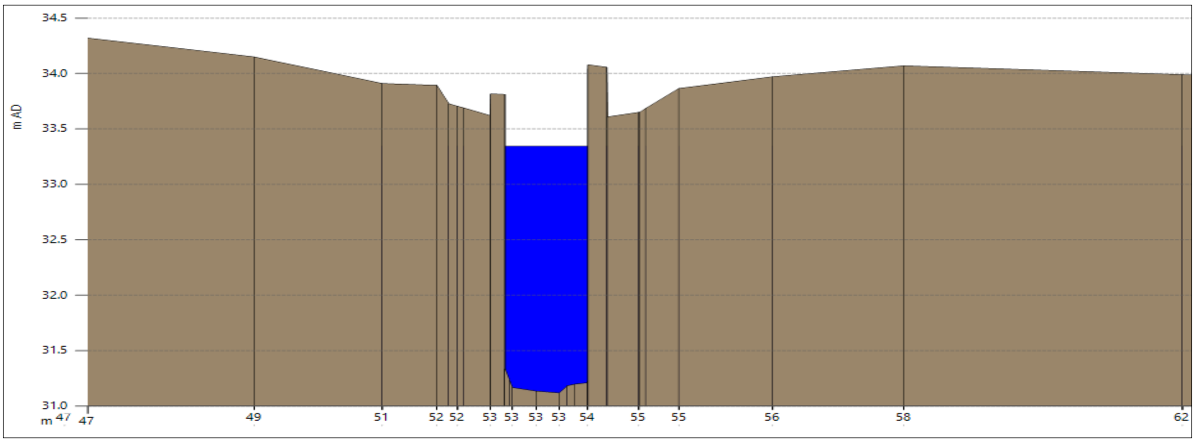


Figure 6-10 Peak 1 in 1000-year flood level at the upstream of the A47 culvert



6.5. Sensitivity analysis

6.5.1. The watercourse is ungauged and, following a review of available data, no specific information could be found of previous flooding. Within the Breckland District Council Strategic Flood Risk Assessment (2017) two incidences of flooding between Honingham and Hockering were recorded in 2002 and 2004, although the exact location is not specified. The model results could therefore not be calibrated or validated.

6.5.2. A series of additional model runs were undertaken to evaluate the sensitivity of the model to different factors. For all scenarios the 100-year event without a climate change event was applied. The parameters assessed included:

- altering the channel roughness by +/- 20%
- altering the inflow hydrographs by +/-20%
- lowering the weir discharge coefficients at Berry Lane weir
- adding a level file to the downstream boundary set to the 1 in 50-year and 1 in 100-year peak water levels in the River Tud

6.5.3. The sensitivity analysis (Table 6-2) indicates that the results are moderately sensitive to variations in roughness and inflows. Applying the 1 in 50-year and 1 in 100-year peak flood levels for the River Tud as the downstream boundary was found to have the greatest effect on peak levels, however, this is most pronounced at the most downstream model cross-section. To account for the downstream influence a bank full level of 27.7m AOD has been applied for all subsequent modelling scenarios. In the absence of calibration and validation the model results should be considered accurate to approximately ± 10cm.

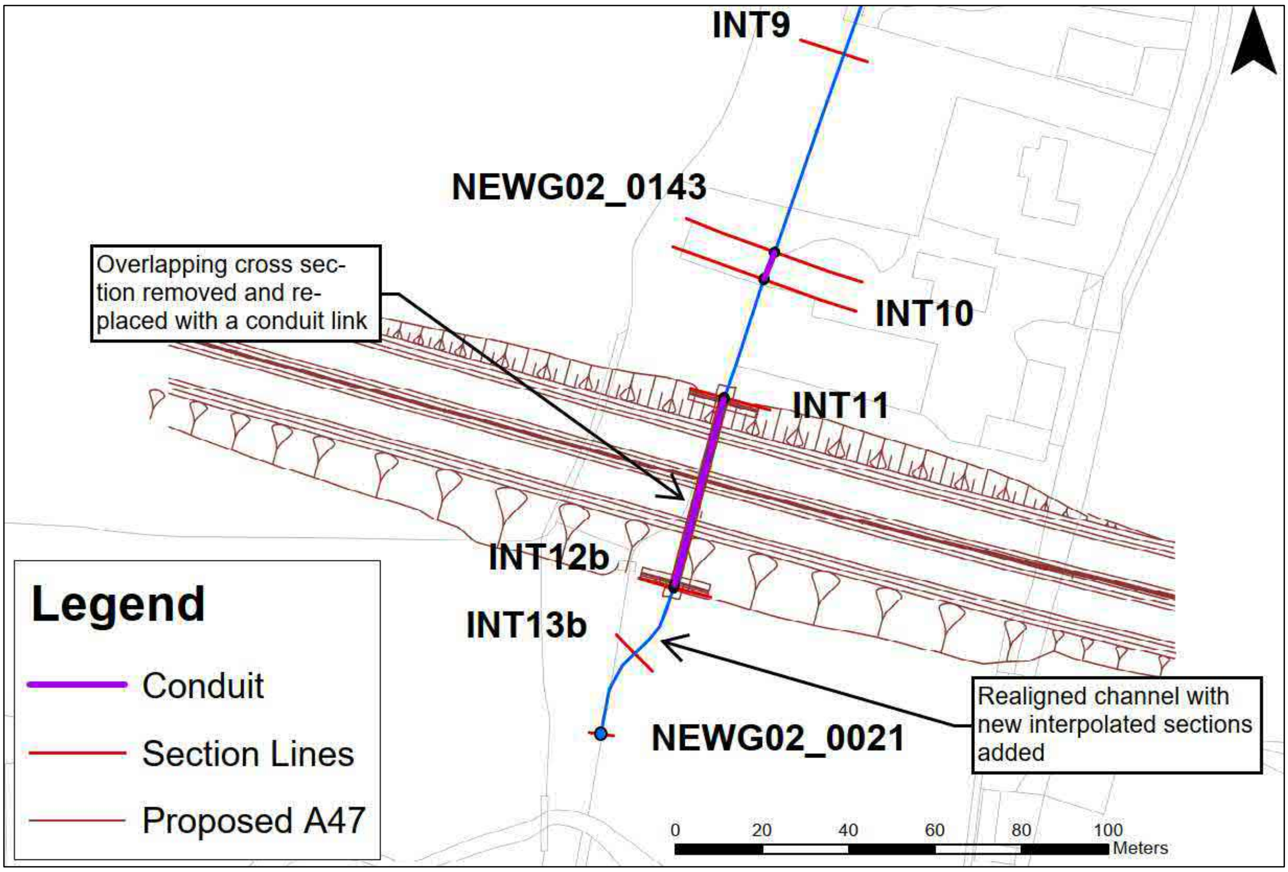
Table 6-2 : Hockering sensitivity analysis results for five cross-sections closest to the proposed crossing

Scenario	Maximum change in peak level (m)	Average change in peak level (m)	Average % change in depth	Maximum % change in depth
+20% Roughness	0.075	0.047	5.5%	8.6%
-20% Roughness	-0.085	-0.059	-6.9%	-9.8%
1 in 50-year for Tud at downstream	0.400	0.097	14.8%	63.4%
1 in 100-year for Tud at downstream	0.466	0.119	17.9%	73.8%
+20% inflows	0.075	0.063	7.9%	9.6%
-20% Inflows	-0.085	-0.074	-9.3%	-11.6%

6.6. Post development modelling

6.6.1. As part of the Proposed Scheme a section of the Hockering watercourse would be culverted and realigned. For the post-development scenario, two interpolated cross section downstream of the realigned A47 were created (INT12b and INT13B in Figure 6-11). The reach between INT11 and IN12b was removed and replaced with a culvert link with inlets and outlets added. The upstream and downstream invert levels of the new culvert were set to the lowest ground elevation of the closest cross section. This ensures that the watercourse gradient is maintained.

Figure 6-11 Overview of the post development model for Hockering



6.6.2. The culvert was specified as rectangular with a width of 2.05m and height of 1.75m. The culvert will have an additional 300mm bed layer hence the base had a Manning's roughness of 0.04 while the top had a roughness of 0.013.

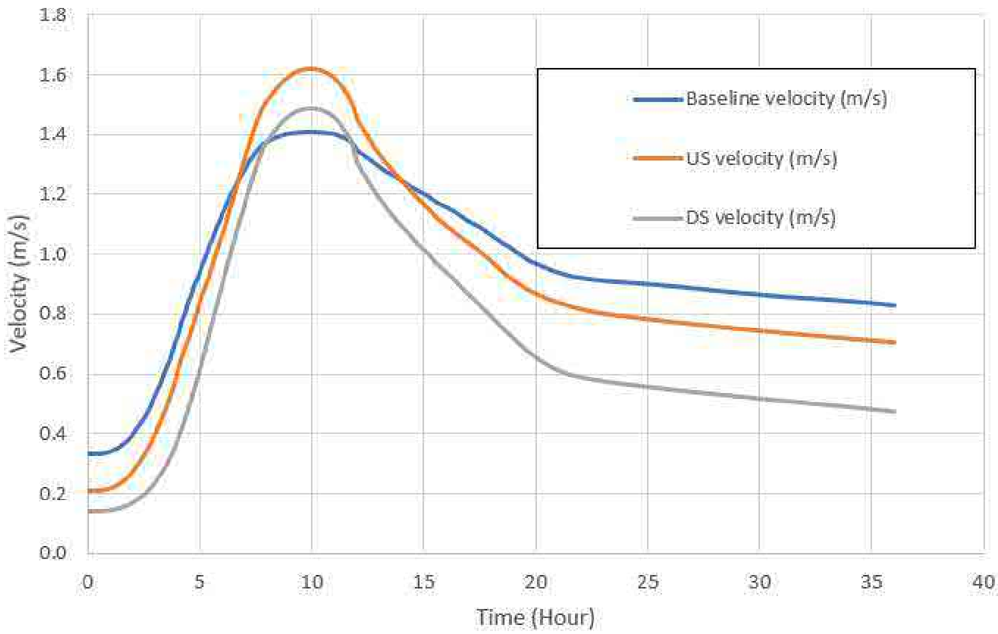
6.6.3. The analysis indicated that the box culvert would be able to transfer the estimated 100-year flows (including a 65% climate change allowance with a freeboard exceeding 600mm (see Table 6-3). This includes a bank full level of 27.7m AOD applied to the downstream boundary of the model.

Table 6-3 Overview of the culvert results

	Upstream cross-section	Downstream cross-section
Bed level (m AOD)	27.501	27.135
100-year event (including a 65% climate change allowance) Water Level (m AOD)	28.477	28.056
Soffit level (m AOD, 1.75m h)	29.251	28.885
Freeboard (m)	0.774	0.829

6.6.4. A comparison of the baseline and post development peak levels and depths can be seen in Appendix L. The results indicate that the new culvert will result in a small drop in water levels at the two cross-sections immediately upstream of the crossing. The effects are however very localised and do not extend beyond the culvert upstream (culvert 4). Figure 6-12 shows that the new culvert will lead to an increase in peak velocities however there was not predicted to be any significant change in flow downstream.

Figure 6-12 Velocity profiles through the proposed conduit with no downstream boundary applied for the 100-year event with a 65% climate change allowance



Blockage scenarios

6.6.5. Further sensitivity analysis was undertaken to assess the potential impact of blockage to the culvert. This was modelled by adding sediment to the conduit at depths of 10% and 50% of the conduit height. The survey photos show the watercourse to be relatively clear and the upstream culverts would likely intercept any large debris hence these values were considered appropriate.

6.6.6. The results (Table 6-4 and Table 6-5) indicate that a 10% blockage would increase water depths upstream by 170mm and by 880mm for the 50% blockage. The impacts are, however, relatively localised and do not extend beyond the footpath culvert upstream.

Table 6-4 Comparison of peak water level for various blockage scenarios for the 100-year event with a 65% climate change allowance

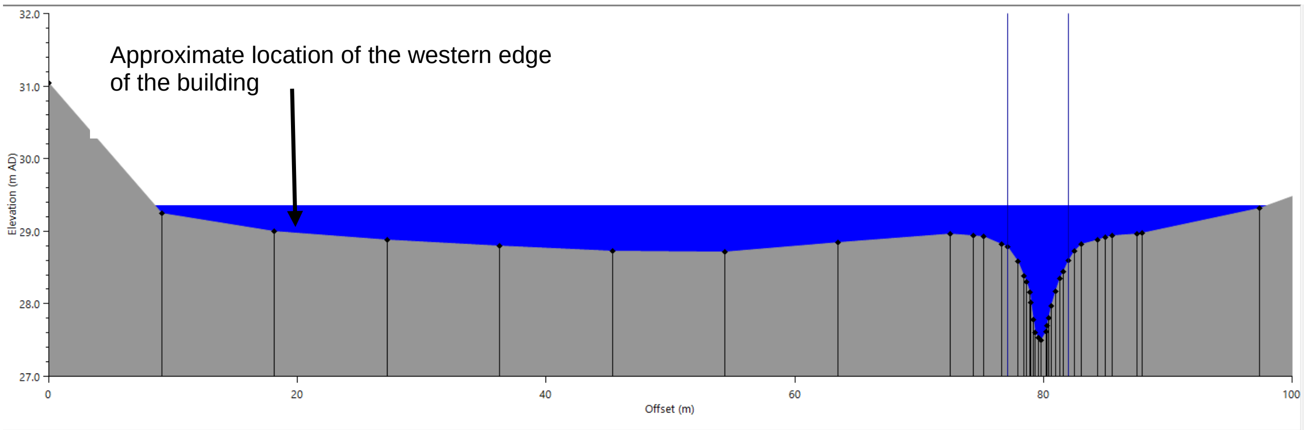
Object ID	No Blockage	10% Blockage		50% Blockage	
	level (m AOD)	Level (m AOD)	Difference (mm)	Level (m AOD)	Difference (mm)
NEWG02_0337	31.04	31.04	0	31.04	0
IINT	30.49	30.49	0	30.49	0
INT	29.945	29.945	0	29.948	3
INT	29.523	29.523	0	29.562	39
NEWG02_0143	29.426	29.426	0	29.489	63
INT	28.808	28.843	35	29.353	545
A47 Inlet	28.477	28.647	170	29.357	880
A47 Outlet	28.056	28.056	0	28.056	0
INT	27.893	27.893	0	27.893	0
NEWG02_0021	27.700	27.700	0	27.700	0

Table 6-5 Comparison of peak depths for various blockage scenarios for the 100 year event with a 65% climate change allowance

Object ID	No Blockage	10% Blockage		50% Blockage	
	Depth (m)	Depth (m)	% Change	Depth (m)	% Change
NEWG02_0337	0.862	0.862	0	0.862	0
IINT	0.908	0.908	0	0.908	0
INT	0.96	0.960	0	0.962	0
INT	1.134	1.134	0	1.173	3
NEWG02_0143	1.633	1.633	0	1.696	4
INT	1.055	1.090	3	1.600	52
A47 Inlet	0.976	1.146	17	1.856	90
A47 Outlet	0.921	0.921	0	0.921	0
INT	0.922	0.922	0	0.922	0
NEWG02_0021	0.919	0.919	0	0.919	0

6.6.7. Applying a 50% blockage results in flooding to the east of the watercourse which is predicted to intercept an existing workshop building. The water depth at the cross-section upstream of the culvert inlet and the approximate position of the building can be seen in Figure 6-13. Note that the cross-section is located 2m downstream of the building. The lowest ground level within the footprint of the building is 28.95 mAOD, which is approximately 400mm below the peak water level of 29.357 mAOD.

Figure 6-13 Flood extent at cross-section upstream of the proposed culvert inlet for the 100 year event with a 65% allowance for climate change



6.6.8. This sensitivity analysis indicates that blockage is a potential risk and regular maintenance and inspection of the culvert should be prioritised. Topographic survey is currently being undertaken and the design will be further reviewed as the project progresses. It is recommended that a trash screen be incorporated at the culvert inlet to further minimise the risk of blockage.

6.7. Summary

6.7.1. Hydraulic modelling has been undertaken to assess the flood risk from a watercourse to the east of Hockering. Baseline modelling indicates that the existing A47 culvert provide a constraint on flows resulting in floodwaters accumulating upstream. Water is predicted to remain within channel at the location of the proposed culvert; however, the results were found to be sensitive to the downstream boundary at the confluence with the River Tud.

6.7.2. Post development modelling indicates that the proposed box culvert provides more than the 600mm freeboard required for the design event. The new culvert was predicted to result in a small reduction in peak water levels upstream due to the increase in velocities through the conduit; however, there was no significant impact on flows downstream.

6.7.3. Blockage scenarios indicate that a 50% blockage to the culvert would result in flooding from the eastern bank which is predicted to intercept a workshop building. Maintenance and inspection of the culvert should be prioritised, and it is recommended that a trash screen is incorporated to minimise the risk.

7. Conclusion

7.1.1. This technical note was prepared to provide a summary of the baseline and Proposed Scheme hydraulic modelling of the River Tud and two ordinary watercourse tributaries at Oak Farm and Hockering. All models were constructed in Infoworks ICM using new survey data collected in 2019 as part of this Scheme and, for the River Tud, a pre-existing Flood Modeller model was utilised. The results are presented for various return periods including the 100-year with a 65% allowance for climate change.

7.2. River Tud modelling

7.2.1. For the River Tud the ICM model produces similar but marginally higher peak water levels at the location of the proposed bridge crossing in comparison to the original Flood Modeller model. Similarly, hydrographs generally show a more rapid response to flood events with steeper rising and receding limbs. This relates to the integration of additional survey which has improved the representation of two secondary channels within the centre of the model reach.

7.2.2. The predicted peak water level at the cross-section close to the upstream face of the proposed A47 bridge is 22.412m AOD for the 100-year event and 22.563m AOD with a 65% climate change allowance.

7.2.3. The only element of the scheme within the floodplain of the River Tud are the two bridge abutments. Compensatory storage would be required to offset the displacement of water.

7.2.4. The abutments are predicted to affect flow pathways along both banks resulting in an increase in water levels upstream and downstream. The impacts are, however, relatively localised with increases of less than 10mm predicted upstream of the existing A47.

7.3. Oak Farm modelling

7.3.1. The baseline modelling of the Oak Farm ordinary watercourse predicted flooding upstream of the existing A47 in the area of interest. This relates to an undersized and potentially blocked culvert immediately downstream of the A47 which provides a significant constraint on flows. Flooding was also predicted downstream at a footpath crossing and at Low Road.

7.3.2. Upstream of the existing A47 a peak water level of 44.070 AOD is predicted for the 100-year event without an allowance for climate change. This increases to 44.687mAOD and 44.849mAOD with a 65% climate change allowance and for the 1 in 1000-year event respectively.

7.3.3. Post development modelling indicates that the installation of an 350mm orifice and embankment restricts flows thereby providing a new betterment in terms of flood risk downstream. The embankment provides over 600mm freeboard above the 1 in 100 year (plus 65% climate change) peak water level and was found to be resilient to blockage.

7.4. Hockering modelling

7.4.1. For the Hockering ordinary watercourse floodwaters are predicted to remain in the channel within the vicinity of the bridge crossing for all modelled events. Peak water levels of 28.374m AOD were predicted for the 100-year event (without an allowance for climate change) close to the location of the proposed culvert inlet. This increases to 28.545mAOD and 28.576mAOD for the 100-year (with a 65% allowance for climate change) and 1000-year events respectively.

7.4.2. The proposed new culvert at Hockering was found to provide over 600mm freeboard for the 100-year event (with a 65% climate change allowance). The culvert results in a small reduction in water levels immediately upstream due to the higher velocities; however, the impact on flow was found to be negligible. The model results are sensitive to blockage.

Appendix A. Catchment descriptors

Table 7-1 Oak Farm catchment descriptors

FEH Catchment Parameter	Catchment downstream of A47	Catchment upstream of A47
AREA	0.75*	0.75*
ALTBAR	44	50
ASPBAR	174	216
BFIHOST19	0.65	0.477
DPLBAR	0.88	0.84
DPSBAR	22.5	8.5
FARL	1	1
SAAR	660	659
SPRHOST	35.41	37.93
URBEXT2000	0	0

*Value changes following a review of available information including OS contour data

Table 7-2 Hockering catchment descriptors

FEH Catchment Parameter	Value
AREA	4.17
ALTBAR	51
ASPBAR	188
BFIHOST19	0.619
DPLBAR	2.1
DPSBAR	17.5
FARL	0.987
SAAR	650
SPRHOST	35.65
URBEXT2000	0.0147

Appendix B. River Tud cross-section locations

Figure 7-1 River Tud

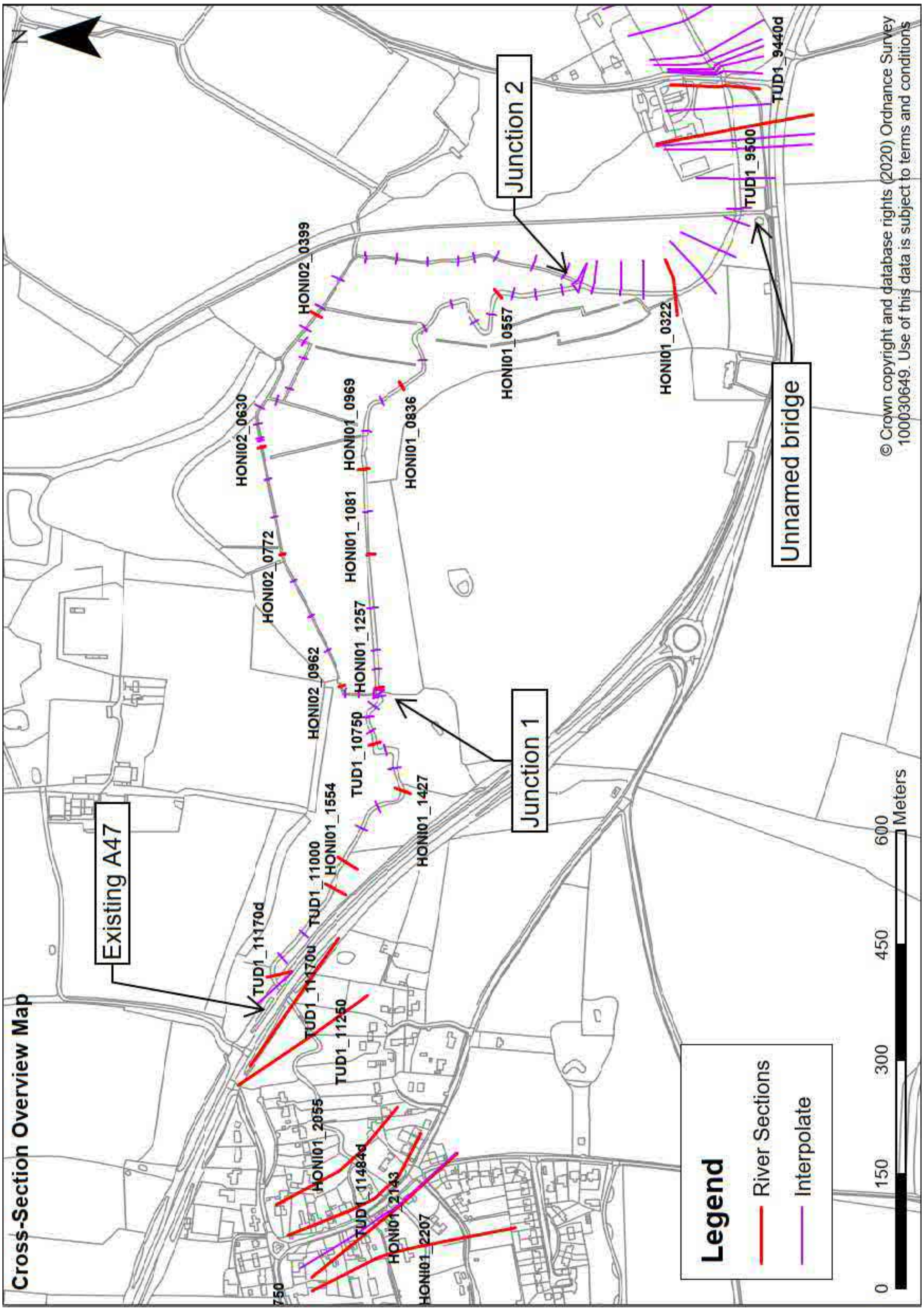


Figure 7-2 Cross-section HONI01_1427

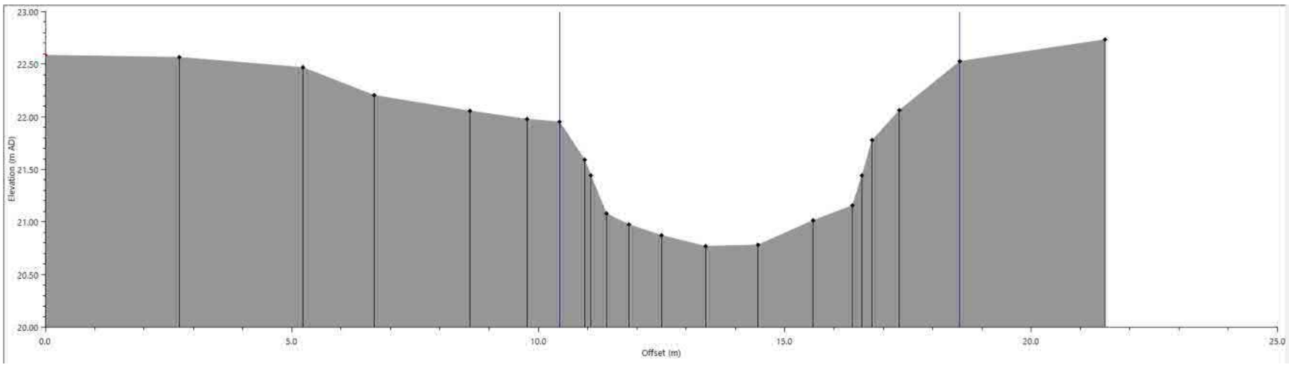


Figure 7-3 Cross-section TUD1_10750

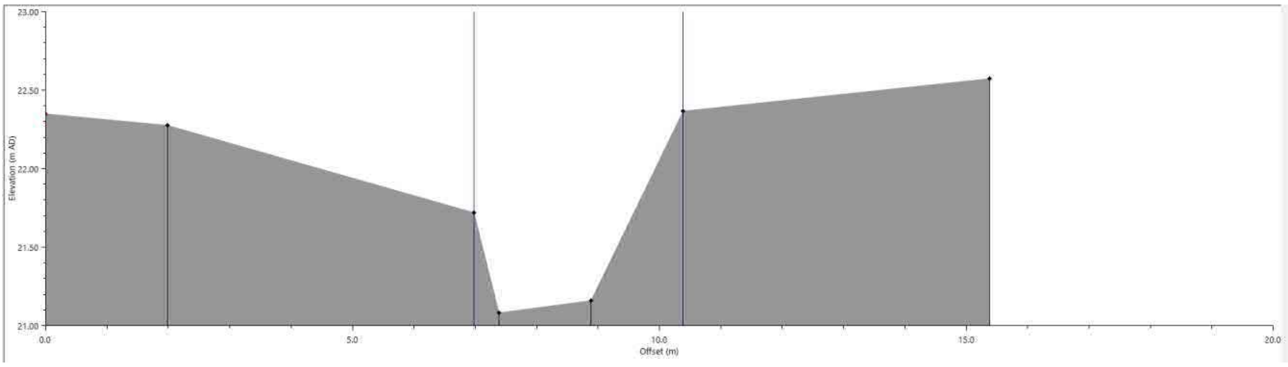
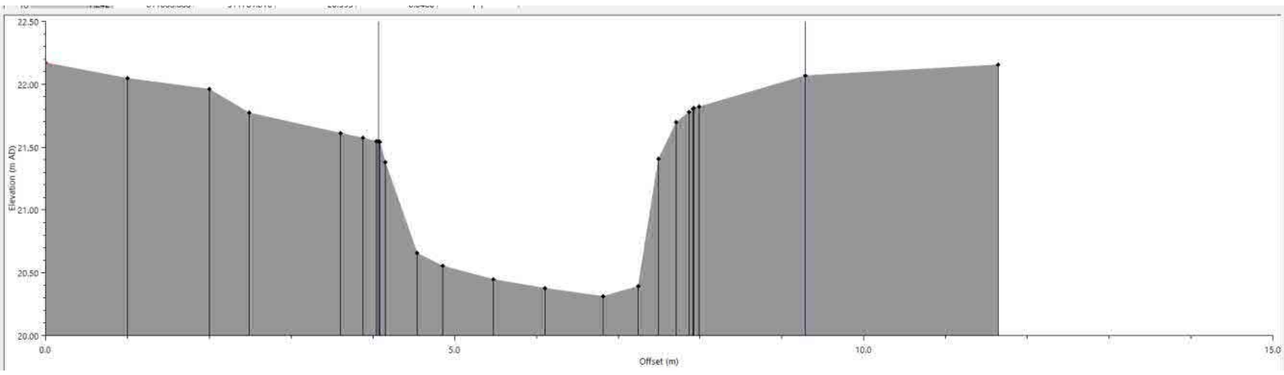


Figure 7-4 Cross-section HONI01_1257



Appendix C. River Tud predicted levels

Table 7-3 Peak water levels. The sections highlighted yellow lie in the vicinity of the proposed River Tud crossing.

Section ID	100yr No CC Peak Level (m AOD)			100yr 35%CC Peak Level (m AOD)			100yr 65%CC Peak Level (m AOD)			1000yr No CC Peak Level (m AOD)		
	Baseline	Post development	Difference (mm)	Baseline	Post Development	Difference (mm)	Baseline	Post Development	Difference (mm)	Baseline	Post Development	Difference (mm)
The Street Bridge												
TUD1_11484d	23.543	23.543	0	23.693	23.693	1	23.801	23.803	1	23.841	23.842	1
HONI01_2055	23.475	23.475	0	23.626	23.627	1	23.742	23.743	2	23.784	23.786	2
TUD1_11250	23.161	23.162	1	23.331	23.335	3	23.464	23.468	5	23.513	23.518	5
TUD1_11170u	23.095	23.097	2	23.261	23.266	4	23.392	23.398	6	23.441	23.447	6
HONI01_1772	23.035	23.037	2	23.189	23.194	5	23.306	23.313	7	23.349	23.356	7
Existing A47 Bridge												
HONI01_1757	23.017	23.019	2	23.171	23.177	5	23.288	23.295	7	23.330	23.338	8
INT	23.000	23.003	2	23.157	23.163	6	23.274	23.282	7	23.317	23.325	8
TUD1_11170d	22.973	22.975	3	23.129	23.135	6	23.245	23.254	8	23.288	23.297	9
INT	22.896	22.900	4	23.039	23.047	8	23.145	23.155	11	23.183	23.195	12
INT	22.827	22.831	5	22.958	22.969	10	23.054	23.068	14	23.088	23.103	15
TUD1_11000	22.756	22.762	6	22.876	22.890	14	22.960	22.979	20	22.989	23.010	22
HONI01_1554	22.709	22.716	7	22.828	22.845	17	22.911	22.937	26	22.941	22.969	28
INT	22.623	22.633	10	22.721	22.744	23	22.788	22.827	39	22.812	22.857	46
INT	22.613	22.623	10	22.709	22.735	26	22.776	22.819	44	22.799	22.850	51
HONI01_1427	22.591	22.602	11	22.685	22.714	29	22.751	22.801	50	22.775	22.833	58
INT	22.559	22.571	12	22.647	22.680	33	22.708	22.764	56	22.730	22.795	65
INT	22.500	22.517	17	22.590	22.636	46	22.654	22.726	72	22.677	22.758	81
TUD1_10750	22.412	22.427	15	22.500	22.544	44	22.563	22.633	70	22.586	22.666	80
INT	22.306	22.316	10	22.397	22.436	39	22.461	22.525	64	22.485	22.557	72
INT	22.228	22.237	9	22.321	22.355	34	22.386	22.439	53	22.410	22.469	59
INT	22.125	22.136	10	22.211	22.246	35	22.271	22.323	52	22.293	22.348	55
INT	22.052	22.062	9	22.130	22.155	24	22.185	22.218	33	22.205	22.239	33
INT	22.048	22.056	8	22.126	22.151	25	22.182	22.212	31	22.201	22.233	32
Junction 1												
INT	22.048	22.056	8	22.126	22.151	25	22.182	22.212	31	22.201	22.233	32
HONI01_1257	22.041	22.048	8	22.118	22.142	24	22.173	22.204	31	22.193	22.225	32
INT	21.973	21.981	7	22.049	22.072	23	22.100	22.129	28	22.119	22.147	29
INT	21.937	21.945	8	22.009	22.031	22	22.056	22.083	27	22.072	22.099	28
INT	21.828	21.835	7	21.894	21.912	18	21.931	21.952	21	21.944	21.965	21
HONI01_1081	21.703	21.710	7	21.765	21.781	16	21.797	21.813	16	21.807	21.823	16
INT	21.612	21.618	6	21.666	21.680	13	21.693	21.706	13	21.701	21.714	13

HONI01_0969	21.513	21.518	5	21.557	21.568	11	21.579	21.591	11	21.587	21.598	11
INT	21.415	21.419	4	21.447	21.455	8	21.464	21.471	8	21.469	21.477	8
INT	21.316	21.319	3	21.341	21.347	5	21.355	21.361	5	21.362	21.367	5
HONI01_0836	21.249	21.252	2	21.272	21.277	5	21.290	21.294	4	21.301	21.305	4
INT	21.116	21.117	2	21.142	21.144	2	21.179	21.181	1	21.203	21.205	1
INT	21.005	21.006	1	21.056	21.057	1	21.126	21.126	0	21.161	21.161	0
INT	20.917	20.918	1	21.007	21.008	0	21.098	21.098	0	21.136	21.137	0
INT	20.861	20.861	0	20.984	20.984	0	21.082	21.082	0	21.123	21.123	0
INT	20.834	20.834	0	20.974	20.974	0	21.075	21.074	0	21.116	21.116	0
HONI01_0557	20.827	20.827	0	20.970	20.970	0	21.071	21.071	0	21.113	21.113	0
INT	20.820	20.820	0	20.966	20.966	0	21.068	21.068	0	21.110	21.110	0
INT	20.813	20.812	0	20.961	20.961	0	21.063	21.063	0	21.105	21.105	0
INT	20.802	20.802	0	20.953	20.953	0	21.055	21.055	0	21.097	21.097	0
INT	20.798	20.798	0	20.950	20.949	0	21.052	21.051	0	21.093	21.093	0
Junction 2												
INT	20.798	20.7979	0	20.950	20.9494	0	21.052	21.051	0	21.093	21.093	0
INT	20.787	20.7866	0	20.940	20.9402	0	21.043	21.043	0	21.084	21.084	0
INT	20.760	20.7594	0	20.916	20.9159	0	21.018	21.018	0	21.059	21.059	0
INT	20.734	20.7334	0	20.894	20.8937	0	20.996	20.996	0	21.038	21.038	0
HONI01_0322	20.713	20.7129	0	20.875	20.8751	0	20.977	20.977	0	21.019	21.019	0
INT	20.688	20.6878	0	20.854	20.8539	0	20.956	20.956	0	20.998	20.998	0
INT	20.662	20.6613	0	20.831	20.8305	0	20.932	20.931	0	20.973	20.973	0
INT	20.621	20.6210	0	20.787	20.7871	0	20.882	20.882	0	20.921	20.921	0
HONI01_0183	20.575	20.575	0	20.726	20.726	0	20.802	20.802	0	20.834	20.834	0
Plantation Access Bridge												
HONI01_0178	20.567	20.567	0	20.717	20.717	0	20.791	20.791	0	20.822	20.822	0
INT	20.568	20.568	0	20.719	20.719	0	20.793	20.793	0	20.824	20.824	0
INT	20.558	20.557	0	20.713	20.713	0	20.789	20.789	0	20.821	20.821	0
INT	20.535	20.534	0	20.692	20.692	0	20.766	20.766	0	20.797	20.797	0
TUD1_9512u	20.515	20.515	0	20.680	20.680	0	20.754	20.754	0	20.785	20.785	0
Unnamed Bridge												
TUD1_9512d	20.511	20.511	0	20.677	20.677	0	20.751	20.751	0	20.782	20.782	0
INT	20.501	20.501	0	20.667	20.666	0	20.739	20.739	0	20.770	20.770	0
TUD1_9500	20.492	20.492	0	20.656	20.656	0	20.725	20.725	0	20.755	20.755	0
INT	20.449	20.449	0	20.626	20.626	0	20.695	20.695	0	20.726	20.726	0
TUD1_9440d	20.339	20.338	0	20.541	20.541	0	20.626	20.626	0	20.654	20.654	0

Appendix D. River Tud predicted depths

Table 7-4 River Tud peak depths. The sections highlighted yellow lie in the vicinity of the proposed River Tud crossing.

Section ID	100yr No CC Peak Depth (m)			100yr 35%CC Peak Depth (m)			100yr 65%CC Peak Depth (m)			1000yr No CC Peak Depth (m)		
	Baseline	Post development	% difference	Baseline	Post Development	% difference	Baseline	Post Development	% Difference	Baseline	Post Development	% Difference
The Street Bridge												
TUD1_11484d	1.253	1.253	0.0	1.403	1.403	0.1	1.511	1.513	0.1	1.551	1.552	0.1
HONI01_2055	1.485	1.485	0.0	1.636	1.637	0.1	1.752	1.753	0.1	1.794	1.796	0.1
TUD1_11250	1.671	1.672	0.1	1.841	1.845	0.2	1.974	1.978	0.2	2.023	2.028	0.2
TUD1_11170u	1.505	1.507	0.1	1.671	1.676	0.3	1.802	1.808	0.3	1.851	1.857	0.3
HONI01_1772	1.255	1.257	0.2	1.409	1.414	0.4	1.526	1.533	0.4	1.569	1.576	0.5
Existing A47 Bridge												
HONI01_1757	1.387	1.389	0.2	1.541	1.547	0.4	1.658	1.665	0.4	1.700	1.708	0.5
INT	1.385	1.387	0.2	1.542	1.547	0.4	1.659	1.667	0.4	1.701	1.709	0.5
TUD1_11170d	1.383	1.385	0.2	1.539	1.545	0.4	1.655	1.664	0.5	1.698	1.707	0.5
INT	1.417	1.420	0.3	1.560	1.568	0.5	1.665	1.676	0.7	1.704	1.716	0.7
INT	1.507	1.511	0.3	1.638	1.649	0.6	1.734	1.748	0.8	1.768	1.783	0.9
TUD1_11000	1.706	1.712	0.3	1.826	1.840	0.7	1.910	1.929	1.0	1.939	1.960	1.1
HONI01_1554	1.624	1.631	0.4	1.743	1.760	1.0	1.826	1.852	1.4	1.856	1.884	1.5
INT	1.659	1.668	0.6	1.756	1.779	1.3	1.823	1.862	2.1	1.847	1.893	2.5
INT	1.738	1.748	0.6	1.834	1.859	1.4	1.900	1.944	2.3	1.924	1.975	2.6
HONI01_1427	1.821	1.832	0.6	1.915	1.944	1.5	1.981	2.031	2.5	2.005	2.063	2.9
INT	1.675	1.688	0.7	1.763	1.797	1.9	1.825	1.881	3.1	1.847	1.912	3.5
INT	1.504	1.521	1.1	1.594	1.640	2.9	1.658	1.730	4.3	1.681	1.762	4.8
TUD1_10750	1.332	1.347	1.2	1.420	1.464	3.1	1.483	1.553	4.7	1.506	1.586	5.3
INT	1.396	1.406	0.7	1.487	1.526	2.6	1.551	1.615	4.1	1.575	1.647	4.6
INT	1.499	1.508	0.6	1.592	1.626	2.1	1.657	1.710	3.2	1.681	1.740	3.5
INT	1.552	1.563	0.7	1.638	1.673	2.1	1.698	1.750	3.0	1.720	1.775	3.2
INT	1.586	1.596	0.6	1.664	1.689	1.5	1.719	1.752	1.9	1.739	1.773	1.9
INT	1.582	1.590	0.5	1.660	1.685	1.5	1.716	1.746	1.8	1.735	1.767	1.8
Junction 1												
INT	1.700	1.708	0.5	1.778	1.803	1.4	1.833	1.864	1.7	1.853	1.884	1.7
HONI01_1257	1.727	1.734	0.4	1.804	1.828	1.3	1.859	1.890	1.7	1.879	1.911	1.7
INT	1.637	1.644	0.5	1.712	1.735	1.3	1.764	1.792	1.6	1.782	1.811	1.6
INT	1.578	1.586	0.5	1.650	1.672	1.3	1.697	1.724	1.6	1.713	1.740	1.6
INT	1.384	1.391	0.5	1.450	1.468	1.3	1.487	1.508	1.4	1.500	1.521	1.4
HONI01_1081	1.230	1.237	0.6	1.292	1.308	1.2	1.324	1.340	1.2	1.334	1.350	1.2
INT	1.320	1.327	0.5	1.375	1.388	1.0	1.401	1.415	1.0	1.410	1.423	0.9

HONI01_0969	1.403	1.408	0.4	1.447	1.458	0.8	1.469	1.481	0.8	1.477	1.488	0.7
INT	1.271	1.275	0.3	1.304	1.311	0.6	1.320	1.328	0.6	1.326	1.333	0.6
INT	1.139	1.142	0.2	1.164	1.169	0.5	1.178	1.183	0.4	1.185	1.190	0.4
HONI01_0836	1.050	1.053	0.2	1.073	1.078	0.4	1.091	1.095	0.4	1.102	1.106	0.4
INT	1.040	1.042	0.1	1.066	1.068	0.2	1.103	1.105	0.1	1.128	1.129	0.1
INT	1.052	1.053	0.1	1.103	1.104	0.1	1.174	1.174	0.0	1.208	1.209	0.0
INT	1.088	1.088	0.1	1.178	1.178	0.0	1.268	1.268	0.0	1.307	1.307	0.0
INT	1.155	1.155	0.0	1.278	1.279	0.0	1.376	1.376	0.0	1.417	1.417	0.0
INT	1.252	1.251	0.0	1.391	1.391	0.0	1.492	1.492	0.0	1.533	1.533	0.0
HONI01_0557	1.317	1.317	0.0	1.460	1.460	0.0	1.561	1.561	0.0	1.603	1.603	0.0
INT	1.346	1.346	0.0	1.492	1.492	0.0	1.594	1.594	0.0	1.636	1.636	0.0
INT	1.394	1.393	0.0	1.542	1.542	0.0	1.644	1.644	0.0	1.686	1.686	0.0
INT	1.446	1.446	0.0	1.597	1.597	0.0	1.699	1.699	0.0	1.741	1.741	0.0
INT	1.472	1.471	0.0	1.623	1.623	0.0	1.725	1.725	0.0	1.766	1.766	0.0
Junction 2												
INT	1.487	1.4869	0.0	1.639	1.6384	0.0	1.741	1.740	0.0	1.782	1.782	0.0
INT	1.506	1.5056	0.0	1.659	1.6591	0.0	1.762	1.761	0.0	1.803	1.803	0.0
INT	1.544	1.5435	0.0	1.700	1.6999	0.0	1.802	1.802	0.0	1.843	1.843	0.0
INT	1.571	1.5704	0.0	1.731	1.7307	0.0	1.833	1.833	0.0	1.875	1.875	0.0
HONI01_0322	1.624	1.6239	0.0	1.786	1.7861	0.0	1.888	1.888	0.0	1.930	1.930	0.0
INT	1.602	1.6016	0.0	1.768	1.7677	0.0	1.870	1.869	0.0	1.911	1.911	0.0
INT	1.578	1.5779	0.0	1.747	1.7471	0.0	1.848	1.848	0.0	1.890	1.890	0.0
INT	1.541	1.5405	0.0	1.707	1.7065	0.0	1.801	1.801	0.0	1.841	1.841	0.0
HONI01_0183	1.495	1.495	0.0	1.646	1.646	0.0	1.722	1.722	0.0	1.754	1.754	0.0
Plantation Access Bridge												
HONI01_0178	1.477	1.477	0.0	1.627	1.627	0.0	1.701	1.701	0.0	1.732	1.732	0.0
INT	1.477	1.477	0.0	1.628	1.628	0.0	1.702	1.702	0.0	1.733	1.733	0.0
INT	1.760	1.760	0.0	1.915	1.915	0.0	1.991	1.991	0.0	2.023	2.023	0.0
INT	2.031	2.030	0.0	2.188	2.188	0.0	2.262	2.262	0.0	2.294	2.293	0.0
TUD1_9512u	2.045	2.045	0.0	2.210	2.210	0.0	2.284	2.284	0.0	2.315	2.315	0.0
Unnamed Bridge												
TUD1_9512d	2.041	2.041	0.0	2.207	2.207	0.0	2.281	2.281	0.0	2.312	2.312	0.0
INT	1.923	1.923	0.0	2.089	2.089	0.0	2.161	2.161	0.0	2.193	2.193	0.0
TUD1_9500	1.572	1.572	0.0	1.736	1.736	0.0	1.805	1.805	0.0	1.835	1.835	0.0
INT	1.469	1.469	0.0	1.646	1.646	0.0	1.715	1.715	0.0	1.746	1.746	0.0
TUD1_9440d	1.299	1.298	0.0	1.501	1.501	0.0	1.586	1.586	0.0	1.614	1.614	0.0

Appendix E. Flood extent maps

Figure 7-5 River Tud full flood extent (west)

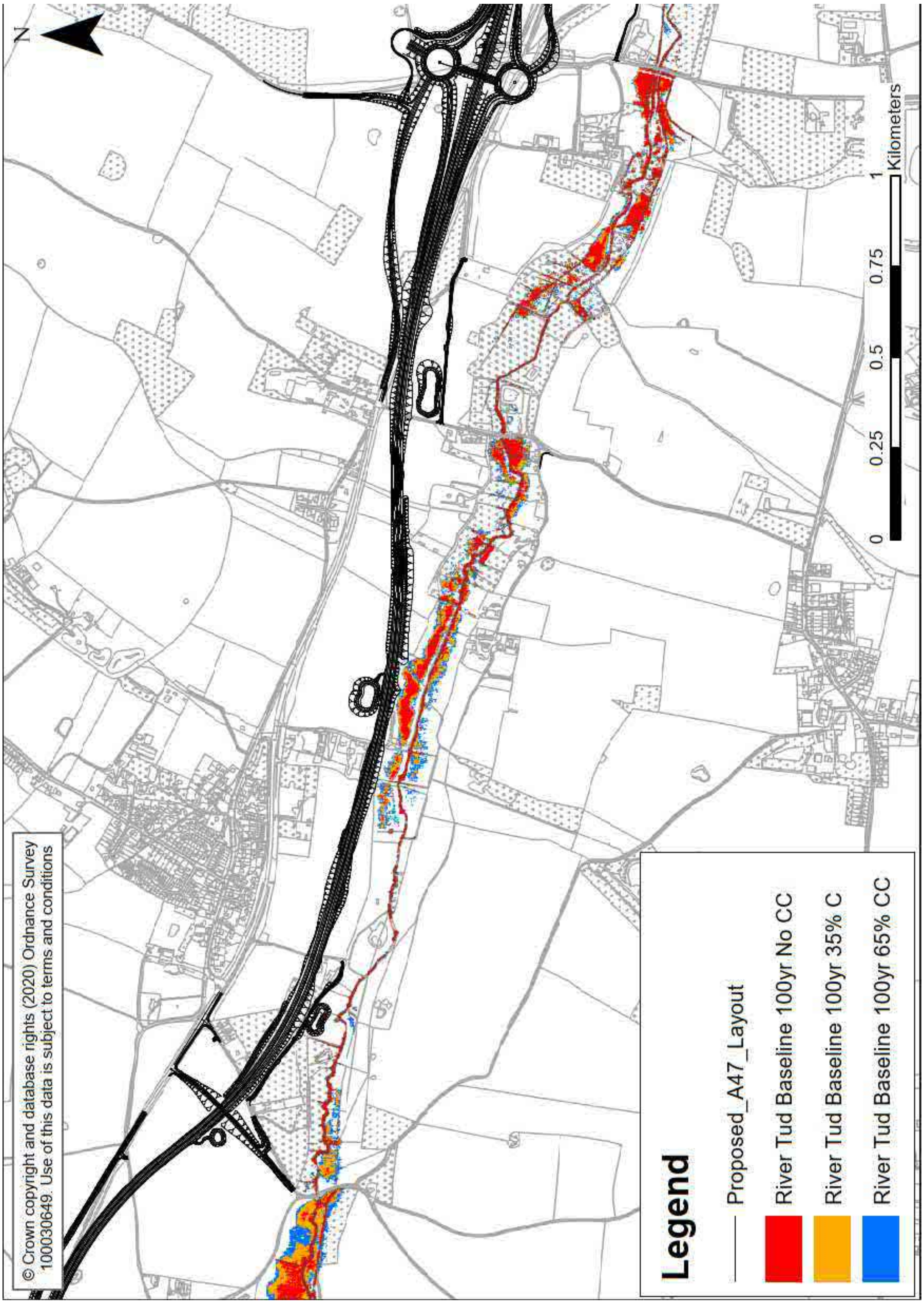
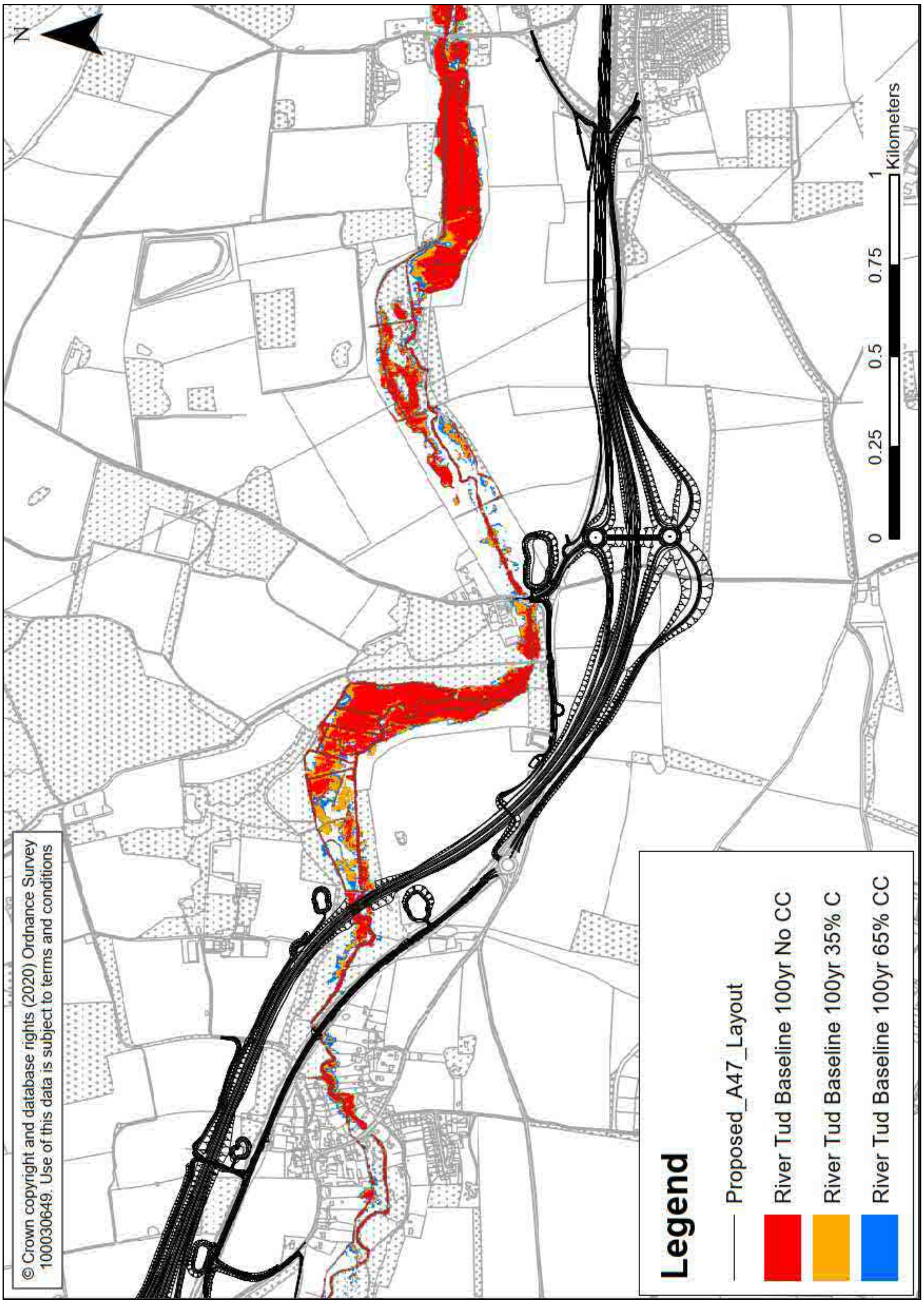


Figure 7-6 River Tud full flood extent (east)



Appendix F. River Tud flood maps

Figure 7-7 Baseline: 1 in 100-year event with no climate change allowance

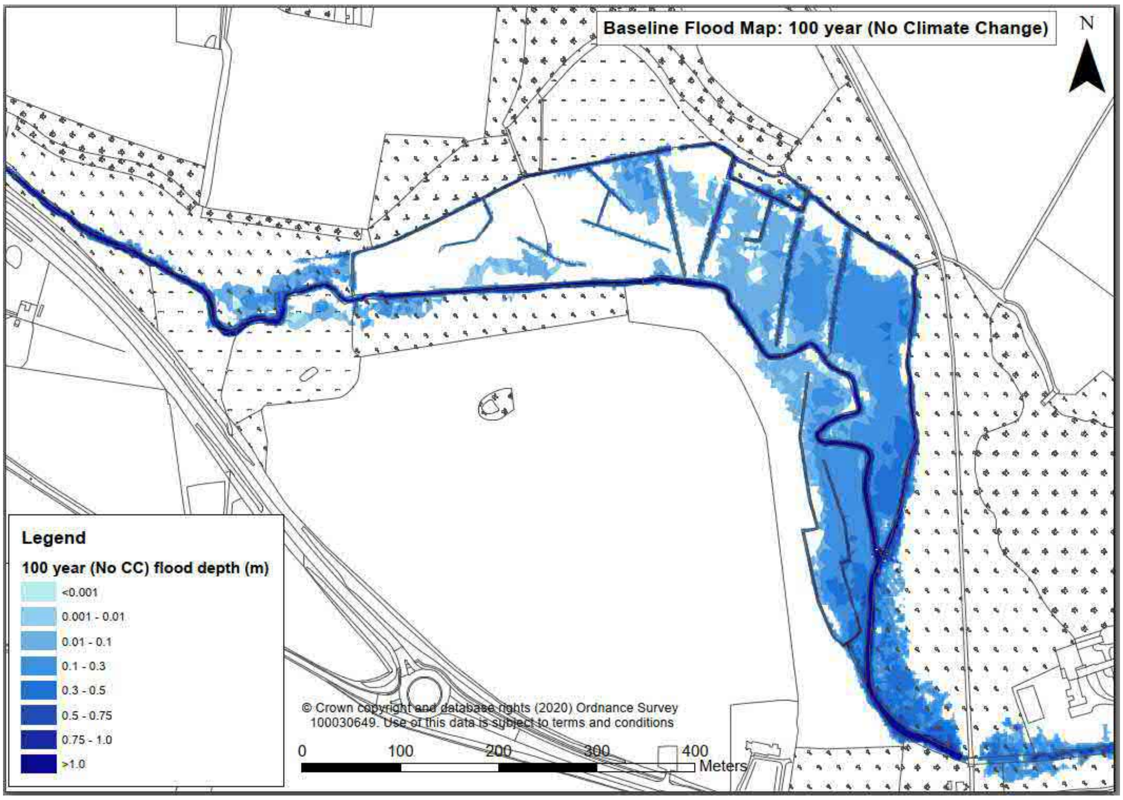


Figure 7-8 Baseline: 1 in 100 year event with a 35% climate change allowance

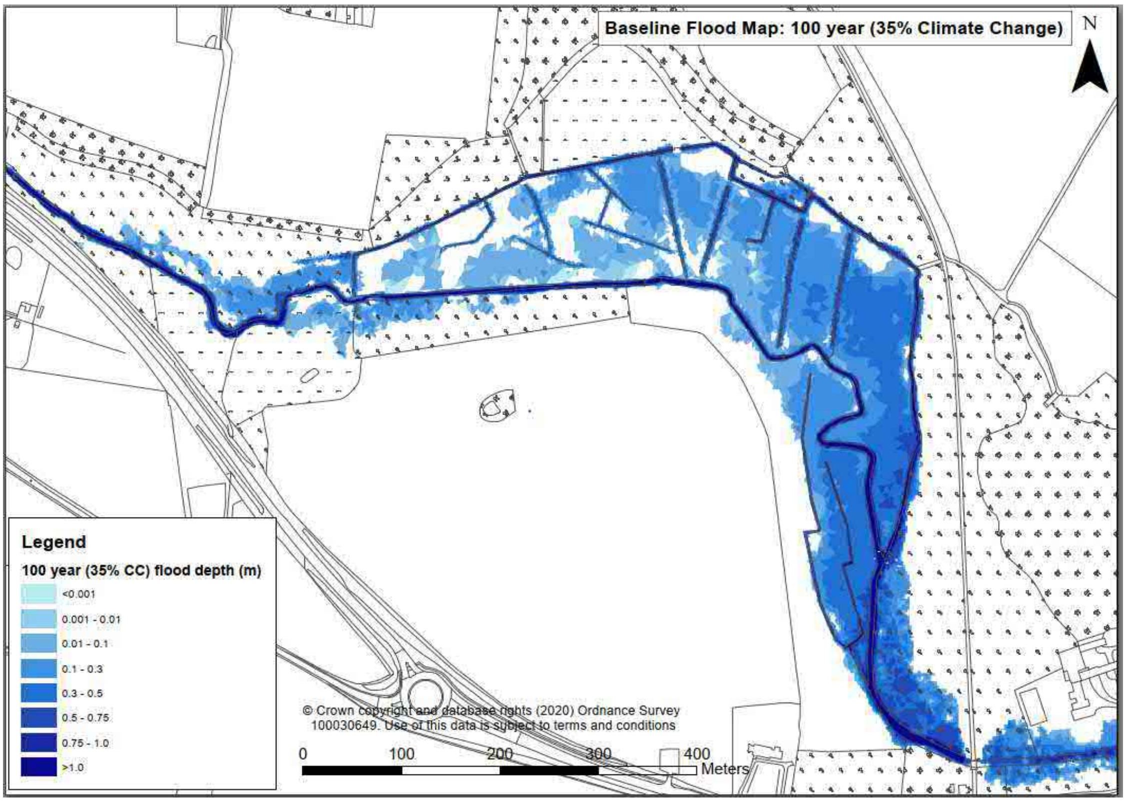


Figure 7-9 Baseline: 1 in 100-year event with a 65% climate change allowance

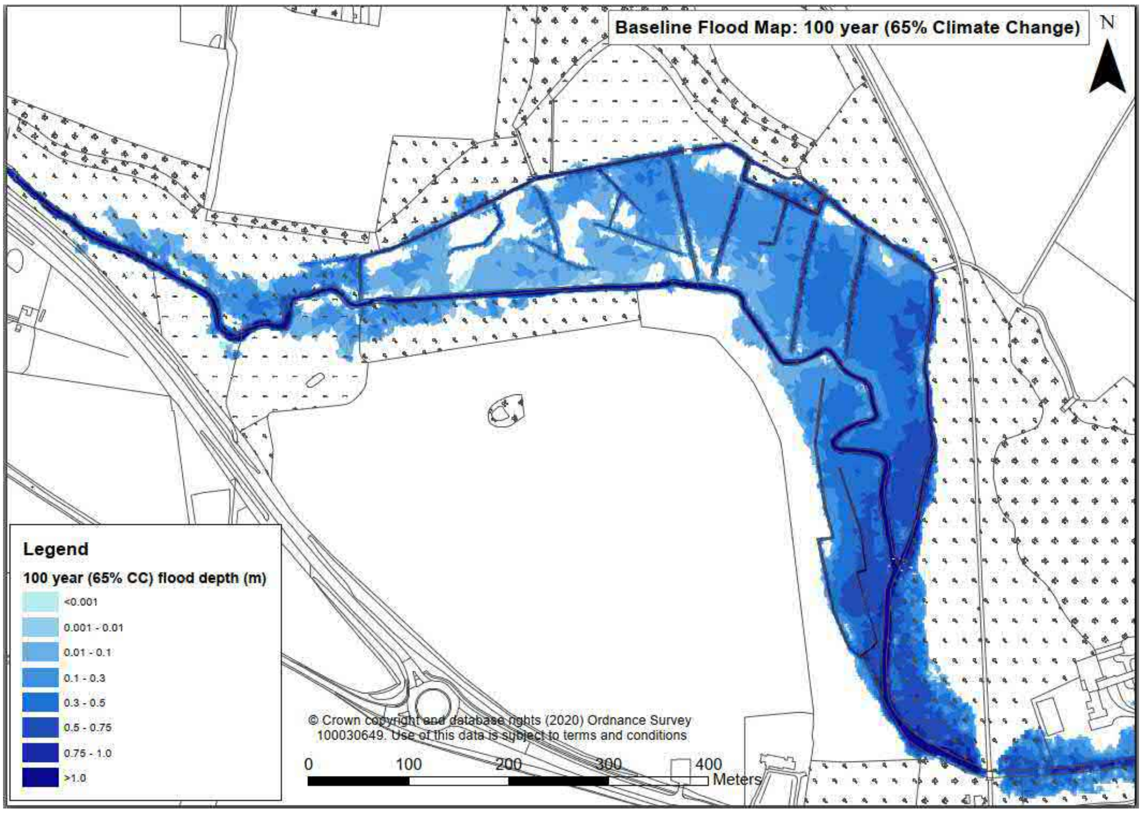


Figure 7-10 Baseline: 1 in 1000 year event with no climate change allowance

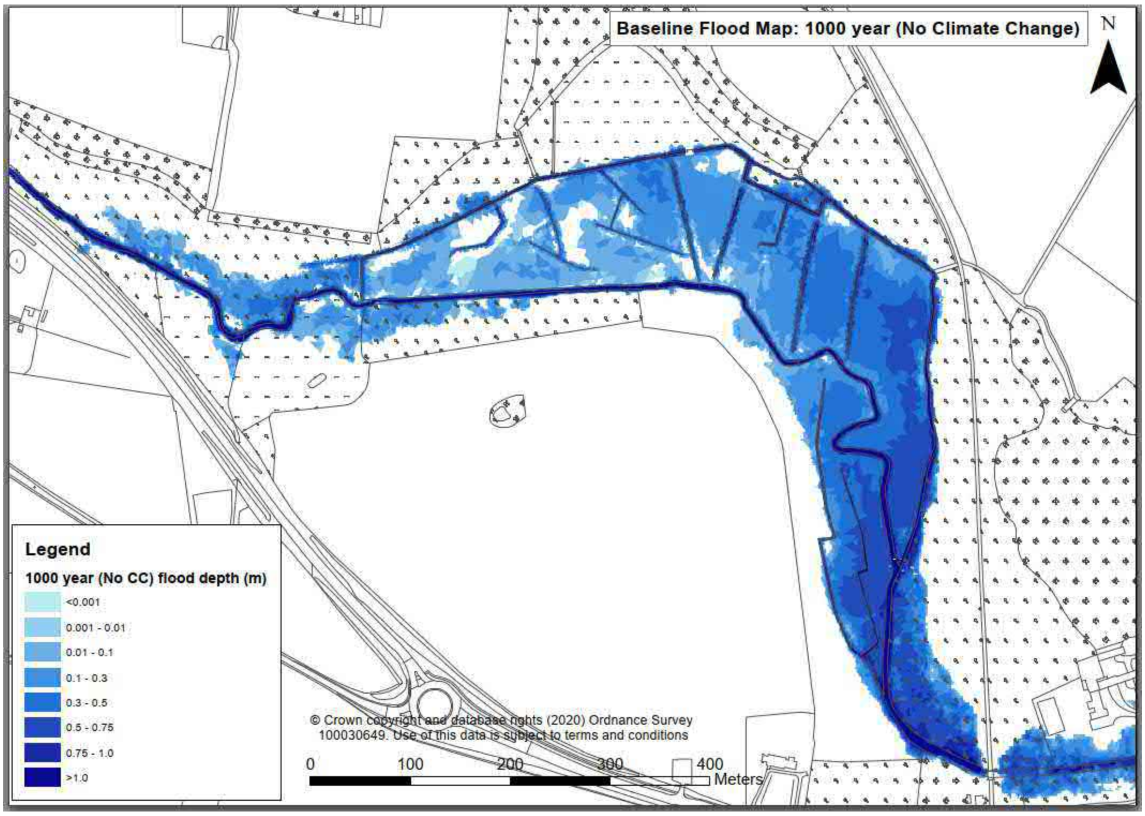


Figure 7-11 Post development: 1 in 100-year event with no climate change allowance

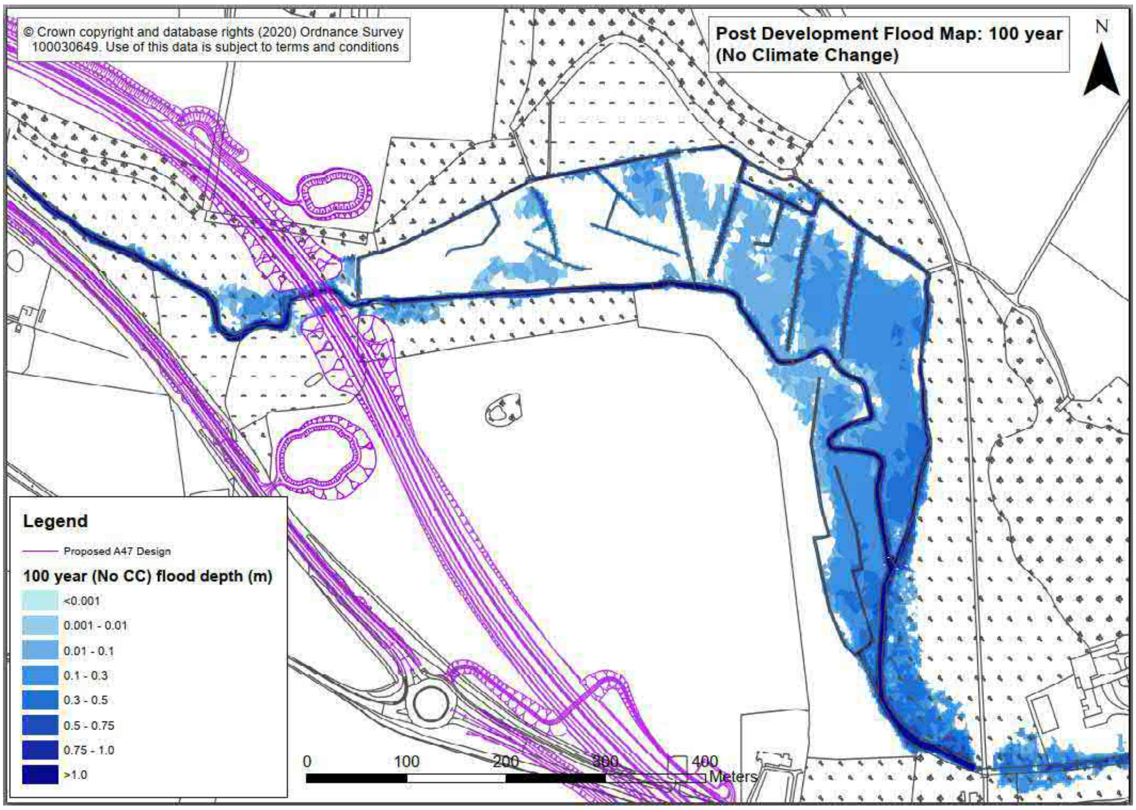


Figure 7-12 Post development: 1 in 100-year with 35% climate change allowance

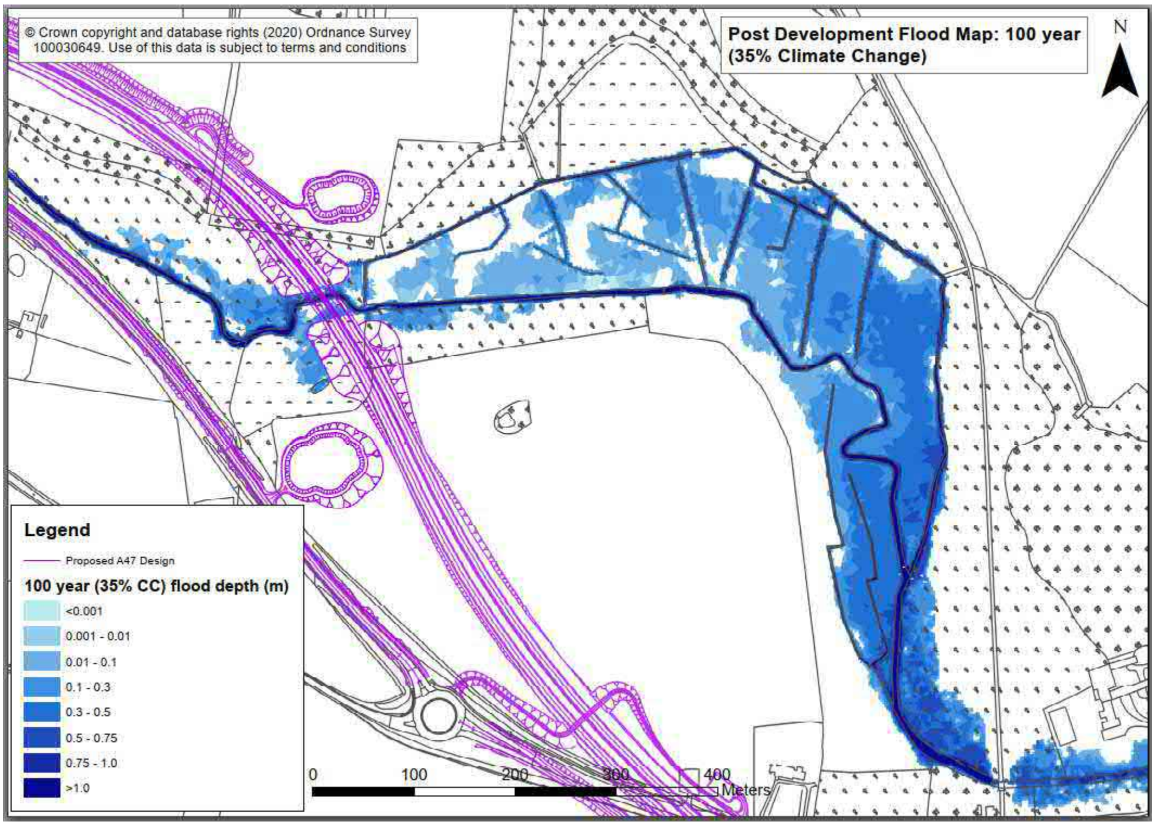


Figure 7-13 Post development: 1 in 100-year with 65% climate change allowance

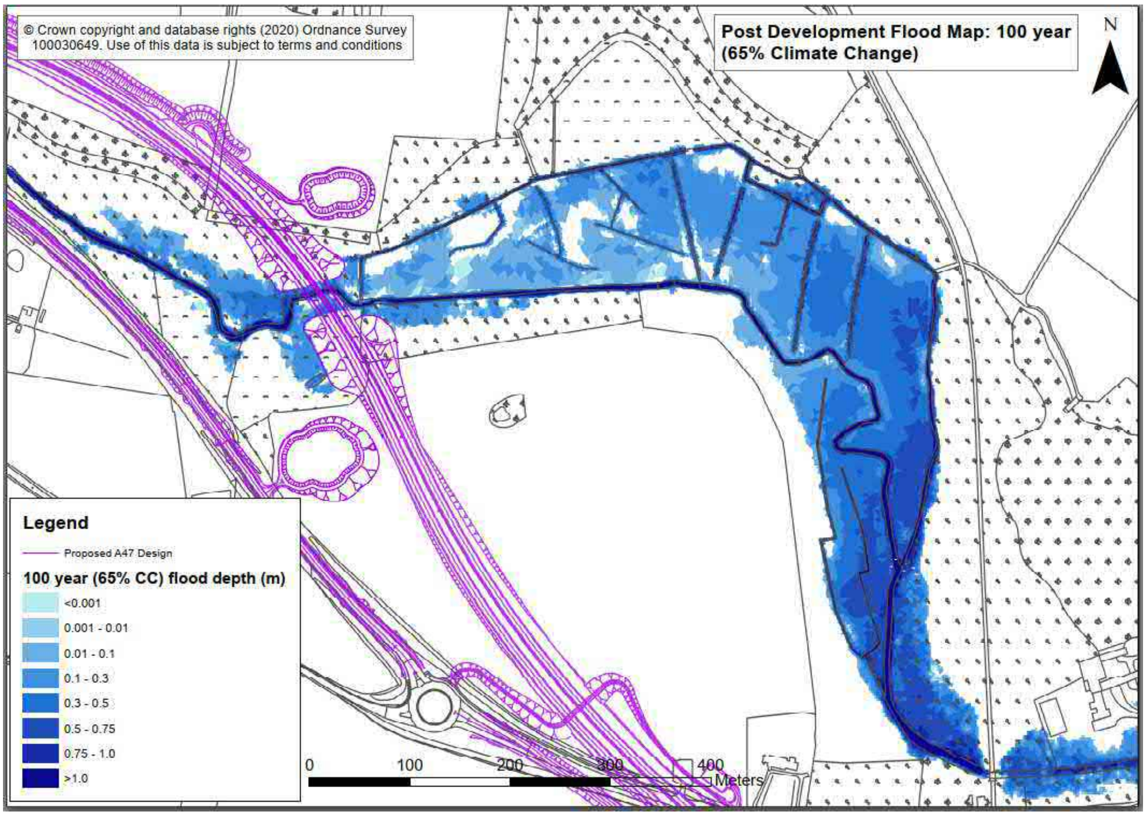
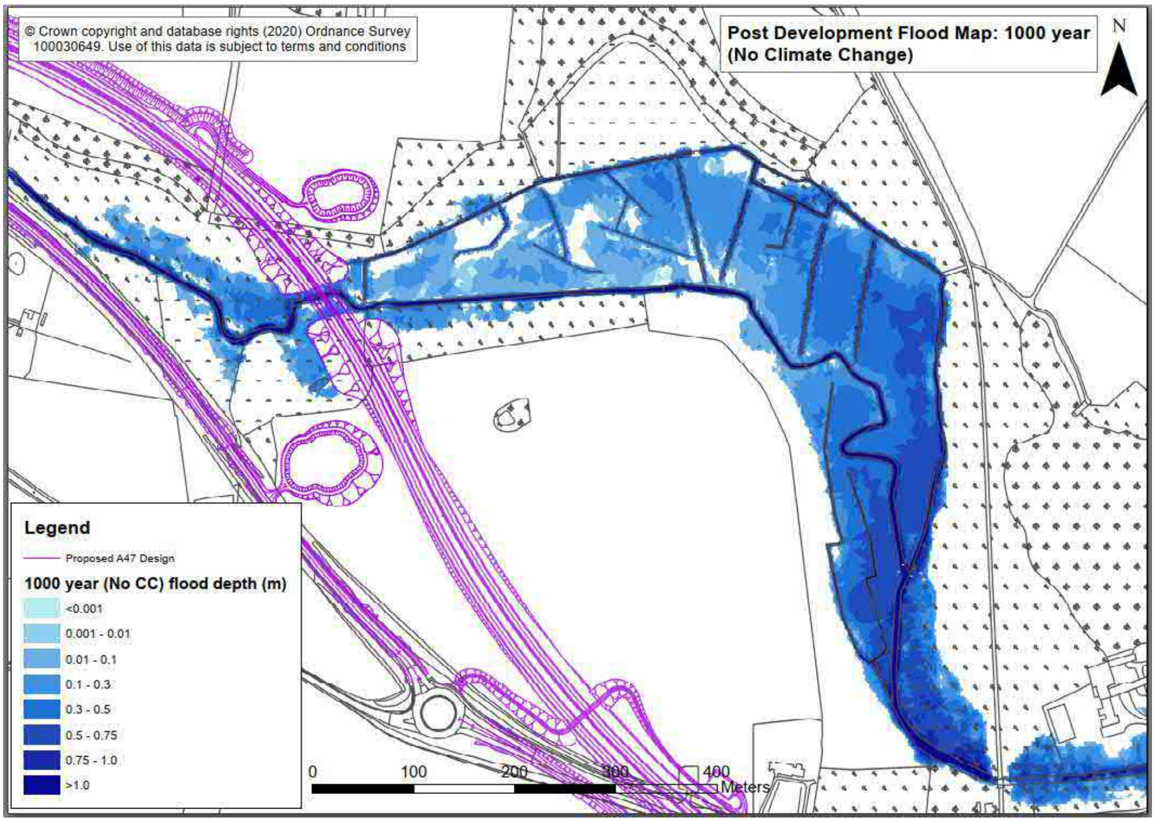


Figure 7-14 Post development: 1 in 1000-year event with no allowance for climate change



Appendix G. River Tud verification results

Table 7-5 Comparison of peak water levels for the 100 year event without an allowance for climate change. The sections highlighted yellow are compared within the report.

Cross-section ID	FloodModeller peak level (m AOD)	ICM 1D-2D Peak Level (m AOD)	Difference (mm)
TUD1_17750u	32.235	32.267	32
TUD1_17000	31.185	31.236	51
TUD1_16500	30.735	30.774	39
TUD1_16000	30.337	30.403	66
TUD1_15000	28.42	28.455	35
TUD1_14250	27.541	27.550	9
TUD1_13750	27.052	27.060	8
TUD1_13000	26.144	26.110	-34
TUD1_11250 (alt)	23.185	23.161	-24
TUD1_11170d	22.971	22.973	2
TUD1_10750 (A47 BRG LCN)	22.373	22.412	39
TUD1_10382/HONI01_0969	21.107	21.513	406
TUD1_9750u/HONI01_0322	20.77	20.713	-57
TUD1_9500	20.551	20.492	-59
TUD1_9250	19.634	19.662	28
TUD1_9000	18.994	19.004	10
TUD1_7500	16.507	16.515	8
TUD1_6750	15.287	15.269	-18
TUD1_5750	13.39	13.460	70
TUD1_5250	12.032	12.027	-5
TUD1_4000	10.617	10.655	38
TUD1_3817u (Gauge)	10.404	10.3694	-35

Appendix H. Oak Farm cross-section locations

Figure 7-15 Oak Farm upstream

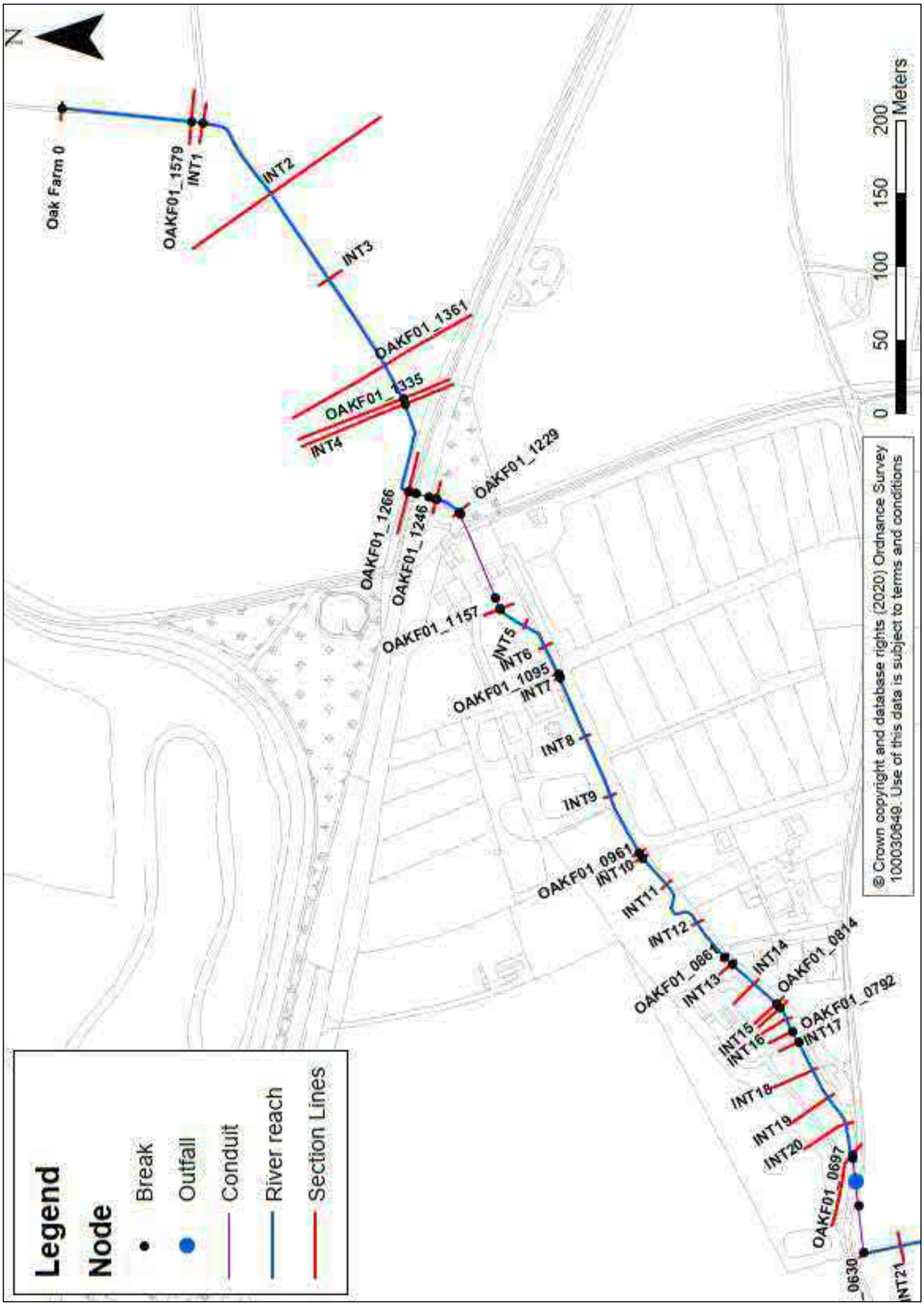


Figure 7-16 Oak Farm downstream

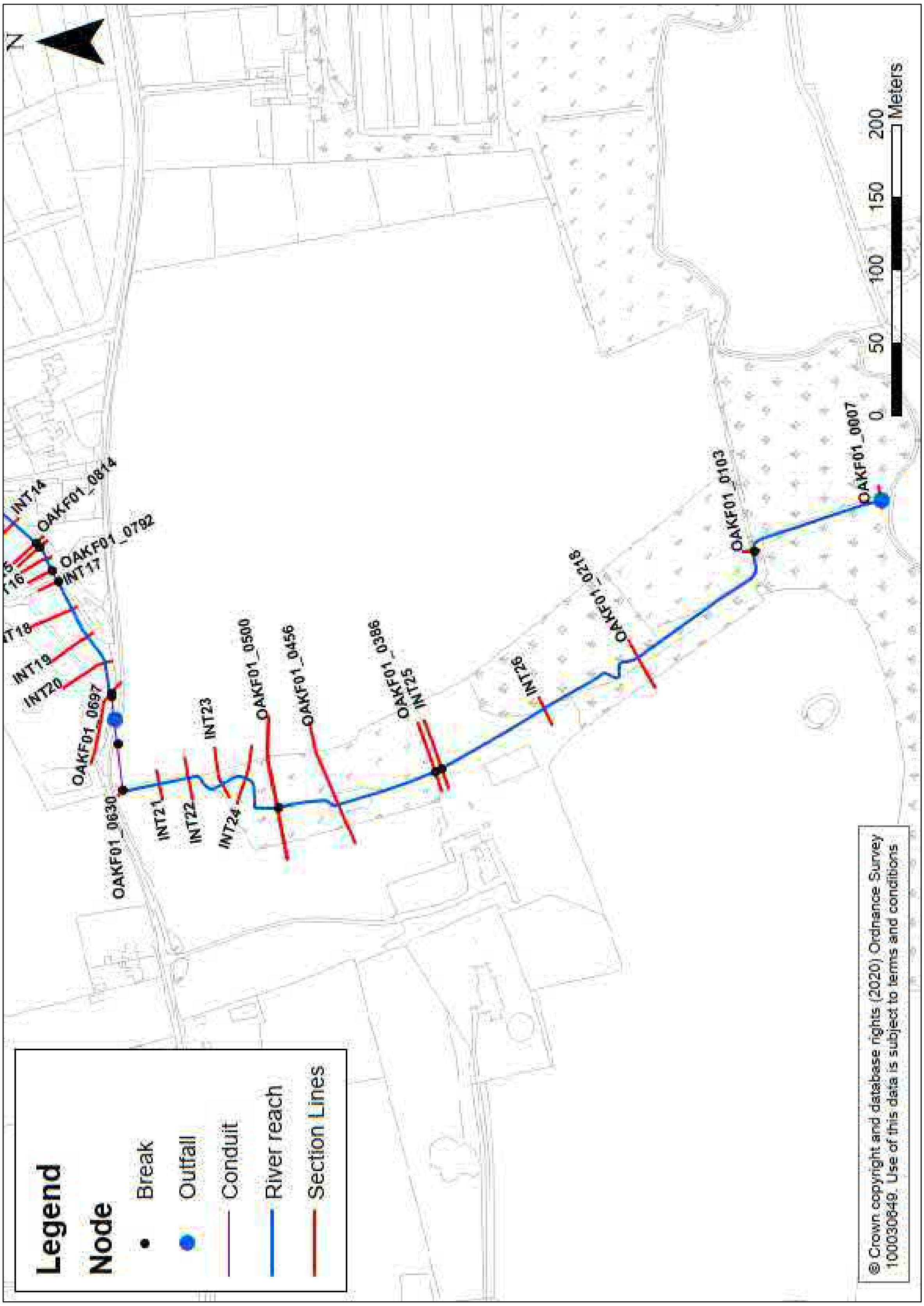


Figure 7-17 Cross-section OAKF01_1246

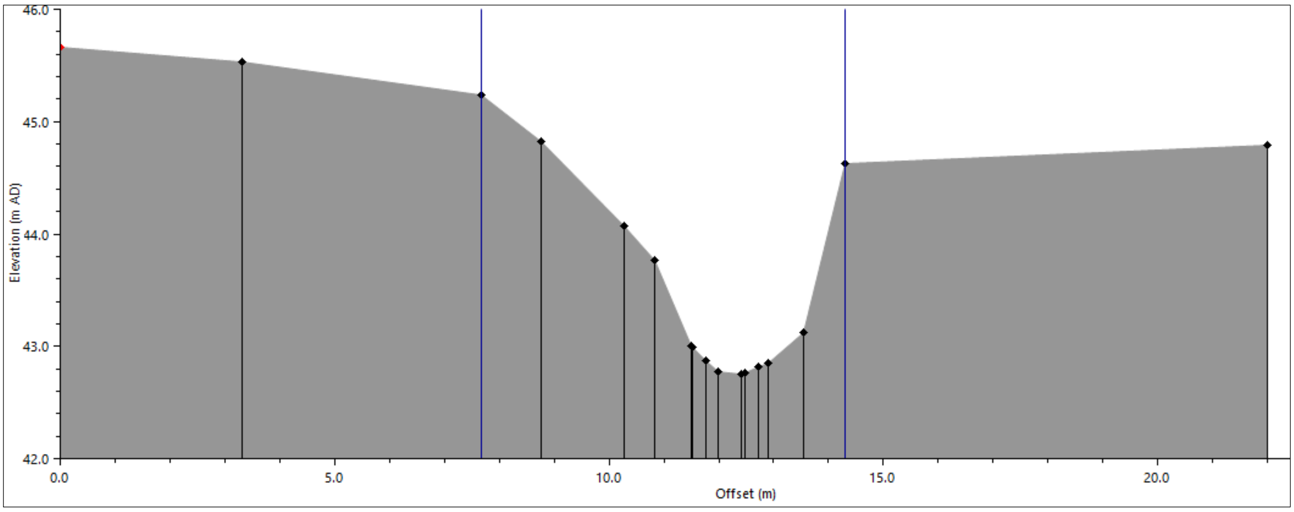
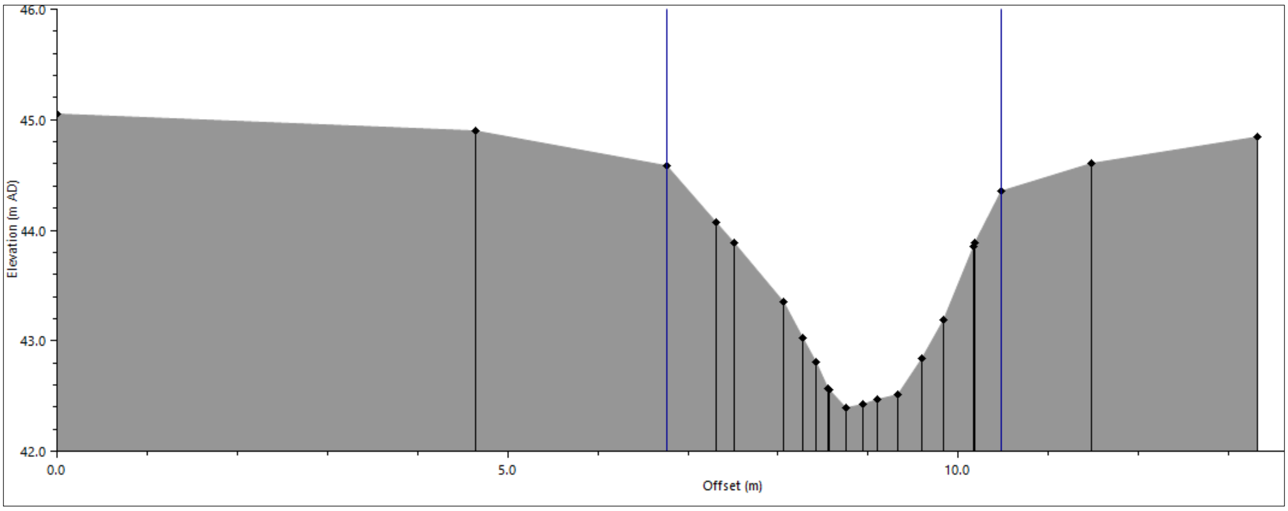


Figure 7-18 Cross-section OAKF01_1229



Appendix I. Oak Farm peak water levels

Table 7-6 Baseline peak water levels

	Baseline Peak Level (m AOD)					
Object ID	30 year (No CC)	100 year (No CC)	100 year + 35% CC	100 year + 65% CC	100 year + 80% CC	1000 year No CC
Oak Farm 0	45.804	45.912	45.965	46.012	46.033	46.032
OAKF01_1579	45.686	45.829	45.845	45.857	45.862	45.862
Culvert 1						
INT1	44.918	44.999	45.080	45.138	45.166	45.164
INT2	44.355	44.436	44.535	44.717	44.878	44.864
INT3	43.883	44.101	44.446	44.689	44.863	44.849
OAKF01_1361	43.826	44.078	44.442	44.688	44.863	44.849
OAKF01_1335	43.822	44.078	44.442	44.688	44.863	44.849
Culvert 2						
INT4	43.577	44.076	44.441	44.688	44.863	44.849
OAKF01_1266	43.517	44.070	44.440	44.687	44.862	44.849
Existing A47						
OAKF01_1246	43.377	43.838	44.150	44.360	44.754	44.566
OAKF01_1229	43.362	43.834	44.148	44.358	44.753	44.564
Culvert 4						
OAKF01_1157	42.693	42.751	42.775	42.791	42.800	42.803
INT5	42.677	42.733	42.754	42.767	42.775	42.778
INT6	42.666	42.720	42.738	42.749	42.756	42.758
OAKF01_1095	42.658	42.716	42.735	42.747	42.754	42.756
Culvert 5						
INT7	42.125	42.141	42.162	42.179	42.191	42.195
INT8	41.528	41.541	41.568	41.591	41.602	41.606
INT9	40.940	41.031	41.074	41.103	41.121	41.126
OAKF01_0961	40.587	40.756	40.783	40.798	40.808	40.811
Culvert 6						
INT10	40.345	40.457	40.503	40.531	40.547	40.552
INT11	40.164	40.263	40.314	40.343	40.359	40.364
INT12	39.912	40.042	40.082	40.106	40.120	40.125
OAKF01_0861	39.832	39.975	40.006	40.024	40.036	40.039
Culvert 7						
INT13	39.527	39.596	39.632	39.656	39.674	39.679
INT14	39.428	39.475	39.498	39.514	39.526	39.529
OAKF01_0814	39.402	39.441	39.459	39.471	39.480	39.483
Culvert 8						
INT15	39.191	39.227	39.245	39.258	39.269	39.272
INT16	39.177	39.204	39.217	39.225	39.232	39.233
OAKF01_0792	39.171	39.196	39.208	39.216	39.222	39.224
Culvert 9						
INT17	39.098	39.141	39.157	39.168	39.176	39.178
INT18	39.087	39.125	39.140	39.150	39.156	39.158
INT19	39.086	39.123	39.138	39.147	39.153	39.155
INT20	39.083	39.120	39.134	39.142	39.149	39.150
OAKF01_0697	39.082	39.118	39.132	39.140	39.146	39.147
Culvert 10						
OAKF01_0630	37.356	37.361	37.362	37.362	37.362	37.362
INT21	36.972	37.012	37.035	37.047	37.054	37.057
INT22	36.804	36.858	36.885	36.901	36.912	36.915
INT23	36.328	36.385	36.420	36.438	36.455	36.460
INT24	36.028	36.084	36.119	36.137	36.152	36.156
OAKF01_0500	35.398	35.405	35.409	35.419	35.431	35.434
OAKF01_0500	35.398	35.405	35.409	35.419	35.431	35.434
OAKF01_0456	35.139	35.358	35.386	35.402	35.413	35.415
OAKF01_0386	35.124	35.352	35.379	35.395	35.405	35.407
Culvert 11						
INT25	34.635	34.726	34.777	34.810	34.834	34.839
INT26	33.182	33.253	33.285	33.302	33.313	33.316
OAKF01_0218	31.789	31.825	31.842	31.853	31.859	31.861
OAKF01_0103	30.897	30.999	31.059	31.092	31.120	31.128
OAKF01_0103	30.897	30.999	31.059	31.092	31.120	31.128
OAKF01_0007	29.789	29.860	29.902	29.931	29.951	29.957
Confluence with River Tud						

Table 7-7 Post development peak water levels

	Post Development Peak Level (m AOD)					
Object ID	**30 year (No CC)**	**100 year (No CC)**	**100 year + 35% CC**	**100 year + 65% CC**	**100 year + 80% CC**	**1000 year No CC**
Oak Farm 0	45.804	45.912	45.965	46.012	46.034	46.032
OAKF01_1579	45.686	45.829	45.846	45.859	45.865	45.865
Culvert 1						
INT1	44.918	45.112	45.344	45.516	45.709	45.672
INT2	44.777	45.090	45.337	45.513	45.708	45.671
INT3 (Modified)	44.771	45.089	45.337	45.513	45.708	45.671
INT PDEV1	44.771	45.089	45.337	45.513	45.708	45.671
Proposed new A47 culvert						
OAKF01_1335 (Modified)	43.396	43.437	43.497	43.543	43.595	43.590
INT PDEV2	43.392	43.434	43.494	43.541	43.593	43.588
INT PDEV3	43.346	43.391	43.464	43.515	43.572	43.567
INT PDEV4	43.258	43.318	43.415	43.478	43.545	43.540
Existing A47						
OAKF01_1246	43.080	43.189	43.279	43.328	43.380	43.377
OAKF01_1229	42.999	43.156	43.258	43.311	43.366	43.363
Culvert 4						
OAKF01_1157	42.593	42.692	42.731	42.753	42.763	42.767
INT5	42.566	42.676	42.714	42.735	42.744	42.747
INT6	42.550	42.666	42.702	42.722	42.730	42.732
OAKF01_1095	42.534	42.657	42.696	42.718	42.726	42.729
Culvert 5						
INT7	42.097	42.125	42.134	42.142	42.151	42.155
INT8	41.497	41.528	41.536	41.542	41.551	41.556
INT9	40.894	40.941	41.002	41.034	41.054	41.060
OAKF01_0961	40.472	40.593	40.733	40.758	40.769	40.774
Culvert 6						
INT10	40.301	40.347	40.421	40.459	40.479	40.487
INT11	40.117	40.166	40.233	40.265	40.287	40.296
INT12	39.842	39.917	40.011	40.044	40.062	40.069
OAKF01_0861	39.741	39.838	39.951	39.977	39.991	39.996
Culvert 7						
INT13	39.486	39.529	39.568	39.598	39.614	39.620
INT14	39.395	39.429	39.458	39.476	39.486	39.490
OAKF01_0814	39.372	39.403	39.428	39.442	39.450	39.453
Culvert 8						
INT15	39.173	39.192	39.213	39.228	39.236	39.239
INT16	39.163	39.178	39.194	39.205	39.210	39.212
OAKF01_0792	39.157	39.172	39.187	39.197	39.202	39.204
Culvert 9						
INT17	39.077	39.100	39.125	39.142	39.149	39.151
INT18	39.065	39.089	39.112	39.126	39.133	39.135
INT19	39.064	39.087	39.111	39.124	39.130	39.133
INT20	39.062	39.085	39.108	39.121	39.127	39.129
OAKF01_0697	39.061	39.084	39.106	39.119	39.125	39.127
Culvert 10						
OAKF01_0630	37.354	37.356	37.360	37.361	37.362	37.362
INT21	36.960	36.973	36.995	37.014	37.024	37.028
INT22	36.781	36.806	36.836	36.860	36.872	36.876
INT23	36.303	36.330	36.364	36.387	36.403	36.409
INT24	36.001	36.030	36.063	36.086	36.101	36.107
OAKF01_0500	35.393	35.401	35.407	35.410	35.409	35.411
OAKF01_0500	35.393	35.401	35.407	35.410	35.409	35.411
OAKF01_0456	35.044	35.197	35.347	35.372	35.383	35.388
OAKF01_0386	35.024	35.185	35.342	35.366	35.376	35.381
Culvert 11						
INT25	34.608	34.650	34.708	34.751	34.769	34.781
INT26	33.160	33.192	33.241	33.269	33.282	33.287
OAKF01_0218	31.778	31.795	31.818	31.833	31.840	31.843
OAKF01_0103	30.872	30.915	30.981	31.030	31.053	31.062
OAKF01_0103	30.872	30.915	30.981	31.030	31.053	31.062
OAKF01_0007	29.770	29.800	29.846	29.879	29.897	29.904
Confluence with River Tud						

Table 7-8 Comparison of peak water levels

	100 year (No CC)			100 year (65%CC)		
Object ID	**Baseline**	**Post Development**	**Difference (mm)**	**Baseline**	**Post Development**	**Difference (mm)**
Oak Farm 0	45.912	45.912	0	46.012	46.012	1
OAKF01_1579	45.829	45.829	0	45.857	45.859	2
Culvert 1						
INT1	44.999	45.112	112	45.138	45.516	379
INT2	44.436	45.090	654	44.717	45.513	797
INT3	44.101	-		44.689	-	
OAKF01_1361	44.078			44.688		
OAKF01_1335	44.078			44.688		
Culvert 2						
INT4	44.076	-		44.688	-	
OAKF01_1266	44.070			44.687		
Existing A47						
OAKF01_1246	43.838	43.189	-650	44.360	43.328	-1032
OAKF01_1229	43.834	43.156	-678	44.358	43.311	-1047
Culvert 4						
OAKF01_1157	42.751	42.692	-59	42.791	42.753	-38
INT5	42.733	42.676	-57	42.767	42.735	-33
INT6	42.720	42.666	-55	42.749	42.722	-28
OAKF01_1095	42.716	42.657	-59	42.747	42.718	-29
Culvert 5						
INT7	42.141	42.125	-16	42.179	42.142	-36
INT8	41.541	41.528	-13	41.591	41.542	-49
INT9	41.031	40.941	-90	41.103	41.034	-69
OAKF01_0961	40.756	40.593	-163	40.798	40.758	-41
Culvert 6						
INT10	40.457	40.347	-110	40.531	40.459	-72
INT11	40.263	40.166	-97	40.343	40.265	-78
INT12	40.042	39.917	-126	40.106	40.044	-61
OAKF01_0861	39.975	39.838	-137	40.024	39.977	-48
Culvert 7						
INT13	39.596	39.529	-67	39.656	39.598	-58
INT14	39.475	39.429	-46	39.514	39.476	-38
OAKF01_0814	39.441	39.403	-38	39.471	39.442	-29
Culvert 8						
INT15	39.227	39.192	-35	39.258	39.228	-31
INT16	39.204	39.178	-26	39.225	39.205	-21
OAKF01_0792	39.196	39.172	-25	39.216	39.197	-19
Culvert 9						
INT17	39.141	39.100	-41	39.168	39.142	-26
INT18	39.125	39.089	-37	39.150	39.126	-24
INT19	39.123	39.087	-36	39.147	39.124	-23
INT20	39.120	39.085	-35	39.142	39.121	-22
OAKF01_0697	39.118	39.084	-35	39.140	39.119	-21
Culvert 10						
OAKF01_0630	37.361	37.356	-5	37.362	37.361	-1
INT21	37.012	36.973	-39	37.047	37.014	-33
INT22	36.858	36.806	-52	36.901	36.860	-41
INT23	36.385	36.330	-56	36.438	36.387	-50
INT24	36.084	36.030	-54	36.137	36.086	-51
OAKF01_0500	35.405	35.401	-3	35.419	35.410	-9
OAKF01_0500	35.405	35.401	-3	35.419	35.410	-9
OAKF01_0456	35.358	35.197	-162	35.402	35.372	-30
OAKF01_0386	35.352	35.185	-167	35.395	35.366	-29
Culvert 11						
INT25	34.726	34.650	-76	34.810	34.751	-58
INT26	33.253	33.192	-61	33.302	33.269	-34
OAKF01_0218	31.825	31.795	-30	31.853	31.833	-19
OAKF01_0103	30.999	30.915	-85	31.092	31.030	-62
OAKF01_0103	30.999	30.915	-85	31.092	31.030	-62
OAKF01_0007	29.860	29.800	-61	29.931	29.879	-52
Confluence with River Tud						

Appendix J. Oak Farm flood extent

Figure 7-19 Baseline flood extents

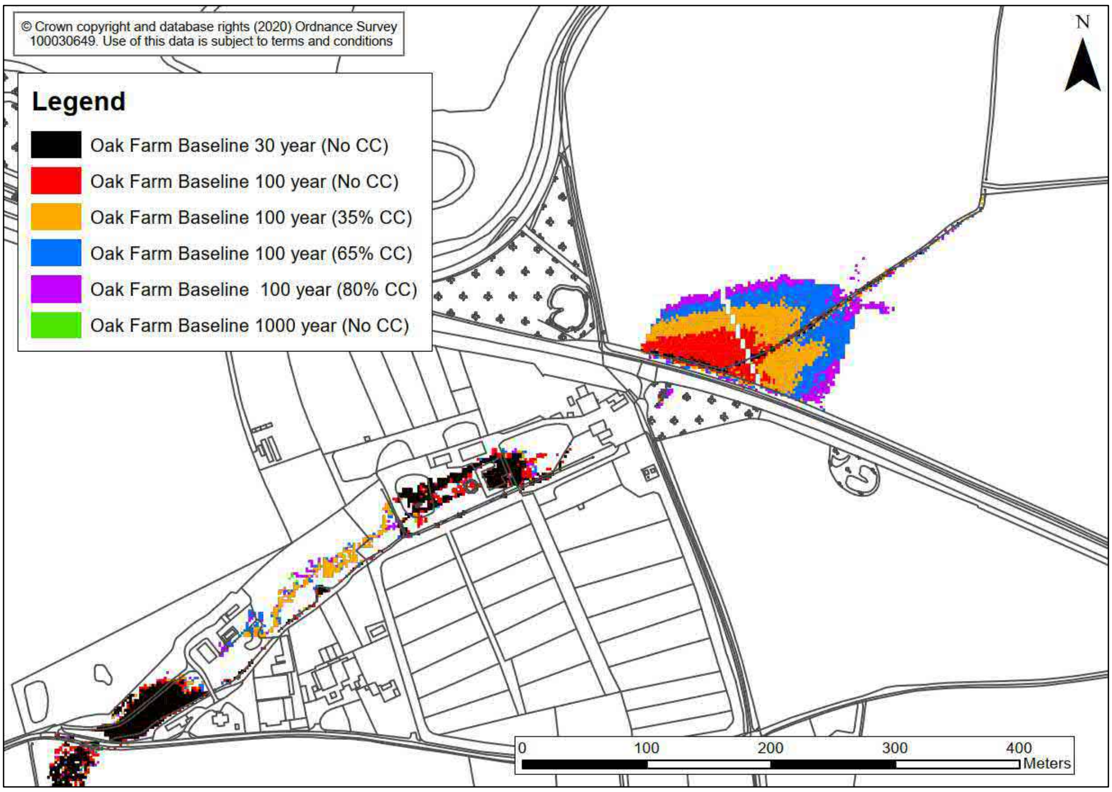


Figure 7-20 Baseline flood extent with A47 proposed scheme

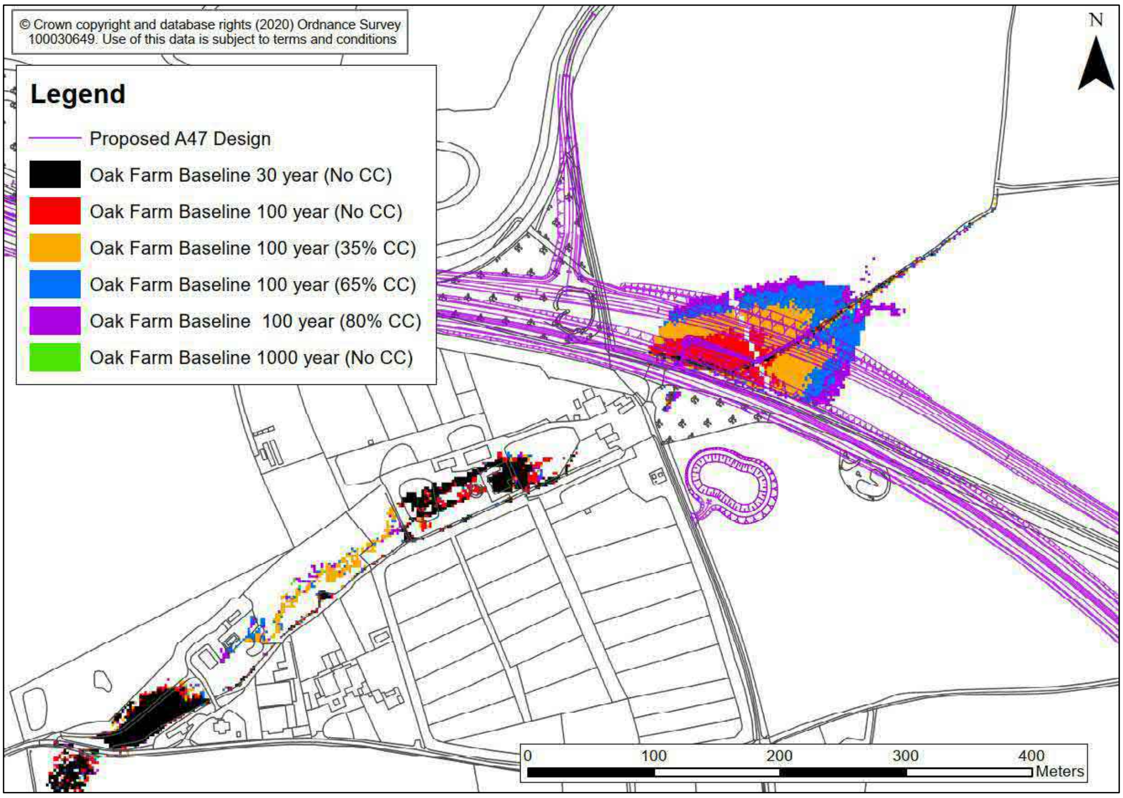
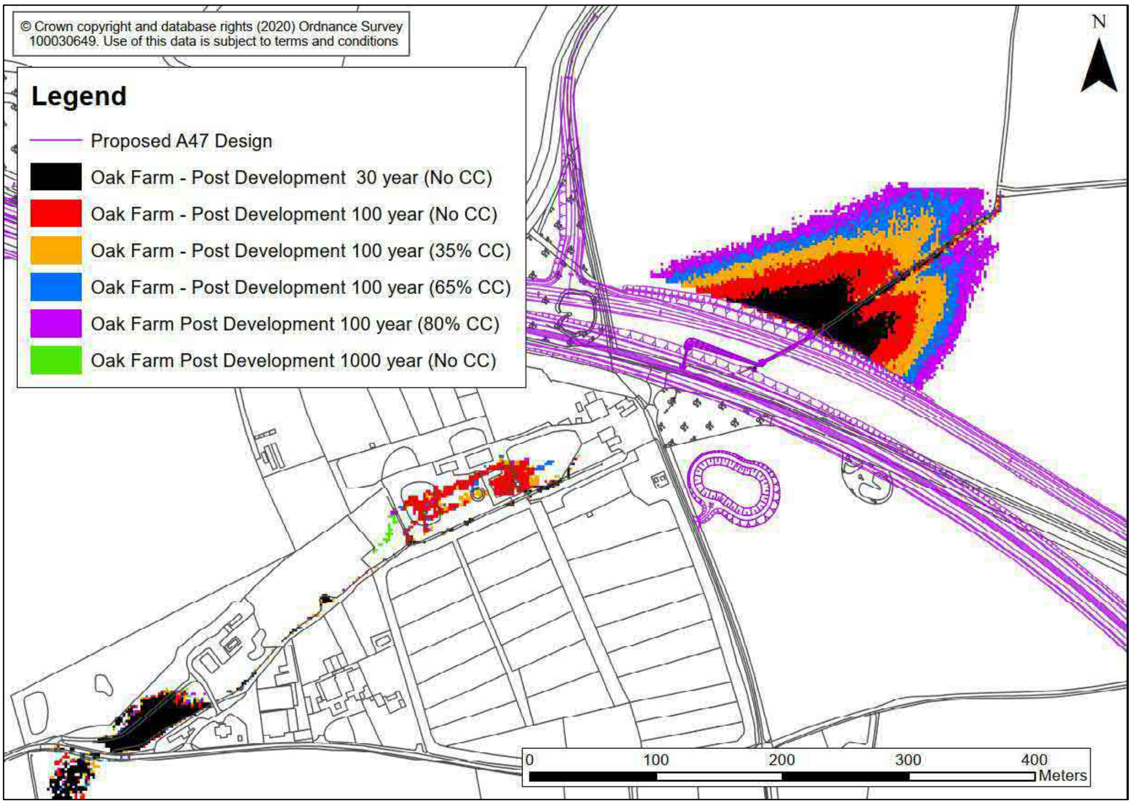


Figure 7-21 Post development flood extents



Appendix K. Hockering cross-section locations

Figure 7-22 Hockering section locations

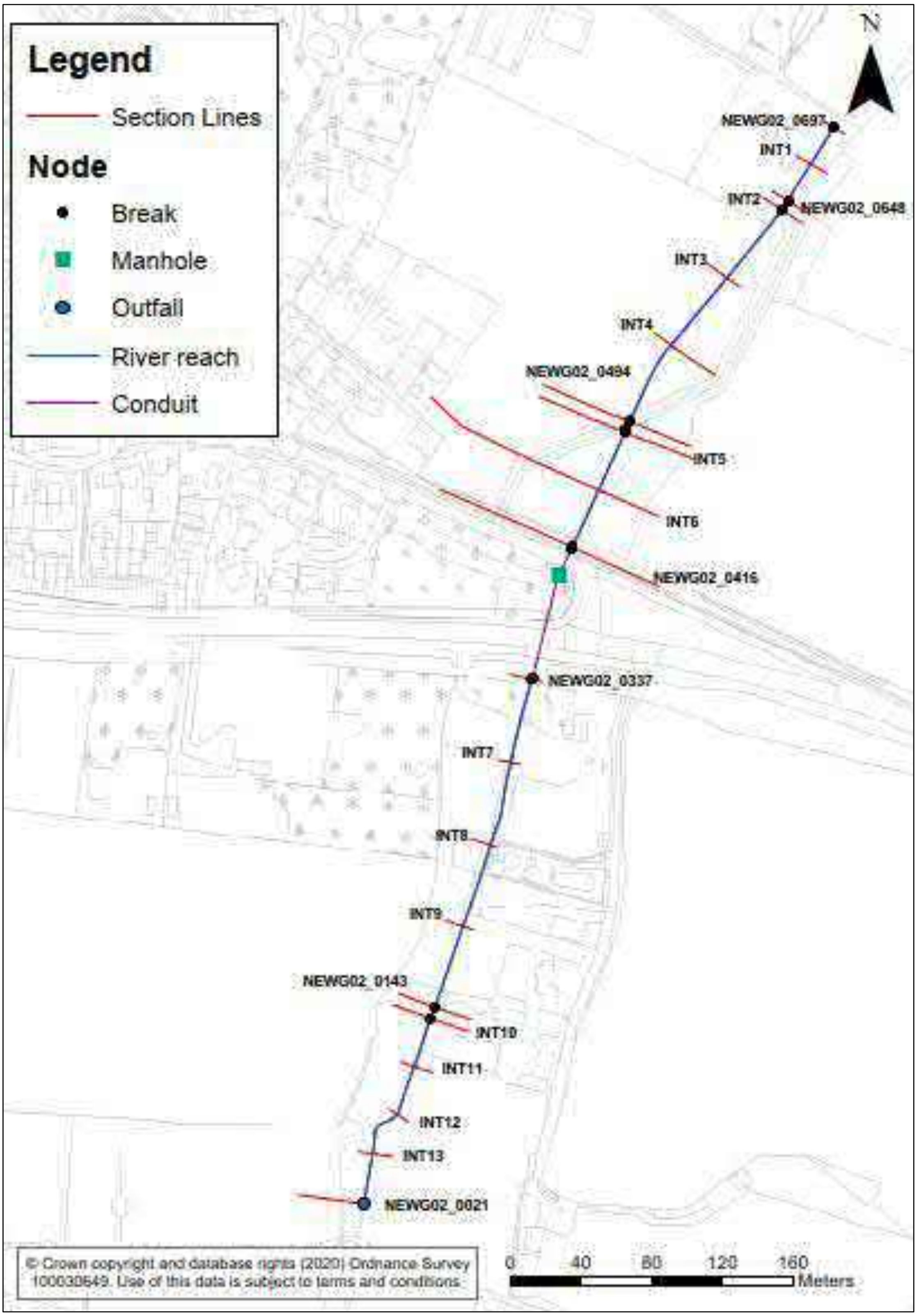


Figure 7-23 Cross-section NEWG02_0143

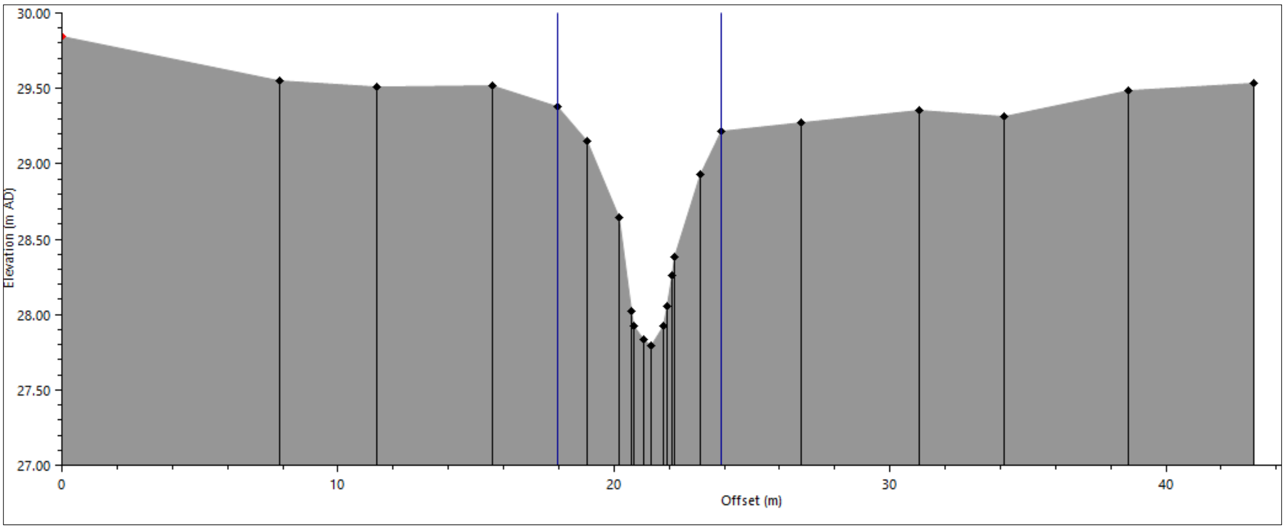
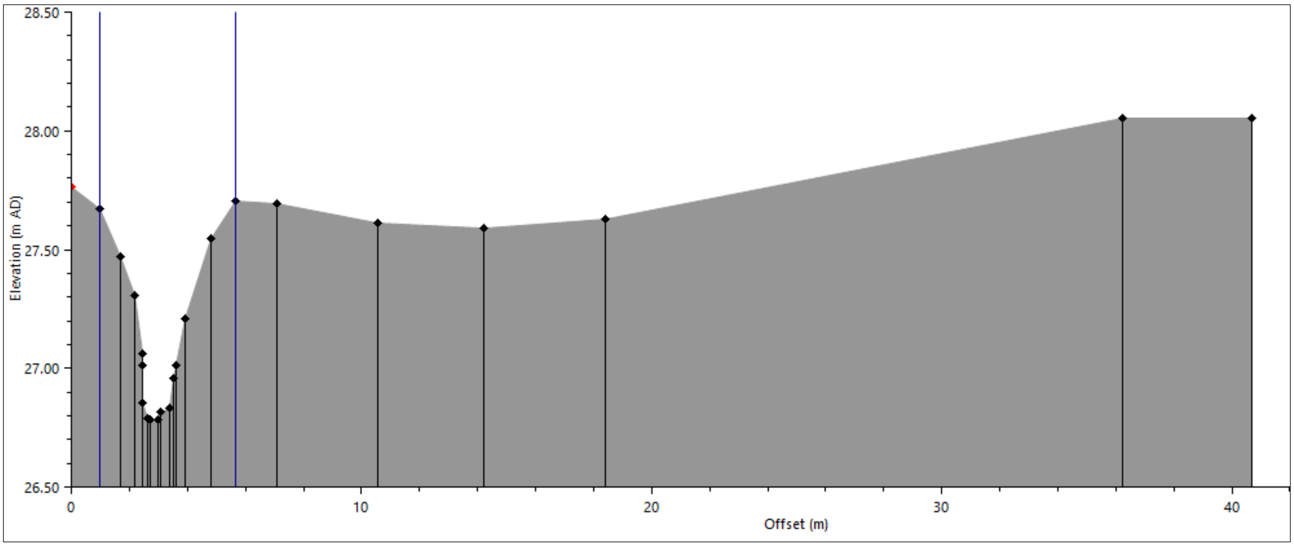


Figure 7-24 Cross-section NEWG02_0021



Appendix L. Hockering peak water levels

Table 7-9 Hockering baseline peak water levels

Object ID	Baseline Peak Level (m AOD)					
	30 year (No CC)	100 year (No CC)	100 year + 35% CC	100 year + 65% CC	100 year + 80% CC	1000 year No CC
NEWG02_0697	34.785	34.898	35.004	35.089	35.133	35.150
INT1	34.646	34.756	34.864	34.956	35.011	35.031
NEWG02_0648	34.354	34.483	34.638	34.789	34.880	34.909
INT2	34.313	34.419	34.512	34.574	34.608	34.616
INT3	33.653	33.758	33.845	33.911	33.942	33.954
INT4	32.998	33.118	33.241	33.332	33.551	33.633
NEWG02_0494	32.694	32.948	33.108	33.222	33.525	33.619
INT5	32.413	32.568	32.722	33.206	33.522	33.617
INT6	32.200	32.428	32.640	33.209	33.523	33.617
NEWG02_0416	32.072	32.326	32.574	33.195	33.515	33.610
Existing A47						
NEWG02_0337	30.739	30.857	30.966	31.040	31.073	31.082
INT7	30.184	30.304	30.415	30.490	30.520	30.529
INT8	29.620	29.748	29.870	29.945	29.976	29.985
INT9	29.081	29.277	29.467	29.523	29.544	29.550
NEWG02_0143	28.903	29.161	29.387	29.426	29.439	29.443
INT10	28.486	28.623	28.744	28.817	28.847	28.856
INT11	28.247	28.374	28.480	28.545	28.570	28.576
INT12	27.991	28.102	28.193	28.251	28.273	28.280
INT13	27.789	27.862	27.935	27.983	28.001	28.006
NEWG02_0021	27.700	27.700	27.700	27.700	27.700	27.700
Confluence with River Tud						

Table 7-10 Hockering post development peak water levels. The sections highlighted green lie in the vicinity of the proposed A47 crossing.

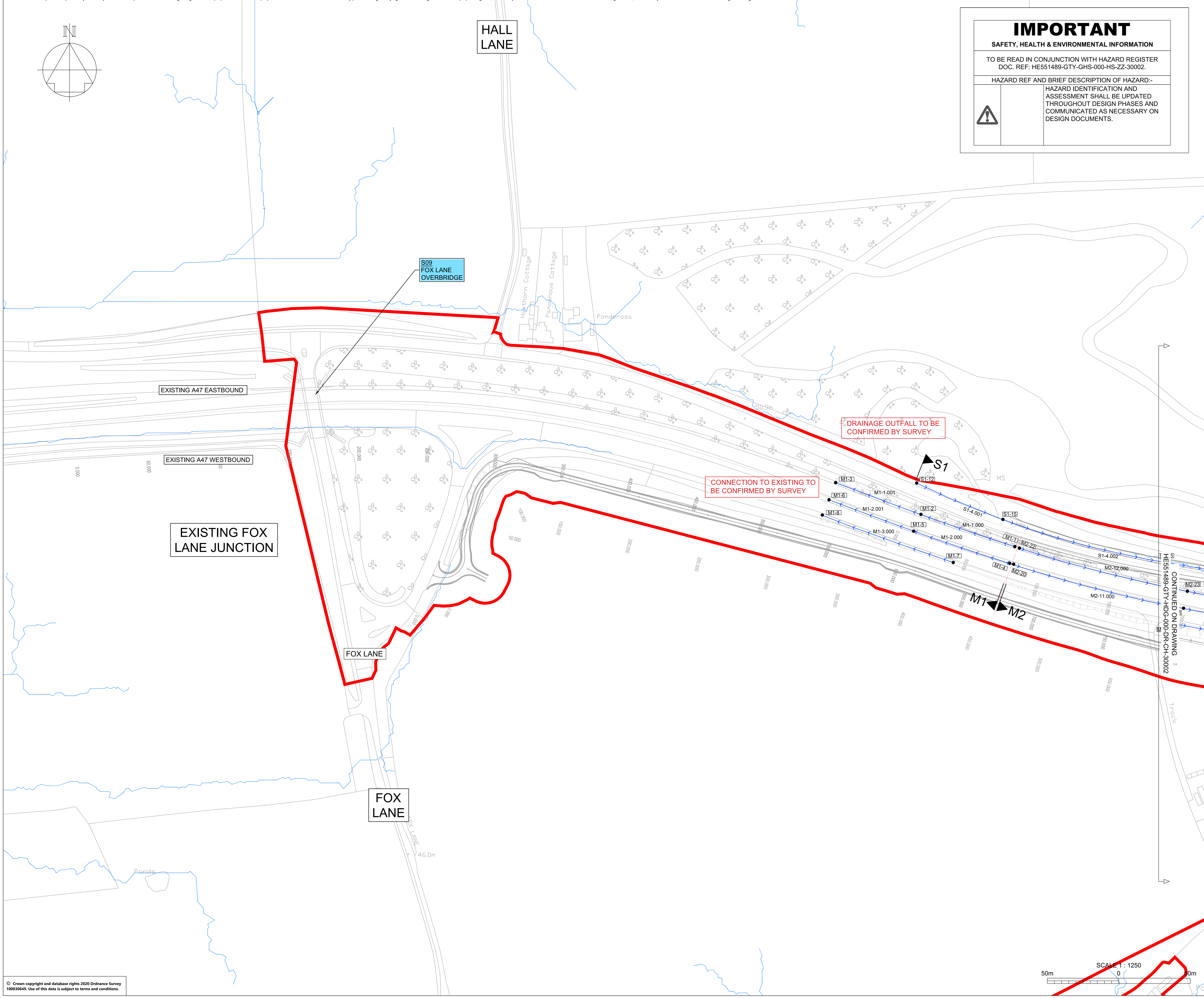
Object ID	Post Development Peak Level (m AOD)					
	30 year (No CC)	100 year (No CC)	100 year + 35% CC	100 year + 65% CC	100 year + 80% CC	1000 year No CC
NEWG02_0697	34.785	34.898	35.004	35.089	35.133	35.150
INT1	34.646	34.756	34.864	34.956	35.011	35.031
NEWG02_0648	34.354	34.483	34.638	34.789	34.880	34.909
INT2	34.313	34.419	34.512	34.574	34.608	34.616
INT3	33.653	33.758	33.845	33.911	33.942	33.954
INT4	32.998	33.118	33.241	33.332	33.551	33.633
NEWG02_0494	32.694	32.948	33.108	33.222	33.525	33.619
INT5	32.413	32.568	32.722	33.206	33.522	33.617
INT6	32.200	32.428	32.640	33.209	33.523	33.617
NEWG02_0416	32.072	32.326	32.574	33.195	33.515	33.610
Existing A47						
NEWG02_0337	30.739	30.857	30.966	31.040	31.073	31.082
INT7	30.184	30.304	30.415	30.490	30.520	30.529
INT8	29.620	29.748	29.870	29.945	29.976	29.985
INT9	29.081	29.277	29.467	29.523	29.544	29.550
NEWG02_0143	28.903	29.161	29.387	29.426	29.439	29.443
INT10	28.463	28.604	28.727	28.807	28.838	28.847
INT11 - CLVT Inlet	28.093	28.228	28.374	28.477	28.519	28.531
INT12b - CLVT Outlet	27.819	27.909	27.999	28.056	28.077	28.083
INT13b	27.746	27.792	27.852	27.893	27.910	27.915
NEWG02_0021	27.700	27.700	27.700	27.700	27.700	27.700
Confluence with River Tud						

Appendix M. Hockering comparison of peak water levels

Table 7-11 Comparison of peak water levels for the Hockering watercourse with no downstream boundary applied. The sections highlighted green lie in the vicinity of the proposed A47 crossing.

Object ID	100 year No CC Peak water level (m AOD)			100 year + 65% CC Peak water level (m AOD)		
	Baseline	post development	Difference (mm)	Baseline	Post Development	Difference (mm)
NEWG02_0697	34.898	34.898	0	35.089	35.089	0
INT1	34.756	34.756	0	34.956	34.956	0
NEWG02_0648	34.483	34.483	0	34.789	34.789	0
INT2	34.419	34.419	0	34.574	34.574	0
INT3	33.758	33.758	0	33.911	33.911	0
INT4	33.118	33.118	0	33.332	33.332	0
NEWG02_0494	32.948	32.948	0	33.222	33.222	0
INT5	32.568	32.568	0	33.206	33.206	0
INT6	32.428	32.428	0	33.209	33.209	0
NEWG02_0416	32.326	32.326	0	33.195	33.195	0
Existing A47						
NEWG02_0337	30.857	30.857	0	31.040	31.040	0
INT7	30.304	30.304	0	30.490	30.490	0
INT8	29.748	29.748	0	29.945	29.945	0
INT9	29.277	29.277	0	29.523	29.523	0
NEWG02_0143	29.161	29.161	0	29.426	29.426	0
INT10	28.623	28.604	-18	28.817	28.807	-10
INT11 - BRG US	28.374	28.228	-145	28.545	28.477	-68
INT12	28.098			28.250		
INT12b - BRG DS		27.897	-		28.052	-
INT13	27.822	-	-	27.970	-	-
INT13b	-	27.712	-	-	27.865	-
NEWG02_0021	27.412	27.412	0	27.581	27.581	0

Annex K. Highway drainage layout plans



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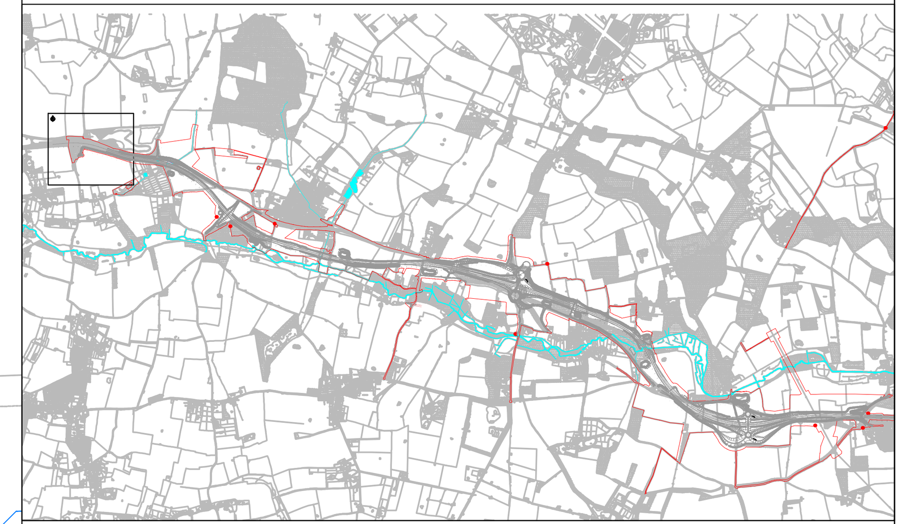

KEY TO SYMBOLS

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- Carrier Drain
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- Narrow Filter/Fin Drain
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- Drainage Ditch for over the edge provision
- PED Ditches (natural catchment)
- PED Filter drains
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- Kerb & Gully
- Manhole/Catchpit
- Headwall
- PED Cross Drain
- DCO Boundary
- Existing Surface water bodies
- Existing Overland Flow Pathways
- Culverts
- Chamber Reference NE-1
- Pipe Reference NE-1.000
- Network Marker Point NE

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P05	30/11/20	DESIGN FIX C	SG	JMcC	BArt
P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE
A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT PLANS
SHEET 1 OF 14

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
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DRAWING NUMBER
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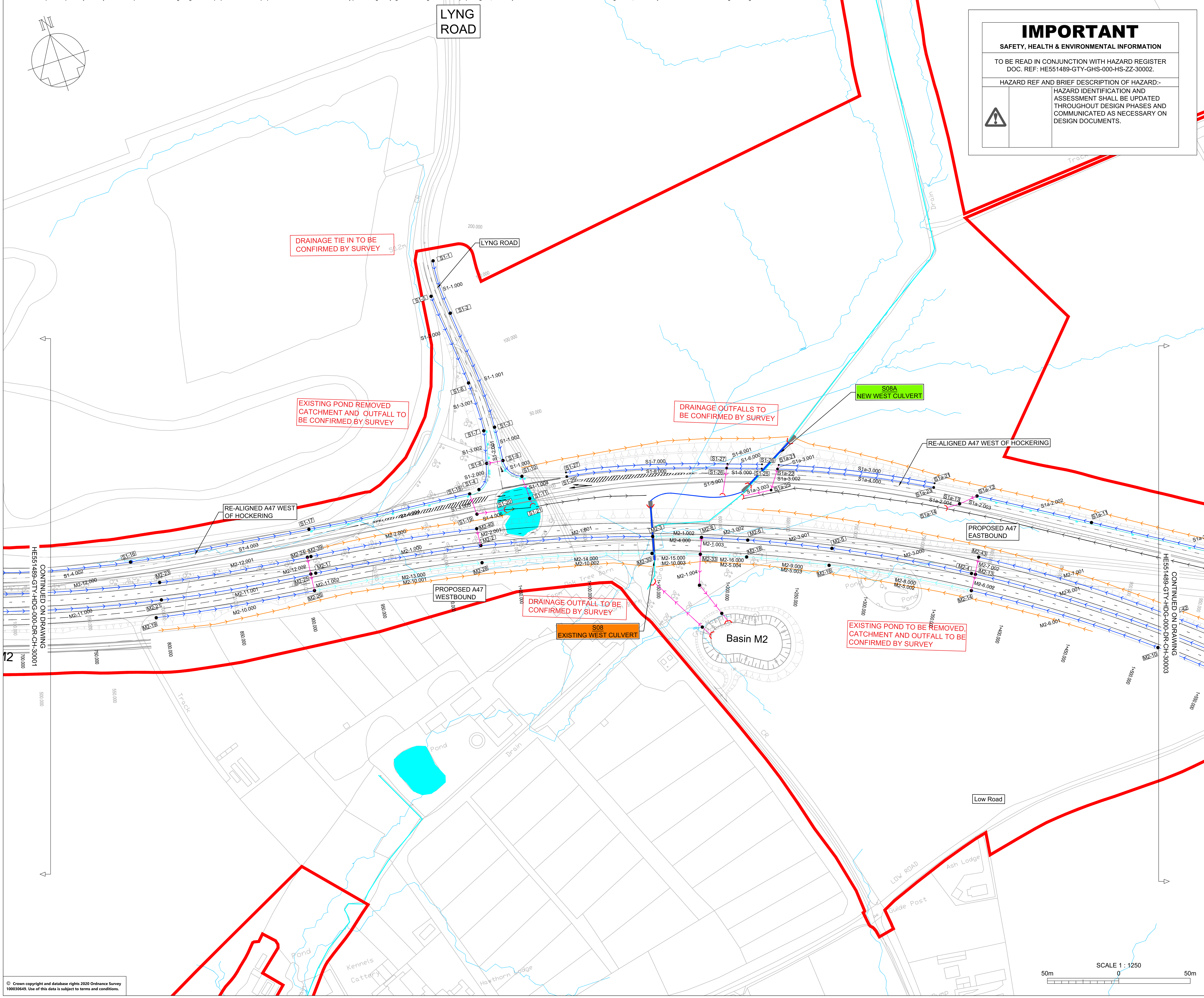

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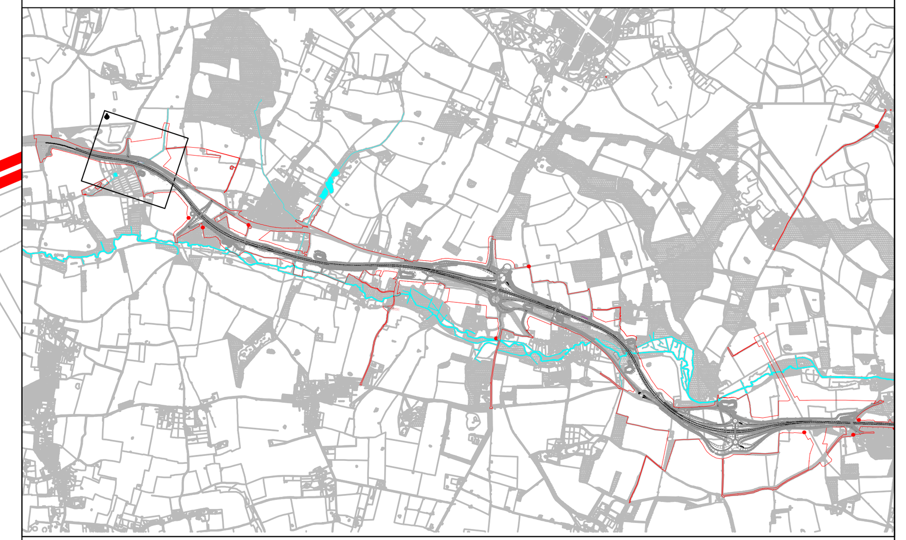

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- PED Filter drains
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- Kerb & Gully
- Manhole/Catchpit
- Headwall
- PED Cross Drain
- DCO Boundary
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- Existing Overland Flow Pathways
- Culverts
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P05	30/11/20	DESIGN FIX C	SG	JMcC	BArt
P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

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CLIENT
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PROJECT TITLE
A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT PLANS SHEET 2 OF 14

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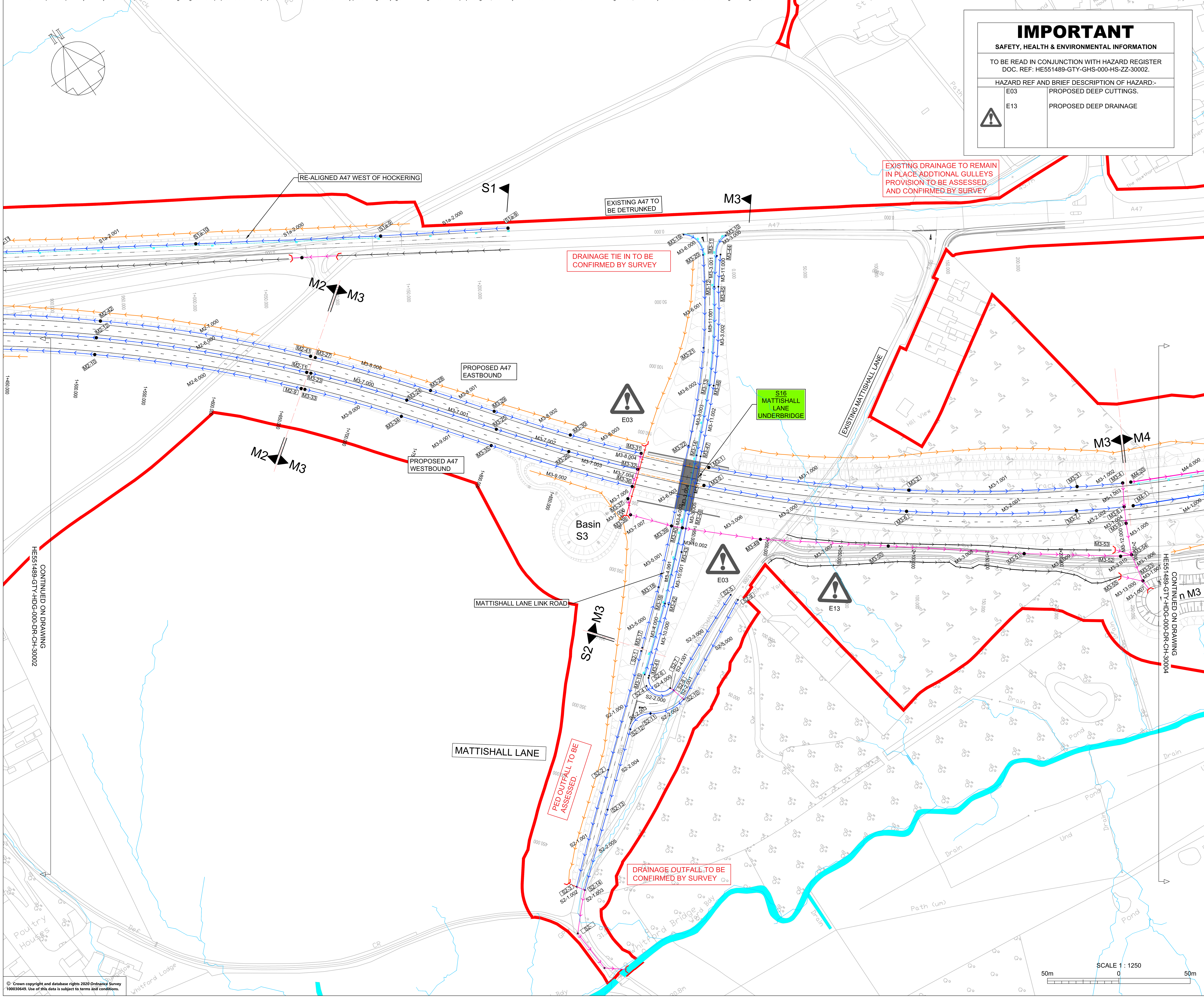

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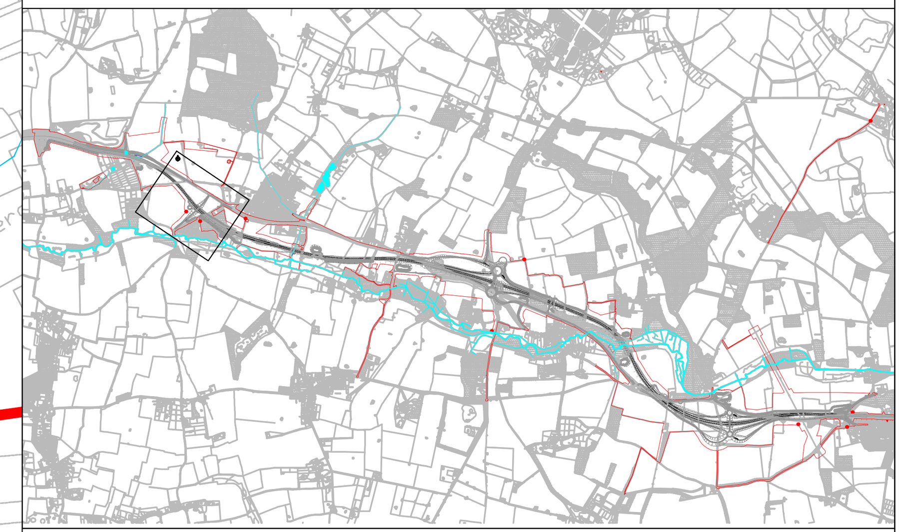

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CLIENT: highways england

PROJECT TITLE: A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: DRAINAGE LAYOUT PLANS SHEET 3 OF 14

SUITABILITY: AUTHORISED AS STAGE 3 COMPLETED

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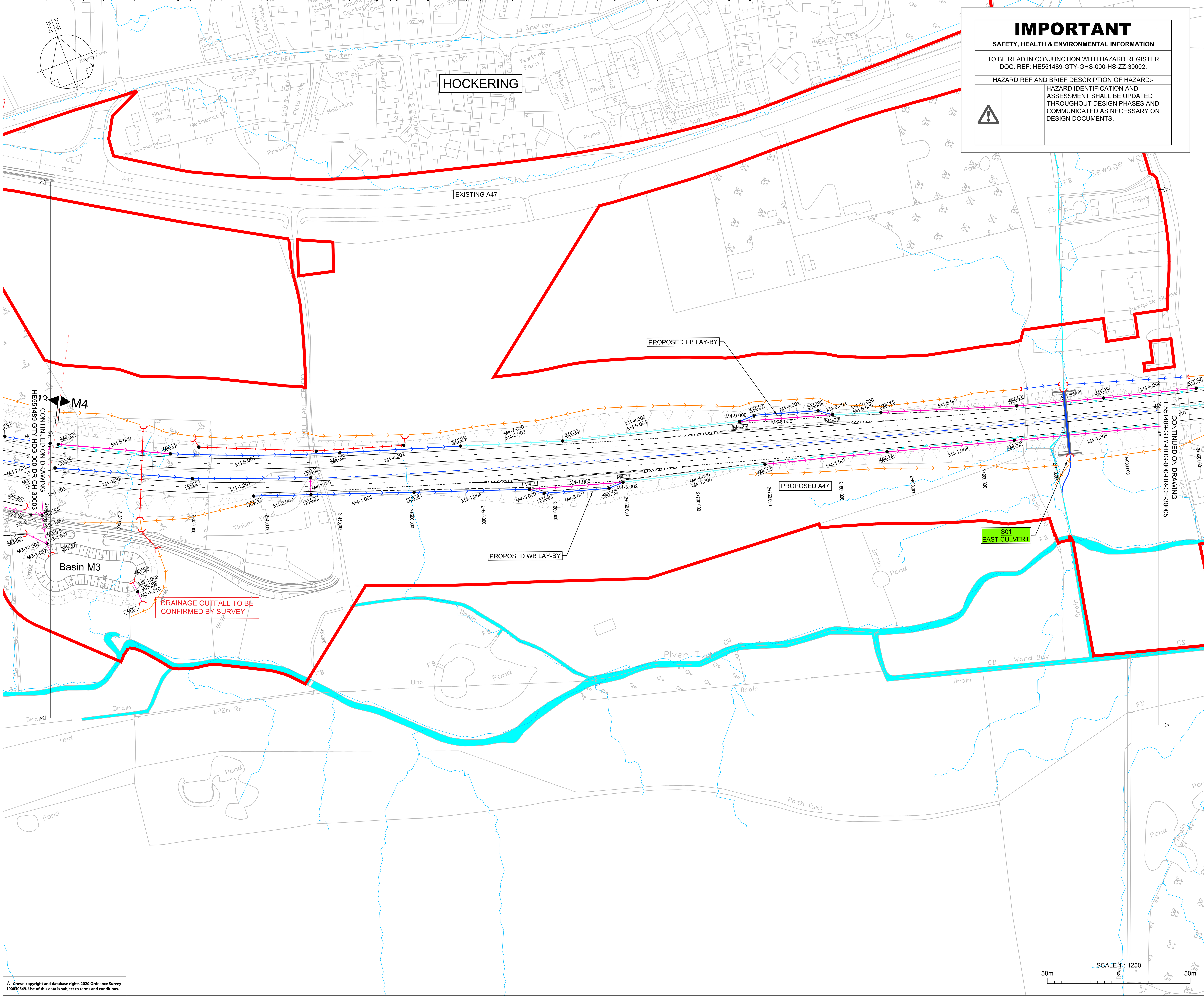

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SWECO

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CLIENT

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A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

DRAINAGE LAYOUT PLANS
SHEET 4 OF 14

SUITABILITY

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SHEET SIZE	SCALE	STATUS	REVISION
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DRAWING NUMBER

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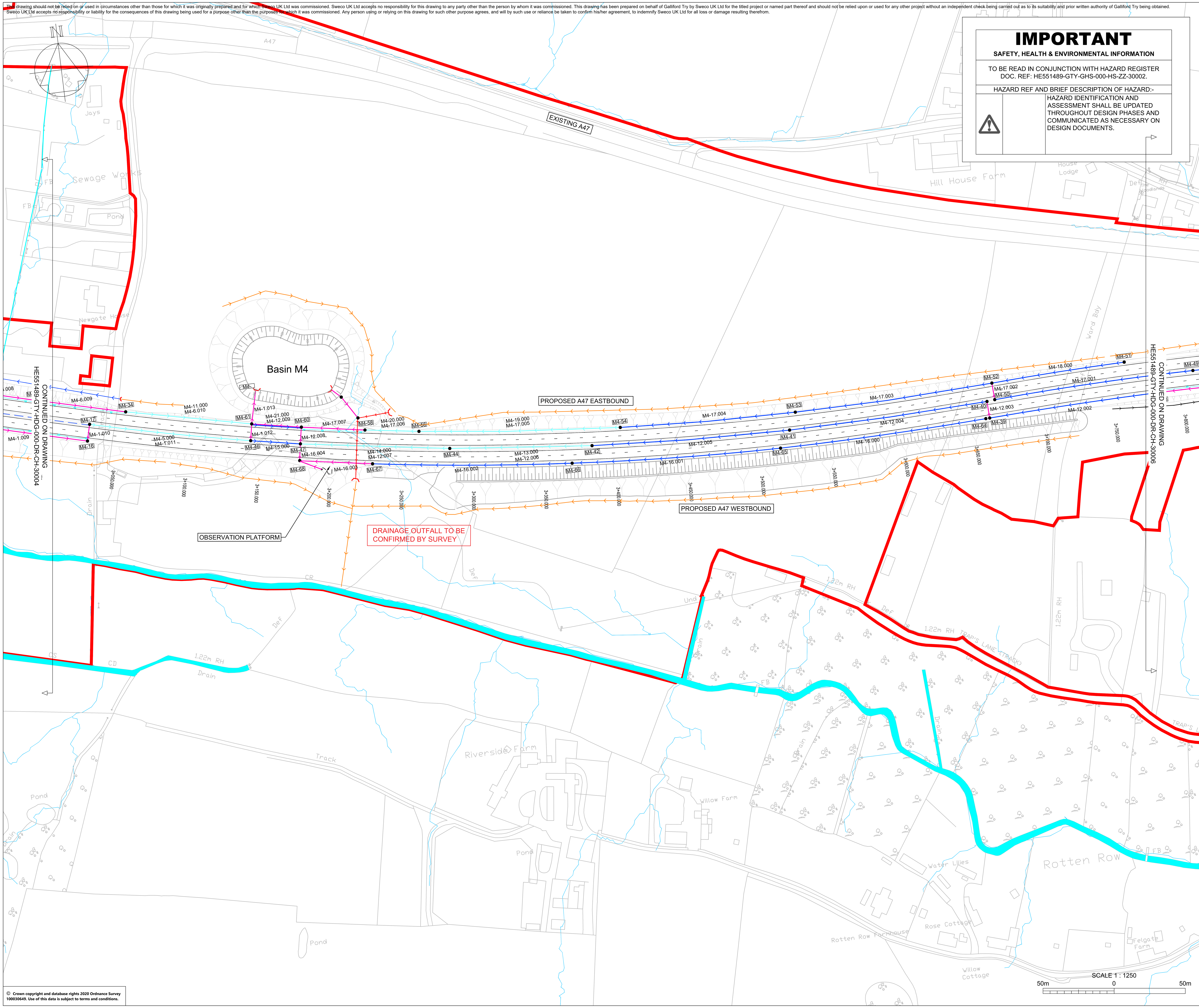

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P01	14/11/19	DESIGN FIX A	BR	BR	BR
P02	19/11/19	DESIGN FIX A UPDATE	BR	BR	BR
P03	29/04/20	DESIGN UPDATED FOR DESIGN FIX B	SG	JM	JM
P04	18/09/20	INTERIM DFC ISSUE	SG	JM	BA
P05	30/11/20	DESIGN FIX C	SG	JMcC	BArt
P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE
A47 NORTH TUDDENHAM TO EASTON DUALLING

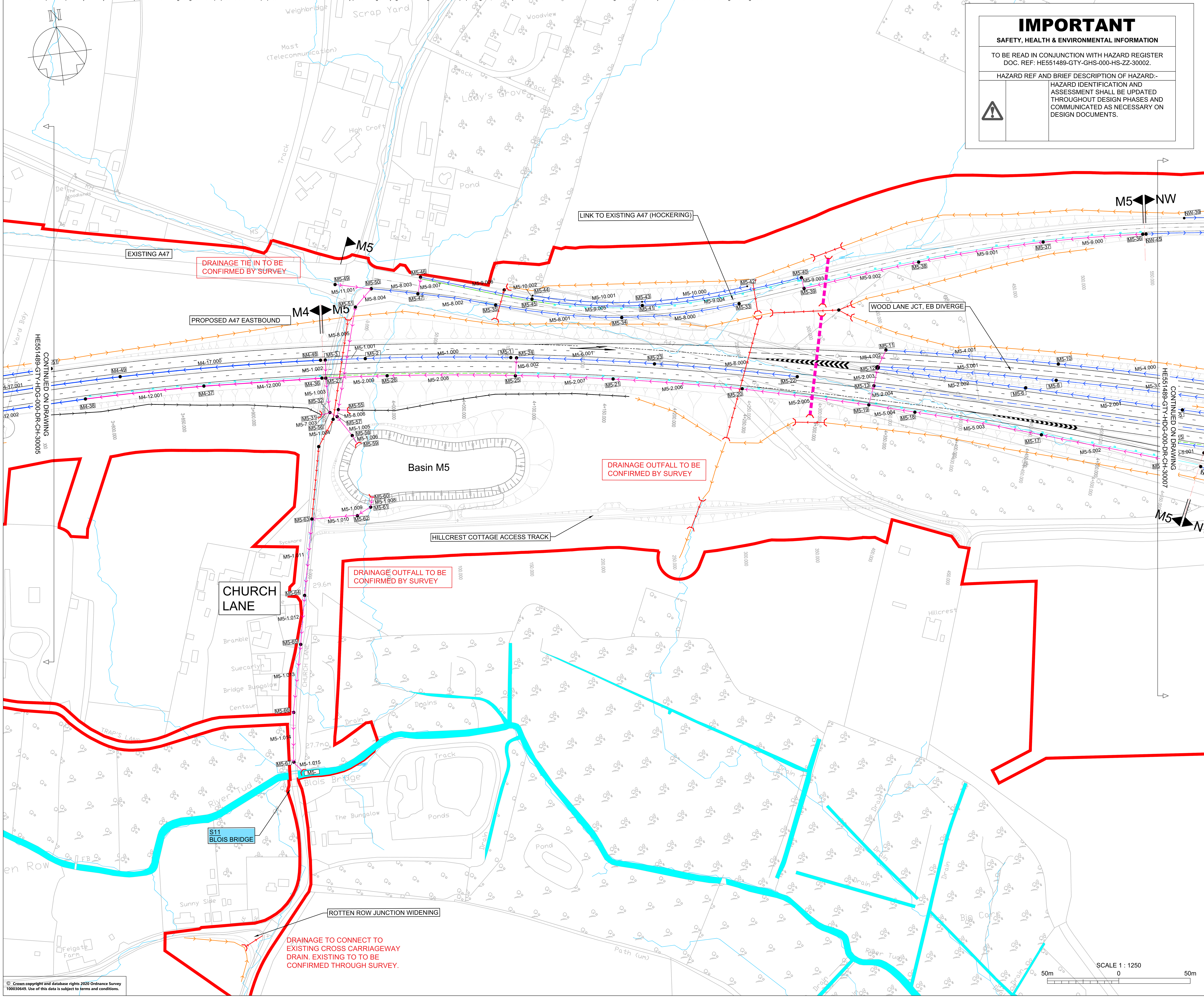
PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT PLANS
SHEET 5 OF 14

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER
HE551489-GTY-HDG-000-DR-CH-30005



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551489-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

HAZARD IDENTIFICATION AND ASSESSMENT SHALL BE UPDATED THROUGHOUT DESIGN PHASES AND COMMUNICATED AS NECESSARY ON DESIGN DOCUMENTS.

NOTES

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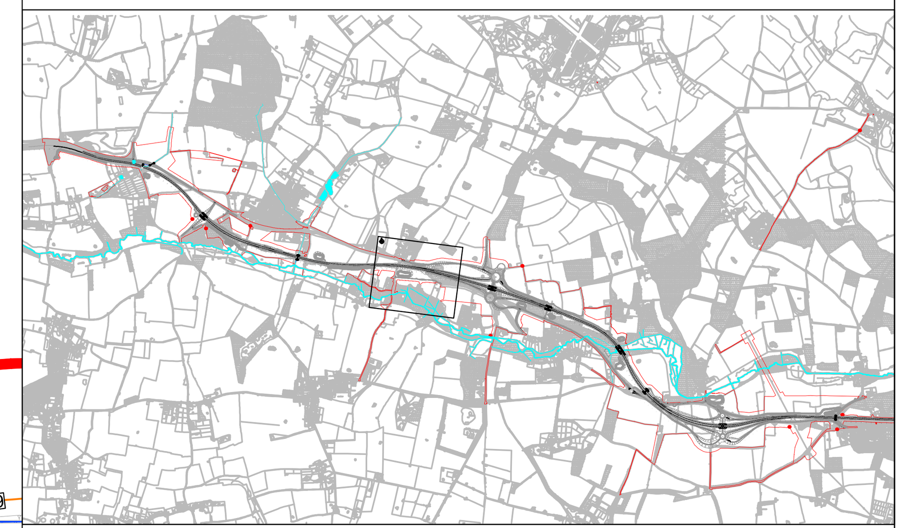
2. THIS DRAWING SHALL ONLY BE USED FOR THE DESIGN ELEMENT STATED IN THE DRAWING TITLE.
3. DRAWINGS ARE TO BE READ IN COLOUR.



KEY TO SYMBOLS

- Combined Drain
- Carrier Drain
- Filter & Lower Carrier Drains
- Narrow Filter/Fin Drain
- Oversized Pipes for Attenuation
- Drainage Ditch for over the edge provision
- PED Ditches (natural catchment)
- PED Filter drains
- Combined Kerb Drain
- Deck Drainage
- Kerb & Gully
- Manhole/Catchpit
- Headwall
- PED Cross Drain
- DCO Boundary
- Existing Surface water bodies
- Existing Overland Flow Pathways
- Culverts
- Chamber Reference NE-1
- Pipe Reference NE-1.000
- Network Marker Point NE

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	14/11/19	DESIGN FIX A	BR	BR	BR
P02	19/11/19	DESIGN FIX A UPDATE	BR	BR	BR
P03	29/04/20	DESIGN UPDATED FOR DESIGN FIX B	SG	JM	JM
P04	18/09/20	INTERIM DFC ISSUE	SG	JM	BA
P05	30/11/20	DESIGN FIX C	SG	JMcC	BArt
P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE: A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: DRAINAGE LAYOUT PLANS SHEET 6 OF 14

SUITABILITY: AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER: HE551489-GTY-HDG-000-DR-CH-30006

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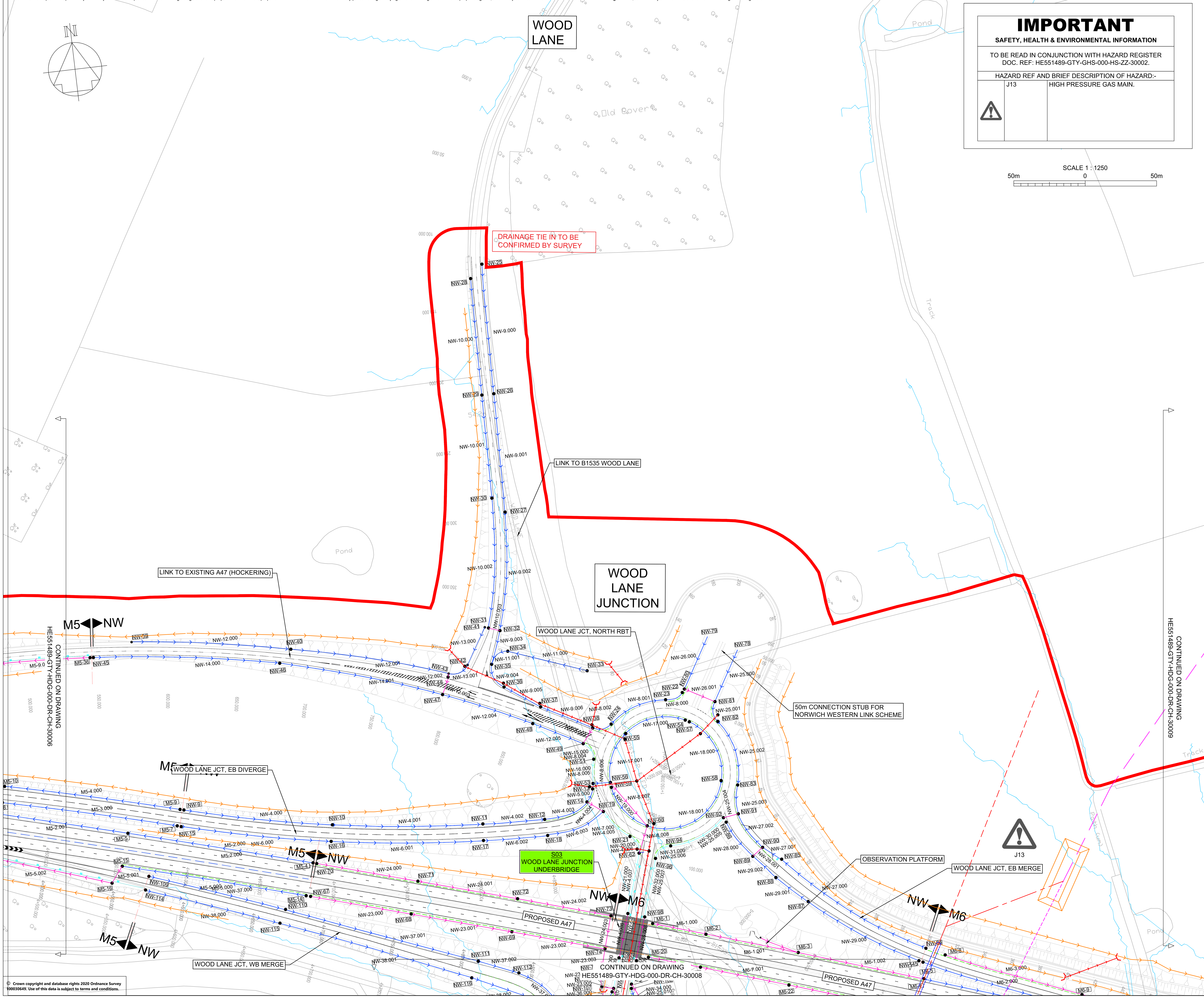

NOTES
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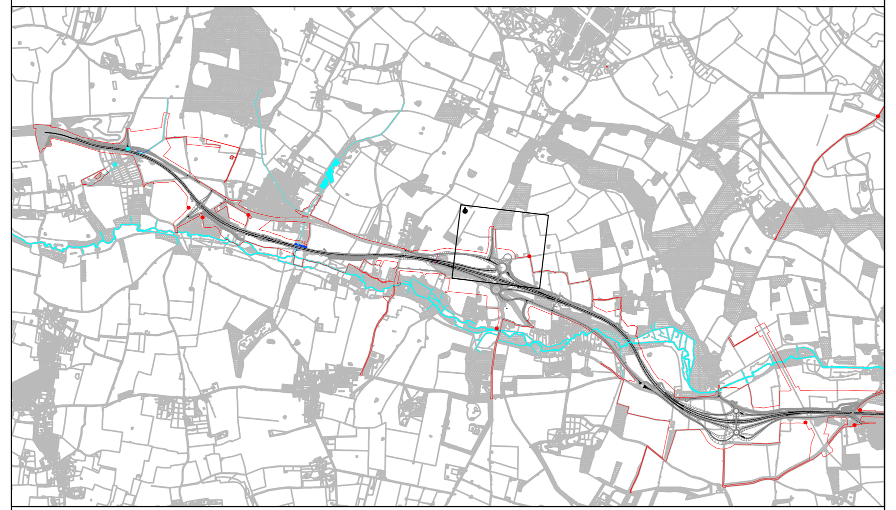

KEY TO SYMBOLS
- Combined Drain
- Carrier Drain
- Filter & Lower Carrier Drains
- Narrow Filter/Fin Drain
- Oversized Pipes for Attenuation
- Drainage Ditch for over the edge provision
- PED Ditches (natural catchment)
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- Kerb & Gully
- Manhole/Catchpit
- Headwall
- PED Cross Drain
- DCO Boundary
- Existing Surface water bodies
- Existing Overland Flow Pathways
- Culverts
- Chamber Reference NE-1
- Pipe Reference NE-1.000
- Network Marker Point NE

REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	14/11/19	DESIGN FIX A	BR	BR	BR
P02	19/11/19	DESIGN FIX A UPDATE	BR	BR	BR
P03	29/04/20	DESIGN UPDATED FOR DESIGN FIX B	SG	JM	JM
P04	18/09/20	INTERIM DFC ISSUE	SG	JM	BA
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P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER
SWECO

CONTRACTOR
Galliford Try

CLIENT
highways england

PROJECT TITLE
A47 NORTH TUDDENHAM TO EASTON DUALLING

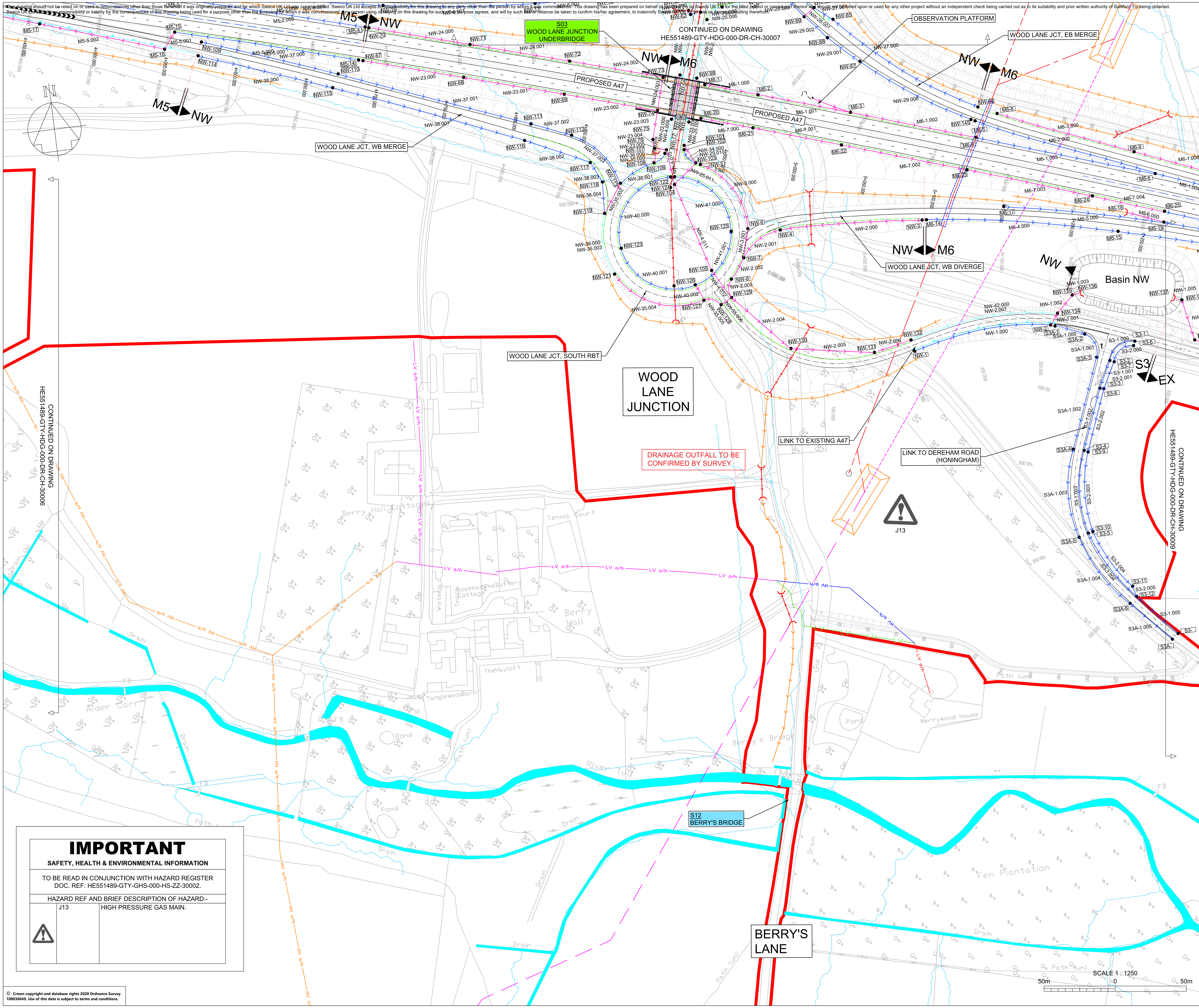
PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT PLANS SHEET 7 OF 14

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER
HE551489-GTY-HDG-000-DR-CH-30007



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551489-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

J13	HIGH PRESSURE GAS MAIN.

NOTES

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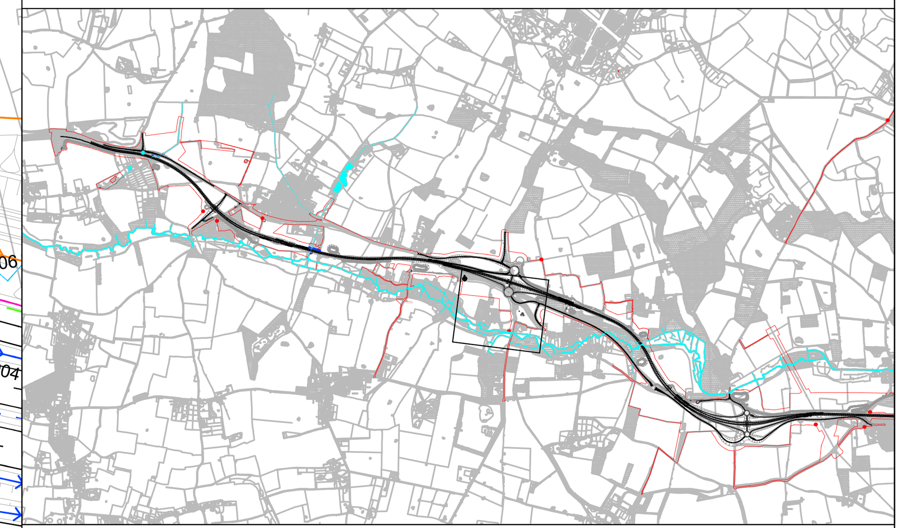

KEY TO SYMBOLS

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P05	30/11/20	DESIGN FIX C	SG	JMcC	BArt
P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: GallifordTry

CLIENT: highways england

PROJECT TITLE

A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE

PCF STAGE 3

DRAWING TITLE

DRAINAGE LAYOUT PLANS
SHEET 8 OF 14

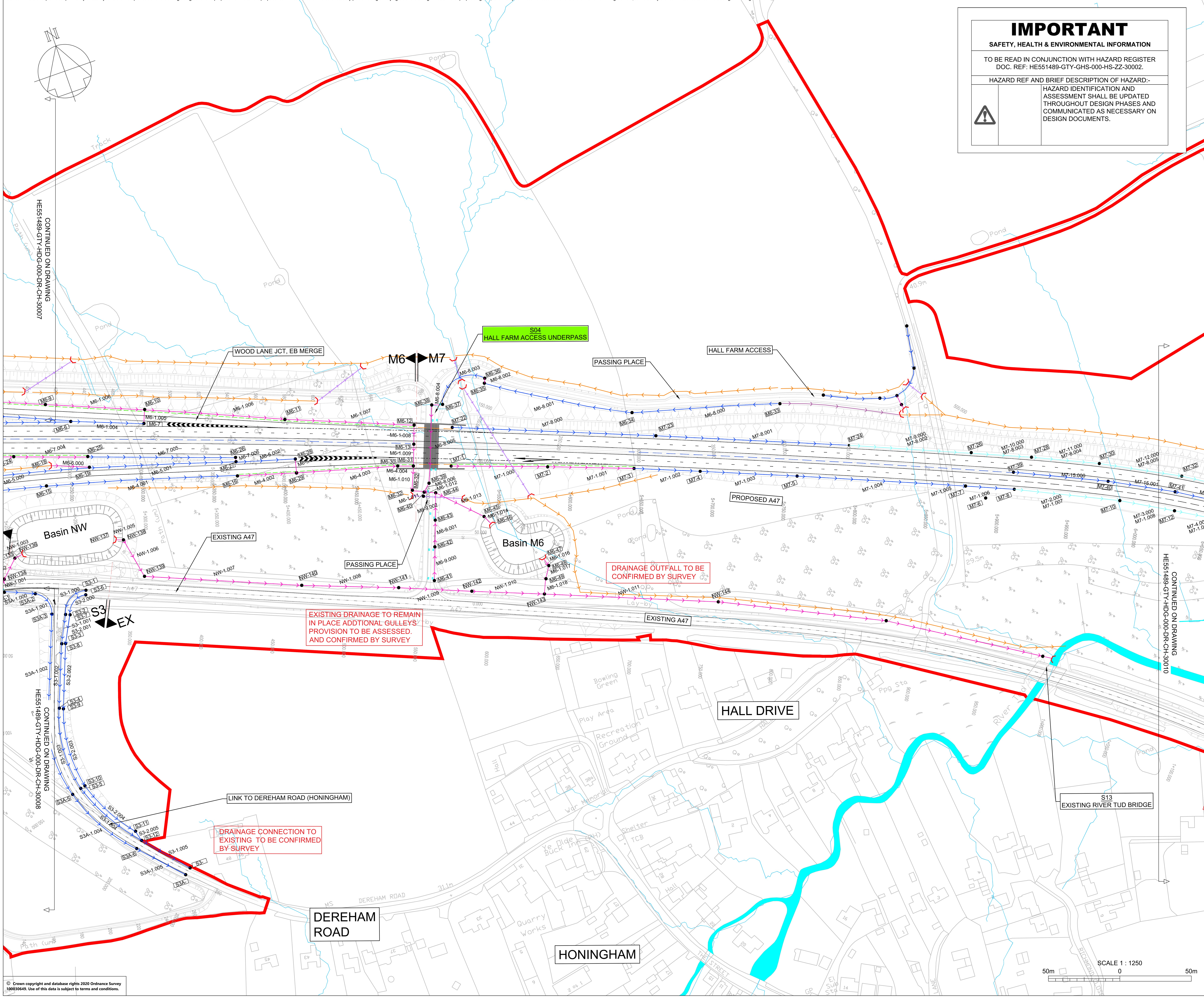
SUITABILITY

AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER

HE551489-GTY-HDG-000-DR-CH-30008



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551489-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

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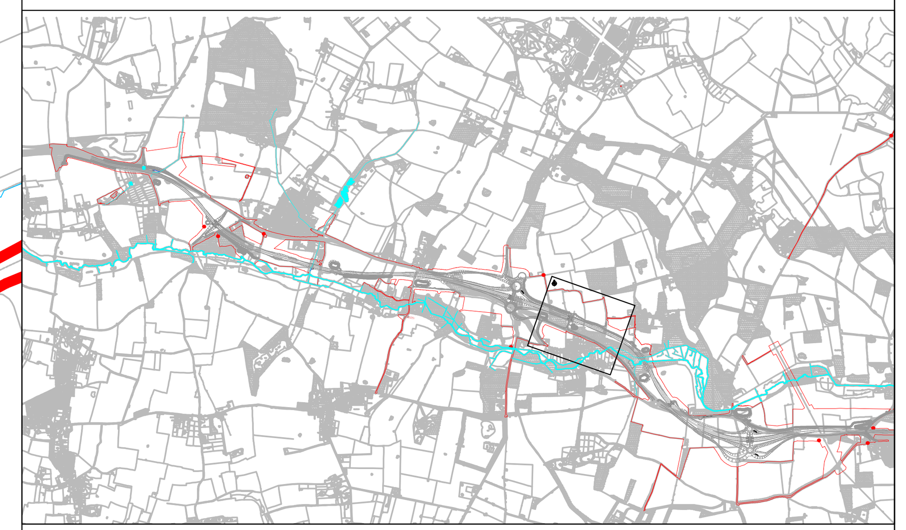

KEY TO SYMBOLS

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P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: Galliford Try

CLIENT: highways england

PROJECT TITLE
A47 NORTH TUDDENHAM TO EASTON DUALLING

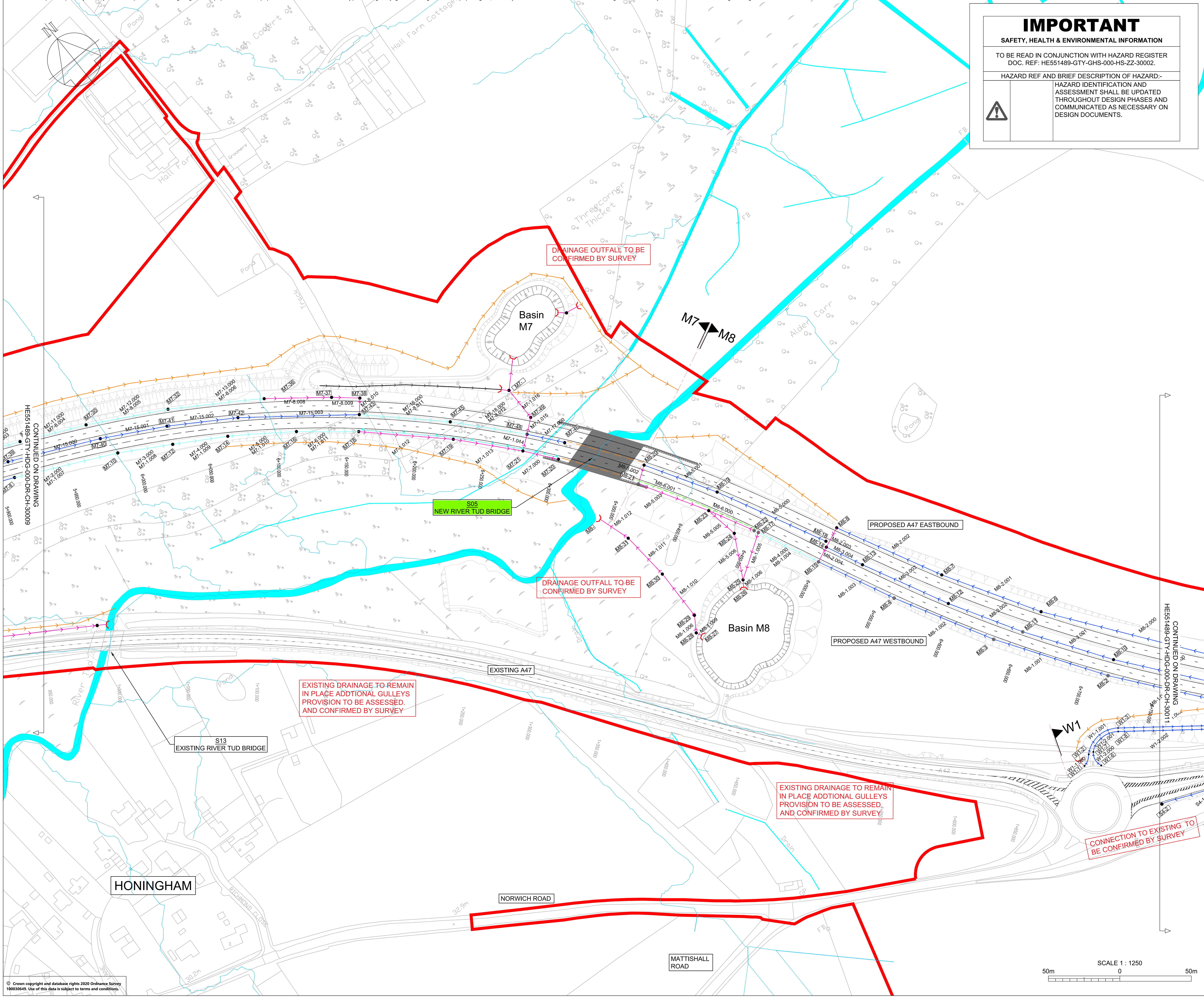
PROJECT STAGE
PCF STAGE 3

DRAWING TITLE
DRAINAGE LAYOUT PLANS
SHEET 9 OF 14

SUITABILITY
AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER
HE551489-GTY-HDG-000-DR-CH-30009



IMPORTANT

SAFETY, HEALTH & ENVIRONMENTAL INFORMATION

TO BE READ IN CONJUNCTION WITH HAZARD REGISTER DOC. REF: HE551489-GTY-GHS-000-HS-ZZ-30002.

HAZARD REF AND BRIEF DESCRIPTION OF HAZARD:-

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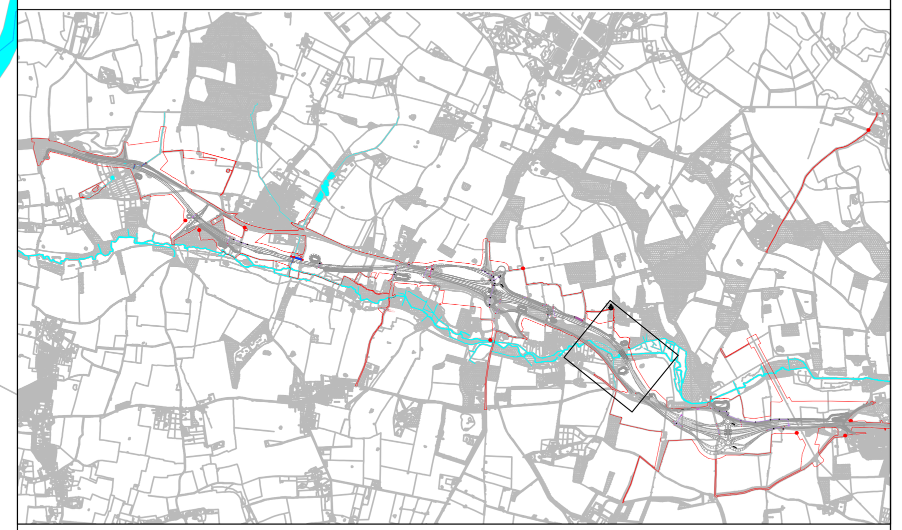

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REV	DATE	REVISION NOTE	ORG	CHK'D	APP'D
P01	14/11/19	DESIGN FIX A	BR	BR	BR
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P06	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur
C01	01/02/21	UPDATED FOR SGAR 3	KMcC	JMcC	MMur

DESIGNER: SWECO

CONTRACTOR: GallifordTry

CLIENT: highways england

PROJECT TITLE: A47 NORTH TUDDENHAM TO EASTON DUALLING

PROJECT STAGE: PCF STAGE 3

DRAWING TITLE: DRAINAGE LAYOUT PLANS SHEET 10 OF 14

SUITABILITY: AUTHORISED AS STAGE 3 COMPLETED

SHEET SIZE	SCALE	STATUS	REVISION
A1	1:1250	A3	C01

DRAWING NUMBER: HE551489-GTY-HDG-000-DR-CH-30010